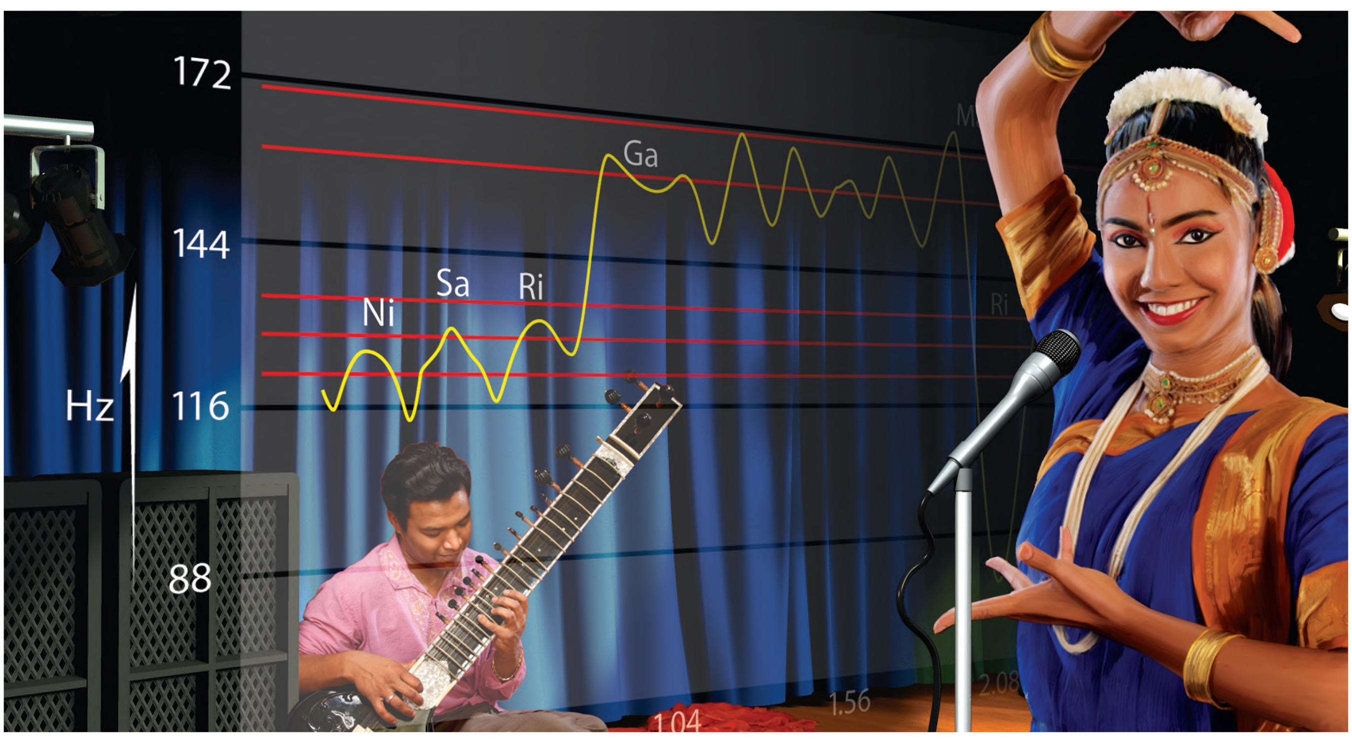
ISSN 0711-6659

canadian acoustics
acoustique canadienne

Journal of the Canadian Acoustical Association - Journal de l'Association Canadienne d'Acoustique

DECEMBER 2012 DECEMBRE 2012
Volume 40 -- Number 4 Volume 40 -- Numéro 4



canadian acoustics

acoustique canadienne

THE CANADIAN ACOUSTICAL ASSOCIATION
P.O. BOX 1351, STATION "F"
TORONTO, ONTARIO M4Y 2V9

L'ASSOCIATION CANADIENNE D'ACOUSTIQUE
C.P. 1351, SUCCURSALE "F"
TORONTO, ONTARIO M4Y 2V9

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

ACOUSTIQUE CANADIENNE publie des articles arbitrés et des informations sur tous les domaines de l'acoustique et des vibrations. On invite les auteurs à soumettre des manuscrits, rédigés en français ou en anglais, concernant des travaux inédits, des états de question ou des notes techniques. Les soumissions doivent être envoyées au rédacteur en chef. Les instructions pour la présentation des textes sont exposées à la fin de cette publication.

CANADIAN ACOUSTICS is published four times a year - in March, June, September and December. Copyright on articles is held by the author(s), who should be contacted regarding reproduction. Annual subscription: $40 (student); $90 (individual, institution); $400 (sustaining - see back cover). Back issues (when available) may be obtained from the CAA Secretary - price $25 including postage. Advertisement prices: $350 (full page- $1200 for four issues); $200 (half page - $700 for four issues); $150 (quarter page - $500 for four issues). Contact the Associate Editor (advertising) to place advertisements. Canadian Publication Mail Product Sales Agreement No. 0557188.

ACOUSTIQUE CANADIENNE est publiée quatre fois par année - en mars, juin, septembre et décembre. Les droits d'auteur d'un article appartiennent à (aux) auteur(s). Toute demande de reproduction doit leur être acheminée. Abonnement annuel: $40 (étudiant); $90 (individuel, société); $400 (soutien - voir la couverture arrière). D'anciens numéros (non-épuisés) peuvent être obtenus du Secrétaire de l'ACA - prix: $25 (affranchissement inclus). Prix d'annonces publicitaires: $350 (page pleine - $1200 pour quatre publications); $200 (demi page - $700 pour quatre publications); $150 (quart de page - $500 pour quatre publications). Contacter le rédacteur associé (publicité) afin de placer des annonces. Société canadienne des postes - Envois de publications canadiennes - Numéro de convention 0557188.

PRESIDENT'S MESSAGE / MESSAGE DU PRÉSIDENT

These are exciting times for the Association. At long last, the CAA is introducing a host of online services to its members and subscribers starting January 2013. In large part, the credit goes to one of the Directors, Jérémie Voix, who tirelessly coordinated the implementation of the new online facilities over the past few months with our Secretary, Treasurer and Editor-in-Chief.

It will now be possible to renew annual membership dues and journal subscriptions via online credit card transactions and other secure means through PayPal. While it will still be possible to pay by cheque, all members and subscribers are strongly encouraged to use the new online facilities to streamline the processing of transactions for everyone. More information on renewals can be found in this issue of Canadian Acoustics or at jcaa.caa-aca.ca

At the same time, and on occasion of the 40th anniversary of quarterly publications by the Association, all past issues of Canadian Acoustics (and its predecessor CCA Newsletter) will become available online at jcaa.caa-aca.ca through an OJS (Open Journal Systems) portal. This will greatly help in disseminating our journal throughout the world, increasing readership and overall visibility for the Association. The most recent publications (i.e. current or prior year) will be available to members/subscribers only. Finally, the submission of manuscripts for publication in Canadian Acoustics and the peer-review process will be managed online through the same portal in the very near future. Stay put!

In other news, Acoustic Week in Canada 2012 was held in beautiful Banff this past October. Our Past President, Stan Dosso, and his team of "not-so-local" organizing committee members once again took on the challenge of hosting our annual conference. We enjoyed a very successful and busy two and a half days of plenary sessions, technical papers, acoustical standards meetings, exhibitor show and social events. A special mention goes to the three award winners for the best student presentations at the conference: Nicolas Ellaham (University of Ottawa), Martin Brummund (École de technologie supérieure) and Tristan Loria (Ryerson University).

2013 will be a very busy year in acoustics in the country. The Canadian Acoustical Association is joining the Acoustical Society of America in hosting the 21st International Congress on Acoustics (ICA) under the aegis of the International Commission on Acoustics. The ICA meeting (www.ica2013montreal.org) will be held in Montreal, 2-7 June, and the general chair is Michael Stinson. The CAA is also sponsoring the International Symposium on Room Acoustics (ISRA), a satellite event of the International Congress on Acoustics. The ISRA meeting (www.caa-aca.ca/conferences/isra2013) is co-chaired by John Bradley and John O'Keefe and will be held in Toronto, 9-11 June. Please mark down these two important events in your calendar and note that the CAA will not hold a separate October meeting in 2013.

Après une longue attente, il me fait plaisir d'annoncer que l'ACA s'apprête à déployer toute une série de services en ligne à ses membres et abonnés à partir de janvier 2013. En grande partie le mérite revient à l'un de nos directeurs, Jérémie Voix, qui a coordonné la mise en œuvre de cette grande aventure au cours des derniers mois avec notre secrétaire exécutive, la trésorière et le rédacteur en chef.

Il sera désormais possible de renouveler en ligne les cotisations annuelles des membres et les abonnements à la revue par carte de crédit ou autres moyens sécurisés par l'entremise de PayPal. Même s'il sera toujours possible de payer par chèque, les membres et les abonnés sont tous fortement encouragés à utiliser les nouvelles méthodes de paiement en ligne pour simplifier le traitement des transactions. Vous trouverez de plus amples renseignements sur les renouvellements dans ce numéro de l'Acoustique canadienne ou en consultant le site jcaa.caa-aca.ca.

De plus, tous les anciens numéros de l'Acoustique canadienne (ainsi que la parution précédente, le CCA Newsletter) seront disponibles en ligne sur le site jcaa.caa-aca.ca par l'entremise d'un portail OJS (Open Journal Systems). Ceci coïncide avec le 40e volume de l'Acoustique canadienne cette année. Cet avènement étendra la portée de notre revue trimestrielle sur le plan international et accroîtra la visibilité de notre association. Les publications les plus récentes (p.ex. année courante ou précédente) seront disponibles pour les membres et abonnés seulement. Enfin, la soumission d'articles dans l'Acoustique canadienne et le processus de révision par les pairs seront gérés en ligne par le même portail dans un avenir rapproché. À suivre!

Par ailleurs, la Semaine canadienne d'acoustique 2012 s'est tenue dans la merveilleuse ville de Banff en octobre dernier. Notre président sortant, Stan Dosso, et son équipe d'organisateurs « pas si locaux » ont une fois de plus relevé le défi d'accueillir notre congrès annuel, lequel a connu encore cette année un franc succès et donnait beaucoup à faire avec ses deux jours et demi de séances plénières, présentations scientifiques, rencontres du comité des normes, exposition technique et activités sociales. Je tiens à souligner les trois lauréats pour les meilleures présentations étudiantes lors du congrès: Nicolas Ellaham (Université d'Ottawa), Martin Brummund (École de technologie supérieure) et Tristan Loria (Ryerson University).

L'année 2013 s'annonce bien chargée au Canada dans le domaine de l'acoustique. L'Association canadienne d'acoustique s'est jointe à l'Acoustical Society of America afin d'accueillir le 21e Congrès international d'acoustique (ICA), sous l'égide de la Commission internationale sur l'acoustique. Le congrès ICA (www.ica2013montreal.org) se tiendra à Montréal du 2 au 7 juin prochain et sera présidé par Michael Stinson. L'Association parraine également le Symposium international sur l'acoustique des salles (ISRA), Many thanks go to Tim Kelsall and Clair Wakefield who just completed six-year terms on the Board of Directors and provided invaluable help in setting up the CAA Acoustical Standards Committee (Tim) and organizing two recent annual meetings (Clair). At the same time, I welcome our newly elected Directors: Bryan Gick (University of British Columbia), Karen Turner (Protec Hearing) and Bill Gastmeier (HGC Engineering).

Finally, I would like to transmit a very special thank you note to Ramani Ramakrishnan, our very dedicated and capable Editor-in-Chief over the past 14 years, who has chosen not to seek re-election after 56 carefully crafted issues of Canadian Acoustics!!! Thanks for his tireless effort, Canadian Acoustics continues to remain a pillar of the Association and will soon be the flagship of our website once issues are put online. Frank Russo, who was on the Board of Directors these past few years, has been elected as our new Editor-in-Chief at the October AGM. This issue of Canadian Acoustics already reflects the results of his new appointment.

Christian Giguère
CAA President

un événement satellite associé au Congrès international d'acoustique. Le symposium ISRA (www.caa-aca.ca/conferences/isra2013) est co-présidé par John Bradley et John O'Keefe et aura lieu à Toronto du 9 au 11 juin prochain. Veuillez inscrire dès maintenant ces deux événements à votre agenda et prendre note que l'ACA ne tiendra pas de congrès distinct en octobre 2013.

Un grand merci à Tim Kelsall et Clair Wakefield, lesquels viennent de terminer des mandats de six ans au sein du conseil d'administration, pour leur aide précieuse à la mise en place du Comité des normes de l'ACA (Tim) et à l'organisation de deux récents congrès annuels (Clair). J'en profite pour souhaiter la bienvenue à trois directeurs nouvellement élus: Bryan Gick (University of British Columbia), Karen Turner (Protec Hearing) et Bill Gastmeier (HGC Engineering).

Enfin, je tiens à remercier tout spécialement notre très dévoué rédacteur en chef des 14 dernières années, Ramani Ramakrishnan, qui a choisi de ne pas briguer un nouveau mandat après 56 numéros soigneusement rédigés de l'Acoustique canadienne ! Grâce à ses efforts inlassables, l'Acoustique canadienne continue d'être un pilier de notre Association et elle sera bientôt le fleuron de notre site internet une fois que les numéros seront disponibles en ligne. Frank Russo, qui siège au conseil d'administration depuis quelques années, a été élu nouveau rédacteur en chef à l'AGA d'octobre. Ce numéro de l'Acoustique canadienne reflète déjà les résultats de sa nouvelle nomination.

Christian Giguère
Président de l'ACA

Editorial Note: I would like to thank Ramani Ramakrishnan for his 14 years of service to the journal and for his support in all matters regarding transition to my new position as Editor-in-Chief. Please note that the membership directory has not been included in this issue. The board of directors is currently reviewing its policy regarding the directory in view of the new online journal content.

Frank A. Russo
Editor-in-Chief

Note du Rédacteur en chef: Je tiens à remercier Ramani Ramakrishnan pour ses 14 ans de service à la revue et pour son aide précieuse lors du passage vers mes nouvelles fonctions de Rédacteur en chef. Veuillez noter que le répertoire des membres n'a pas été inséré dans ce numéro. Le conseil de direction est en train de revoir la politique d'accès au répertoire compte tenu des nouveaux services en ligne.

Frank A. Russo
Rédacteur en chef

DEPARTURES FROM THE ACOUSTICAL PARAMETERS IN THE INTONATION OF SOUTH INDIAN MUSICAL INTERVALS

Madhu Mohan Komaragiri
14, Geddy Street, Whitby, Ontario, L1P 1P8, k_madhumohan@hotmail.com.

ABSTRACT

All evolved music cultures have engaged in the study of musical intervals. Indian musical intervals are melodic. Indian music was not structured acoustically[1]. But in recent times scholars began to give precise acoustical values for the musical notes. This paper shows the departures from such acoustical parameters and explores the pitch profiles characteristic to the South Indian *rāga* music. It demonstrates the dynamic variability in the intonation of the South Indian musical intervals. A holistic view incorporating hearing and perception are vital to the understanding of culturally sensitive idiomatic pitching of the musical intervals.

SOMMAIRE

Toutes les cultures avancées se sont intéressées de tout temps à l'étude des accords et intervalles musicaux. Les accords de la musique indienne sont mélodiques. La musique indienne n'était pas structurée d'un point de vue acoustique. Mais avec le temps les chercheurs ont commencé à attribuer des valeurs acoustiques précises aux différentes notes musicales. Cet article montre le point de départ de tels paramètres acoustiques et s'intéresse aux caractéristiques du profil mélodique de la musique rāga de l'Inde du Sud. La variabilité changeante de l'intonation des intervalles musicaux de l'Inde du Sud sera mise en évidence. Une perception holistique, incorporant l'ouïe et la perception, est vitale pour la bonne compréhension des accords musicaux dans leur contexte idiomatique et culturel.

Editor's NOTE: The superscripts refer to explanatory notes provided in Appendix A.

1. INTRODUCTION

This paper examines the pitching of musical intervals in the classical music tradition of South India. The extant theory of intonation demands fixed frequency values for the musical intervals. But based on the evidence provided by the computer pitch analysis of select audio samples, departures from such acoustical parameters can be clearly demonstrated. In section 2, a brief background on the ancient system of Indian music, systemic changes in later times and the adaptations of the western concepts of intonation are provided to set the stage for the current discussion. Section 3 talks about the melodic nature of the South Indian musical intervals and explains why certain basic harmonic intervals are used as well. This section briefly alludes to hearing and perception, and discusses aspects of consonance and neurological recognition of pitch contours. Section 4 presents the empirical pitch analysis. It provides select pitch plots along with the explanations of these pitch profiles accompanied by a table capturing the departures from the theoretically expected fixed frequency values given by the modern scholars. Section 5 elaborates on the departures from the acoustical parameters. This section talks about the *intonational imperatives*, elucidating the dynamic variability in intonation in the performance of South Indian *rāga* music. This section also examines the influence of the accompanying *tambūra* [2] on the intonation. Section 6 summarizes the conclusions. The appendices with the explanatory notes give further information.

The word 'Indian' specifically refers to 'South Indian' music because the supporting evidence provided in this paper is the empirical pitch analysis of South Indian *rāga*-s. Also, the word *rāga* specifically means South Indian or *Karṇāṭaka* (Carnatic) *rāga*.

2. BACKGROUND

Musical intervals in Indian music have been traditionally expressed in terms of the number of *śruti*-s between them. In the ancient Indian music, *śruti*-s were a means of measurement of *svara*-s (Indian musical notes). In the modern parlance we might refer to them as microtonal octave divisions. Ancient musical treatises in Sanskrit explained the musical intervals in the context of the theory of 22 *śruti*-s [3]. (Refer also to Appendix B). Bharata, in his *opus* the *Nāṭyaśāstra*, has explained the theory of 22 *śruti*-s. Subsequent treatises reiterated this theory but with varying interpretations. The modern scholars, in the last 150 years or so, have given a mathematical interpretation to the theory of 22 *śruti*-s and wrongly attributed them to Bharata for authenticity.

In the ancient fixed-interval *grāma* system, *śruti* was a means to express the intervals as well as the *svara*-s. In the *Sa-grāma*, *Sa*, *Ma* and *Pa* were referred to as *catuḥśrutika* (four-*śruti*-ed) *svara*-s, *Ri* and *Dha* as *triśrutika* (three-*śruti*-ed) *svara*-s and *Ga* & *Ni* as *dviśrutika* (two-*śruti*-ed) *svara*-s. These intervals were fixed. Different scales were generated by shifting the tonic. In the current fixed-tonic *mēla* system, the intervals are variable. According to Powers (1970: P62), the original intent and usage of the word *śruti* had lost its currency as the system changed from *grāma* to *mēla*. But modern scholars [4] continued to use *śruti* in the same old sense. The ancients never derived *śruti*-s mathematically nor were they concerned about the acoustics. This is evident from a chronological study of the original ancient texts in Sanskrit. The seven notes in ancient music were positioned within the 22 *śruti*-s' schematic. *Śruti* was only a conceptual measure; not an acoustical quantity and it was never expressed in the form of m/n until the modern times.

Pythagoras based his tuning system on the octave (2:1) and used the simple relationship of the pure fifth (3:2) to arrive at the other intervals expressed in ratios in the form of m/n (Barbour, 1953, *xi*). The treatment was mathematical. Early Indians like Bharata positioned the musical notes (*svara*-s) in terms of the *śruti* intervals. The treatment here was not mathematical. As Rowell (1992, P52) points out, ancient Indian musicians described the musical sound by the 'word' whereas the Greeks and the medieval Europeans used the 'number' to describe it. The ancient Indians considered the musical sound as a continuous and dynamic flow of the vital breath. The Greeks on the other hand considered it as a static material substance. One understood it as a quality, while the other took it as a quantity.

In the modern period (i.e. post seventeenth century) however, alien western concepts of acoustics and Pythagorean and Just tuning systems have been forcibly applied to the study of Indian *śruti* intervals assigning precise mathematical values. These adaptations have caused irreconcilable discrepancies. They began to treat *śruti*-s as physical quantities and assigned fixed values. (Refer also to the table of commonly accepted modern *śruti* values in Appendix B). The horizontal lines in the pitch plots, presented in Figures 1 through 14, indicate the theoretically expected frequency values from the table of Appendix B. Despite such adaptations by the modern scholars, the original intent of the 22 *śruti*-s is not compatible with any of these western tuning concepts. There is no consistent predilection for Pythagorean or Just or any other 'natural' intervals (Komaragiri, 2005, P92). This is the case even in the western music (Burns, 1999, P246). Today however, notes are positioned on the musical instruments, particularly the fretted stringed instruments, in line with the natural consonance, but determined aurally. The study of intonation based on the concept and terminology of *śruti* remained academic and confined to musicologists. Latter-day musicologists like Veṅkaṭamakhī [5] conceived music in terms of 12 notes (with 16 *svara* names) [6], excerpted from the 22 *śruti*-s. The '12 notes' system is currently in practice. North Indian musicians always talked about their music in terms of 12 notes.

Even if the musical intervals are studied in terms of mathematical ratios, mathematical simplicity in itself is almost irrelevant to the study of acoustics or of music (Benade, 1976, P264), because of the complexity of *rāga* music. In other words, if the pitch profiles were to be mathematically modeled, simple ratios in the form of m/n will not suffice. The non-linear, context-dependent dynamic variability of musical pitches will necessitate higher order mathematical formulations. The individual artistic idiosyncrasies (human element) will further complicate the modeling.

Musical intervals are essentially of two types; harmonic and melodic. Harmonic intervals are formed between two simultaneous notes whereas melodic intervals are formed between two sequential notes (Lloyd, 1963, P125). Melodic intervals constitute a distance, whereas harmonic intervals can be expressed in ratios in the form of m/n for non-zero positive integers (Levarie, 1980, P17). Because melodic intervals do not constitute beating upper partials, mathematical rigidities do not apply to melodic intervals even if the notes are formed from the natural harmonic series (Benade, 1976, P293). This has been amply corroborated psycho-physiologically. For instance, beats do not occur on the basilar membrane (inside the inner ear) between successive notes (Moore, 2003, P227). Musical intervals cannot be defined entirely with harmonic ratios of their frequencies and with physical concordance (zero / minimum beats) of the upper partials. The wholesome process of pitch perception is essential to the understanding of musical intervals. It should be noted that the physical concordance is not the same as the musical consonance (Lloyd, 1963, P136).

3. SOUTH INDIAN MUSICAL INTERVALS

South Indian musical intervals are melodic, as are the intervals of North Indian music. Although mathematical rigidities do not apply to melodic intervals, certain basic intervallic relationships, such as the octave, the fifth, the fourth and the major third hold true for several reasons. The *tambūra* (*tānpūra*), the fret-less stringed instrument that provides the tonic key also provides certain basic natural harmonics such as the octave, the fifth, major third etc. Training with the *tambūra* accompaniment tunes up and conditions the tonotopic [7] organization. The tonotopic pitch mapping in the primary auditory cortex actually alters and firms up upon deliberate learning and training. This tonotopic organization is retained in memory (Weinberger, 1999, P55). And the memory guides the perception of melodic intervals (Burns, 1999, P230), particularly if the delay between the two successive tones is less than about ½ second (Benade, 1976, P288).

Other than these basic harmonic intervals, South Indian musical intervals are basically melodic and are therefore flexible. Since the tonotopic organization is based on pitch and not on frequency (Weinberger, 1999, P62), the intervallic relationships follow individual learning patterns and cultural contexts as opposed to frequencies of the acoustical stimuli. The neuronal responses are driven by the type of stimuli (Pickles, 1988, Chap 7; Moore, 2003, P50) and therefore psycho-physiologically, melodic intervals are pitched and perceived differently from the harmonic intervals and are not solely dependent on the physics of vibrations.

The resonance region on the basilar membrane shifts by the same distance for a given pitch transition regardless of the octave (i.e. frequency range) (Roederer, 1995, P26). That is, we hear logarithmically. The ear's non-linearity has been established physically, physiologically, anatomically (masking and facilitation), psychologically and psycho-acoustically (Komaragiri, 2005, P106). This non-linearity in hearing renders simplistic mathematical ratios, which pertain to pure sinusoids, untenable. Musical intervals have complex waveforms comprising inharmonic upper partials. It may be interesting to point out that combination tones, also sometimes referred to as heterodyne frequencies are created due to the non-linearity in the cochlea (Pickles, 1988, P154). These heterodyne beat frequencies are helpful in the tuning of musical instruments. But they relate to the harmonic partials. As explained above, the composition of the melodic intervals is different from that of the harmonic intervals; the zero-beat condition does not pertain to the melodic intervals.

Musical scale and consonant harmonic intervals are not compatible in an exact sense (Pierce, 2001, P177). That is, the progression of consonant intervals will not lead to the perfect octave. Scale on the other hand is a collection of tempered notes arranged within the octave. Such tempered notes are approximations of the consonant intervals for practical purposes. This is not an issue for equal temperament. But Indian intervals being melodic and therefore being flexible and contextual can be reconciled artistically with the scale of the *rāga* set within the octave. It should however be emphasized that the Indian *rāga*-s are *not* mere scale patterns. They are characterized by melodic intervals and consequently by melodic intonation. In other words, *rāga*-s are characterized by definite pitch profiles. They are not arbitrary. A set of *rāga*-specific reference pitches and pitch profiles can be empirically obtained for specific conditions. Indian melodic intervals transcend rigid pitch fixations in performance.

The focus of this paper is on the departures from fixed frequency values in intonation and not on consonance. But, it may be germane to qualify musical consonance, as intervals of a *rāga* must have musical consonance. Musical consonance has several layers. In a fixed-tonic scale system, the tonic provides the overall reference. All the other notes therefore become intervals with reference to the fixed tonic, provided by the accompanying *tambūra*. The pitch plots presented in Figures 1 through 14 pertain to these intervals. Musical intervals are also perceived between any two notes in mutual relationship. In the rendering of a *rāga*, the melodic intervals between any two notes are pitched with the first of the two notes as the reference. This is one layer of musical consonance. Another layer of musical consonance is that of the intervals within a characteristic phrase. Pitch plots of Figures 13 and 14 give a preliminary glimpse of the intervallic balance. Rao (2000, P81-83) also supported this view for the North Indian music. As already noted above, this does not submit to the frequency fixations of the whole-number ratios. Yet another layer of consonance is the mutual setting of the different phrases within the overall balance of the *rāga*. That is, an inherent balance in the musical intervals, judged aurally, which varies dynamically within the overall *rāga* gestalt. These multiple layers of musical consonance are not hierarchical.

The characteristic phrases of *rāga*-s have recognizable pitch contours. It is pertinent to note that the functional connections among neural cells are not fixed but rather depend on the pattern of tone sequences comprising a contour (Weinberger, 1999, P75). Neuronal groups are responsive to the contour despite the variability in musical intervals within a given contour or a phrase. The responsiveness of the same tone differs from contour to contour, at least in some cases (Weinberger, 1999, P73), indicating that the musical intervals vary contextually rather than merely acoustically. This implies that a particular phrase in a *rāga* or an overall sequence of musical intervals comprising a contour is recognized even if the musical intervals comprising the phrase vary, as long as the overall balance is maintained to preserve the phrase or the contour.

4. EMPIRICAL PITCH ANALYSIS

The pitch plots presented in Figures 1 through 14 have been excerpted from Komaragiri (2005). These pitch plots pertain to the South Indian music. A similar analysis may be extended to the North Indian classical music also. The pitch plots of the figures show the pitch profiles of various *rāga*-s are marked with the following abbreviations: MBK for M Balamurali Krishna (vocal); TNK for T N Krishnan (violin) and NRK for N Ravi Kiran (citra-vina). *Gaula*, *Sāvēri*, *Hindōlaṃ* (or, *Mālkauns*) and *Haṃsānandī* (or, *Sōhini*) are the names of the *rāga*-s presented in this paper. The seven notes in the Indian music are represented by *Sa* (the tonic), *Ri* (the second), *Ga* (the third), *Ma* (the fourth), *Pa* (the fifth), *Dha* (the sixth) and *Ni* (the seventh). The actual names of the musical notes used in the South Indian music are given in the Appendix B. Most modern musicologists have acoustically interpreted the ancient theory of 22-*śruti*-s pertaining to the *grāma* system, deriving 22 harmonic frequency values, measured from *Sa*. These theoretical frequency values are also given in Appendix B.

The pitch plots, presented in Figures 1 through 14, are drawn with pitch in Hertz along the ordinate and time in seconds along the abscissa. The horizontal lines are the expected theoretical values (the acoustical parameters). They are indicated both in frequency ratios and in cents [8]. The measured pitch values are also given in cents, c, for easy comparison. See Appendix B for all the cent values. Table 1 given below summarizes the empirical pitch analysis results. The variability in the mean pitch values and their departures from the acoustical parameters can be clearly seen. The negative sign indicates dipping below the datum *Sa*. The datum *Sa* for MBK was 123 Hz; for TNK, 350 Hz and for NRK, 199 Hz. The variation is datum *Sa* was up to 20 cents. There is variation even in the octave, sometimes measuring less than 1200 cents. The intensities measured were 60 dB, 45 dB and 40 dB for MBK, TNK and NRK respectively.

Table 1: Expected Acoustical Values and Departures

PP No	Mean	Max	Min	Range
***Ri*:** 256/243 = 90 cents & 16/15 = 112 cents				
01	-12	146	-74	220
02	**23**	121	-9	130
03	**24**	74	-5	79
04	**88**	129	9	120
05	**23**	77	-19	96
06	**67**	126	6	120
***Dha*:** 128/81 = 792 cents & 8/5 = 814 cents				
07	**724**	798	687	111
08	**796**	856	745	111
***Ni*:** 16/9 = 996 cents & 9/5 = 1018 cents				
09	**1005**	1025	977	48
10	**1056**	1122	1002	120
***Ni*:** 15/8 = 1088 cents & 243/128 = 1110 cents				
11	**1078**	1129	1032	97
12	**1162**	1214	1111	103

Several combinations of the same artiste rendering the same intervals and different artistes rendering the same intervals are selectively presented here. Figures 1 through 4 show the departure from the acoustical values for the interval *Ri* in the *rāga Gaula*. Intervals are measured from the tonic, *Sa*. The variation in *Ri* is about a semitone. There is variation even within the same musical context (*Ma-Ri-Pa-Ma*). Figures 5 through 8 show similar departures in the intervals *Ri* and *Dha* in the *rāga Sāvēri*. The variation in the two *Dha*-s is about 70 cents but NRK's *Dha* ranged from 724 cents to 817 cents. Figures 9 through 12 show the two varieties of *Ni*, the seventh note. Figure 10 showed a departure of 38 cents above the reference and overshooting the higher *Ni*. This raised pitch is in spite of the downward movement of *Ni* in the musical context *Sa-Ga-Ma-Ni-Dha*. Perceptually, *Ni* is well pitched within the pentatonic *Hindōlaṃ* (or, *Mālkauns*), despite having a quarter tone difference between the two artistes. Figure12 showed a departure of 52 cents above the reference. And this is just 38 cents below the octave. The mean value of the note itself ranged over 54 cents. But such raised pitch did not occur in MBK's rendering in Figure 11. In addition to the variations in the measured mean pitch values for various intervals by various artistes, even for each individual measurement there is a significant range oftentimes covering a semitone (See Table 1). This shows that the characteristic pitch movements (contours) are essential to the Indian *rāga* music instead of the individual pitch values.

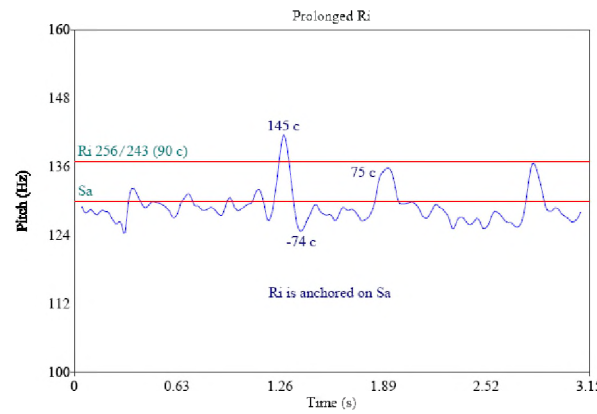


Figure 1. MBK-*Gaula-Ri*

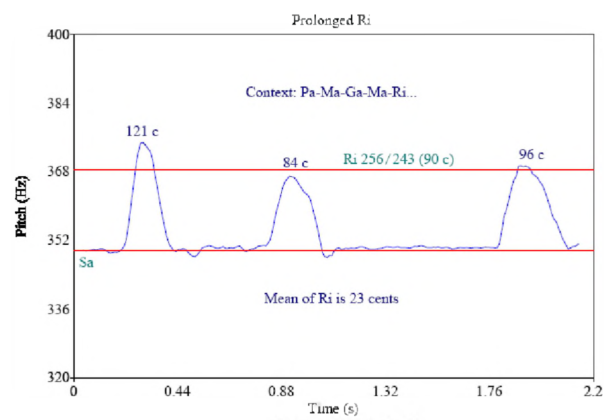


Figure 2. TNK-*Gaula-Ri*

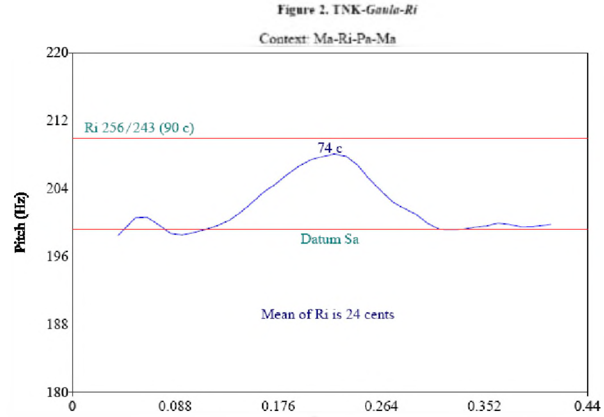


Figure 3. NRK-*Gaula-Ri* - 1

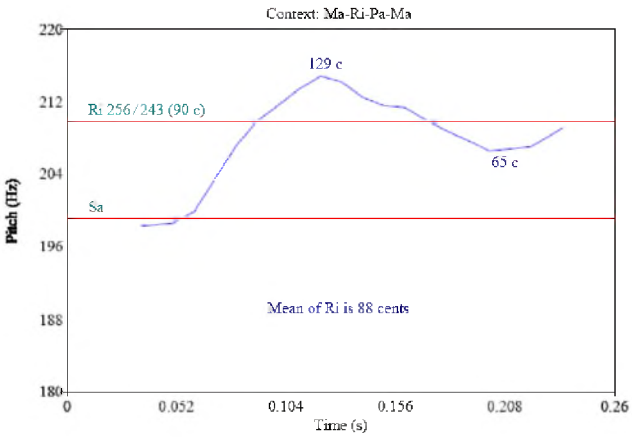


Figure 4. NRK-*Gaula-Ri* - 2

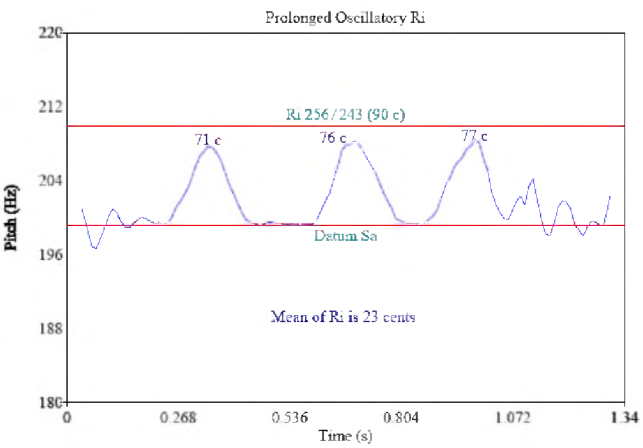


Figure 5. NRK- *Sāvēri–Ri* - 1

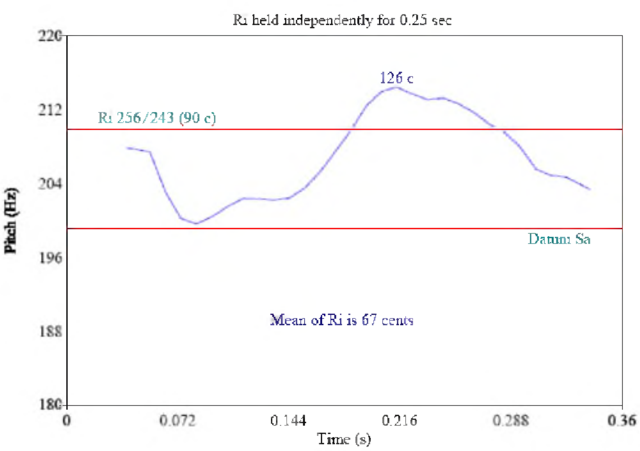


Figure 6. NRK- *Sāvēri–Ri* - 2

In addition to the study of intervals, it is interesting to notice the intervallic balance in similar phrases within the same rendition. For example, Figures 13 and 14 show similar phrases in the same *rāga Gaula,* sung by the same artiste, MBK, in the same rendition. These two plots illustrate the intervallic balance. In Figure 13, *Ri-Ga* measured a mean of 369 cents and *Ga-Ma*, 73 cents. In Figure 14, *Ri-Ga* measured a mean of 333 cents and *Ga-Ma*, 142 cents. That is, in Figure 13, as *Ri-Ga* interval is higher, *Ga-Ma* interval is rendered lower than the corresponding interval in Figure 14, showing a propensity for intervallic balance within similar phrases. Figure 13 depicts the phrase *Ni-Sa-Ri-Ga-Ma-Ri* with a prolonged *Ga* and Figure 14 shows the phrase *Ri-Ga-Ma-Ri* with a shorter *Ga*. And, the difference of 33 cents in the *Ri-Ma* interval between these two phrases, also illustrates the variability in the intonation of these intervals. The datum *Sa* for this particular rendition measured at 130 Hz.

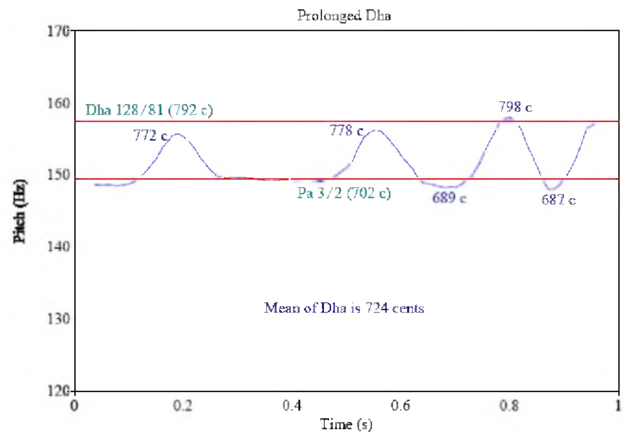


Figure 7. NRK- *Sāvēri–Dha*

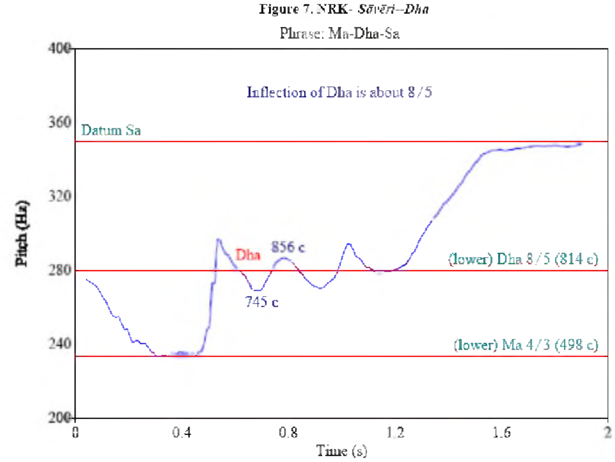


Figure 8. TNK- *Sāvēri–Dha*

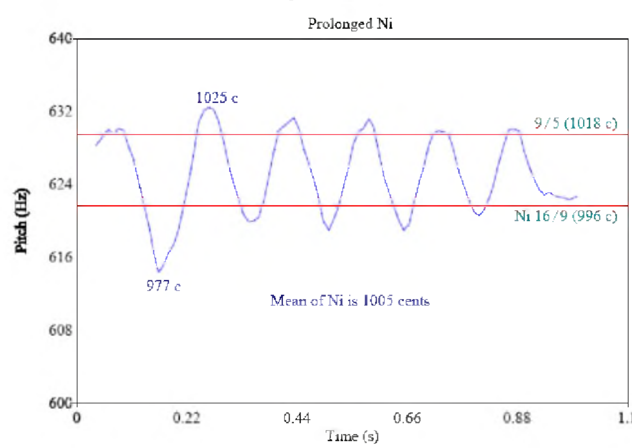


Figure 9. TNK- *Hindōlam-Ni*

This type of intervallic balance can be seen in several other instances. But when such balance is not seen in the immediate context, larger contexts might have to be examined, which is outside the scope of the current paper. It may also be noted here that there is similarity in the overall pitch movements of similar phrases when depicted visually (Subramanian, 2007: P3).

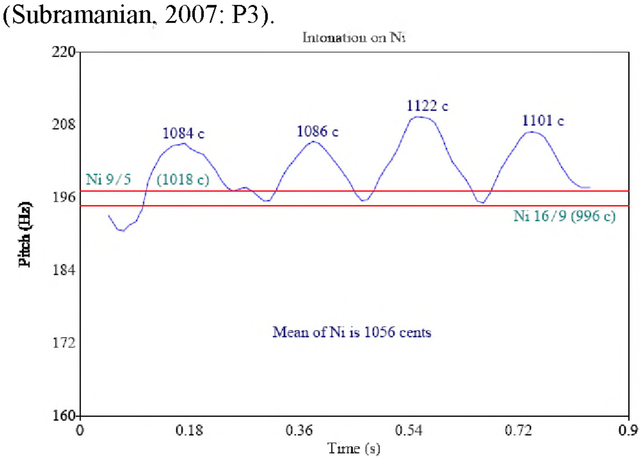


Figure 10. MBK- *Hindōlam-Ni*

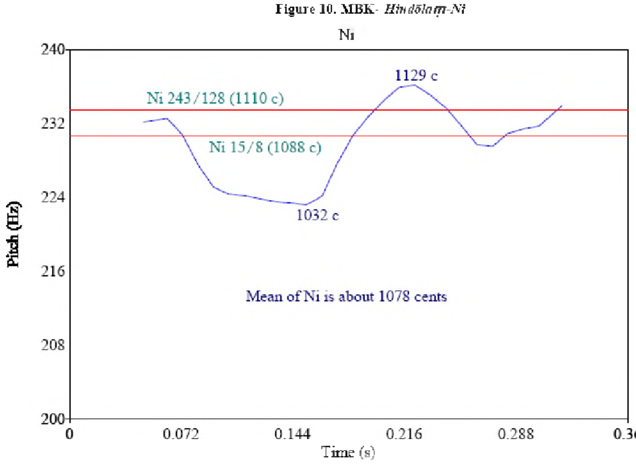


Figure 11. MBK- *Haṃsānandi–Ni*

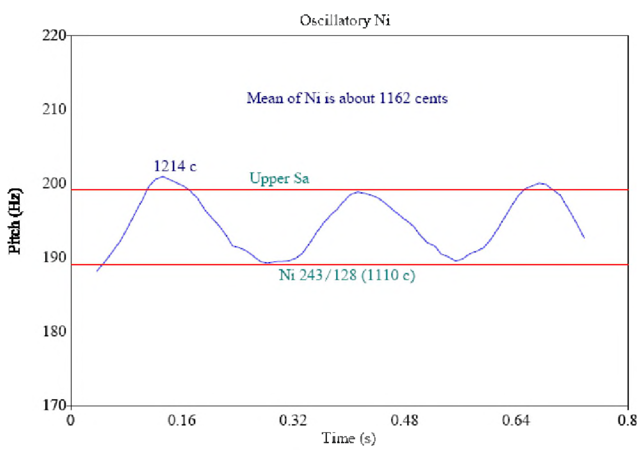


Figure 12. NRK- *Haṃsānandi-Ni*

5. DEPARTURES FROM THE ACOUSTICAL PARAMETERS

Departures from the theoretically calculated acoustical values are clearly demonstrated in the South Indian *rāga* music. The intervals vary dynamically depending upon the artistic individuality and the musical context. The notes are intoned differently in different *rāga*-s and differently in different phrases within the same *rāga*. Different artistes intone the same notes differently in a given *rāga* and differently at different times when repeated. All these different cases constitute different musical contexts. Intonation in the South Indian *rāga* music is not acoustically based; it does not submit to the mathematical rigidities.

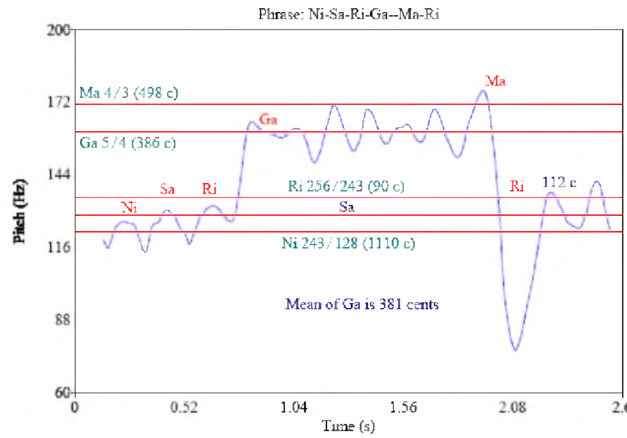


Figure 13. MBK- *Gaula*-Phrase-1

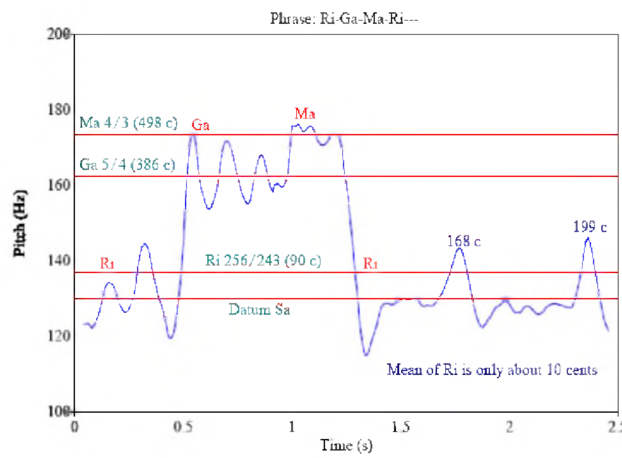


Figure 14. MBK- *Gaula*-Phrase-2

The inverse relationship between periodicity (time) and frequency (pitch) places an unavoidable restriction on the precision of pitch measurement and perception and therefore on the intonation. Physiologically also there is inverse relation between temporal and spatial resolutions (Winckel, 1967, P5 & P121). Further, the sensitivity areas of say, the two types of thirds overlap and as a result, depending upon the context, either of the two types of the third is perceived (Winckel, 1967, P124-125). That is, in the absence of one whole tone, it would be very difficult to know precisely which of the two whole tones is being perceived (Levarie, 1980, P203). Therefore the distinction between any two types of the whole tones, 9/8 and 10/9, for example, is unrealistic because of the uncertainty in the perception of their intervallic relationships in an absolute sense. Such uncertainty defies mathematical precision. The pitch plots presented above illustrate this succinctly.

The process of determining a melodic interval is not a basic sensory process, but it involves memory and learning within a cultural context. There is considerable latitude in the acceptance of melodic intervals as they carry the appropriate melodic information within this latitude (Burns, 1999, P231). In Indian music, the accompaniment of *tambūra* (*tānpūra*) restricts this latitude for certain basic harmonic intervals such as the octave and the fifth.

The accompaniment of the *tambūra* guides intonation as indicated above. The *tambūra* might have been introduced around the fifteenth century (Deva, 1981, P61). The modern-day *tambūra* has a curved bridge and the strings pass over a thread, called the *jīvam* or *juari*. As a result, the strings actually leave the bridge and make contact again repeatedly (Modak, 1977, P8). Thus the string length continually changes, resulting in a continual change in the fundamental frequency. Variations in the fundamental are between 0.5 to 1% (Modak, 1977, P14). Addition of this thread decreases the strength of the fundamental in relation to the harmonics, as also pointed out by C.V. Raman and Modak. The fundamental is not always dominant and at times can even be missing (Deva, 1981, P32). Deva says that the 3rd and the 5th harmonics are the strongest. Spurts of certain partials (harmonic and inharmonic) can be heard as well (Deva, 1981, P35). When the fundamental is missing, the ear will provide it because of the non-linear nature in its perception (Roederer, 1995, P45). Modak had shown that the fundamental and the harmonics build and decay at different rates and that the phase difference between them continually changes. As a result of phase fluctuations, even the second harmonic, which is the octave, is not exactly in the ratio of 2:1, and is out of phase with the fundamental. This is attributed to the curved shape of the bridge. Raman CV (1921, P471) had shown that the strings of the *tambūra* do not obey Young and Helmholtz law [9]. The *tambūra* seems to produce an envelope of continually changing inharmonic partials. The *tambūra* however demands a final resolution to the tonic.

The inharmonicity in the accompanying *tambūra* is one of the reasons why precise harmonic frequency ratios lose meaning. Tempering of the pitches of the musical notes is necessitated by the idiomatic requirements of the music under study. Acceptance of musical intervals depends on cultural conditioning.

Intonation is guided by the tonotopic organization in the brain. The functional connectivity among the neural cells varies dynamically with the acoustical contexts (Weinberger, 1999, P81). The complex non-linearity in hearing along with the process of pitch perception within the context of cultural particularities culminating in the cognition of pitch in the tonotopic organization in the primary auditory cortex renders simplistic linear models unrealistic. And hence, acoustical parameters such as frequency and concordance must be replaced by their counterparts in pitch and musical consonance. A holistic approach is essential to the understanding of the musical phenomena.

6. CONCLUSION

The modern theory of intonation in South Indian *rāga* music calls for fixed frequency values for the 22 divisions of the octave, called *śruti*-s. These modern theories of pitch fixation have been attributed to Bharata for authenticity. But the ancient concept of *śruti* is not applicable to the current system of *rāga* music. The prevailing theory also places these fixed *śruti*-s among the various *rāga*-s in vogue today. Empirical pitch analysis of South Indian *rāga* music presented in this paper clearly shows that the pitching of the musical intervals varies dynamically and does not submit to the mathematical rigidities imposed by the acoustical interpretations of the modern theories of 22 *śruti*-s. South Indian *rāga* music employs flexible melodic intervals. The musical pitches are not fixed unitary quantities but they do have definite characteristic pitch profiles. The mean pitch values aren't unique either. The multiple mean pitch values demonstrate departures from the theoretically proposed frequency values. The intonation is not acoustically based and therefore transcends the acoustical parameters; intonation is psycho-physiologically driven. A holistic approach involving the dynamic process of pitch perception and the cultural context are necessary to uncover this fact.

ACKNOWLEDGEMENTS

I would like to acknowledge the review and inputs from Professor N. Ramanathan, retired HOD, Department of Indian Music, Madras University, Chennai, Mr. M. Subramanian, research scholar in Indian musical acoustics, Chennai and Prof. Lewis Rowell, Indiana University, Bloomington, USA. I also wish to thank Mr. David Weenink and Mr. Paul Boersma of the Institute of Phonetic Sciences, University of Amsterdam, for developing an excellent pitch analysis software tool called **Praat**, and allowing me to use it.

REFERENCES

Barbour, J. Murray (1953). *Tuning and Temperament*. Michigan State College Press.

Benade, H. A. (1976). *Fundamentals of Musical Acoustics*. Oxford University Press. New York.

Burns, E. M. (1999). "Intervals, Scales, and Tuning." In Deutsch, D. Ed. *The Psychology of Music*, 2nd ed. New York: Academic Press.

Deva, B.C. (1981). *The Music of India: A Scientific Study*. Munshiram Manoharlal Publishers Pvt. Ltd. India.

Komaragiri, M (2005). *Pitch Analysis in Karṇāṭaka Music - An Examination of Intonation and Modern Theories of 22 Śruti*-s. Doctoral Dissertation. Department of Indian Music, Madras University, Chennai, India.

Levarie, S. & Levy, E. (1980). Tone – A Study in Musical Acoustics. 2nd Ed. Kent State University Press. U.S.A.

Lloyd, S. Ll. (1963). *Intervals, Scales and Temperaments*. Macdonald, London.

Modak, H. V. (1977). "Physics of Tanpura: Some Invstigation." In *Workshop on Tanpura*. Organized by ITC-SRA (Western Region) 6th July 1977 at NCPA. Mumbai.

Moore, B.C.J. (2003). *An Introduction to the Psychology of Hearing*, 5th ed. London: Academic Press.

Pickles, O. J. (1988). *An Introduction to the Physiology of Hearing*. 2nd ed. Academic Press. London.

Pierce, J. (2001). "Consonance and Scales." In Cook, P. R. Ed. *Music, Cognition, and Computerized Sound: An Introduction to Psychoacoustics*. Cambridge: The MIT Press.

Powers, **H** (1970). "An Historical and Comparative Approach to the Classification of Raga-s (With an Appendix on Ancient Indian Tunings)." In Selected Reports Vol. 1, No. 3, Pp 2 – 78, Institute of Ethnomusicology, University of California, Los Angeles, California.

Raman, C.V. (1921). "On Some Indian Stringed Instruments." Proc. Indian Assoc. Cultiv. Sci. 7 29 – 33. In Ramaseshan, S. Ed. *Scientific Papers of C.V. Raman*. Vol. II. Acoustics. 1988. Indian Academy of Sciences. Bangalore.

Rao, S. (2000). *Acoustical Perspective on Raga-Rasa Theory*. Munshiram Manoharlal Pub. Pvt. Ltd. New Delhi.

Roederer, G. Juan (1995). *The Physics and Psychophysics of Music – An Introduction*. 3rd ed. Springer-Verlag, New York.

Rowell, L. (1992). *Music and Musical Thought in Early India*. The University of Chicago Press, Chicago and London.

Sathyanarayana, R. (1970). "Sruti: The Scalic Foundation" Sangeet Natak no. 17. pp 58-74.

Subramanian M (2007). "Carnatic Ragam Thodi: Pitch Analysis of Notes and Gamakams." Journal of the Sangeet Natak Akademi, New Delhi, India Vol. XLI, No. 1; pages 3-28, 2007.

Weinberger, N. M. (1999). "Music and the Auditory System." In Deutsch, D. Ed. *The Psychology of Music*, 2nd ed. New York: Academic Press.

Winckel, F. (1967). *Music, Sound and Sensation: A Modern Exposition*. New York: Dover Publications, Inc.

APPENDIX A - EXPLANATORY NOTES (for superscripted numerals)

1. The word 'Acoustic' implies determining musical intervals based on the natural harmonic series and / or on some kind of progression of cycles of fifths, fourths and thirds, leading to a mathematical formulation of musical intervals. This is a Western import. Most modern scholars have used this approach to calculate the 22 *śruti*-s elucidated by Bharata in the *Nāṭyaśāstra*. The ancients however did not employ this acoustical approach to position the 7 *svara*-s. [Abstract]
2. *Tambūra* is a fretless 4-stringed pitch instrument strum to provide the tonic and an envelope of partials to guide intonation. [Sections 1 & 5]
3. Several ancient musical treatises in Sanskrit language like the *Nāṭyaśāstra* of Bharata, *Dattilam* of Dattila, *Bṛhaddeśī* of Mataṅga and others talk about the theory of 22 *śruti*-s. According to this theory (applied to the old and now non-functional fixed-interval *grāma* system) there are 22 *śruti*-s to the octave. The intervallic arrangement in the *ṣaḍja-grāma* or the *Sa-grāma* is as follows: the third (*Ga*) and the seventh (*Ni*) notes have two *śruti*-s each, the second (*Ri*) and the sixth (*Dha*) notes have three *śruti*-s each and the first (tonic - *Sa*), the fourth (*Ma*) and the fifth (*Pa*) notes have four *śruti*-s each in them, totaling 22 *śruti*-s. Changing the *grāma* would change this intervallic arrangement. For instance, in the *madhyama-grāma* or the *Ma-grāma* the fifth note becomes a three-*śruti*-ed interval and the sixth note a four-*śruti*-ed interval. [Section 2]
4. Modern scholars such as K.B. Deval, E. Clements, F. Strangways, Abraham Pandither, B.C. Deva, Alain Daniélou, G.H. Ranade, F. Framjee, C.S. Ayyar, H.V. Modak, S. Ramanathan, P. Sambamurthy and several others are votaries of the 22-*śruti* theory**;** noted exceptions are N. Jairazbhoy, M. Levy, H. Powers, N. Ramanathan etc. (Komaragiri, 2005: P69) [Section 2]
5. Veṅkaṭamakhī was the celebrated author of the musical treatise, *Caturdaṇḍiprakāśikā*, written in the seventeenth century. [Section 2]
6. In the South Indian system of music, the 12 notes are conceived as 16 notes. The four additional notes are enharmonic. For example, the minor third is also taken as the enharmonic equivalent of the augmented major second. [Section 2]
7. Tonotopic organization is the characteristic pitch mapping in the primary auditory cortex (brain). These pitch maps actually alter upon deliberate learning and training. This guides the intonation. [Section 3]
8. Cent is a unit of octave measurement. It divides each semitone into 100 equal parts and the octave into 1200 equal parts. This was introduced by Englishman, J. Ellis in the 19th century in the context of equal temperament. One cent, $C = 2^{1/1200} = \sqrt[1200]{2}$ and therefore N cents = 2

$^{N/1200}$. To find the number of cents, N, in any frequency ratio, R, the formula to use is 3986 * log R to the base 10 [i.e., C = (1200/log 2) * log R]. For example, cents of the fifth note, *Pa* = 3986 * log (3/2) ≈ 702 cents. Working with cents enables multiplication to be converted into addition for easy comparison. [Section 4]

9. Young and Helmholtz law states that if a string is plucked at a point of *aliquot division*, the harmonics having a *node* at the point of excitation should be entirely absent. But the *tambūra* defies this law according to C. V. Raman (1921, P471). *Aliquot* means forming an exact proper divisor, for example: an aliquot part of 15 is 5. And, *node* is a point where the amplitude of a (standing) wave is zero, i.e. a point where there is no vibration. [Section 5]

APPENDIX B - Table of Modern *Śruti* Values with *Sa* = 1

These are the commonly accepted *śruti* (frequency) values given by the modern scholars[4]. These figures are collated from various authors (Komaragiri, 2005: Appendix C). There are many other values. Sathyanarayana (1970: P70) says that there are about 250 values suggested so far. Scholars tried to hypothesis the existence of these frequencies among the different *rāga*-s. The horizontal lines in the pitch plots given in this paper indicate these expected values. Typically, the two varieties of a *svara* are separated by 22 cents. All the cent values are rounded off.

Svara (Note)	Symbol	The 22 *Śruti* Divisions	Frequency	Cents
ṛṣabha	*Ri* [Second Note]	*śuddha ṛṣabha*-1	256/243	90
		śuddha ṛṣabha-2	16/15	112
		catuḥ śruti ṛṣabha-1	10/9	182
		catuḥ śruti ṛṣabha-2	9/8	204
gāndhāra	*Ga* [Third Note]	*sādhāraṇa gāndhāra*-1	32/27	294
		sādhāraṇa gāndhāra-2	6/5	316
		antara gāndhāra-1	5/4	386
		antara gāndhāra-2	81/64	408
madhyama	*Ma* [Fourth Note]	*śuddha madhyama*-1	4/3	498
		śuddha madhyama-2	27/20	520
		prati madhyama-1	45/32	590
		prati madhyama-2	64/45	610
pañcama	*Pa* [Fifth Note]	*Pañcama*	3/2	702
dhaivata	*Dha* [Sixth Note]	*śuddha dhaivata*-1	128/81	792
		śuddha dhaivata-2	8/5	814
		catuḥ śruti dhaivata-1	5/3	884
		catuḥ śruti dhaivata-2	27/16	906
niṣāda	*Ni* [Seventh Note]	*kaiśika niṣāda*-1	16/9	996
		kaiśika niṣāda-2	9/5	1018
		kākalī niṣāda-1	15/8	1088
		kākalī niṣāda-2	243/128	1110
ṣadja	*Sa* [Tonic]	*tāra ṣadja*	2/1	1200

SPECTROGRAM ANALYSIS OF CIRCUMFERENTIAL MODES PROPAGATING AROUND THE CIRCULAR CYLINDRICAL SHELL IMMERSED IN WATER

M. Laaboubi[1], A. Dliou[1,2], R. Latif[1,2], E. Aassif[1], G. Maze[3]
[1] LMTI, Laboratoire de Métrologie et Traitement d'Information, Ibn Zohr University, Agadir, Morocco,
[2] ESSI-ENSA, École Nationale des Sciences Appliquées, Ibn Zohr University, Agadir, Morocco,
[3] LOMC, Laboratoire Ondes et Milieux Complexes FRE CNRS 3201, Le Havre University, Le Havre, France.

ABSTRACT

In this study, we show that the characterization of an elastic tube can be made from the cut-off frequencies of the circumferential waves and the wave velocities in the material constituting the tube. The time-frequency spectrogram is applied to an acoustic signal backscattered by an Aluminum tube for identification of circumferential wave. The cut-off frequencies of the each circumferential wave modes such as A_1, A_2 (Antisymmetric modes) and S_1 (Symmetric mode) are estimated from the spectrogram images, and are compared with those calculated via the normal modes theory. The transverse and the longitudinal velocities of Aluminum material, determined from the spectrogram images, are in good agreement with those given in the scientific literature.

RESUME

Dans ce travail, nous exposons la possibilité de mettre œuvre la caractérisation d'un tube élastique à partir de la fréquence de coupure des ondes circonférentielles et des vitesses des ondes propageant dans le matériau constituant le tube. La représentation temps-fréquence de Spectrogramme est appliquée à un signal acoustique rétrodiffusé par un tube d'Aluminium afin de pouvoir identifier les ondes circonférentielle. La fréquence de coupure de chaque mode d'onde circonférentielle tels que : A1, A2 (modes antisymétriques) et S1 (mode symétrique) sont estimées à partir des images temps-fréquence de Spectrogramme puis elles sont comparées avec celles calculées par la théorie des modes propres. Les vitesses transversales et longitudinales du matériau en Aluminium, déterminées à partir des images temps-fréquence, sont en bon accord avec celles données dans la littérature scientifique.

1. INTRODUCTION

Previous theoretical and experimental studies on the acoustic scattering field have shown that the acoustic resonances of a simple shape target (plate, cylinder, tube…) depend on its physical and geometrical characteristics. The analysis of the acoustic signals backscattered by a target is done either in the frequency domain using the Fourier transform (backscattered spectrum and/or resonance spectrum) or in the time domain (observation of the form and the periodicity of the echoes) [1-12]. These two one-dimensional representations prove to be insufficient to visualize the frequential components evolution versus the time, to observe the circumferential waves trajectories and obtain directly their cut-off frequencies. Latif et. al. have analyzed the signal by the time-frequency Wigner-Ville representation which takes into consideration both the time t and frequency f of the acoustic signal [13]. This analysis is focused to determine the cut-off frequency of the circumferential anti-symmetric wave A_1 and study the evolution of this frequency as a function of the radius ratio b/a of a tube (b: internal radius and a: external radius).

The present paper is especially concerned with the application of an alternate time-frequency representation called Spectrogram. The new study will extend the work started on an earlier study by the time-frequency Wigner-Ville technique and improve the limitation of the earlier study of Refeerncfe13. The time-frequency spectrogram representation has been chosen as it will decrease the number of cross-term components, a principal drawback of the time-frequency Wigner-Ville technique [14-22]. The new representation has been used to determine the cut-off frequency of circumferential waves such as A_1, A_2 (Antisymmetric modes) and S_1 (Symmetric mode) and calculate the transverse and longitudinal velocities of the tube material.

The spectrogram representation allows one to obtain a synthetic circumferential waves dispersion image and determine, directly, physical and geometrical parameters. The spectrogram representation is applied to analyze a theoretical acoustic signal backscattered by an aluminum tube of radius ratio b/a immersed in water. The aim of this study was to test the spectrogram effectiveness and accuracy in determining the circumferential wave cut-off frequencies as well as to compare the transverse and the longitudinal velocities derived from the spectrogram analysis with those derived from the theory. When the wall of the cylindrical shell is thin (radius ratio b/a tends to 1) the circumferential waves are identical to the Lamb waves [23-29]. The cut-off frequencies of these waves are first determined from the spectrogram image and then the velocities of these waves of the tube material are then calculated. These velocities are then compared with those calculated by the normal modes theory [13, 30].

2. THEORETICAL BACKGROUND

2.1 Time-frequency representation of the spectrogram

The Short Time Fourier Transform (STFT) can be interpreted as a Fourier analysis of successive sections of the signal weighted by a temporal window such as Gabor, Hamming, and Blackman. The expression of the STFT is given by [14,15,31,32]:

$$STFT(t,f)=\int_{-\infty}^{+\infty} s(\tau)h_{t,f}^{*}(\tau)d\tau=\int_{-\infty}^{+\infty} s(\tau)h^{*}(\tau-t)e^{-2\pi i f\tau}d\tau \qquad (1)$$

where, $h_{t,f}^{*}(\tau)$ is the complex conjugate of the analysis window $h_{t,f}(\tau)$, t the time, f the frequency, τ the integral variable, s(t) the temporal signal. This relation represents the scalar product between the signal *s(t)* and the function $h_{t,f}(\tau)$. In practice, the Spectrogram (*SP*) is the squared modulus of the STFT and is given by [14, 15,17,18]:

$$SP(t,f)=\left|STFT(t,f)\right|^{2} \qquad (2)$$

The integral of the *SP(t,f)* with respect to the frequency yields produces the instantaneous signal power P [15]:

$$P=\int_{-\infty}^{+\infty} SP(t,f)df=\left|s(t)\right|^{2} \qquad (3)$$

The time integral of the *SP(t,f)* produces the signal power density spectrum D :

$$D=\int_{-\infty}^{+\infty} SP(t,f)dt=\left|S(f)\right|^{2} \qquad (4)$$

where *S(f)* is the Fourier transform of the signal *s(t)*.

With regard to numerical calculations, one won't be able to reach the true spectrogram distribution. To resolve this problem, numerically, we use the discrete time version of this distribution SP_S. The distribution expression is given by [14,15]:

$$SP_{s}(n,f)=\left|\sum_{k=-N+1}^{N-1} h^{*}[k]\; s[n+k]\; e^{-2\pi i f k}\right|^{2} \qquad (5)$$

where n is the sampled time, 2N+1 is the smooth window length and k = -N+1,…,N-1.

2.2. Acoustic scattering by an elastic cylinder

The study of the acoustic scattering by targets of simple geometrical shape is the object of many works [1-12]. In this paper we will use a plane harmonic wave incident on an infinite tube of radius ratio, *b/a*„ with an air-filled cavity (Fig. 1). The mathematical approach of impulse response of tube is based on the Rayleigh series formations that consist in the decomposition of the backscattered pressure field into infinite sum of modal components [8], depending on both the mechanical properties and the geometry of the target.

The general geometry for the backscattering of a plane wave by a tube is illustrated in Figure 1.

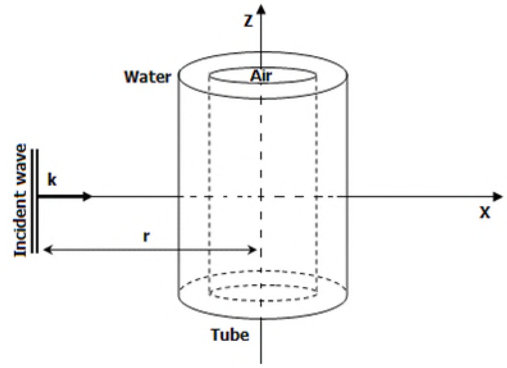


Figure 1. Problem Geometry.

The mechanisms of the echo formation of the circumferential waves and the Sholte wave are shown in Figure 2 [33,34]. Scholte waves are acoustic waves propagating at a fluid/solid interface. They are localized in the neighborhood of the phase boundary in the sense that they decay exponentially in both directions along the normal to the interface [35].

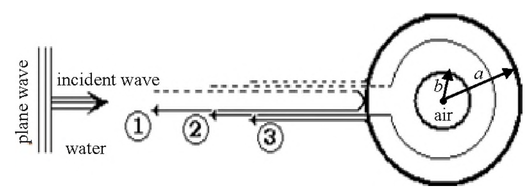


Figure 2. Mechanisms of the echo formation
(1- specular reflection, 2- circumferential waves and 3- Scholte wave)

The different echoes, of the circumferential waves and the Sholte wave presented in the Figure 2, constitute the backscattering complex pressure. This complex pressure in far filled of the cylindrical shell immersed in water (Fig. 1) is given by the expression [1,4]:

$$P_{scat}(\omega)=P_{0}\sum_{n=0}^{\infty}\frac{D_{n}^{[1]}(\omega)}{D_{n}(\omega)}H_{n}^{(1)}(kr) \qquad (6)$$

where ω is angular frequency, $k=\omega/c$ is the wave number with respect to wave velocity in the external fluid and *c* is the sound velocity in water. P_0 is the plane incident wave amplitude and *r* is the receiver position. $D_{n}(\omega)$ and $D_{n}^{[1]}(\omega)$ are determinants computed from the boundary conditions of the problem (continuity of radial stress and displacements of both interfaces). $H_n^1(kr)$ is the Hankel function of the first kind.

With the mechanism above (Fig. 2), we store the backscattering complex pressure P_{scat}, as illustrated in Figure 4.

2.3 Lamb wave dispersion

In this work, we have used a thin tube with radius ratio b/a=0.95 close to 1. From the similarities between the plates and the thin tubes with the same thickness we have used the dispersion curves relationships of the lamb wave propagating in the plate [13,30,36]. Figure 3 presents the dispersion curves of symmetric and antisymmetric Lamb waves in an aluminum plate.

The phase velocity is calculated from the resonance frequencies that correspond to Lamb waves propagating in the plate. Thus from each resonance frequency, an integer number of wavelengths fits the thickness of the plate, and the following relation holds [35] :

$$C_{ph}(f) = \frac{2\pi fe}{n} \quad (7)$$

where n is the Lamb wave mode.

The function of the dimensionless frequency ka is defined by the expression below [2,9]:

$$ka = \frac{2\pi fa}{c} \quad (8)$$

For a thin tube wall, it can be shown that the plate Lamb wave and the tube circumferential wave are similar at very low frequencies [37]. The reduced frequency *fe/2* (where *(fe/2)* is the frequency-thickness product for a plate in MHz, *e* is the plate thickness in mm (*e=a-b*)) used to calculate these curves are related to the dimensionless frequency used in the case of cylindrical shell with the relation [13,30]:

$$ka = \frac{4\pi}{c(1-\frac{b}{a})} f \frac{e}{2} \quad (9)$$

Due to the similarity between the circumferential waves and Lamb waves, it is possible to use the classical relations on the Lamb waves. These relations allow us to determine the value of the cut-off frequency of the circumferential wave in the case of a tube [37-39]. In the case of a thin plate, the cut-off frequencies of the symmetric and anti-symmetric Lamb waves are provided, respectively using the dispersion curve of Lamb wave on a plate [13,20-22]:

$$fe = \begin{cases} m_s\, c_T \\ (m_s + \frac{1}{2})\, c_L \end{cases} \quad (10)$$

$$fe = \begin{cases} m_a\, c_L \\ (m_a + \frac{1}{2})\, c_T \end{cases} \quad (11)$$

where c_T and c_L are transverse and longitudinal velocities of the material constituting the tube. m_s and m_a are the integer numbers indicating symmetric and anti-symmetric modes of plate vibrations respectively. From equations (9), (10) and (11) we determine the relation between the cut-off frequencies (ka) and the transverse velocity c_T and the longitudinal velocity c_L.

$$ka = \frac{2\pi}{c(1-\frac{b}{a})} \begin{cases} m_s\, c_T \\ (m_s + \frac{1}{2})\, c_L \end{cases} \quad (12)$$

$$ka = \frac{2\pi}{c(1-\frac{b}{a})} \begin{cases} m_a\, c_L \\ (m_a + \frac{1}{2})\, c_T \end{cases} \quad (13)$$

The cut-off frequency of the A1, S2, S1 and A2 Lamb waves are calculated with the relation (10) and (11) determined from Figure 3 (the cut-off frequency of each Lamb wave is indicated by a vertical arrow). Table 1 gives these cutoff frequencies and their relations with the cutoff frequencies observed in the case of cylindrical shells, calculated with the relation (9).

3. Method

3.1 The backscattering spectrum

Figure 4 illustrates the theoretical backscattering spectrum of an air-filled aluminum tube immersed in water, which is obtained theoretically by the expression (6).

3.2 The synthetic time-domain signal and the resonance spectrum

The backscattering spectrum in Figure 4 shows that it is broad-band in nature but with abrupt shape transitions corresponding to resonances.

The time signal $s(t)$ of a tube is calculated by the inverse Fourier transform of the backscattering spectrum.

$$s(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} h(\omega) P_{scat}(\omega) e^{i\omega t} d\omega \quad (8)$$

where $h(\omega)$ is the pass-band of the transducer.

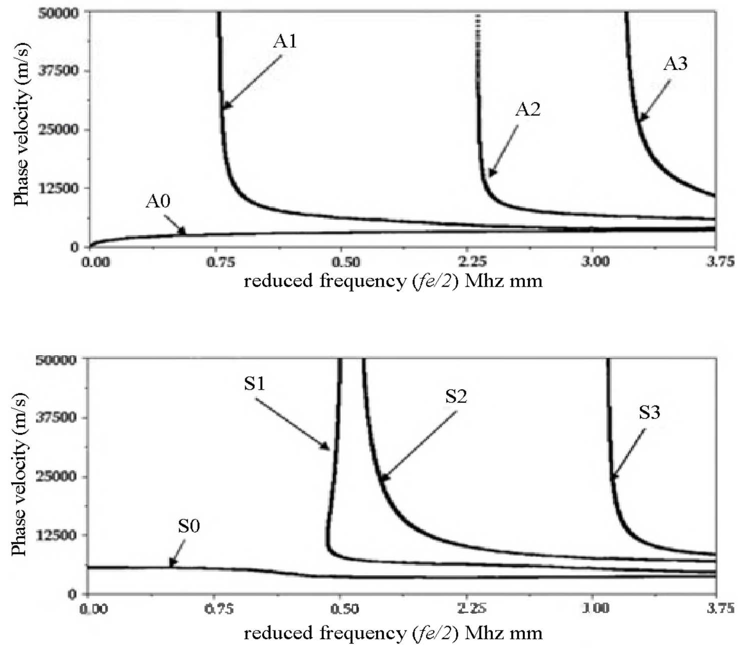
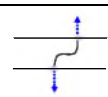
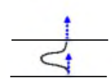


Figure 3. Dispersion curves of symmetric and antisymmetric Lamb waves in an aluminum plate

Table 1. Cutoff frequency of Lamb waves in plate and in cylindrical shells (m_a and m_s are integer numbers)

Lamb wave type	Form vibration modes		*fe/2* (MHz mm)	*ka*
A1	m_a=1		0. 775 ± 0. 020	132. 24 ± 3. 41
S1	m_s=1		1. 550 ± 0. 020	264. 87 ± 3. 41
S2	m_s=2		1. 595 ± 0. 020	272. 56 ± 3. 41
A2	m_a=2		2. 325 ± 0. 020	397. 30 ± 3. 41

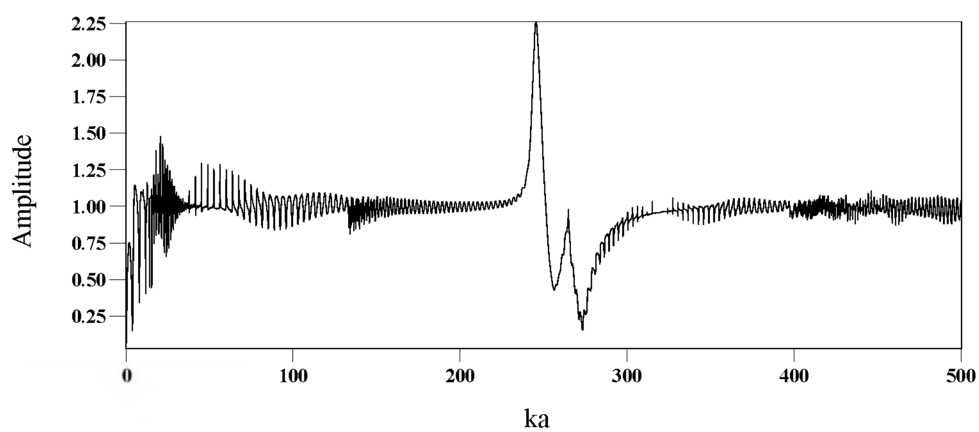


Figure 4. Backscattering spectrum of an air-filled aluminum cylindrical shell immersed in water, b/a = 0.95, a=3cm.

The resonance spectrum is obtained as follows: first a theoretical temporal signal is calculated from the backscattered spectrum with an inverse Fourier transform, it corresponds to the time signal observed when the tube is excited with a broadband impulse (Fig. 5a); on this time signal, various echoes related to the circumferential waves are observed, second the specular echo related to the reflection on the tube is deleted with a Personal Computer and replaced by zeros (Fig. 5b); third a new Fourier transform is applied to the filtered time signal. The resulting resonance spectrum is shown in Figure 6. For each transition in Figure 4, a peak resonance is observed in Figure 6. Resonances which appear on the backscattering resonance spectrum (Fig. 6) are related to the circumferential waves propagating around the tube circumference [40].

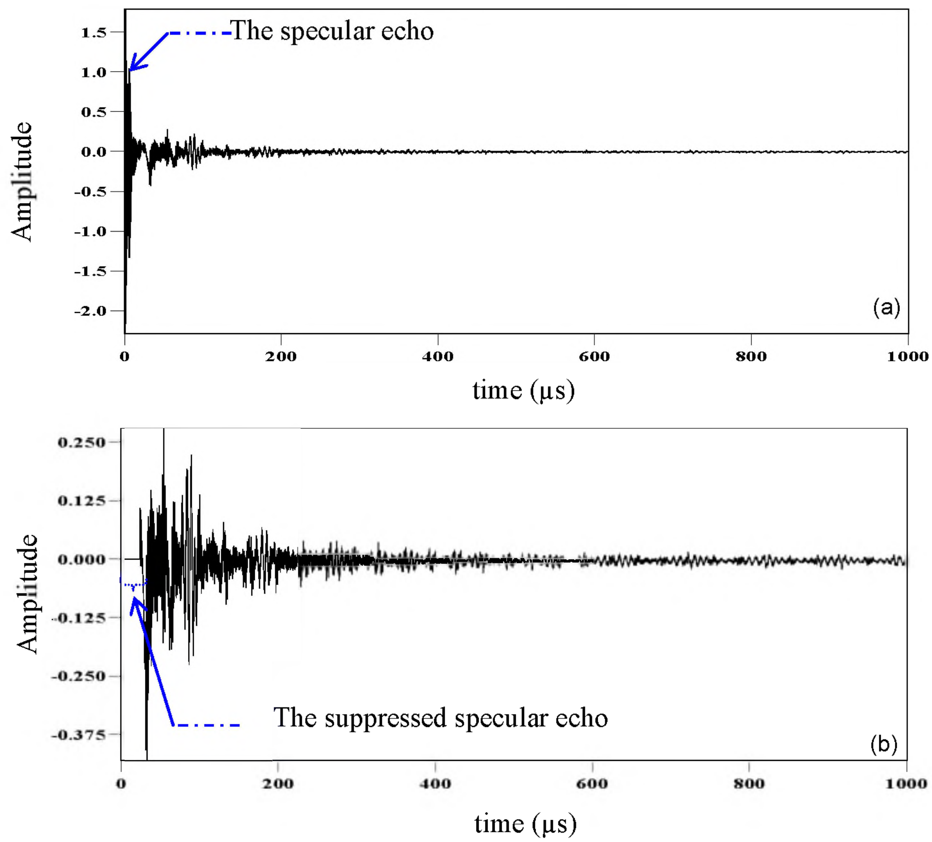


Figure 5. Temporal signal of an aluminum tube b/a=0.95, (a) is the global signal and (b) is the signal (a) with deleted specular echo.

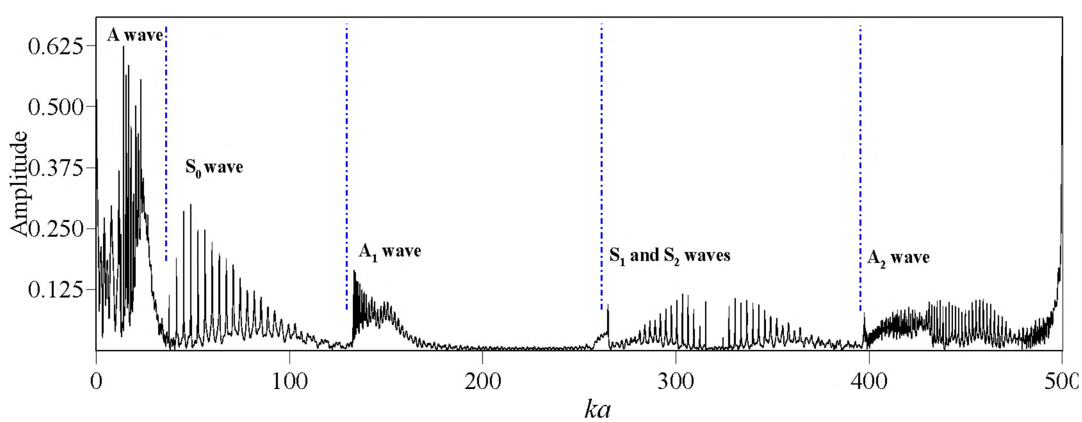


Figure 6. Resonance spectrum of an air-filled aluminum cylindrical shell immersed in water, b/a = 0.95, a=3cm.

Different families of resonances are observed from Figure 6, such as,

- A1 wave resonances at frequency, *ka* =132,
- S1 wave resonances at frequency, *ka* = 260,
- S2 wave resonances at frequency, *ka* = 270,
- A2 wave resonances at frequency, *ka* = 397.

3.3 Spectrogram images

The time-frequency method is a representation that allows a two dimensional characterization of the signal projection. Thus, one can follow the spectrum content's temporal evolution of the circumferential waves propagating around the tube circumference [4,21,22]. The spectrogram distribution from Eq. 5 is applied to the temporal signal backscattered by an air-filled aluminum tube with b/a = 0.95.

Figure 7 shows the time-frequency spectrogram image of the theoretical temporal signal using a Blackman window of 200 points (Fig. 5b). This representation illustrates the synthetic image of the multimode related to the circumferential waves such as S_0, A_1, S_1, S_2 and A_2 which appear in the signal.

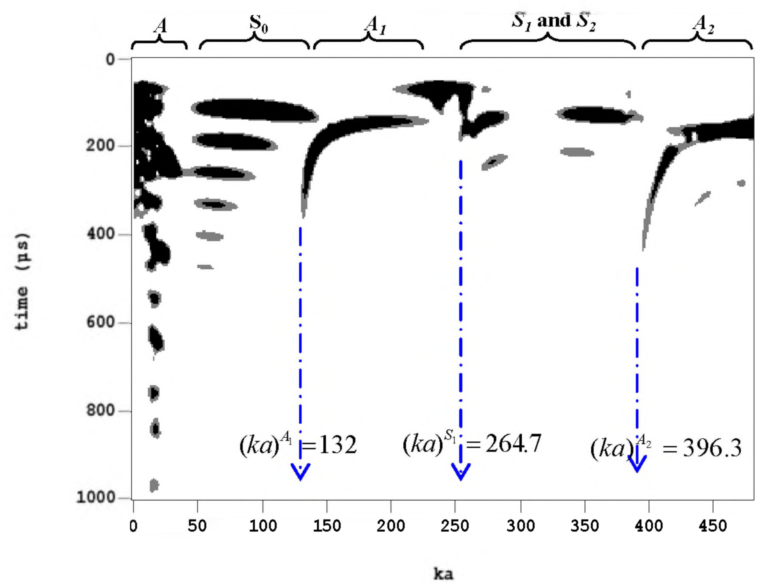


Figure 7. Spectrogram time-frequency image of the theoretical temporal signal (Blackman window of the 200 points).

Applying a digital filter on the spectrum (Figure 6), allow us to extract the spectrum for each circumferential wave mode. The application of the inverse Fourier transform to different spectrums acquired by the digital filtering provides temporal signals corresponding to different mode wave (Figures 8.a, 9.a, 10.a and 11.a). Figures 8, 9, 10 and 11 present the spectrogram synthetic images for the anti-symmetric and symmetric waves S_0, A_1, S_1 and A_2 respectively with Blackman window of 200 points.

These figures present also the original temporal signals (figures 8a, 9a, 10a and 11a), from which the Spectrogram images were obtained (figures 8b, 9b, 10b and 11b), and the resonance spectrums correspondents (figures 8c, 9c, 10c and 11c).

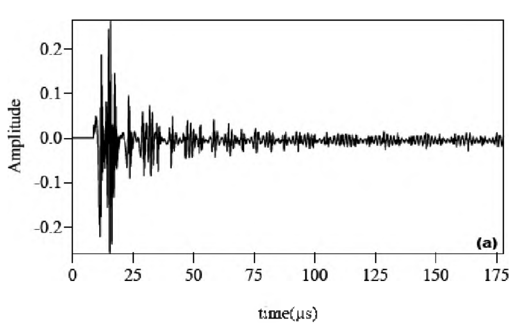


Figure 8 (a) Time Signal of Scholte A and the symmetric S_0 waves

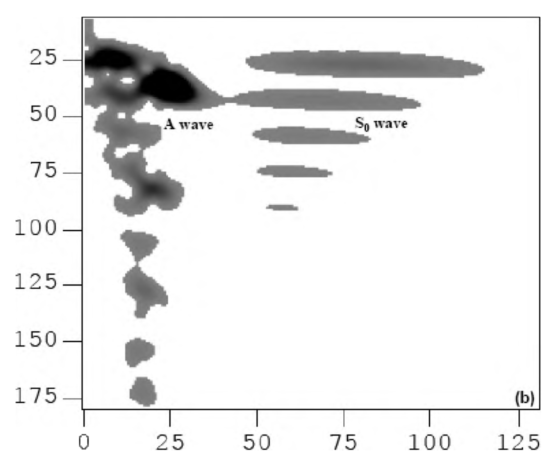


Figure 8 (b) Spectrometric Image of Scholte A and the symmetric S_0 waves

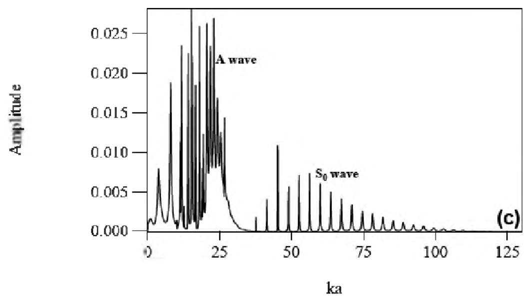


Figure 8 (c) Resulting Resonance Spectra of Scholte A and the symmetric S_0 waves

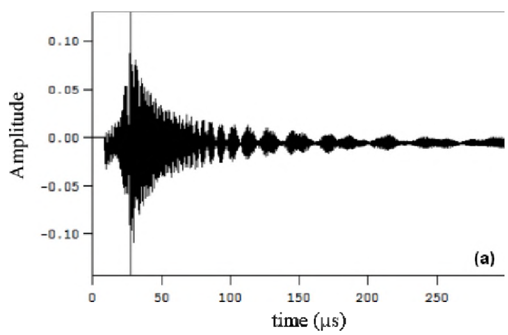


Figure 9 (a) Time Signal of the antisymmetric A_1 wave

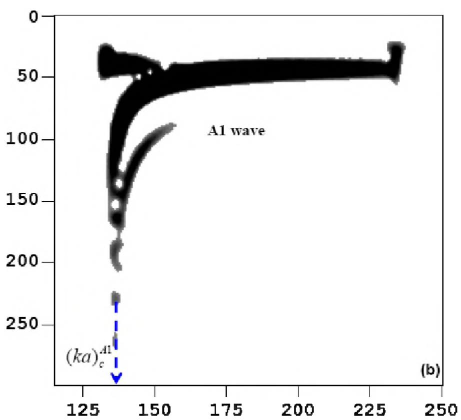


Figure 9 (b) Spectrometric Image of the antisymmetric A_1 wave

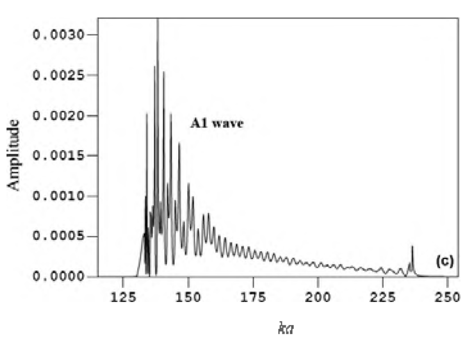


Figure 9 (c) Resulting Resonance Spectra of the antisymmetric A_1 wave

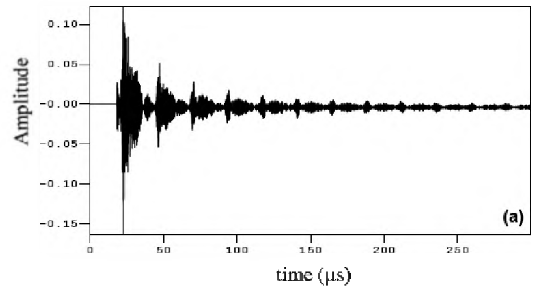


Figure 10 (a) Time Signal of the symmetric S_1 wave

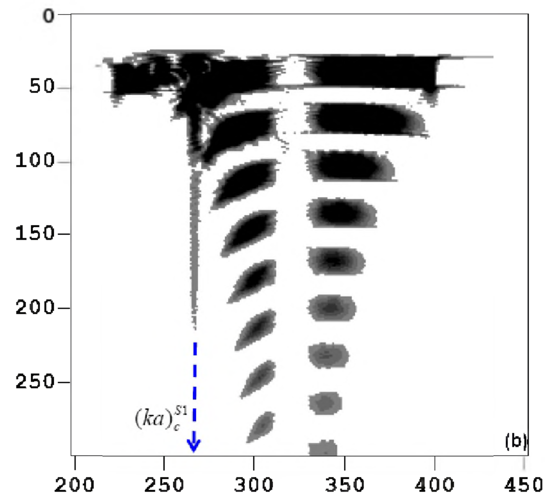


Figure 10 (b) Spectrometric Image of the symmetric S_1 wave

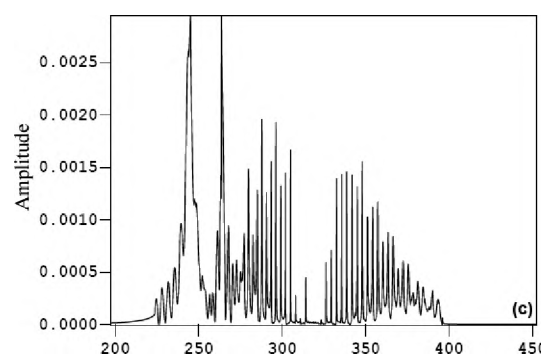


Figure 10 (c) Resulting Resonance Spectra of the symmetric S_1 wave

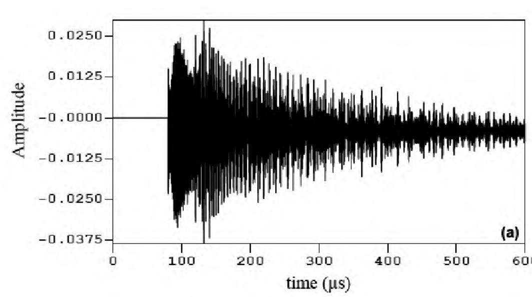


Figure 11 (a) Time Signal of the antisymmetric A_2 wave

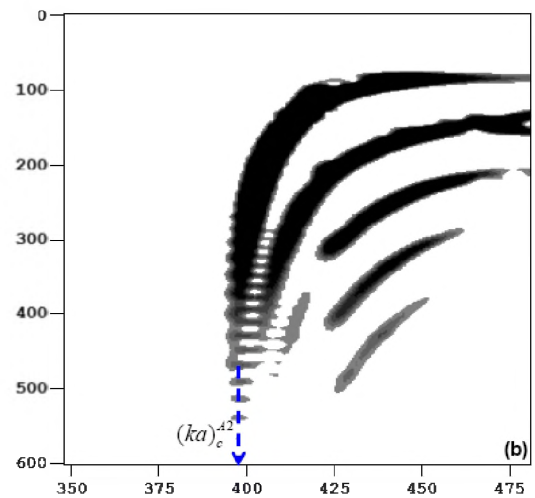


Figure 11 (b) Spectrometric Image of the antisymmetric A_2 wave

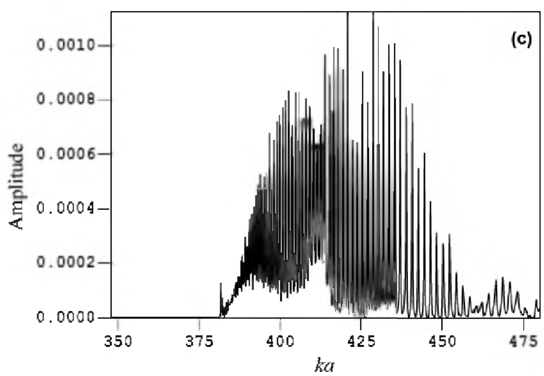


Figure 11 (c) Resulting Resonance Spectra of the antisymmetric A_2 wave

4. RESULTS

4.1 Cut-off Frequency

The spectrogram images in Figures 9, 10 and 11, show clearly the evolution of the antisymmetric A_1, symmetric S_1 (with *m*=2) and antisymmetric A_2 waves, on the time-frequency plane (remark 31) respectively (the reduced frequencies ranges are *ka*>132, 200< *ka* <400 and 395< *ka*<500 respectively). With increasing time, the trajectory associated with these different waves tends to asymptotic values which equal the reduced cut-off frequencies $(ka)_c^{A_1}$, $(ka)_c^{S_1}$ and $(ka)_c^{A_2}$ respectively. This reduced cut-off frequencies are the intersection points of the wave's asymptotic trajectories and the reduced frequency axis.

The recorded values are,

$(ka)_c^{A_1}$ = 132.0 ± 0.8 (Fig. 9b),

$(ka)_c^{S_1}$ = 264.7 ± 0.5 (Fig. 10b) and,

$(ka)_c^{A_2}$ = 396.3 ± 0.8 (Fig. 11b).

The comparison between the results obtained by the time-frequency spectrogram method and the other method mentioned above (Table 2) are in good agreement. The following table summarizes the comparison between the various methods results.

Table 2. Comparison between the obtained results

Wave type	Lamb wave		Circumferential waves
	fe/2(Mhz mm)	*Ka*	*ka* (spectrogram method)
A_1	0.775±0.020	132.5±3.41	132 ± 0.5
S_1	1.550±0.020	264.8±3.41	264.7±0.5
A_2	2.325±0.020	397.5±3.41	396.3± 0.5

4.2 Transverse and Longitudinal Velocities

For the antisymmetric A_1 and A_2 waves (with m=1 and m=3 respectively), the transverse velocity, of the aluminum material of the tube, determined by the Spectrogram images (Fig 9.b and 11.b respectively) are C_T = 3088 ± 18.0 m/s and C_T = 3090.6 ± 18.0 m/s respectively.

For the symmetric S_1 wave (with m=2), the longitudinal velocity estimated by the Spectrogram image (Fig 10.b) is C_L = 6192.8 ± 9.0 m/s. Moreover, we note that the transverse velocities estimated by the antisymetric A_1 and A_2 waves and the longitudinal velocity obtained by the symmetric S_1 wave agree with those given by the normal mode [13,30,36,41] (C_T =3 100 m/s and C_L = 6380 m/s).

5. CONCLUSIONS

The time-frequency spectrogram representation can be utilized as a good technique for characterizing a thin elastic tube. The characterization consists in determining different parameters such as the cut-off frequencies, the longitudinal and transverse velocities. This representation gives a good energy distribution in the time-frequency plane. The spectrogram images allow identifying the circumferential waves propagating around the tube circumference, and follow the evolution of the frequency contents of each circumferential wave with respect to time. This representation allows us to determine, with precision, the cut-off frequencies of the A_1, S_1 and A_2 waves. The comparison between the cut-off frequencies obtained from the spectrogram images and those calculated theoretically by the normal modes theory are in good agreement. Thus, we can consider measurements of the cut-off frequencies in situations where theoretical results are not available. Moreover, in the majority of composite materials (very complex structures), the prediction of the circumferential waves characteristics from theory is almost impossible. However, one can easily measure them by using the spectrogram time-frequency representation. Finally this representation permits the determination of the transverse and longitudinal velocities of an aluminum tube. The results of the velocities are seen to be in good agreement with those measured by earlier experimental methods found in the literature.

REFERENCES

1. P. L. Marston and N. H. Sun, "Backscattering near the coincidence frequency of a thin cylindrical shell: surface wave properties from elastic theory and an approximate ray synthesis", J. Acoust. Soc. Am. vol. 97, pp. 777-783, 1995.
2. G. Maze, F. Léon, N. Veksler, L. Ripoche, "Resonance identification of a solid axisymetric finite length target" J. Acoust. Soc. Am. 95, 3000, 1994.
3. Farid Chati, Fernand Léon, Gérard Maze, "Acoustic scattering by a metallic tube with a concentric solid polymer cylinder coupled by a thin water layer. Inflence of the thickness of the water layer on the two Scholte-Stoneley waves" J. Acoust. Soc. Am. 118 2820, 2005.
4. S. F. Morse and P. L. Marston, "Backscattering of transients by tilted truncated cylindrical shells: Time-frequency identification of ray contributions from measurements", J. Acoust. Soc. Am. vol. 111, pp. 1289-1294, 2002.
5. G. Maze D. Décultot, A. Klauson, J. Metsaveer, "Acoustic scattering by immersed circular cylindrical shell stiffened by internal lengthwise rib" J. Acoust. Soc. Am. 95 2868, 1994.
6. G. Maze, F. Lecroq, D. Décultot, J. Ripoche, Sus an K. Numrich, H. Überall, "Acoustic scattering from finite cylindrical elastic objects" J. Acoust. Soc. Am. 90 3271, 1991.
7. G. Maze, J. Ripoche, Xiao-Ling Bao, H. Überall, "Acoustic scattering from elastic cylindriers" J. Acoust. Soc. Am. 89 1993, 1991.
8. D. Décultot, F. Lecroq, G. Maze, J. Ripoche, "Acoustic scattering from immersed axisymetric objects. Cylindrical shell limited by hemispherical encaps" J. Acoust. Soc. Am. 95, 3000, 1994.
9. G. Maze, "Acoustic scattering from submerged cylinders. MIIR Im/Re: Experimental and theoretical study", J .Acoust. Soc.Amer., vol. 89, pp. 2559–2566, 1991.
10. M. Castaings, P. Cawley, "The generation, propagation and detection of Lamb waves in plates using air-coupled ultrasonic transducers" J. Acoust. Soc. Am. 100, 3070, 1996.
11. N. H. Sun and P. L. Marston, "Ray synthesis of leaky Lamb wave contributions to backscattering from thick cylindrical shells", J. Acoust. Soc. Am. vol. 91, pp. 1398-1402 , 1992.
12. M. Talmant, G. Quentin, J.L. Rousselot, J.V. Subrahmanyam, and H. Ubreall, "Acoustic resonances of thin cylindrical shells and the resonance scattering theory", J. Acoust. Soc. Am 84(2), 681-688, 1988.
13. R. Latif, E. Aassif, A. Moudden, D. Decultot, B. Faiz, G. Maze, "Determination of the cut-off frequency of an acoustic circumferential wave using a time-frequency analysis", NDT&E International 33, 373-376, 2000.
14. L. Cohen, "Time-frequency analysis", Prentice Hall, New Jersey, 1995.
15. P. Flandrin, "Temps-fréquence", Hermès, Paris, 1993.
16. N. Yen, R. Dragonette Louis, K. Numrich Susan, "Time-freqency analysis of acoustic scattering from elastic objects", J. Acoust. Soc. Am. 87(6), 2359-2370, 1990.
17. F. Léonard, "Spectrogramme de phase et spectrogramme de fréquence", Revue du Traitement du Signal 17 (4), 269–286, 2001.
18. M. Niethammer, L.J. Jacobs, J. Qu, J. Jarzynski, "Time–frequency representation of Lamb waves using the reassigned spectrogram", J. Acoust. Soc. Am. 107, 19–24, 2000.
19. P. Flandrin, J. Sagéloli, J. P. Sassarego and M. E. Zakharia "Application of time-frequency analysis to the characterization of surface waves on elastic targets", Acoustics letters vol. 10, pp 23-28, 1986.
20. R. Latif, E. Aassif, A. Moudden, B. Faiz, G. Maze, "The experimental signal of a multilayer structure analysis by the time-frequency and spectral methods", Journal of Non Destructive Testing & Evaluation International, Vol. 39, 349-355, 2006.
21. R. Latif, E. Aassif, A. Moudden, B. Faiz, "High-resolution time-frequency analysis of an acoustic signal backscattered by a cylindrical shell using a modified Wigner-Ville representation", Meas. Sci. Technol. 14, 1063-1067, 2003.
22. R. Latif, E. H. Aassif, G. Maze, A. Moudden, B. Faiz, "Determination of the group and phase velocities from time-frequency representation of Wigner-Ville", Journal of Non Destructive Testing & Evaluation International, Vol. 32, 7, 415-422, 1999.
23. Viktorov, I.A., "Rayleigh-type waves on a cylindrical surface", Soviet Phys.–Acoust., 4, 131–136, 1958.
24. Qu, J., Berthelot, Y., and Li, Z., "Dispersion of guided circumferential waves in circular annulus", Rev. Prog. Quant. Nondestructive Evaluation, 15, 169–176, 1996.
25. Liu, G. and Qu, J., "Guided circumferential waves in a circular annulus", J. Appl. Mech., 65, 424–430, 1998a.
26. Cerv, J., 1988, "Dispersion of elastic waves and rayleigh-type waves in a thin disc", Acta Technica Csav, 89, 89–99, 1988.

27. Mindlin, R.D., and McNiven, H.D., "Axially symmetric waves in elastic rods", J. Appl. Mech., 82, 145–151, 1960.
28. Pao, Y.H. and Mindlin, R.D., "Dispersion of flexural waves in an elastic, circular cylinder", J. Appl. Mech., 27, 513–520, 1960.
29. N. D. Veksler, M. E. Kutser, "Asymptotics of the pressure field in a specific discontinuity for diffraction of a plane acoustic wave on an elastic cylindrical shell", Journal of Applied Mathematics and Mechanics, Volume 40; Issue 3, Pages 464-474, 1976.
30. R. Latif, E. Aassif, G. Maze, D. Decultot, A. Moudden and B. Faiz, Analysis of the circumferential acoustic waves backscattered by a tube using the time-frequency representation of Wigner-Ville", Meas. Sci Technol.11 pp. 83-88, 2000.
31. D. Gabor. "Theory of communication", Journal of the Institute for Electrical Engineers, 93:429-439, 1946.
32. M. Destrade, Explicit secular equation for Scholte waves over a monoclinic crystal, Journal of Sound and Vibration 273 (2004) 409–414.
33. J.B. Allen and L.R. Rabiner. "A unified approach to STFT analysis and synthesis", Proceedings of the IEEE, 65:1558 - 1564, November 1977
34. F. Magand, P. Chevret, "Time-frequency analysis of energy distribution for circumferential waves on cylindrical elastic shells" acta acoustica, Vol. 82, pp. 707-716, 1996.
35. J.P. Sessarego, J. Saheloli, P. Degoul, P. Flandrin, M. Zakharia "analyse temps-fréquence des signaux en milieux dispersifs. Application à l'étude des ondes de Lamb" J. Acoustique 3, pp. 273-280, 1990.
36. G. Maze, J.L. Izbicki, J. Ripoche, " Resonances of plates and cylinders: Guided waves ", J. Acoust. Soc. Amer. vol 77, pp. 1352-1357, 1985.
37. J. Qu, L. Jacobs, "Cylindrical Waves and Their Applications in Ultrasonic Evaluation," in Ultrasonic NDE for Engineering and Biological Material Characterization, ed. T.Kundu, CRC Press, p.311- 36, 2004.
38. R. Fiorito, W. Madogosky, H. Überall, "Theory of ultrasonic resonances in viscoelastic layer", J. Acoust. Soc. Am. Vol. 77, No. 2, Februry, 489-498, 1985.
39. R. Fiorito, W. Madogosky, H. Überall, "Resonance theory of acoustic waves interacting with an elastic plate", J. Acoust. Soc. Am. Vol. 66, No. 6, December, 1857-1866, 1979.
40. L. Derbesse, P. Pernod, V. Latard, A. Merlen, D. Décultot, N. Touraine, G. Maze, "Acoustic scattering from complex elastic shells: visualization of S0,A0 and A waves", Ultrasonics, Volume 38, Issue 1-8, March Pages 860-863, 2000.
41. P.L. Marston and N.H. Sun, " Backscattering near the coicidance frequency of a thin cylindrical shell: surface wave properties from elastic theory and an approximate ray synthesis", J. Acoust. Soc. Am. vol 97, pp. 777-783, 1995.

ACOUSTICS OF SUSPENDED CEILINGS AND SPEECH PRIVACY

H. S. Seddeq
Housing & Building Research Center, Building Physics Institute, Egypt, hudasoliman@yahoo.com

ABSTRACT

Acoustics is an integral factor of indoor environmental quality, and it's essential that suspended ceilings systems of modern office building provide adequate acoustical separation. This paper evaluates the acoustic performance for different suspended ceilings systems installed in rooms with dividing partitions as to their speech privacy characteristics. The relation between speech privacy index and ceiling attenuation class (CAC), articulation class (AC), and subjective speech privacy rating has also been presented in this paper.

RÉSUMÉ

L'acoustique est un facteur intégrante de la qualité de l'environnement intérieur, et il est essentiel que les systèmes de suspension des plafonds de immeuble de bureaux moderne de fournir suffisamment de séparation acoustique. Cet article évalue la performance acoustique pour différents systèmes de plafonds suspendus installés sur les chambres de séparation des partitions à des fins de confidentialité de la parole. En outre la relation entre l'indice de la confidentialité des conversations et le plafond d'atténuation de classe CAC, classe d'articulation, AC et subjective Note confidentialité de la parole a été présenté dans le présent document.

1. INTRODUCTION

Modern office buildings are usually designed with large office areas where all services (including electricity, plumbing, and air supply ducts) are installed above a suspended ceiling. The plenum space above the suspended ceiling permits offices to be constructed with demountable walls and provides a flexible space to suit the occupants' needs. The partition wall extends up to the underside of the suspended ceiling to provide enough acoustical isolation between the rooms (offices). The sound propagates through the suspended ceiling, across the plenum space and back down through the ceiling of the other room [1]. Offices and meeting rooms are often intended for confidential discussions. Speech originating inside such a room being difficult to hear or understand in the adjoining spaces implies that the room provides good speech privacy. In cases where the degree of privacy is sufficiently high, one can speak of architectural speech "security". Improved security would be provided, for instance, by a room constructed with boundaries having higher sound transmission loss [2]. The typical private office provides far less than the minimum required level of confidential speech privacy. Most offices allow occupants located outside these private offices to easily overhear and understand sensitive conversations that occur inside [3]. This paper evaluated acoustically different ceiling systems installed over spaces that have partition wall of high sound insulation extending up to the underside of these systems for their speech privacy characteristics between closed rooms.

2. ACOUSTIC METRICS

The following acoustic descriptors have been used for different suspended ceilings systems to evaluate its speech privacy performance of closed rooms.

2.1 Speech privacy

The degree of privacy offered by a closed room is an indication of how audible or intelligible conversations occurring within are in the adjoining spaces [4]. ASTM Standard, E 1130, describes a means of measuring speech privacy objectively between locations in open offices. The standard uses acoustical measurements, published information on speech levels, and provides a method for assessing speech communication. The standard could also be adapted for measuring the speech privacy between fully enclosed spaces [6]. While both the articulation index and the ASTM E1130 standard can be expected to reliably predict average speech privacy, neither predicts the specific degree of speech privacy afforded to closed office occupants. The useful scale for speech privacy is called Privacy Index, (PI). It is expressed in percent and can be calculated from the Articulation Index, (AI) as follows [5]:

$$PI = (1 - AI) \mathrm{X} 100\% \qquad (1)$$

2.2 Articulation Class (AC)

Articulation class is a single number rating that can be used for comparing building systems and subsystems for speech privacy purposes. The rating is designed to correlate with transmitted speech intelligence between office spaces. In particular, the AC considers that the effect of signal attenuation articulation class is the result of the attenuation provided by a single component. AC is calculated according to ASTM E 1110 [6]. AC is used as a tool to classify and compare ceiling systems. Articulation class shows the performance of individual components and fittings that affect speech privacy.

AC is a weighted single value using scaled ANSI S3.5 [7] weighting factors defined for Articulation Index. For each source-receiver location, the weighted attenuations for all involved frequencies are added together and rounded off to the nearest multiple of 10, giving the AC value for a given location. The lowest AC figure shall be presented and expressed as minimum AC value [6, 8].

2.3 Ceiling Attenuation Class (CAC)

With the current light construction, walls often do not extend to the structure. The path for sound through the ceiling plenum is the weakest path between offices. The sound path is related with a ceiling attenuation class (CAC) that is analogous to a sound transmission class rating. The CAC value is measured in accordance with ASTM Standard E1414 [9] and measures the sound transfer from one room to another room through ceiling, plenum and then back to the adjacent room through the ceiling tiles.

The measurement of a normalized ceiling attenuation requires that the value of a normalization term dependent upon the amount of sound absorption present in the receiving room be known. The ceiling attenuation (Dc) between the source and receiving rooms where flanking transmission by all paths are at least 10 decibels lower than the path through the ceiling and plenum is determined as follows [9]:

$$D_c = \overline{L_S} - \overline{L_R} \quad (2)$$

where $\overline{L_S}$ is the average one-third octave band sound pressure level in the source room,

$\overline{L_R}$ is the average one-third octave band sound pressure level in the receiving room

Normalized ceiling attenuation ($D_{n,c}$) is the ceiling attenuation adjusted to account for receiving room absorption as follows:

$$D_{n,c} = D_C + N_f \quad (3)$$

where N_f is the normalization term for receiving room absorption. The normalization term is given by the formula [9]:

$$N_f = 10 \log \frac{A_0}{A} \quad (4)$$

where, A_0 = 12 metric sabins, and A is the sound absorption of the receiving room in metric sabins measured by the decay method

The ceiling attenuation class (CAC) is a single figure rating derived from the normalized ceiling attenuation values in accordance with ASTM Standard E413 [10].

3. THE EXPERIMENT

Acoustic measurements for different ceiling systems have been carried out in Housing and Building National Research Center, HBRC. The acoustic measurements included:

- Ceiling attenuation class (CAC)
- Articulation class, (AC)
- Privacy Index, (PI)
- Subjective speech privacy rating

The laboratory test facility consists of an outer shell divided into two rooms by a partition and a suspended ceiling (the test specimen). The rooms are built so that the only significant sound transmission path between them is that provided by the test specimen and the ceiling plenum. One continuous 10m × 5m ceiling with 1 m deep plenum was constructed with a STC 65 partition, resulting in two rooms, 4m × 5m source room and 6m × 5m receiving room as shown in Figure 1.

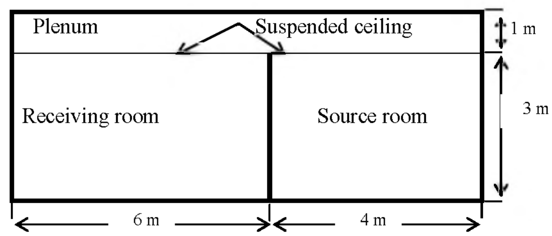


Figure 1. Details of the Two Rooms

The ceiling attenuation is determined in each of the test frequency bands, by placing a sound source in one room and then calculating the difference of the average sound pressure levels in both rooms. All internal surfaces of the two rooms were covered with ordinary cementatious material and the floor of the two rooms was ceramic tiles. Different ceiling systems were installed over the partition with the same plenum depth. The codes and specifications of these ceiling are summarized in Table 1.

Table 1. Description of the tested ceiling systems

ID	Ceiling description
SA1	Metal tiles 0.5 cm thick without perforation and thin PVC black layer, weight 5.8 kg/m^2
SA2	Metal tiles 0.5 cm thick of perforation 20% with thin PVC black layer, weight 4.5 kg/m^2
SA3	Metal tiles 0.5 cm thick of perforation 20% with thin PVC black layer, weight 4.5 kg/m^2 and 1.25 cm rock wool of density 50 kg/m^3
SA4	Metal tiles 0.5 cm thick of perforation 20% with thin PVC black layer, weight 4.5 kg/m^2 and 2.5 cm rock wool of density 50 kg/m^3
SA5	Metal tiles 0.5 cm thick of perforation 20% with thin PVC black layer, weight 4.5 kg/m^2 and 3.8 cm rock wool of density 50 kg/m^3
SA6	Metal tiles 0.5 cm thick without perforation and thin PVC black , weight 5.8 kg/m^2 and of 5 cm rock wool of density 50 kg/m^3
SA7	2.44m × 0.3 m × 20 mm perforated panel MDF with matte veneer and 5 cm rock wool of density 50 kg/m^3, Perforation: diameter of hole 12 mm of percentage open area 15%, weight 7.5 kg/m^2

The partition that divided the two rooms has the following construction layers as shown in Figure 2.

1. single layer of 13 mm type X gypsum board
2. single layer of 13 mm type X gypsum board
3. 40 mm steel studs at 610 mm on centre
4. 40 mm of mineral fibre insulation in cavity 50kg/m^3
5. 90 mm air gap
6. 40 mm steel studs at 610 mm on centre
7. 40 mm of mineral fibre insulation in cavity 50kg/m^3
8. single layer of 13 mm type X gypsum board
9. single layer of 13 mm type X gypsum board

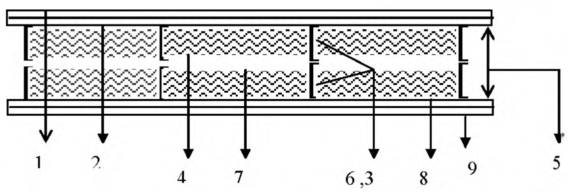


Figure 2. Construction of Partition Wall between Source and Receiving Room

The sound transmission of this partition was measured according to ASTM E90 [12] the transmission results are shown in Figure 3.

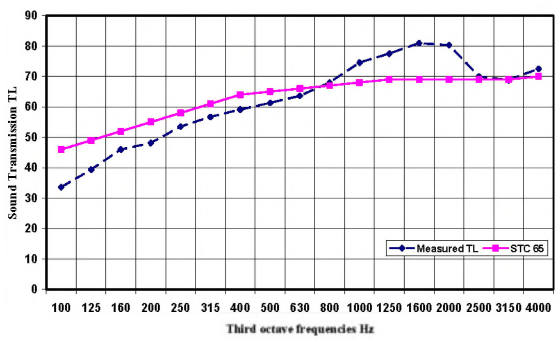


Figure 3 Measured Transmission Loss and STC

3.1 Ceiling Attenuation Class

The sound signals used for these tests were random noise having a continuous spectrum within each test frequency band from 100 to 4000 Hz generated by Bruel & Kajer sound source type 4292. The sound source was far enough away from the test partition and pointing in to the test specimens. The sound source radiated enough sound above the back ground noise (more than 10 dB). The sound level meter type 2270 connected to microphone type 4189 (B&K) that was calibrated by using calibrator type 4231 (B&K) to measure the sound pressure levels in the source room and receiving room. Fixed microphone is used in 5 positions which were 1.5 from the sound source at least in source room and 5 positions in the receiving room which were 1 m at least from any surface in the rooms. The sound decay rates in the receiving room have been measured 3 time for two positions of sound source. The average decay and reverberation time determined to calculate the sound absorption in receiving room according ASTM E 2235 [11].

The CAC values were then determined by applying Equations 2, 3 and 4.

3.2 Speech Privacy Index

The speech privacy in the receiving room was evaluated as follows. At the listener location, the ambient sound pressure levels were measured in each one-third octave-band from 200 to 5000 Hz as well as the overall A-weighted sound level, dBA. The Bruel & Kajer sound source type 4224was located at two positions in the source room and oriented towards the receiving room location. The source was driven with pink noise at a level sufficient to increase the one-third octave-band sound pressure levels at the measurement location. The sound pressure levels at different distances, at least 1m from the source were measured. The sound pressure levels, in the receiving room, in one-third octave bands, were also measured at 5 positions with the source on with the microphone, located 1.2 m above the floor. The level reduction in each one-third octave band has been calculated, that is, the difference in average sound pressure levels produced by the sound source at the source room and receiving room. The one-third octave-band sound pressure levels for the speech spectrum at the receiving room were evaluated by subtracting the measured level reductions from the speech spectrum male speech peaks from as shown Table 2 [5].

Table 2. Speech peaks for males

Third octave band center frequency, Hz	Sound pressure levels of speech peaks for normal voice effort , dB
200	60
250	64
315	63
400	65
500	66
630	64
800	58
1000	58
1250	59
1600	56
2000	52
2500	53
3150	53
4000	50
5000	46

With the test signal off, the average background sound pressure level was measured in each one-third octave band over a time period of 1 min at the five selected positions in the receiving room. The average one-third octave-signal to noise ratio was thus established. The Articulation Index was determined as follows [5]:

$$AI = \sum_{i=1}^{i=15} W_i R_i \qquad (5)$$

where:
AI = Articulation Index,

Wi = weighting factor (table 2) for band i, and
Ri = signal-to-noise ratio for band i.

Privacy Index, (PI) was expressed in percent and calculated from the Articulation Index, (AI) from Eq. (1). The required weighting factors are shown in Table 3.

3.3 Articulation Class

The Articulation Class (AC) is determined by a similar procedure. The attenuation that is, the difference in average sound pressure levels produced by the sound source at the source room and receiving room is determined. Articulation class (AC) is the sum of the weighted sound attenuations in a series of 15 test bands from 200 to 5000 Hz. It is calculated as follows:

$$AC = \sum_{f_i} A(f_i) W_i(f_i) \quad (6)$$

where,

f_i = the center frequency of the bands from 200 to 5000 Hz,
$A(f_i)$ = the measured attenuation in decibels in the one third octave band with center frequency fi, that is the difference in average sound pressure levels measured at the source room and receiving room and
$W(fi)$ = the weighting for that band, from Table 3.

Table 3: Articulation Index Weighting Factors [5], [6]

Third octave center frequency, Hz	Weighting factors	
	Articulation index	Articulation class
200	0.0004	0.12
250	0.0010	0.3
315	0.0010	0.3
400	0.0014	0.42
500	0.0014	0.42
630	0.0020	0.6
800	0.0020	0.6
1000	0.0024	0.72
1250	0.0030	0.9
1600	0.0037	1.11
2000	0.0038	1.14
2500	0.0034	1.02
3150	0.0034	1.02
4000	0.0024	0.72
5000	0.0020	0.6

3.4 Subjective Test

Subjective listening tests were conducted with subjects in the receiving room. The phonetically-balanced Arabic sentences as speech material were played in the source room. 50 Arabic speech sentences were played over loudspeaker at three locations in the source room. Five listeners at five locations in the receiving room identify the speech material. The subjects record their response of the sentence lists. The Arabic speech sentences were recorded using computerized speech lab. model 4300. The recorded speech material was played back at different levels over a range of 58 to 65 dBA at 1m from the source. The average of speech privacy score is then calculated by determining the number of incorrect answer and expressing this as percentage [13].

4. RESULTS AND DISCUSSION

Results of subjective rating of speech privacy scores, SPS, were classified to 4 classes as follows:

- Confidential Privacy (Excellent Privacy) when normal speech can not be heard and can not be understand for SPS greater than 95%
- Good Speech Privacy when normal speech can be heard with great difficulty for SPS greater than 80% and less than 95%
- Poor Speech Privacy when normal speech can be heard and can understand with difficulty for SPS greater than 65% and less than 80%
- Bad Speech Privacy when normal speech can be heard and can understand for SPS greater less than 65%

The subjective rating of speech privacy scores, SPS, and their classifications are summarized in Table 4. All the acoustic measurements results for the tested ceiling systems are summarized in Table 5

. Table 4: Speech Privacy Scores

Classification	Speech privacy Scores, SPS	Speech Hearing and understanding
Excellent	100>SP≥95	Normal speech can not be heard and/or understood
Good	95>SP≥80	Normal speech can be heard with difficulty and cannot be understood
Poor	80>SP≥65	Normal speech can be heard and can be understood with difficulty.
bad	SP<65	Normal speech can be heard and can be understoodd.

Table 5. Results for Different Ceiling Systems

ID	CAC	AC	PI	SPS
SA1	25	250	93%	Good
SA2	12	120	52%	bad
SA3	20	200	77%	Poor
SA4	27	300	94%	Good
SA5	25	250	93%	Good
SA6	32	300	95%	Good
SA7	40	400	98%	Excellent

The results reflect connection between the ceiling type and the acoustic measurements SPS, PI, AC, CAC and can be summarized as follows:

- the results of ceiling system SA2 is lower than the results of ceiling system SA1 because the perforation added to ceiling system SA2 increases the sound transmission between the two room;s
- the results for ceiling systems SA3, SA4, SA5, SA6 were compared to ceiling system SA2 because adding layer of sound absorptive material increases the reduction in sound transmission between the two rooms
- the ceiling systems SA4, SA5, SA6 were better than the ceiling system SA3 because increasing the thickness of sound absorptive material increases the reduction in sound transmission between the two adjacent rooms
- ceiling type SA7 achieved higher acoustic results due to increase of mass.

Generally the sound attenuation (reduction in sound transmission) via ceiling system path between the two adjacent rooms can be increased with added mass of the ceiling system and adding sound absorptive materials inside these systems. The increase of the sound transmission loss via ceiling system path between the two rooms improves the acoustic measurements (acoustic performance) SPS, PI, AC, CAC.

5. CONCLUSIONS

This paper evaluated the acoustic performance of suspended ceilings systems installed over rooms with dividing partitions from a speech privacy perspective. The objective acoustic metrics were ceiling attenuation class (CAC), articulation class, (AC) and privacy Index, (PI) were evaluated for seven ceiling systems. In addition, the subjective speech privacy test was carried out to establish the relationship between the subjective and objective acoustic measurements.

The results showed that sound attenuation via the ceiling system path between the two adjacent rooms can be increased with the increase of weight of the ceiling system. Also adding sound absorptive materials inside the ceiling system was found to increase the sound reduction. The increase of sound transmission loss via the common ceiling system path between the rooms was shown to improve the values for the performance metrics, SPS, PI, AC, CAC for the closed spaces under these ceiling systems

The results also showed that the closed spaces with common ceiling system of CAC values equal to or greater than 35 and AC values equal or greater than 350 are desirable for speech privacy. On the other hand ceiling system of CAC values less than 20 and AC less than 200 are not adequate for speech privacy. Ceiling system with PI value greater than 97% can achieve confidential privacy (Excellent Privacy) but PI less than 77% may not be adequate for speech privacy.

REFERENCES

1 R. E. Halliwell and J. D. Quirt, "Controlling interoffice sound transmission through a suspended ceiling," J. Acoust. Soc. Am. Vol. 90 (3), pp. 1146-1153, 1991.

2 Bradford N. Gover and John S. Bradley , "Measures for assessing architectural speech security (privacy) of closed offices and meeting rooms," J. Acoust. Soc. Am., Vol. 116(6), pp. 3480-3490, 2004.

3 Traditional Closed Offices Lack Confidential Speech Privacy, www.soundmasking.com

4 Bradford N. Gover and John S. Bradley, "Statistical Basis For Rating Speech Privacy Of Closed Rooms," Canadian Acoustical Association Conference, Montreal, QC., Oct. 9-12, 2007.

5 ASTM E1130 "Standard Test Method for Objective Measurement of Speech Privacy in Open Offices Using Articulation Index," ASTM Volume 04.06 Thermal Insulation; Building and Environmental Acoustics, 2006.

6 ASTM E 1110 "Standard Classification for Determination of Articulation Class," ASTM Volume 04.06 Thermal Insulation; Building and Environmental Acoustics, 2006

7 ANSI S3.5 "Methods for the Calculation of the Speech Intelligibility Index." 1997 (R2007)

8 Nils-Åke Andersson and Pierre Chigot, "Is the Privacy Index a good indicator for acoustic comfort in an open plan area?" The 33rd International Congress and Exposition on Noise Control Engineering August 22, 2004.

9 ASTM E1414 "Standard Test Method for Airborne Sound Attenuation Between Rooms Sharing a Common Ceiling Plenum," ASTM Volume 04.06 Thermal Insulation; Building and Environmental Acoustics, 2006.

10 ASTME 413, "Classification for Rating Sound Insulation," ASTM Volume 04.06 Thermal Insulation; Building and Environmental Acoustics, 2006.

11 ASTM E 2235 "Standard Test Method for Determination of Decay Rates for Use in Sound Insulation Test Methods," ASTM Volume 04.06 Thermal Insulation; Building and Environmental Acoustics, 2006.

12 ASTM E 90 "Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements," ASTM Volume 04.06 Thermal Insulation; Building and Environmental Acoustics, 2006.

13 J.S. Bradley and B.N. Gover "Criteria for Acoustic Comfort in Open-plan Offices." The 33rd International Congress and Exposition on Noise Control Engineering inter-noise, Prague, Czech Republic, Aug. 22-25, pp. 1-6, 2004.

NEW TYPE 4448 PERSONAL NOISE DOSE METER

Damaged hearing costs you dearly

Preventing it doesn't

TYPE 4448
FROM BRÜEL & KJÆR

Home of the world's best sound and vibration instrumentation

Type 4448 – Helping to improve workplace noise assessment

Simple reliability
No cables, no connectors

Forget it is there
Secure shoulder mount with pin or clip attachment

Ready when you are
Long 28 hour battery-life

Verify your Standards compliance
HML option – verify hearing protection requirements

Works with Protector PC software – for intuitive analysis and reporting

www.bksv.com/Type4448

BN 1054–11

HEADQUARTERS: Brüel & Kjær Sound & Vibration Measurement A/S · DK-2850 Nærum · Denmark
Telephone: +45 77 41 20 00 · Fax: +45 45 80 14 05 · www.bksv.com · info@bksv.com
Local representatives and service organisations worldwide

Brüel & Kjær
creating sustainable value

PERCEPTION OF NATURAL VOWELS BY MONOLINGUAL CANADIAN-ENGLISH, MEXICAN-SPANISH, AND PENINSULAR-SPANISH LISTENERS

Geoffrey Stewart Morrison
Forensic Voice Comparison Laboratory, School of Electrical Engineering & Telecommunications,
University of New South Wales, UNSW Sydney, NSW 2052, Australia
e-mail: geoff-morrison@forensic-voice-comparison.net

ABSTRACT

On the basis of a previously-reported synthetic-vowel perception experiment, it was hypothesized that the location of the perceptual boundary between Spanish /i/ and /e/ differed for monolingual Peninsular-Spanish and Mexican-Spanish listeners (north-central Spain and Mexico City), and that this would affect the perception of the Canadian-English /i/–/ɪ/ contrast (western Canada): Peninsular-Spanish listeners were predicted to identify almost all tokens of Canadian-English /i/ as Spanish /i/ and almost all tokens of Canadian-English /ɪ/ as Spanish /e/ (two-category assimilation); whereas Mexican-Spanish listeners were predicted to identify almost all tokens of Canadian-English /i/ as Spanish /i/, but identify some tokens of Canadian-English /ɪ/ as Spanish /i/ and some as Spanish /e/. Monolingual Peninsular-Spanish and Mexican-Spanish listeners' perception of natural tokens of English /i/, /ɪ/, /e/, and /ɛ/ produced by monolingual Canadian-English speakers was tested. Both the Peninsular-Spanish and the Mexican-Spanish listeners had results consistent with the perceptual pattern predicted for the Peninsular-Spanish listeners. The results call into question the assumption that first-language-Spanish learners of English have difficulty learning the English /i/–/ɪ/ contrast because they initially assimilate most tokens of both English vowel categories to a single Spanish vowel category, Spanish /i/.

RÉSUMÉ

En nous fondant sur les résultats d'une expérience antérieure consacrée à la perception de voyelles synthétiques, nous avons émis l'hypothèse qu'en espagnol, la frontière perceptive entre /i/ et /e/ différait chez les auditeurs monolingues en fonction de leur origine géographique (nord-est de l'Espagne vs ville de Mexico) et que cela était susceptible d'affecter la perception que les auditeurs hispanophones ont du contraste entre les voyelles anglo-canadiennes /i/ et /ɪ/ (de l'ouest du Canada). Plus précisément, nous postulons 1. que les auditeurs hispanophones originaires d'Espagne identifieront, respectivement, la quasi-totalité des occurrences des voyelles /i/ et /ɪ/ produites par des locuteurs anglo-canadiens comme des occurrences des voyelles espagnoles /i/ et /e/ (l'assimilation en deux catégories); 2. que les auditeurs mexicains identifieront également la quasi-totalité des occurrences de la voyelle anglaise /i/ comme celles d'un /i/ espagnol, mais que certaines occurrences de la voyelle anglaise /ɪ/ seront identifiées comme des /e/ espagnols alors que d'autres seront associées à un /i/ espagnol. Nous avons testé la perception que des auditeurs hispanophones monolingues avaient des voyelles anglaises /i/, /ɪ/, /e/, et /ɛ/ telles que produites par des locuteurs anglo-canadiens monolingues. Il s'avère que tant les auditeurs natifs d'Espagne que ceux originaires du Mexique présentent des résultats conformes à l'hypothèse 1 visant les auditeurs originaires d'Espagne. Ces résultats mettent en question la supposition selon laquelle les apprenants ayant l'espagnol comme première langue éprouvent des difficultés, lors de leur apprentissage de l'anglais, à appréhender le contraste entre /i/ et /ɪ/, car ils ont, en premier lieu, assimilé une majorité des occurrences appartenant à deux classes vocaliques distinctes en anglais à une classe vocalique unique en espagnol, le /i/.

1. INTRODUCTION

The present paper is the second in a series of two papers of which Morrison (2008b) "Perception of *synthetic* vowels by monolingual Canadian-English, Mexican-Spanish, and Peninsular-Spanish listeners" is the first.

First-language Spanish speakers have often been reported to have difficulty learning the English /i/–/ɪ/ contrast (e.g., Bohn, 1995; Flege, Bohn, & Jang, 1997; Escudero & Boersma, 2004; Morrison, 2008a, 2009), and it has been hypothesized that this is because they assimilate most tokens of both English vowel phonemes (English /i/ and /ɪ/) to a single Spanish phoneme (Spanish /i/). Results of studies on Peninsular-Spanish and American-Spanish speakers listening to English from the south east of England (Álvarez González, 1980, ch. 5; Escudero, 2005, §1.2.2), and studies of American-Spanish speakers listening to English from the United States (Flege, 1991; Møller Glasbrenner, 2005) have found that:

1. First-language Spanish second-language English (L1-Spanish L2-English) listeners misidentify L1-English speakers' productions of English /i/ as English /ɪ/ and vice versa.
2. Monolingual-Spanish listeners assimilate the majority of tokens of English /i/ to the Spanish /i/ category.
3. Monolingual-Spanish listeners assimilate the majority of tokens of English /ɪ/ to the Spanish /i/ category.

However, these studies also report that Spanish listeners assimilate some tokens of English /ɪ/ to Spanish /e/, and identify some tokens of English /ɪ/ as English /ɛ/.

It is well known that English vowel-phoneme realizations can vary substantially across dialects (Wells, 1982) and it is not therefore unexpected that Spanish listeners' perception of the English /i/–/ɪ/ contrast varies according to the dialect of English spoken. For example, /i/ and /ɪ/ in Scottish English have a larger first-formant (F1) separation and less difference in duration than their counterparts in English from the south east of England (Escudero & Boersma, 2004). Escudero (2005, §1.2.2) found that Peruvian-Spanish listeners assimilated tokens of Scottish English /i/ and /ɪ/ via a two-category assimilation to the Spanish /i/ and /e/ categories respectively, but assimilated tokens of southeastern-England English /i/ and /ɪ/ via a single-category or category-goodness-difference assimilation to the Spanish /i/ category (see Best's, 1995, Perceptual Assimilation Model for these terms).

What is less immediately apparent is whether there are

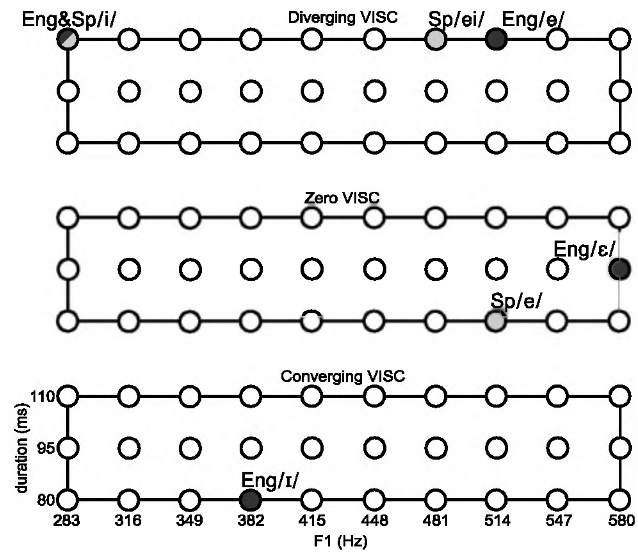


Figure 1. Properties of synthetic stimuli. Reproduced from Morrison (2008b).

differences in vowel-phoneme realizations across Spanish dialects which may lead to Spanish listeners of different dialects perceiving the English /i/–/ɪ/ contrast differently. It has not been uncommon in L2 speech-perception research for L1 Spanish listener groups to be made up of speakers of a mixture of different Spanish dialects (e.g., Flege, Bohn, & Jang, 1997; Escudero & Boersma, 2004; Morrison, 2008a, 2009) implying at least a tacit assumption that the listeners' Spanish dialect is not particularly relevant to their perception of the English /i/–/ɪ/ contrast.

Godínez (1978) tentatively suggested that there were differences in vowel formant values between Peninsular, Mexican, and Argentinean Spanish, but the number of participants in the study was too small to draw any stronger conclusion. Comparing Peninsular- and Peruvian-Spanish vowels in isolated vowels produced at the end of a carrier sentence, Morrison & Escudero (2007) failed to find significant differences in formant values with the exception of a mean 11% difference (as measured in hertz) in the second-formant (F2) value for /o/; however, comparing vowels in nonce words including various consonant contexts at the end of a carrier sentence, Chládková, Escudero, & Boersma (2011) found significant differences for F1 in /a/ (6.3%) and F2 in /e/ and /o/ (4.1% and 4.8%), and more widespread differences in certain consonant contexts.

Escudero & Williams (2012) found that L1 Spanish L2 Dutch listeners' first dialect influenced their perception of Dutch vowels. Peninsular-Spanish listeners were better than Peruvian-Spanish listeners at discriminating the Dutch /a/–/ɑ/ and /i/–/ɪ/ contrasts, and had higher correct-

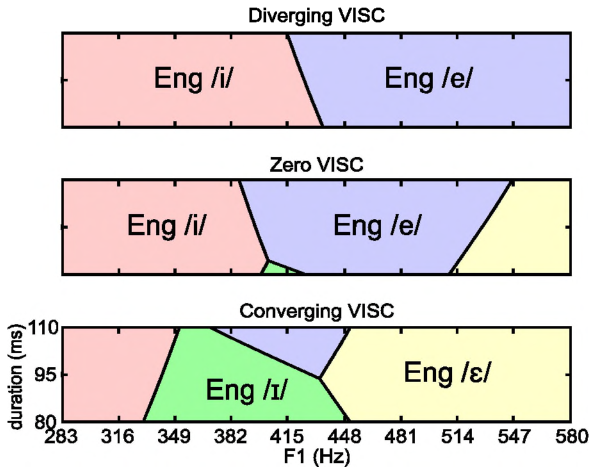


Figure 2. Territorial map of modal response areas from logistic-regression model of Canadian-English listeners' identification of synthetic stimuli. Reproduced from Morrison (2008b).

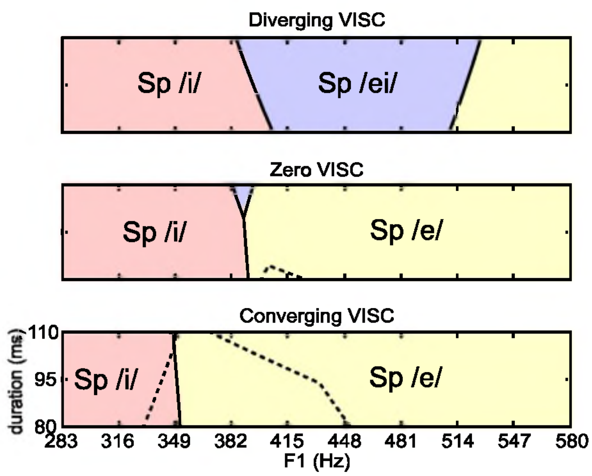


Figure 3. Territorial map of modal response areas from logistic-regression model of Peninsular-Spanish listeners' identification of synthetic stimuli. Reproduced from Morrison (2008b).

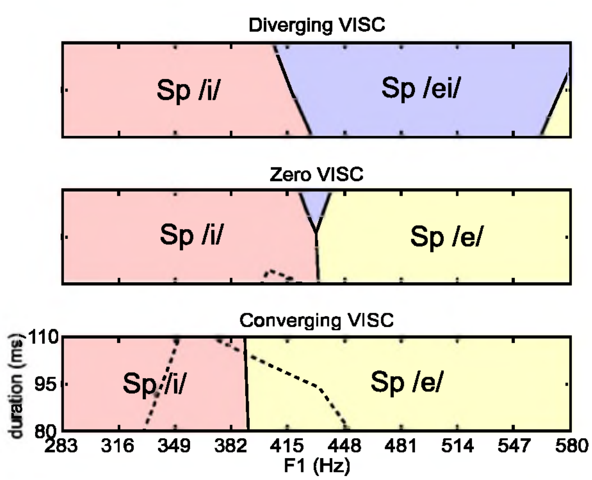


Figure 4. Territorial map of modal response areas from logistic-regression model of Mexican-Spanish listeners' identification of synthetic stimuli. Reproduced from Morrison (2008b).

classification rates for identification of Dutch /ɔ/, /ɑ/, /a/, /ɛ/, and /ʏ/. Also, as discussed below, Morrison (2008b) found evidence suggesting that there is a difference in monolingual Peninsular-Spanish and Mexican-Spanish listeners' vowel perception which could affect their perception of the English /i/–/ɪ/ contrast.

Morrison (2008b) tested the perception of a set of synthetic vowel tokens by monolingual Canadian-English, Peninsular-Spanish, and Mexican-Spanish listeners (19, 17, and 20 listeners respectively from western Canada, north-central Spain, and Mexico City). The synthetic vowels were imbedded in the word /bVpa/ in English and Spanish carrier sentences (the final non-stressed Spanish /a/ was acceptable as a schwa for the English listeners). Fig. 1 shows the duration and spectral values of the synthetic vowels in the stimulus set. Initial F2 covaried with initial F1 (F2 values were 2090, 2050, 2010, 1970, 1930, 1890, 1850, 1810, 1770, 1730 Hz). F1 and F2 either diverged [−99 Hz, +120 Hz], stayed flat [±0 Hz, ±0 Hz], or converged [+99 Hz, −120 Hz] over the timecourse of the vowel (diverging, zero, or converging vowel inherent spectral change, VISC), with the trajectory being a straight line in a log-hertz by milliseconds space. The durations given in Fig. 1 include 25 ms of consonant transitions. The filled circles in Fig. 1 represent the stimuli selected in pilot tests as the best exemplars of English /i/, /ɪ/, /e/, and /ɛ/, and Spanish /i/, /ei/, and /e/. The 90 stimuli were played in random order, each stimulus presented between 2 and 6 times to each listener (stimuli were selected using an adaptive procedure, Morrison, 2006a, for a total of 360 trials per listener). On each trial the listener identified the stimulus as one of English /i/, /ɪ/, /e/, or /ɛ/ if the listener was a monolingual English speaker, or one of Spanish /i/, /ei/, or /e/ if the listener was a monolingual Spanish speaker. Logistic regression models were fitted to the listeners' responses and territorial maps showing the modal response areas for each vowel category were made on the basis of these models, see Figs. 2–4. In Figs. 3 and 4 the modal response area for English /ɪ/ from Fig. 2 is superimposed on the Spanish /i/ and /e/ modal response areas (dashed lines).

For Peninsular-Spanish listeners the boundary between their modal response areas for Spanish /i/ and /e/ fell close to the boundary between the Canadian-English listeners' modal response areas for English /i/ and /ɪ/, but for Mexican-Spanish listeners the boundary between their modal response areas for Spanish /i/ and /e/ fell in the middle of the Canadian-English listeners' modal response area for English /ɪ/. This leads to the hypothesis that Peninsular-Spanish listeners will assimilate most tokens of Canadian-English /i/ to Spanish /i/ and most tokens of Canadian-English /ɪ/ to Spanish /e/ – a two category assimilation. If this is the case then Peninsular-Spanish learners of Canadian English could transfer their Spanish /i/–/e/ boundary and have little difficulty perceiving and learning the English /i/–/ɪ/ contrast (there are anecdotal reports that this is the case). In contrast, Mexican-Spanish listeners are hypothesized to assimilate most tokens of Canadian-English /i/ to Spanish /i/, some tokens of Canadian-English /ɪ/ to Spanish /i/, and some tokens of Canadian-English /ɪ/ to Spanish /e/ – likely a mixture of category-goodness-difference assimilation and two-category assimilation. If this is the case then Mexican-Spanish learners of Canadian English could be expected to have substantial difficulty learning the English /i/–/ɪ/ contrast.

The present study tests whether the difference between monolingual Peninsular-Spanish and Mexican-Spanish listeners' Spanish /i/–/e/ boundary for synthetic vowels found in Morrison (2008b) is also manifested as a difference between their perception of natural tokens of Canadian-English /i/ and /ɪ/. Perception of an expanded set of Canadian-English vowels /i/, /ɪ/, /e/, and /ɛ/ is tested. Monolingual Canadian-English listeners' perception of the Canadian-English vowels are tested as a control. Also as controls, Peninsular-Spanish listeners' perception of tokens of Peninsular-Spanish /i/, /ei/, and /e/ is tested, and Mexican-Spanish listeners' perception of tokens of Mexican-Spanish /i/, /ei/, and /e/ is tested. To further explore whether there is a difference in Peninsular- and Mexican-Spanish listeners' Spanish /i/–/e/ boundary, Mexican-Spanish listeners were also tested on tokens of Peninsular-Spanish /i/, /ei/, and /e/. Canadian-English listeners' were also tested on tokens of Peninsular-Spanish /i/, /ei/, and /e/.

2. METHODOLOGY

2.1 Acoustic stimuli collection

Acoustic stimuli consisted of recordings of Spanish /i/, /ei/, and /e/ and English /i/, /ɪ/, /e/, and /ɛ/ vowels produced by monolingual Spanish and monolingual English speakers respectively.

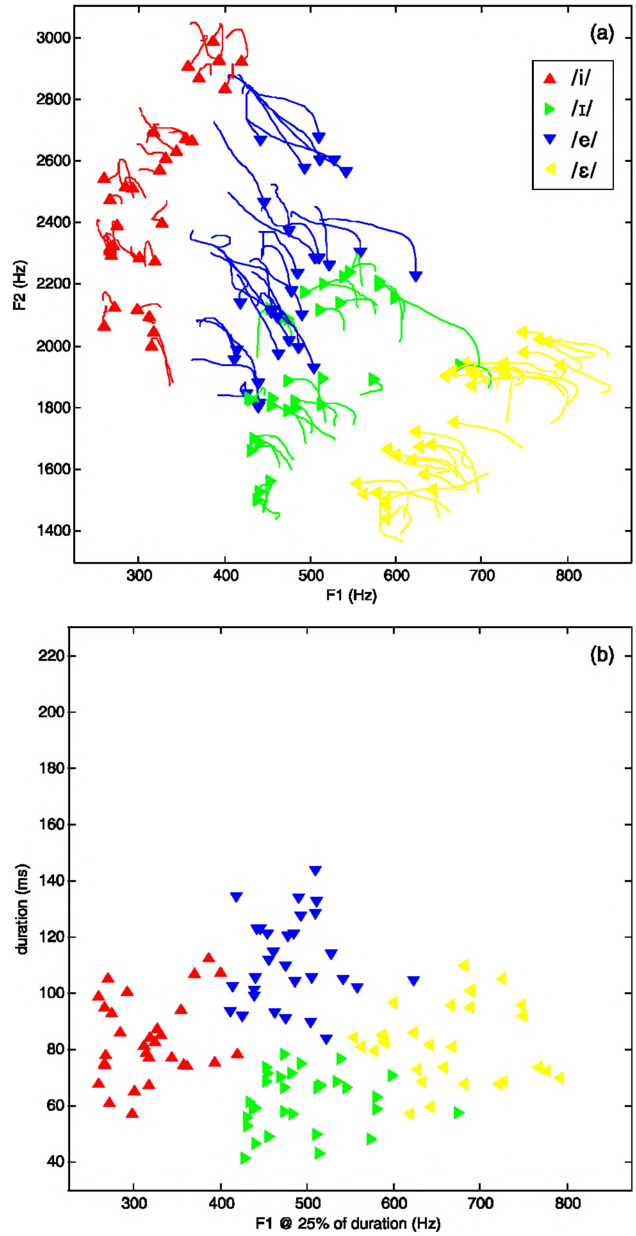


Figure 5. Acoustic properties of the Canadian-English speakers' vowel tokens used as stimuli in the present study. In the comet plots in (a), F1 and F2 at 25% of the duration of the vowel are represented by the symbol, and the trajectory from 25% to 75% of the duration of the vowel is represented by the tail. In (b) the symbol represents F1 at 25% of the duration of the vowel (*x*-axis) and the duration of the vowel (*y*-axis).

2.1.1 Speakers

Nineteen monolingual English speakers (8 male, 11 female) were recruited in Edmonton, Alberta, Canada. They came from western Canada (Alberta and Saskatchewan), and ranged in age from 18 to 54. None reported knowledge of any language other than English.

Seventeen monolingual Spanish speakers (8 male, 9 female) were recruited in Vitoria-Gasteiz, Autonomous

Region of the Basque Country, Spain (Vitoria-Gasteiz is traditionally a monolingual Spanish speaking part of the Basque Country). They came from several regions in north-central Spain (The Basque Country, Navarre, Burgos, León, and Madrid), and ranged in age from 25 to 53. None reported knowledge of any language other than Spanish beyond the level *some* from a choice of *a-little*, *some*, *well*, and *near-native*, and reported being unable to hold a conversation in any language other than Spanish.

Thirty five monolingual Spanish speakers (17 male, 18 female) were recruited in Mexico City. They came from Mexico City and the surrounding area and ranged in age from 18 to 31. None reported knowledge of any language other than Spanish beyond the level *some*, and reported being unable to hold a conversation in any language other than Spanish.

Potential participants who reported hearing or speech impediments were not included in the study.

2.1.2 Prompts

For the Canadian-English speakers, prompts consisted of written sentences "The next word is ____", and the prompt words were *BEEPA*, *BIPPA*, *BAYPA*, and *BEPPA* corresponding to /bipə/, /bɪpə/, /bepə/, and /bɛpə/. For the Peninsular-English speakers, prompts consisted of written sentences "La próxima palabra es ____" ("The next word is ____"), and the prompt words were *BIPA*, *BEPA*, and *BEIPA* corresponding to /bipa/, /bepa/, and /beipa/. The essentially-identical consonant contexts result in possible but non-existent words in the tested dialects of both languages. For the Mexican-Spanish speakers, prompt words were the same as for the Peninsular-Spanish speakers, but the written sentences were "En ____ tienes ____" ("In ____ you have ____"). The prompt word occurred in both lacunae but only the second reading of the prompt word was used in the present study. The Mexican-Spanish speakers also responded to prompt words including other vowel phonemes and other consonant contexts.

2.1.3 Procedure

Prompts were presented and responses recorded using custom-written software (a revised version of the software, *Acoustic recording software for speech production experiments*, is available from the author's website: http://geoff-morrison.net/). The monolingual English speakers completed the spelling-to-sound-correspondence

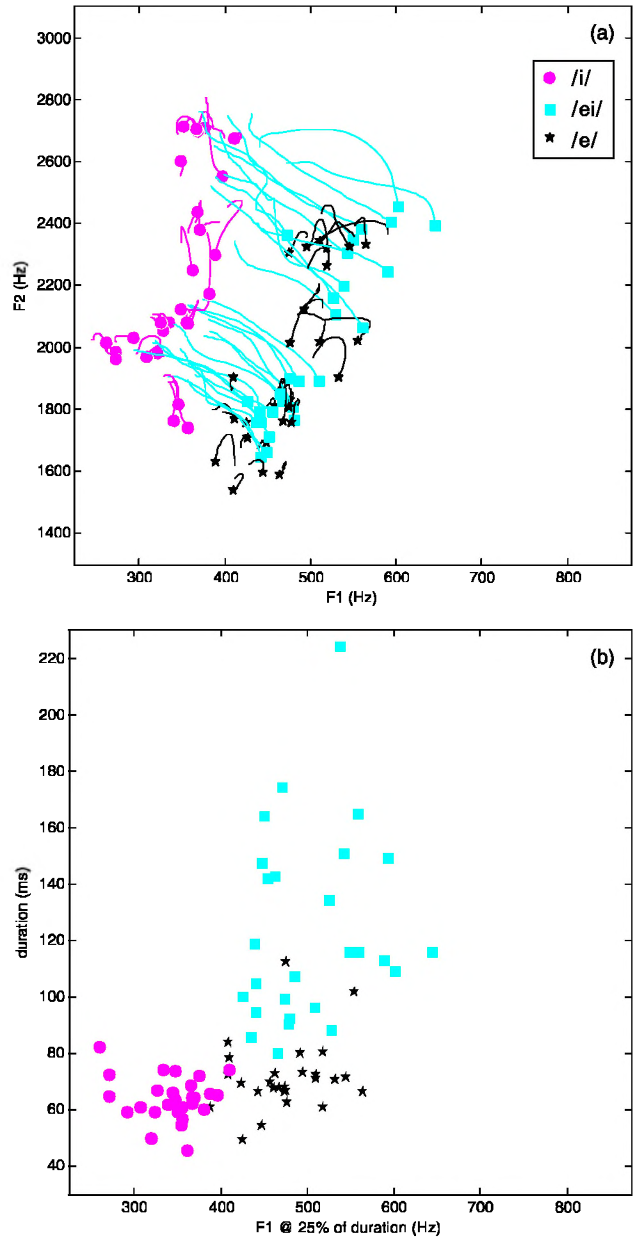


Figure 6. Acoustic properties of the Peninsular-Spanish speakers' vowel tokens used as stimuli in the present study.

training first. Speakers saw the prompt sentences and practiced reading them out loud until the researcher was confident that they could read the sentences smoothly without stumbling over the prompt words. Each prompt sentence was presented multiple times in randomized blocks (ten times for the Canadian-English and Peninsular-Spanish speakers, and three times for the Mexican-Spanish speakers, who also produced responses to a number of other prompts). The speaker heard a beep, saw a prompt sentence on a computer screen, and read the sentence out loud. The researcher monitored the recordings, and rejected recordings with problems such as stuttering, extraneous noise, and clipping. Prompts corresponding to rejected recordings were repeated in randomized order at the end of each block. Prior to the experiment, listeners saw the instructions on the screen and heard them read out.

Recordings were made in sound booths at a sampling frequency of 44.1 kHz using a Sennheiser HMD 280 PRO headset and a Roland ED UA-30 USB Audio Interface with a Rolls MP13 preamplifier for the Canadian-English and Peninsular-Spanish speakers, and a Sennheiser HSP 2 head-mounted microphone with P48 XLP adapter and an Edirol UA-25 USB Audio Interface for the Mexican-Spanish speakers.

2.2 Acoustic stimuli preparation

Ten Canadian-English speakers (5 males and 5 females) were randomly selected. The speakers selected ranged in age from 19 to 28. Three recordings of each stimulus word were randomly selected from the recordings produced by each of these speakers. For each recording, the /bVpa/ was extracted from the sentence and normalized to 99% peak amplitude.

The above procedure was repeated for 9 randomly-selected Peninsular-Spanish speakers (5 males and 4 females aged from 34 to 50, data from an additional female speaker could not be used because of technical problems), and 10 randomly-selected Mexican-Spanish speakers (5 males and 5 females aged from 18 to 30).

F1 and F2 trajectories, and the durations of the natural stimuli are shown in Figs. 5–7. To allow for comparison, the synthetic stimuli from Morrison (2008b) are plotted in Fig. 8 on the same axes and using the same scale as in Figs. 5–7. The spread of natural stimuli along the diagonal of positive correlation between F1 and F2 can be explained by vocal-tract length differences between the speakers. Different phonemes are spread along the diagonal of negative correlation between F1 and F2.

The Mexican-Spanish speakers' /e/ tokens generally have higher F1 and lower F2 compared to those of the Peninsular-Spanish speakers. This difference is consistent with the difference in the location of the Spanish /i/–/e/ boundary found for the perception of synthetic stimuli in Morrison (2008b). Also consistent with the perception of synthetic stimuli in Morrison (2008b), the Peninsular-Spanish speakers' /e/ tokens have similar acoustic properties to the Canadian-English speakers' /ɪ/ tokens (although the English /ɪ/ tokens are generally shorter than

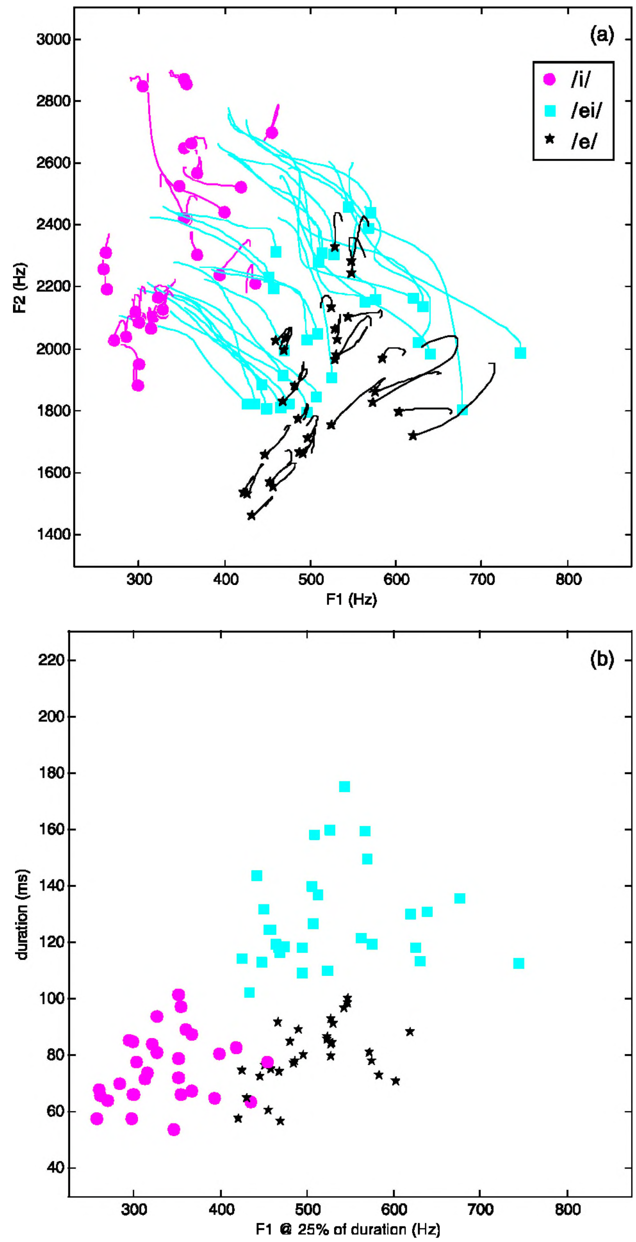


Figure 7. Acoustic properties of the Mexican-Spanish speakers' vowel tokens used as stimuli in the present study.

the Spanish /e/ tokens, and generally have falling F1 and rising F2, which is not the case for the Spanish /e/ tokens).

2.3 Listeners

Eleven monolingual Canadian-English listeners (1 male, 10 female) were recruited in Edmonton, Alberta. They came from western Canada (Alberta and Saskatchewan), and ranged in age from 18 to 27. None reported knowledge of any language other than English.

Eighteen monolingual Peninsular-Spanish listeners (11 male, 7 female) were recruited in Madrid, Spain. They all came from the Comunidad de Madrid, and ranged in age from 18 to 27. None reported knowledge of any language other than Spanish beyond the level *a-little* from a choice of *a-little*, *some*, *well*, and *near-native*, and reported being unable to hold a conversation in any language other than Spanish.

Twenty monolingual Mexican-Spanish listeners (12 male, 8 female) were recruited in Mexico City. They all came from Mexico City and surrounding area, and ranged in age from 18 to 42. None reported knowledge of any language other than Spanish beyond the level *a-little* from a choice of *a-little*, *some*, *well*, and *near-native*, and reported being unable to hold a conversation in any language other than Spanish.

Potential participants who reported hearing or speech impediments were not included in the study.

2.4 Procedure

Listeners were tested one at a time. Testing of the Peninsular-Spanish listeners took place in a quiet conference room, and testing of the other two groups of listeners took place in sound booths. For the Spanish listeners, stimuli were presented using an Edirol UA-25 USB Audio Interface and AKG K701 headphones, and for the English listeners, stimuli were presented using a Roland Edirol UA-30 USB Audio Interface and a Sennheiser HMD 280 PRO headset.

Custom-written software was used to present stimuli and record responses In each trial, listeners heard a stimulus word and responded by clicking on the response button which corresponded to their identification of the word. A replay button allowed the stimulus to be heard up to two more times. A new stimulus was presented 750 ms after a response was given. In the Spanish experiment the response buttons were labelled *BIPA*, *BEIPA*, and *BEPA* representing /bipa/, /beipa/, and /bepa/ respectively, and in the English experiment the response buttons were labelled *BEEPA*, *BIPPA*, *BAYPA*, and *BEPPA* representing /bipə/, /bɪpə/, /bepə/, and /bɛpə/ respectively. Stimuli were presented in random order blocked by speaker. Each stimulus was presented once, except that, to allow for adaptation to each new voice, a single stimulus from the block was randomly selected and presented before the block proper. The response to this extra stimulus was not recorded. If a listener accidentally pressed a button other than their intended response button a "mistake" button was available after the presentation of the next stimulus. If the "mistake" button was pressed the current stimulus and the previous stimulus on which the mistake had been made were re-cued for presentation in random order at the end of the block, and a fresh stimulus was presented for identification.

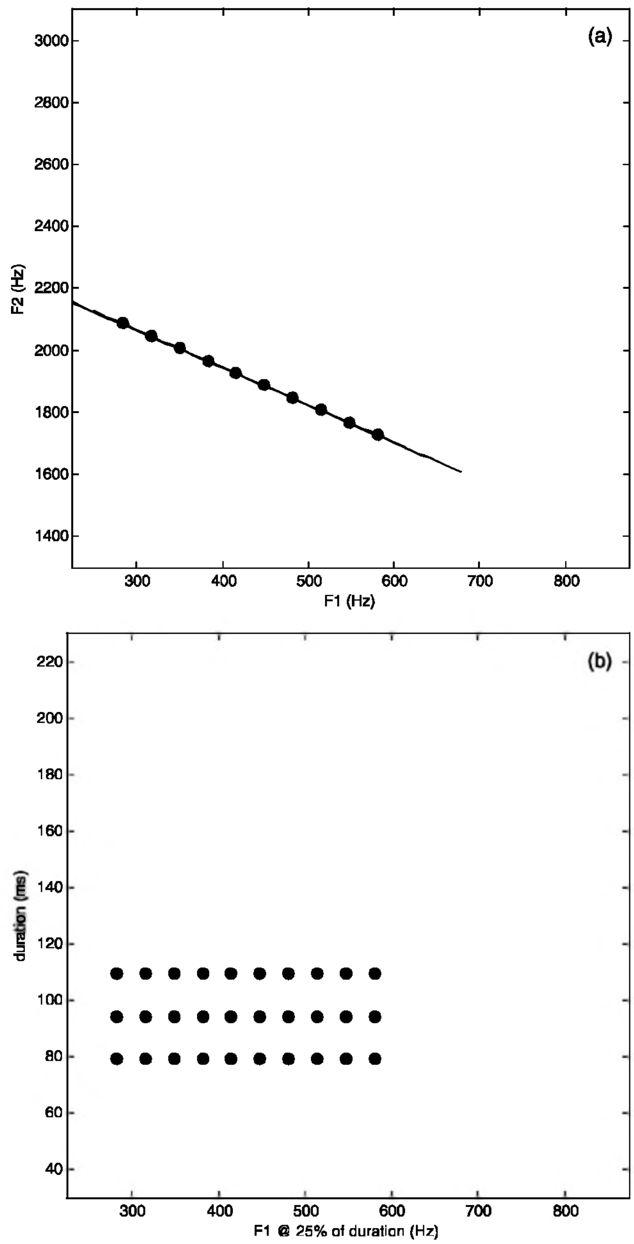


Figure 8. Acoustic properties of the synthetic vowel tokens used as stimuli in Morrison (2008b).

Prior to the experiment, listeners saw the instructions on the screen and heard them read out. They also completed a practice experiment in which they identified stimuli spoken by a speaker of their first language whose stimuli were not included in the experiment proper (the practice speaker was a Canadian-English speaker for the monolingual English listeners and a Colombian-Spanish speaker for the monolingual Spanish listeners). Prior to the instructions and practice, monolingual-English listeners also underwent the same spelling-to-sound correspondence training as described in §2.1.3 above.

3. RESULTS AND DISCUSSION

Tables I–III show confusion matrices for the control tests, each group of listeners identifying vowel tokens from their own first language and dialect. For all groups, the group's correct-identification rates were above 97% for all vowel categories except for Canadian-English listeners' identification of Canadian-English /ɪ/ tokens, which were identified as English /ɛ/ at a rate of 9%. A possible explanation for this could be related to the vowels having been produced in a sentence context but presented to the listeners in a word context. Another possible explanation for this could be related to a putative diachronic vowel shift in Canadian English in which (in traditional terms) /ɪ/ and /ɛ/ are lowering (Boberg, 2005; Clarke, Elms, & Youssef, 1995; Esling & Warkentyne, 1993; Hagiwara, 2006; Morrison, 2006b, §3.1) and in which perception lags behind production (Preston, 2007). One Canadian-English /ɪ/ token was an outlier and clustered with the /ɛ/ tokens, see Fig. 5. It is possible that this token was mis-spoken; however, removal of responses to this stimulus only reduced the percentage of /ɪ/ tokens identified as /ɛ/ to 7.2%.

TABLE I. Confusion matrix of monolingual Canadian-English listeners' identification of English vowel tokens produced by monolingual Canadian-English speakers. The number in each cell represent the proportion of tokens from the category given for the row identified as the category given for the column.

Produced	Classified			
	Eng /i/	Eng /ɪ/	Eng /e/	Eng /ɛ/
Eng /i/	**0.979**	0.021		
Eng /ɪ/		**0.885**	0.024	0.091
Eng /e/	0.003	0.009	**0.985**	0.003
Eng /ɛ/	0.012	0.009	0.003	**0.976**

TABLE II. Confusion matrix of monolingual Peninsular-Spanish listeners' identification of Spanish vowel tokens produced by monolingual Peninsular-Spanish speakers.

Produced	Classified		
	Sp /i/	Sp /ei/	Sp /e/
Sp /i/	**0.975**	0.023	0.002
Sp /ei/	0.004	**0.994**	0.002
Sp /e/	0.004		**0.996**

TABLE III. Confusion matrix of monolingual Mexican-Spanish listeners' identification of Spanish vowel tokens produced by monolingual Mexican-Spanish speakers.

Produced	Classified		
	Sp /i/	Sp /ei/	Sp /e/
Sp /i/	**0.988**	0.002	0.010
Sp /ei/	0.002	**0.998**	
Sp /e/	0.010	0.007	**0.983**

TABLE IV. Confusion matrix of monolingual Peninsular-Spanish listeners' identification of English vowel tokens produced by monolingual Canadian-English speakers.

Produced	Classified		
	Sp /i/	Sp /ei/	Sp /e/
Eng /i/	**0.985**	0.007	0.007
Eng /ɪ/	0.030	0.011	**0.959**
Eng /e/	0.037	**0.831**	0.131
Eng /ɛ/	0.013	0.030	**0.957**

TABLE V. Confusion matrix of monolingual Mexican-Spanish listeners' identification of English vowel tokens produced by monolingual Canadian-English speakers.

Produced	Classified		
	Sp /i/	Sp /ei/	Sp /e/
Eng /i/	**0.980**	0.015	0.005
Eng /ɪ/	0.030	0.022	**0.948**
Eng /e/	0.030	**0.837**	0.133
Eng /ɛ/	0.023	0.023	**0.953**

TABLE VI. Confusion matrix of monolingual Mexican-Spanish listeners' identification of Spanish vowel tokens produced by monolingual Peninsular-Spanish speakers.

Produced	Classified		
	Sp /i/	Sp /ei/	Sp /e/
Sp /i/	**0.974**	0.017	0.009
Sp /ei/	0.006	**0.991**	0.004
Sp /e/	0.006	0.009	**0.985**

Table IV shows the confusion matrix for the Peninsular-Spanish listeners' identification of the Canadian-English speakers' English vowel tokens. Consistent with the prediction from Morrison (2008b), English /i/ tokens were identified as Spanish /i/ at a rate of 99% and English /ɪ/ tokens were identified as Spanish /e/ at a rate of 96%.

Table V shows the confusion matrix for the Mexican-Spanish listeners' identification of the Canadian-English speakers' English vowel tokens. English /i/ tokens were identified as Spanish /i/ at a rate of 98%, but, contrary to the prediction from Morrison (2008b), English /ɪ/ tokens were identified as Spanish /e/ at a rate of 95% and as Spanish /i/ at a rate of only 3%. Table VI shows the confusion matrix for the Mexican-Spanish listeners' identification of the Peninsular-Spanish speakers' Spanish vowel tokens. The correct-identification rate was 98%. Any difference which may exist in the location of the Spanish /i/–/e/ boundary for Mexican-Spanish versus Peninsular-Spanish listeners did not lead to a substantial difference in their perception of either the Peninsular-Spanish of the Canadian-English vowel tokens.

Table VII shows the confusion matrix for the Canadian-English listeners' identification of the Peninsular-Spanish speakers' Spanish vowel tokens. Spanish /i/ was identified as English /i/ at a rate of 94%, but identifications of Spanish /e/ were spread relatively evenly across English /e/ and /ɪ/ (44% and 38%) with a minority of /ɛ/ responses (17%). These results are consistent with the results found for Peninsular-Spanish listeners' perception of Canadian-English vowels: they almost always identified English /ɪ/ as Spanish /e/. This is consistent with Peninsular-Spanish /e/ being more spectrally similar to Canadian-English /ɪ/ than to Canadian-English /ɛ/ (see Figs. 5 and 6). Since Peninsular-Spanish /e/ has relatively little formant movement, and Canadian-English /ɪ/ and /e/ have relatively large magnitudes of formant movement but in opposite directions to each other, duration may be the primary factor determining whether the Canadian-English listeners gave English /ɪ/ or /e/ responses (see Fig. 2).

TABLE VII. Confusion matrix of monolingual Canadian-English listeners' identification of Spanish vowel tokens produced by monolingual Peninsular-Spanish speakers.

Produced	Classified			
	Eng /i/	Eng /ɪ/	Eng /e/	Eng /ɛ/
Sp /i/	**0.936**	0.040	0.024	
Sp /ei/	0.003		**0.997**	
Sp /e/	0.010	0.380	**0.441**	0.168

4. CONCLUSION

A synthetic-vowel perception experiment (Morrison, 2008b) found evidence to suggest that the location of the perceptual boundary between Spanish /i/ and /e/ differed for monolingual Peninsular-Spanish listeners (north-central Spain) and monolingual Mexican-Spanish listeners (Mexico City), and that this would affect their perception of the Canadian-English /i/–/ɪ/ contrast (western Canada): Peninsular-Spanish listeners were predicted to identify almost all tokens of Canadian-English /i/ as Spanish /i/ and almost all tokens of Canadian-English /ɪ/ as Spanish /e/ (two-category assimilation); whereas Mexican-Spanish listeners were predicted to identify almost all tokens of Canadian-English /i/ as Spanish /i/, but identify some tokens of Canadian-English /ɪ/ as Spanish /i/ and some as Spanish /e/.

The present study tested monolingual Peninsular-Spanish and monolingual Mexican-Spanish listeners' perception of natural tokens of English /i/, /ɪ/, /e/, and /ɛ/ produced by monolingual Canadian-English speakers. Consistent with the predictions from Morrison (2008b), Peninsular-Spanish listeners identified almost all tokens of Canadian-English /i/ as Spanish /i/ and almost all tokens of Canadian-English /ɪ/ as Spanish /e/; however, inconsistent with the prediction, the Mexican-Spanish listeners also identified almost all tokens of Canadian-English /i/ as Spanish /i/ and almost all tokens of Canadian-English /ɪ/ as Spanish /e/. If there is any difference between Peninsular-Spanish and Mexican-Spanish with respect to the location of the Spanish /i/–/e/ perceptual boundary, it was not found to have any substantial differential effect on monolingual Peninsular-Spanish versus Mexican-Spanish listeners' perception of natural tokens of Canadian-English /i/ and /ɪ/.

Given the caveats that the present study tested a single dialect of English and only two dialects of Spanish, and tested a single consonant context, the results call into question the assumption that L1-Spanish learners of English have difficulty learning the English /i/–/ɪ/ contrast because they assimilate most tokens of both English vowel categories to a single Spanish vowel category, Spanish /i/. The results indicate that for at least this consonant context both monolingual Peninsular-Spanish and Mexican-Spanish listeners assimilate tokens of Canadian-English /i/ and /ɪ/ to Spanish /i/ and /e/ via a two-category assimilation. On perceptual grounds, Peninsular-Spanish and Mexican-Spanish learners of Canadian-English would therefore not be expected to have difficulty learning the English /i/–/ɪ/ contrast. Given that there is evidence indicating that Mexican-Spanish learners of English do have difficulty learning the Canadian-English /i/–/ɪ/ contrast (Morrison, 2002, 2008a, 2009), one must therefore consider whether there are non-perceptual explanations for this difficulty. The most likely non-perceptual explanations would seem to be (mis)education, students are often taught that English has a long "i" and a short "i" (Flege et al., 1997; Wang and Munro, 1999), and orthography, "i" in Spanish orthography corresponds to Spanish /i/ whereas "i" in English orthography most often corresponds to English /ɪ/ and never to English /i/ (Escudero & Wanrooij, 2010; Morrison, 2009).

ACKNOWLEDMENTS

This research was supported in part by Doctoral and Postdoctoral Fellowships from the Social Sciences and Humanities Research Council of Canada. Data collection took place between 2005 and 2010 when the author was affiliated with, sequentially, the Department of Linguistics, University of Alberta; the Department of Cognitive & Neural Systems, Boston University; the School of Language Studies, Australian National University; and the School of Electrical Engineering & Telecommunications, University of New South Wales. The author wishes to thank the speakers and listeners who volunteered to take part in the research and all those who assisted with recruitment and facilities at, sequentially, the Centre for Comparative Psycholinguistics, University of Alberta; the Phonetics Laboratory, University of the Basque Country; the Phonic Studies Laboratory, College of Mexico; the Biometric Recognition Group, Autonomous University of Madrid; and the Acoustics Laboratory, National Autonomous University of Mexico. Thanks to Vincent Arnaud for the French translation of the abstract.

REFERENCES

Álvarez González, J. A. (**1980**). *Vocalismo español y vocalismo inglés* (Spanish and English vowels), (PhD diss., Universidad Complutense de Madrid).

Best, C. T. (**1995**). "A direct realist view of cross-language speech perception," in *Speech perception and linguistic experience: Issues in cross-language research*, edited by W. Strange (York Press, Timonium, MD), pp. 171–204.

Bohn, O.-S. (**1995**). "Cross-language speech perception in adults: First language transfer doesn't tell it all," in *Speech perception and linguistic experience: Issues in cross-language research*, edited by W. Strange (York Press, Timonium, MD), pp. 279–304.

Boberg, C. (**2005**). "The Canadian shift in Montreal," Lang. Variation and Change, **17**, 133–154. doi:10.1017/S0954394505050064

Chládková, K., Escudero, P., & Boersma, P. (**2011**). "Context-specific acoustic differences between Peruvian and Iberian Spanish vowels," J. Acoust. Soc. Amer., **130**, 416–428. doi:10.1121/1.3592242

Clarke, S., Elms, F., & Youssef, A. (**1995**). "The third dialect of English: Some Canadian evidence," Lang. Variation and Change, **7**, 209–228. doi:10.1017/S0954394500000995

Escudero, P. (**2005**). *Linguistic perception and second language acquisition: Explaining the attainment of optimal phonological categorization*, (PhD diss., University of Utrecht / LOT, Utrecht, The Netherlands).

Escudero, P., & Boersma, P. (**2004**). "Bridging the gap between L2 speech perception research and phonological theory," Stud. Second Lang. Acq. **26**, 551–585. doi:10.1017/S0272263104040021

Escudero, P., & Wanrooij, K. (**2010**). "The effect of L1 orthography on non-native vowel perception," Lang. Speech **53**, 343–365. doi:10.1177/0023830910371447

Escudero, P., & Williams, D. (**2012**). "Native dialect influences second-language vowel perception: Peruvian versus Iberian Spanish learners of Dutch," J. Acoust. Soc. Amer., **131**, E406–E412. doi:10.1121/1.3701708

Esling, J. H., & Warkentyne, H. J. (**1993**). "Retracting of /æ/ in Vancouver English," in *Varieties of English Around the World, Vol. G11, Focus on Canada*, edited by S. Clarke (John Benjamins, Philadelphia, PA), pp. 229–246.

Flege, J. E. (**1991**). "The interlingual identification of Spanish and English vowels: Orthographic evidence," Quart. J. Exp. Psych. **43**, 701–731. doi:10.1080/14640749108400993

Flege, J. E., Bohn, O.-S., & Jang, S. (**1997**). "Effects of experience on non-native speakers' production and perception of English vowels," J. Phonetics **25**, 437-470. doi:10.1006/jpho.1997.0052

Godínez, M. Jr. (**1978**). "A comparative study of some romance vowels," UCLA Working Papers in Phonetics **41**, 3–19.

Hagiwara, R. (**2006**). "Vowel production in Winnipeg," Can. J. Ling. **51**, 127–142.

Møller Glasbrenner, M. (**2005**). *Vowel identification by monolingual and bilingual listeners: Use of spectral change and duration cues* (MSc diss., University of South Florida).

Morrison, G. S. (**2002**). "Perception of English /i/ and /ɪ/ by Japanese and Spanish listeners: Longitudinal results," *Proceedings of the North West Linguistics Conference 2002* edited by G. S. Morrison, & L. Zsoldos (Simon Fraser University Linguistics Graduate Student Association, Burnaby, BC), pp. 29–48.

Morrison, G. S. (**2006a**). "An adaptive sampling procedure for speech perception experiments," in *Proceedings of the Ninth International Conference on Spoken Language Processing: Interspeech 2006 — ICSLP, Pittsburgh* (ISCA, Bonn, Germany), pp. 857–860.

Morrison, G. S. (**2006b**). *L1 & L2 production and perception of English and Spanish vowels: A statistical modelling approach.* (PhD diss., University of Alberta).

Morrison, G. S. (**2008a**). "L1-Spanish speakers' acquisition of the English /i/–/ɪ/ contrast: Duration-based perception is not the initial developmental stage," Lang. Speech **51**, 285–315. doi:10.1177/0023830908099067

Morrison, G. S. (**2008b**). "Perception of synthetic vowels by monolingual Canadian-English, Mexican-Spanish, and Peninsular-Spanish listeners," Can. Acoust. **36**(4), 17–23. [Typesetting errata published in **37**(1), 34]

Morrison, G. S. (**2009**). "L1-Spanish speakers' acquisition of the English /i/–/ɪ/ contrast II: Perception of vowel inherent spectral change," Lang. Speech **52**, 437–462. doi:10.1177/0023830909336583

Morrison, G. S., & Escudero, P. (**2007**). "A cross-dialect comparison of Peninsular- and Peruvian-Spanish vowels" in *Proceedings of the 16th International Congress of Phonetic Sciences: Saarbrücken 2007* edited by J. Trouvain & W. J. Barry (Universität des Saarlandes, Saarbrücken, Germany), pp. 1505–1508.

Preston, D. R. (**2007**). "Why can't you understand your own language?" in *LACUS Forum XXXIII* edited by P. Reich, W. J. Sullivan, A. R. Lommel, & T. Griffen (Linguistic Association of Canada and the United States, Houston, TX), pp. 5–18.

Wang, X., & Munro, M. J. (**1999**). "The perception of English tense-lax vowel pairs by native Mandarin speakers: The effect of training on attention to temporal and spectral cues," in *Proceedings of the 14th International Congress of Phonetic Sciences: San Francisco 1999* edited by J. J. Ohala, Y. Hasegawa, M. Ohala, D. Granville, and A. C. Bailey (University of California Berkeley), pp.125–128.

Wells, J. C. (**1982**). *Accents of English* (Cambridge University Press, Cambridge, UK). Vol. 1 pp. 1–277, vol. 2 pp. 279–465, vol. 3 pp. 466–673.


For Digital Recorders
Introducing
For USB A/D Systems
PHANTOM POWER
7052PH
Measurement Mic System
7052H Type 1.5TM
Titanium Diaphragm
3Hz to >20 kHz
<20 dBA > 140 dBSPL
MK224 (<14 dBA to >134 dBSPL) Optional
4048 Preamp
Superior
IEC 1094 Type 1
Long-term Stability
Temperature and Humidity
Performance
Now in Stock
Phantom
to IEPE/ICP
Adaptor
Supplies 3-4 mA
Power
Accelerometers
Microphones
ICP1248
ACOustics Begins with ACO
TM
MATTtm
Family
MATT TM
Mic
Attenuator
Handle Higher Sound Pressure Levels
ACO Pacific, Inc., 2604 Read Ave., Belmont, CA 94002
Tel:(650) 595-8588 FAX: (650) 591-2891 E-Mail: sales@acopacific.com
Web Site: www.acopacific.com

SCALE-MODEL INVESTIGATION OF THE EFFECTS OF SURFACE ABSORPTION AND NEARBY FOLIAGE ON NOISE-BARRIER PERFORMANCE

Shira Daltrop and Murray Hodgson
Acoustics and Noise Research Group, University of British Columbia
3rd Floor, 2006 East Mall, Vancouver, BC, Canada V6T1Z3
[sdaltrop@gmail.com; murray.hodgson@ubc.ca]

ABSTRACT

Two factors that may affect the acoustical performance of highway noise barriers – surface absorption and nearby vegetation – were investigated using a 1:31.5-scale model highway. Model materials were chosen by performing excess-attenuation measurements and a best fit to find the effective flow resistivity. Surface absorption was tested on single and parallel noise barriers of varying heights, allowing for a comparison between adding absorption and increasing the height. Foliage tests were performed on single and parallel barriers with various configurations of model trees. Barrier absorption prevented the amplification of sound between parallel barriers; in this case, adding absorption to the full source side of the barriers was equivalent to increasing the height of the barriers by 0.33 m. The foliage test results showed that both scattering and absorption occurred, increasing and decreasing barrier performance by up to 4 dB.

SOMMAIRE

Deux facteurs qui peuvent influencer la performance acoustique des écrans routiers – l'absorption des surfaces et de la végétation adjacente – ont été étudiés à l'aide de la maquette d'une configuration routière à l'échelle réduite de 1:31.5. Les matériaux pour la maquette ont été choisis par l'intermédiare de tests d'atténuation excédentaire qui permettaient de determiner la meilleure approximation de la résistivité à l'écoulement à partir des mesures prises. L'effet de l'absorption surfacique a été testé sur des écrans simples et paralèlles de différentes hauteurs, ce qui a permis une comparaison entre les effets de l'absorption et d'un écran plus haut. D'autres tests ont été faits avec des écrans simples et paralèlles en présence de diverses configurations de végétation. L'absorption surfaçique a empêché l'amplification du son entre les écrans paralèlles; le rajout de l'absorption à la surface entière de l'écran côté source a été équivalent à une augmentation de la hauteur de l'écran de 0,33 m. Quant à la végétation, elle a causé et de la diffusion et de l'absorption, tout en augmentant et diminuant la performance jusqu'à 4 dB.

1 INTRODUCTION

Roadside noise barriers are a commonly used method of traffic-noise control. Two factors which may affect the performance of roadside noise barriers were under consideration here. The first was using absorptive surfaces to reduce unwanted amplification between parallel reflective barriers. The second was the effect of foliage near a barrier; noise behind the wall may decrease, due to back-scattering and absorption of the foliage, or increase, because sound which would normally pass over the wall is scattered into the shadow zone. Acoustical scale-modelling was used to investigate these, as it allows ideal conditions to be created. Full details of the study are found in [1].

Some work has already been done to study absorptive noise barriers using scale-modelling. Osman [2] developed a 1:16 scale-model facility, used to study different shapes of noise barriers, both reflective and absorptive [3]. Menge [4] studied the effects of using sloped barriers instead of absorption to reduce amplification between parallel barriers, using a 1:30-scale model. Trucks were the dominant source of noise in the specific case considered; therefore the 250-, 500- and 1000-Hz octave bands were studied. He used 16-mm medium-density overlay plywood with smooth, dense paper glued to both sides to model concrete, asphalt, brick and steel, as well as the reflective, sloped barriers. He used fiberglass for the absorptive barriers. He used an electric spark discharge as an impulsive sound source and a ¼-inch microphone as the receiver. Hothersall *et al.* [5] used a 1:20-scale model to test reflective and absorptive railway noise barriers. They used a polished-aluminum surface to simulate rigid ground and specially manufactured, 8-mm-thick porous plastic plates to simulate grass. The barriers were modelled using plastic or steel and were made absorptive by adding a layer of felt.

Busch [6] created a scale model to investigate noise walls, earth berms, and a combination of the two. He used an air-jet noise source and performed excess-attenuation experiments to determine both the optimal scale factor and the materials to be used. He chose a scale-factor of 31.5 and created the model in an anechoic chamber to represent outdoor conditions. He tested the anechoic chamber thoroughly and determined that it was an appropriate testing environment for the scale-model. He used varnished particle-board to model roadways, dense polystyrene to simulate noise walls, and expanded polystyrene to model soft ground and earth berms. He used felt and expanded polystyrene to make the earth berms softer and harder, respectively.

When discussing the cost effectiveness of absorptive noise barriers, as opposed to reflective barriers, it is convenient to know the equivalent barrier height increase required to obtain the same IL improvement as an absorptive barrier. This was a specific objective of this absorption work.

While much work has been done on studying sound propagation through foliage, there have been only a few studies on the effects of the performance of barriers located near foliage. Cook and Van Haverbeke [7] studied the combination of barriers and trees as a method of noise control. They compared the total, A-weighted sound levels behind different configurations, including bare walls, trees and walls with trees, with no walls or foliage. They found that trees gave approximately 4-5 dBA of attenuation, while a bare wall gave 10-11 dBA and trees with a wall gave 13-14 dBA. Renterghem *et al.* [8] studied the effect of using tree foliage as a wind screen to prevent the refraction of sound around a barrier in a downwind direction. They created a 1:20 scale model in a wind tunnel and used wind screens to model the scale-model trees. They first confirmed the decrease in IL when wind was present, finding IL decreases of up to 8 dB at a distance of 10 times the barrier height away from the barrier. Once the wind screens were inserted, in the absence of wind they found that the change in IL was very small and sometimes negative. They attributed this to the scattering by the wind screen. At greater distances, when wind was present, the windscreen always increased the IL, by up to 4 dB. When the receiver was closer than five times the height of the barrier, no effect was greater than 1 dB. They did not present any frequency-dependent data in this study.

Renterghem *et al.* [9] also performed field tests, in which measurements behind a noise barrier with and without trees were compared. They did a frequency-dependent study on noise levels behind a barrier with and without a single row of 8 m tall trees behind it in the absence of wind. They found that, at low frequencies, noise levels in the no-trees case were higher; above 1000 Hz they found that noise levels in the treed case were higher, with all effects under 5 dB.

In previous studies, the effect of wind was shown to be an important factor affecting barrier performance, but wind was not studied here. In previous studies on the effects of foliage on noise barriers, little frequency-dependent data was reported. However, in studies focusing on sound propagation, the attenuation provided appeared to depend heavily on frequency. Therefore, performing a full frequency-dependent study of the effects of foliage was an objective here. The 1:31.5-scale model originally developed by Busch [6] was redeveloped here and tested in the same anechoic chamber that he used, to examine the two factors under investigation: absorptive barriers and foliage near barriers.

2 THEORY

When creating an accurate scale model, there are many factors that must be taken into consideration. For a scale factor n, all dimensions and distances are scaled by $1/n$. The

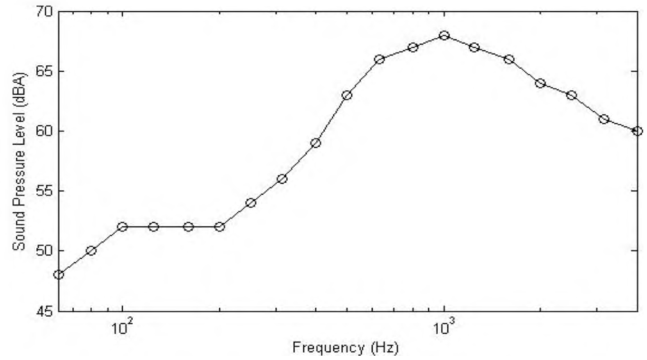


Figure 1. Typical A-weighted traffic-noise spectrum used to determine total A-weighted IL's [6].

speed of sound remains the same in the scale model; to ensure that the relation between distance and the acoustical wavelength remain constant, the wavelength must become λ/n; therefore the frequency f must be scaled up to nf. Issues occur at these higher frequencies, such as air absorption becoming very significant. The directionality of the microphones is also a problem at high frequencies, as one wants the microphone to be as omni-directional as possible, and therefore the smallest microphones available must be used. Furthermore, because the wavelengths of the frequencies of interest are small, the protection grid on the microphone must be accounted for, as it is no longer a negligible size at these frequencies and may affect the frequency response. It is assumed here that effects such as diffraction and interference are consistent under scaling.

Selecting appropriate scale-model materials is crucial to the accuracy of a scale model. The method of selection here was used by Hutchins *et al.* [10] and Busch [11]. Materials to be used in an acoustical scale model must be found which have the same acoustical impedances at scaled-up test frequencies as real-world materials do at full-scale frequencies. The impedance of a fibrous material can be predicted approximately by the simple Delany-Bazley empirical model [12]:

$$Z = 1 + 9.08\left(f/\sigma\right)^{-0.75} + i11.9\left(f/\sigma\right)^{-0.73}$$

where σ is the flow resistivity in c.g.s. Rayls/cm. Since the frequency is scaled by the scale factor n in the model measurements, the flow resistivity must also be scaled by n to keep Z constant. It is the flow resistivity divided by the scale factor n, called the effective flow resistivity, which is compared to real-world values.

The results in this work that are presented as A-weighted insertion losses (IL's) were calculated using the A-weighted traffic-noise spectrum in Figure 1 – determined from many traffic-noise measurements – as a reference. The power output of the sound source was subtracted from the measured noise levels; then the A-weighted traffic spectrum was added, before summing the levels over all frequencies to get a total, A-weighted value. The A-weighted IL was the difference between the values with and without the barrier.

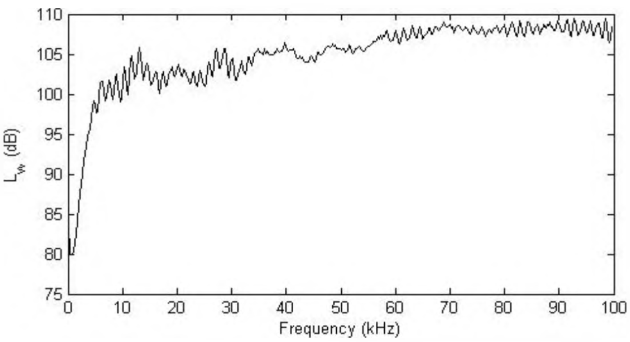


Figure 2. The output sound-power level of the air-jet source.

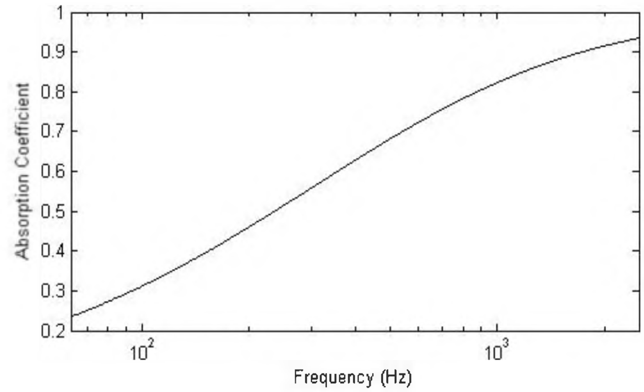


Figure 4. The effective absorption coefficient of the fuzzy blanket.

3 EXPERIMENTAL SET UP

The scale-model measurements were performed in an anechoic chamber with dimensions 4.1 m x 4.7 m x 2.6 m. A 1/4” Bruel & Kjaer type 4135 free-field microphone, the smallest available, was used as the receiver, with a type 2669 pre-amplifier and a 1/2” to 1/4” adaptor. A Nexus Conditioning Amplifier was used mainly for cable-adaptation, and was set as a high-pass filter with a cut-off frequency of 20 Hz. The output sensitivity of the amplifier was set to 31.6 mV/Pa. A Stan-ford Research Systems SR-770 FFT Network Analyzer was used to average and record the acoustic signal in 400 spectral bins, 250-Hz wide, from 0-250 Hz up to 99,750-100,000 Hz. Each measurement involved 2000 spectral averages. The results were stored on 3.5” floppy disks and analyzed in MATLAB. In order to determine the air absorption, the temperature and humidity were measured with a Psychro-Dyne psychrometer.

3.1 Air-Jet Source

The sound source used here was the air-jet source used and tested by Busch [6], who provided a detailed description and the results of in-depth tests of the source in the anechoic chamber. The air-jet source, designed specifically for scale-model traffic noise, was developed from the description by Novak [13]. An ideal source must have sufficient power output for a broadband spectrum up to 100 kHz, which corresponds to about 3000 Hz at full scale, and be approximately omnidirectional. The output sound-power level spectrum of the air-jet was measured and is shown in Figure 2. The source was made of six co-planar jets, each with a diameter of 0.3 mm, spaced at 60° intervals around a cylinder with a diameter of 6.5 mm. The outer housing and the core piece were both made of brass. The core piece had resonant cavities which amplified the source power at lower frequencies. Figure 3 shows the source in cross-section.

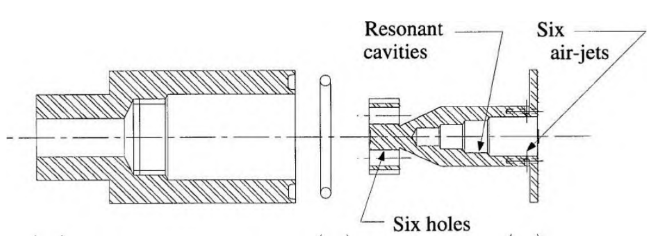


Figure 3. The air-jet noise source in cross-section [13].

3.2 Scale-Model Materials

The model-material selection process used here was used by Hutchins *et al.* [10] and Busch [11]. The flow resistivity values were estimated by taking excess-attenuation measurements; scale-model materials were then chosen by comparing these values with real-world material values. Asphalt was modelled by 3/4” painted plywood, the roadside by two layers of linen, a green fabric was used to model grass, 3-mm-thick dense plastic modelled the reflective barriers and a fuzzy blanket was added to the source side of reflective barriers to make them absorb like commercial sound-absorptive barriers [1]. Figure 4 shows the effective absorption coefficient of the absorptive blanket; Table 1 lists the effective flow resistivities of the scale-model materials.

3.3 Scale-Model Trees

Scale-model trees were used to model tree foliage approximately; one of the trees is shown in Figure 5. The model trees were 17.5-cm tall, corresponding to a full-scale height of 5.5 m. To characterize the foliage, scattering and absorption by the trees were measured. The sound source, at a full-scale height of 1 m, was located over grass, modelled by the green fabric, 10 m from a line of trees. Receivers were placed 5 m in front of and 5 m behind the row of trees, at a height of 1 m. The sound pressure level was measured at both receiver positions, with and without the row of trees present. From this, the tree IL was calculated, by subtracting the level with trees from that without trees.

This measurement was repeated at full-scale, on a hedge along the length of a rugby field on the University of

Table 1. Effective flow resistivities (σ_{eff}) of scale-model materials.

Material	σ_{eff} (c.g.s. Rayls/cm)
Fuzzy blanket	33
Green fabric	253
Two layers of linen	430
Dense plastic	20,000

Plywood	35,500

Figure 5. Scale-model tree.

British Columbia campus [1]. The insertion losses from both the scale-model measurements and the full-scale measurements are presented in Figure 6.

There were some similarities and some large differences between the scale model and the full-scale field results. Attenuation through the foliage was seen in both cases: the trees attenuated sound by up to 3 dB in the scale-model tests and 5 dB in the full-scale tests, due to scattering or absorption. However the IL's in the field tests were smaller below and higher above 600 Hz.

In the scale-model results, the trees had very little effect at the receiver in front of the trees. In the field tests, however, sound levels actually decreased in front of the barrier when the trees were present. One reason for this was the change of ground surface between measurements [14]. The tests in the no-trees case were done in the middle of a grass field, while the ground beneath the hedge contained roots which added porosity, increasing the ground absorption. This could also increase the occurrence of attenuation due to foliage in the measurements taken behind the trees. In the scale-model measurements, the ground remained the same, as the removal of the trees did not affect the model ground.

Another reason for the differing results is likely the leaf size; the leaves in the full-scale hedge were much smaller than the full-scale dimensions of the scale-model trees. The full-scale tests were done on an evergreen hedge with much smaller leaves. In contrast, the leaves on the scale-model

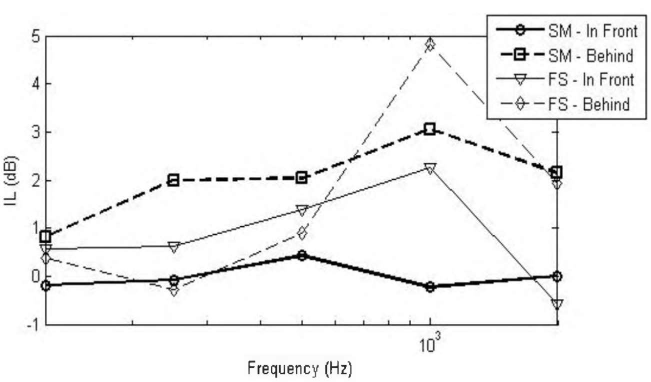


Figure 6. The measured IL in octave bands of a row of trees, measured 5 m in front and 5 m behind the foliage. Full-scale measurements (FS) are compared to scale-model measurements (SM).

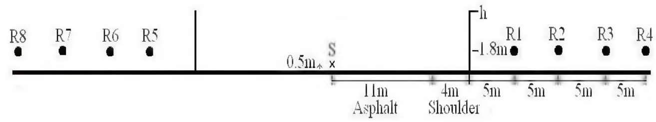


Figure 7. The scale-model test configuration.

trees were quite large compared to the wavelength – approximately 2-mm wide, corresponding to a full-scale size of 6 cm. This is a closer model to a broad-leafed tree. Attempts to locate such foliage for testing were unsuccessful.

The small change due to foliage seen in front of the hedge in the scale-model measurements, where the ground was consistent, and the much greater decrease in sound which reached the back suggested that energy was being scattered or absorbed by the foliage, while little was being back-scattered. The foliage absorbed energy by transferring the sound energy into vibrational energy in the leaves and branches. Sound was scattered in many directions, as opposed to being transmitted through the foliage to the receiver on the other side.

4 RESULTS

Insertion-loss tests were performed using both single and parallel noise barriers. In both configurations, described here using the corresponding full-scale dimensions, a 22-m wide, four-lane highway was modelled. The shoulder – the space between the asphalt and the barrier – was 4-m wide. A distance of 30 m between the parallel barriers was chosen due to the facts that a smaller distance is rarely found in the field, and that the amplification effects are reduced at larger distances. The sound source was placed 0.5-m high, in the center of the highway, 11 m from the shoulder. Receivers were placed 5, 10, 15 and 20 m behind the barrier(s) at a height of 1.8 m. Barrier heights of 3, 4 and 5 m were tested. Figure 7 shows the configuration used.

4.1 Absorption

The effects of barrier absorption on the source side of the barrier were examined for three different barrier heights: 3, 4 and 5 m. Several configurations were measured: reflective and absorptive single barriers, reflective and absorptive parallel barriers, and parallel barriers with one reflective and one absorptive. In the last of these configurations, the reflective barrier was the one between the source and receiver positions R1-R4, while the one between the source and positions R5-R8 was absorptive. When testing one barrier, the barrier between the source and receivers R5-R8 was removed; the IL's for those tests at those receivers were close to zero and are not shown.

Figure 8 shows the octave-band IL at receiver position R2 for the 5-m-high reflective parallel barriers, which ranges from 11-16 dB. Figure 9 shows the IL differences between the reflective parallel barriers and the other barrier and absorption configurations. The IL shown in Figure 7 has been subtracted from the IL's for the other configurations; therefore a positive change in IL is a decrease in noise levels

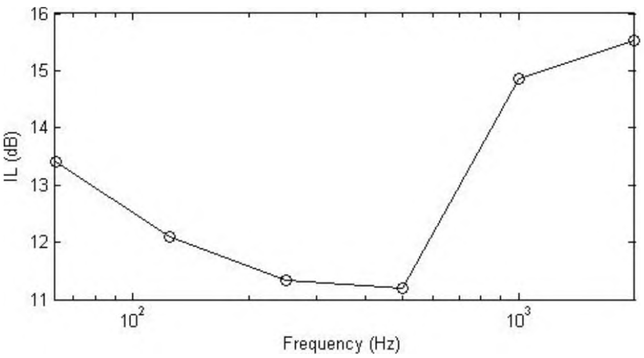


Figure 8. The measured IL in octave bands at receiver position R2 for the 5-m-high reflective parallel barriers.

and an improvement in barrier performance. At low frequencies, the effect of adding a second barrier is apparent; the IL is 1 dB higher for a single barrier than for parallel barriers. Here, absorption increased IL by 1 dB for the parallel barriers. At high frequencies, adding absorption to a single barrier increased IL by 1 dB. For parallel barriers, making them absorptive increased IL by up to 3 dB. Adding absorption to one of the parallel barriers improved IL slightly, making the IL just slightly lower than that of a single reflective barrier.

The A-weighted IL's for the different configurations, at each receiver position and for a barrier height of 5 m, are shown in Figure 10. Changing from a single 5-m reflective barrier to 5-m parallel reflective barriers decreased the IL by approximately 1 dBA. This demonstrates the amplification that occurs between parallel barriers. With absorptive barriers, the parallel barriers gave IL's which were very similar to those of a single barrier. Absorption added to the reflective walls increased the IL very slightly (< 0.2 dBA), but reduced reflections from the wall by up to 1 dBA.

Figure 11 shows the A-weighted IL's for parallel barriers at receiver position R2 for the three barrier heights: 3, 4 and 5 m. Based on these results, increasing the height of a barrier by 1 m increased the IL by more than adding absorption to a smaller noise barrier. By using a best-fit line, it was found that adding absorption increased the IL by the same amount as increasing the height by 0.33 m. This result

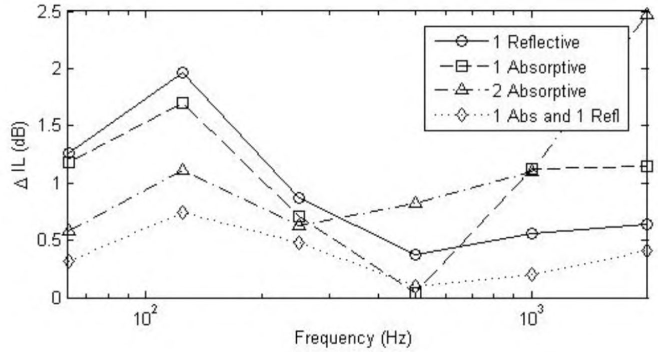


Figure 9. The measured differences in IL between reflective parallel barriers and other configurations. Shown in octave bands and measured at receiver position R2 for the 5-m-high barriers.

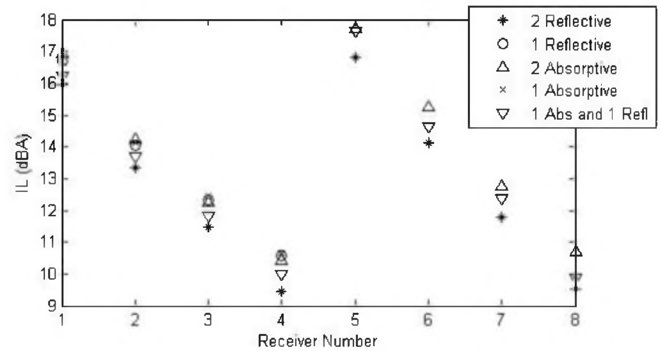


Figure 10. The measured A-weighted IL's for the 5 m tall barriers at the eight receiver positions.

is specific to these data and not necessarily generalizable.

4.2 Foliage: Parallel Barriers

The effect of adding a row of trees along the source sides of 5-m-high parallel barriers is shown in Figure 12. The trees were approximately 5.5-m high, so they overtopped the wall slightly. The measured change in octave-band IL in the case of reflective barriers with and without the rows of trees, measured at position R2, is shown. The foliage had negligible effect up to 500 Hz, then decreased the IL at frequencies up to 1000 Hz. Above this band, the foliage increased IL, acting as a scatterer; sound that would normally reflect from one barrier and diffract around the other is scattered in other directions. Below 1250 Hz, the foliage which overtopped the barrier scattered sound into the shadow zone, causing the decrease in IL.

Figure 13 shows the total, A-weighted IL of reflective and tree-lined parallel barriers at all receiver positions. The trees on the source sides of the barriers decreased the total IL by up to 1 dBA. The increase observed at high frequencies is not enough to balance the decrease below 1250 Hz.

4.3 Foliage: Single Barrier

The effects of foliage at different positions around the barrier were examined using a single, 3-m-high barrier. Only four receiver positions, R1-R4, were behind the single barrier, therefore measurements were taken only at those four positions. The trees were placed at different positions around the barrier: directly behind the barrier, directly in front of the barrier, and 10 m behind the barrier such that

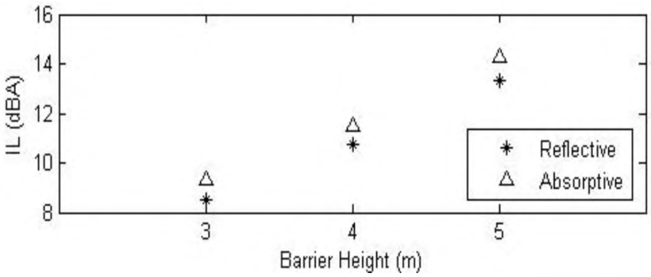


Figure 11. The measured total, A-weighted IL's at R2 for absorptive and reflective parallel barriers of three heights.

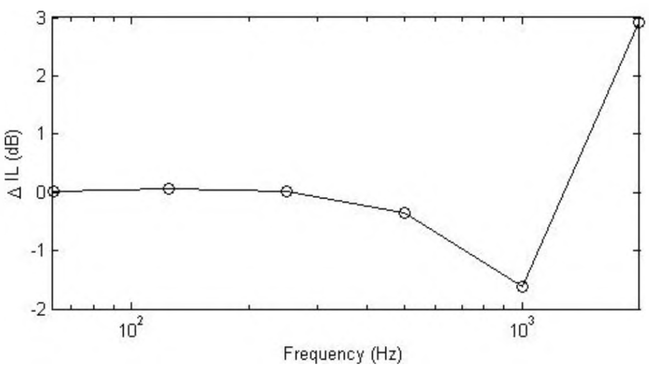


Figure 12. The measured change in IL in the case of parallel barriers with and without a line of trees along the source sides of the barriers. Shown in octave bands and measured at receiver R2 for 5-m-high parallel barriers.

receiver position R1 was between the trees and the barrier. Two different foliage heights were used: 5.5 and 7.2 m. With the taller trees, both the regular density of trees – where the tree bases were placed approximately 1.5 m apart – and with a thicker row of trees – where tree bases were placed 0.9 m apart – were tested. The differences in IL between a reflective barrier and the different foliage configurations are shown in Figures 14 and 15 for the shorter and taller trees, respectively. Placing the foliage directly next to the barrier, either in front or behind, had little effect at low frequency and caused an increase in IL at mid-frequencies. Here the sound was absorbed and back-scattered by the foliage. At high frequencies, the IL decreased by up to 4 dB. At these frequencies, sound was scattered by the foliage into the shadow zone. For taller trees, the attenuation at lower frequencies was greater, and scattering into the shadow zone began to occur at a lower frequency. At low frequencies, the taller trees provided more opportunity for sound absorption and back-scattering, much like increasing the height of a noise barrier. At higher frequencies, there was more effective foliage surface area to scatter the noise. Similar frequency-dependent behaviour has reported been reported in the literature [9, 15]

Placing the trees behind the receiver position had very

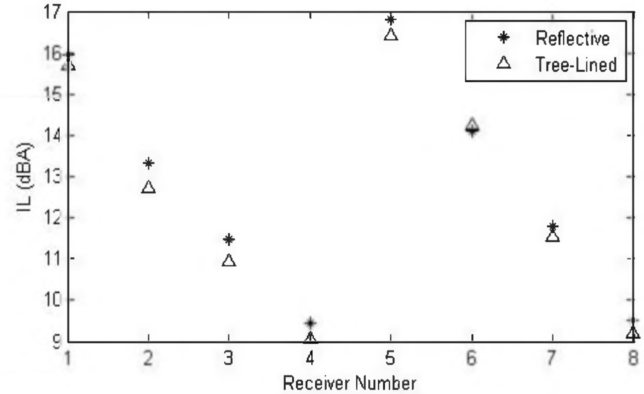


Figure 13. The measured A-weighted IL's for the 5-m-tall barriers at the eight receiver positions, with and without a line of trees along the source sides of the barriers.

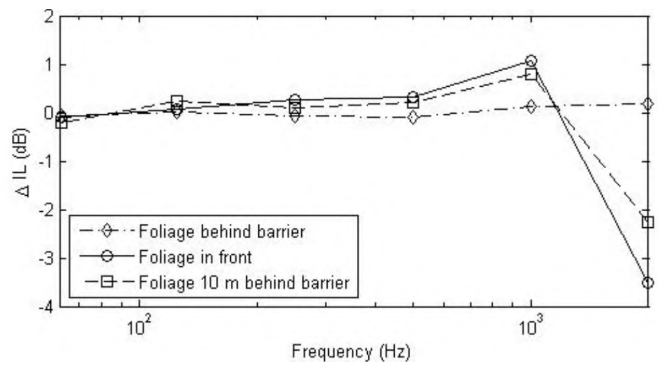


Figure 14. The measured change in IL between a reflective barrier and the different foliage configurations. Shown in octave bands at receiver R1 for a 3-m-high barrier, with 5.5-m-tall trees.

little effect on the IL, in agreement with earlier tests that found little sound is back-scattered from a row of trees. Using denser foliage also had a small effect on the IL. In general, IL increased very slightly, indicating that the denser foliage attenuated more sound, as expected.

5 CONCLUSIONS

A scale model was developed to test two factors that may affect noise barriers. Excess-attenuation measurements were performed to select appropriate model materials. A four-lane highway configuration was then set up, with the option of having a single barrier or parallel barriers. Absorptive barriers of varying height were investigated. It was shown that adding absorption to the source side of parallel barriers increased the total IL by 1 dBA which, in this case, was found to be equivalent to increasing the height of the barrier by 0.33 m. It was also seen that using absorptive barriers prevented the 1 dBA decrease in IL when adding a second barrier, as occurred with reflective barriers. The effects of tree foliage near barriers were also examined using the scale model. Comparisons between measurements done with the scale-model trees and similar measurements done at full scale showed the model trees to be reasonable models of broad-leaf trees. The model trees were then placed in differ-

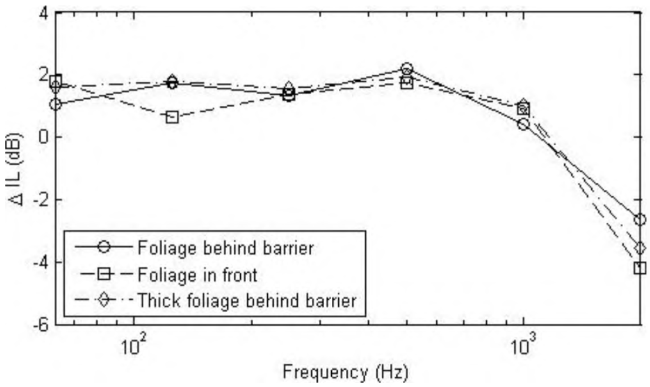


Figure 15. The measured change in IL between a reflective barrier and the different foliage configurations. Shown in octave bands at receiver R1 for a 3-m-high barrier, with 7.2-m-tall trees.

ent positions near the barrier. It was seen that foliage directly in front of or behind the barrier scattered up to 4 dB of sound into the shadow zone, causing the barrier to be less effective, at high frequencies. It was also seen that foliage attenuated sound by up to 2 dB, increasing the effectiveness of the barrier, at mid-frequencies.

REFERENCES

[1] S. Daltrop, "Investigation of factors affecting the performance of roadside noise barriers", M.A.Sc. (Mechanical Engineering) Thesis, University of British Columbia (Aug 2011).

[2] M. M. Osman, "MTC Scale model facility for transportation noise problems: Materials choice and validation for scale modelling", Technical Report 77-AC-4, Ontario Ministry of Transportation and Communications (1977).

[3] D. N. May and M. M. Osman, "Highway noise barriers: New shapes", Journal of Sound and Vibration 71(1), 73–101 (1980).

[4] C. W. Menge, "Highway noise: Sloped barriers as an alternative to absorptive barriers", Noise Control Engineering 14(2), 74–78 (1980).

[5] D. C. Hothersall, D. B. Horoshenkov, P. A. Morgan and M. J. Swift, "Scale modelling of railway noise barriers", Journal of Sound and Vibration 243(2), 207–223 (2000).

[6] T. Busch, "Scale-model investigation of highway traffic noise barriers", Master's Thesis, Department of Mechanical Engineering, University of British Columbia (1997).

[7] D. I. Cook and D. F. Van Haverbeke, "Suburban noise control with plant materials and solid barriers", In: Heisler, Gordon M.; Herrington, Lee P., eds. Proceedings of the Conference on Metropolitan Physical Environment; Gen. Tech. Rep. NE-25. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, 234-241, (1977).

[8] T. Van Renterghem, D. Botteldooren and W. M. Cornelis and D. Gabriels, "Reducing screen-induced refraction of noise barriers in wind by vegetative screens", Acta Acustica united with Acustica 88, 231–238 (2002).

[9] T. Van Renterghem and D. Botteldooren, "Effect of a row of trees behind noise barriers in wind", Acta Acustica united with Acustica 88, 869–878 (2002).

[10] D. A. Hutchins, H. W. Jones and L. T. Russell, "Model studies of acoustic propagation over finite impedance ground", Acustica 52(3), 169–178 (1983).

[11] T. A. Busch and M. R. Hodgson, "Improved method for selecting scale factors and model materials for scale modelling of outdoor sound propagation", Journal of Sound and Vibration 243(1), 173–181 (2001).

[12] M. E. Delany and E. N. Bazley, "Acoustical properties of fibrous absorbent materials", Applied Acoustics 25(114), 339–344 (1971).

[13] J. Novak, "Technical note: Sound source for scale-model measurements of traffic noise", Applied Acoustics 24(1), 63–70 (1988).

[14] W. Huisman and K. Attenborough, "Reverberation and attenuation in a pine forest", Journal of the Acoustical Society of America 90, 2664-2677 (1991).

[15] W. M. Schuller and J. H. de Zeeuw, "Acoustic effect of trees on barrier", Proc. Internoise 1981, 253-256 (1981)

CSA S304 Technical Committee on Occupational Hearing Conservation

Tim Kelsall
Director of Noise and Vibration, Hatch, 2800 Speakman Drive, Mississauga, ON L5K 2R7 - tkelsall@hatch.ca

The Canadian Standards Association S304 Technical Committee on Occupational Hearing Conservation consists of one subcommittee writing a standard on Hearing Conservation Management, five subcommittees covering such aspects as Hearing Protection, Noise Exposure Assessment and Control, Hearing Surveillance, and Vibration Exposure. This paper will give the history of its formation, its current activities and discuss how people can get involved in our work

1. INTRODUCTION

For over 30 years, the Canadian Standards Association (CSA) Technical Committee Z107 was the main body involved with acoustical standards in Canada, (with TC Z94.2 handling a single standard on hearing protection). In 2009, CSA decided to focus their standards efforts on occupational noise and handed over other aspects of acoustics to the Canadian Acoustical Association.

A new CSA Technical Committee, TC S304 on occupational noise, was formed which combined the former Z107 standards related to occupational noise with the Z 94.2 standard on hearing protectors.

The work is done by a series of subcommittees discussed below. Those interested in working on these issues are invited to contact the author (who chairs S304) or the subcommittee chairs.

2. SC1 - HEARING PROTECTION DEVICES– ALBERTO BEHAR

S304 is still responsible for the Z94.2 standard on Hearing Protection. For many years this standard has advocated the use of type A, B, and C hearing protectors. These ratings are not widely used, because most protectors are also sold in the US, where by law they must be labelled with the protector's NRR rating, which is thus much more widely known.

The NRR system, put in place in 1974, meanwhile, is now recognised by most experts as quite flawed because the number shown grossly overstates the actual protection received. The new draft Z94.2 is advocating the NIOSH approach to derating the NRR ratings which derates the NRR by 25-70% depending on the type of protector (minus 7 dB to account for the difference between dBA and dBC).

At this point a new draft of the standard has been written, but there is a concern that if CSA comes out with it before the US decides how they are going to address these ratings, we could again be out of step with that large market for hearing protection.

3. SC2 NOISE EXPOSURE ASSESSMENT AND CONTROL – STEPHEN BLY

This subcommittee is responsible for several standards inherited from the former TC Z107:

3.1 CSA Z107.56

The most widely used of the Z107 series, Z107.56 covers the measurement of occupational noise exposure. A new version is now being proposed which will extend its scope to cover noise exposure under headsets. The new approach encompasses measurements with probe microphones in real ears, measurements using mannequins and artificial ears and a new calculation method using the NR of the headset and the measured sound level outside the headset.

The use of probe microphones and mannequins is covered by Australian and international standards, to which the new version refers. However the calculation method is new. It is intended to be a low cost initial assessment compared to the other systems. It is based on research indicating that most people adjust the volume on a headset to be about 15 dB above the existing background sound inside the protector.

3.2 CSA Z107.58

This standard describes in one location all that Canadians need to know to navigate the variety of standards, codes and regulations which make up the system whereby the sound produced by machinery is documented and available to prospective buyers and users. Health Canada has recently recommended its use by Canadian industry and a new version is expected which will update the constantly changing standards on which the system is based. This system helps industry buy quiet equipment and helps manufacturers provide purchasers with information about sound levels produced by their equipment

4. SC 3 HEARING SURVEILLANCE – CHRISTIAN GIGUERE

SC3 looks after the former Z107.6 standard on Pure Tone Air Conduction Threshold Audiometry. They also will be providing guidance on hearing testing for the Hearing Conservation Management standard.

5. SC 4 VIBRATION EXPOSURE ASSESSMENT & CONTROL – TONY BRAMMER

This subcommittee provides a liaison with the committee responsible for ISO 2631, which Tony Brammer also chairs and will be responsible for writing the vibration section of the Hearing Conservation Management standard.

6. SC5 HEARING CONSERVATION MANAGEMENT – JEFF GOLDBERG

CAALL-OSH, the Occupational Safety and Health Committee of the Canadian Association of Administrators of Labour Legislation, agreed to fund the development of a new Canadian standard on Hearing Conservation Management, which gave a large impetus to the new Technical Committee. This new standard would be part of CSA's OHS Management systems standards series. It would encompass prevention of occupational hearing loss, control of noise in the working environment and be applicable to all occupational sectors and to all workers and occupations. This work was undertaken by SC1 chaired by Jeff Goldberg, who have just completed the first draft of the standard.

MAPPING PERCEPTUAL DISTANCES BETWEEN SIBILANT AND PALATAL FRICATIVES

Corey Telfer
Dept. of Linguistics, University of Alberta, 4-32 Assiniboia Hall, Alberta, Canada, T6G 3E7, corey.telfer@ualberta.ca

1. INTRODUCTION

The perception of fricatives is not well understood, in part because they are generated with air turbulence, which complicates their articulatory and acoustic properties (e.g. Shadle 2012). Sibilant fricatives are especially difficult to characterize because, unlike other obstruents, "…place as well as manner cues are signaled primarily by the spectral structure of the segment itself" (Toda et al. 2010:343), rather than by the formant transitions. While acoustic models of sibilants such as those of Howe & McGowan (2005) and Toda et al. (2010) continue to improve our understanding of these speech sounds, the precise organizational principles behind their perception remain unknown.

Sibilant fricatives can be ordered along a one-dimensional continuum defined by the spectral mean, as seen in Figure 1 (after Boersma & Hamann 2008).

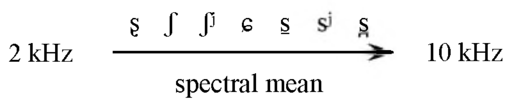


Figure 1. Continuum of seven sibilants based on increasing spectral mean.

The spectral mean is inversely proportional to the volume of the sublingual cavity, so as the place of articulation approaches the anterior of the mouth, the spectral mean increases. While this simple representation captures the basic facts, it fails to account for more subtle distinctions, such as Fujisaki & Kunisaki's (1978) finding that the Japanese alveolar fricative [s] is best modeled using a spectral distribution with two spectral peaks and one valley, rather than just a single peak.

This study investigated whether or not certain pairs of sibilant and palatal fricatives were more difficult to differentiate than others. This was done by presenting listeners with synthesized stimuli in an AX discrimination task and recording their reaction times (RTs). The RTs from correct responses were then transformed and analyzed using multidimensional scaling (MDS) in order to reveal the relative perceptual distances between these fricatives.

2. STIMULI

A continuum of thirteen synthesized fricative stimuli was generated by filtering Gaussian white noise. The filter shapes were based on observations and measurements taken from recordings of four 'anchor' fricatives: postalveolar [ʃ] and alveolar [s] from Canadian English, alveolo-palatal [ɕ] from Mandarin Chinese, and palatal [ç] from Russian and German. The palatal fricative [ç] is not a sibilant, but was included due to its shared similarities with this class of speech sounds. Like sibilants, it has very little energy in the lower frequencies, a relatively sharp and well-defined peak, and a gradual decrease in amplitude in the high frequencies. It differs from sibilants primarily in peak amplitude.

In an effort to focus on the primary perceptual cues used to identify sibilants and palatal fricatives, the filter shapes were modeled as simplistically as possible, using only seven sets of frequency and amplitude values for each filter.

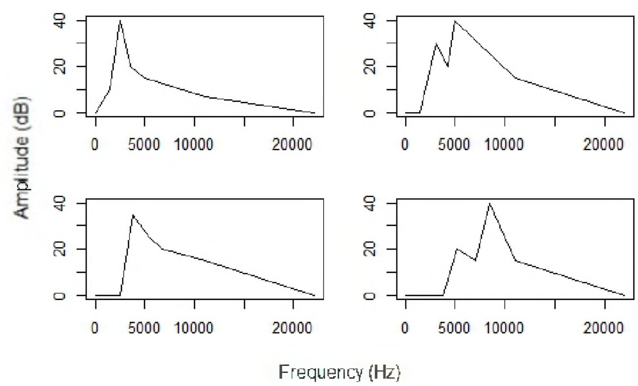


Figure 2. Filter shapes for the four anchor stimuli: [ʃ, ɕ, ç, s].

Note that while the sibilants had amplitude ranges of 40 dB, the palatal fricative [ç] had a range of only 35 dB. The frequency and amplitude values of the four anchor filters went through a two-stage process of interpolation in order to create a continuum of thirteen filters. The anchor stimuli [ʃ, ɕ, ç] and [s] correspond to positions 1, 5, 9 and 13 in the stimulus continuum.

A 600 ms sample of white noise was generated using Praat (Boersma & Weenink 2010), with the first and final 100 ms tapered down to 0 dB in order to approximate the spectral envelope of naturally-produced fricatives. This tapered white noise was then passed through each of the thirteen filter shapes using MATLAB's `filter` function (MathWorks 2008) in order to create the final stimulus continuum.

3. METHOD

The participants were 30 native speakers of Canadian English from the University of Alberta. They received partial course credit in exchange for their participation.

The participants were presented with an AX (same-different) discrimination task where they were asked to determine if pairs of synthesized fricative stimuli were instances of the same stimulus, or two different stimuli. They were heard 312 'same-different' stimulus pairs and an equal number of 'same-same' pairs, presented in random order, for a total of 624 trials per participant.

The stimuli were presented using E-Prime 2.0 (Psychology Software Tools 2002). Participants were given feedback after each trial indicating whether their previous response was correct or incorrect, and, if correct, their reaction time was also displayed. This was done to help participants respond as quickly and accurately as possible.

4. RESULTS & ANALYSIS

The overall error rate was 13.7%; the pair [ʃ-ɕ] had the highest error rate, at 7.5%.

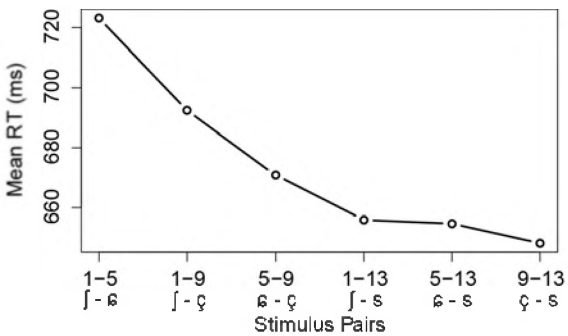


Figure 3. Mean RTs for 'anchor' stimulus pairs.

Pairs that involved a contrast with alveolar [s] had the lowest reaction times, suggesting this fricative was easily distinguished from the others.

The mean RTs for each stimulus pair were transformed into dissimilarity proximities by taking their reciprocal (1/RT). These proximities were then analyzed using the `cmdscale()` function included in the Base Package of the statistical analysis program R (R Core Team 2012). The data was modeled in three dimensions (stress value: 7.47). MDS analyses are most easily viewed in a two-dimensional format, and in this case the most noteworthy comparison is found between dimensions one and three, seen in Figure 4.

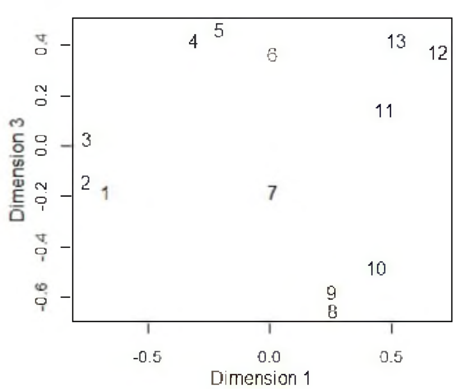


Figure 4. MDS model of dimensions 1 and 3 for all stimuli. Key for anchor stimuli: [ʃ]=1, [ɕ]=5, [ç]=9 and [s]=13.

We see here that the majority of the stimuli are clustered in four groups, and each group is formed around one of the four anchor stimuli. The relatively long distances between the clusters indicates that English listeners did not find it difficult to distinguish the four anchor stimuli, including the non-English fricatives [ɕ] and [ç].

5. DISCUSSION

The dimensions assigned by the MDS model are inherently meaningless, but they tend to reflect underlying structure in the data. In this case, the first dimension in Figure 4 seems to reflect a general increase in the spectral mean, much like the diagram seen in Figure 1. Dimension three serves primarily to differentiate the amplitude of the spectral means, with the non-sibilant palatal fricative [ç] separated from the sibilants [ʃ, ɕ] and [s].

This study demonstrated that it is possible to learn about the perceptual organization of sibilant and palatal fricatives using only listeners' RTs. The palatal fricative [ç] was seen to fall within the sibilant fricative continuum, and non-phonemic fricatives were reliably distinguished by English listeners. Further investigation will consider more fine-grained differences in spectral shape, as well as including vocalic environments in order to better emulate fricatives as they appear in natural speech.

REFERENCES

Boersma, Paul, and Silke Hamann. (2008). The Evolution of Auditory Dispersion in Bidirectional Constraint Grammars. *Phonology*, 25, 217–270.

Boersma, Paul, and David Weenink. (2010). Praat: doing phonetics by computer. http://www.praat.org/.

E-Prime 2.0. (2002). Pittsburgh, PA: Psychology Software Tools.

Fujisaki, H., and O. Kunisaki. (1978). Analysis, recognition, and perception of voiceless fricative consonants in Japanese. *IEEE Transactions on Acoustics, Speech and Signal Processing*, 26, 21–27.

Howe, M. S., and R. S. McGowan. (2005). Aeroacoustics of [s]. *Proceedings: Mathematical, Physical and Engineering Sciences*, 461, 1005–1028.

MATLAB. (2008). Version 7.6.0.324 (R2008a). Natick, MA: MathWorks, Inc.

R Core Team. (2012). R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. http://www.R-project.org/.

Shadle, Christine H. (2012). The Acoustics and Aerodynamics of Fricatives. *The Oxford Handbook of Laboratory Phonology*, ed. by A. C. Cohn, C. Fourgeron, and M. Huffman. Oxford: Oxford University Press.

Toda, Martine, Shinji Maeda, and Kiyoshi Honda. 2010. Formant-cavity affiliation in sibilant fricatives. *Turbulent sounds - an interdisciplinary guide*, ed. by Susanne Fuchs, Marzena Zygis, and Martine Toda, 343–374. Walter de Gruyter.

ACKNOWLEDGEMENTS

This research was supported by the Social Sciences and Humanities Research Council of Canada, grant number 752-2011-1538. I would also like to thank Santiago Barreda for his help with the stimulus synthesis and Dr. Ben Tucker for his supervision of this project.

EXTENDING THE CAPABILITY OF THE COMPLEX EFFECTIVE DEPTH APPROXIMATION

David J. Thomson[1] and Gary H. Brooke[2]
[1]733 Lomax Road, Victoria, BC, Canada, V9C 4A4 drdjt@shaw.ca
[2]Brooke Numerical Services, 3440 Seaton Street, BC, Canada, V8Z 3V9 gab.bns@gmail.com

1. INTRODUCTION

The Pekeris waveguide, comprising a homogeneous water layer of sound speed c_w and density ρ_w above a homogeneous fluid half-space (usually of greater sound speed and density), provides a canonical configuration for studying low-frequency sound propagation in shallow water. Numerical results for the pressure in the upper layer due to a water-borne harmonic point source are readily obtained using an acoustic propagation code derived from one of the standard representations for the field, e.g., wavenumber integration, normal mode, multipath expansion, or parabolic equation [1]. Although the Pekeris waveguide represents an idealized description of a shallow water environment, it is important conceptually as it exhibits several features that are characteristic of normal mode propagation. Even for this simple configuration, however, the normal mode wave-numbers satisfy a complicated dispersion relation. As a result, they must be determined numerically using root-finding procedures. A detailed numerical analysis of a modal solution to the Pekeris waveguide for the case of a lossy fluid bottom was recently presented by Buckingham and Giddens [2].

In contrast to this exact modal approach, the "effective depth" approximation for the Pekeris waveguide, introduced by Weston [3], replaces reflection from a lossless fluid half-space by reflection from a free surface located at an appropriate distance below the actual bottom. This paradigm has undergone generalizations in recent years e.g., [4]–[7]. The effective-depth approach was modified by Chapman *et al.* [4] to derive approximate modal wavenumbers in the case of a lower half-space that supports shear. Later, Balasubramanian and Muni [5] showed that the exact modal wavenumbers could be obtained by iterating the effective-depth equations mode by mode. All of the above work ignored energy loss on reflection so that the features of the effective reflecting surface depended only on the phase of the bottom reflection coefficient. This limitation was overcome by Zhang and Tindle [6] who used the full reflection coefficient to account for energy loss on reflection. In this case, the resulting effective depth of the perfect reflector becomes complex to account for this sea-bottom loss. Subsequently, Tindle and Zhang [7] used an approximate normalization of the modal sum, based on the complex effective-depth method, to avoid sudden jumps in the behaviour of the field during modal cutoff that occurs for upslope adiabatic propagation over a sloping elastic bottom.

In this paper, we extend the effective-depth method to include two boundary features that can effect propagation in shallow water. First, we show how the coherent scattering effects due to a rough sea-surface can be accommodated within the context of the Kirchhoff approximation. Second, we demonstrate how the basic equations can be readily modified to take into account a layered ocean bottom structure. As a result, the complex effective-depth approach can be applied without difficulty to a more general class of shallow water propagation environments. Following a brief summary of the necessary equations and iteration algorithm, we present an example that exhibits the effects on normal mode propagation for a Pekeris type waveguide having a layered ocean bottom and a rough surface.

2. BASIC THEORY

For acoustic propagation in a shallow water isovelocity waveguide of depth H, the horizontal wavenumber $\boldsymbol{k}$ of each normal mode satisfies the eigenvalue condition,

$$\left[1 - R_s(k)R_b(k)\exp(2i\gamma H)\right]_{k=k_n} = 0 \ . \qquad (1)$$

Here $R_s(k)$ is the plane wave reflection coefficient at the sea surface, $R_b(k)$ is the plane wave reflection coefficient at the sea bottom, and $\gamma = (\omega^2/c_w^2 - k^2)^{1/2}$ is the vertical wavenumber corresponding to $\boldsymbol{k}$. For a flat pressure-release surface, $\boldsymbol{R_s = -1}$. To accommodate coherent scattering from a rough pressure-release surface characterized by an rms roughness, $\boldsymbol{\sigma}$, we use the Kirchhoff approximation, $\boldsymbol{R_s = -\exp(-2\sigma^2\gamma^2)}$, to write Eq. (1) in the form

$$\left[1 + \Re(k)\exp(2i\gamma H)\right]_{k=k_n} = 0 \ , \qquad (2)$$

where we have set $\Re(k) = R_b(k)\exp(-2\sigma^2\gamma^2)$. Defining the complex phase of $\Re$ via $\boldsymbol{\psi(k) = -i\ln[\Re(k)]}$ leads to an equivalent form of Eq. (2), namely

$$2\gamma(k)H + \psi(k) - \pi = 2(n-1)\pi \ . \qquad (3)$$

At this point we remark that $\boldsymbol{R_b}$ can be generalized to take into account the effects of multiple uniform layers atop a basement half-space by making use of the recursion formulas described in [1]. The complex effective-depth approximation is obtained by defining

$$\Delta H(k) = [\psi(k) + \pi]/2\gamma(k) \qquad (4)$$

and by using Eq. (4) to write Eq. (3) as

$$\gamma(k) = n\pi/[H + \Delta H] \ . \qquad (5)$$

Eq. (5) is recognized as the eigenvalue equation for the vertical wavenumber of a normal mode in an ideal isovelocity waveguide of complex depth $H+\Delta H$. Exact modal eigenvalues to the original penetrable waveguide can be obtained iteratively as follows [5],[6]: for each n, assume an initial value for k_n, use Eq. (4) to find ΔH, then Eq. (5) to find γ, and finally use $k=(\omega^2/c_w^2-\gamma^2)^{1/2}$ to obtain an improved value of k_n. The process is repeated until the value of k_n converges to a given tolerance. It is worthwhile remarking that this complex effective-depth representation allows for the treatment of both trapped and leaky modes. The acoustic pressure in the isovelocity water due to a point source at depth h is then given by

$$p(r,z)= 2i\pi\sum_n [H+\Delta H(k_n)]^{-1}\sin(\gamma_n h)\sin(\gamma_n z)H_0^{(1)}(k_n r)\,. \quad (6)$$

The factor $2/[H+\Delta H(k_n)]$ is the approximate normalization for the n^{th} normal mode in an ideal waveguide with a sea-bottom at its appropriate complex effective depth.

3. EXAMPLE

To illustrate our extensions to the complex effective-depth method, we consider the shallow-water Pekeris type waveguide depicted in Fig. 1. For the modal calculations, the sediment region is modelled by a stack of 50 uniform layers each 2-m thick whose sound speeds track the gradient there. Transmission losses (TLs) vs range at 100 Hz are computed between a source and receiver at mid-depth in the water column for both flat surface ($\sigma=0$ m) and rough surface ($\sigma=2$ m) conditions. The modal TLs (ZTmode) are compared against the TLs computed using the benchmark wavenumber integration code SAFARI [8]. For the SAFARI results, 4 sublayers were used to approximate the linear variation of sound speed in the sediment region.

The transmission loss comparisons are shown in Fig. 2 for the flat surface scenario and in Fig. 3 for the rough surface scenario. The SAFARI results (shown as triangular points) have been subsampled for clarity. It is observed that the agreement between the two numerical approaches is excellent. The effects of surface roughness are seen to increase the TL due to stripping of the higher-order modes.

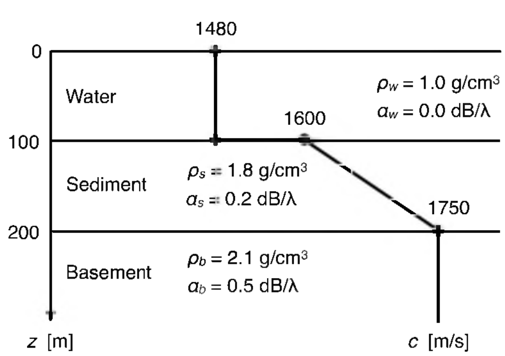


Figure 1. Pekeris type waveguide with a sediment layer.

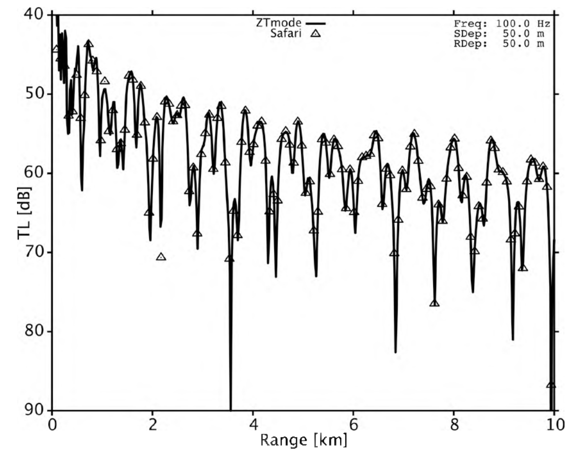


Figure 2. TL comparison for a flat surface.

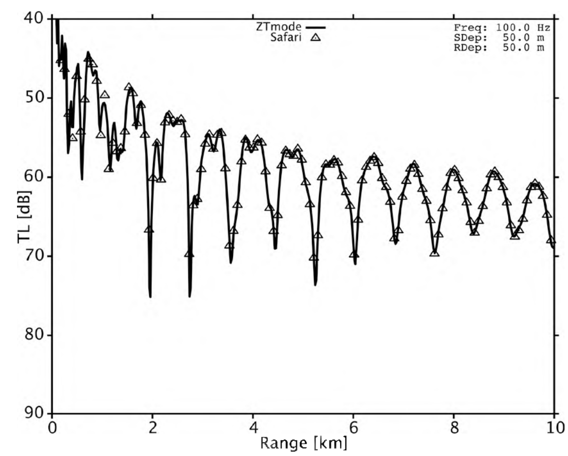


Figure 3. TL comparison for a 2-m rms rough surface.

REFERENCES

[1] Jensen, F.B, W.A. Kuperman, M.B. Porter and H. Schmidt, Computational Ocean Acoustics, 2nd Ed. (Springer, New York, 2011).

[2] Buckingham, M.J. and E.M. Giddens (2006), "On the acoustic field in a Pekeris waveguide with attenuation in the bottom half-space," J. Acoust. Soc. Am. **119**, 123–142.

[3] Weston, D.E. (1960), "A Moire fringe analog of sound propagation in shallow water," J. Acoust. Soc. Am. **32**, 647–654.

[4] Chapman, D.M.F., P.D. Ward and D.D. Ellis (1989), "The effective depth of a Pekeris ocean waveguide, including shear wave effects," J. Acoust. Soc. Am. **85**, 648–653.

[5] Balasubramanian, P. and M.M. Muni (1990), "A note on the effective depth of a Pekeris ocean waveguide, including shear wave effects," J. Acoust. Soc. Am. **88**, 564–565.

[6] Zhang, Z.Y. and C.T. Tindle (1993), "Complex effective depth of the ocean bottom," J. Acoust. Soc. Am. **93**, 205–213.

[7] Tindle, C.T. and Z.Y. Zhang (1997), "An adiabatic normal mode solution for the benchmark wedge," J. Acoust. Soc. Am. **101**, 606–609.

[8] Schmidt, H. (1988), "SAFARI Seismo-Acoustic Fast field Algorithm for Range-Independent environments," SACLANTCEN Report SR–113, SACLANT Undersea Research Centre, San Bartolomeo, Italy.

Wind Turbine Noise
Editors: Dick Bowdler and Geoff Leventhal
Multi Science Publishing Co., 2011
List price: US$94.50 (Softcover)
260 pp., ISBN: 978-1-907132-30-8

Wind turbine noise and impact of wind farms have been in the forefront of rural confrontational politics in Ontario between wind farm developers and rural homesteads. Unscientific and anecdotal descriptions of the noise impact of wind turbines have been headline news in major media in Ontario. And hence, *Wind Turbine Noise* is a timely release as it provides an excellent reference guideline of wind turbine noise.

In a nutshell, *Wind Turbine Noise* edited by Dick Bowdler and Geoff Leventhall provides a summary of wind turbine noise generation, measurement, and evaluation. It is a compilation of the existing knowledge about wind turbine noise and its impact. As will be seen later, quite a few chapters need revisions with results from future studies. The eight chapters (and two appendices) were written by professionals with experience in the different aspects of wind turbine noise. The eight chapters are: 1) Basic Acoustics by Geoff Leventhall, UK (consultant); 2) Primary Noise Sources by Stefan Oerlemans (Netherlands), National Aerospace Laboratory, NLR; 3) Sound Propagation form Wind Turbines, Andrew Bullmore (UK) and Andrew Peplow (UK), Hoare Lea Acoustics; 4) Wind Turbine Noise at the Receiver, Bo Søndergard (Denmark), Grontmij Acoustica; 5) Amplitude Modulation, Frits van den Berg (Netherlands) and Dick Bowdler (UK);6) Effects of Sound on People, Frits van den Berg (Netherlands), GGD Amsterdam Public Health Service;7) Measuring and Analyzing Wind Turbine Noise, David Hessler (USA), Hessler Associates, Inc.; 8) Criteria, Mark Bastasch (USA), CH2M Hill. Appendix 1 deals with the "Detection of Sound Sources Using Phased Microphone Arrays" and Appendix 2 discusses "Background Noise Wind Shear and Shelter."

Chapter 1 is a basic introduction to acoustical terms without technical details. The one drawback is the missing discussion on low-frequency measurement instrumentation. Chapter 2 is one of the best chapters of this compendium and deals with the different mechanisms of turbine noise generation. Many sections are from the original work of the author and the chapter also presents methods to reduce the noise output of wind turbines.

Chapter 3 presents methods to evaluate the propagation of the noise from the turbines to the receptor. All the difficulties, uncertainties and risks involved in any simplified process to predict, with any semblance of accuracy, the wind turbine noise at receptor locations are enumerated first. The important factors that govern the prediction models are discussed in detail. The available prediction models such as engineering methods, semi-analytical methods and numerical methods are analysed. The chapter then provides a summary of the results from the different models by applying them to well chosen examples. The one main conclusion that can be inferred from this chapter is that the prediction model based on the ISO Standard 9613-Part 2 is the least accurate.

Chapters 4, 5 and 6 need substantial revisions as well as require substantive support for the hasty conclusions presented to be credible, in particular, in chapters 5 and 6. Chapter 4 supposed to present wind turbine noise at receptor locations. The chapter is poorly written and the flow is uneven between sections. It looks as if the author has not read the previous two chapters. Two main conclusions of Chapters 2 and 3, infra sound is minimal from wind turbines and ISO9613-Part 2 process is the least accurate, the author discussed simulation results using ISO Standard 9613 –Part 2 methods and discusses general impact of low frequency noise. No supporting evidence of actual measurements was forthcoming. Specular reflection of wind turbine from building facades is simulated by assuming the wind turbine to be a single point source. The author should have presented experimental results to support that specular reflection of large rotating blade actually increases the receptor noise levels from local reflections. Similarly, the section on low frequency noise describes general impacts of low-frequency noise, but does not provide the relationship of low-frequency noise of wind turbines and its impact on humans. A major study conducted for the Ontario Ministry of the Environment concluded that the low frequency noise of wind turbines is not significant. Many of the plots are difficult to discern (small fonts, invisible colour etc.). The purpose of Chapter 4 is completely lost on this reviewer.

Chapters 5 and 6 are gift to the powerful anti-wind farm lobby. Chapter 5, in a brief seven pages, discusses "Amplitude Modulation" effects of wind turbines. Chapter 2 already identified that there is amplitude modulation and the effect is called swish. Based on a few anecdotal discussions, the chapter purports to show that the swish becomes thumping due to a presence of favourable wind conditions such as "stable" and "neutral" etc. However, the chapter never defines what "thumping" is. No characteristics of thumping (it even calls it beating) such as frequency components, time variation and their signal level are provided to the readers to understand the significance of Amplitude Modulation. The chapter presents results from one wind farm of 10 wind turbines and another one of five wind turbines in Figures 1, 2 and 3. A cursory perusal of these figures does not provide any evidence of swish changing to thump. One needs much better set of results to make valid conclusion that there is 'thump.' Once again, based on one wind farm data, the chapter conjectures the reasons for strong presence of the swish at receptor locations. Two factors are suggested – the local wind condition such as "stable wind" and interferences from many wind turbines. Once again, the above two factors are just speculations and no strong experimental and theoretical evidences are forthcoming. To present speculations in a textbook is a disservice. Perhaps, one could have waited for later editions of the book to present results of "Amplitude Modulation" with strong scientific backing.

Chapter 6 discusses the effects of noise on people. It presents all possible effects of noise, but this book is supposed to discuss the wind turbine noise. Many of the effects have no relation to wind turbines. Each noise effect is presented with snippets from articles in the literature without any evaluation by the author himself. These effects are presented as if they are from wind turbines without supporting scientific evidence. Two cases in point: a) VVVD – Quoting Pierpoit's book, the book speculates that low-frequency noise and vibration can cause Visceral Vibration Vestibular Disease. Where is the supporting evidence that wind turbines have strong low frequency vibration and noise? B) VAD – based on anecdotal evidence from a single family, Alvares-Periera and Branco speculated that VibroAcoustic Disease is caused by wind turbine noise. Chapter 6 simply repeats their speculations without proper analysis. The only conclusion of Chapter 6, after a reader intelligently dismisses most of the effects of humans outlined, that can be made is that the main impact of wind turbine noise is human annoyance.

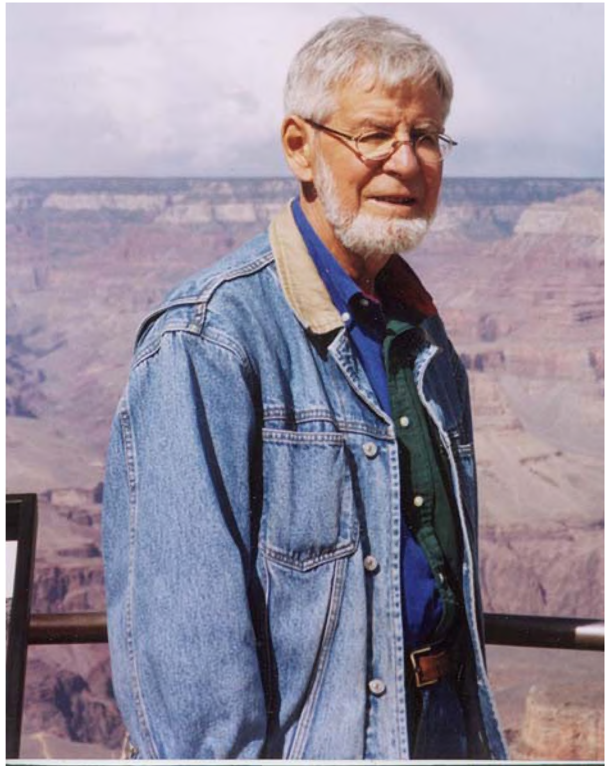
Chapter 7 discusses, with insight, the different processes involved in measuring noise and analyzing the results, both from approvals as well as from complaint investigation perspectives. The author is very careful to list the pitfalls inherent in the measurement procedures. The presentation is methodical and to the point. Chapter 8 provides a comprehensive summary of regulatory process used in different countries, a valuable addition to the compendium.

After reading this anthology, the main issues that are still unresolved are: a) a standard acceptable prediction model, b) universally acceptable measurement procedures, c) amplitude modulation and its effects on humans, d) wind shear effects and local topography, and e) human impact of wind turbine noise that raises the existing rural noise levels by more than 10 dB. Finally to conclude, most of the authors are practicing specialists (consultants) and many of them do not have the resources to conduct deep study of the issues of wind farm noise that need to be addressed. However, *Wind Turbine Noise* is a welcome introduction to the vexing conflict between "green energy" and "social impact." However, a few chapters are badly presented with nothing but summary snippets from papers available in the literature. Many of the shortcomings of the book have been highlighted in this review. It is clear that a lot more research needs to be undertaken to settle the few main concerns of wind farm noise and this reviewer wished that the book, under review, acknowledged its shortcomings.

NOTE: The readers of *Canadian Acoustics*, interested in wind turbine noise issues, should also refer to the two issues of *Acoustics Australia*, Vol. 40, Nos. 1 and 2, which deal with many aspects of the wind farm issues in Australia with insight. The current book, with all its shortcomings, and the two journal issues form a good reference material set to aid the practicing noise consultants.

Prof. Ramani Ramakrishnan
Department of Architectural Science
Ryerson University, Toronto
rramakri@ryerson.ca

OBITUARY / OBITUARE – Dr. Don. L. Allen



Dr. Don Allen died peacefully at Thompson House in Don Mills, on Sept. 7th, 2012 – at a ripe age of 81, after a courageous struggle with Lewy Body Dementia. He is survived by his wife of 58 years, Kaireen, four children and nine grandchildren . Don was born in a small farming community in Nova Scotia. He attended Dalhousie University (BSc.), Nova Scotia Technical College (B.Eng), and University of Toronto (M.A.Sc & Ph.D). He was founder and owner of Vibron Limited from 1959 to 1997, a unique engineering and manufacturing company specializing in noise and vibration control. During these years he was an Assistant Professor of Mechanical Engineering at U of T mentoring many an eager student.

Prepared by his family

Prof. Ramani Ramakrishnan of Ryerson University adds the following:

I have known Dr. Allen for the past 30 years and he was a well known noise and vibration specialist in Canada. Many of his accomplishments in noise and vibration control stand tall such as his state-of-the design of the Tuned Mass Damper for Toronto's CN Tower and many innovative noise control designs. His seminal Noise and Vibration Control course at the University of Toronto was one of the most popular courses in the Mechanical Engineering Department. Dr. Allen was instrumental in making noise and vibration control a mainstay in many industrial and residential development applications. Most of the senior acoustic consultants owe their acoustical training to Dr. Allen, as they learned at the feet of a true master, when they worked at Vibron Limited. He was a great teacher, a brilliant mentor and he will be truly missed by the acoustical community of Canada.

OBITUARY / OBITUARE – Mr. Mike Cardillo

It is with great sadness that we have to inform you that Mr. Mike Cardillo passed away on September 9th, 2012. At the age of 37 years old, he leaves behind his wife and three lovely girls. Mike had been with Dalimar for 15 years now and was handling the province of Ontario. He was a hard working individual with always one thing in mind… making sure his customers were 100% satisfied. His premature departure leaves a big void for Dalimar and we have already started the process to find a someone to handle Ontario. Finding an individual as dedicated as Mike will be a hard task but Dalimar will make sure it happens.

Prepared by Dalimar Instruments

Canadian Acoustical Association

Minutes of the Board of Directors Meeting

Banff, Alberta
October 9, 2012

Present: Christian Giguère (chair), Jérémie Voix, Hugues Nélisse, Tim Kelsall, Clair Wakefield, Stan Dosso, Ramani Ramakrishnan, Dalila Giusti, Chantal Laroche, Roberto Racca, Kathy Pichora-Fuller, Frank Russo, Sean Pecknold

The meeting was called to order at 5:10 p.m. Minutes of the previous Board of Directors' meeting on June 2nd, 2012 were approved as published in the June 2012 issue of *Canadian Acoustics. (Moved by T. Kelsall, seconded by C. Wakefield, carried).*

President's Report

Christian Giguère reported that several initiatives are underway that will soon simplify the administration of the Association and benefit members. These include the advent of an online membership dues renewal system, and an online paper submission system and Journal access. He mentioned that these are exciting times for the Association and thanked everyone involved in these initiatives.

He proposed that the next BoD meeting and AGM be held in Montreal in June 2013, during the ICA conference. Minutes from those two meetings would be published in the September issue of Canadian Acoustics. A BoD meeting will also take place in October 2013, details to be announced..

(Moved by S. Pecknold, Seconded by F. Russo, carried)

Secretary's Report

Chantal Laroche reported that membership and renewals are significantly up from last year (Table below). There are 365 active members (regular, emeritus, student and sustaining subscriber members) compared to only 232 reported last year during the Board of Directors Meeting held on October 11th 2011.

Category	**Paid 2011**	**Paid 2012**	**Change from 2011**
Member	148	250	+ 102
Emeritus	2	2	0
Student	33	59	+ 26
Sustaining subscriber	49 (35*)	50	+ 15**
Total	232 (218*)	365	+ 133

* 14 of the 49 sustaining subscribers listed in the table had not renewed their membership in 2011, reducing the actual number to 35, for a total of 218 active members in 2011.

** This number is based on actual paid sustaining subscribers in 2011 and 2012.

Renewal and application forms have been updated, as found in the September 2012 issue of the journal, to reflect the fact that sustaining subscribers are not considered regular members and need to pay regular membership for voting privileges during the Annual General Meeting and for participation in CAA functions.

Jeremie Voix is developing a new system that will allow CAA to transition to online payments and database management for the next round of membership renewals (i.e. January 2013), if feasible.

(Approval of report moved by R. Ramakrishnan, seconded by T. Kelsall, carried)

Treasurer's Report

The Treasurer, Dalila Giusti, submitted a report including a preliminary financial statement for the fiscal year. CAA finances are in reasonable standing. Revenue from membership dues and advertising has increased from last year because reminders were sent to members. The 2011 Conference (Quebec) also made a substantial profit and journal advertizing revenues were significantly on the rise.. Overall, Association revenues well exceeded expenses and the costs for student awards.

Due to the timing of the Conference with our year end, year-end statements for the 2012 fiscal year will be available in spring 2013.

Dalila will transfer $10,000.00 from the Operating Account to the Capital Account to cover Student Awards. Jeremie Voix has requested a budget of $6500.00 for the online journal. With this additional expenditure, the difference between the proposed expenses and the proposed revenue is about $3650.00, which could represent the average spending capital for the 2013 fiscal year if 2012 Conference revenues are not high.

In light of this, Dalila proposed the following increases in membership dues:

· Members: currently $80.00; proposed $90.00

· Students: currently $35.00; proposed $40.00

·Sustaining Subscribers: currently $350.00; proposed $400.00

(Motion for the increase in membership rates as indicated above: Moved by D. Giusti, seconded by R. Ramakrishnan: In favour: 9, opposed: 3)

The Treasurer's report was accepted. *(Moved by R. Ramakrishnan, seconded by F. Russo, carried)*

Editor's Report

Different issues were addressed during the Editor's report. Copyright was discussed and C. Giguère will send examples of wording to F. Russo who will then submit a proposal via email to the BoD for approval. Joining EBSCO was also discussed in length. K. Pichora-Fuller suggested the implementation of an editorial board to address this issue, but no decisions were made.

J. Voix presented the new online system for paper submission, membership renewal and paper consultation. Trials for membership renewals will be performed with BoD members to validate the system. The renewal and subscription forms will be modified to allow online payment. The BoD thanked Jérémie for his work on the online system.

The Editor-in-Chief, Ramani Ramakrishnan, is not seeking re-election after 14 years (56 issues) of service. The BoD warmly thanked Ramani for his leadership and dedication during all those years.

Rich Peppin resigned as the advertising editor, with Clair Wakefield taking over this position. T. Kelsall will be in charge of the postal box in Toronto.

CAA Conferences – Past, Present & Future

2011 (Quebec): A final report for the conference has been received from conference chair C. Giguère, with the final transfer of funds. The Board thanked the organizers for the high quality of the very successful meeting.

2012 (Banff): Conference Chair Stan Dosso has reassembled the successful team from Victoria 2010, with Roberto Racca as Technical Chair and a team of five others organizing the exhibition, Everything is in place for a very successful meeting.

Subsequent meetings: The 2013 CAA conference will be integrated into the International Congress on Acoustics (ICA) to be held in Montréal in June 2013. Also, CAA will sponsor a satellite International Symposium on Room Acoustics (ISRA) in Toronto, in coordination with the ICA. The 2014 meeting will be held in Winnipeg with Karen Turner as convener. For 2015, different venues were discussed including Toronto, London, Guelph and Ottawa.

Awards

Frank Russo presented a report summarizing decisions from all individual prize coordinators. Eligible applications were available for all awards and winners have been selected, except for the Directors' awards (which will be decided soon).

Winners will be announced on October 11th during the banquet, and in the December 2012 issue of *Canadian Acoustics*.

Hugues Nelisse is replacing Frank as the new Awards coordinator.

Acoustical Standards Committee

Tim Kelsall reported on the status of the CAA Acoustical Standards Committee, which will meet concurrently with the CSA standards committee on October 10th. A report will be printed in the December 2012 issue of the journal.

CAA Website

Sean Pecknold advised that a major revision is still on hold until the new member database and registration system become available online. There is now a specific heading on the main page for Acoustical Standards activities.

Other Business

Directors' liability insurance was discussed and Dalila presented a quote from an insurance company. BoD proposed to take a coverage of 1 000 000$ at a cost of 950$/year. Dalila will clarify some points with the company before finalizing any decision.

Adjournment

Meeting adjourned at 10:00 p.m. *(Moved by J. Voix, seconded by C. Laroche, carried)*

Canadian Acoustical Association

Minutes of Annual General Meeting

Banff, Alberta
October 11, 2012

Call to Order

President Christian Giguère called the meeting to order at 5:02 p.m. with 32 members in attendance, and presented the Agenda for acceptance *(Moved by R. Ramakrishnan, seconded by S. Dosso, carried.)*

Minutes of the previous Annual General Meeting held on October 13, 2011 in Quebec were approved as printed in the December 2011 issue of *Canadian Acoustics. (Moved by N. Ellaham, seconded by C. Wakefield, carried)*

President's Report

Christian Giguère briefly summarized his report to the Board meeting on October 9th. He emphasized that the society is in good standing financially, that membership is strong and that Journal operations are running smoothly. Annual conferences continue to be highly successful. Several initiatives of benefit to members are up coming, including online dues renewal and Journal (see below).

Secretary's Report

Chantal Laroche provided an overview of membership and operational activities.

- The total of 365 paid renewals and new memberships is up from last year, presumably due to reminders sent to members.
- Jeremie Voix is developing a new system that would allow CAA to transition to online payments and database management for the next round of membership renewals (i.e. January 2013), if feasible.

(Acceptance of Secretary's report moved by T. Kelsall, seconded by H. Forester, carried.)

Treasurer's Report

Dalila Giusti presented an overview of her written report to the Board on CAA finances. CAA is in good financial standing, with total assets of $340 527 at fiscal year-end (before audit).

In 2013, a small loss (3650$) is predicted due to the development of the online system. To overcome this loss in revenue, Dalila proposed the following increases in membership dues:

· Members: currently $80.00; proposed $90.00

· Students: currently $35.00; proposed $40.00

·Sustaining Subscribers: currently $350.00; proposed $400.00

(Motion for the increase in membership rates moved by A. Behar, seconded by R. Racca: Unanimous)

The Treasurer's report was accepted. *(Moved by R. Peppin, seconded by T. Kelsall, carried)*

Editor's Report

J. Voix presented the new online system for paper submission, membership renewal and paper consultation.

The Editor-in-Chief, Ramani Ramakrishnan, is not seeking re-election after 14 years (56 issues) of service.. The members warmly thanked Ramani for his leadership and dedication during all those years.

Rich Peppin resigned as the advertising editor, with Clair Wakefield taking over this position.

Lifetime membership and reduced rates for retired members were suggested and will be discussed at the next BoD.

Award Coordinator's Report

Frank Russo presented a report summarizing decisions from all individual prize coordinators. Eligible applications were available for all awards and winners have been selected, except for the Directors' awards (to be decided soon). Winners will be announced on October 11th during the banquet, and in the upcoming issue of *Canadian Acoustics*. Two awards (500$ each) have been added for 2013: Psychological Acoustics and Architectural Acoustics.

Hugues Nelisse will be replacing Frank as the new Awards coordinator.

Past and Future Meetings

2011 (Quebec): A final report for the conference has been received from conference chair C. Giguère, with the final transfer of funds. The Board thanked the organizers for the high quality of the very successful meeting.

2012 (Banff): Conference Chair Stan Dosso has reassembled the successful team from Victoria 2010, with Roberto Racca as Technical Chair and a team of five others organizing the exhibition, Everything is in place for a very successful meeting.

Subsequent meetings: The 2013 CAA conference will be integrated into the International Congress on Acoustics (ICA) to be held in Montréal in June 2013. Also, CAA will sponsor a satellite International Symposium on Room Acoustics (ISRA) in Toronto, in coordination with the ICA. The 2014 meeting will be held in Winnipeg with Karen Turner as convenor. For 2015, different locations were discussed including Toronto, London, Guelph and Ottawa.

Acoustical Standards Committee

Tim Kelsall reported on the status of the CAA Acoustical Standards Committee, which met with the CSA standards committee on October 10th. A report will be printed in the December 2012 issue of the journal. Tim asked for volunteers to translate in French parts of the standards.

Website

Sean Pecknold advised that a major revision is still on hold until the new member database and registration system become available online. He also mentioned that minutes from the Acoustical Standards committee are now available on the website.

Nominations and Election

CAA corporate bylaws require that each year we elect the Executive and Directors. The Past President, Stan Dosso, presented nominations and managed the election process.

For the election process, Stan read the name of the nominee(s) and asked if there were other nominees from the floor.

- Five of the eight current Directors (namely Roberto Racca, Kathy Pichora-Fuller, Sean Pecknold, Jérémie Voix, and Hugues Nelisse) were eligible for re-election and indicated their willingness to stand.
- Tim Kelsall and Clair Wakefield have served the maximum term of 6 years and were therefore not eligible for re-election. Frank Russo is stepping down as director since he is seeking election as Editor in chief. Stan identified Karen Turner, Bill Gastmeier and Bryan Gick as nominees for the final Director positions.
- Three of the four Executives (Christian Giguère for President, Dalila Giusti for Treasurer, Chantal Laroche for Executive Secretary) were eligible for re-election and indicated their willingness to stand. Ramani Ramakrishnan resigned as the Editor in chief. Frank Russo is nominated by the Board as Editor in chief.

In each case, there were no other nominations from the floor, so these nominees were declared elected by acclamation. Tim, Ramani and Clair were thanked for their service.

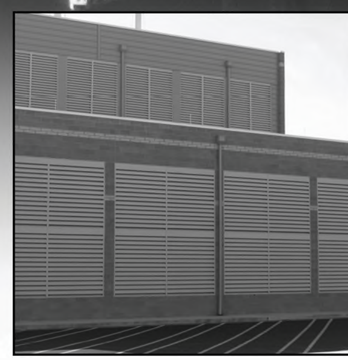
Adjournment

Meeting adjourned at 6:06 p.m. *(Moved by R. Peppin, seconded by D. Giusti, carried)*

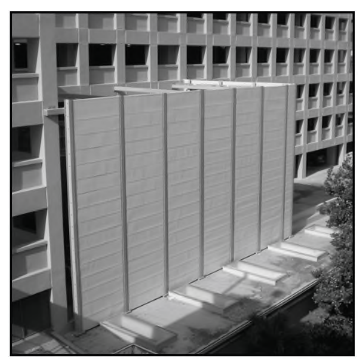
Environmental Noise Control

Community friendly solutions for chillers and cooling towers

- Over 50 Years of Proven Design and Performance
- Independently Tested Products
- On Grade or Roof Top Applications
- Maximum Noise Reduction
- Low System Pressure Loss



Central Energy Plant Louvers



Cooling Tower Barrier Wall System

KINETICS Noise Control

Canadian Acoustical Association
Association canadienne d'acoustique

2012 PRIZE WINNERS / RÉCIPIENDAIRES 2012

SHAW POSTDOCTORAL PRIZE IN ACOUSTICS /
PRIX POSTDOCTORAL SHAW EN ACOUSTIQUE

Jorge Quijano (University of Victoria)

BELL GRADUATE STUDENT PRIZE IN SPEECH COMMUNICATION AND HEARING /
PRIX ÉTUDIANT BELL EN COMMUNICATION VERBALE ET AUDITION

Takashi Mitsuya (Queen's University)

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

Dugald Thomson (University of Victoria)

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

Guilhem Viallet (École de Technologie Supérieure)

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

Sin Tung Lau, Jacob Maracle and Dario Coletta (University of Toronto at Mississauga)

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

Usman Kamran (Westwood Community High School, Fort McMurray, AB)

Directors' Awards / Prix des Directeurs

Non-student / Non-étudiant:

John Bradley, Institute of Research in Construction, NRC

Student / Étudiant:

Judith Wiedman, Ryerson University

Student Presentation Awards / Prix pour Communications Étudiantes
Banff (AB), October 10-12, 2012

Martin Brummund (École de Technologie Supérieure)
Sponsored by Scantek

Nicolas Ellaham (University of Ottawa)
Sponsored by Kinetics Noise Control

Tristan Defrancesco-Loria (Ryerson University)
Sponsored by Jade Acoustics

CONGRATULATIONS / FÉLICITATIONS

Student presentation winners Martin Brummond (left) and Nicolas Ellaham (right), with Awards Coordinator Hugues Nélisse, at Acoustics Week in Canada 2012.

PRIZE ANNOUNCEMENT • ANNONCE DE PRIX

Prize

Edgar and Millicent Shaw Postdoctoral Prize in Acoustics
Alexander G. Bell Graduate Student Prize in Speech Communication and Hearing
Eckel Graduate Student Prize in Noise Control
Fessenden Graduate Student Prize in Underwater Acoustics
Raymond Hetu Undergraduate Student Prize in Acoustics
Graduate Student Prize in Architectural and Room Acoustics
Graduate Student Prize in Psychological Acoustics

Prix

Prix Post-doctoral Edgar et Millicent Shaw en Acoustique
Prix etudiant Alexander G. Bell en Communication orale et audition (2^{e} ou 3^{e} cycle)
Prix etudiant Eckel en Controle du bruit (2^{e} ou 3^{e} cycle)
Prix etudiant Fessenden en Acoustique sous-marine (2^{e} ou 3^{e} cycle)
Prix etudiant Raymond Hetu en Acoustique (1er cycle)
Prix etudiant en Acoustique Architecturale et Acoustique des Salles (2^{e} ou 3^{e} cycle)
Prix etudiant en Psychoacoustique (2^{e} ou 3^{e} cycle)

Deadline for Applications:
April 30th 2013

Date limite de soumission des demandes:
30 Avril 2013

Consult CAA website for more information
Consultez le site Internet de l'ACA pour de plus amples renseignements
(http://www.caa-aca.ca)


Concerto
4-Channel Multi-Function Acoustic Measuring System
All you need in one system:
- 4-channel SLM Class 1
- RT60, EDT, C80, D50 & Ts
- 4-channel Data Logger
- 4-channel Spectrum Analyzer
- Building and Human Vibration
- Monitoring Station with Remote Access
Custom Modules Available
See demo : www.softdb.com/concerto.php
Remote access via iPhone or PC


I-Track
Automatic Real-Time Sound Mapping
See demo : www.softdb.com/itrack.php
Automotive
Industrial
Laboratory
Architectural
5-Minute Mapping
Freehand Scanning Without Grid

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 $90.00 for individual members and $40.00 for student members. This includes a subscription to ***Canadian Acoustics***, the journal of the Association, which is published 4 times/year, and voting privileges at the Annual General Meeting.

Subscriptions to *Canadian Acoustics* *or* Sustaining Subscriptions

Subscriptions to ***Canadian Acoustics*** are available to companies and institutions at a cost of $90.00 per year. Many organizations choose to become benefactors of the CAA by contributing as Sustaining Subscribers, paying $400.00 per year (no voting privileges at AGM). The list of Sustaining Subscribers is published in each issue of ***Canadian Acoustics*** and on the CAA website.

Please note that online payments will be accepted at http://jcaa.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 $ 90.00
[ ] CAA Student Membership $ 40.00

Corporate Subscriptions (4 issues/yr)
[ ] $90 including mailing in Canada
[ ] $98 including mailing to USA,
[ ] $105 including International mailing

[ ] Sustaining Subscription $400.00
(4 issues/yr)

Please note that the preferred method of payment is by credit card, online at *http://jcaa.caa-aca.ca*

For individuals or organisations wishing to pay by cheque, please download the application form at http://www.caa-aca.ca and mail to:

Executive Secretary, The Canadian Acoustical Association, PO Box 74068, Ottawa, Ontario, K1M 2H9, Canada

Formulaire d'adhésion

L'adhésion à l'ACA est ouverte à tous ceux qui s'intéressent à l'acoustique. La cotisation annuelle est de 90.00$ pour les membres individuels, et de 40.00$ pour les membres étudiants. Tous les membres reçoivent ***l'Acoustique Canadienne***, la revue de l'association publiée quatre fois par année, et ont droit de vote à l'assemblée générale annuelle.

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

Les abonnements à la revue ***Acoustique Canadienne*** sont disponibles pour les corporations et institutions au coût annuel de 90.00$. Plusieurs organisations choisissent de devenir bienfaiteurs de l'ACA en souscrivant à un abonnement de soutien de 400.00$ par année (sans droit de vote à l'AGA). La liste des abonnés de soutien est publiée dans chaque numéro de la revue ***Acoustique Canadienne*** et sur le site internet de l'ACA.

Noter que les paiements en ligne sont effectués à http://jcaa.caa-aca.ca

Pour correspondance administrative 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	5. Physio / Psycho-acoustique	9. Acoustique sous-marine
2. Génie acoustique / Contrôle du bruit	6. Chocs et vibrations	10. Traitement des signaux /Méthodes numériques
3. Acoustique physique / Ultrasons	7. Audition	
4. Acoustique musicale / Électro-acoustique	8. Parole	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 90.00 $
[ ] Membre étudiant(e) 40.00 $

Abonnement corporatif (4 numéros/année)
[ ] 90 $ à l'intérieur du Canada
[ ] 98 $ vers les États-Unis
[ ] 105 $ tout autre envoi international

[ ] Abonnement de soutien 400.00 $
(4 numéros/année)

Noter que la méthode de paiement privilégiée est par carte de crédit, en ligne à *http://jcaa.caa-aca.ca*

Les individus et organisations préférant payer par chèque doivent télécharger le formulaire d'adhésion disponible à http://www.caa-aca.ca et le poster à l'adresse suivante:

Secrétaire exécutif, Association canadienne d'acoustique, CP 74068, Ottawa, Ontario, K1M 2H9, Canada

INSTRUCTIONS TO AUTHORS
FOR THE PREPARATION OF MANUSCRIPTS

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

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 39(1) 2011. 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 - 0.75"; bottom - 0.75" minimum; sides - 0.75".

Title: Bold, Times New Roman 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 technical 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. For electronic submissions, do not number pages.

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. Le manuscrit peut être aussi acheminé par voie électronique.

Présentation générale: Le manuscrit doit être soumis avec mise en page en format de publication. Dimension 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 39(1) 2011. 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: Haut - 0.75"; bas - minimum 0.75" ; côtés,- 0.75".

Titre du manuscrit: Caractères gras, Times New Roman 14 pt,avec espace interligne de 14 pt, lettres majuscules, texte centré.

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

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

Titres des sections: **T**ous 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.

Équations: Minimiser le nombre et les numéroter. Insérer directement dans le texte les équations très courtes.

Figures/Tableaux: De petites tailles. Les insérer dans le texte au haut ou au 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 techniques 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 numérisées: Doivent être au minimum de 225 dpi et au maximum de 300 dpi. Les schémas doivent être en format bitmap tif. Les photos noir et blanc doivent en format tif sur une échelle de tons de gris et toutes les photos couleurs doivent être en format CMYK tif.

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. Ne pas paginer si le manuscrit est envoyé par voie électronique.

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

SUSTAINING SUBSCRIBERS / ABONNES DE SOUTIEN

The Canadian Acoustical Association gratefully acknowledges the financial assistance of the Sustaining Subscribers listed below. Their annual donations (of $350.00 or more) enable the journal to be distributed to all at a reasonable cost.

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 $350.00 et plus) rendent le journal accessible à tous nos membres.

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.
Dr. J.G. Migneron - (418) 834-1414
courrier@acoustec.qc.ca - St-Nicolas, QC

ACOUSTIKALAB Inc.
Jean Laporte - (514) 692-1147
jlaporte@acoustikalab.com - Montréal, QC

AECOM
Frank Babic - (905) 712-7054
frank.babic@aecom.com - Mississauga, ON

Aercoustics Engineering Ltd.
Mr. John O'Keefe - (416) 249-3361
johno@aercoustics.com - Toronto, ON

ARMTEC
Ron Galloway - (905) 521-0999
ron.galloway@armtec.com - Hamilton, ON

Bruel & Kjaer North America Inc.
Mr. Andrew Khoury - (514) 695-8225
andrew.khoury@bksv.com - Pointe-Claire, QC

Conestoga-Rovers & Associates
Tim Wiens - (519) 884-0510 x2352
twiens@craworld.com - Waterloo, ON

Dalimar Instruments Inc.
Mr. Daniel Larose - (514) 424-0033
daniel@dalimar.ca - Vaudreuil-Dorion, QC

Dessau Inc.
Jacques Boilard - (418) 839-6034
jacques.boilard@dessau.com - Québec, QC

DuraSystems Barriers Inc.
Fred Woo - (905) 660-4455
fred.woo@durasystems.com - Vaughan, ON

Eckel Industries of Canada Ltd.
- (613) 543-2967
eckel@eckel.ca - Morrisburg, ON

G.R.A.S. Sound & Vibration
- (330) 425-1201
sales@gras.us - Twinsburg, OH

H.L. Blachford Ltd.
Duncan Spence - (905) 823-3200
amsales@blachford.ca - Mississauga, ON

Hatch Associates Ltd.
Mr. Tim Kelsall - (905) 403-3932
tkelsall@hatch.ca - Mississauga, ON

HGC Engineering Ltd.
Mr. Bill Gastmeier - (905) 826-4044
bgastmeier@hgcengineering.com;janstey@hgcengineering.com - Mississauga, ON

Hydro-Québec
- (514) 879-4100 x5309
gosselin.blaise@hydro.qc.ca - Montréal, QC

Integral DX Engineering Ltd.
Mr. Greg Clunis - (613) 761-1565
greg@integraldxengineering.ca - Ottawa, ON

J.E. Coulter Associates Ltd.
Mr. John Coulter - (416) 502-8598
jcoulter@on.aibn.com - Toronto, ON

Jacobs & Thompson Inc.
Chris Brand - (416) 749-0600
cmaida@jacobs-thompson.com - Toronto, ON

Jade Acoustics Inc.
Ms. Dalila Giusti - (905) 660-2444
dalila@jadeacoustics.com - Concord, ON

JASCO Research Ltd.
Mr. Scott Carr - (902) 405-3336
scott@jasco.com - Dartmouth, NS

Kinetics Noise Control Inc.
Mr Mehrzad Salkhordeh - 905-670-4922
msalkhordeh@kineticsnoise.com - Mississauga, Ontario

Mc SQUARED System Design Group
Mr. Wade McGregor - (604) 986-8181
info@mcsquared.com - North Vancouver, BC

MJM Conseillers en Acoustique Inc.
M. Michel Morin - (514) 737-9811
mmorin@mjm.qc.ca - Montréal, QC

Novel Dynamics Inc.
Stan Thompson - (613) 598-0026
stan@noveldynamics.com - Ottawa, ON

OZA Inspections Ltd.
Mr. David Williams - (800) 664-8263 x25
oza@ozagroup.com - Grimsby, ON

Peutz & Associés
M. Marc Asselineau - +33 1 45230500
m.asselineau@peutz.fr - Paris,

Pinchin Environmental Ltd.
Ms. Robin Brown - (905) 363-0678
- Mississauga, ON

Pliteq Inc.
Wil Byrick - (416) 449-0049
wbyrick@pliteq.com - Toronto, ON

Pyrok Inc.
Mr. Howard Podolsky - (914) 777-7770
info@pyrok.com - Mamaroneck, NY

RWDI AIR Inc.
Peter VanDelden - (519) 823-1311
peter.vandelden@rwdi.com - Guelph, ON

Scantek Inc.
Mr. Richard J. Peppin - (410) 290-7726
peppinr@scantekinc.com - Columbia, MD

SNC-Lavalin inc., division Environnement
M. Jean-Luc Allard - (514) 393-1000
jeanluc.allard@snclavalin.com - Longueuil, QC

Soft dB Inc.
M. André L'Espérance - (418) 686-0993
contact@softdb.com - Sillery, QC

Sound & Vibration Solutions Canada, Inc.
Mr. Andy Metelka - (519) 853-4495
ametelka@cogeco.ca - Acton, ON

Soundtrap Inc.
Roger Foulds - (705) 357-1067
roger@soundtrap.ca - Sunderland, ON

State of the Art Acoustik Inc.
Dr. C. Fortier - (613) 745-2003
cfortier@sota.ca - Ottawa, ON

Tacet Engineering Ltd.
Dr. M.P. Sacks - (416) 782-0298
mal.sacks@tacet.ca - Toronto, ON

True Grit Consulting Ltd.
Ina Chomyshyn - (807) 626-5640
ina@tgcl.ca - Thunder Bay, ON

Valcoustics Canada Ltd.
Dr. Al Lightstone - (905) 764-5223
solutions@valcoustics.com - Richmond Hill, ON

Vendatech Inc.
Behrou Ghazizadeh - (416) 787-8797
behrou@vendatech.com - Toronto, ON

Vibro-Acoustics
Mr. Tim Charlton - (800) 565-8401
tcharlton@vibro-acoustics.com - Scarborough, ON

Wakefield Acoustics Ltd.
Mr. Clair Wakefield - (250) 370-9302
clair@wakefieldacoustics.com - Victoria, BC

West Caldwell Calibration Labs
Mr. Stanley Christopher - (905) 595-1107
info@wccl.com - Brampton, ON

Wilrep Ltd.
Mr. Don Wilkinson - (905) 625-8944
info@wilrep.com - Mississauga, ON

Xscala Sound & Vibration
Jim Ulicki - (403) 274-7577
caa@xscala.com - Calgary, AB

SoundSeal
Bill Devin-(413) 789-1770
bdevin@soundseal.com- Agawan, MA

FFA Consultants in Acoustics and Noise Control
(403) 508-4996
info@ffaacoustics.com- Calgary, AB