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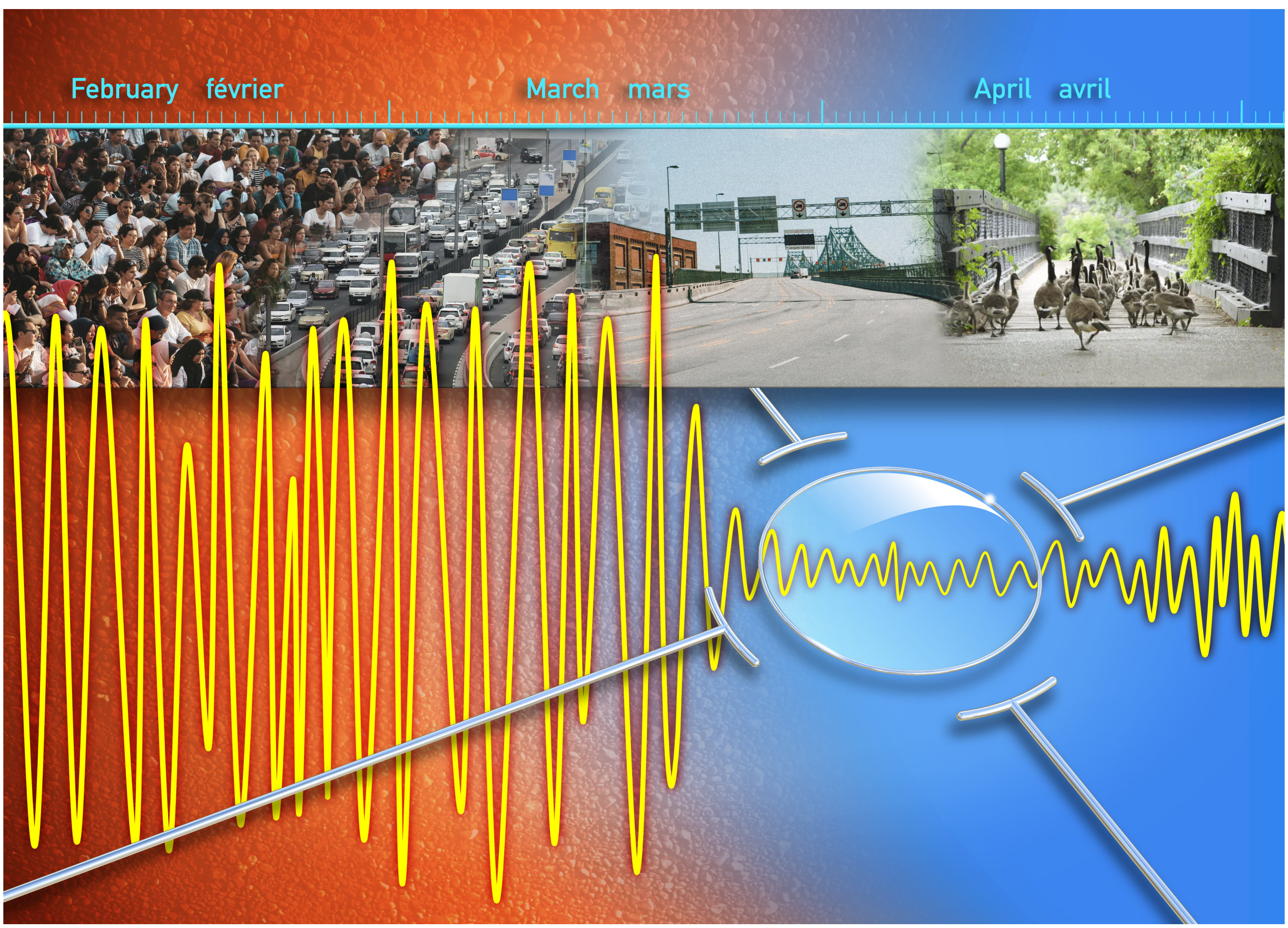

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The quite world of COVID-19: a lesson for our listening

Dear reader, I welcome you during these tough times. It was supposed to be International Year of Sound (IYS 2020), and around the world, it has been transformed in the year of physical separation, virtual-only interactions, and lockdown. As a society, we have learned some new (lost) dimensions of our world and we understood new meanings of the word globalization. Thus, we have realized how we are connected and should be aware of the global issues, which can impact our world.

Over the last three months, we have been exposed to new soundscapes. Cities are populated by more than ever bird voices. We see geese among skyscrapers. Meanwhile, acousticians are measuring extremely low sound levels, and we have seen nature taking advantage of human-free environments. Almost unexpectedly, this issue provides original researches about environmental acoustic issues. Hernández-Molina and other Spanish colleagues present to us with a new methodology to assess the influence of noise on natural areas. Then, Oiamo and Stefanova from Ryerson University in Toronto, reports the result of a long campaign of measurements about neighborhood context and composition for noise annoyance dose-responses. This June issue is completed with a room acoustic case study from Italy, and a numerical and experimental study of various nsource identification methods with circular microphone arrays.

Now, some housekeeping announcements. The President of the International Commission for Acoustics has announced that the International Year of Sound (IYS 2020) will be extended to the entire 2021. We will find ways to plan many events of the CAA. We also have decided to postpone our yearly national conference – the Acoustics Week in Canada – planned in Sherbrooke (Québec) to the next year so, on October 6-8, 2021. You will find the announcement at the end of the present issue. Finally, although we will not have AWC next October, we are working to dedicate a week in the fall to have local chapter seminars and online virtual meetings to bring Canadian acousticians together.

I wish you a pleasant reading of this issue.
Umberto Berardi
Editor in Chief.

Le monde silencieux de la COVID-19 : une leçon d’écoute

Chère lectrice, cher lecteur, je vous souhaite la bienvenue en ces temps difficiles. L’année 2020, qui était censée être l'Année internationale du son (IYS 2020), est devenue l’année de la séparation physique, des interactions virtuelles et du confinement. En tant que société, nous avons entrevu notre monde d’une tout autre manière et appréhendons maintenant le mot mondialisation autrement. Ainsi, nous avons réalisé combien nous sommes connectés et combien nous devons être conscients des problèmes mondiaux ayant un impact sur notre monde.

Au cours des trois derniers mois, nous avons été exposés à de nouveaux paysages sonores. Les villes sont plus que jamais peuplées de voix d'oiseaux. Nous voyons des oies parmi les gratte-ciel. Les acousticiens mesurent en ce moment des niveaux sonores extrêmement bas et nous voyons la nature reprendre ses droits. De façon inattendue, ce numéro propose des recherches portant sur des problématique d’acoustiques environnementales. Hernández-Molina et ses collègues espagnols nous présentent une nouvelle méthode pour évaluer l'influence du bruit sur les espaces naturels. Ensuite, Oiamo et Stefanova de l'Université Ryerson à Toronto, rapportent le résultat d'une longue campagne de mesures portant sur le contexte et la composition de quartiers vis-à-vis de la réponse aux nuisances sonores. Ce numéro de juin est complété par l’étude d’un cas d’acoustique de salle en Italie, ainsi que d’une étude numérique et expérimentale comparant diverses méthodes d'identification de sources avec des réseaux circulaires de microphones.

Maintenant, quelques annonces de gestion courante. Le président de la Commission internationale d'acoustique a annoncé que l'Année internationale du son (IYS 2020) sera étendue à l'ensemble de 2021. Nous trouverons des moyens de planifier les événements de la CAA. Nous avons également décidé de reporter d’un an notre conférence nationale annuelle prévue à Sherbrooke (Québec) - la Semaine de l'acoustique au Canada - soit les 6 et 8 octobre 2021. L'annonce est disponible à la fin de ce numéro. Enfin, dépourvus d'AWC en octobre prochain, nous travaillons à l’organisation d’une semaine cet auto-mne ou auront lieu des séminaires locaux comme des réunions virtuelles permettant de réunir les acousticiens canadiens.

En vous souhaitant une agréable lecture.
Umberto Berardi
Rédacteur en chef

THE SOUND OF A MONUMENTAL ARCHITECTURE

Giulia Fratoni*[1]
[1]DIN – University of Bologna, Viale Risorgimento, 2, 40126 Bologna, Italy

Résumé

Le présent ouvrage se veut un commentaire scientifique sur la performance sonore “SynAsTex Korrektur” de l'artiste allemand Florian Hecker. Le choix du lieu de la représentation est tombé sur l'atrium rationaliste de l'École des Ingénieurs de l'Université de Bologne, qui fait partie d'un bâtiment historique datant des années 1930. L'étude tente de répondre à certaines questions. Quel rôle l'acoustique d'un atrium monumental - constitué de marbre et de surfaces réfléchissantes - peut-elle jouer lors de performance électronique? Dans quelle mesure la présence du public debout peut-elle influencer l'acoustique de la salle? Quelles sont les particularités de la répartition de l'énergie sonore dans ce type de champ sonore fortement non diffus? L'évaluation de l'état acoustique a été réalisée par des simulations acoustiques, en utilisant une approche basée sur les rayons sonores.

Mots clefs: atria acoustique, GA simulation, performance électroacoustique, champ sonore non diffus

Abstract

The present work is intended to be a scientific commentary on the “SynAsTex Korrektur” sound performance by the German artist Florian Hecker. The choice of the venue for the performance fell on the rationalist atrium of the School of Engineering of the University of Bologna, which is part of a historical building dating back to the 1930s. The study tries to answer some questions. Which role can be played by the acoustics of a monumental atrium - which is made by marble and reflective surfaces - in an electronic performance? How much may the presence of the standing audience influence the room acoustics? Which are the peculiarities of the sound energy distribution in this kind of strongly non-diffuse sound field? The assessment of the acoustic condition was carried out through acoustic simulations, employing a ray-based approach.

Keywords: atria acoustics, GA simulation, electroacoustic performance, non-diffuse sound field

1. Introduction

Thermal performances and lighting strategies of atria [1] are well treated in the scientific literature [2, 3], but only in recent years scholars also focused on the acoustics of such spaces [4–9]. In general, atria have high reverberation times, due to the low sound absorption of the surfaces. The geometry and the materials can increase the scattered sound field, enhancing the listener envelopment [10]. The coupling between large and small volumes changes the sound energy distribution [11] and influences the frequency response (considering the different situations, a similar effect is due to the orchestra pit in opera houses [12]). In the specific case of atria, the comfort of visitors was studied by [13] and the perception of background music in [14].

Such kind of places can be intentionally used as music spaces [15]. The large reverberation and the coupling effects may enhance some music genres, as large worship spaces do for the Gregorian chant [16]. The perception of the music in reverberant field is discussed either by acoustical [17, 18] or phenomenological approaches [19, 20]. Regarding the latter one, the interest of some scholars was focused on the electroacoustic performance [21].

Since the 1970s, concrete and electronic music have employed multichannel reproduction through multiple sound sources. It should be noted that with this approach the single loudspeaker is considered as a single part of a composition.

According to the aesthetic intention of the composer/performer, the loudspeaker own-directivities are used to enlarge the apparent source width or to enhance the listener envelopment. In the early approaches to this technique, the sound sources were placed as the orchestra instruments. This way, the listening experience was similar to the one you may have in an opera house, with early reflections and late reverberation. This is the case of the so-called *Acousmonium,* which was discussed in [22]. In other cases, the composer chose to place several loudspeakers in a reverberant space, enhancing the spatial experience of the listener [23–27]. The case under study belongs to the latter situation.

The occasion of “SynAsTex Korrektur” sound performance, hosted in the atrium of a rationalist building, led the authors to develop a virtual model of the space. The simulation considers the multi-channel configuration of the electroacoustic performance and its relationship with the audience. Moreover, the simulation helps understanding how the presence of listeners influences the acoustic behaviour of the sound field. Finally, the model may help the organizers of performances in large reverberant spaces to consider the sound experience of the listeners.

* giulia.fratoni2@unibo.it

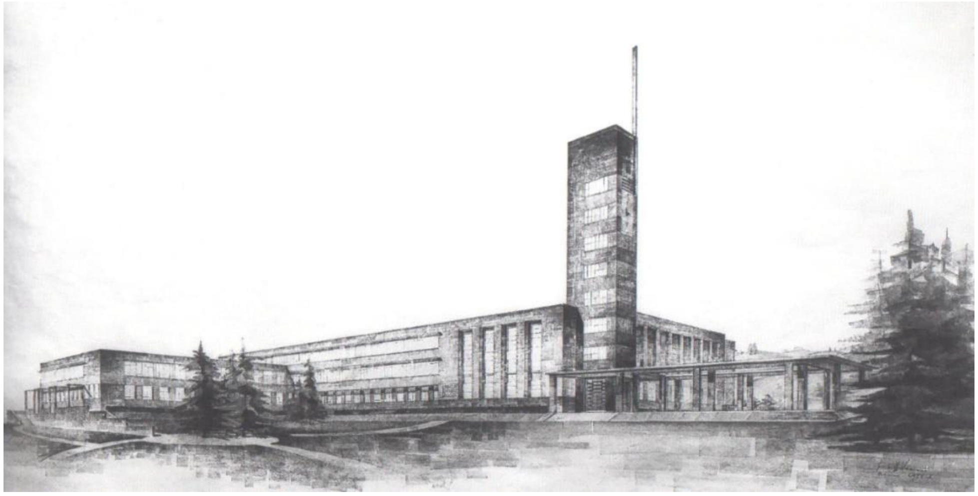

Figure 1: Sketch of the building done by architect Giuseppe Vaccaro (1896–1970). Credits image: Maristella Casciato, Giuliano Gresleri, eds. Giuseppe Vaccaro. Architetture per Bologna [28].

Figure 2: Inside views of the atrium of School of Engineering during the SynAsTex Korrektur performance. Photo by: Luca Ghedini, courtesy Xing. Credits photo: F. Hecker, SynAsTex Korrektur sound performance (première) curated by Xing, in the ART CITY event (ARTE FIERA), Bologna 2019, 31/01/2019 - 01//02/2019, University of Bologna, School of Engineering.

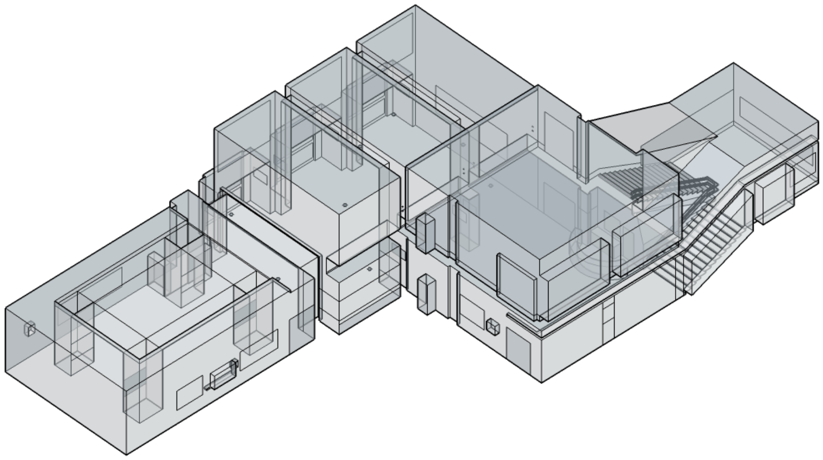

Figure 3: View of the virtual 3D model created with SketchUp software for acoustic simulations.

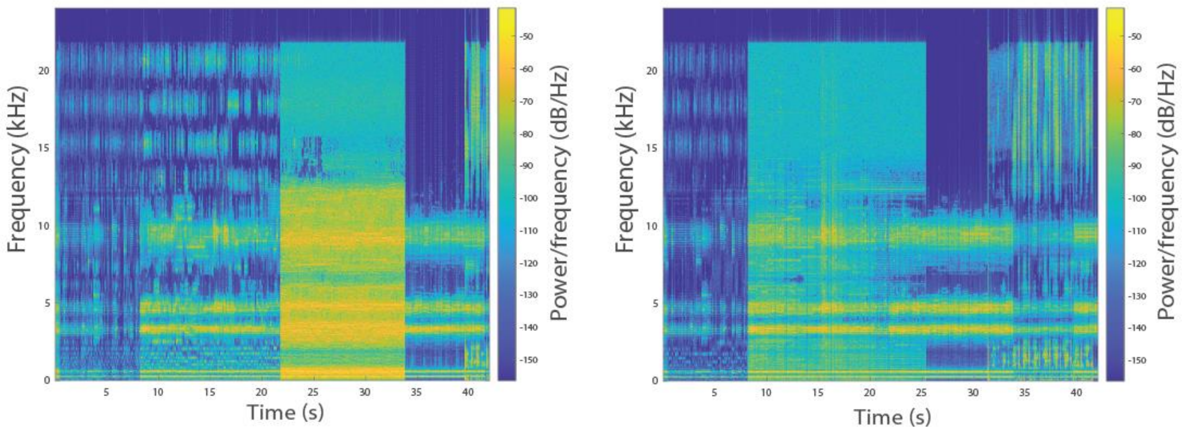

Figure 4: Spectrograms (4192 points at 48 kHz, Overlap 10%) of extract from music signals of Hecker's composition. Two out of nine channels are shown.

2. Simulation strategy

The building under study was designed by Giuseppe Vaccaro (1896-1970) to host the "new" School of Engineering in Bologna (see fig. 1). The construction was completed in 1935 and it is considered one of the most remarkable example of rationalist architecture in Italy [28–31]. Vaccaro's work was characterised by a broad use of concrete, marble, and wide windows with iron frame. The atrium shows the original configuration, including materials, window frames and furniture. The false ceiling was renovated in the early 2000s for safety reasons.

The "SynAsTex Korrektur" sound performance (première) curated by Xing as an ART CITY event (ARTE FIERA), which took place on the 31st of January 2019, entailed a quality assessment of the huge marble entrance - about 3000 m^3 - of the historical building (see fig. 2).

The aim of the present study is to evaluate the acoustics of the rationalist atrium during a contemporary music performance through acoustic simulation techniques. A 3D virtual model of the atrium was created and then imported in the acoustic simulation software. A Geometrical Acoustics (GA) algorithm - ODEON Room Acoustics v. 15 [32] - was chosen as simulation approach.

The 3D CAD model of the atrium was realized with SketchUp modelling software according to state-of-the-art guidelines (see fig. 3) [33, 34]. During the modelling process a reduction of the complexity of the geometry is usually done for computational efficiency. In the present case, considering the rationalist style of the architecture, drawing the model was quite straightforward.

The performance by Florian Hecker involved a series of nine T10 d&b audiotechnik loudspeakers, to envelop the audience (see fig. 2). The directivity factor Q of each loudspeaker may be assumed equal to 20, since 90° and 35° are the dispersion angles of the horizontal and the vertical directivities. Each loudspeaker played one channel of a multi-channel composition, resulting in dynamic and spectral variation among sources. The music was composed with Matlab and performed through Supercollider. The signals are coded as 32-bit floating point, allowing a very high dynamic range. Selecting 40 seconds from an excerpt of "SynAsTex Korrektur" composition, the spectrograms of two out of nine channels are shown in figure 4. As can be seen, Hecker's electronic compositions may show components in a wide frequency range and very high differences in the dynamics between the channels - more than 50 dB.

In the virtual model, nine sound sources were placed following the same layout of the actual performance (see fig. 5), including the corresponding heights, orientations, and directivities. For the aim of the present study, to analyse the sound field behaviour within the atrium, a virtual grid of 380 receivers was set at 1.5 meters above the floor.

The 3D model and the material properties of the atrium are available in a free repository [35]. They can be useful to compare various music contexts through multiple-input-multiple-output auralizations, employing multi-channel anechoic signals [36, 37]. The model can also return the former acoustics of the original configuration of the atrium, whose ceiling was reflective [28]. The whole buildings has been declared an intangible cultural heritage by Italian Authorities. The acoustics of the former hall can be considered as an intangible cultural heritage as well; and it could be virtually replicated, like it has been done in similar works [16, 38, 39].

2.1. Calibration of the virtual model

The material properties play a key role during the calibration process, as accurate values are required for reliable simulations. It was preferred to use a minimum number of material layers to reduce the uncertainty resulting from the assignment of absorption and scattering coefficients. Hence, the virtual model was organized in six layers according to the main construction materials (see tab. 1): marble, plaster, false ceiling, glass, masonry, and furniture.

According to reference studies [40], the calibration process was developed in the following steps. In a first phase, absorption coefficients were taken from databases [41] and applied to the surfaces of the model. The values corresponding to the false ceiling may depend on the particular mounting, e.g. on the air-cavity width between the false ceiling and the ceiling.

In a second phase, a measurements campaign was done according to ISO 3382 [42] to tune the materials properties in some frequency bands, as the false ceiling at mid-low frequencies. The sound absorption of this material may affect the sound intensity distribution [43], increasing the attenuation of sound energy versus the source-receiver distance. This corresponds to a non-diffuse sound field condition [44, 45] as could be expected from the presence of single and double heights. To quantify the influence of the false ceiling, the sound energy distribution was measured along a line (see fig. 5). Therefore, during the measurements the microphone receivers were placed with increasing distance from the sound source, according to ISO 14257 [46]. The measurements were done using an omni-directional sound source, whose power level was measured according to ISO 3741 [47]. The sound source was placed in a central position, in-axis with the line of receivers and impulse responses were measured for each source-receiver pair.

In a third phase, the omnidirectional sound source present during the calibration measurements was introduced in the virtual model. Temperature and relative humidity were recorded during the measurements – whose values were, respectively, 16 °C and 40% – and then set in the numerical simulations. The model was firstly calibrated based on sound strength values along the line of receivers. The calibration process was carried out by matching the results of the measurements to the ones of iterated simulations. For that, some absorption coefficients taken from previous literature were slightly adjusted, yet chosen within a reliable range of values, and the acoustic properties of the false ceiling were fine tuned. It should be also noted that, at high frequencies, the sound absorption of air is not negligible, due to the low sound absorption of boundary materials in the atria [13].

As shown in figure 6, the spatial attenuation in the octave band centred at 1000 Hz has a larger slope than the 2000 Hz band. This probably means that the absorption coefficients of the false ceiling show a bell behaviour in frequency, centred around 1000 Hz. Moreover, the panels of false ceiling are very thin, and they are mounted with an air gap, contributing to another broad absorbing peak at 125 Hz.

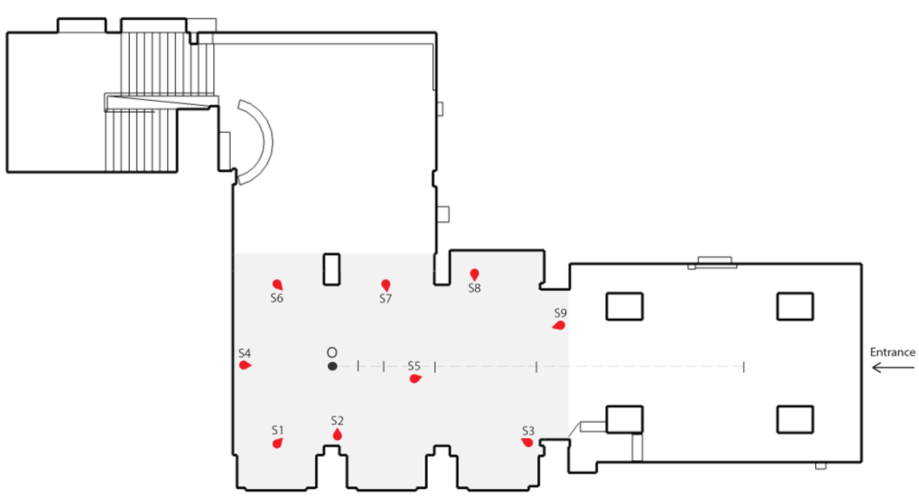

Figure 5: Plan of the atrium of the historical building under study: positions of the sound sources (S1 - S9) set by Florian Hecker during his sound performance. IRs were measured in the calibration process, placing omni-directional sound source (O) and receivers along the dashed line. Grey zone corresponds to the audience area during the performance (see fig. 2).

Table 1: Absorption (α) and scattering (s) coefficients for all the materials involved in the simulation [32, 41].

Materials	Surface		Absorption/Scattering coefficients					
	%		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Marble	40	α	0.01	0.01	0.01	0.01	0.02	0.02
		s	0.01	0.01	0.01	0.01	0.02	0.03
Plaster	18	α	0.02	0.02	0.03	0.04	0.05	0.05
		s	0.01	0.01	0.01	0.10	0.20	0.25
False ceiling	16	α	0.28	0.23	0.17	0.17	0.12	0.08
		s	0.01	0.01	0.01	0.01	0.02	0.03
Glass	11	α	0.18	0.06	0.04	0.03	0.02	0.02
		s	0.01	0.01	0.01	0.01	0.02	0.03
Masonry	5	α	0.08	0.09	0.12	0.16	0.22	0.24
		s	0.01	0.05	0.15	0.35	0.45	0.50
Furniture	4	α	0.30	0.25	0.20	0.10	0.10	0.15
		s	0.01	0.10	0.45	0.65	0.75	0.85
Audience	6	α	0.16	0.29	0.55	0.80	0.90	0.92
		s	0.01	0.10	0.45	0.65	0.75	0.85

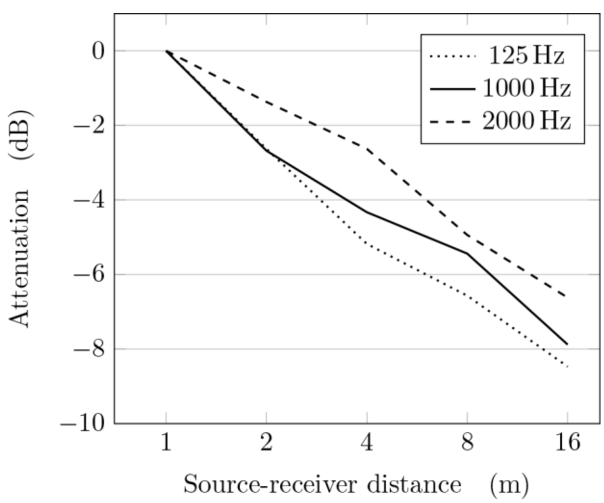

Figure 6: Measured spatial attenuation in the atrium. The resulting DL_2 value, as average on 125-4000 Hz octave bands, is equal to 1.9 dB.

The scattering coefficients employed as input values in the calculation setup are chosen according to the roughness of the surfaces and thus, they are quite low due to the characteristics of the main materials of the atrium (see tab. 1). The main materials - marble, plaster and glass - are pretty hard and reflective surfaces with a low degree of roughness. Therefore, it should be noted that the scattered sound field in environments like atria is mostly determined by the edge diffraction, i.e. directly by the geometry and the shape of the architecture.

The impulse response length was set at 4000 ms, the number of rays used in the calculations at 20,000 and the transition order between early and late reflections at 2.

2.3. Sound field behaviour with the audience

Inside atria there are not seats and the audience is standing. Consequently, sound absorption is mostly due to the audience, with drastic differences in the acoustics of the unoccupied versus occupied conditions (see fig. 7). It should be also noted that the air absorption is as well influenced by the audience, whose presence can increase the temperature and the relative humidity, and by the daylight conditions [48]. In the simulations, the audience was modelled as a box 1.5 meters high above the floor, similarly to the usual practice employed for modelling the presence of seats [32]. The estimated amount of people corresponds to a density of 1 person/m^2 over the area considered (see fig. 2 and the corresponding grey area in fig. 5). Sound absorption coefficients referred to such density were applied to the surfaces of the 'audience box', as well as a scattering coefficient equal to 0.7 at mid frequencies.

3. The listening experience of a multi-channel performance in a non-diffuse sound field

It is well known that in a diffuse sound field - when the source-receiver distance is higher than the so-called critical

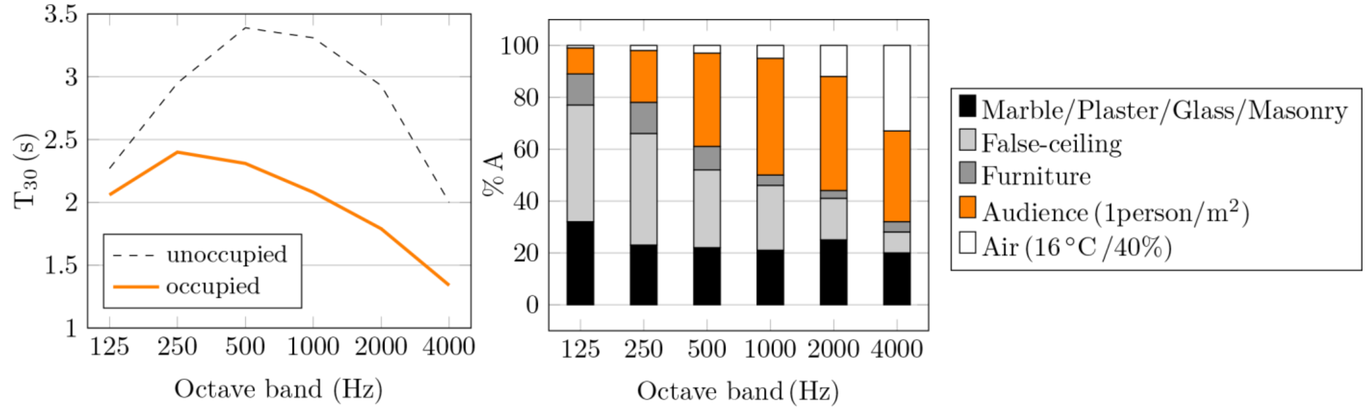

Figure 7: On the left, mean values of simulated reverberation time (T_{30}) in the unoccupied and occupied conditions. On the right, percentages of equivalent absorption area (% A) of the materials involved in the simulations

distance - the sound level values are quite constant in space. In this condition, the sound fields of multiple sound sources are 'blended', returning the same sound pressure level over the space - outside of the critical radius of each sound source.

In a non-diffuse sound field, the sound levels throughout the room vary more than in a diffuse sound field. It should be noted that this happens even if the sound sources are omnidirectional. In the case under study, the sound-sources – spatially spread in the atrium – show high directivity at mid-high frequencies. Both the strongly non diffuse field and the high directivity of the sound sources influence the listener's experience depending on his/her location. The spatial distribution of A-weighted sound pressure level in the occupied condition is shown in figures 9 and 10, considering, respectively, a single sound source and all the sound sources involved in the performance.

Assuming the semi-reverberant theory hypothesis, the critical distance is expressed as $r_c = \sqrt{QR/16\pi}$ m. In the present case, the critical distance of the atrium equals to 7.5 meters, considering R as the equivalent absorption area A, the reverberation time at mid frequency in the unoccupied condition (T_{30}=3.4 s), the volume of the entrance (V=3000 m^3) and the directivity of each sound source (Q=20). This means that within 7.5 meters from each loudspeaker the direct field is prevalent rather than the reverberant field.

The simulation results in figures 9 and 10 show that when the listener is moving among the spread sound-sources, he is primarily hit by the direct sound of the nearest sound source. The high directivity of the loudspeaker contributes to make the early reflections of the same sound source weaker and attenuated. The late reverberation – from all the sound sources – arrives after several milliseconds. For these reasons, the listening experience of multichannel sound performance is very different from the one of symphonic music in a concert hall. Even if in both situations there are several sound sources blended by the environment, in a concert hall the envelopes of signals coming from distributed sound sources (i.e. instruments) are preserved by early reflections, influencing the spaciousness and other subjective parameters [49]. Given the high directivity of the sound sources, there are fewer reflections from side walls, so the same envelopes are preserved by direct field only. This can be confirmed by the simulation of the lateral fraction (LF_{80}) values throughout the space (see the spatial distribution in fig. 11), with low values corresponding to few early reflections. It is the placement of the loudspeakers, rather than the hall geometry, that contributes to the spaciousness, which is a predominant factor in the listening experience of electronic compositions [50]. Numerical simulation is a viable tool for predicting and adjusting some of these effects during a multi-channel sound performance. In this case, the peculiarities of the rooms and the predominant effect of the occupancy were considered. Numerical simulation, then, can be beneficial to the composer or the performer during the performance design, e.g by optimising the distances between the sound sources in order to provide a more immersive listeners' experience.

Final considerations concern the peculiarities of composition in the context of the atrium under study. The composer should consider both spatial and temporal behaviour. Concerning the spatial properties, the composer minimises the effect of the hall, influencing the listener's spatial impression through the multi-channel composition. Moreover, some techniques used by Florian Hecker, such as spectral aliasing [51], should be related to the temporal responses of the hall. For instance, they can influence the time delay between two sound sources of the threshold time between the direct and the reverberant part of the impulse response.

4. Conclusions

The paper discussed the peculiarities of an electronic performance in a non-diffuse field through the results of simulations. In 2019, the monumental atrium of one of the most relevant Italian rationalist building hosted a première of the "SynAsTex Korrektur" performance by German composer Florian Hecker. The setup of the performance was re-created in a GA model. Due to the strongly non-diffuse properties of the atrium, the model was calibrated by the spatial decay of the sound energy. It was shown how the audience contributes to about half of the total acoustic absorption of the environment. The latter two instances – respectively, the non-diffuse properties and the audience absorption – have particular effects on the listening experience. This involves only the direct fields from multiple sound sources placed in the space and the late reverberation. Early reflections do not contribute to the listener experience, as opposed to the standard approach of concert hall acoustics.

Finally, these acoustic peculiarities were discussed based on Florian Hecker's music.

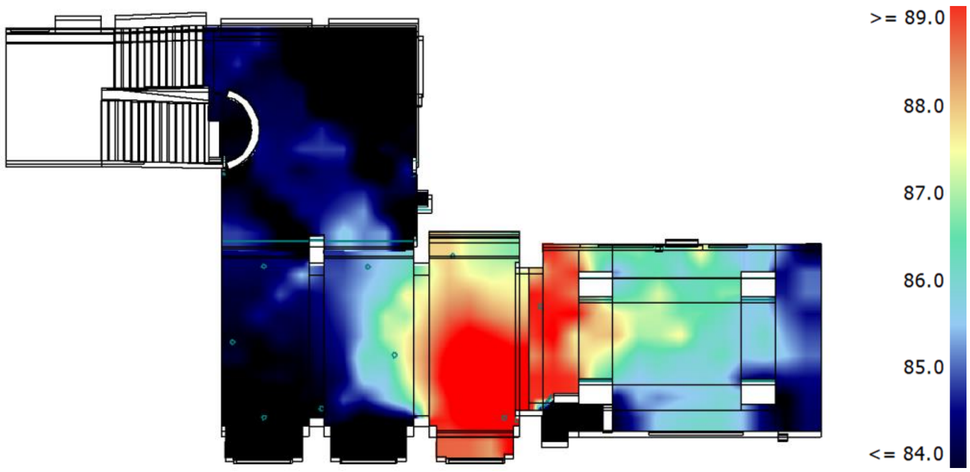

Figure 9: Simulated values of A-weighted sound pressure level (SPL(A) in dB(A)) in the occupied condition with the loudspeaker S3 active (see fig. 5).

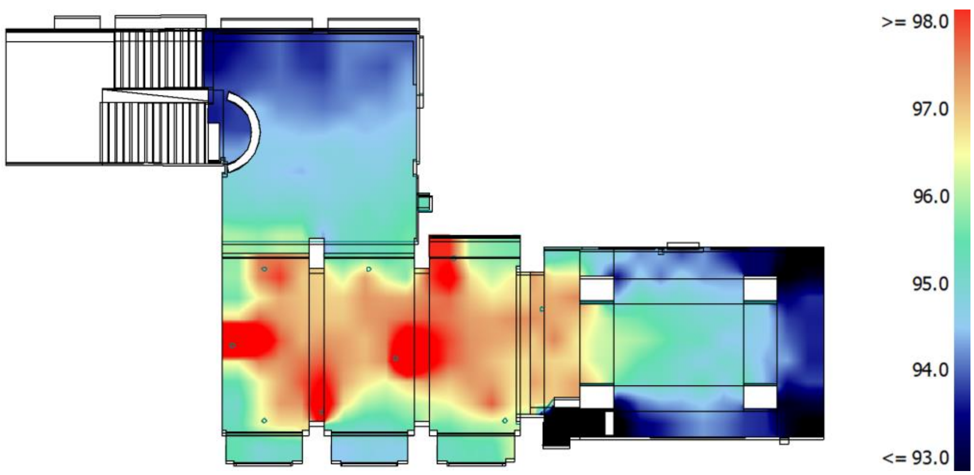

Figure 10: Simulated values of A-weighted sound pressure level (SPL(A) in dB(A)) in the occupied condition with nine loudspeakers active (see fig. 5).

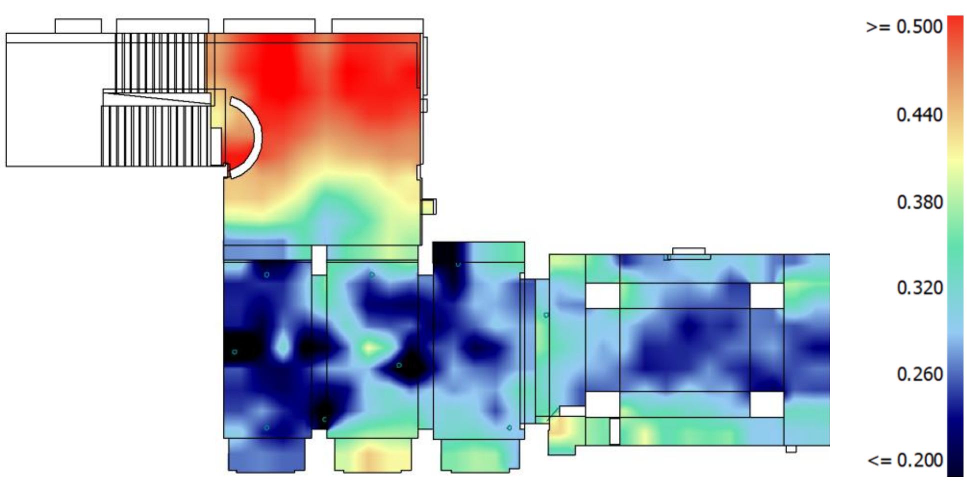

Figure 11: Simulated values of lateral fraction (LF_{80}) at 500 Hz in the occupied condition.

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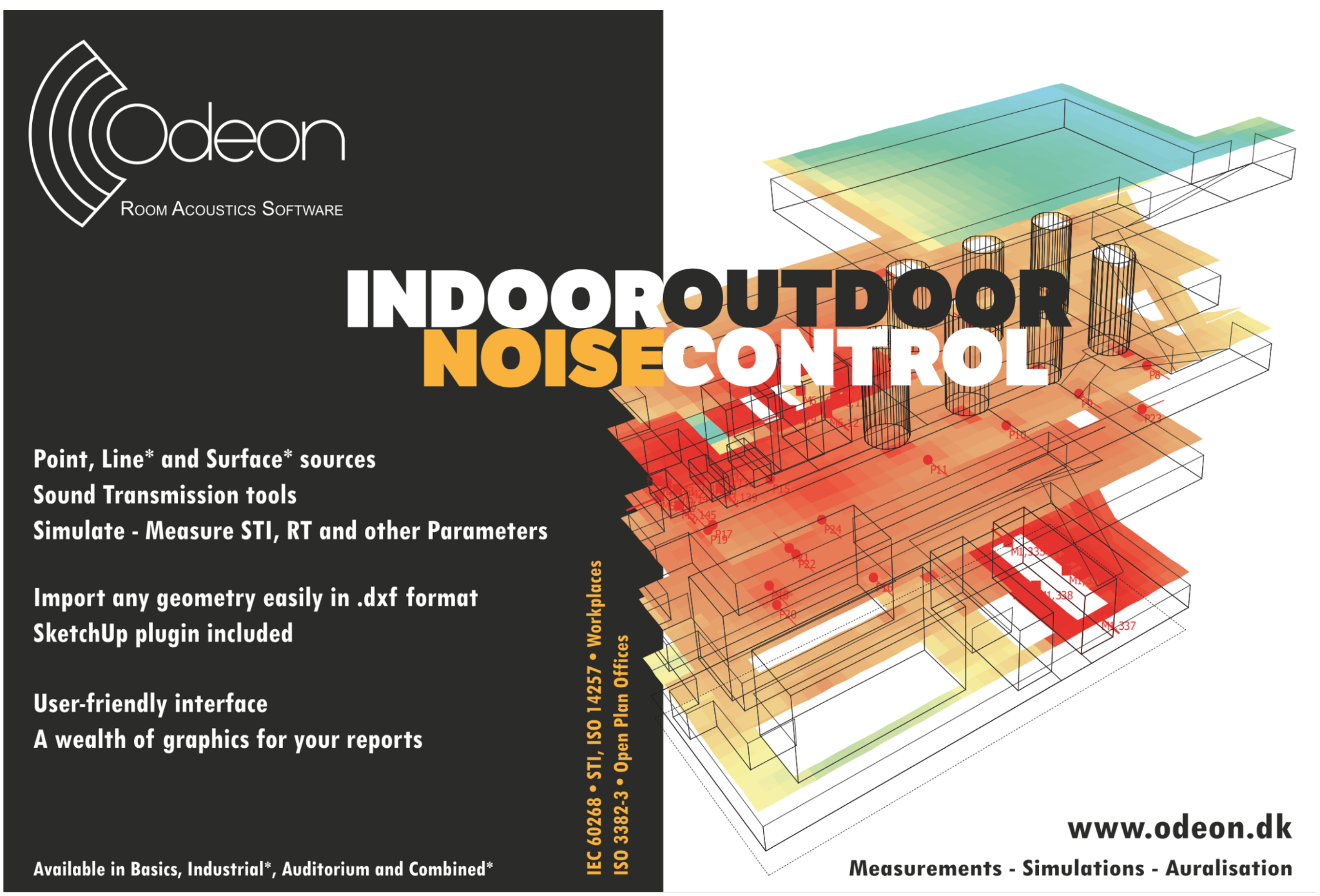

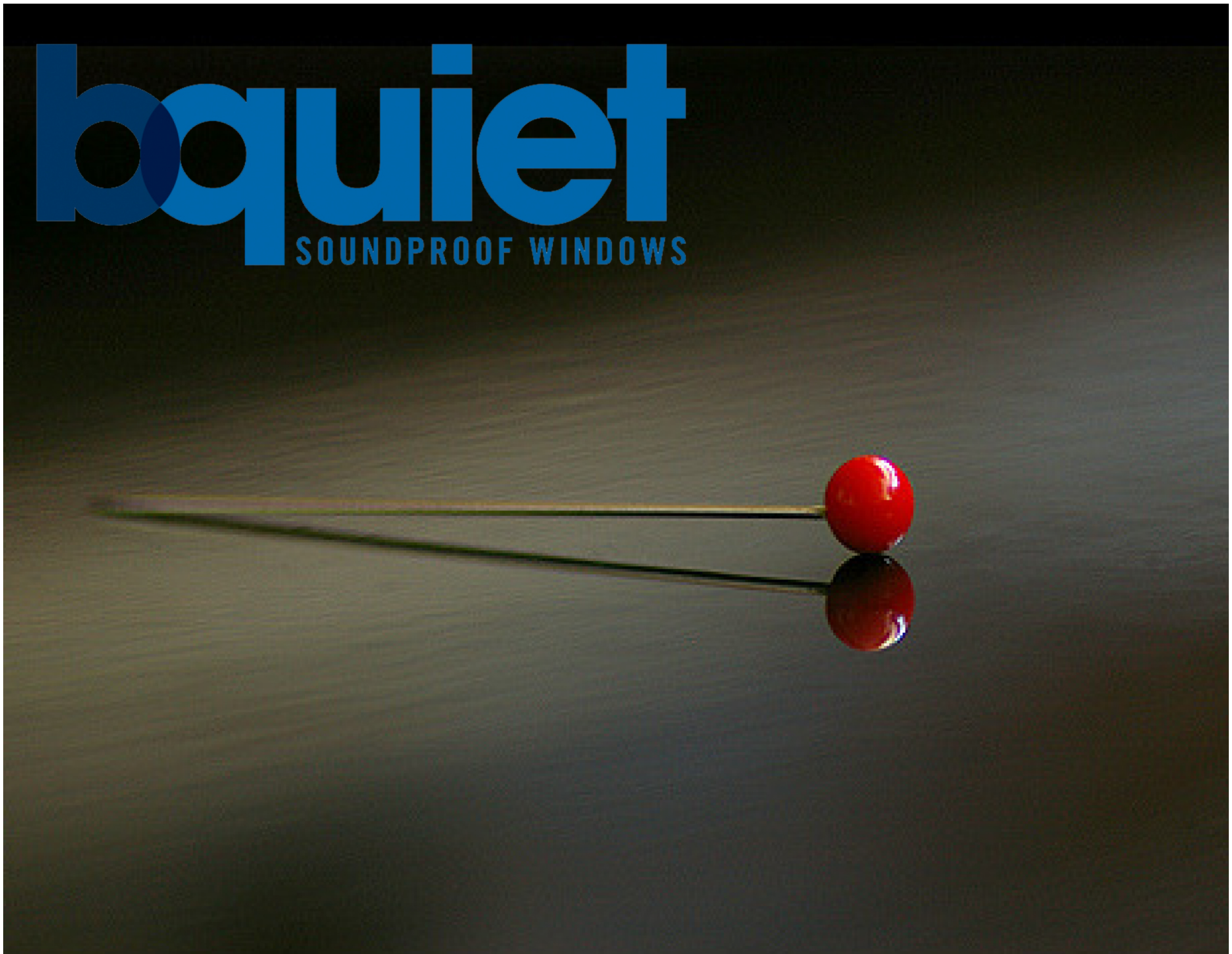
bquiet
SOUNDPROOF WINDOWS

First Steps Towards a Methodology to Assess the Influence of Noise on a Natural Area

Ricardo Hernández-Molina *[1], Francisco Fernádez-Zacarías †[1], David Bienvenido-Huertas ‡[2], and José Luis Cueto ♦[1]
[1]Acoustic Engineering Laboratory, University of Cadiz, Puerto Real-Cadiz, Spain.
[2]Department of Building Construction II, University of Seville, Seville, Spain

Résumé

Les sons naturels font partie intégrante de l'environnement naturel et sont fréquemment associés aux parcs naturels et aux zones similaires. Ils sont incontestablement des composantes inhérentes aux paysages et à leur contenu de caractéristiques naturelles et historiques, et en particulier de leur faune. Les sons naturels constituent un indicateur de la santé de l'habitat faunique et des divers écosystèmes qui composent ces zones. La génération actuelle a une obligation reconnue de conserver ces ressources naturelles au profit de celles à venir. Dans le processus de planification permettant d'atteindre les objectifs en terme de qualité acoustique du paysage sonore naturel, la principale méthode est la préservation du paysage sonore à des niveaux compatibles avec les caractéristiques du parc. Lorsque des lacunes sont identifiées, des mesures d'atténuation doivent être prises pour restaurer le paysage sonore à son état naturel. L'objectif de ce projet est d'analyser l'existence de bruits «non naturels» étrangers au milieu naturel et de protéger le paysage sonore naturel des impacts acoustiques intrusifs. L'étude a été réalisée sur la "zone naturelle" d'Anceu, située dans la municipalité de Pontecaldelas dans la province de Pontevedra, Galice (Espagne).

Mots clefs : bruit environnemental, paysage sonore, sons naturels, bruit anthropique, zones calmes, pollution sonore

Abstract

Natural sounds are integral elements of the natural environment that are frequently associated with natural parks and similar areas. They are, indisputably, inherent components of landscapes and their contents of natural and historical features, and particularly of their wildlife. Natural sounds constitute an indicator of the health of the wildlife habitat and the diverse ecosystems that comprise such areas. The present generation has an acknowledged obligation to conserve these natural resources for the benefit of those to come. In the planning process to achieve the objectives of the acoustic quality of the natural soundscape, the primary principle is the preservation of the soundscape at levels compatible with the characteristics of the park. When deficiencies are identified, mitigation measures must be taken to restore the soundscape to its natural condition. The objective of this project is to analyze the existence of "non-natural" noises foreign to the natural environment and protect the Natural Soundscape from intrusive acoustic impacts. The study was carried out on the "natural area" of Anceu, located in the municipality of Pontecaldelas in the province of Pontevedra, Galicia (Spain).

Keywords: environmental noise, natural soundscape, quiet areas

1 Introduction

Since the late 1960's various types of sound maps have been produced, initially for the largest cities of Europe and the USA. Noises due to transport and industry are the main sources of pollution generated by human activity. The coexistence of these types of sounds has lasted for years, but it is evident that at present the anthropic activities caused by noise and traffic must be considered noise and estimate that it damages the rest.

According to the report released by Environmental European Agency (EEA) in 2006 [1], a great extension of European protected areas (20%) are potentially adversely affected by noise pollution. Concerning what is meant by quiet areas, there is no exact definition. Most of the interpretations are due to state regulations and based on professional experiences [2]. Some factors, such as noise limit values, steric values or extension, allow defining potentially quiet areas [2].

A key aspect of quiet areas is their soundscape [3]. According to ISO 12913-1: 2014 [4] soundscape is the acoustic environment as perceived or experienced and / or understood by a person or people, in context. The soundscape must be understood as a complex system that boats multiple variables of different nature that interact in a site and at a certain time [5, 6]. The perception of the different sound sources is fundamental in the soundscapes [7]. This causes that before the great variety of possible sources that exist in a soundscape (biological, environmental, etc.), the sound-scapes must be investigated in an interdisciplinary way [8].

The natural soundscape is constituted by the sum of all the natural sounds present in a particular natural environment, whether it is a designated park, a protected natural space, or a natural area; this concept encompasses the physical

* ricardo.hernandez@uca.es
† francisco.fernandez@uca.es
‡ jbienvenido@us.es
♦ joseluis.cueto@uca.es

capacity for transmitting those sounds. Therefore, the soundscape can be defined as the "total" acoustic environment associated with a particular area such for example, a natural park. In a natural environment, the soundscape may be constituted by natural sounds alone – a natural soundscape – or else by these plus those sounds generated by certain human activities. However, although there is unanimity on the value and importance of natural sounds, these are often found to be degraded by the noises originating from the human activity of diverse origins such as industry, agriculture, forestry, mining, transport, construction, tourism, sport, and urban life in general.

Natural sounds often transcend the auditory range of human beings and can be transmitted through various media: the air, water, and solid matter. Natural sounds are integral elements of the natural environment that are frequently associated with the natural habitat. They are, indisputably, inherent components of the landscape and its natural features, and particularly of its wildlife. In reality, they constitute an indicator of the health of the diverse ecosystems present in a natural area and should be recognized as one more resource of the natural environment [9].

Human beings with normal hearing ability can perceive sounds between 20 Hz and 20 kHz, although the distribution of the amplitude of sounds varies in function of the frequency. In fact, it is known that the greatest auditory sensitivity is found at the frequency of 1/4 kHz, whereas at low and high frequencies, sensitivity is much lower. This ability is shared with other species.

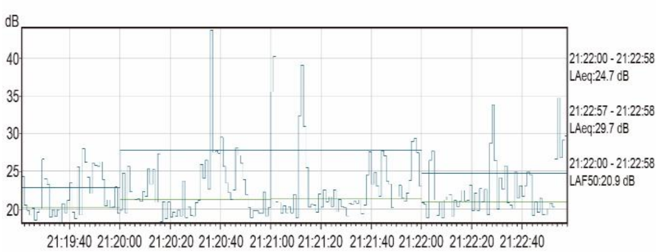

Figure 1: The behavior of the noise $L_{Aeq,\,T=1s}$ during the time interval shown.

Figure 1 shows an anthropogenic noise interval obtained in a natural area in the district of Anceu (Pontevedra), in a rural environment, during the evening [10]. The sharpest peaks correspond to the barking of dogs (Could this be considered a natural sound?) while the rest correspond to the noises made by various insects, the movement of the leaves of the trees, and the presence of sheep nearby.

Given the importance that the natural sounds have for the ecosystem and visitors to a natural area, it should be noted that, in many instances, these sounds are being masked by a wide variety of anthropogenic activities. This is due to that these soundscapes can positively influence society [11–13]. In some cases, the influence of these activities is so great that the natural sounds have disappeared or cannot be discerned. Intrusive sounds are indeed a cause for concern for visitors to a park; in a survey conducted by the National Parks Service of the United States, it was found that 91% of the visitors reported that experiencing the "soundscape" was the motive for their visit, as against 93% who said their visit aimed to enjoy the views [14]. However, it is no less true that preservation of the soundscape in natural parks has implications beyond the current enjoyment of all the resources of a park; it influences the habitat and the entire ecosystem. Its preservation is an important part of the obligation to ensure that these resources can continue to be enjoyed by future generations.

In effect, this means measuring the influence that the sounds of anthropogenic origin have on these environments. The ultimate aims of this analysis are to restore to their natural conditions, provided this is feasible, the soundscapes in the natural areas that may have been degraded by the effect of "non-natural" sounds, foreign to the natural environment; and to protect it from any unacceptable acoustic impacts that might occur.

This said certain specific questions must be answered: Which sounds can be considered appropriate, and which not? When the objectives of the park conflict with the preservation of the natural soundscape, is it necessary to develop standardized methods or protocols to enable reliable data to be obtained? And if so, what acoustic data should be considered?

An important consideration in this context is that the objectives and uses made of any particular natural area can be very varied. A wide variety of activities may take place in the park or area - recreational activities, cultural events, visitor centers, transport infrastructures, and many others. These activities can generate high levels of noise in particular zones within the park. It is thus important to be aware that, when human activities, whether within or close to the park, generate excessive noise levels, these can present a threat to the natural soundscape of the park, and can have adverse effects on the resources of the park and the purposes for which it exists or was created.

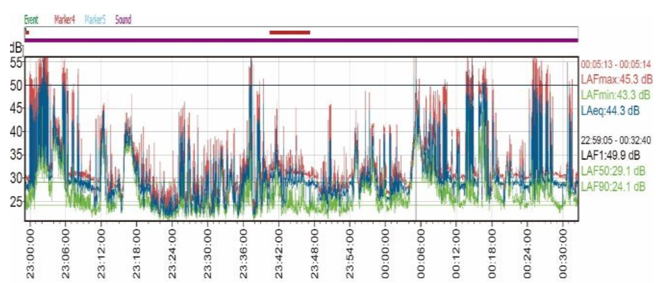

Figure 2: The behavior of the noise $L_{Aeq,\,T=1s}$ during a 1 hour of the night.

Figure 2 shows the values of the equivalent noise measurements carried out second by second, for one hour. The graph contains the sounds generated by the natural area itself (intervals free of non-natural noise) and those anthropogenic sounds that affect the natural environment.

The definition that`s used as a basis for determining the "healthy natural environment", for purposes of planning of the natural parks in other countries, and for defining the actions of environmental compliance derived from human activity, and that can give rise to inadequate or intrusive impacts on the soundscape of a park, is that of the "natural soundscape". In the majority of cases, this's considered as synonymous with the term "natural quiet" or the silence of Nature.

A study published in the journal “Trends in Ecology and Evolution” [15] states that the noise produced by vehicular traffic, industrial plants, construction machinery, electricity transformers, etc., causes harmful interference in communication for many animals. The authors maintain that auditory contamination has become so intense that it is threatening biodiversity.

Most of the natural sounds that contribute to the soundscape of an ecosystem form part of the biological and physical resources of the park; these include sounds produced by deer, birds, bats, frogs, insects, and other wildlife and those generated by physical phenomena like the wind in the trees, rainfall, and thunder [16].

Studies of the quiet zones and soundscapes in natural parks are relatively recent multidisciplinary initiatives. Nevertheless, during the last ten years, some very interesting studies have been carried out, some of them orientated to conurbations, as is the case of the Project: “Quiet areas definition and management in action plans” [17] and others orientated to the study of the sound levels in particular natural parks. An example of the latter is the study undertaken by the Local Authority of Vizcaya, together with the company Labein, on the Urquiola Park [18] involving sound recordings in the natural parks of Vizcaya. Apart from these very recent initiatives in 2010, the authors of the present study do not know about similar activities in Europe. However, in the United States and Japan, very important steps have been taken towards recovering and protecting natural soundscapes. One notable project is titled: “100 Soundscapes of Japan”, endorsed by the Japanese Ministry of the Environment and carried out by the Japan Soundscape Study Group over several years.

1.1 Planning

Several important considerations arise in the process of planning how to analyze the acoustic quality of the natural soundscape. One of these is the objectives that should be set for defining the future conditions of the soundscape. These objectives should be compatible with the objectives and plans of the park as such and should be sufficient for restoring the natural conditions of the soundscape as far as is possible, and at the same time should allow visitors to enjoy the benefits of being physically integrated into the natural environment Figure 3.

Figure 3: Two views of Anceu, the conserved natural surroundings of the Eiras reservoir (Pontevedra, Galicia region, Spain).

In practical terms, planning how to obtain the acoustic data means deciding what acoustic data should be recorded, and selecting the most suitable places and periods in which to make measurements. On the one hand, it is necessary to evaluate the noise generated by the activities routinely taking place in the park, and that generated by other authorized activities taking place both inside the park and in nearby zones; on the other, the activities occurring external to the park that has a negative influence on the natural soundscape also need to be assessed and measured.

In all cases, those conducting the study must collaborate constructively with those responsible for the noise-generating activities, so as to be able to implement corrective actions designed to mitigate the undesirable acoustic influences identified in the study. It will also be necessary to define in qualitative and quantitative terms the “natural” reference level that represents the acoustics of a healthy natural environment. The sources of the sounds, the sound levels, and their effects must be identified. The origins of the internal and external noise sources must be identified, and finally, the conditions of the soundscape for the future need to be established.

All this should provide basic information for defining the acoustic objectives in each area of the park, and for determining the nature and the level of impact that the noise has on the environment. It should also indicate where intervention by the park management can contribute most effectively to the protection of the resources of the park. The frequency, magnitude, and duration of the “non-natural sounds” present variations over the total area of the park; the values of these parameters are generally higher in those sectors that are more developed [19]. In those sectors, and areas adjacent to the park, those responsible must take noise measures to prevent or reduce the negative effect on the soundscape of the park. To this end it is necessary to obtain measurements of noise and, if possible, to monitor the sound levels in the various ecosystems that constitute the natural area, to establish the levels that are acceptable, and which require corrective actions for their control.

1.2 The aim of this paper

The objective of this work is to improve the diagnosis of the health of soundscapes in natural areas in Spain. The interest of this work is because a good diagnosis of the problem is the best guarantee to protect this kind of soundscape from any degradation caused by non-natural noise. For doing so, in this paper, the sound quality of a case study is analyzed applying the concept of "Sound Level of the Natural Environment" as defined by the U.S. National Parks Service.

2 Method

2.1 The flow of the methodology for the evaluation of environmental noise on a natural area

Based on the current procedures for the evaluation of environmental noise, the methodology proposed must consider three distinct phases (see Figure 4).

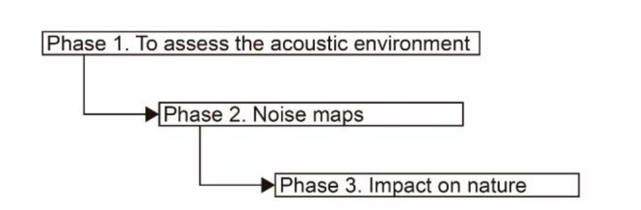

Figure 4: Flowchart of the methodology.

In the first phase, it is necessary to apply the specific methodology for establishing the most suitable parameters for assessing the acoustic environment of the natural area studied, and its influence on the habitat.

In the second phase, noise maps must be drawn, to provide a global evaluation of exposure to noise over the total area of the study zone. In this phase, it is necessary to define clearly the time interval for measurements. It is recommended that the interval should be as long as possible, in order to obtain data that are as representative as possible of the degree of exposure. Another important consideration is determining the ranges that the isophone lines are going to represent. These should span levels of sound pressure corresponding to the natural sounds characteristic of the natural area studied.

These maps should include enough information on the location of the towns and the most relevant infrastructures present in the area. Thus, sound maps should be obtained for each type of source that affects the study area. This step is very important since it establishes the degree to which this influence is perceived, and the time periods in which it is most serious.

In the third phase, from the data previously obtained, an analysis must be made of the extent to which the sound levels existing in the study area have an influence on the species that inhabit the area. This last phase requires the expert knowledge of biologists to determine as the non-natural sounds may affect species in their habitual behavior and reproductive activities.

2.2 Acoustic parameters

The acoustic studies in a natural park should measure the percentage of the time that anthropogenic noise is audible, the intervals free of noise have to be determined, and the sources that generate the sounds have to be identified.

The substantial restoration of the natural soundscape requires that "Natural Quiet" should be predominant during 75% of the time, in at least 50% of the area of the park [10]. In order to reach this objective, it is necessary to identify the natural sounds that are specific to each ecosystem and determine their characteristics. Natural sounds are understood to be those autochthonous sounds of the ecosystem independent and separate from any sound due to human action.

The sound level of the natural setting of a park is determined by the natural soundscape of that park. Under these conditions, the sounds are very varied but are often perceived in unison, as one single type of sound. In an acoustic environment subjected to high levels of noise caused by human activities, the sound of the natural environment can be masked by noise from other sources. For this reason, as a first step, it is necessary to determine the characteristic sounds emitted by all the sources that can be perceived in a specific area. For this, a parameter that is known as the 'existing environmental sound level' is employed. Generally, the existing level of environmental sound in an area is identified by reference to the L_{50} percentile. However, it is necessary to determine whether this parameter is the most appropriate or not. The calculation of the existing levels of sound is a simple procedure, by which the 50 percentile (L_{50}) value is taken, from all the data obtained for a given period (including the natural and non-natural sounds).

If those periods when the noises caused by the human activity are audible are excluded from the measurements made of total noise during a specified interval of time, the sound level corresponding to all the natural sounds present in that area during that time is obtained [11]. This concept is designated as the “Sound Level of the Natural Environment" (L_{nat}). This is often considered synonymous with the term “natural silence”. However, since nature is not usually completely silent, the term “sound level of the natural environment” is more appropriate when the object is to determine the noise derived from the interference of human activity in nature, or the "affected natural environment", and in other environmental evaluations related to the human actions that produce adverse or intrusive impacts on the soundscape of the park.

The calculation of the L_{nat} for each hour is not simple. In any natural park the two types of sound, the natural and the anthropogenic, will be audible; thus, to obtain the L_{nat} implies being able to exclude the influence of the sounds caused by man. The most appropriate method would be to obtain the L_{50} of all the data recorded at times when there is no influence from the noises generated by human activities. In this case, the problem presented is one of cost: it would be a costly exercise to make long-term measurements to eliminate the set of acoustic data that includes sounds of human origin.

For this reason, the usual procedure is to employ the statistical concept L_x (dB), which indicates the level of sound pressure that is exceeded for x% of the time of observation. If the data corresponding to that continuous period when only natural sounds are audible, or when there is actual silence, are removed from the total data obtained in the measurement made during a specified interval of time, what remains will be an interval free from noise. This parameter is known as the “Noise Free Interval” (NFI); it should not be calculated during brief periods of time. The NFI provides valuable information when the intervals of time are sufficiently long [12].

The environmental sounds attributable to human activities in natural parks are all those sounds that have their origin in anthropogenic activities. In the setting of a natural area, these sounds can be caused by the activities integral to the daily functioning of the park or they can be independent of park operations and originate outside the park. These are the sounds and noise levels that should be measured and evaluated in the processes of planning the natural area, to determine if are they compatible with or harmful to the management objectives of the soundscape. These sounds are known as "Man-made Sound Levels" (i.e., sounds of anthropogenic origin).

In all cases, the technicians making the measurements must be able to separate the natural sounds from the man-made sounds and be able to determine the percentage of time that these latter sounds are audible. It is also necessary to set the time periods during which to assess the soundscape. In this type of study two periods are considered, one diurnal between 07:00 and 23:00 hours, and the other nocturnal, between 23:00 and 07:00 hours, for one day, one month, one season of the year or one year.

It is important to keep a record, in situ, of the time when a non-natural sound is audible (e.g., when a vehicle passes, a note should be made of the time when the sound is first perceived and the time when it ceases to be perceived); the interval between the two times corresponds to the period of time in which that sound is present in the natural medium. When the recordings are carried out for measurements over a continuous period of long duration, it will be necessary to identify the source of the non-natural sound and the corresponding interval of time that it is audible. From the relationship between the total time of the recording and the time when the sound level is influenced by these sources of unwanted sounds, the percentage of time in which the noises caused by human activity are audible, and hence the L_{nat}, can be established. If the set of data only contains natural noise, the L_{50} is used to determine the L_{nat}. However, when the influence of sounds generated by human activities is detected, this can lead to an over-estimation of the sound values of the natural environment.

The L_{90} value represents the value of the sound that has been present during 90% of the total time of measurement. In these situations, the L_{90} can lead to an under-estimation of the sound values of the natural environment. Therefore, the calculation of the L_x of the set of data based on the audition of human sounds in each place of measurement, and the application of the L_x to the set of data, leads to a more accurate estimation of the sounds of the natural environment.

For the analysis described, the L_x method is employed [10]. This method consists of obtaining samples of the period of measurement to determine the percentage of audible noise of human origin present in the recordings. Because these sounds caused by human activities are usually, but not always, audible above the natural noises, they generally have higher values.

To obtain a set of acoustic data without sounds of human origin, the data are ranked from the lowest to the highest (in dB), and the percentage of the highest sounds determined by sampling the ranked data are discounted. The median value of the rest of the data set, and its corresponding L_x, is an approximation of the noise level of the natural environment, of the sub-sample. To calculate the natural level of the environmental sound for the period of measurement, this L_x is applied to the set of data (dBA and 1/3 octave band). x is obtained from the Eq. (1):

$$x = \frac{100 - P}{2} + P \tag{1}$$

where P is the percentage of the time in which the human sounds are audible.

For example, if the non-natural sounds are audible during 40% of the time, the values from L_{max} to L_{40} would correspond to the highest sounds (usually the non-natural), and the values from L_{40} to L_{min} would correspond to the lower sounds. The mean between L_{40} and L_{min} is L_{70}. Therefore, the sound level that is exceeded during 70% of the time will be used as the base level for characterizing the sound level of the natural environment.

One worrying aspect of this method is that some loud natural sounds, like thunder, could be removed from the data before calculating the sound levels of the natural environment, and the results may thus be an under-estimation of the actual true sound levels of that natural environment. These events, however, are relatively infrequent; therefore, the elimination of these data should not have a significant impact on the calculated sound levels of the natural environment. On the other hand, some non-natural sounds that are relatively low may remain present in the sample, and the results may be an over-estimation of the sound levels of the natural environment. However, these events could be identified and dealt with, thus reducing the impact on the calculations of the natural sound levels.

2.3 Meteorological data

These data are especially relevant in the modeling of the noise maps of the areas exposed. For the wind, in general, the levels of environmental noise tend to increase the higher the wind velocity; the characteristics of the tree foliage also have an influence, since denser vegetation produces higher noise values. Jakobsen and Andersen [13] regard the natural sound of the wind (sounds generated by air turbulence), and that generated by the movement of the vegetation with the wind, as natural sounds. However, sounds caused by air turbulence on the recording microphone or the windscreen shielding of the microphone are considered non-natural sounds.

2.4 Sampling

The spatial and temporal sampling in the various areas of the park is done employing seasonal acoustic monitoring campaigns, sound recording, and records of environmental conditions. This includes the frequency, distribution, and sound pressure level of the sounds of natural origin and those generated by human activities. A priority task in this phase is identifying the most sensitive areas of natural sounds

2.5 Audio recordings

It is necessary to obtain audio recordings that allow the identification of the sounds specific to each ecosystem of the park, and that enables an acoustic profile representative of each zone to be developed. These recordings can be reproduced later for visitors to enhance their general knowledge and enjoyment of the park.

2.6 Presentation of results

The results are presented in the following order:

- **Noise maps**: Area in km² of the total natural area studied exposed to noise in the ranges:
    - <39 dBA.

- 40-44 dBA.
- 45-49 dBA.
- 50-54 dBA.
- 55-59 dBA.
- 60-64 dBA.
- 65-69 dBA.
- >70 dBA.

- In-situ, noise measurement campaigns
- **Audio recordings and Observations**:
  - Spatial and time identification and distribution of sound sources.
  - Time and date annexed to the audio recordings.
  - Number/duration of events, by each source.
- **Acoustic Indices**: For each interval and period of measurement (time history, day, month, a season of the year):
  - L_{Aeq}.
  - L_{max}.
  - L_{min}.
  - L_{eq} Spectra in 1/3 octave band between 20-20,000Hz.
- **Time of integration**: 1 second.
- **New Parameters**:
  - Percentage of time in which the noises caused by human activity are audible.
  - The sound level of the natural environment (L_{nat}).
  - The continuous period during which only the natural sounds are audible.
  - Noise-free interval (NFI).

3 Results and discussion

To aid in understanding the procedures described in this article, the results of the measurement campaign carried out in a particular natural area are reported. The study area comprises the parish district of Anceu, constituted by three localities: Anceu and Os Ramís. This district has a population of approximately 300 inhabitants; 85 dwellings are covering a total area of 17.4 Ha. As can be observed in Figure 5, the principal infrastructures that affect the study area are:

- The stretch of local highway between Esfarrapada and Barbudo;
- The local highway between Anceu and Barbudo;
- The road PO-255 between Puentecaldelas and Forzans;
- The road V-103 between the PO-250 and S. Adrian Calvos;
- The road EP-0208 between Barbudo and S. Adrian Calvos;
- and the stretch of Forest Track between Anceu and the Eiras reservoir.

However, for this example, the only road taken into account is the stretch of PO-0203 between the PO-255 and the village of Os Ramís, since that is the highway that runs through the village of Anceu where this study was carried out.

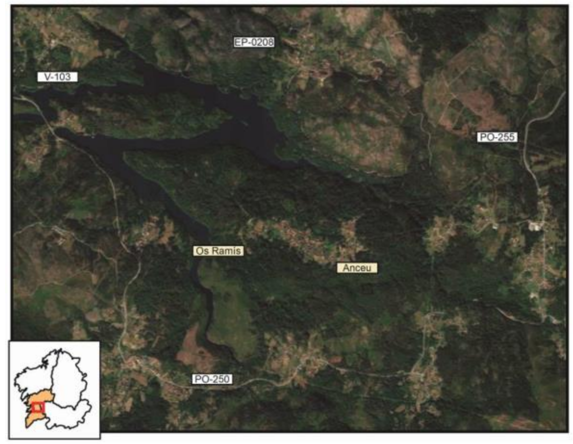

Figure 5: Case study of this research.

The test was carried out during the night period, at a point situated outside the village of Anceu (see Figure 6), where it was possible to perceive the sounds originating from the village and the PO-0203 highway. The duration of the test was slightly more than 93 minutes (1:33:35), continuously.

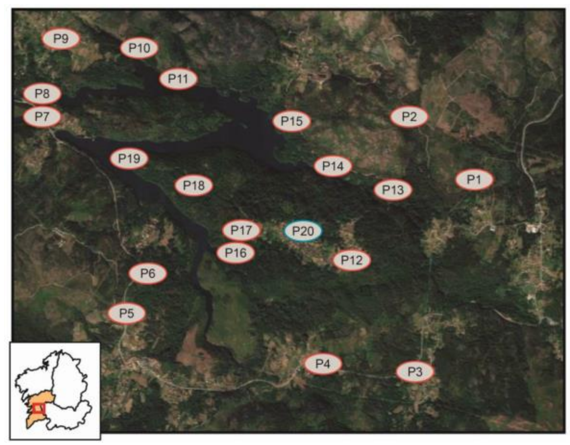

Figure 6: The natural area of the Eiras reservoir [3].

The instruments employed in the test were a model 2270 analyzer with a UA1650 windscreen, and a type 4189 microphone, polarized, of ½'' free field. For the analysis of the data, a BZ550 3 and an Evaluator type 7820 V4.16.2 of Brüel & Kjaer, were employed. The measurements were made on the night of August 12-13, 2012, between 22:59:05 and 00:32:40 hours, with a total duration of 1:33:35 hours. The recordings were taken every second in the 1/3 octave band, and the time of measurement was recorded simultaneously with the sound recording. In Figure 7 the temporal recording with the events recorded marked above the graph, can be observed.

Different soundscape recordings were rated on the characteristics given in Table 1. The procedure for determining the L_{nat} is as follows: The period of evaluation (anthropogenic sound plus natural sound) is 1 hour and 33 minutes, approximately. During the 93 minutes, the time in which sounds of anthropogenic origin are perceived is approximately 45 minutes.

The Percentage of anthropogenic noise is: 100x 45/93 = 48.4%. Therefore, x = (100+48.4)/2=74.2%.

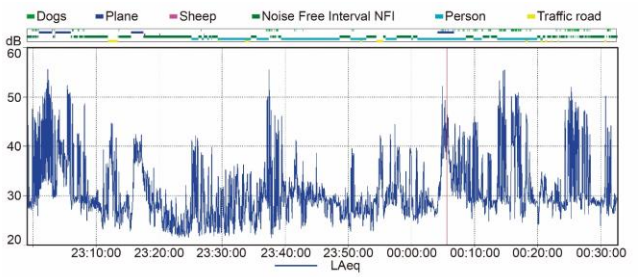

Figure 7: Time series of $L_{Aeq,\ T=1s}$ in P20.

The Evaluator software gives the value of the L_{74} =27.3 dBA. Therefore, L_{74} will be used as the base level for characterizing the sound level of the natural environment.

The L_{nat} corresponds to (100-48.4)% ≅ 52% of the time; the level corresponding to L_{52} = 27.3 dBA.

Table 1: Acoustic data - Anceu, Point 20, Village, Night

Name / duration (h:m:s)	L_{Aeq} (dBA)	$L_{AFmáx}$ (dBA)	$L_{AFmín}$ (dBA)	L_{AF10} (dBA)	L_{AF50} (dBA)	L_{AF90} (dBA)
Existing noise (1:33:35)	37	62.4	20.8	39.3	29.1	25
Aircraft passing (0:09:14)	42.5	59.3	23.2	47.2	37.6	31.2
Vehicles passing (0:05:43)	35.6	56.6	22.2	38.8	30.9	26.3
People (0:29:50)	37.1	62.4	21.2	39.6	29.6	26
Anthropogenic noise (0:44:47)	36.8	59.3	21.2	39	29.9	26.1
Dogs (0:08:59)	43.9	62.4	21.4	47.7	40.7	33
Sheep (0:00:35)	32.3	42.8	21.7	35.8	31.2	24.3
Noise Free Interval NFI (0:39:33)	*28.7*	*48.1*	*20.8*	*30.3*	*28*	*23.7*
Natural noise (0:48:48)	37.1	62.4	20.8	39.7	28.5	24.2

In the light of these results, the conclusion is that, although the values are low (in general), in percentage terms, for 48.4% of the time, the sounds generated by human activities are audible. Accepting that the noise produced by the tinkling of the sheep bells and the barking of the dogs in the nearby dwellings counts as natural sound, the percentage rises to 57% of the total time of the measurement. This means that only 43% of the time of measurement is free from any sound of the anthropogenic character. Figure 8 will let to understand more easily the dates given in Table 1.

Finally, the noise maps showed the most affected areas in the case study (see Figure 9). As can be seen, the isophones show how there is a wide surface of the case study with levels above 40 dB (A). This aspect is of great importance since the noise conditions are not consistent with Quiet Area conditions. This means the potential impact generated by infrastructure on the living conditions of the fauna of the area.

4 Conclusion

With respect to the planning process, when the soundscape is not affected by inappropriate sources of noise, the objective will be the maintenance of those conditions. However, when the soundscape is found to be degraded by the influence of noises foreign to the natural environment, the objective must be to devise and implement corrective actions aimed at restoring the natural soundscape.

Effective soundscape management requires the determination of, first, those specific sounds that must be preserved, with the object of the protection of biodiversity; and second, the nature of those unwanted sounds that have a negative impact on the fauna and flora in the various ecosystems of the park. It then requires the identification and specification of the actions the actions that could be taken to mitigate adverse effects, with the object of making it possible for visitors to experience directly the authentic sounds of the natural area visited.

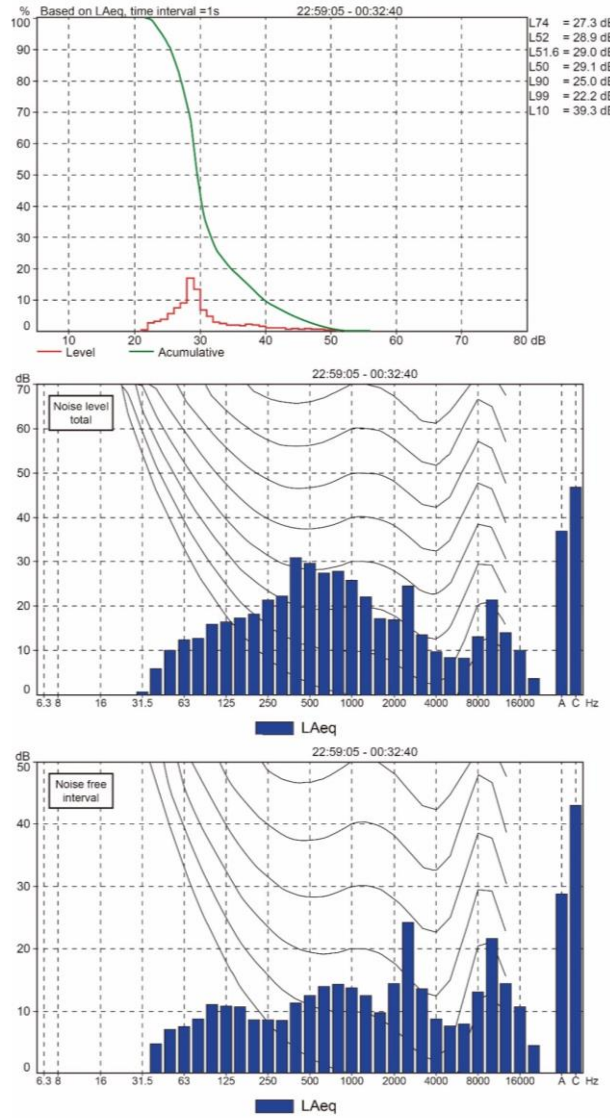

Figure 8: Example of noise measurement values representing the noise equivalent levels during the period comprised between 22:59:05 and 00:32:40 of the day after.

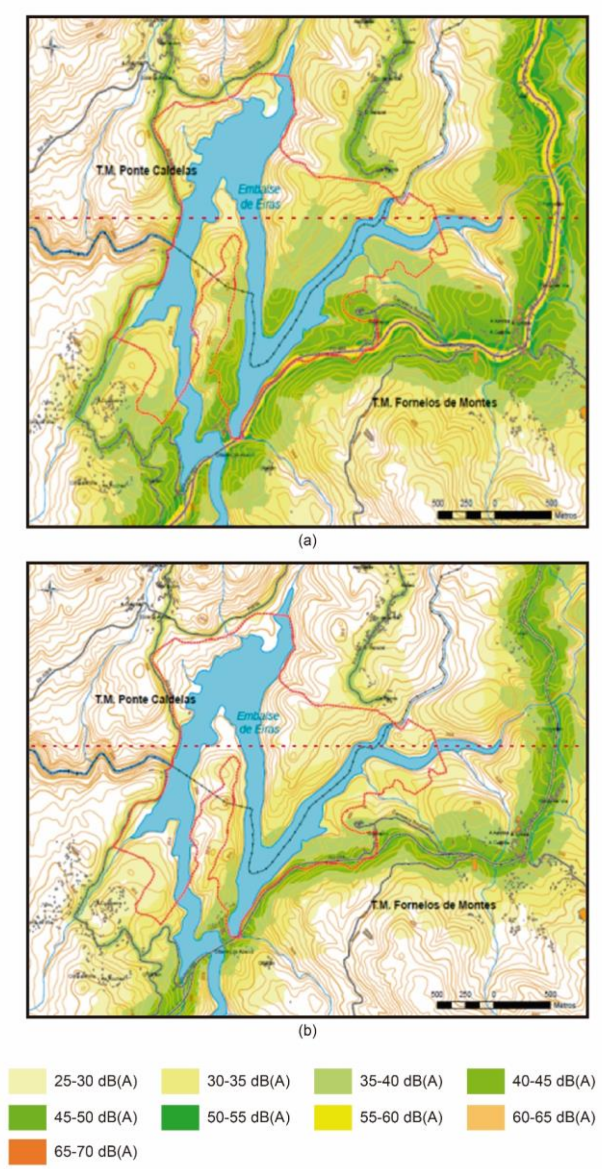

Figure 9: Influence of road traffic. Sound Maps for the day (a) and night (b) periods.

The calculation of the parameters described represents an approach for the establishment of base indices in the interests of the restoration and preservation of the natural soundscape. The determination of the most objective parameters for this task requires profound knowledge of the particular natural environment under study, in order to be able to establish what acoustic elements are harmful for the autochthonous life of that area. The results of this study suggest that, in certain zones, such as rural areas, it is relatively difficult to achieve a state of “Natural Quiet”.

It will be necessary to carry out further studies to gain a better understanding of the scope and the nature of the acoustic impacts on the resources of natural parks and protected areas. On this topic, it is in the interest of the relevant authorities to support and promote studies for the cataloguing and conservation of the Soundscape in natural habitats of ecological value.

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Numerical and Experimental Study of Various Interior Source Identification Methods With Circular Microphone Arrays

Iman Khatami *[1] **and Alain Berry** †[2]
[1]Departement of Mechanical Engineering, Chabahar Maritime University, Iran
[2]Departement of Mechanical Engineering, Universite de Sherbrooke, Canada

Résumé

Cette étude évalue plusieurs méthodes d'identification de sources basées sur des antennes microphoniques circulaires, dans le cas de sources intérieures au réseau circulaire. Plusieurs techniques sont comparées, dont la formation de voie classique (CB), les méthodes inverses régularisées (régulariation de Tikhonov), la formation de voie inverse généralisée L1 (L1-GIB), les méthodes de déconvolution CLEAN-PSF, CLEAN-SC, ainsi que des méthodes plus récentes utilisant une régularisation par formation de voie (BFR). De plus, nous proposons une nouvelle méthode (CLEAN-BFR), qui combine les approches itératives de CLEAN-SC et BFR. Pour mettre en évidence les avantages et désavantages de ces méthodes, plusieurs exemples d'application numériques et expérimentaux sont discutés. Lorsque des sources multiples doivent être identifiées, les résultats montrent que la méthode à choisir dépend de la corrélation, de la directivité et du niveau relatif des sources.

Mots clefs : méthodes d'identification de sources, antenne microphonique circulaire, formation de voie, méthodes inverse, déconvolution.

Abstract

This study addresses an assessment of some sound identification methods using circular microphone arrays for sources interior to the array circle. Various techniques are compared, including classical beamforming (CB), regularized inverse methods (Tikhonov regularization), L1- generalized inverse beamforming (L1-GIB), deconvolution methods CLEAN-PSF, CLEAN-SC, as well as more recent inverse methods using beamforming regularization (BFR). Furthermore, a new method (CLEAN-BFR) combining the iterative concepts of CLEAN-SC and BFR has been proposed. To highlight the advantages and disadvantages of these methods, several numerical and experimental application examples are discussed. When multiple sources are searched, the results show that the method of choice depends on the correlation, directivity and relative level of the sources.

Keywords: noise identification methods, circular microphone array, beamforming, inverse method, deconvolution

1 Introduction

The disturbing effects of noise on people motivate researchers to identify and maintain noise under a certain level. Extensive work has been done to develop methods to identify, locate and quantify various types of noise sources in many different contexts. This work is mainly concerned with the identification of aircraft engine inlet and exhaust noise. Aircraft engines are subject to static, ground tests for noise level certification, in which engine noise is measured externally in different directions by a circular microphonic antenna placed in the far field of the engine (to see more details refer to [1]). The possibility of using these measurements to discriminate and quantify engine inlet and exhaust noise has not yet been studied.

Researchers have investigated a number of algorithms to detect noise sources and have attempted to increase the spatial resolution and accuracy of source strength maps by removing or filtering side lobes from the map. These algorithms are usually based on Phased Array Beamforming [2-4] or Inverse Methods [3, 5, 6]. Beamforming is a very common method that successfully identifies the sound source even when the source intensity is well below the background noise level. Sarradj [7] proposed a subspace-based beamforming method focused on signal subspace and leading to a computationally efficient estimation of the source strength and location, with monopole or multipole radiation patterns [8]. Bravo et al [3] tested beamforming and inverse methods for the localization of in-duct sources.

Michel et al [5] compared inverse methods with conventional beamforming for the source distribution along the axis of a high bypass ratio aero-engine.

Recently, a few hybrid methods using subspace analysis and beamforming have been proposed, such as inverse methods with a regularization based on an initial beamforming solution [9-12], the Multiple Signal Classification(MUSIC) [13] and the application of a subspace invariance approach (ESPRIT) [14]. In MUSIC and ESPRIT, the useful signal and measurement noise components are split into identified subspaces to minimize the effect of noise. This differs from "deconvolution" approaches in which the aim is to attenuate the effect of the point-spread function in the beamforming map and consequently refine the localization of the sources.

* iman.khatani81@gmail.com
† alain.berry@usherbrooke.ca

The main deconvolution approaches are CLEAN [15] and DAMAS [16, 17]. Susuki [18, 19] developed the Generalized Inverse Beamforming (GIB) to resolve coherent or incoherent, distributed or compact aerodynamic sound sources using an eigenmode decomposition of the cross-spectral matrix of microphone signals.

In this paper, the applicability of five sound identification methods as well as two novel methods, BRF and CLEAN-BRF, is evaluated in the context of acoustic source separation using a circular microphone array configuration.

The remainder of this paper is organized as follows: in section 2, the source identification algorithms are briefly explained. In section 3, the applicability of the proposed algorithms is investigated for various simulated sound sources. In section 4, the simulation study is validated through experiments using a circular microphone array.

2 Source Identification Methods

2.1 Beamforming

Beamforming is a technique that separates desired signals from noise. In the output of beamforming, the desired signals added coherently whereas noise is added incoherently.

We assume here that the identified acoustic sources are represented by a set of L candidate point sources distributed over a target grid domain and that there are M microphones to measure the magnitude of the sound sources. The sound pressure field of a point source at location $\mathbf{r}$ is given by [20]:

$$p_m(\mathbf{r},\omega) = \frac{q_0\, e^{-jk|\mathbf{r}-\boldsymbol{r}_m|}}{|\mathbf{r}-\boldsymbol{r}_m|}, \tag{1}$$

where q_0 is the source strength, $\mathbf{r}_m$ ($m = 1,2,3 \ldots M$) is the location of the m^{th} microphone, k is the wavenumber and ω is the angular frequency. The normalized beamforming output is given by [21]:

$$B(\mathbf{r},\omega) = \alpha \sum_{m=1}^{M} g_m{}^* p_m(\mathbf{r},\omega) = \alpha \mathbf{g}^{\mathrm{H}}\mathbf{p} \tag{2}$$

where α is the weight vector normalization coefficient, $g_m = e^{-jk|\mathbf{r}-\boldsymbol{r}_m|}/|\mathbf{r}-\boldsymbol{r}_m|$ is the m^{th} component of the $M \times 1$ steering vector $\mathbf{g}$, ***** is the complex conjugate and $^{\mathbf{H}}$ is the Hermitian transpose. This vector consists of complex pressure amplitudes emanated by a unit monopole point source in $\mathbf{r}$. The average power of equation 2 is given by:

$$\begin{aligned} A(\mathbf{r},\omega) = |B(\mathbf{r},\omega)|^2 &= \alpha^2 \mathbf{g}^{\mathrm{H}}\mathbf{p}\mathbf{p}^{\mathrm{H}}\mathbf{g} \\ &= \alpha^2 \mathbf{g}^{\mathrm{H}}\mathbf{C}\mathbf{g} \end{aligned} \tag{3}$$

where $\mathbf{C} = \mathbf{p}\mathbf{p}^{\mathrm{H}}$ is the $M \times M$ Cross Spectral Matrix (CSM). The appropriate normalization coefficient α can be derived in the following way. If a set of L point sources is considered at locations $\mathbf{y}_l$, the model for the pressure ($\mathbf{p}$) at microphone positions can be written by [21]:

$$\mathbf{p} = \sum_{l=1}^{L} \mathrm{q}_l\, \mathbf{g}_l \tag{4}$$

where q_l is the strength of source at point $\mathbf{y}_l$ and $\mathbf{g}_l$ is the the $M \times 1$ vector of components $g_{ml} = e^{-jk|\mathbf{r}_l-\boldsymbol{r}_m|}/|\mathbf{r}_l-\boldsymbol{r}_m|$. Substituting equation 4 into equation 3 for a single source l and for $\mathbf{r} = \mathbf{y}_l$ gives:

$$\mathrm{A}_{ll} = \alpha^2 q_l q_l{}^* \mathbf{g}_l{}^{\mathrm{H}}\mathbf{g}_l\mathbf{g}_l{}^{\mathrm{H}}\mathbf{g}_l\,. \tag{5}$$

Since it is requested that $q_l q_l{}^* = \mathrm{A}_{ll}$, equation 5 can be written as:

$$\mathrm{A}_{ll} = \alpha^2 \mathrm{A}_{ll}\mathbf{g}_l{}^{\mathrm{H}}\mathbf{g}_l\mathbf{g}_l{}^{\mathrm{H}}\mathbf{g}_l\,. \tag{6}$$

Therefore, solving for α gives:

$$\alpha = \frac{1}{\sqrt{(\mathbf{g}_l{}^{\mathrm{H}}\mathbf{g}_l)^2}} = \frac{1}{\sqrt{\sum_{(m,n)\in S}|g_{ml}|^2|g_{nl}|^2}} \tag{7}$$

where S is assumed to be a subset of all possibilities of (m,n)-combinations, and m and n are microphone indices. Defining the array weight vector by $\mathbf{W} = \alpha\mathbf{g}$, equation 3 can be rewritten [15]:

$$A = \mathbf{W}^{\mathrm{H}}\bar{\mathbf{C}}\,\mathbf{W}\,, \tag{8}$$

$\bar{\mathbf{C}}$ is the cross spectral matrix (CSM) of microphone signals where the diagonal of the matrix is removed. The diagonal removal eliminates the effect of uncorrelated measurement noise among microphone signals, which is therefore restricted to microphone auto-spectra.

The normalized beamforming delay-and-sum operation can also be written by

$$\mathbf{q}_{\mathrm{BF}} = \alpha\mathbf{G}^{\mathrm{H}}\mathbf{p} \tag{9}$$

where $\mathbf{q}_{\mathrm{BF}}$ is the $L \times 1$ beamformer output vector at the L candidate source locations and $\mathbf{G}$ is the $M \times L$ matrix of free-field Green's functions between the L point sources and M sound pressure measurement points. Therefore, the beamformer power output matrix is defined by

$$\mathbf{A} = \mathbf{q}_{\mathrm{BF}}\mathbf{q}_{\mathrm{BF}}{}^{\mathrm{H}} = \alpha^2\mathbf{G}^{\mathrm{H}}\bar{\mathbf{C}}\mathbf{G}\,. \tag{10}$$

2.2 Inverse Method

For practical sound field identification based on inverse problem theory, the general inverse problem must be discretized in terms of the source description. We assume here again that the acoustic sources are represented by a set of L point sources and that there are M microphones. The matrix form of equation 4 which is the sampled direct radiation problem is written as

$$\mathbf{p} = \mathbf{G}\mathbf{q} \tag{11}$$

where $\mathbf{p}$ is the $M \times 1$ vector of complex sound pressure values at the microphone locations, $\mathbf{G}$ is the $M \times L$ vector matrix of free-field Green's functions between the L point sources and M sound pressure measurement points, $\mathbf{q}$ is the $L \times 1$ vector of unknown complex source strengths. In the inverse method, the 2-norm of the error between the reconstructed sound pressure $\mathbf{p}$ assuming a set of L point sources and the measured sound pressure $\mathbf{p}$ is minimized.

The problem is then to find the optimal q for the minimization problem

$$\mathbf{q}_{\mathrm{opt}} = \arg\min\{|\mathbf{p} - \mathbf{G}\mathbf{q}|^2\}. \tag{12}$$

Most of the time the inverse problem is ill-conditioned, implying that the solution $\mathbf{q}_{opt}$ is very sensitive to measurement noise and model uncertainty. To prevent this problem, Tikhonov regularization is used [6, 9]. Therefore, the regularized inverse problem is:

$$\mathbf{q}_{\text{opt}} = \text{argmin}\,\{|\mathbf{p} - \mathbf{Gq}|^2 + \epsilon^2|\mathbf{Lq}|^2\} \tag{13}$$

where ϵ is the regularization parameter and L is the discrete smoothing norm used to shape the regularization. In this work, the optimal regularization parameter is based on the well-known L-curve criterion [22].

The L-curve is a plot of the norm of the regularized solution versus the norm of the corresponding residual for all valid regularization parameters. The curve very often has an "L" shape and the corner of the L-curve balances the minimization of the residual norm ($\|\mathbf{Gq} - \mathbf{p}\|^2$) and the norm of $\|\mathbf{q}\|^2$. The solution of this minimization problem is:

$$\mathbf{q}_{\text{opt}} = (\mathbf{G}^{\text{H}}\mathbf{G} + \epsilon^2\mathbf{L})^{-1}\mathbf{G}^{\text{H}}\mathbf{p} \tag{14}$$

The simplest form of Tikhonov regularization uses $\mathbf{L} = \mathbf{I}$ where $\mathbf{I}$ is the identity matrix therefore the a $L \times L$ source power matrix provided by the inverse solution is given by:

$$\mathbf{A} = \mathbf{q}_{\text{opt}}\mathbf{q}_{\text{opt}}^{\text{H}} = (\mathbf{G}^{\text{H}}\mathbf{G} + \epsilon^2\mathbf{I})^{-1}\mathbf{G}^{\text{H}}\bar{\mathbf{C}}\,\mathbf{G}[\,(\mathbf{G}^{\text{H}}\mathbf{G} + \epsilon^2\mathbf{I})^{-1}]^{\text{H}}. \tag{15}$$

2.3 Inverse Solution using Beamforming Regularization (BFR)

In this section, a novel method combining the iterative concepts of CLEAN-SC and BFR has been presented. The main idea behind the proposed regularization approach is to find a "best" smoothing norm L in our problem [9]. This can be performed by observing that part of the solution given by equation 14 involves the beamforming delay-and-sum operation

$$\mathbf{q}_{\text{BF}} = \mathbf{G}^{\text{H}}\mathbf{p}\,. \tag{16}$$

Therefore, an application of the general Tikhonov regularization problem (equation 13) is to use the special case where the regularization matrix L is related to the beamforming output,

$$\mathbf{L} = [\text{diag}(|\mathbf{G}^{\text{H}}\mathbf{p}|/\|\mathbf{G}^{\text{H}}\mathbf{p}\|_\infty)]^{-1} \tag{17}$$

where diag($|\mathbf{a}|$) indicates that the absolute value of the $1 \times L$vector $\mathbf{a}$ is mapped on the main diagonal of a $L \times L$matrix. The infinity norm of a vector $\mathbf{v}$ is denoted $\|\mathbf{v}\|_\infty$ and is defined as the maximum of the absolute values of its components. Note that the beamforming output $\mathbf{G}^{\text{H}}\mathbf{p}$ has been normalized by its infinity norm $\|\mathbf{G}^{\text{H}}\mathbf{p}\|_\infty$ to ensure that the regularization is normalized in terms of beamformer signal level. Thus, the minimization problem (equation 13) becomes:

$$\mathbf{q}_{\text{opt}} = \text{argmin}\,\{|\mathbf{p} - \mathbf{Gq}|^2 + \epsilon^2|[\text{diag}(|\mathbf{G}^{\text{H}}\mathbf{p}|/\|\mathbf{G}^{\text{H}}\mathbf{p}\|_\infty)]^{-1}\mathbf{q}|^2\}. \tag{18}$$

Therefore, the inverse solution with such a regularization matrix favors source positions or directions for which classical beamforming yields a large output. The square diagonal matrix $[\text{diag}(|\mathbf{G}^{\text{H}}\mathbf{p}|/\|\mathbf{G}^{\text{H}}\mathbf{p}\|_\infty)^2]^{-1}$ is called the beamforming regularization matrix. It is important to note that this approach involves a data-dependent regularization which somewhat differentiates this method from most classical regularization methods. The solution of the above minimization problem then becomes:

$$\mathbf{q}_{\text{BFR}} = (\mathbf{G}^{\text{H}}\mathbf{G} + \epsilon^2[\text{diag}(|\mathbf{G}^{\text{H}}\mathbf{p}|/\|\mathbf{G}^{\text{H}}\mathbf{p}\|_\infty)^2]^{-1})^{-\mathbf{1}}\,\mathbf{G}^{\text{H}}\mathbf{p}\,. \tag{19}$$

As a consequence, the source power map of the BFR method is given by:

$$\mathbf{A} = \mathbf{W}_{\text{BFR}}{}^{\text{H}}\bar{\mathbf{C}}\mathbf{W}_{\text{BFR}} \tag{20}$$

where $\mathbf{W_{BFR}} = (\text{G}^{\mathbf{H}}\text{G} + \boldsymbol{\epsilon}^{\mathbf{2}}[\mathbf{diag}(|\mathbf{G}^{\mathbf{H}}\mathbf{p}|/\|\mathbf{G}^{\mathbf{H}}\mathbf{p}\|_\infty)^2]^{-\mathbf{1}})^{-\mathbf{1}}\,\mathbf{G}^{\mathbf{H}}$.

2.4 L1-Generalized Inverse Beamforming (L1-GIB)

Similar to the beamforming method, pre-defined monopoles and dipoles are considered in L1-GIB to obtain the source distribution. The source distribution is solved as an L1 norm problem using Iteratively Re-weighted Least Squares (IRLS). The source detection problem is defined to be a minimization of the following L_p norm cost function [18, 19]:

$$J_p = \sum_i^{L_{\text{type}}L} |\mathbf{q}_i|^p + \vec{\lambda}\,(\mathbf{v}_i - \mathbf{Gq}_i), \tag{21}$$

where $\mathbf{q}_i$ is a $L_{\text{type}}L \times 1$ vector that consists of complex source amplitudes for all source types and for all target domain grid points , L_{type} indicates the number of specified source types (monopoles, dipoles and possibly higher-order multipoles) and L is the number of grid points. Also, $\mathbf{v}_i$ are the eigenmodes, defined as the normalized $M \times 1$ eigenvectors of the cross-spectral matrix C, G is the $M \times L_{type}L$ propagation matrix from all sources to all microphones and $\vec{\lambda}$ is the Lagrange multiplier vector.

The minimization of equation 21 is solved using the IRLS method [23] which iteratively solves general L_p norm problems. Equation 21 can be written as

$$J_p = \sum \text{w}_i^{-1}|\mathbf{q}_i|^2 + \vec{\lambda}(\mathbf{v}_i - \mathbf{Gq}_i) \tag{22}$$

where $\text{w}_i^{-1} = |\mathbf{q}_i|^{p-2}$. This function is iteratively minimized using a generalized iterative method as

$$\mathbf{q}_i{}^{(n+1)} = \mathbf{W}_i{}^{(n)}\mathbf{G}^{\text{H}}\big(\mathbf{G}\mathbf{W}_i{}^{(n)}\mathbf{G}^{\text{H}} + \epsilon\mathbf{I}\big)^{-1}\mathbf{v}_i\,, \tag{23}$$

where $\mathbf{W}_i{}^{(n)}$ is the $(L_{\text{type}}L) \times (L_{\text{type}}L)$ diagonal matrix in which the diagonal component is given by $\text{w}_i = |q_i|^{2-p}$, q is a component of vector $\mathbf{q}$ and the superscript n is the iteration counter.

2.5 CLEAN-PSF

CLEAN-PSF (based on point spread function) is a deconvolution method that helps compensating for Point Spread Functions (PSF's) in source plots. This method attempts to substitute these PSF's with single points, or beams with narrow widths. The steps of CLEAN-PSF are as follows [15]:

- Obtaining the source plot using classical beamforming ("dirty map")
- Searching for the peak location in the dirty map
- Subtracting the appropriately scaled PSF from the dirty map
- Replacing the PSF by a clean beam
- This process is performed iteratively to detect all sources

In the first iteration ($i = 0$) $\bar{\mathbf{D}}^{(i)}$ is defined as the cross-spectral matrix with diagonal components removed $\bar{\mathbf{C}}$

$$\bar{\mathbf{D}}^{(\mathrm{i})} = \bar{\mathbf{D}}^{(0)} = \bar{\mathbf{C}} \tag{24}$$

Source powers $A_j^{(0)}$ using classical beamforming (which are components of **A** in equation 10 are given by:

$$A_j^{(0)} = \mathbf{W}_j^{\mathrm{H}}\bar{\mathbf{C}}\mathbf{W}_j = \mathbf{W}_j^{\mathrm{H}}\bar{\mathbf{D}}^0\mathbf{W}_j \tag{25}$$

where $\mathbf{W}_j$ is the weigth vector for the scan (or grid) point j . The next step ($i \geq 1$) is the detection of the grid location $\mathbf{y}_{max}$ for which the source power map is maximal and the amplitude of this peak ($A_{max}^{(i-1)}$) from the dirty map. Then, the contribution of the source associated with the peak power is subtracted from the dirty map. At this point, the PSF associated with the peak source is removed in the degraded source powers $A_j^{(i)}$. These degraded source powers are given by:

$$A_{\mathrm{j}}^{(i)} = A_{\mathrm{j}}^{(i-1)} - \mathbf{W}_{\mathrm{j}}^{\mathrm{H}}\bar{\mathbf{G}}^{(i)}\mathbf{W}_{\mathrm{j}}, \tag{26}$$

where $\bar{\mathbf{G}}^{(i)}$is the CSM with the diagonal removed, obtained for the source in $\mathbf{y}_{max}$,

$$\mathbf{G}^{(i)} = A_{max}^{(i-1)}\mathbf{g}_{max}^{(i)}\,\mathbf{g}_{max}^{(i)\mathrm{H}} \tag{27}$$

where $\mathbf{g}_{max}^{(\mathrm{i})}$ is the steering vector related to $\mathbf{y}_{max}$. The main objective of this method is to update the dirty map by subtracting a scaled PSF related to $\mathbf{y}_{max}$. This PSF is substituted by a clean beam:

$$Q_j^{(i)} = A_{max}^{(i-1)}\Phi(\mathbf{y}_j - \mathbf{y}_{max}) \tag{28}$$

where Φ is a normalized clean beam ($\Phi(0) = 1$) of specified width. In the following, Φ is chosen as a Dirac Delta function to satisfy this property. The degraded CSM is defined as:

$$\mathbf{D}^{(\mathrm{i})} = \mathbf{D}^{(i-1)} - A_{max}^{(i-1)}\mathbf{g}_{max}^{(i)}\,\mathbf{g}_{max}^{(i)\mathrm{H}}\,. \tag{29}$$

The process is then repeated from equation 25. After I iterations, the final source power map at location j is obtained as the summation of the clean beams and the remaining dirty map:

$$A_j = \sum_{i=1}^{I} Q_j^{(i)} + A_j^{(I)} \tag{30}$$

2.6 CLEAN-SC

CLEAN-SC (based on spatial source coherence) has the ability to detect incoherent sources with suitable resolution [15]. The side lobes in a source plot are coherent with the main lobe. The CLEAN-SC method uses this fact to improve the source power map. Physically, this method subtracts all the information which is coherent with the larger mainlobes of the map (strong sources) in order to extract smaller mainlobes (weaker sources) that can be masked by sidelobes of stronger sources. This process is performed iteratively in order to detect all mainlobes (sources) in the source maps. Source cross powers are defined by [15]:

$$\mathrm{A}_{jk} = \mathbf{W}_j^{\mathrm{H}}\bar{\mathbf{C}}\mathbf{W}_k \tag{31}$$

where j and k are scan points. Similar to the CLEAN-PSF method, the degraded source powers $A_j^{(i)}$ are obtained by equation 26, but a different matrix $\bar{\mathbf{G}}^{(i)}$ is selected for the CLEAN-SC. Here, $\bar{\mathbf{G}}^{(i)}$ is determined such that the source cross-powers of any scan point $\mathbf{y}_j$ are coherent with the source corresponding to the peak location $\mathbf{y}_{max}$. This means that:

$$\mathbf{W}_j^{\mathrm{H}}\bar{\mathbf{D}}^{(i-1)}\mathbf{W}_{max}^{(i)} = \mathbf{W}_j^{\mathrm{H}}\bar{\mathbf{G}}^{(i)}\mathbf{W}_{max}^{(i)}, \text{ for all possible } \mathbf{W}_j, \tag{32}$$

where $\mathbf{W}_{max}^{(i)}$ is the weight vector related to $\mathbf{g}_{max}^{(i)}$. To satisfy equation 32:

$$\bar{\mathbf{D}}^{(i-1)}\mathbf{W}_{max}^{(i)} = \bar{\mathbf{G}}^{(i)}\mathbf{W}_{max}^{(i)} \tag{33}$$

By assuming that $\mathbf{G}^{(i)}$ is due to a single coherent source component $\mathbf{h}^{(i)}$, The solution of equation 33 is:

$$\mathbf{G}^{(i)} = A_{max}^{(i-1)}\mathbf{h}^{(i)}\mathbf{h}^{(i)\mathrm{H}} \tag{34}$$

where **h** is a function that represents a distribution of source strengths over grid points.
The trimmed version of equation 34 can be written as:

$$\bar{\mathbf{G}}^{(i)} = A_{max}^{(i-1)}\overline{\mathbf{h}^{(i)}\mathbf{h}^{(i)\mathrm{H}}} = A_{max}^{(i-1)}(\mathbf{h}^{(i)}\mathbf{h}^{(i)\mathrm{H}} - \mathbf{H}^{(i)}) \tag{35}$$

where $\mathbf{H}^{(i)}$ is given by:

$$H_{mn}{}^{(i)} = \begin{cases} 0 & , \text{for } (m,n) \in S \\ h_m{}^{(i)}h_n{}^{(i)*} & , \text{for } (m,n) \notin S \end{cases} \tag{36}$$

As mentioned in equation 7, S is assumed to be a subset of all possibilities of (m,n) combinations, where m and n are microphone indices. To satisfy equation 33, $\mathbf{h}^{(i)}$ must be:

$$\mathbf{h}^{(i)} = \frac{1}{\left(1 + \mathbf{W}_{max}^{(i)}{}^{\mathrm{H}}\mathbf{H}^{(i)}\mathbf{W}_{max}^{(i)}\right)^{1/2}} \cdot \left(\frac{\bar{\mathbf{D}}^{(i-1)}\mathbf{W}_{max}^{(i)}}{A_{max}^{(i-1)}} + \mathbf{H}^{(i)}\mathbf{W}_{max}^{(i)}\right). \tag{37}$$

The expression for $\mathbf{h}^{(i)}$ is not explicit since $\mathbf{H}^{(i)}$ contains (the diagonal) elements of $\mathbf{h}^{(i)}\mathbf{h}^{(i)H}$. However, equation 37 is solved iteratively by starting with $\mathbf{h}^{(i)} = \boldsymbol{g}_{max}^{(i)}$. After a few iterations equation 37 is usually satisfied. Now a new expression for $\mathbf{G}^{(i)}$ which is different from equation 27 is obtained.

The next steps are exactly identical to the CLEAN- PSF method. The CLEAN-SC is an improved version of the classical clean algorithm. Since the CLEAN-SC does not assume a theoretical beam pattern (PSF), there is better resolution in the results than that of the classical methods. However, this method can only identify incoherent sources.

2.7 CLEAN-BFR

The basis of the CLEAN-BFR approach is quite similar to the CLEAN-SC. CLEAN-BFR again uses the spatial coherence of sidelobes and mainlobe of a given source in order to identify the sources. Here, all the steps of the CLEAN-SC are repeated but with a weight vector $\mathbf{W}_{\mathrm{BFR}}$ which is obtained from the inverse solution with beamforming regularization. Therefore, source cross powers for CLEAN-BFR are given by [11]:

$$A_{jk} = {\mathbf{W}_{\mathrm{BFR}}}_j^{\mathrm{H}} \bar{\mathbf{C}} {\mathbf{W}_{\mathrm{BFR}}}_k \tag{38}$$

where $\mathbf{W}_{\mathrm{BFR}}$ is the weight vector given by equation 20, $\mathbf{W}_{\mathrm{BFR}} = (\mathbf{G^H G} + \boldsymbol{\epsilon}^2[\mathrm{diag}(|\mathbf{G}^{\mathrm{H}}\mathbf{p}|/\|\mathbf{G}^{\mathrm{H}}\mathbf{p}\|_\infty)^2]^{-1})^{-1}\mathbf{G^H}$. All the subsequent steps of the CLEAN-BFR are identical to CLEAN-SC replacing W by $\mathbf{W}_{\mathrm{BFR}}$.

3 Simulation study

3.1 Sound Field Simulation

The objective of this section is to simulate the sound propagation from simple source models to the microphone array, in order to simulate the various source identification approaches investigated in the previous section. We consider in general two compact sources at locations $\mathbf{r}_1$, $\mathbf{r}_2$ with specific far-field directivity functions $D_1(\theta)$, $D_2(\theta)$ and source magnitudes $q_1(\omega)$, $q_2(\omega)$, such that the sound pressure at the location of microphone *m* is

$$p_m(\omega) = D_1(\theta) q_1(\omega) \frac{e^{-jk|\mathbf{r}_1 - \mathbf{r}_m|}}{|\mathbf{r}_1 - \mathbf{r}_\mathrm{m}|} + D_2(\theta) q_2(\omega) \frac{e^{-jk|\mathbf{r}_2 - \mathbf{r}_m|}}{|\mathbf{r}_2 - \mathbf{r}_\mathrm{m}|}. \tag{39}$$

The case of monopoles, dipoles and quadrupoles radiating in the far-field will be considered. A dipole is represented by two closely spaced monopoles of magnitudes $-q_i(\omega), +q_i(\omega)$ with a separation d (such that $kd \ll 1$) [24]. For a dipole at location $\mathbf{r}$, the sound pressure at the location of microphone *m* is:

$$p_m(\omega) = kd \cos\theta \, q_i(\omega) \frac{e^{-jk|\mathbf{r} - r_m|}}{|\mathbf{r} - \mathbf{r}_\mathrm{m}|} \tag{40}$$

Here, the directivity is $D_i(\theta) = \cos\theta$ where θ is the angle relative to the dipole axis and the dipole magnitude is given by $q_{dip,i}(\omega) = jkdq_i(\omega)$ where $= |\mathbf{k}|$.

A tesseral quadrupole is represented by four closely spaced monopoles of magnitudes $+q_i(\omega), -q_i(\omega), -q_i(\omega), +q_i(\omega)$ with separations d along the two orthogonal axes (such that $kd \ll 1$). For a quadrupole, $D_i(\theta) = \cos\theta \sin\theta$ and the quadrupole magnitude is given by $q_{quad,i}(\omega) = -k^2 d^2 q_i(\omega)$ [24].

The cross-spectral power of sound pressures at two distinct locations ($\mathbf{r}_\mathrm{m}$ and $\mathbf{r}_\mathrm{n}$) is given by:

$$\begin{aligned} C_{nm} &= p_n^* p_m = D_1(\theta)^2 S_{11} \frac{e^{jk(|\mathbf{r}_1 - \mathbf{r}_n| - |\mathbf{r}_1 - \mathbf{r}_m|)}}{|\mathbf{r}_1 - \mathbf{r}_m||\mathbf{r}_1 - \mathbf{r}_n|} \\ &+ D_2(\theta)^2 S_{22} \frac{e^{jk(|\mathbf{r}_2 - \mathbf{r}_n| - |\mathbf{r}_2 - \mathbf{r}_m|)}}{|\mathbf{r}_2 - \mathbf{r}_m||\mathbf{r}_2 - \mathbf{r}_n|} \\ &+ D_1(\theta) D_2(\theta) S_{12} \frac{e^{jk(|\mathbf{r}_2 - \mathbf{r}_n| - |\mathbf{r}_1 - \mathbf{r}_m|)}}{|\mathbf{r}_2 - \mathbf{r}_n||\mathbf{r}_1 - \mathbf{r}_m|} \\ &+ D_1(\theta) D_2(\theta) {S_{12}}^* \frac{e^{jk(|\mathbf{r}_1 - \mathbf{r}_n| - |\mathbf{r}_2 - \mathbf{r}_m|)}}{|\mathbf{r}_1 - \mathbf{r}_n||\mathbf{r}_2 - \mathbf{r}_m|} \end{aligned} \tag{41}$$

where $S_{11} = q_1(\omega) {q_1}^*(\omega)$, $S_{22} = q_2(\omega) {q_2}^*(\omega)$ are the auto-spectral power densities of the two sources and $S_{12} = q_1(\omega) {q_2}^*(\omega)$ is their cross-spectral power density. The value of S_{12} relative to S_{11} and S_{22} allows simulating coherent, incoherent or partially coherent sources. The cross spectral matrix $\mathbf{C}$ is the input of phased array techniques which are applied is this study, and the output is the source power map. Equations 39 and 40 can be easily expanded to more than two sources. The source properties can be defined by changing the source directivity and the correlation parameters of source spectral densities (S_{11}, S_{22} and S_{12}).

3.2 Simulation of source identification methods

In this section, the various source identification algorithms detailed in section 3 are tested through simulations. A regular circular array configuration of 60 microphones on a circle with radius $R = 45$m is considered for the various methods and for different source types. In the following, source power maps are plotted as a function of positions normalized to the acoustic wavelength λ . The scan zone for the simulation study is a rectangular area where $-2\lambda < x < 2\lambda$, $-2\lambda < y < 2\lambda$ and the resolution is 0.1λ The microphone array radius is R = 132 λ (See Figure 1)

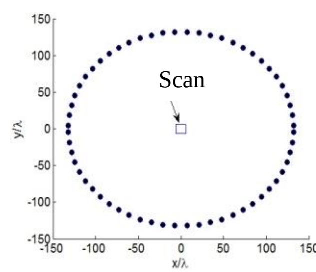

Figure 1: Microphone array configuration

In the situations considered in the following, sources are inside the array and close to the array center. These conditions are similar to the configuration used for static aero-engine noise certification tests (using a semi-circular microphone array) [10].

Figure 2 show the results of conventional beamforming for 1800 microphones, $\frac{d}{\lambda} = 0.45$ (Left) and 60 microphones, $\frac{d}{\lambda} = 14.01$ (Right). The results show the microphones seperation regardless of spatial aliasing condition, in the particular situation of sources close to array center does not essential effect in the map resolution. This aspect needs more investigations.

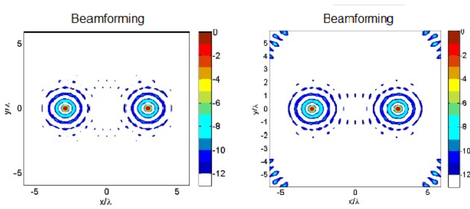

Figure 2: Conventional beamforming output for 1800 microphones and 60 microphones

Identification of sources with unequal amplitude

The application of the approaches for sources with unequal strengths is investigated. Two uncorrelated monopole sources at positions $\frac{x}{\lambda} = -1, +1$ with a 6dB difference in source powers are considered ($S_{11} = 1[\mathrm{kg}^2\mathrm{s}^{-4}]$, $S_{22} = 4[\mathrm{kg}^2\mathrm{s}^{-4}]$, $S_{12} = 0[\mathrm{kg}^2\mathrm{s}^{-4}]$).

Figure 3 shows the source power maps of two uncorrelated monopoles in dB relative to the peak value for the different methods. The plot range in this figure is 12 dB, which is almost the same as the dynamic range (peak level minus highest side lobe level) of the microphone array that was used. In the results, ϵ is the regularization parameter and it is the number of iterations in L1-GIB, CLEAN-PSF, CLEAN-SC and CLEAN-BFR. It can be observed that conventional beamforming and the regularized inverse method are able to correctly identify the relative amplitude values and the location of the sources. However, both methods display strong sidelobes that can potentially mask weaker sources. The BFR method is not able to determine the weaker sources because of the large penalization being applied to a weaker source (see equation 13), resulting in an underestimation of source strength for this source. CLEAN-PSF, CLEAN-SC, L1- GIB and CLEAN-BFR provide high resolution maps. The dB value of the weaker source is shown in figure 3 for all the methods.

Identification of Correlated and Uncorrelated Sources

Identification algorithms are applied for uncorrelated ($S_{11} = 1[\mathrm{kg}^2\mathrm{s}^{-4}]$, $S_{22} = 1[\mathrm{kg}^2\mathrm{s}^{-4}]$, $S_{12} = 0[\mathrm{kg}^2\mathrm{s}^{-4}]$), correlated ($S_{11} = 1[\mathrm{kg}^2\mathrm{s}^{-4}]$, $S_{22} = 1[\mathrm{kg}^2\mathrm{s}^{-4}]$, $S_{12} = 1[\mathrm{kg}^2\mathrm{s}^{-4}]$) and partially correlated sources ($S_{11} = 1[\mathrm{kg}^2\mathrm{s}^{-4}]$, $S_{22} = 1[\mathrm{kg}^2\mathrm{s}^{-4}]$, $S_{12} = 0.25[\mathrm{kg}^2\mathrm{s}^{-4}]$) (See Figure 4).

The CLEAN-SC and CLEAN-BFR methods detect partially correlated sources as well as uncorrelated sources. However, these methods do not satisfactorily detect correlated sources.

In the first iteration of these algorithms, the mainlobe of the strongest source and all coherent parts in the source power map will be removed. Accordingly, weaker sources that are coherent with the mainlobe will also be removed. This reveals that the CLEAN-SC and the CLEAN-BFR are inappropriate for coherent sources. BFR and L1-GIB show consistent results for uncorrelated sources as well as correlated and partially correlated sources

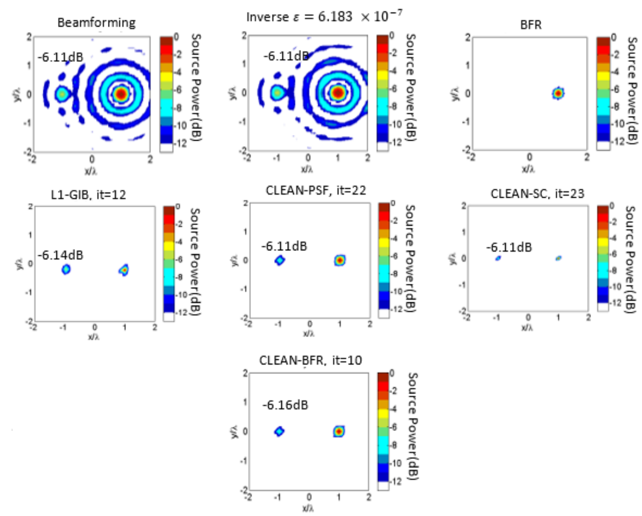

Figure 3: Source power maps for two uncorrelated monopoles in dB relative to the peak value for the different methods (with a 6dB level difference)

3.3 Identification of monopole, Dipole and Quadrupole Sources

In this section, the methods are tested for multipole source identification. For both dipole and quadruple sources, $kd = 0.369$ (see section 3.1). The sources are uncorrelated and are positioned on $[\lambda, 0]$ and $[-\lambda, 0]$. Both dipole and quadrupole sources are parallel to the array plane. As seen in Figure 5, the dipole source is oriented along the *x*-axis and two intensity peaks are on the source maps that the central point between the peaks corresponds to the dipole position ($\frac{x}{\lambda} = +1, \frac{y}{\lambda} = 0$). The crosses in the figure represent actual source positions. The quadrupole is considered as four monopoles (see section 3.1). The Four intensity peaks are seen on the source maps that the central point among the peaks corresponds to the quaropole position($\frac{x}{\lambda} = -1, \frac{y}{\lambda} = 0$).

The auto-spectral power densities (S_{qq}) of the monopole source is equal to $1[\mathrm{kg}^2\mathrm{s}^{-4}]$. The dipole source consists of two monopole sources with $S_{qq} = 4[\mathrm{kg}^2\mathrm{s}^{-4}]$ and the quadrupole source consists of four monopole sources with $S_{qq} = 16[\mathrm{kg}^2\mathrm{s}^{-4}]$.

As shown in Figure 5 all algorithms can identify uncorrelated monopole, dipole and quadrupole sources. However, the best results are provided by BFR, L1-GIB, CLEAN-SC and CLEAN-BFR.

Table 1 compares the different methods in various aspects. The check mark (✓) indicates the concept "yes" and the ✕ mark is used to indicate "no". It is obvious that BFR, CLEAN-PSF, CLEAN-SC, L1- GIB and CLEAN-BFR provide higher resolution maps compared to conventional beamforming and the regularized inverse. Choosing one of these methods as the best method entirely depends on the problem's circumstances and the type of sound sources.

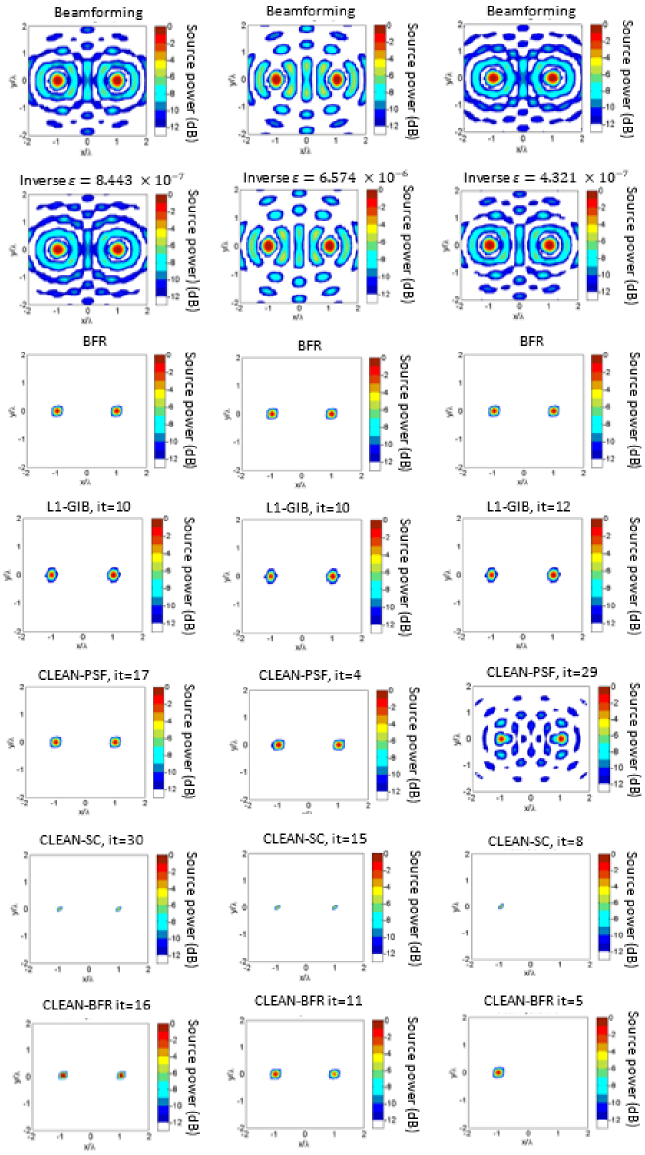

Figure 4: Source power maps for the various methods: Left: Two uncorrelated monopoles, Center: Two partially correlated monopoles, Right: Two fully correlated monopoles

4 Experiment

The laboratory test set-up designed to validate the source identification approaches uses two Audiophile DX4 satellite loudspeakers placed back-to-back on the floor of the Sherbrooke university hemi-anechoïc chamber (Figure 6). Each loudspeaker was fed independently with a broadband input. Loudspeakers were moved along the red line in figure 4 to validate the application of the various approaches for different source locations.

The measurements were provided by a 1.78 m radius semi-circular array of B&K4189 ½ inch free-field microphones installed on the ground. Although the anticipated application is for far-field, outdoor microphones and noise source separation of aero-engines, a small microphone antenna was tested in laboratory to validate the results of simulations.

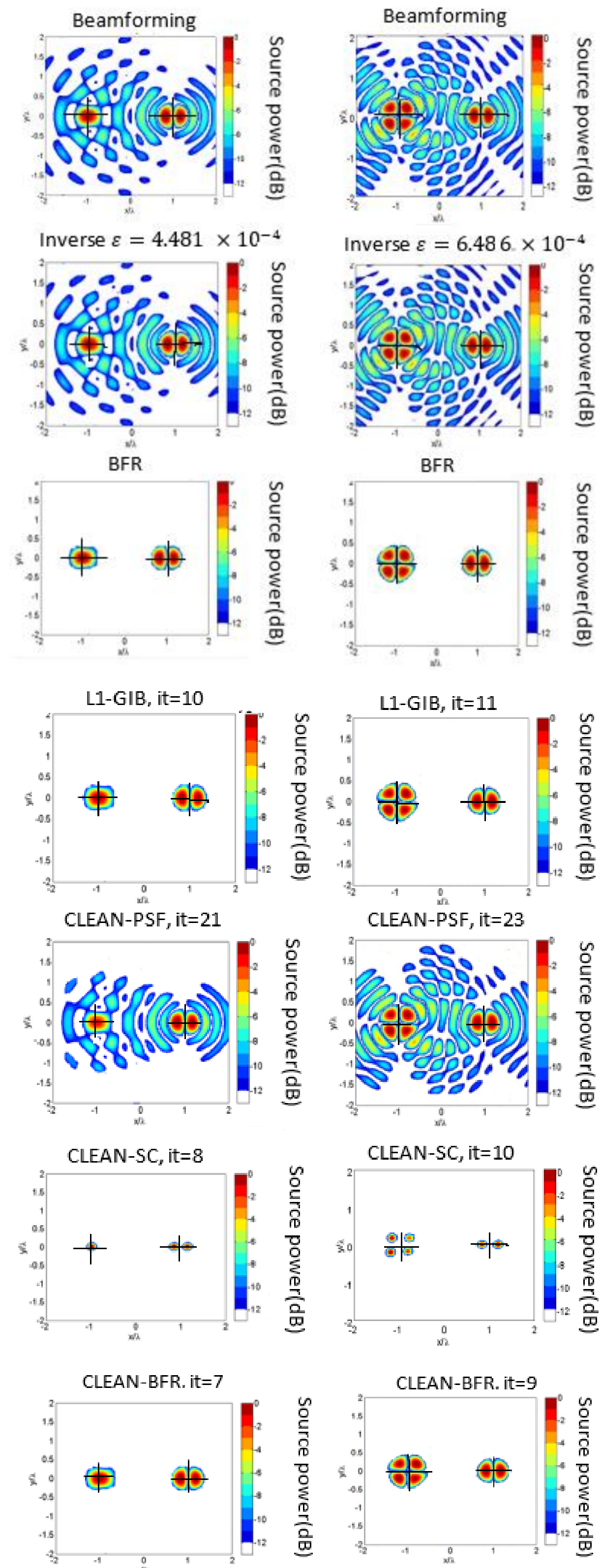

Figure 5: Source power maps for monopole, dipole and quadrupole sources:(left) one monopole and one dipole source (Right) one quadrupole and one dipole source

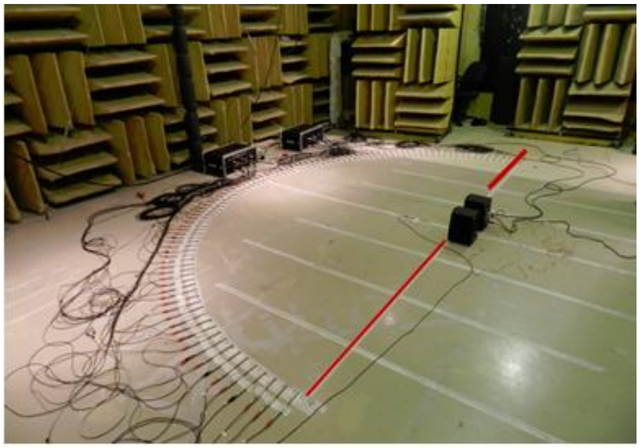

Figure 6: Experimental set-up in the laboratory

The semi-circular array has 94 microphones, with a microphone separation of approximately 6 cm. A second semi-circular array of microphones is virtually created by assuming axi-symmetry of the sound radiation from the loudspeakers with respect to the axis-line (red line in Figure 6). This configuration has the advantage of virtually increasing the number of sound pressure data and array aperture without implying additional physical measurements. The presence of a hard ground in the experiments induces pressure doubling at the microphones with respect to a free-field situation. Since only normalized source power maps are presented, no special modification of microphone signals was carried to account for the reflective ground surface. Microphone signals were acquired on a Bruel&Kjaer Pulse system. Then, the cross spectral matrix of microphone signals was built. The loudspeaker inputs were Gaussian noise in the frequency range from 0 to 12,000Hz. The scan zone is in the plane of microphones, and for all tests is $-1.4\text{m} < x < 1.4\text{m}$ and $-1.4\text{m} < y < 1.4\text{m}$, and the scan grid resolution is 0.02m.

Three source configurations were tested:

1- Two loudspeakers driven by uncorrelated broadband inputs with the same amplitude, at positions (0.3 m, 0) and - 0.3 m, 0)
2- Two loudspeakers driven by uncorrelated broadband inputs with 7dB difference in amplitudes, at positions (0.75 m, 0) and (-0.75 m, 0)
3- Two loudspeakers driven with the same Gaussian white noise, at positions (0.75 m, 0) and (-0.75 m, 0)

Figure 7 shows the source power maps for the two uncorrelated loudspeakers with identical amplitudes at positions (0.3 m, 0) and (- 0.3 m, 0) at $f = 1$ kHz. The crosses in the figures represent actual loudspeaker positions (position of front face). As shown in figure -7 most approaches correctly detect the source positions and relative magnitudes. However, conventional beamforming and the regularized inverse method display many sidelobes like for numerical simulations. Although the CLEAN-PSF partially removes side lobes, it still does not satisfy expectations of a source power map with high resolution. The L1-GIB results show that while source distances are decreased, the performance of L1-GIB drops (compare L1-GIB results in figures 8 and9).

The best results are provided by the CLEAN-SC, the CLEAN-BFR and the BFR methods. This conclusion is consistent with the simulation results of section 3.

Figure 8 shows results at $f = 1$ kHz for two uncorrelated broadband sources with 7 dB level difference. The two speakers are set up at (0.75 m, 0) and (-0.75 m,0). The measured power of the weak source relative to the strong source is provided in the figure.

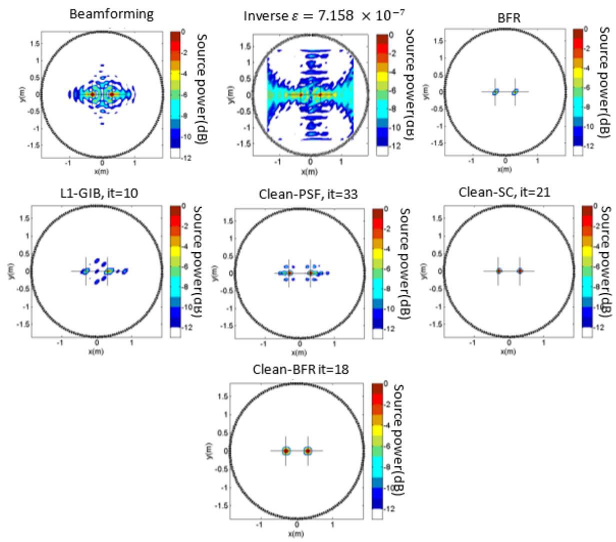

Figure 7: Source power maps for two loudspeakers driven by uncorrelated inputs with the same amplitude, at positions (0.3 m, 0) and - 0.3 m,0) at $f = 1$ kHz. (The circle is the microphone array)

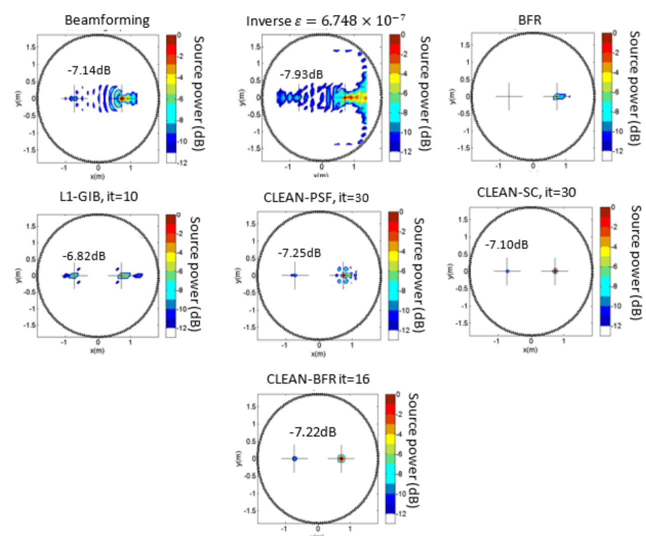

Figure -8: Source power maps,for two loudspeakers driven by uncorrelated inputs with 7 dB level difference, at positions (0.75 m,0) and (-0.75 m, 0) at $f = 1$ kHz. (The circle is the microphone array)

All methods correctly detect the sound radiation from the strongest source. However, due to strong sidelobes, conventional beamforming and the inverse method cannot detect the weaker source with enough resolution. The BFR method, as shown in the simulation section, is unable to detect weaker sources in the presence of the strong sources. This is due to the largest penalization being applied to a weaker source in

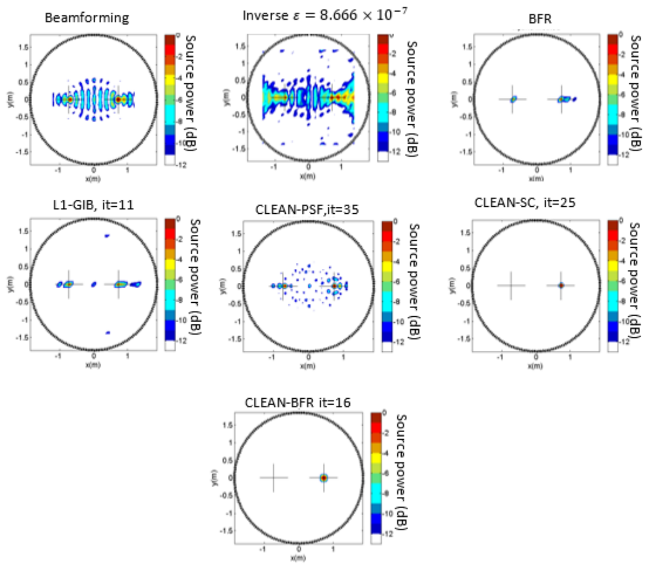

Figure -9: Source power maps for two loudspeakers driven by correlated inputs with 7 dB level difference, at positions (0.75 m,0) and (-0.75 m,0) at $f = 1$ kHz. (The circle is the microphone array)

the BFR method (see equation 19), which results in the underestimation of source strength for this source. Similar to the simulation study, the CLEAN-SC and the CLEAN-BFR provide the best results.

In the last experiment, the two loudspeakers are driven by the same Gaussian white noise signal. The two sources are therefore perfectly correlated. As seen in figure 9, the results indicate that similar to the simulation results, source correlation is not a significant parameter for conventional beamforming, the regularized inverse method, the BFR method and the L1-GIB. The CLEAN-PSF improves the resolution of source maps. As mentioned in the simulation section, the CLEAN-SC and CLEAN-BFR methods are based on the idea that sources in source plots are spatially coherent with their sidelobes. Therefore, for two correlated sources, one of the sources is identified as a coherent sidelobe of the other source and is therefore automatically removed from the map after the first iteration. The CLEAN-SC and the CLEAN-BFR are therefore not applicable for coherent sources. Overall, the BFR method provides the best results for two coherent sources.

5 Conclusion

This paper has examined the use of a circular microphone arrays to identify noise sources near the array center. An important application is for separation of exhaust / inlet noise of aero-engines using far-field circular microphone antenna. To this end, established methods have been tested (conventional beamforming, regularized inverse approach, CLEAN-PSF, CLEAN-SC, L1-GIB) as well as well more recent approaches (Beamforming Regularization Method, BFR). A new method (CLEAN-BFR) combining the iterative concepts of CLEAN-SC and BFR has been proposed. The findings of numerical simulations have been validated through laboratory experiments using a small antenna.

The principal conclusions are:

- BFR, CLEAN-PSF, CLEAN-SC, L1- GIB and CLEAN-BFR provide higher resolution maps compared to conventional beamforming and the regularized inverse.
- For sources with unequal magnitudes, the BFR method is not able to determine the weaker sources because of the large penalization applied to this weaker source, resulting in an underestimation of source strength for this source.
- CLEAN-SC and CLEAN-BFR are inappropriate for coherent sources
- BFR, L1-GIB, CLEAN-SC and CLEAN-BFR perform effectively for uncorrelated, dipole or quadrupole sources.

Acknowledgments

The authors wish to thank NSERC and Pratt & Whitney Canada for their financial support

Table 1: Comparison of the sound identification methods in various aspects

Methods	High resolution	Identification of various types of sound sources				Rank of methods based on computation time
		Multipole sources	Correlated sources	Uncorrelated sources	Sources with different amplitudes	
Beamforming	✕	✓	✓	✓	✓	1
Inverse	✕	✓	✓	✓	✓	2
BFR	✓	✓	✓	✓	✕	3
L1-GIB	✓	✓	✓	✓	✓	6
CLEAN-SC	✓	✓	✕	✓	✓	7
CLEAN-PSF	✕	✓	✓	✓	✓	5
CLEAN-BRF	✓	✓	✕	✓	✓	4

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Wooden structures
2 FILL IN THE INPUT DATA
Indicate if you want to isolate a floor or a ceiling. Then introduce the weight per square meter and distance between hangers/ mounts.
3 SELECT THE PERFORMANCE LEVEL
Introduce the natural frequency that you require. If you ignore this value you can select if your preference is high isolation or cost effectiveness. You can also select if the elastic material is rubber, Sylomer or spring.
Location
CEILING
FLOOR
Metric
METRIC
IMPERIAL
Load 6,6 lb/ft2
Distance between points
40 in
24 in
Freq 9 Hz
I know the natural frequency
Material
RUBBER
SYLOMER
SPRING
CONTINUE
4 SELECT THE INSTALLATION TYPE
In case that you want to isolate a ceiling, you must indicate if the hanger has to be anchored to the slab, to the metallic beam or between rods. This will provide you a range of selected hangers and mounts that will fulfill your requirement.
Finally select the hanger that suits best.
Straight to profile
Straight to slab
Between threaded rods
SEARCH RESULTS
AKUSTIK GB + SYLOMER®
Number of items in this product range:
2
AKUSTIK LATERAL + SYLOMER®
Number of items in this product range:
2
5 OBTAIN RESULTS
This will lead you to a page where you will be able to check the isolation level. On this page you will be able to receive the complete vibration isolation level, data sheet, installation video or even request a quotation/offer.
AKUSTIK LATERAL + SYLOMER 30 TYPE B
REFERENCE 23510
DEFL. 0.15 in
LOAD 66.52%
NAT. FREQ. 8.73 Hz
Name AKUSTIK LATERAL + SYLOMER® - Akustik Lateral + Sylomer 30 Type B
Date: 5/24/2019 12:45 PM
Reference 23510
Load (lb.) 43.99
Load (%) 66.52 %
Defl. (in) 0.15
Nat. Freq. (Hz) 8.73 Hz
DATA SHEET
Lateral Acoustic Hangers
Frequency (Hz) | Isolation (%) | Decibel (dB)
5 Hz | -48.87 % | -3.46 dB
10 Hz | -219.46 % | -10.09 dB
15 Hz | 48.83 % | 5.82 dB
20 Hz | 76.48 % | 12.57 dB
25 Hz | 86.12 % | 17.15 dB
35 Hz | 93.37 % | 23.57 dB
50 Hz | 96.86 % | 30.06 dB
75 Hz | 98.63 % | 37.25 dB
100 Hz | 99.23 % | 42.3 dB
200 Hz | 99.81 % | 54.39 dB
300 Hz | 99.92 % | 61.44 dB
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NEIGHBOURHOOD CONTEXT AND COMPOSITION MODERATE THE NOISE ANNOYANCE DOSE-RESPONSE

Tor H. Oiamo*[1], et Desislava Stefanova †[2]
[1]Department of Geography and Environmental Studies, Ryerson University, 350 Victoria Street, Toronto, ON, M5B 2K3, Canada
[2]Yeates School of Graduate Studies, Ryerson University, 350 Victoria Street, Toronto, ON, M5B 2K3, Canada

Résumé

La croissance de la population urbaine, les conflits d'utilisation des sols et l'augmentation du trafic aggravent la pollution sonore dans les zones urbaines. Toronto est l'une des villes qui doit relever un défi en luttant contre le bruit ambiant. L'importance de cette recherche repose sur une absence relative de littérature sur la manière dont la sensibilité au bruit et la gêne sont affectées par des facteurs non acoustiques, tels que les constructions environnantes, la démographie et les facteurs socio-économiques. Les données d'une enquête sur le bruit dans les quartiers (n=552) en 2017 ont été combinées avec des données spatiales sur les constructions environnantes et les expositions au bruit prévues. L'analyse bivariée et la régression multivariée ont montré que les facteurs socio-économiques et d'environnement physique influencent les réponses de nuisance sonore. Plus précisément, les résidents d'un quartier au statut socio-économique élevé et ayant accès à des espaces verts, et dont le niveau de bruit nocturne est faible, étaient plus de deux fois plus susceptibles (rapport de cotes : 2,35 ; $p<0{,}001$) de signaler une gêne élevée lors de l'évaluation du paysage sonore du quartier par rapport aux résidents de quartiers au statut socio-économique modéré et ayant un accès plus faible à des espaces verts. Bien que les niveaux de bruit nocturnes semblent être un prédicteur important des différences entre les quartiers en termes de nuisances sonores à la maison et dans le voisinage, les résultats montrent que les perceptions du bruit sont déterminées en partie par les contextes des quartiers, tels que la qualité de l'environnement et les caractéristiques individuelles. Pour les futures recherches sur la perception du bruit, les résultats justifient la prise en compte explicite des perceptions communes des quartiers en matière de bruit et d'attentes environnementales.

Mots clefs : Paysage sonore, bruit environnementale, perception du bruit, nuisance sonore, sensibilité au bruit, qualité de vie.

Abstract

Growing urban populations, conflicting land uses, and more traffic are exaggerating noise pollution in urban areas. Toronto is one of the cities facing challenges in tackling environmental noise. The significance of this research is based on a relative absence of literature on how noise sensitivity and annoyance are affected by non-acoustic factors, such as the built environment, demographic, and socio-economic factors. Data from a neighbourhood noise survey (n=552) in 2017 was combined with spatial data on the built environment and predicted noise exposures. Bivariate analysis and multivariate regression showed that socioeconomic and physical environment factors influence the noise annoyance responses. Specifically, residents in a neighborhood with high socioeconomic status and access to green space, and low night time noise levels, were more than twice as likely (Odds Ratio:2.35; $p<0.001$) to report high annoyance when evaluating the neighbourhood soundscape relative to residents of neighbourhoods with moderate socio-economic status and lower access to green space. Although nighttime noise levels appeared to be a strong predictor of neighbourhood differences in noise annoyance at home and in the neighbourhood, the findings demonstrate that noise perceptions are determined in part by neighbourhood contexts such as environmental quality and individual characteristics. For future research on noise perception the results warrant explicit consideration of shared neighbourhood perceptions of noise and environmental expectations.

Keywords: Soundscape; environmental noise; noise perception; noise annoyance; noise sensitivity; quality of life.

1 Introduction

The most common effects of environmental noise exposure are noise annoyance and sleep disturbance [1-4]. Annoyance is used and promoted as a metric to guide policy development, but it is also a challenging metric to use because of its subjective nature [5, 6]. To this end, this study helps clarify what types of individual (composition) and environmental (context) characteristics affect levels of noise annoyance. Advancing knowledge on environmental noise effects is crucial to support the development of policies and reduce harmful effects of noise. It is an important challenge with a global scope: 125 million Europeans are exposed to levels of road traffic noise above those recommended by the World Health Organization, and noise is the most significant health threat after air pollution [7]; 40% of Australians are exposed to

* tor.oiamo@ryerson.ca
† dstefanova@ryerson.ca

harmful levels of traffic noise [8]; noise pollution is a foremost quality of life problem in New York City [9]; In Toronto, noise complaints increased by 312% for the period 2009-2015 [10]. Although the EU Noise Directive as well as national and local regulations around the world are good examples of progress, these are scattered efforts and within North America do not appear to have any notable impacts on reducing exposures.

Noise annoyance can be considered a health outcome of noise exposure but has more traditionally been considered as an indicator of wellbeing or a moderator of adverse health outcomes [11]. Noise annoyance is associated with disturbance, unpleasantness, and anger and can lead to aggressive behavior, fatigue, and negative emotions [12-14]. Other health effects include increased stress and associated effects on the cardiovascular system [15, 16], reduced cognitive performance among students [17], and general impairment of cognition and reduced mental health [18]. Laboratory-based experimental research on the effects of sounds on humans confirm the relationship between neuroendocrine responses and auditory stimuli [19]. Although biomedical research on noise has contributed to the current understanding of adverse health effects, there is still a limited understanding of how individual experiences modify these health effects [20].

There is a long history of research trying to understand the relationship between noise exposures and noise perception [21-24]. However, progress is challenged by the use of different metrics and methods for noise exposure assessment, as well as inconsistent measurements of noise annoyance and sensitivity. Although the equivalent sound pressure level (Leq) is the predominant predictor variable of annoyance, this method is not entirely satisfactory because annoyance has long been understood to be a strongly subjective factor [25]. It is not clear how noise sensitivity affects annoyance or how sensitivity is affected by acoustic or non-acoustic factors [26, 27]. Sensitivity may also be a group characteristic as Schomer et al. [26] found that different communities exposed to the same level of noise can exhibit varying levels of annoyance. Nonetheless, both acoustic and non-acoustic factors such as socio-economic status and attitudinal variables influence noise annoyance [28, 29]. Soundscape research on tranquility shows that in addition to noise levels, the presence of certain sound sources and visual elements are influential [30]. Taken together, these findings show that characteristics of sound (e.g. tone, temporal structure, and spectrum, etc.), individual characteristics (e.g. health, age, noise sensitivity), and socio-economic factors all play a role [13, 26, 31].

Built form and architectural design, arrangement, existence of open spaces, absorption characteristics of building materials, and shape can influence noise levels and perceptions. Silva et al. [32] examined ten types of built form and found that historic urban forms with their characteristics such as narrow streets, complex road networks, medium building height, and numerous intersections leads to lower traffic noise levels. In contrast, cities built after the introduction of cars and their characteristics of more space dedicated to roads and high-rise buildings generally produce higher levels of traffic noise [33]. Traffic noise is associated with a stressful sound environment and is one of the most clearly established predictors of annoyance. However, other types of transportation noise as well point sources of noise are also strong predictors of annoyance. This includes railway noise characterized by rail squeals and screeching as well as vibration. Licitra et al. [34] suggest that the effects of these sources can be underestimated in urban areas because they represent relatively high noise peaks and deviations from background levels. Interestingly, results of aggregated noise surveys show that the Ldn dose-response curve is flatter for railway noise and steeper for air traffic when compared to traffic noise, though these results do not consider the effects of noise peaks [23].

Conversely, sounds that signal a human presence like footsteps and voices along with natural sounds (e.g. bird song) are associated with a relaxing, positive sound environment [35, 36]. Echevarria Sanchez et al. [37] showed that geometrical street designs can reduce the street canyon effect and therefore, reduce negative noise perceptions for pedestrians and other affected population. To this end, vegetation can also be effective in absorbing and scattering sounds [38, 39]. Green space and vegetation are associated with reducing negative perceptions of sound, and therefore reducing noise annoyance [40, 41]. Furthermore, there is extensive literature showing the importance of green space and vegetation as therapeutic landscapes that contribute to physical and mental health and wellbeing [39, 42-44] .

There are multiple pathways between urban green space and health, including noise and air pollution buffering and reduced cardiovascular morbidity [39]. With such a profound effect on human health it can be expected that green space and vegetation are factors that influence noise annoyance. This study uses a novel study design to examine the influence of neighbourhood context and individual characteristics on noise perception. Binomial logistic regression modeling was utilized to examine the demographic, socio-economic, and health characteristics along with the built environment contribute to noise annoyance among residents in three distinct neighbourhoods of Toronto, Ontario, Canada.

2 Methods

2.1 Study area

Toronto is located along Lake Ontario in the southern part of Ontario, the most populous province in Canada. The city covers approximately 630.21 km2 and has a population of 2.7 million [45]. Toronto is the capital of Ontario and it is ranked the largest city in Canada by population. As such it is a global city, considered as one of the most multicultural and cosmopolitan cities worldwide. Toronto is characterized by urban forms commonly observed in other large cities throughout North America with high-rise buildings and high density in the downtown core and variety of residential builds and mixed land uses outside of the downtown. The study focused on three neighbourhoods located in the central business district, inner and outer suburbs of the city: (1) Trinity-Bellwoods, (2) Church-Yonge and Bay Corridor (referred to as Downtown), and (3) Banbury - Don Mills (referred to as Don Valley) (Figure 1). The three neighbourhoods were chosen to represent the diversity of built forms and environments commonly found in Toronto and other North American cities.

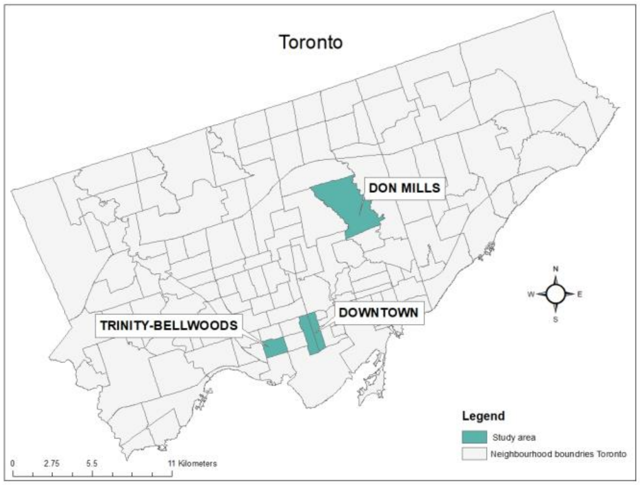

Figure 1: Location of neighbourhood study areas within the City of Toronto

Trinity-Bellwoods is an inner-city middle density neighbourhood where most residents live in semi-detached houses. The Downtown neighbourhood is adjacent to the central business district in the city, with mixed residential and commercial buildings of high density. Most of the residents live in high-rise condominiums, but fringes of the neighbourhood include low-rise buildings, detached and semi-detached houses. The Don Valley neighbourhood (Banbury - Don Mills) is a suburb originally developed as a master-planned community outside previous city boundaries with low density and high socioeconomic status. The majority of this area is residential with detached houses and a relatively dense tree canopy.

2.2 Neighbourhood noise survey

Residents were recruited by postcard invitations to complete an online survey instrument. Distribution of the postcards took place in July 2017, with approval of the recruitment and consent method as well as the survey instrument from the Ryerson University Research Ethics Board. Approximately 2000 households were targeted in each of the 3 neighbourhoods of interest. Survey participant addresses were georeferenced and linked to noise metrics to characterize their exposures. The survey was designed using ISO/TS 15666:2003 standard questions for assessment of environmental noise annoyance based on two questions: (1) Verbal rating scale with five answer options to the question "Thinking about the last 12 months or so, when you are here at home, how much does outdoor noise bother, disturb or annoy you?": "Not at all?; Slightly?; Moderately?; Very?; Extremely?" and (2) Numerical rating scale with 11 answer options to verify the consistency of the respondents answers: "What number from 0 (no disturbance) to 10 (intolerable disturbance) best represents how much you are annoyed by noise [at home]/[in the neighbourhood]?" [46]. In the questions with a 5-point verbal scale, an annoyance cut-off was used to evaluate high annoyance as responding "very" or "extremely" annoyed. In the questions with 11-point numerical scale, an annoyance cut-off of 7 and above was used to evaluate high annoyance. Questions on demographic and socioeconomic information were also included.

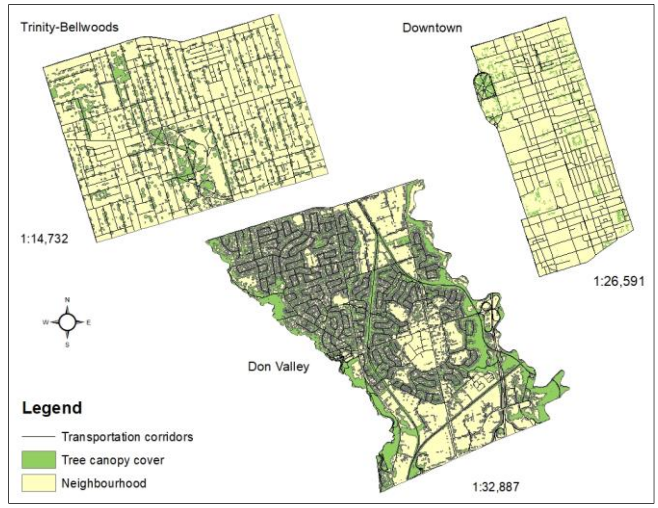

Figure 2: Sampling areas, road network, and tree canopy cover in the three neighbourhoods

2.3 Built environment and noise exposure variables

Noise data was collected during the summer of 2016 from 220 locations throughout Toronto. The sampling sites covered the entire city and were selected randomly or from candidate locations produced in a location-allocation model. Factors such as railways, road network and population densities were used to identify candidate locations. A one-week monitoring period per site was chosen to obtain an adequate representation of noise levels during different times of the weekday as well as weekends. Noise was measured using a Type 2 Noise Sentry RT sound level meter data logger (Convergence Instruments, Sherbrook, QC, Canada) at a sampling rate of 4 Hz and data integration of 1 Hz (Leq an LMax). Post-processing of data allowed development of all relevant metrics such as daytime, evening, nighttime, weekday, weekend, and weighted 24-hour equivalent sound pressure levels. Details on monitoring, modelling and model validation are described in Oiamo et al. [47].

In brief, two types of environmental noise models were developed and used for exposure assessment in the current study. This included (1) a traffic noise propagation model based on the United States Federal Highway Administration Traffic Noise Model (TNM2.5) standard assessed at building facades (Traffic (24h)), and (2) hybrid traffic noise propagation and land use regression models to represent total environmental noise, assessed at building facades (façade level Day/Night/24h) and street centrelines in front of respondent residences (street level Day/Night/24h). City of Toronto traffic survey data represented as the annual average daily traffic (AADT) volume of vehicles on all city streets were used in the traffic noise propagation model. Standardized traffic histograms were used to distribute AADTs by type of vehicle (light, medium and heavy), by time of day and for different road types. The propagation model included topography and three-dimensional building representations as it is well known that buildings can have a strong effect on sound acoustics [32]. The façade noise assessments were based on estimated levels on the loudest building façade. Noise exposures were categorized according to the lower threshold recommended by the WHO at 55dBA and 10 dB intervals [48]. Variables to represent neighbourhood greenspace and natural areas included the linear distance to the nearest part or natural area, tree canopy cover within 200m and 500m buffers, and area of parks within 200m and 500m buffers. Tree canopy cover was calculated from high resolution land cover data (30 cm) from the City of Toronto Open Data Catalogue. The buffers were chosen to correspond with WHO findings on health benefits of parks and green space within a 5 minute or maximum 15-minute walk [49]. The tree canopy cover around each participant's residence was divided into quartiles that represent the same number of residents exposed to each level of tree canopy near their residence and within each neighbourhood.

2.4 Analysis

Logistic regression is a commonly applied approach in socio-acoustic studies, where there is a mixed use of continuous and categorical variables. Logistic regression models can accommodate both categorical and continuous variables as predictors to understand their effect on a binary outcome variable, which in this case was to predict high levels of noise annoyance (HA) at home and in the neighbourhood. The final models included the following variables: Model 1 tested the differences in the three neighbourhoods; Model 2 added the demographic variables age and sex; Model 3 tested the effect of the socio-economic factors housing tenure (ownership), educational attainment (high school vs. post-secondary), and employment status (full-time vs. part-time/unemployment and student/ homemaker/ retiree); Model 4 controlled for noise sensitivity, self-reported general health status, and hearing problems; Model 5 controlled for neighbourhood greenspace as measured by tree canopy cover, and; Model 6a, 6b, and 6c tested the influence of day and night total noise levels and 24-hour traffic noise levels, respectively. The odds ratios (OR) estimated by the logistic regression are reported to represent the relationship between predictors and high annoyance at home and in the neighbourhood. All data processing and analyses were done with SPSS 24 (IBM, Armonk, NY, USA) and ArcGIS 10.4 (ESRI, Redlands, CA, USA).

3 Results

3.1 Sample characteristics & bivariate analysis

The study recruited 552 participants and the response rate based on the number of distributed postcards was 9%. The response rate in Downtown was higher than the other neighbourhoods and represented 66% of the sample (Table 1). The highest proportion of respondents in Trinity-Bellwoods were in the age category 35-54, while participants Downtown were predominantly aged 18-34 and 35-54. In Don Valley, most respondents were aged 55-75 (66%). The Downtown sub-sample had a higher proportion of males (60%) compared to Trinity-Bellwoods (63% female) and Don Valley (56% female). The proportion of respondents reporting their occupational status as full-time or self-employed ranged from 42% to 62%, while the remaining respondents reported a mix of different statuses, such as homemaker, retired, and student. However, a large proportion of respondents in Don Valley were retired and homemakers (45.9%). In all three neighbourhoods a high proportion of respondents had completed post-secondary schooling (87-89%) and reported a good or very good level of general health (36-43%).

Most residents Downtown rented their property (62%) but the reverse was the case for Trinity-Bellwoods (37%) and Don Valley (15%). Most participants in Trinity-Bellwoods lived in semi-detached houses, while 53% of Downtown participants lived in high-rise building, and the majority of residents in Don Valley lived in detached houses (72%). A lower proportion of the Downtown sub-sample reported being very sensitive to noise, but this difference was not significant (Table 1). Likewise, there were varying but non-significant differences in the proportion of residents reporting high noise annoyance at home. Conversely, there were significant differences in levels of high noise annoyance while in the neighbourhood around participant residences, with the highest percentages observed in Don Valley (36.5%) and Downtown (35.8%), compared to 20.4% in Trinity-Bellwoods. The noise exposure assessment showed that participants were exposed to façade daytime noise levels between 55-65 dB (Table 2). However, average façade levels at night in the Downtown study area was above the threshold of 55 dB, while participants in the other two neighbourhoods were below this threshold. Chi-square tests showed significant neighbourhood differences in the proportion of residents exposed to high levels of noise.

The differences in noise levels between the three neighbourhoods are also illustrated as continues variables in Table 3. Mean residential street level nighttime noise was similar in Trinity-Bellwoods (53.47 dB) and Don Valley (53.15 dB), but in Downtown the mean nighttime noise level was notably higher (64.38 dB). Similar results were observed with the other noise metrics. The continuous variable of green space showed that the mean tree canopy cover in Trinity-Bellwoods was 15%, comparable to 13% in Downtown, both of which were much lower than Don Valley at 45%. The range of categorical tree canopy cover value based on quartiles within each of the three neighbourhoods also showed notably higher levels in Don Valley, where residents in the highest quartile had more than 50% cover around their residence (Table 4).

3.2 Logistic regression on high annoyance at home

The regression models were based on self-reported levels of high annoyance (HA) as measured by the question "Thinking about the last 12 months or so, when you are here at home, how much does outdoor noise bother, disturb or annoy you?"

Table 1: Descriptive table of categorical variables and chi-squared tests for differences between the three neighbourhoods.

Variables		Neighbourhood Full Sample (n=552)	Trinity Bellwoods (n=98)	Downtown (n=369)	Don Valley (n=85)	Chi-Sq. (*p*-value.)
Age (%)	18-34	31.0	33.7	35.5	8.2	
	35-54	33.0	41.8	32.8	23.5	54.05
	55-75	33.5	22.4	29.0	65.9	(0.000)
	75 and above	2.5	2.0	2.7	2.4	
Gender (%)	Female	47.1	64.3	40.4	56.5	21.30
	Male	52.9	35.7	59.6	43.5	(0.000)
General Health (%)	Very Good/Excellent	93.8	94.9	93.0	96.5	1.71
	Poor/Fair/Good	6.2	5.1	7.0	3.5	(0.426)
Hearing problems (%)	No	81.5	79.6	81.8	82.4	0.31
	Yes	18.5	20.4	18.2	17.6	(0.858)
Noise induced hearing loss (%)	No	94.0	93.9	94.3	92.9	0.23
	Yes	6.0	6.1	5.7	7.1	(0.889)
Noise Sensitivity (%)	Not at all	42.9	42.9	43.9	38.8	3.22
	Moderately	36.6	32.7	37.7	36.5	(0.522)
	Very	20.5	24.5	18.4	24.7	
Education (%)	High school	12.0	10.2	12.2	12.9	0.38
	Higher Education	88.0	89.8	87.8	87.1	(0.825)
Employment (%)	Full-time Job	58.5	57.1	62.6	42.4	
	Part-time job/ Unemployed	10.7	18.4	8.4	11.8	20.12
	Student/Retired/Homemaker	30.8	24.5	29.0	45.9	(0.000)
HA at home (%)	Not Annoyed	67.4	79.6	64.2	67.1	8.32
	Highly Annoyed	32.6	20.4	35.8	32.9	(0.16)
HA in neighbourhood (%)	Not Annoyed	67.8	81.6	65.0	63.5	10.58
	Highly Annoyed	32.2	18.4	35.0	36.5	(0.005)

Table 2: Descriptive table of categorical variables of noise (dB) and chi-squared tests for differences between the three neighbourhoods.

		Neighbourhood Full sample (n=552)	Trinity-Bellwoods (n=98)	Downtown (n=369)	North West Don Valley (n=85)	Chi-Sq. (sign)
Facade level [Lday] (%)	< 55	3.4	7.1	2.7	2.4	68.02
	55 – 65	52.9	77.6	43.4	65.9	(0.000)
	65– 75	24.1	11.2	26.6	28.2	
	75 dB+	19.6	4.1	27.4	3.5	
Facade level [Lnight] (%)	< 55	37.3	81.6	16.5	76.5	212.63
	55- 65	28.8	12.2	35.5	18.8	(0.000)
	65 – 75	28.1	5.1	39.6	4.7	
	75 dB+	5.8	1.0	8.4	0.0	
Facade level [L24h] (%)	< 55	13.8	37.8	5.7	21.2	111.74
	55 – 65	48.2	52.0	45.0	57.6	(0.000)
	65 – 75	23.0	7.1	27.6	21.2	
	75 dB+	15.0	3.1	21.7	0.0	
Street level [night] (%)	< 55	34.6	80.6	11.4	82.4	269.44
	55 – 65	34.4	16.3	45.5	7.1	(0.000)
	65 – 75	22.5	2.0	30.6	10.6	
	75 dB+	8.5	1.0	12.5	0.0	
Street level [day] (%)	< 55	2.0	1.0	2.7	0.0	64.99
	55 - 65	55.6	81.6	44.2	75.3	(0.000)
	65 – 75	21.9	14.3	25.5	15.3	
	75 dB+	20.5	3.1	27.7	9.4	
Street level [24h] (%)	< 55	3.3	4.1	3.5	1.2	71.24
	55 – 65	58.5	83.7	46.6	81.2	(0.000)
	65 – 75	18.5	9.2	22.5	11.8	
	75 dB+	19.7	3.1	27.4	5.9	
Traffic [24h] (%)	<55	44.7	80.6	32.5	56.5	91.59
	55 – 65	28.8	16.3	31.2	32.9	(0.000)
	65 – 75	26.3	3.1	36.0	10.6	
	75 dB+	0.2	0.0	0.3	0.0	

Model 1 showed that without controlling for other covariates, residents in Downtown were 2.17 (p<0.01) times more likely to report high annoyance than residents in the Trinity-Bellwoods reference neighbourhood (Table 5). Compared to the age group 18-35, respondents aged 35-54 and 55-74 were significantly more likely to report HA. When controlling for socio-economic factors it was observed that homeowners were 1.90 (p<0.01) times more likely to report high annoyance at home, compared with people that rent their homes. Model 4 showed that people with high noise sensitivity were5.96 (p<0.001) times more likely to be highly annoyed than participants reporting no or low levels of noise sensitivity. Those who reported being somewhat sensitive had a 2.73 (p<0.001) higher likelihood of reporting high annoyance. When controlling for green space it was observed that participants with moderately low access to green space (3rd quartile) were 2.14 (p<0.01) times more likely to be highly annoyed when they are at home compared to those with high access to green space (4th quartile).

Table 3: Descriptive table of continuous variables of noise (dB) and green space for the three neighbourhoods and the full sample with F-test value and significance.

	Full Sample					Anova F (sig.)
	Mean	Median	St. Dev.	Min	Max	
Facade level [L24h]	64.0	62.2	8.4	45.6	82.2	78.50 (0.000)
Street level [24h]	65.5	62.7	7.7	50.0	83.4	46.24 (0.000)
Traffic [24h]	58.6	56.0	7.5	42.0	76.0	44.64 (0.00)
Facade level [Lday]	65.9	63.6	8.0	46.9	85.0	8.30 (0.000)
Street level [day]	66.5	63.7	7.6	43.5	85.0	35.59 (0.000)
Facade level [Lnight]	60.4	59.9	9.5	43.7	77.6	162.77 (0.000)
Street level [night]	60.7	58.8	9.1	40.5	82.3	132.27 (0.000)
Tree Canopy in 500m	0.18	0.14	0.12	0.02	0.55	1007.13 (0.000)
	Trinity-Bellwoods					
Facade level [L24h]	57.6	56.3	5.9	49.7	82.1	
Street level [24h]	60.4	59.4	5.1	53.5	83.3	
Traffic [24h]	53.2	52.0	5.0	47.0	75.0	
Facade level [Lday]	60.5	59.0	5.9	51.9	85.0	
Street level [day]	61.9	60.8	5.1	54.9	84.8	
Facade level [Lnight]	52.4	50.8	6.2	44.7	76.0	
Street level [night]	53.5	52.3	5.0	46.9	76.3	
Tree Canopy in 500m	0.15	0.15	0.04	0.06	0.22	
	Downtown					
Facade level [L24h]	66.7	64.8	8.1	45.6	79.6	
Street level [24h]	67.5	64.6	7.8	50.0	83.4	
Traffic [24h]	60.4	58.0	7.7	42.0	76.0	
Facade level [Lday]	68.1	66.1	8.1	46.9	81.6	
Street level [day]	68.2	66.1	7.9	43.5	85.0	
Facade level [Lnight]	64.5	64.2	8.1	48.1	77.6	
Street level [night]	64.4	62.2	8.3	40.4	82.3	
Tree Canopy in 500m	0.13	0.12	0.06	0.02	0.27	
	Don Valley					
Facade level [L24h]	59.3	57.2	5.8	51.0	72.8	
Street level [24h]	62.6	60.7	5.5	53.6	80.2	
Traffic [24h]	56.9	55.0	5.9	47.0	75.0	
Facade level [Lday]	63.1	61.1	5.6	54.8	75.8	
Street level [day]	64.3	62.4	5.5	55.2	81.9	
Facade level [Lnight]	52.0	49.4	6.3	43.7	66.1	
Street level [night]	53.1	51.3	6.2	44.6	72.6	
Tree Canopy in 500m	0.45	0.46	0.08	0.21	0.55	

Table 4: Descriptive table of Tree Canopy Cover ratio in 500 m variable split into 4 quartiles for each of the three neighbourhoods.

Tree Canopy Cover (500m)	Trinity-Bellwoods	Downtown	Don Valley
1st quartile	<= 0.11	<= 0.09	<= 0.42
2nd quartile	0.11 - 0.15	0.09 - 0.12	0.42 -0 .46
3rd quartile	0.15 - 0.16	0.12- 0.18	0.46 - 0.50
4th quartile	0.16+	0.18+	0.50+

The effects of different noise variables on HA were tested separately in Model 6. The results showed that there was no significant effect on noise annoyance at home from daytime or 24-hour noise levels. However, nighttime noise levels were a significant predictor for HA. Residents exposed to levels between 55 to 65 dB were 2.76 ($p<0.01$) times more likely to be highly annoyed than those exposed to levels below 55 dB. Those exposed to levels above 75 dB were 3.78 ($p<0.01$) times more likely to report high annoyance. When controlling for nighttime noise levels the effect of residing in the Downtown neighbourhood disappeared and the effect of tree canopy cover was reduced.

3.3 Logistic regression on high annoyance in the neighborhood

Interesting differences were observed for HA at home versus in the neighbourhood. Residents in both Downtow and Don Valley sub-samples were 2.39 ($p<0.01$) and 2.55 ($p<0.05$) more likely to report HA in the neighbourhood than participants in Trinity-Bellwoods (Table 6). However, the effects of residing in Don Valley disappeared in Model 2, suggesting that differences in neighbourhood demographics influenced responses to environmental noise. Similar to the logistic regression analysis of high annoyance at home, respondents aged 35-74 and with high noise sensitivity were also more likely to report high annoyance in the neighbourhood. Tree canopy cover was significant as a predictor for high annoyance. It was observed that residents in the lowest quartile were not more annoyed compared with those with the highest access to tree canopy cover, while residents in the 2nd and 3rd quartile were more likely to report high annoyance. When controlling for tree canopy cover there was a shift in the neighbourhood significance as a predictor for high annoyance. The effect of residing in Downtown increased to 2.47 ($p<0.01$), and Don Valley had an increased likelihood of high annoyance 2.31 ($p<0.05$) times higher than Trinity-Bellwoods. The significance of Don Valley remained when con-

Table 5: Logistic regression model odds ratios for effects on noise annoyance at home.

Parameter estimates	FULL SAMPLE							
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6a Lday	Model 6b Lnight	Model 6c L24h
(Reference: Trinity)								
Downtown	2.17**	2.25**	1.85**	1.98**	2.14*	2.34**	1.12	2.28**
Don Valley	1.92	1.43	1.47	1.51	1.62	1.66	1.68	1.62
Age (*Reference: 18-34*)								
35-54		2.40***	3.16***	3.34***	3.50***	3.53***	3.58***	3.46***
55-74		3.11***	3.69***	3.62***	3.55***	3.61***	3.58***	3.53***
75 and above		1.64	1.49	1.27	1.26	1.23	1.34	1.24
Sex *(Reference: Female)*		0.98	0.95	1.12	1.07	1.03	1.08	1.06
Housing tenure (*Reference: Owner)*			1.90**	1.90**	1.85**	1.94**	1.63*	1.86**
Noise Sensitivity (*Reference: Not Sensitive*)				***	***	***	***	***
Somewhat sensitive				2.73***	2.80***	2.73***	3.15***	2.85***
Highly sensitive				5.96***	6.15***	6.06***	6.96***	6.31***
Tree Canopy in 500m (*Reference: Q4)*						*	*	*
Quartile 1					1.45	1.53	1.23	1.54
Quartile 2					1.77	1.91*	1.62	1.87*
Quartile 3					2.14**	2.34**	1.94*	2.33**
Noise (*Reference: below 55dBA)*							*	
55-65 dB						2.75	2.76**	2.30
65-75 dB						2.03	2.20*	1.75
>75 dB						2.62	3.78**	2.29
Hosmer & Lemeshow $\chi 2$ (df), significance	0.00(1), 1.00	7.41(8), 0.49	6.14(8), 0.63	11.73(8) 0.16	6.01(8), 0.65	2.49(8), 0.96	4.20(8), 0.84	2.13(8), 0.98
Nagelkerke R2	0.02	0.08	0.11	0.22	0.24	0.25	0.26	0.25

p<0.1, *p<0.05, **p<0.01, ***p<0.00

trolling for each noise variable.

The results from the logistic regression model on high annoyance in the neighbourhood showed that nighttime noise levels were still a strong predictor for high annoyance. Residents exposed to 55 to 65 dB were 2.35 ($p<0.05$) times more likely to report high annoyance compared with those exposed to below 55 dB. Furthermore, when controlling for nighttime noise levels the effect of Downtown disappeared, but for Trinity-Bellwoods slightly increased. Residents in Don Valley were 2.35 times more likely to be highly annoyed compared with the residents in Trinity-Bellwoods. A notable increase of the likelihood of high neighbourhood noise annoyance with an increase of 24h noise levels was also observed. Those exposed to 55 – 65 dB were 5.97 ($p<0.05$) times more likely to report high annoyance compared to those exposed to below 55 dB. Furthermore, those exposed to 65-75 dB were 6.29 ($p<0.05$) times more likely to be highly annoyed. Removing the neighbourhood covariate increased the effect of noise, but did not change the effect of other covariates.

Table 6: Logistic regression model odds ratios for effects on noise annoyance in the neighbourhood.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6a Lday	Model 6b Lnight	Model 6c L24h
(Reference: Trinity)								
Downtown	2.39**	2.46**	2.06*	2.22*	2.47**	2.61**	1.47	2.70**
Don Valley	2.55**	1.87	1.92	2.08	2.31*	2.33*	2.35*	2.32*
Age (*Reference: 18-34*)		***	***	***				
35-54		2.29**	2.82***	2.81***	2.97***	3.02***	3.01***	3.01***
55-74		3.22***	3.94***	3.60***	3.50***	3.55***	3.51***	3.46***
75 and above		1.67	1.75	1.40	1.39	1.33	1.50	1.32
Sex *(Reference: Female)*		0.98	0.96	1.08	1.03	1.01	1.05	1.03
Housing tenure (*Reference: Owners)*			1.73*	1.69**	1.62*	1.64*	1.43	1.56
Noise Sensitivity (*Reference: Not Sensitive*)				***	***	***	***	***
Somewhat sensitive				3.26***	3.43***	3.34***	3.74***	3.54***
Highly sensitive				5.72***	6.07***	6.17***	6.66***	6.43***
Tree Canopy in 500m (*Reference: Quartile 4)*					**	**	*	*
Quartile 1					1.43	1.54	1.22	1.57
Quartile 2					1.88*	1.88*	1.74	1.82
Quartile 3					2.52**	2.64**	2.40**	2.78***
Noise (*Reference: below 55dBA)*								
55-65 dB						5.35	2.35*	5.97*
65-75 dB						5.84	2.10*	6.29*
> 75 dB						5.02	2.16	5.12
Hosmer & Lemeshow χ2 (df), significance	0.00 (1), 1.00	10.08(8), 0.26	5.83(8), 0.67	14.21(8), 0.08	6.91(8), 0.55	5.13(8), 0.70	3.66(8), 0.89	9.40(8), 0.31
Nagelkerke R2	0.03	0.08	0.11	0.23	0.25	0.26	0.26	0.26

$p<0.1$, $*p<0.05$, $**p<0.01$, $***p<0.001$

4 Discussion

The goal of this study was to better understand levels of noise annoyance and its distribution in Toronto, the role of neighbourhood context and composition versus environmental noise exposures. Michaud et al. [5] reported that 6.7% of all participants in a national survey in Canada were highly annoyed by road traffic noise. This study found that 32% of the full sample reported high noise annoyance. Interestingly, participants in Downtown and Don Valley had similar levels of noise annoyance despite notable differences in noise exposure. This confirmed that noise exposure cannot solely predict noise annoyance. This study found that other predictors of noise annoyance include socioeconomic characteristics, the built environment, green space, noise sensitivity and nighttime noise levels. Our findings also suggest that nighttime noise is an important predictor of noise annoyance even among people that may be 'desensitized' by living in noisy environments.

Noise sensitivity in the Downtown neighbourhood (18%) was lower than the other two neighbourhoods. In Downtown Toronto, gentrification and attraction to a central location are strong influences on residential preference. Naturally, central locations are associated with higher noise levels due to a high concentration of commercial, and cultural and recreational activities [29]. It is unclear whether lower sensitivity reduces vulnerability to adverse health effects from noise, but this study showed that despite the relatively low level of noise sensitivity in Downtown Toronto, residents of this neighbourhood were still highly annoyed by traffic noise. Considering noise annoyance as a stress response that can lead to more severe health outcomes, our findings further compels the targeted reduction of nighttime noise as a priority for reducing adverse health outcomes. Noise sensitivity has been largely ignored in various epidemiological and biomedical research on noise and health due to its complexity as a non-unified concept [31, 50, 51]. Nevertheless, several studies have investigated the relationship of noise sensitivity and health [1, 52-54]. Shepherd et al. [54] investigated the relationship between environmental noise and health-related quality of life (HRQOL) in Auckland, New Zealand and found that annoyance and sleep disruption are mediators of noise sensitivity. As such, noise annoyance and sensitivity might degrade HRQOL and compromise sustainable development during the unprecedented growth and densification of Toronto and cities undergoing similar transformations elsewhere.

Observed differences in neighbourhood sensitivity may be partially attributed to differences in built form and residential densities in the study neighbourhoods [33, 37, 41]. The Downtown area is associated with more constant background noise from commercial traffic, large HVAC systems and entertainment activities, which are exaggerated by the street canyon effect of dense and high-rise buildings [55]. In contrast, Don Valley's built form is predominantly low density residential, lacking the "hum" of the busy Downtown streets. Detached and low-density housing combined with more tree canopy cover creates a different sonic and visual environment in Don Valley, further differentiated by different noise sources such as landscaping equipment, residential HVAC, and other machinery. In this environment, peak noise events such as emergency vehicles or air traffic are more noticeable. The reaction to these peak noise events may contribute to elevated noise annoyance and higher sensitivity, despite the relatively low noise levels. Further, factors such as the type of buildings and the quality of their envelope, infrastructure, and floor of occupation might be influential to individual's noise sensitivity and annoyance, however the tests of these variables in the current study did not show significance.

Miedema and Vos [51] suggest that noise sensitivity might be related to a general environmental dissatisfaction and greater concern for environmental problems. The Don Valley neighbourhood can be characterized as a neighbourhood with high environmental quality (e.g. access to green space; low crime). This study suggests that expectations of environmental quality rather than a general environmental dissatisfaction can moderate noise perceptions in high-income neighbourhoods. Access to greenspace and tree canopy cover are often associated with higher property values [56-58]. Although access to greenspace did not correspond to lower annoyance between neighbourhoods, we observed that lower tree canopy cover within neighbourhoods increased the likelihood of noise annoyance. Gidlöf-Gunnarsson and Öhrström, [59] found that greater availability to green space of residents of Stockholm was related to reduced long-term noise annoyance. Our study confirms these results within neighbourhoods in Toronto, but also shows that overall neighbourhood levels of noise annoyance are subject to group perceptions. The findings in this study suggest that there is a threshold of green space above which people develop an expectation of the environment and are more likely to exhibit noise sensitivity report high annoyance from noise.

Previous research shows that annoyance is reduced in environments where expectations are congruent with the observed soundscape. Using noise surveys and subjective appraisals of three urban parks in Naples, Italy, Brambilla and Maffei [60] observed that participants' expectations of a particular soundscape in a specific environment influences their annoyance. To this end, the use of equivalent sound pressure level metrics may conceal nuanced differences between soundscapes that influence annoyance. Although equivalent sound pressure levels are the most common noise metrics, their use has been criticized because of the limitation on exposure assessment [61-63]. Equivalent sound pressure levels provide information on loudness, but do not identify different types of sound, which may lead to an incomplete understanding what type of noise exposure a community is experiencing [26]. Factors such as irregular intervals of sound exposures and distinct sounds can affect individuals' noise perception.

5 Conclusion

This study observed alarmingly high levels of noise annoyance in three differing neighbourhoods of Toronto, levels of annoyance that far exceed national trends in Canada [64]. While we observed a significant effect of nighttime noise levels, we also observed high levels of noise annoyance in a neighborhood with high income and access to green space, and relatively low nighttime noise levels, likely influenced by individual soundscape expectations. Extending previous research, the findings suggest that high environmental quality might be related to high expectations for quietness. The study was limited by use of the loudness noise metric, as well as sample size and potential self-selection bias among participants. Nonetheless, the results warrant explicit consideration of shared neighbourhood perception of noise and environmental expectations in future research on noise perception. None of the neighbourhoods in the current study were located near airports or flightpaths, or contained railways, and since noise exposures were limited to sound pressure levels the study was not able to consider the potential effects of noise source mixture and diversity. Future research should therefore also focus on understanding how these factors may affect shared neighbourhood perceptions of environmental noise

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THE MEANU: UNIVERSITY-OF-ALBERTA ACOUSTICAL LABORATORY

Corjan Buma, M.Sc., P.Eng. *[1]
[1]Department of Mechanical Engineering, University of Alberta, Edmonton

Résumé

Le MEANU est un laboratoire d'acoustique relevant de l'Université de l'Alberta qui permet d'effectuer des essais commerciaux sur des produits et assemblages communément utilisés en construction au Canada, et pour d'éventuellement de la recherche.

Mots clefs : MEANU, Université de l'Alberta, Laboratoire d'acoustique

Abstract

The MEANU is an acoustical laboratory under the University of Alberta that provides capability for commercial testing of products and assemblies commonly used in construction in Canada and for possible research.

Keywords: MEANU, University of Alberta, Acoustics Lab

1 Introduction

The MEANU is a unique entity on the Canadian acoustical landscape. The **M**echanical **E**ngineering **A**coustics and **N**oise **U**nit ("MEANU") encompasses two Reverberation Chambers (310 m^3 and 227m^3) and typical supporting infrastructure. It is an off-Campus Lab under Mechanical Engineering of the University of Alberta (Edmonton). Primarily, it currently is used for commercial testing, though it has the capability for research. The following provides a brief description of facility history, test chambers and an overview of typical current testing projects.

2 History

The MEANU was founded in the early-1970's by Eugene Bolstad, P.Eng. The vision was that the facility would serve as home-base to a full-service acoustical company, including acoustical consulting, product testing and research. It operated as such for just over a decade, at which point, in the wake of a changing marketplace, the MEANU became an asset of the University of Alberta. The "ribbon-cutting" as a University facility was done with then (federal) Minister of State for Science and Technology, the Honorable Tom Siddon, himself trained as an acoustics researcher.

The deployment as a Mechanical Engineering asset was facilitated and overseen by lead researchers in acoustics and vibration Gary Faulkner (Ph.D.) and Tony Craggs (Ph.D.). Gerald ("Gerry") Kiss, P. Eng., was the Research Associate in charge of managing project work, developing testing procedures in accordance with ASTM (and other) standards, and maintaining and upgrading equipment. Gerry was a member of the ASTM Technical Committee responsible for several of the standards that form the core of current MEANU testing. Thus, he developed customized testing software that exactly tracked with the requirements of the standards; Gerry "had a passion" for measurement accuracy. He was honoured by local colleagues in late-1999 for his work and, unfortunately, passed away in early-2000. His legacy lives on in current MEANU-work as well as his contributions to international standards.

The present author was invited by Mechanical Engineering to continue MEANU work as of Spring 2000.

3 Facility Description

The primary testing feature of the MEANU is its reverberation-chamber suite. This consists of two chambers, built as two independent rooms, each constructed of concrete block (floor is smooth concrete, unpainted; ceiling/roof is pre-cast concrete planks). The shared wall between the Chambers is comprised of the two block walls which are sand-filled, set 100m apart and with this gap filled with fibrous insulation. A sound-intensity test of this assembly indicated an STC-rating in the range of STC-70. On the shared wall between the two Chambers there is a wood-framed test opening 2.7m wide by 2.4m high (nominal) on the Small-Chamber wall and steel-framed on Large-Chamber side. The only physical connection between the two Chambers is a thin strip of lead flashing bridging the 100mm gap.

For some types of testing a "plug-wall" is inserted into the Test Opening (from Large Chamber) so as to acoustically segregate the Chambers. The plug-wall, comprised of a steel surround frame and supporting 11 layers of drywall, is moved by means of a custom designed-and-built wheeled gantry. Both Chambers are equipped with "acoustical doors", whose ratings are in the range of STC-50.

The Chambers are each equipped with a set of curved plywood diffusers which are hung at random angles so as to aid with sound diffusion.

* meanu@ualberta.ca

4 Typical Project Work

In the "early years" as a University facility various student projects based at the MEANU facilitated in the granting of advanced degrees. Since retirement of both lead researchers this has become infrequent.

The majority of current MEANU project work consists of commercial testing in accordance with ASTM test procedures E90 (for the derivation of sound transmission loss) and C423 (for the quantifying of sound absorption), with occasional requests for noise isolation and/or insertion loss (per ASTM E596). Results can also be generated per the corresponding ISO standards.

A sampling of the types of products/assemblies tested include: (per ASTM E90) glazing assemblies (with or without framing), a wide variety of wall assemblies including insulated metal (especially for the petro-chemical sector), foam-based walls, multi-element modular (wood/insulated), concrete-block, hemp-block, various types of demountable walls, roadside barriers comprised of (among others) poly-vinyl, recycled poly-ethylene, compressed rubber-crumb, heavy wood planking, and sand+soil-filled bags; (per ASTM C423) stage curtains, sport/recreation-facility ceiling baffles and wall panelling, felt baffles/panels, vinyl planking, plywood, acoustical-foam, perforated-metal panels, among others. It is not uncommon with smaller-sized specimens submitted for E90-testing that part of the Test Opening is filled with a portion of Filler Wall (whose STC-rating is more than 10 STC points above that anticipated for the test specimen). For C423-testing most commonly the specimen is either an 8ft-by-9ft specimen laid in the A-mounting (on Small Chamber floor) at a diagonal to the Chamber's cardinal dimensions and with its outer perimeter blocked-and-sealed OR suspended in various "baffle" configurations from a set of cables strung diagonally across the test Chamber. Though much less common, large-scale specimens can be tested in the Large Reverberation Chamber (for C423 testing) and alternate mountings (per ASTM E795) can be accommodated in either Chamber.

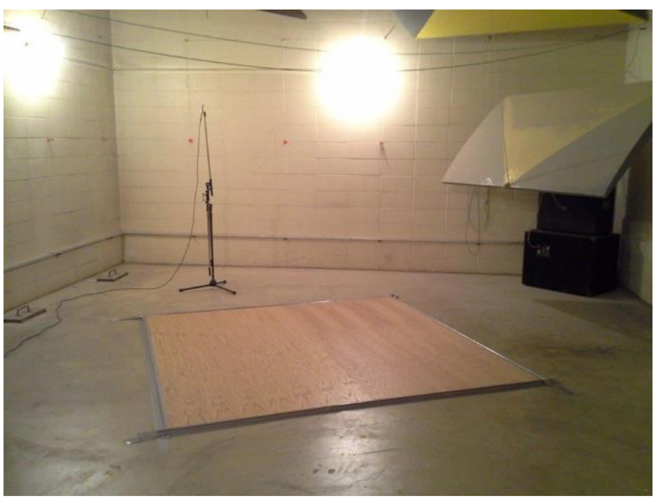

Figure 1: Specimen prepared for ASTM C423 testing.

Figure 2 : Window Specimen prepared for STC-testing, showing Filler Wall above Specimen

5 Closing

Lastly, as an entity within the University of Alberta, the MEANU has recently become part of the Sound Studies Initiative ("SSI"), a forum that facilitates collaboration between any-and-all researchers at U-of-A engaged in some aspect of research involving SOUND. A link to the MEANU web-page can be found on the SSI web-page: [soundstudies.ualberta.ca] .

Acknowledgment

MEANU work continues thanks to those who followed through with their original vision (named above) and current University leadership, and with thanks to Clientele who continue to support it through on-going project–work.


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Canadian Acoustical Association

Minutes of the Board of Directors Meeting

Thursday, April 30th, 2020 2:00 PM – 4:30 PM (EDT)
Zoom video conference

1. Call to Order

Meeting called to order 14:03 (EDT)

Present in room: Jérémie Voix (chair), Alberto Behar, Umberto Berardi, Bill Gastmeier, Bryan Gick, Dalila Giusti, Andy Metelka, Hugues Nélisse, Roberto Racca, Joana Rocha, Frank Russo, Mehrzad Salkhordeh, Benjamin Tucker.
Regrets: Michael Kiefte
Guest: Romain Dumoulin, Olivier Robin.

Agenda approved: Moved by Jérémie, seconded by Dalila.

2. President's Report (Jérémie)

The Online Journal System (OJS) portal, which gives digital access to Canadian Acoustics and provides online management of memberships, has undergone major server upgrades; regrettably, this has led to problems with purchases of new memberships. A new version of OJS (v 3.2) is due to be rolled out soon, which will improve the access experience but will not address the purchasing bug which is being investigated separately.

New ways are being sought to recognize and enhance the impact and societal relevance of the journal to its readership under the terms of the Declaration of Research Assessment that the Association has endorsed. On that note a Task Force Group has been working on an article based on a survey of the Association's membership with special focus on sustaining organizations, now being finalized to be published in an upcoming issue of the journal.
Canada Wide Science Fair – The Board deemed not financially feasible to support a booth at this annual event, unless a local university can run it as will be the case in 2020 for Edmonton with Prof. Tucker.

The position of Standards Committee coordinator is vacant since the recent passing of the much missed colleague Tim Kelsall. Alberto Behar has been volunteering in the interim, but the torch has now to be passed to a new coordinator yet to be identified.

The ISO TC43 international standards committee for acoustics has been seeking a North American venue for its Spring 2023 plenary meeting, a large event. Montréal has been proposed as the host city and a small organizing committee has been formed; the CAA can benefit from participating in some official form in this important gathering.

The current restrictions on travel and large in-person gatherings imposed by the COVID-19 pandemic may require considering a virtual format for the next Acoustics Week in Canada annual conference (to be discussed as a later agenda item), but interesting new concepts being developed for Virtual Reality gatherings could warrant holding such events as a complementary feature also farther into the future. Jérémie is exploring a range of current and emerging solutions and techniques that could even provide a VR equivalent of the social interactions and side conversations that are part of the fabric of an in-person congress.

In discussion of the previous point, Frank mentioned that a trial experience the previous year of a virtual meeting of an international society had an overall negative impact, especially because it had not been generally felt as a necessity. The meeting had been organized with a hybrid format in which delegates had gathered physically in four cities around the world with virtual links between them; this had generated a negative reaction that could even affect future meetings and membership or the organization. Jérémie pointed to an online resource that lists technologies and discusses experiences for holding successful virtual events

Dalila raised the point of what to do with the online registration bug and problems with membership associated with it. Jérémie indicated that internal volunteer resources may not be sufficient to address the issue and it may be necessary to engage an expert to correct the problem and potentially to recode the payment module. A contingency budget allocation of 2500$ to cover this eventuality would be requested in the later discussion of finances.

Jérémie asked for suggestions of potential candidates to fill the volunteer position of standards coordinator, noting that a description of the role and call for interest had been posted on the web site. Mehrzad said he would contact a person he had in mind to and might be interested; Jérémie also suggested contacting the people currently involved in convening the 2023 ISO TC43 plenary meeting in Canada. An Action item was raised for Jérémie to provide further information on the role to Mehrzad and to approach the TC43 organizing committee members. Jérémie also noted the importance of having people mentored in essential roles such as standards coordinator to ensure continuity.

3. Past and Upcoming Meetings

AWC 2019 – Edmonton: (Jérémie for Ben Tucker, AWC 2019 chair)

- A comprehensive summary report for the conference was published in the December issue of Canadian Acoustics; the conference did well in attracting both delegates and exhibitors or sponsors. Jérémie complimented Ben to the Board for a well-organized and successful event.

- Dalila as CAA treasurer would still need to do a final review of the financials but based on submitted numbers the conference was profitable for the Association.

AWC 2020 – Sherbrooke: (guest Olivier Robin, AWC 2020 chair)

- Olivier stressed the difficulty to assess at that time whether the meeting could go ahead as planned. Before the COVID-19 pandemic struck, preparations were well underway on both the technical and social fronts, with venues identified and activities planned. Clearly all that had changed very rapidly.

- He outlined three options that his organizing committee had originally identified and considered:
    - Keep the conference as planned, hoping that the pandemic would have subsided by the autumn.
    - Postpone by a couple of months to give more time for the situation to return more normal.
    - Transform the event to an entirely virtual conference.

The committee saw the e-conference option as a potential opportunity but had concerns about their readiness and capability to set up such a new format and doubts about how well it would be received. Olivier then outlined another two options more recently considered in discussion with Jérémie and others:

- A hybrid solution with physical gatherings at local hubs that would also give greater opportunity to more students across the country to be involved, combined with digital feeds between the hubs. A corollary would be to stream live video of the presentations during the conference but also make a recording available after the event for a smaller fee than registration. Olivier stressed the opportunities that a flexible hybrid format could offer also for future events in normal circumstances.
- Lastly, a full cancelling of AWC 2020 and return to the conventional scheduling and organizing of the event for autumn 2021.

- Olivier noted that regardless of when and in what format the next AWC would take place, a special topic session should be added to the program about the repercussions of the pandemic from an acoustics standpoint.

- Considerable discussion took place among the participants, in which numerous points were raised and opinions voiced. In summary a few key ideas emerged:
    - It appeared unlikely that in October 2020 conditions would be back to normal, also considering the risk of a resurgence of cases in a second wave of the pandemic and the responsibility to the membership to provide a safe environment for a meeting.
    - Although some members raised the possibility that a breakthrough in the management of the pandemic might still enable a physical event to take place in 2020, it was clear that a cancellation would have to be decided soon, before any contractual commitments could result in costly penalties. Olivier noted that Sherbrooke university planned to reopen in the fall and have administration and faculty work as usual, but with the contingency on the ready to go to virtual teaching.
    - Transitioning AWC 2020 to e-format in the short time available was generally seen as unfeasible, and Board members expressed doubts that the feel of the event could be captured suitably in a virtual environment.

- o Various concepts were suggested for holding in place of the 2020 conference some combination of one-day local events and a digital sharing platform so that the annual occasion of the Canadian acoustics community to come together would still be preserved.
- o Board members representing companies that regularly sponsor and exhibit at AWC stated the view, also in terms of future events, that virtual solutions would not work as platforms for personal contacts with clients and demonstration of products and services. They thought that although their own companies would remain supportive of any initiative proposed by the association, other more "conventional" exhibitors would shun a non-physical event.

- The unanimous decision of the Board was to cancel AWC 2020 and focus on finalizing as soon as possible the choice of dates and venue for AWC 2021 given that many other conferences were being rescheduled to that year and people's calendars would likely be uncommonly busy. It was agreed that a discussion of alternative community events to hold around the time of AWC 2020 would take place separately through e-mails and online meetings, led by the few Board members who had expressed specific ideas in the discussion.

<u>AWC 2021 – St-John's:</u>

- Jérémie and Dalila indicated that conveners Benjamin Zendel and Len Zedel had already made some key decisions regarding venue and basic infrastructure. It would be important therefore to determine soon in consultation with the respective organizers on whether to have a leapfrogging of Sherbrooke to 2022 or a linear shift of Sherbrooke to 2021 and St. John's to 2022.

- An Action Item was raised for Jérémie and Frank to call a meeting with the conveners of AWC 2020 and 2021 to address this matter.

<u>AWC 2022 – Ottawa?:</u>

- Jérémie noted that at the 2019 conference Joana Rocha had informally expressed interest in hosting the event for 2022.

- Joana indicated that she had not given any thought yet to the organizing, but she would be open for a 2023 possibility under the current circumstances.

<u>AWC 2023 – ?:</u>

- No proposals have been made, but Jérémie remarked that at the 2019 conference there had been talk of bringing the event back west and possibly to an alternative locality like the Okanagan valley.

- With the current reshuffling, of course, Ottawa might become the 2023 venue.

<u>ISO TC43 – Montréal 2023:</u> (Jérémie)

- Jérémie provided some additional detail on that event that he had mentioned earlier, noting that it would bring together a large and diverse global community of delegates. Canada had been chosen as the ideal host country on the North-Central American continent because it did not preclude access to some ISO member countries as the USA would have.

- Both Toronto and Montréal had expressed interest; the latter was selected, and all is currently on course to host the event in spring of 2023.

<u>AWC 2024 – Toronto?:</u>

- Umberto Berardi has expressed interest in convening that event, but no specific plans have been made at this time.

4. Treasurer's Report (Dalida)

Dalila had submitted ahead of time the report for the Board's review and only gave a rapid overview of key points. Financial statements had been completed and taxes had been filed. Dalila noted that the financial position of the company as of 2019 remained strong with few changes from the previous year, though the exact yield of investments would only be known with some lag and their future performance given the economic downturn from the pandemic could not be foreseen.

The exact revenue from the 2019 conference was not yet finalized but the event had turned a modest net profit in the order of a few thousand dollars. Due to the decision made in view of the pandemic, 2020 would now be a calm year with no conference related financial activities. Dalila remarked that unpaid receivables had been accruing for the advertising income from the journal, and payments would have to be pursued with some zeal.

The full budget and financial forecast would be presented for approval, as customary, at the autumn Board meeting. Dalila noted that she would include in the expenditures the $2500 requested by Jérémie to deal with the ongoing bug in the online membership system.

Motion to adopt the report was made by Dalila, seconded by Roberto.

5. Secretary's Report (Roberto)

Roberto began his verbal account noting that he had only circulated to Board members at the last minute a version of his written report with the current numbers for membership and subscriptions, as he had been working with the journal circulation team to ensure that the database tallying scripts had identified correctly the most recent updates. That notwithstanding, the latest numbers showed a drop in regular membership by over 25% year on year (on a basis of around 150) though the number of student members had increased since the last reporting; a few sustaining subscribers had also not renewed. A plausible reason from information just acquired was that notification emails sent automatically were reportedly not being received (a fact confirmed by various Board members), resulting in numerous people being unaware of their membership's lapsing.

Roberto noted that under the circumstances there would be little point in speculating on ulterior causes for the drop in numbers, and effort should be focused on reaching out with reminders to all recently lapsed members and subscribers. He pointed out that his practice of reaching out to sustaining subscribers upon every renewal with a grateful acknowledgement and offer of assistance with setting up their networked access to the journal had not changed, nor his best effort to ensure that any member experiencing technical issues with their renewal or access to the journal would be looked after. He also noted that the ongoing glitch with the payment system not enabling new members to complete the process might be taking a toll on the rate of new adhesions, as possibly only a small proportion would be contacting him directly for assistance compared to those who would just abandon the process or perhaps think that they had in fact registered and would be billed later.

Roberto also noted the still ongoing problem with indirect subscriptions to the journal (taken out through subscription agencies) that because of inefficiencies in the current renewal process with emailed instructions and offline payments often result in missed mailing of issues around the renewal time. He recommended that an improved process be considered, if possible, whereby subscription agencies would be able to renew online on behalf of their client institutions thereby avoiding delays and billing issues. A corollary to this would be a revisiting of the pricing structure currently in place for indirect subscriptions which had not been reviewed for years.

In discussion of these matters, the following Action Items were raised:

- Jérémie would identify in the database both recently lapsed members and new users who had not completed their membership registration for follow-up with targeted mailings, to attempt rebuilding the numbers lost to technical issues. On a related note, the matter of automated notification emails not reaching their recipients would be investigated and addressed, including efforts to increase the trust index of emails in the common heuristics of spam filtering.

- A small task group including Roberto, Dalila, Jérémie and Umberto (editor in chief of the journal) would revisit current policies regarding indirect subscribers with the aim to determine suitable pricing, enable if possible direct renewals online, and examine whether the option of providing online access to the journal site to all the members for example of a foreign institute of higher learning might not be superior to the current physical mailing of a copy of the journal to their library. On that note, the possibility of offering a digital-only option to the general membership was again raised for consideration.

- A further effort would be made to reach out individually to sustaining subscribers both current and lapsed to identify how they could be better engaged, to ensure that their contribution would be properly recognized (e.g. ensuring that all their contact information would be accurately and promptly reflected on the Association's web site).

6. Awards Coordinator's Report (Joana)

Joana noted that the deadline for award applications had just passed so she only had partial information, as not all coordinators of individual prizes had reported in yet. There had been no applicants for the Shaw postdoctoral award, the Fessenden Student

Prize in Underwater Acoustics, or the Bregman Student Prize in Psychological Acoustics, two applicants for the Eckel Student Prize in Noise Control, and one entrant each for the other named awards.

The point was raised, and discussion followed, on the matter of clarity in awards eligibility rules; in particular, there could be ambiguity in the status of a candidate regarding enrolment in a qualified academic institute for post-graduate work. The suggestion was also made to build into the rules a provision to limit the ability of a past winner of a major prize to apply subsequently for the same or other similar prizes, a criterion that otherwise would be applied pragmatically by debate among the Board as was the case at the present meeting for one of the awards. An Action Item was raised for Joana to propose suitably edited award rules to be applied in the future and amend the application forms accordingly.

Dalila recommended that because of the impossibility to hold the Canada Wide Science Fair in 2020 because of the pandemic, the Science Fair Award prize be reassigned to a different cause like a special 2020 award. Also, given the cancelling of AWC 2020, Dalila proposed to expand the Directors' Awards to additional student papers (increasing them to four) to take the place of the three student presentation awards. An Action Item was taken by Jérémie to facilitate with Joana and the Sherbrooke organizing committee the process of defining a suitable allocation of the 2020 conference awards, which could potentially still recognize outstanding student presentations given in an alternative event format should such an initiative take place.

7. Editor's Report (Umberto)

Umberto reported that the journal was in good shape; the March issue had been published reasonably on schedule and the June issue was coming together well, with three or four papers already accepted and others in the editorial process. Without AWC 2020 the September issue, which normally would be dedicated to the proceedings, will have to hold regular content; enough submissions are in the queue, however, that there should be no problem.

Representation of the various disciplines of acoustics was somewhat low in the areas of ultrasound, bioacoustics, and underwater acoustics. It would be very beneficial to have dedicated editors for those disciplines or at least stronger presence on the editorial board, especially to champion and expedite peer reviewing of papers in the mentioned areas of research.

Umberto noted that transition to OJS 3.1 for managing the papers workflow was well established and working smoothly; version 3.2 was due to roll out soon and no major problems were expected. A couple of new people on the journal staff had fit in quite well and the editorial and publishing process was continuously improving and becoming easier for the entire team.

Submissions of papers to the journal remained at steady and adequate level, with a couple of international articles and a few from Canadian authors being entered into the workflow at every quarter; one notable exception had been obtaining papers from award recipients; Umberto felt that it should be made a mandatory requirement for receiving an award so that the community would be aware of the quality of the work being recognized. The submissions could even be just summary papers or 2-page extended abstracts which would not require an extensive review process. Dalila suggested requiring that the paper be featured in the September issue for the recipient to receive the award at the AWC in October, or at least to have the prize money disbursed; missing the September issue would delay the payment. Frank made the additional suggestion that award winners be required to create a 30-second video describing their research; this would be posted on the CAA social media and provide greater visibility and impact for the work of young members of the Association – in a format widely appreciated by their generational peers. From this discussion an Action Item was raised for Joana to include these suggested conditions in the updated awards rules and forms along with other changes previously agreed.

Lastly Bryan proposed that the traditional "AWC proceedings" issue should still go ahead in 2020 with a collection of short papers, in a similar format as the usual conference issue. Umberto responded that it could not be assumed that such an approach would fill the September issue, but the contents should rather be a mix of regular full papers, the awards winners' submissions, and submitted short papers. This distinctive format would help sustain the idea that AWC was alive and well despite the challenges.

8. Social Media Editor's Report (Romain)

Romain gave a short slide presentation on how the social media program had evolved since its inception, including the approaches followed on Twitter and LinkedIn and related analytics showing an increase in following. He began by intensifying the frequency of postings by relaying any relevant content to build following, then focused increasingly on creating original content including video and advanced media.

He concluded by outlining his plan to work closely with the Canadian Acoustics editorial team to draw on any new publications for social media material and asked for continuing input of content and ideas from Board members and others. An Action Item was taken by Jérémie to include links to the CAA's social media platforms in all the Association's email templates.

9. Varia

Jérémie brought up once more the work of the Membership Task Force and the survey report that Alberto and he were drafting as a paper for publication in Canadian Acoustics. He mentioned that the manuscript had been circulated by email and asked for contribution from any interested members of the Board to its review and final authorship. An Action Item was raised for Alberto to review and consolidate any input and provide final comments to the Board at large.

10. Next meeting :

Date to be confirmed in October 2020; virtual meeting.

11. Motion adjourned at 17:03 (EDT)

Announcement

ACOUSTICS WEEK IN CANADA

Sherbrooke (Québec) October 6-8, 2021

View of Mont-Orford from downtown Sherbrooke

Following its report in 2020, Acoustics Week in Canada 2021 will be held on October 6-8, in Sherbrooke, Québec.

You are invited to be part of this three-day conference featuring the latest developments in Canadian acoustics and vibration. Sherbrooke is well known in acoustics for the Groupe d'Acoustique de l'Université de Sherbrooke (GAUS) founded in 1984.

The conference will be an excellent opportunity to visit or rediscover the GAUS during the International Year of Sound!

The keynote talks and technical sessions will be framed by a welcome reception, conference banquet, Acoustical Standards Committee meeting, technical tour and an exhibition of products and services related to the field of acoustics and vibration.

Take a few days before or after the conference to enjoy the area and the cultural activities! Especially have a look to the beautiful surrounding nature during Fall colors with Mont-Bellevue downtown and the nearby 'Mont-Orford' National Park. Three other parks can also be found within a radius of 100 km.

Various demos and activities will be held at the Groupe d'Acoustique de l'Université de Sherbrooke (GAUS) and at Université de Sherbrooke campus - A series of innovative workshop activities will be a part of the program; we are open to proposals along this line (challenges, measurements, simulations).

Venue and Accommodation – The conference will be held at the Hotel Delta by Marriott in Sherbrooke. A block of rooms in the hotel will be available at a special rate. Complimentary city bus passes will be offered to all the participants to promote the use of public transport during the conference. A shuttle is also available to provide a direct link between International Montréal Trudeau Airport and the conference venue. Please refer to the conference website for further details and registration: https://awc.caa-aca.ca/index.php/AWC/AWC21

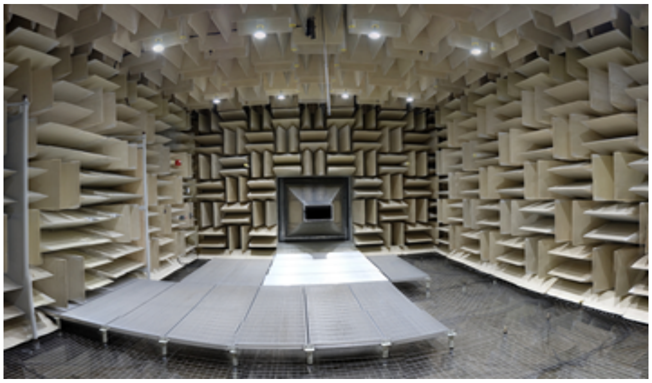
Plenary, Technical and Workshop Sessions are planned throughout the conference. Each day will begin with a keynote talk of broader interest and relevance to the acoustics community. Technical sessions are planned to cover all areas of acoustics including:

AEROACOUSTICS / ARCHITECTURAL AND BUILDING ACOUSTICS / BIO-ACOUSTICS AND BIOMEDICAL ACOUSTICS / MUSICAL ACOUSTICS / NOISE AND NOISE CONTROL / PHYSICAL ACOUSTICS / PSYCHO- AND PHYSIO-ACOUSTICS / SHOCK AND VIBRATION / SIGNAL PROCESSING / SPEECH SCIENCES AND HEARING SCIENCES / STANDARDS AND GUIDELINES IN ACOUSTICS / ULTRASONICS / UNDERWATER ACOUSTICS

A General Public Session is currently planned on the afternoon of the last conference's day and linked to the International Year of Sound 2020-2021, a global initiative to highlight the importance of sound and related sciences and technologies for all in society (https://sound2020.org/). This event will be held on Université de Sherbrooke campus and opened to scholars and to the population. The organizing committee welcomes any proposal for this session, a rare occasion of explaining our everyday job and implications for society.

Exhibition and Sponsorship – The conference offers opportunities for suppliers of products and services to engage the acoustic community through exhibition and sponsorship.

The tabletop exhibition facilitates in-person and hands-on interaction between suppliers and interested individuals. Companies and organizations that are interested in participating in the exhibition should contact the Exhibition and Sponsorship coordinator for an information package. Exhibitors are encouraged to book early for best selection.



Anechoic room and wind-tunnel opening at GAUS

The conference will be offering sponsorship opportunities of various conference features. In addition to the platinum, gold and silver levels, selected technical sessions, social events and coffee breaks will be available for sponsorship. Additional features and benefits of sponsorship can be obtained from the Exhibition and Sponsorship coordinator and on the conference website. Demos can also be organized at Groupe d'Acoustique de l'Université de Sherbrooke.

Students are strongly encouraged to participate. Students presenting papers will be eligible for one of three Best Presentation Student prizes to be awarded. Conference travel bursaries will also be available to those students whose papers are accepted for presentation.

For Registration details, please refer to the conference web site https://awc.caa-aca.ca/index.php/AWC/AWC21

Contacts

Conference Chair:
Olivier Robin
(Olivier.Robin@USherbrooke.ca)

Technical co-Chairs:
Patrice Masson and
Sebastian Ghinet
(Patrice.Masson@USherbrooke.ca)
(Sebastian.Ghinet@nrc-cnrc.gc.ca)

Exhibits and Sponsorships:
Julien Biboud
(Julien.Biboud@mecanum.com)

Enjoy the Mont Bellevue in the center of Sherbrooke during Fall

Annonce

SEMAINE CANADIENNE D'ACOUSTIQUE

Sherbrooke (Québec) 6-8 Octobre 2021

Vue du Mont-Orford depuis le centre-ville de Sherbrooke

Suite à son report en 2020, la Semaine canadienne d'acoustique 2021 se tiendra du 06 au 08 octobre 2021 à Sherbrooke, Québec.

Nous vous invitons à prendre part à cette conférence de trois jours sur les derniers développements en matière d'acoustique et de vibrations au Canada. Sherbrooke est reconnue en acoustique pour le Groupe d'Acoustique de l'Université de Sherbrooke (GAUS) fondé en 1984.

La conférence sera le moment idéal pour visiter ou redécouvrir le GAUS durant l'année internationale du son !

Les exposés principaux et les séances techniques seront encadrés par une réception de bienvenue, un banquet, une réunion du comité des normes acoustiques, une visite technique et une exposition de produits et services liés au domaine de l'acoustique et des vibrations.

Prenez quelques jours avant ou après la conférence pour profiter de la région et des activités culturelles ! Découvrez la nature environnante durant la flambée des couleurs d'automne, avec la proximité du Parc National du Mont-Orford. Trois autres parcs nationaux sont accessibles dans un rayon de 100 km.

Diverses démonstrations et activités seront organisées au sein du Groupe d'Acoustique de l'Université de Sherbrooke (GAUS) et sur le campus principal de l'université de Sherbrooke. Des ateliers participatifs seront intégrés dans le programme; nous sommes ouverts à toute proposition (concours, mesures, simulations).

Lieu et hébergement – La conférence aura lieu au Centre de congrès de l'Hôtel Delta Sherbrooke. Un bloc de chambres dans l'hôtel sera disponible à un tarif spécial. Des passes de bus seront offertes à tous les participants afin de favoriser l'usage du transport en commun durant la conférence. Une navette directe entre l'aéroport international Trudeau de Montréal et le lieu de la conférence est également accessible sur demande. Veuillez consulter le site Web de la conférence pour plus de détails et pour l'inscription: http://awc.caa-aca.ca/AWC/AWC21

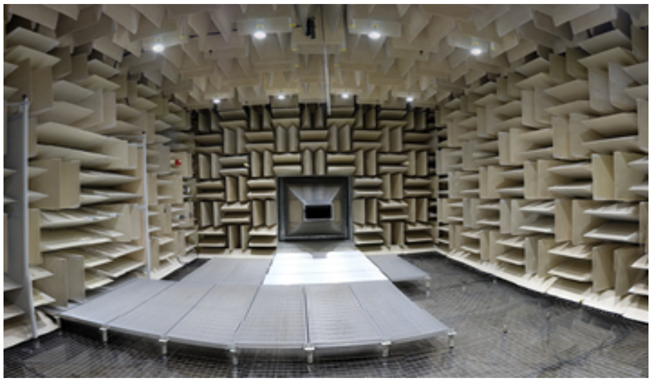
Des séances plénières, techniques et des ateliers sont prévus tout au long de la conférence. Chaque journée débutera par une plénière d'un intérêt et d'une pertinence plus larges pour la communauté de l'acoustique. Des sessions techniques sont prévues pour couvrir tous les domaines de l'acoustique, y compris

AÉROACOUSTIQUE / ACOUSTIQUE DU BÂTIMENT ET ARCHITECTURALE / BIOACOUSTIQUE / ACOUSTIQUE BIOMÉDICALE / ACOUSTIQUE MUSICALE / BRUIT ET CONTRÔLE DU BRUIT / ACOUSTIQUE PHYSIQUE / PSYCHOACOUSTIQUE / CHOCS ET VIBRATION / LINGUISTIQUE / AUDIOLOGIE / ULTRASONS / ACOUSTIQUE SOUS-MARINE / NORMES EN ACOUSTIQUE

Une session grand public est planifiée en après-midi du dernier jour de la conférence, et liée à l'année internationale du son 2020-2021, une initiative globale destinée à illustrer l'importance du son et de ses sciences et technologies dans la société (https://sound2020.org/). Cet évènement se déroulera sur le campus de l'Université de Sherbrooke et sera ouvert aux scolaires et à la population. Le comité organisateur est ouvert à toute proposition pour cette session, une rare occasion d'expliquer notre travail et ses implications pour la société.

Exposition et Parrainage - La conférence offre aux fournisseurs de produits et de services la possibilité de faire participer la communauté acoustique par l'exposition et le parrainage.

L'exposition sur le plateau facilite l'interaction en personne des fournisseurs et des personnes intéressées. Les entreprises et organisations désirant participer à l'exposition doivent contacter le coordonnateur de l'exposition et du parrainage pour obtenir un dossier d'information. Les exposants sont encouragés à réserver tôt pour obtenir de meilleures opportunités.



Salle anéchoïque et soufflerie au GAUS

La conférence offrira des possibilités de parrainage de divers évènements de la conférence. Outre les niveaux platine, or et argent, des séances techniques, des événements sociaux et des pauses café seront disponibles pour le parrainage. Les commanditaires peuvent placer leur logo sur le site Web de la conférence dans les 10 jours suivant leur parrainage. Les caractéristiques et avantages supplémentaires du parrainage peuvent être obtenus auprès du coordonnateur des expositions et des commandites ou sur le site Web de la conférence.

Les étudiants sont fortement encouragés à participer. Les étudiants qui présenteront seront admissibles à l'un des trois prix pour les meilleures présentations. Des subventions de voyage seront également offertes aux étudiants dont les communications sont acceptées pour présentation.

Pour plus d'informations sur l'inscription, veuillez consulter le site Web de la conférence : http://awc.caa-aca.ca/AWC/AWC21.

Contacts

Président de la conférence :
Olivier Robin
(Olivier.Robin@USherbrooke.ca)

Présidents techniques :
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Exposants et commandites :
Julien Biboud
(Julien.Biboud@mecanum.com)

Appréciez le Mont Bellevue au centre de Sherbrooke durant l'automne

CANADIAN ACOUSTICS ANNOUNCEMENTS - ANNONCES TÉLÉGRAPHIQUES DE L'ACOUSTIQUE CANADIENNE

Looking for a job in Acoustics?

There are many job offers listed on the website of the Canadian Acoustical Association!

You can see them online, under http://www.caa-aca.ca/jobs/

August 5th 2015

Acoustics Week in Canada 2020

Because of the COVID-19 situation, the Acoustics Week in Canada (AWC) originally planned for October 2020 in Sherbrooke (QC) will be postpone to October 2021. Nevertheless, and as a ”warm up”, Sherbrooke”s organising committee is currently looking into setting up a little 1-day online celebration for October 2020. You can find more information on the AWC20 and AWC21 websites. Please note that St-John's (NL) will host the AWC2022 conference.

May 3rd 2019

Acoustics Week in Canada 2021

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May 3rd 2019

2020: International Year of Sound

The International Year of Sound (IYS 2020) is a global initiative to highlight the importance of sound in all aspects of life on earth and will lead towards an understanding of sound-related issues at the national and international level.

Inspired by the achievements of La Semaine du Son (The Week of Sound), and following naturally as an important contribution to UNESCO Resolution 39 C/49 25 September 2017 on "The Importance of Sound in Today's World: Promoting Best Practices", the International Commission for Acoustics (ICA) is mobilizing its Member Societies and International Affiliates to promote best practices in sound during the year of 2020 to create an International Year of Sound (IYS 2020). For more info, visit http://sound2020.org/

May 3rd 2019

COVID-19 Situation

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May 13th 2020

À la recherche d'un emploi en acoustique ?

De nombreuses offre d'emploi sont affichées sur le site de l'Association canadienne d'acoustique !

Vous pouvez les consulter en ligne à l'adresse http://www.caa-aca.ca/jobs/

August 5th 2015

Semaine canadienne de l'acoustique 2020

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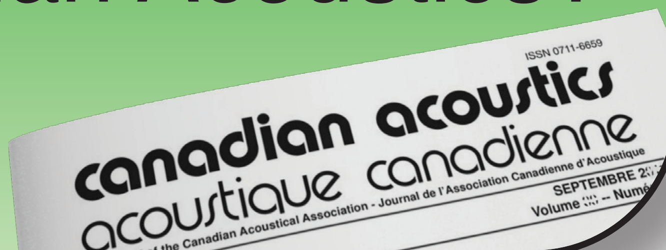
May 13th 2020

Why publish in Canadian Acoustics?



Because, it is...

- A respected scientific journal with a 40-year history uniquely dedicated to acoustics in Canada
- A quarterly publication in both electronic and hard-copy format, reaching a large community of experts worldwide
- An Open Access journal, with content freely available to all, 12 months from time of publication
- A better solution for fast and professional review providing authors with an efficient, fair, and constructive peer review process.

- Une revue respectée, forte de 40 années de publications uniquement dédiée à l'acoustique au Canada
- Une publication trimestrielle en format papier et électronique, rejoignant une large communauté d'experts à travers le monde
- Une publication "accès libre" dont le contenu est disponible à tous, 12 mois après publication
- Une alternative intéressante pour une évaluation par les pairs, fournissant aux auteurs des commentaires pertinents, objectifs et constructifs

Application for Membership

CAA membership is open to all individuals who have an interest in acoustics. Annual dues total $120.00 for individual members and $50.00 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 $120.00 per year. Many organizations choose to become benefactors of the CAA by contributing as Sustaining Subscribers, paying $475.00 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 $ 120.00
[ ] CAA Student Membership $ 50.00

Corporate Subscriptions (4 issues/yr)
[ ] $120 including mailing in Canada
[ ] $128 including mailing to USA,
[ ] $135 including International mailing

[ ] Sustaining Subscription $475.00
(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 organizations wishing to pay by check, please register online at *http://jcaa.caa-aca.ca* and then mail your check to:

Executive Secretary, Canadian Acoustical:
Dr. Roberto Racca
c/o JASCO Applied Sciences
2305–4464 Markham Street
Victoria, BC V8Z 7X8 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 120.00$ pour les membres individuels, et de 50.00$ pour les étudiants. Tous les membres reçoivent ***l'Acoustique Canadienne***, la revue de l'association.

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

Les abonnements pour la revue ***Acoustique Canadienne*** sont disponibles pour les compagnies et autres établissements au coût annuel de 120.00$. Des compagnies et établissements préfèrent souvent la cotisation de membre bienfaiteur, de 475.00$ par année, pour assister financièrement l'ACA. La liste des membres bienfaiteurs est publiée dans chaque issue de la revue ***Acoustique Canadienne***..

Notez que tous les paiements électroniques sont acceptés en ligne 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 120.00 $
[ ] Membre étudiant(e) 50.00 $

Abonnement institutionnel
[ ] 120 $ à l'intérieur du Canada
[ ] 128 $ vers les États-Unis
[ ] 135 $ tout autre envoi international

[ ] Abonnement de soutien 475.00 $
(comprend l'abonnement à *L'acoustique Canadienne*)

Merci de noter que le moyen de paiement privilégie est le paiement par carte crédit en ligne à *http://jcaa.caa-aca.ca*

Pour les individus ou les organisations qui préféreraient payer par chèque, l'inscription se fait en ligne à *http://jcaa.caa-aca.ca* puis le chèque peut être envoyé à :

Secrétaire exécutif, Association canadienne d'acoustique :
Dr. Roberto Racca
c/o JASCO Applied Sciences
2305–4464 Markham Street
Victoria, BC V8Z 7X8 Canada

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Association canadienne d'acoustique

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Dalila Giusti
Jade Acoustics Inc.
treasurer@caa-aca.ca

Editor-in-Chief
Rédacteur en chef

Umberto Berardi
Ryerson University
editor@caa-aca.ca

DIRECTORS - ADMINISTRATEURS

Alberto Behar
Ryerson University
albehar31@gmail.com

Bill Gastmeier
HGC Engineering
bill@gastmeier.ca

Bryan Gick
University of British Columbia
gick@mail.ubc.ca

Michael Kiefte
Dalhousie University
mkiefte@dal.ca

Andy Metelka
SVS Canada Inc.
ametelka@cogeco.ca

Hugues Nelisse
Institut de Recherche Robert-Sauvé en Santé et Sécurité du Travail (IRSST)
nelisse.hugues@irsst.qc.ca

Joana Rocha
Carleton University
Joana.Rocha@carleton.ca

Mehrzad Salkhordeh
dB Noise Reduction Inc.
mehrzad@dbnoisereduction.com

Upcoming Conference Chair
Directeur de conférence (future)

Olivier Robin
Université de Sherbrooke
conference@caa-aca.ca

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EERS
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RWDI
web@caa-aca.ca

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