Final Book of Abstracts

from the

INTER-NOISE 2021 Proceedings
Pleanaries, Keynotes, Technical Sessions,
Latin American Symposium, and Workshops

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Session Number 04.00 Signal Processing, Measurements, Sound Reproduction, Diagnostics for Noise and Vibration Engineering, General, Part 1 -
Channel 1

6:40 AM 01-Aug-2021 **IN21_1136.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1136

Distortion measurements of sound pressure level generated by a pistonphone

Thiago Antônio Bacelar Milhomem, Zemar Martins Defilippo Soares, Gustavo Palmeira Ripper, Peter Hanes, Adrian Solano Mena, Federico Ariel Serrano, Giancarlos Miguel Guevara Chuquillanqui, Juan Pablo Ayala Breña

A supplementary interlaboratory comparison on pistonphone calibration was performed between 2018 and 2020 under the auspices of the Inter-American Metrology System. Seven national metrology institutes took part in this comparison. One pistonphone was circulated among the participants for measurement of the generated sound pressure level, frequency, total distortion + noise and total harmonic distortion. This paper presents the results of distortion measurements and analyzes them. From the stability check, notable variances with respect to reported measurement uncertainty were observed. From reported results, a large difference between the estimated uncertainties by the participants was noted. Convergence between results was found when measurements were performed using one-inch microphone while some divergence between results was found when measurements were performed using half-inch microphone. In addition, these results (using one-inch and half-inch microphones), even when obtained by the same institute, sometimes were different. Reasons for these findings are discussed and suggestions for future comparisons are presented.

7:00 AM 01-Aug-2021 **IN21_2557.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2557

MEMS digital microphone and Arduino compatible microcontroller: an embedded system for noise monitoring

Felipe Ramos de Mello, William D'Andrea Fonseca, Paulo Henrique Mareze

Noise assessment and monitoring are essential parts of an acoustician's work since it helps to understand the environment and propose better solutions for noise control and urban noise management. Traditionally, equipment to carry out this task is standardized, and, eventually, expensive for the early career professional. This work develops a high-quality (and cost-effective) prototype for an embedded noise monitoring device based upon a digital I2S MEMS microphone and an Arduino compatible microcontroller, named Teensy. Its small size and low power consumption are also advantages designed for the project. The system captures and processes sound in real-time, computes A and C frequency-weighted equivalent sound levels, along with time-weighted instant levels with a logging interval of 125 ms. Part of the software handles the audio environment, while the biquadratic IIR filters present in the Cortex Microcontroller library are responsible for the frequency-

and time-weightings — using floating-point for enhanced precision. The prototype results were compared against a Class 2 Sound Level Meter, rendering very similar results for the tested situations, proving a powerful and reliable tool. Improvements and further testing are also being conducted to refine its functioning and characterization. Ultimately, the prototype achieved promising performance, confirming as a solution for noise monitoring.

7:20 AM 01-Aug-2021 **IN21_1580.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1580

Visualization of magnetic field corresponding to acoustic signal and estimation of magnetic source based on symmetry of magnetic field distribution

Takuto Kurosawa, Takuto Kurosawa, Eri Ishizuka, Yasuhiro Oikawa, Masatoshi Asakawa, Yuya Suzuki

A magnetic field corresponding to an acoustic signal is generated from an antenna, and by using a coil, can be again converted to an acoustic signal. It is possible to estimate where the invisible antenna is with the distribution of the received signal. The estimation is applied to a maintenance of a gas pipe on the situation that the distance from the entrance to a maintenance area is known, but piping route isn't. It is possible to identify maintenance areas of a gas pipe by inserting the antenna to it. The estimation has been done by listening to the received signal manually. However, it is difficult for people to identify accurate point because the difference in the volume for each places is subtle. To solve this problem, we visualized the distribution of the received signal, and estimated the magnetic field with only the acoustic signal. Then, we proposed a method to calculate where the invisible antenna is automatically by using symmetry of the distribution of the received signal.

7:40 AM 01-Aug-2021 **IN21_3112.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3112

Measurement of loudspeaker mechanical impedance by changing the sound load at the throat of loudspeaker

Shichun Huang, Liang Yu, Weikang Jiang

A loudspeaker is a device that converts electrical energy into acoustic energy by coupling between electrical impedance, mechanical impedance, and radiation impedance. The loudspeaker electro-mechanical-acoustic coupling model provides the experimental feasibility to measure the characteristic parameters. In this paper, an economical and practical measurement method of loudspeaker mechanical impedance is proposed. First, the mathematical relationship between loudspeaker electrical impedance and mechanical impedance is obtained based on the loudspeaker electro-mechanical-acoustic coupling model. Second, two electrical impedances with different known radiation impedance are measured by using a developed measurement system. Finally, the real and imaginary parts of the mechanical impedance are obtained according to the mathematical relationship. This method neither assumes that the loudspeaker mechanical impedance is constant in a frequency band nor does it build FEM models based on structural parameters. A loudspeaker is measured by using a developed measurement system. The result shows that the mechanical impedance and the force factor are functions of frequency. Moreover, a radiation impedance measurement is performed to verify the feasibility and accuracy of the proposed method.

8:00 AM 01-Aug-2021 **IN21_2757.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2757

Comparison of Estimation Methods of Room Impulse Responses in Local Region Using Small Number of Microphones

Haruka Matsuhashi, Izumi Tsunokuni, Yusuke Ikeda

Measurements of Room Impulse Responses (RIRs) at multiple points have been used in various acoustic techniques using the room acoustic characteristics. To obtain multi-point RIRs more efficiently, spatial interpolation of RIRs using plane wave decomposition method (PWDM) and equivalent source method (ESM) has been proposed. Recently, the estimation of RIRs from a small number of microphones using spatial and temporal sparsity has been studied. In this study, by using the measured RIRs, we compare the estimation accuracies of RIRs interpolation methods with a small number of fixed microphones. In particular, we consider the early and late reflections separately. The direct sound and early reflection components are represented using sparse ESM, and the late reflection component is represented using ESM or PWDM. And then, we solve the two types of optimization problems: individual optimization problems for early and late reflections decomposed by the arrival time and a single optimization problem for direct sound and all reflections. In the evaluation experiment, we measured the multiple RIRs by moving the linear microphone array and compare the measured and estimated RIRs.

Session: Plenary Lecture
Channel 1

9:45 AM 01-Aug-2021 **IN21_1302.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1302

Soundscape: Progress in the past 50 years and challenges in the next 50 years

Jian Kang

Soundscape is defined by the ISO as the ‘acoustic environment as perceived or experienced and/or understood by a person or people, in context’. Different from conventional noise control engineering, soundscape promotes a holistic approach, regarding sounds as ‘resources’ rather than just ‘wastes’. This paper first briefly reviews the soundscape progress in the past 50 years, showing that there has been a recognised focus shift from noise control to soundscape creation, and also a step change from soundscape concept to practice. Then the current developments and needs in soundscape are dis-cussed in terms of soundscape understating and exchanging, collecting and documenting, harmonis-ing and standardising, creating and designing, and outreaching, showing that while considerable works have been carried out, much work is still needed, in terms of basic research, and more im-portantly, research towards practice. Finally, some major challenges in the next 50 years are ex-plored, considering the new industrial revolution, climate change and changing living styles.

Session: Latin American Symposium: Environmental Noise Management
Channel 1

11:30 AM 01-Aug-2021 **Oral Only**

Environmental noise management in Latin America: a general panorama

Priscila Wunderlich

The Latin American Symposium aims to increase the visibility of the acoustic reality of this region, besides fostering the debate on the major challenges to be faced by the stakeholders of the acoustics field in these countries. This introductory presentation will give an overview on the environmental noise management panorama in the most populated Latin America countries.

11:45 AM 01-Aug-2021 **Oral Only**

Environmental noise regulations and noise mappings in Brazil

Juan Frías de Pierrard

The national standard NBR 10151 is the reference for the assessment of environmental noise in Brazil, which had become federal legislation since it was mentioned in the 1990 Resolution of the National Environmental Council (Conama). After almost 20 yeas, the standard NBR10151 was revised in 2019, resulting in a much more complete but also complex version. Some cities in Brazil also have its own noise regulations, which are not always harmonized with the latest version of technical standards and federal legislation. In the last few years, some large cities such as São Paulo, Rio de Janeiro or Porto Alegre have included the requirement of making strategic noise maps in their municipal legislation.

12:00 PM 01-Aug-2021 **Oral Only**

Noise mapping and environmental policies: the Chilean experience

Jorge Arenas

The regulation of environmental noise in Chile had an important milestone in 1994 when the government enacted Law 19,300 on the Environmental General Bases. This legislation regulates the environmental management instruments, their creation, and application processes. The emission and environmental quality regulations and the environmental impact assessment system (SEIA) stand out among them. Chile enacted its updated emission regulations for fixed and moving noise sources in 2011 and 2019, respectively. Other important sources of environmental noise (airports, roads, railroads) are also regulated through the SEIA. Although not mandatory, since 2009 the Chilean Ministry of Environment (MMA) has commended noise maps of some of the most important cities in the country to external teams after open calls for tenders. This task has been performed mainly by the University Austral of Chile. Based on this diagnosis, the MMA has implemented the first public noise monitoring network and announced a future environmental quality acoustic standard. With this standard, decontamination plans (similar to the action plans of the European Directive 2002/49/EC) would be established. For these initiatives, a number of collaborative research programs are underway such as an integrated system for the analysis of environmental noise sources, which will be based on artificial intelligence.

12:15 PM 01-Aug-2021 **Oral Only**

Current challenges of noise management in Uruguay

Alice Elizabeth Gonzalez

Uruguay is a small country with about 3.500.000 people. Its administrative organization is in 19 municipalities. The National Noise Act was approved on 2004; eventhough, Uruguay still has not a National Decree to make it operative. Thus, each of the counties has a different local regulation that refers to different issues, allows different sound pressure levels for the same source and establishes different penalties for the same contravention. Some trials of writing the National Noise Decree have been done; the last of them was prepared in 2013 and it completed the public audience period without problems. Now, eight years later, the national context has not changed. A few municipal regulations have been updated, but the incompatibilities between different counties still survive.

Uruguay is currently faced to another important challenge: the renewal of train facilities for charge transportation from the center to the country to the Port of Montevideo. The railway cross through some cities; Montevideo is one of them. Basic noise and vibrations studies have been held in the frame of the Environmental Impact Assessment, but the design of mitigation measures has not achieved the detailed project level. People are anxious because of the high number of formations that will run: between 2 and 4 per hour. Noise is going to change their lives and invade their homes. Not only legislation is needed, but also engineering measures to mitigate adverse noise impacts.

12:30 PM 01-Aug-2021 **Oral Only**

Roundtable discussion on environmental noise management

Carolina Monteiro

Session: Latin American Symposium: Acoustic Comfort in Buildings
Channel 1

1:30 PM 01-Aug-2021 **Oral Only**

Building acoustic regulations in Latin America: a general panorama

Carolina Monteiro

The Latin American Symposium aims to increase the visibility of the acoustic reality of this region, besides fostering the debate on the major challenges to be faced by the stakeholders of the acoustics field in these countries. This introductory presentation will give an overview on the building acoustic regulations panorama in the most populated Latin America countries.

1:45 PM 01-Aug-2021 **Oral Only**

Acoustic performance in dwellings in Brazil - From regulation to reality

Marcos Holtz

Since 2013, with the NBR 15575 enforcement, the construction of dwellings in Brazil has been reorganized in order to follow new performance requirements, such as thermal, lighting, safety, security, etc., and acoustic performance is one of them. As the acoustical requirements is something new for most of Brazilian professionals, it is possible to notice an evolution in building design, supply network, building construction systems and the laboratories network, responsible for testing and evaluating the standard compliance. This presentation will show a timeline describing the enforcement, the first years development and the recent NBR 15575 revision draft(2021). A summary of mandatory and informative criteria will be presented, as well as examples of typical Brazilian solutions and the main difficulties to achieve the criteria. The next steps are under discussion right now, as well as the need to make the criteria more strict to ensure that our dwellings can achieve a minimum performance level, regarding health preservation and acoustic comfort.

2:00 PM 01-Aug-2021 **Oral Only**

Acoustic comfort: Applications of Standards in Argentina building codes

Arturo Raúl Maristany

Acoustic comfort is increasingly considered as a quality requirement for sustainable buildings in Argentina. At the moment, it is almost exclusively linked to the problem of acoustic insulation. However, this indicator is not yet fully incorporated into building codes. With respect to standards, The Argentine Institute for Standardization and Certification, IRAM, has been making important progress in the drafting of quality standards, such as IRAM 4044 where insulation values are recommended for the parameters R´w, L´n,w and D2m,nT,Ctr. These recommendations are not always adopted in mandatory use regulations. In Argentina, there is no law that regulates the insulation conditions, that are regulated by local governments. However, the building code of Buenos Aires includes a chapter on acoustic comfort, establishing minimum insulation values. There, it is proposed to associate the necessary insulation in facades with the levels of the city noise map, formulating a dynamic and sustainable criterion in the definition of insulation based on real acoustic environmental conditions. It is necessary to work so that other cities adopt this model by updating their own codes or starting to incorporate acoustic comfort in it. Regulations must receive feedback from usual construction techniques and building forms, which are often the product of the building codes themselves.

2:15 PM 01-Aug-2021 **Oral Only**

Building acoustic requirements: current situation in Uruguay

Gonzalo Fernández Brescia

The acoustic regulations applicable to buildings in Uruguay are formulated with little technical rigor, does not cover aspects such as impact noise and reverberation time and there is no coordination between the demands at the national level and with the demands of local governments. Although the texts have these weaknesses, they also have a virtue: they propose effective constructive solutions, based on surface mass. For example, the requirement of a separating wall between houses of not less than 20 cm thick and not more than 20% of holes built with pieces of ceramic masonry or the requirement of a solid mezzanine with a minimum thickness of 20 cm. These requirements lead the designer to propose massive enclosures, which ensure good insulation against airborne noise. The work describes the regulations currently in force in the country, analyzes their technical quality and proposes a way of working for the future. In addition, approval processes for a non-traditional lightweight construction solution are described and analyzed.

2:30 PM 01-Aug-2021 **Oral Only**

Roundtable discussion on acoustic comfort in buildings

Carolina Monteiro

Session: 20.15 Classic Papers in Noise Control Engineering
Channel 1

3:00 PM 01-Aug-2021 **Oral Only**

An overview of Leo Beranek's paper on "The Forty-fifth Thomas Hawksley Lecture: The Transmission and Radiation of Acoustic Waves by Structures" and its influence on architectural acoustic research

Jonathan Broyles, Nathan C. Brown

The transmission and radiation of acoustic sound in the auditory frequency range is of interest to building, vehicular, and mechanical designers. In the design of buildings, the amount of sound transmission through a wall or floor has a direct impact on the occupant experience in the surrounding spaces. Over sixty years ago, Leo Beranek investigated the sound transmission of single and double walls, including plates, concrete

walls, and masonry walls. Beranek also explored the impact of the coincidence frequency and damping materials of structures and their implications in acoustic design. This presentation provides an overview of Beranek's main findings and expands the discussion of sound transmission in buildings. While acoustic metrics for sound transmission such as Sound Transmission Class and Impact Insulation Class have been developed and included in building design code, designers often neglect acoustics in the initial design of most buildings. Further, as building designers aim to reduce the cost and environmental impact of buildings through substituting more sustainable materials or directly reducing material amounts, consequences can include increased sound transmission through building structures. Drawing from early contributions by Beranek, contemporary researchers can make informed design decisions for walls and floors to meet the acoustic needs of occupants.

3:20 PM 01-Aug-2021 **Oral Only**

Overview of J. E. Ffowcs Williams' 1984 paper on anti-sound

Dazhuang He

A review of J. E. Ffowcs Williams' 1984 paper on anti-sound is presented. The paper was an up-to-date review of studies on active noise control. The early development and experimental attempts of active noise control were summarized. The theoretical fundamentals of active noise control were reviewed, from both linear pressure field and energetic point of views. Several approaches of active noise control were reviewed, with an emphasis on the creation of small silent zones. Theoretical and practical limitations of active noise control were discussed. Several novel applications of anti-sound technique were introduced, involving mitigation of machinery vibration with anti-sound principle, attenuation of noise induced by turbulent combustion and control of flow instability by introducing anti-sound. Several subsequent related researches are also reviewed by the author.

3:40 PM 01-Aug-2021 **Oral Only**

Overview of Dah-You Maa's 1987 paper on 'Microperforated-panel wideband absorbers'

Zhuang Mo

Dah-You Maa's paper 'Microperforated-Panel Wideband Absorbers', published in 1987 on Noise Control Engineering Journal, is a classic work of the design of various acoustic treatments which involves microperforated panels. In this paper, practical tools of microperforated panel designs are provided. The acoustic behavior of microperforated panels under oblique and random incidence, and the double resonator system consists of two microperforated panels are also analyzed in this paper. In this presentation, the theory developed in the classic paper is reviewed, with some of the results reproduced and compared with simulation output. The impact of the classic paper is illustrated by introducing the relevant works following the classic paper. The development of the theory and design of microperforated panel itself and the acoustic system with these panels from the classic paper to nowadays research is discussed.

4:00 PM 01-Aug-2021 **Oral Only**

Overview of Biot's 1956 paper on theory of propagation of elastic waves in a fluid-saturated porous solid 1. Low-frequency range.

Guochenhao Song

In this presentation, a discussion of Biot's 1956 JASA paper on theory governing propagation of stress waves in a porous, elastic solid containing a compressible viscous fluid (where the fluid and solid are of comparable densities) will be presented. The assumption has been made that for low-frequency waves, the relative motion of fluid in the pores is of the Poiseuille type. The wave solutions consist of two dilatational waves and one rotational wave, in contrast to the elastic solid case, in which two waves propagate (one dilatational and one rotational), and the fluid case, in which only a single dilatational wave propagates. Then, the case of a material containing a viscous fluid is developed and discussed numerically. The phase velocity dispersion curves and attenuation coefficients for the three types of waves are plotted as a function of the frequency for various combinations of the characteristic parameters to illustrate the nature of the various wave types. The theory and effect of characteristic parameters are summarized, and then applications and recent generalizations of Biot's theory will be presented.

4:20 PM 01-Aug-2021 **Oral Only**

Overview of Sung, S.H. and Nefske, D.J.'s 1984 paper on A Coupled Structural-Acoustic Finite Element Model for Vehicle Interior Noise Analysis

Srinivasa-Rao Ippili

Coupled structural-acoustic models are of a great interest in the automotive industry for improving prediction accuracy of the vibration-induced noise within the vehicle compartment. In this paper by authors Sung and Nefske, they discussed the underlying governing equations and forced frequency response solution for a coupled system. The coupled system involves a combination of 3D finite element model of vehicle cavity with structural finite element model of vehicle body. Especially at lower frequencies below 100 Hz, their model fairly predicts the interior acoustic response for forced harmonic excitation. Also, in the paper they briefly described an example case where the modal and panel participation leading to the overall acoustic response of a vehicle structure were identified from the results obtained.

4:40 PM 01-Aug-2021 **Oral Only**

Overview of M. J. Lighthill's and M. H. A. Newman's 1952 paper on "On Sound Generated Aerodynamically. 1. General Theory."

Seth Donkin

M.J. Lighthill presents a theory for estimating the sound radiated from a fluid flow with rigid boundaries which cause regular fluctuations or turbulence. Lighthill's theory is based on the equations of motion for gas and proposes that a distribution of static quadrupoles produces the sound field. The theory shows that the sound field's intensity depends on the strength of the quadrupoles and the frequency. Due to these relationships, the sound field's intensity is found to increase in proportion to the eighth power of the flow's velocity. As the generation of aerodynamic sound is of interest in a range of fields, Lighthill takes the time to derive the model for estimating the sound field both mathematically and by examining the physical mechanism behind the conversion of kinetic of the flow to acoustic energy. The model stands out from past attempts at predicting aerodynamic noise. It considers the inefficiency at which kinetic energy is converted to acoustic energy and the increase in efficiency seen by the flow velocity increase. This increase in efficiency is particularly true for sound emitted in parallel with the flow velocity vector, in other words, forwards.

5:00 PM 01-Aug-2021 **Oral Only**

Overview of Hunt, F. V., Beranek, L. L., and Maa, D. Y.'s 1939 paper on "Analysis of Sound Decay in Rectangular Rooms"

Jared Schmal

In the 1939 paper, Analysis of Sound Decay in Rectangular Rooms, by Hunt, Beranek, and Maa the calculation of a frequency dependent decay rate in a simple rectangular room was examined and experimentally validated. The required variables are the room dimensions and a single material property (acoustical impedance) of the surfaces. Two cases were examined: 1.) a bare room with the same material on each surface, and 2.) the same room with high absorption placed on a single wall. The decay rate equation was constructed using free wave theory and standing wave theory to enable the calculation of the entire audible frequency spectrum. The results from a finite element method (FEM) acoustic model of a similarly sized reverberation room has been completed and will be compared to results contained within this classic paper.

Session: 03.02 - Modeling & Numerical Simulation, Part 1
Channel 1

7:00 AM 02-Aug-2021 **IN21_2156.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2156

Vibroacoustic analysis of a thin laminated composite plate with surface-boned piezoelectric patches and subjected to general boundary conditions

Zhengmin Hu, Kai Zhou, Yong Chen

In this paper, a semi-analytical model is proposed to deal with the vibroacoustic problems of laminated composite plates with surfaced-boned piezoelectric patches and subjected to general boundary condition using the modified Fourier series method. Based on Kirchhoff plate theory, the dynamic equation of the laminated composite plate is derived using Hamilton’s principle. In order to satisfy general boundary conditions, the displacement solution of the plate is expressed in the form of two-dimensional Fourier series and serval auxiliary functions. The acoustic response of the laminated composite plate due to a harmonic concentrated force is obtained with the Rayleigh integral. Besides, the mass and stiffness contribution of the piezoelectric patch are taken into consideration in the present study. Through enough convergent studies and comparative studies, the convergence, accuracy and universality of the proposed method are validated. The developed semi-analytical model can be used for efficient and accurate analysis and design of laminated composite plates equipped with shunted piezoelectric patches. Finally, the effects of the resistor and inductor shunt damping circuits on the vibration and acoustic response is discussed.

7:20 AM 02-Aug-2021 **IN21_1985.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1985

Free vibration analysis of rectangular plates with arbitrary elastic boundary conditions

Zhenshuai Wan

boundary conditions are In this paper, an improved Fourier series method is presented for the free vibration analysis of rectangular plates with arbitrary elastic conditions. The stiffness value of the restraining springs is determined as required to simulate the arbitrary elastic boundary conditions. The exact solution of plates with arbitrary elastic boundary conditions is solved by the introduced supplementary func-tions. The matrix eigenvalue equation of plates is derived by using boundary conditions and the governing equations. Compared with exist methods, the presented method can be easily applied to most of plate vibration problems with different boundary conditions. To validate the accuracy of the presented method, numerical simulations with different boundary conditions are presented.presented.

7:40 AM 02-Aug-2021 **IN21_2641.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2641

Development of a virtual biomechanical manikin used in vibrations studies in occupied spaces

Eusebio Conceição, Mª Inês Conceição, Mª Manuela Lúcio

In this paper is developed and applied a virtual biomechanical manikin used in occupied spaces. This multi-nodal numerical model is applied in the vibrations of the different sections of the human body, under transient conditions. The integration of second order equations systems, based in Newton equation, after being converted in a first order equation system, is solved through the Runge-Kutta-Fehlberg method with error control.

This multi-nodal numerical model will be used, in this work, in the study of the vibrations that a standing person is subjected when stimuli are applied to the feet. The influence of various types of stimuli is analyzed, with periodic irregularities, in the dynamic response of the vibrations in different sections of the human body. The signals of the stimuli, the displacement of some sections of the body and the power spectrum of the same signals will be presented. In the study the influence of the floor vibration in the human body sections is analyzed and presented.

8:00 AM 02-Aug-2021 **IN21_3037.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3037

Numerical modeling of ground-borne vibrations induced by pile driving with a simple and direct material damping approach

Tales Sofiste, Luís Godinho, Delfim Soares, Pedro Alves Costa

Ground-borne vibrations are an increasingly common problem in large cities due to its considerable disturbance in terms of human comfort and health. In this sense, construction operations stand as a significant source of vibrations and may be critical since construction sites are frequently adjacent to existing buildings. In the present work, vibrations induced by pile driving are studied. A time-domain finite element model is developed and a post-processing approach is proposed to simulate the material damping of the soil. This damping formulation stands as a simple and direct approximation of the material damping in the system. In order to do so, the numerical response is computed without material damping, which is introduced as a post-processing procedure. An explicit and highly efficient method is applied for the time integration of the equation of motion, considering an axisymmetric formulation. A numerical application is carried out and the obtained results are compared to previous numerical and in-situ measurements available in the literature, indicating a good agreement with previous studies.

8:20 AM 02-Aug-2021 **IN21_2078.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2078

Structural Dynamics, Noise and Vibration: Buildings Adjacent to Train Lines

Pablo Reboredo Gasalla

In architecture and civil engineering there is a growing interest in the study of the dynamics of structures. The dynamic effects are due to various actions, but their influence is widened or reduced according to the design of the structure.
Structures can be highly susceptible to the action of dynamic loads produced by the action of wind, earthquake, industrial activities, blasting activities, construction sites, road vehicles, trains, building services and human activities. Noise and vibration can have significant environmental impact on buildings and structures and can damage track components, crack roadways, unsettle foundations, affect sensitive equipment, impact human comfort and damage structures.
Structure-borne noise and vibration can be a major and often overlooked consideration in the planning, design and operation of existing or new developments. A reliable, considered approach to assessing noise and vibration is needed to achieve outcomes that meet client expectations while maintaining on-going compliance with relevant standards and regulatory and planning requirements.
The proposed paper will focus on a general overview of the structure-borne noise and vibration risks, associated with new developments that are adjacent to existing rail lines during the early design stages, from commercial and residential buildings to sensitive research facilities. It will further explain the general description of the design process, including problem descriptions, measurements of ground and structural vibration levels at the proposed site, vibration criteria, finite element analysis and provisions of the isolation system required to be considered at the building to achieve the relevant criteria.

Session: Keynote Lecture
Channel 1

9:00 AM 02-Aug-2021 **Oral Only**

Developing deep noise suppression for Microsoft Teams and Skype

Ross Cutler, Robert Aichner

Session: 01.01 Fan and Turbomachinery Noise, Part 3
Channel 1

11:00 AM 02-Aug-2021 **IN21_1970.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1970

Experimental study of wavy trailing edge serrations on flat rotor blades

Sai Manikanta Kaja, K. Sriinivasan, A. Jaswanth Kalyan Kumar

A detailed experimental study is conducted to observe the effect of various parameters like wavelength, depth of serrations, and pitch angle on serrated blades' acoustic emissions at low speeds up to 2000 rpm. Experiments are conducted on flat blade rotors with sinusoidal serrations on the trailing edge of blades with different amplitudes and wavelengths. A total of 7 blades with different serration configurations, including a base configuration, are studied, five of them have serrations throughout the span of the blade, and one configuration has serration of varying amplitude on the farther half of the blade. It is observed that some blade configurations have resulted in tonal noise reduction noise as much as 8dB, whereas some of the serration configurations reduce very little to none, there is no significant effect of T.E serrations on the broadband noise emitted by the rotor. Directivity of noise generated from the rotor, the effect of serrations on the directivity of the noise is studied.

11:20 AM 02-Aug-2021 **IN21_2142.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2142

Study on the effect of separation and reattachment flow between blades on fan noise

Sho Kosaka, Masaharu Sakai, Hideaki Sato, Kaori Seki

With the growth of the EV/HV market, the main cause of cabin noise has changed from engine driving sound to air conditioner noise. The blower noise is the largest in the air conditioner noise, and the noise reduction is urgent. Separated and reattached flows between fan blades are considered to be the main sources of blower noise. In the past, we tried to reduce the noise by reducing the separation. This time, the blade

shape to further reduce the separation was produced and evaluated. As a result, the noise was greatly reduced, but a new problem was found that there was a flow velocity condition in which the noise increased despite the small separation. Therefore, we visualized the flow between blades by PIV, investigated the state of separated and reattached flow in detail, and investigated the factors related to noise increase and decrease by measuring noise and pressure fluctuation of blade surface simultaneously. As a result, it was found that the noise generation condition in the separation reattachment flow between blades is not only the size of separation but also the distance of separation shear layer from blade surface and the strength of vortex generated in shear layer.

11:40 AM 02-Aug-2021 **IN21_2633.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2633

Directivity of sound propagation from an commercial supersonic engine inlet

Mitchell Sugar, Paul Slaboch

The effects of mean flow variations on sound propagation from an axisymmetric commercial supersonic engine inlet were studied using numerical methods. A finite element model of the inlet was constructed in Ansys Fluent and used to solve for flow fields given by different initial conditions. Results from this model were fed into the aeroacoustic solver, Actran, and used to calculate far field radiated noise as well as the directivity of that noise. The acoustic source of this noise was a plane wave of a known strength placed at the fan face. In addition to assessing the effects of mean flow on the radiated noise transfer functions, the duct modes of the model were compared across different flow regimes. Relationships between mean flow parameters and the directivity of duct modes are developed. The results of this study will be used in further studies to gain a deeper understanding of how the underlying physics which govern the system create favorable or unfavorable directivity patterns.

12:00 PM 02-Aug-2021 **IN21_3181.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3181

Industrial fan vibration signature characterization

Timothy Copeland, Arthur Kohn, Orrin Southall

Technique for measuring and reducing industrial fan vibration and noise is detailed. A method used to characterize the vibration signature for 100% industrial fan systems shipped is described. A fan system consists of motor, propeller and cage. We measure triax accelerometer vibration, microphone (both sound pressure level in dBA and raw signal in Pa) along with the current of three phase power for each fan shipped. Comparisons are done immediately with the ISO 14694:2003 standard and troubleshooting and design changes are implemented if vibration limits are exceeded. The method and results are provided for several cases. Troubleshooting and best practices are described for various designs. A portable system takes measurements in the field which are compared to the factory baseline characterization in real time to solve installation problems.

Session: 01.02 Computational Methods in Flow-Induced Noise & Vibration, Part 1
Channel 1

12:20 PM 02-Aug-2021 **IN21_1108.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1108

Chracterization of trailing edge broadband noise from wind turbine blades

Bhargava Vasishta, Naidu N.V. Swamy, Satya Prasad Maddula

Wind turbine noise is a critical issue for siting and its operation in offshore and terrestrial conditions. In this work, we analysed trailing edge bluntness vortex shedding noise source for a land based turbine of size 2MW and blade span of 38m using modified BPM noise solver. A regression approach has been implemented to predict the shape function in terms of thickness to chord ratio of aerofoils used for blade. For trailing edge height of 1 % chord, computations for sound power level were done at wind speed of 8m/s, 17 RPM, and showed that present regression approach predicts the noise peak of 78dBA at f ~ 10 kHz. These results were also validated using experiment data from GE 1.5sle, Siemens 2.3MW turbines with blade lengths of 78 -101m and agreed within 2 % at very high frequencies, f > 5kHz. In addition, results from present approach agreed with original BPM and modified BPM by Wei et al at high frequencies, f ~ 10kHz where the bluntness noise becomes predominant. The slope of noise curves from present approach, and modified BPM methods are lower when compared with original BPM and show sound level coincidence with peak Strouhal number of ~ 3.3.

12:40 PM 02-Aug-2021 **IN21_2597.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2597

Prediction of wind turbine blade trailing edge noise under various flow conditions for a passive damage detection system

Murat Inalpolat, Caleb Traylor

Noise generated by turbulent boundary layer over the trailing edge of a wind turbine blade under various flow conditions is predicted and analyzed for structural health monitoring purposes. Wind turbine blade monitoring presents a challenge to wind farm operators, and an in-blade structural health monitoring system would significantly reduce O&M costs. Previous studies into structural health monitoring of blades have demonstrated the feasibility of designing a passive detection system based on monitoring the flow-generated acoustic spectra. A beneficial next step is identifying the robustness of such a system to wind turbine blades under different flow conditions. To examine this, a range of free stream air velocities from 5 m/s to 20 m/s and a range of rotor speeds from 5 rpm to 20 rpm are used in a reduced-order model of the flow-generated sound in the trailing edge turbulent boundary layer. The equivalent lumped acoustics sources are predicted based on the turbulent flow simulations, and acoustic spectra are calculated using acoustic ray tracing. Each case is evaluated based on the changes detected

when damage is present. These results can be used to identify wind farms that would most benefit from this monitoring system to increase efficiency in deployment of turbines.

1:00 PM 02-Aug-2021 **IN21_2264.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2264

Energy fluctuations in recorder pipes during transient sound attacks and steady state sound

Hirofumi Onitsuka, Tetsuro Shoji, Katsuya Uchida, Akira Miki

The evaluation of temporal and spatial fluctuations of energy using compressible fluid analysis is proposed as an effective method to clarify the fundamental mechanism of the self-sustained oscilla-tions in a actual recorder. The main factors of the self-sustained oscillations are investigated in more detail by evaluating not only the steady state of the sound where the flow field and the sound field are completely coupled, but also the characteristics at the attack transient of the sound before the coupling is established. By analyzing the large energy fluctuations that occur just below the edge of the labium in the attack transient, it was shown that this phenomenon may be one of the main causes of the self-sustained oscillations. And the characteristics of the energy fluctuations and sound power generation during the steady state of the sound are discussed. It was also focused on the energy variations in another region that is near the exit of the windway.

Session: 01.02 Computational Methods in Flow-Induced Noise & Vibration, Part 2
Channel 1

7:20 PM 02-Aug-2021 **IN21_2467.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2467

Two-step computational aeroacoustics approach for underhood cooling fan application

Parag Chaudhari, Jose Magalhaes, Aparna Salunkhe

Aeroacoustic noise is one of the important characteristics of the fan design. Computational Aeroacoustics (CAA) can provide better design options without relying on physical prototypes and reduce the development time and cost. There are two ways of performing CAA analysis; one-step and two-step approach. In one-step CAA, air flow and acoustic analysis are carried out in a single software. In two-step approach, air flow and acoustic analysis are carried out in separate software. Two-step CAA approach can expedite the calculation process and can be implemented in larger and complex domain problems. For the work presented in this paper, a mockup of an underhood cooling fan was designed. The sound pressure levels were measured for different installation configurations. The sound pressure level for one of the configurations was calculated with two-step approach and compared with test data. The compressible fluid flow field was first computed in a commercially available computational fluid dynamics software. This flow field was imported in a separate software where fan noise sources were computed and further used to predict the sound pressure levels at various microphone locations. The results show an excellent correlation between test and simulation for both tonal and broadband components of the fan noise.

7:40 PM 02-Aug-2021 **IN21_1330.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1330

Turbulent model validations with CFD/wind tunnel test and application to SEA for wind noise prediction

Kai Aizawa, Susumu Terakado, Masashi Komada, Hidenori Morita, Richard DeJong, Steve Sorenson

Wind noise is becoming to have a higher priority in automotive industry. Several past studies investigated whether SEA can be utilized to predict wind noise by applying a turbulent spectrum model as the input. However, there are many kinds of turbulent models developed and the appropriate model for input to SEA is still unclear. Due to this, this paper focuses on clarifying an appropriate turbulent model for SEA simulation. First, the input turbulent pressure spectrum from five models are validated with wind tunnel tests and CFD. Next, a conventional numerical approach is used to validate models from the aspect of response accuracy. Finally, turbulent models are applied to an SEA model developed for a wind tunnel, and the SEA response is validated with test data. From those input/response validations, an appropriate turbulent model is investigated.

8:00 PM 02-Aug-2021 **IN21_3067.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3067

Wake-body interaction Noise Simulations by Coupling CFD and BEM

Masaaki Mori

In many engineering applications, the wake-body interaction or body-vortex interaction (BVI) occurs. In the wake-body interaction, vortices shed from an upstream obstacle interact with downstream obstacle and generate noise, for example blades in a turbomachinery, tubes in a heat exchanger, rotating blades like a helicopter and wind turbine and so on. The rod-airfoil and airfoil-airfoil configurations are typical models for the wake-body interaction. A rod and an airfoil are immersed upstream of the airfoil. In this paper, we reviewed the noise mechanism generated by the wake-body interaction and show the numerical results obtained by the coupling method using commercial CFD and acoustic BEM codes. The results shows that depending on the spacing between the rod or airfoil and the airfoil, the flow patterns and noise radiation vary. With small spacing, the vortex shedding from the upstream obstacle is suppressed and it results in the suppression of the sound generation. With large spacing, the shear layer or the vortices shed from the upstream obstacle impinge on the downstream obstacle and it results in the large sound generation. The dominant peak frequency of the generated sound varies with increasing of the spacing between the two obstacles.

8:20 PM 02-Aug-2021 **IN21_2675.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2675

Investigation into effects of side-window rubber sealer on cabin interi-or noise due to external flow disturbances of vehicle

Sangheon Lee, Songjune Lee, Cheolung Cheong, Hyerin Kwon, Changman Seo

Electric vehicles' rapid commercialization increases the relative importance of wind noise, especially for cabin interior noise. In this study, systematic numerical methods are developed to assess the wind noise insulation performance of side-window rubber seals in a design stage. First, the simplified automotive cabin model (SACM) is constructed to test the rubber seals' sound insulation performance due to external flow disturbance generated by jet flow. The pressure signals due to the jet flow are measured inside and outside the SACM. The difference between the two signals is used as sound insulation performance criteria, so-called insertion loss (IL). Second, a numerical methodology is developed to predict the IL. The surface pressure field on the side window due to jet flow is predicted by using the high-accurate Lattice Boltzmann Method. The predicted surface pressure fluctuations are applied as input load causing side-window vibration. The interior sound is then computed by using the calculated window vibration as input. The validity of numerical methods is confirmed by comparing the predicted results with the measured ones. Finally, the present methods' ability as a design tool is confirmed by comparing the IL of the pad-added rubber seal with that of the regular seal.

8:40 PM 02-Aug-2021 **IN21_1787.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1787

Implementation of Direct Acoustic Simulation using ANSYS Fluent

Dennis Huang, Zhigang Yang, Randolph Chi Kin Leung

Direct Acoustic Simulation (DAS) is a powerful Computational Aero Acoustics method that obtains hydrodynamic and acoustic solutions simultaneously by solving compressible Navier-Stokes equation together with state equation of ideal gas. Thus, DAS has advantages for cases with flow acoustic coupling and high Mach numbers (). With an increasing demand of massive-scale calculations, a robust numerical solver for DAS is required. ANSYS Fluent is a suitable CFD platform with proven robustness. However, there is no direct implementation of DAS in the current version of ANSYS Fluent. The present study, therefore, aims to investigate an approach for implementing DAS using ANSYS Fluent. Given the acoustic part of fluctuations is much smaller than the hydrodynamic part in amplitude, a DAS solver requires high accuracy and low dissipation. Based on these needs, proper solution methods, spatial discrete methods and boundary conditions are firstly determined through simple calculations of two dimensional propagating plane waves. Afterwards aeroacoustics of a two-dimensional cavity flow at 0.6 is calculated to verify the capability for solving separating flow with the aforementioned set-up. Finally, aeroacoustics of a cylindrical bluff body at a turbulent regime and 0.2 is calculated in three-dimensions to verify the capability for solving turbulent flow using Monotonically Integrated Large Eddy Simulation.

Session: 01.01 Fan and Turbomachinery Noise, Part 1
Channel 2

6:00 AM 02-Aug-2021 **IN21_1380.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1380

Optimization of Low Noise Blade of Small Axial Fan at Low Reynolds Number

Peixun Yu, Junqiang Bai, Xiao Han

A multidisciplinary optimization design to simultaneously enhance the aeroacoustic and aerodynamic performance of an cooling fan is performed. The flow analysis of the cooling fan is conducted by solving three dimensional steady-state RANS equations with shear-stress transport turbulence model. Based on the results of the steady flow, aeroacoustic analysis is performed by using the Hanson and Brooks model. A multi-objective optimization is performed to simultaneously improve the efficiency and reduce the sound pressure level through an improved non-dominated sorting gentic algorithm. A Kriging surrogate model is used to approximate the function value while reducing computational cost. Series of optimum designs on the pareto front yielded increases in efficiency and decreases in the sound pressure level compared to the reference design. Through numerical analysis and experimental test, the aerodynamic efficiency is increased by 5% and the total sound pressure level is reduced by 4dB without loss of air volume for the selected optimized cooling fan. The thining of rotor boundary layer and inward load shift are the main factors to improve aerodynamic efficiency and reduce noise of the cooling fan.

6:20 AM 02-Aug-2021 **IN21_1578.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1578

Aeroacoustic simulation of a cross-flow fan using lattice Boltzmann method with a RANS model

Kazuya Kusano, Masato Furukawa, Kenichi Sakoda, Tomoya Fukui

The present study developed an unsteady RANS approach based on the lattice Boltzmann method (LBM), which can perform direct aeroacoustic simulations of low-speed fans at lower computational cost compared with the conventional LBM-LES approach. In this method, the k-ω turbulence model is incorporated into the LBM flow solver, where the transport equations of k and ω are also computed by the lattice Boltzmann method, similar to the Navier-Stokes equations. In addition, moving boundaries such as fan rotors are considered by a direct-forcing immersed boundary method. This numerical method was validated in a two-dimensional simulation of a cross-flow fan. As a result, the simulation was able to capture an eccentric vortex structure in the rotor, and the pressure rise by the work of the rotor can be reproduced. Also, the peak sound of the blade passing frequency can be successfully predicted by the present method. Furthermore, the simulation results showed that the peak sound is generated by the interaction between the rotor blade and the flow around the tongue part of the casing.

6:40 AM 02-Aug-2021 **IN21_2507.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2507

Reduced order model analysis to identify possible aerodynamic noise sources of small axial fan: POD and CNN

Wataru Obayashi, H. Aono, T. Tatsukawa, K. Fujii, K. Takemi

This paper reports computational analysis of location and strength of sound source of the noise generated by a small axial fan widely used as an air-cooling system. High-fidelity Navier-Stokes simulations with high-resolution compact scheme are conducted with an implicit Large Eddy Simulation (LES) method on a HPC system and the resultant large-scale data confirms existence of unsteady vortex structures and their interactions around the impellers, boss and casing of the fan. To identify location and strength of the sound sources, reduced order model analysis is conducted for the distribution of pressure fluctuations in space and time. Snapshot POD (Proper Orthogonal Decomposition) analysis both in time and in circumferential direction, together with conventional FFT analysis, identifies location and strength of the sound sources. In addition, Convolutional Neural Network (CNN) is attempted, which shows more physical mode decomposition and separates some of the important features shown in the snapshot POD analysis. The study shows that the two data-mining techniques considered here identify possible aerodynamic noise sources of the axial fan clearly in comparison to those in the previous studies.

7:00 AM 02-Aug-2021 **IN21_2667.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2667

Development of virtual fan flow and acoustic performance testers based on RANS solvers and acoustic analogy

Seo Yoon Ryu, Cheolung Cheong, Jong Wook Kim, Byung il Park

As the potential of computational resources dramatically increases, the so-called computer-aided engineering readily replaces experiment-based engineering in related industrial fields. In this study, the virtual fan flow and acoustic performance testers are developed using the RANS solvers and the acoustic analogy. Two types of forward-curved centrifugal fans are selected for numerical and experimental investigations into its flow and acoustic performances. First, to experimentally evaluate the performances of the centrifugal fan units, their P-Q curves and sound power levels are measured using a fan flow performance tester and a semi-anechoic chamber, respectively. Second, the virtual fan flow and acoustic performance testers are constructed using the RANS solvers and the acoustic analogy based on the FW-H equation and CFD method. The validity of the current virtual methods is confirmed by comparing the prediction results with the measured ones. During the validation, the effects of the wall functions, y+ distribution, and turbulence models on predicted flow performance accuracy are closely examined. The effects of the integral surfaces used for the computation of the FW-H equations are also assessed on the predicted spectral levels of sound pressure.

Session: 01.01 Fan and Turbomachinery Noise, Part 2
Channel 2

7:20 AM 02-Aug-2021 **IN21_2481.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2481

Design of axial flow fans for reduced noise and improved efficiency

Erika Quaranta, Malcolm Smith

Axial flow fans are used in a wide variety of applications, from cooling systems for electronics to ventilation in buildings. Whatever the application, there will be competing design constraints which make it difficult to achieve the required pressure-flow performance characteristic, within a specified space envelope, whilst meeting a target aerodynamic efficiency and noise level.

This paper describes a design methodology for optimizing aerodynamic performance and noise. It is based on use of a semi-analytic 2-D design tool for preliminary predictions and design, combined with a 3-D numerical CFD analysis to visualize the flow. Both models can be extended to the design of multi-stage systems.

The 2-D model predicts the flow velocity at the trailing edge of the blades for each point on the fan performance curve, which is then used to estimate self-noise characteristics of the rotor using a classical model of airfoil trailing edge noise. The CFD analysis provides detailed validation of assumed airfoil characteristics, including the effect of 3D design features such as blade sweep, and confirms the flow and aerodynamic efficiency predictions; it can also used to estimate parameters such as turbulence intensity that is a key driver for the noise level.

7:40 AM 02-Aug-2021 **IN21_1809.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1809

Numerical simulations of flow induced noise from a dual rotor cooling fan used in electronic cooling systems

Sahan Wasala, Sahan Wasala, Yutong Xue, Lon Stevens, Tim Persoons

Hard Disk Drive (HDD) system enclosures in a data center require effective cooling systems to avoid HDD overheating. These systems often rely on air cooling because of their cost efficiency and maintainability. Air cooling systems typically consist of an array of axial fans which push or pull the air through the system. These fans emit high level tonal noise particularly at high tip-speed ratios (TSR). High-capacity HDDs, on the other hand, are sensitive to high acoustic noise, which consequently increases the risk of read/write error and deteriorates drive performance. Therefore, cooling fan noise adversely affects the function of the HDD enclosure systems and emphasizes the need to understand the noise sources and develop methods to mitigate HDD noise exposure. This study focuses on understanding the aerodynamic properties and related aeroacoustic behavior of a contra-rotating fan representative of the types used in a modern data center cooling system. A numerical investigation was conducted using high fidelity Large Eddy Simulation (LES) and the Ffowcs Williams and Hawkings (FW-H) acoustic analogy, as well as using experimentally measured acoustic data as a validation. Initial simulation results showed a good agreement with the experimental data and led to a better understanding of noise directivity.

8:00 AM 02-Aug-2021 **IN21_1666.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1666

Computationally efficient source grid selection and source interpolation in computational aeroacoustics applied to an axial fan.

Andreas Wurzinger, Manfred Kaltenbacher, Stefan Schoder

The noise generation of an axial fan is mainly caused by flow-induced noise and can therefore be extracted from its aeroacoustics. To do so, a hybrid approach separating flow and acoustics is well suited due to its low Mach number. Such a computationally efficient hybrid workflow requires a robust conservative mesh-to-mesh transformation of the acoustic sources as well as a suitable mesh refinement to guarantee good convergence behavior. This contribution focuses on the mesh-to-mesh transformation, comparing two interpolation algorithms of different complexity towards the applicability to the aeroacoustic computation of an axial fan. The basic cell-centroid approach is generally suited for fine computational acoustic (CA) meshes and low phase shift, while the more complex cut-volume method generally yields better results for coarse acoustic meshes. While the cell-centroid interpolation scheme produces source artifacts inside the propagation domain, a grid study using the grid convergence index shows monotonic convergence behavior for both interpolation methods. By selection of a proper size for the source grid and source interpolation algorithm, the computational effort of the experimentally validated simulation model could be reduced by a factor 4.06.

8:20 AM 02-Aug-2021 **IN21_3114.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3114

Effects of moisturized inflow on compressor performance and aerodynamic noise

Changhong Sun, Yipeng Cao, Chen Liu

The effects of moisturized inflow on turbocharger compressor performance and aerodynamic noise were numerical analyzed in this paper. The gas-liquid two-phase flow method based on Euler-Lagrange model was firstly introduced. The influence of water concentration and water droplet diameter on compressor performance and internal flow characteristics at design speed were studied using the two-phase flow method. The compressor aerodynamic noise was also predicted at design condition under two different inflow conditions, including ideal inflow and moisturized inflow with 0.1% water concentration. The results indicate that moisturized inflow with an appropriate water concentration can reduce the outlet temperature of the compressor and improve the compressor performance, in which the water concentration is a dominant parameter. There is a phase transition process of water in the compressor with moisturized inflow, but moisturized inflow has little effects on the compressor internal flow characteristics. Moreover, the moisturized inflow also has influence on compressor aerodynamic noise.

8:40 AM 02-Aug-2021 **IN21_1414.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1414

Lighthill's analogy applied to a automotive turbocharger compressor

Clemens Freidhager, Martin Heinisch, Andreas Renz, Stefan Schoder, Manfred Kaltenbacher

Computing transient CFD simulations of turbocharger compressors is computationally very demanding. It is of fundamental importance to resolve turbulent structures at the location of their generation and to establish a fine enough grid to allow propagation of the resolved structures. This results in high-resolution grids, existing of more than 20 million cells. Applying Lighthill's analogy, it is possible to only resolve turbulent structures at their location of generation and compute the pressure propagation by using an additional, not that demanding, acoustic grid. This allows using coarser CFD grids in the inlet and outlet section. For transferring Lighthill's source terms from the CFD to the acoustic grid, advanced interpolation algorithms are used. The simulation results are validated by measurements of a cold gas test rig are considered.

Session: 02.00 Vibro-acoustics and Structure-borne Noise, General
Channel 2

11:00 AM 02-Aug-2021 **IN21_1730.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1730

Vibration of a stiffened pipe filled with a bubbly liquid: analysis of resonance frequencies in function of bubble fraction

Sanae Serbout, Laurent Maxit, Frédéric Michel

The characterization of the presence of bubbles in industrial fluid circuits may be extremely important for many safety issuses. It is well known that the acoustic properties of liquids can be drastically modified by a small amount of gaz content in the liquid. At sufficiently low frequencies, the speed of sound depends primarily on the gas volume fraction. The variation of the gas fraction may then induce some variations in the vibroacoustic behavior of the pipe transporting the liquid. Analysis of the pipe vibrations can then help in the monitoring of the bubble presence. In such a context, the aim of this study is to show how the the presence of bubbles in the liquid could affect the resonance frequencies of the pipe. A numerical vibroacoustical model has been developed to predict the vibroacoustical behavior of a stiffened cylindrical shell filled with a bubbly liquid exhibiting low frequency resonances. The model, experimentally verified with a well-characterized bubbly liquid, is then used to analyse the frequency shifts of the shell resonances in function of the bubble.

Keywords : pipe, heavy fluid, numerical modelling, circumferential admittance approach, cylindrical shell, resonance frequency, void fraction

11:20 AM 02-Aug-2021 **IN21_2389.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2389

Acoustic analysis of impact sound on vibrating circular membranes

Evaggelos Kaselouris, Chrysoula Alexandraki, Yannis Alexandraki, Makis Bakarezos, Michael Tatarakis, Nektarios A. Papadogiannis, Vasilis Dimitriou

A finite element method (FEM) - boundary element method (BEM) model is developed to compute the sound generated by of a force acting on a circular membrane (drumhead). A vibro-acoustic analysis that combines modal FEM analysis, a FEM steady state dynamic analysis (SSD), considering harmonic loading and boundary element acoustics, is performed. The drumhead vibrates due to the force impact and the sound is emitted in the air. The vibration of structural response is initially computed, and the obtained results are set to be the boundary conditions of the acoustic analysis in the vibro-acoustic simulation. The radiated sound can be computed at any point of the solution domain. Various materials used by drumhead manufacturers are tested and a parametric analysis focusing on the mesh density of the models is presented. The impact sound and the acoustical characteristics of the simulated test cases are evaluated. The Rayleigh method is also applied to the acoustic simulations and is further compared to the BEM simulation results. The outcomes of this study may be further used as reverse engineering inputs, to machine learning models for the estimation of the physical and mechanical parameters of drumheads from audio signals.

11:40 AM 02-Aug-2021 **IN21_2221.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2221

Experimental sound power from curved plates using the radiation resistance matrix and a scanning vibrometer

Trent Bates, Ian C. Bacon, Caleb B. Goates, Scott D. Sommerfeldt

Vibration-based sound power (VBSP) methods based on elemental radiators and measurements from a scanning vibrometer have been shown to be accurate for flat plates and cylinders. In this paper, the VBSP method is extended to account for simple curved structures, with a constant radius of curvature. Data are also presented that suggest the VBSP method is more accurate than the ISO 3741 standard for measuring sound power when significant background noise is present. Experimental results from ISO 3741 and the VBSP methods are compared for three simple curved plate structures with different radii of curvature. The results show good agreement for all three structures over a wide frequency range. The experimental results also indicate that the VBSP method is more accurate in the low frequency range where the curved plates radiated relatively little and significant background noise was present.

12:00 PM 02-Aug-2021 **IN21_2387.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2387

Influence of the plate thickness and material properties on the violin top plate modes

Evaggelos Kaselouris, Yannis Orphanos, Makis Bakarezos, Michael Tatarakis, Nektarios A. Papadogiannis, Vasilis Dimitriou

In this paper we analyze the vibrational behavior of the violin top plate, for varying plate thickness and material properties via finite element method (FEM) numerical simulations. It is well known that the vibrational properties of the top plates of string instruments influence their sound emission characteristics. Due to the impact of global warming on wood formation and due to their configurability, many manufacturers investigate the use of composite materials to produce musical instruments. Therefore, composite, carbon fiber reinforced epoxy (CFRE) prepreg along with traditional wooden material, such as spruce, are adopted in this study. FEM modal analysis along with a frequency response function (FRF) FEM analysis are performed. The vibrational variations of the plate's response are computed under free conditions. The main vibrational modes and the natural frequencies obtained by the simulations show the influence of the different mechanical and geometric properties on the top plate's vibrational response. The resulting eigenmode frequencies and shapes of the plate in relation to the varying thickness and the material properties used, are discussed. The results of this study offer valuable information on the evaluation of the acoustical characteristics of violins and may be further used on their vibrational behavior optimization and control.

12:20 PM 02-Aug-2021 **IN21_3246.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3246

Simulation of rubber grommets and correlation with test at low frequencies

Caoyang Li, David Herrin, John Baker, Asad M. Sardar

Residential air conditioning units include several sources which can lead to vibrational and noise issues. The most important structure-borne source is the compressor which controls the noise and vibration in certain frequency ranges. Compressors are mounted on four relatively stiff rubber grommets which partially isolate the basepan from the compressor motion while also ensuring that the compressor does not move too much. In this work, the grommets are simulated using the finite element method and results are correlated with measurement results with good agreement. It is demonstrated that the hyperelastic properties of the grommets should be increased due to the Payne effect to improve correlation.

12:40 PM 02-Aug-2021 **IN21_2661.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2661

Shaping acoustic radiation induced by vibrotactile rendering on a touch surface

Sangwon Park, Wheejae Kim, Dongjoon Kim, No-Cheol Park

Many electronic devices with touch-sensitive surfaces aim to provide vibrotactile feedback, along with visual or auditory feedback, to facilitate the interaction between the user and the interface. In parallel to these efforts, recent studies developed various vibration rendering techniques, enabling more complex vibration patterns to be generated on the touch surface. However, few have addressed sound radiation induced by vibrotactile rendering on a touch surface, which could significantly impact the haptic interaction's overall perception. This study presents a method to shape the acoustic radiation due to rendering high-fidelity vibrotactile feedback on a touch surface. The proposed method utilizes measured frequency response functions and a vibroacoustic representation of the touch surface to define the relationship

between actuator driving signals, vibration responses on the touch surface, and radiated sound power. Proper actuator driving signals are derived from the optimization problem formulated using the relationship. The proposed method was demonstrated through vibration rendering experiments on a touch surface comprising an acrylic plate and voice coil actuators. The results showed that the proposed method could shape the acoustic radiation while rendering target vibration patterns at desired positions on the touch surface. This study's proposed method could allow haptic engineers to design vibrotactile feedback and sound radiation simultaneously for a more compelling haptic experience.

Session: 04.00 Signal Processing, Measurements, Sound Reproduction, Diagnostics for Noise and Vibration Engineering, General, Part 2
Channel 2

2:40 PM 02-Aug-2021 **IN21_1035.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1035

Research on the Layout Optimization of Acoustic Radiation Power Flow Reinforcement Based on Weight-Guide method

Xiaoyan Teng, Qiang Li, Xudong Jiang, Zhihua Yan

In order to reduce the noise radiation of the plate and shell structure, the Weight-Guide method is used to optimize the layout of stiffeners for acoustic radiation power flow. Firstly, Rayleigh integral method and Helmholtz equation are used to derive the acoustic radiation power flow, and the sensitivity is calculated by using explicit approximation technique, which takes the acoustic power flow as the objective function. Secondly, the guide weight method is used to update the design variables to optimize the layout of stiffeners and change the shape of the vibration structure, so as to transform the structure into a weak radiator to reduce the radiated sound power. Finally, the optimized structure can optimize the frequency of the partial frequency band reduction by the analysis of numerical examples, and at the same time, the full band optimization of the sound power spectrum can be achieved by changing the number and position of the peaks.

3:00 PM 02-Aug-2021 **IN21_1950.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1950

Determination of tonal signal parameters based on zero crossing detection

Michal Luczynski, Stefan Brachmanski, Andrzej Dobrucki

This paper presents a method for identifying tonal signal parameters using zero crossing detection. The signal parameters: frequency, amplitude and phase can change slowly in time. The described method allows to obtain accurate detection using possibly small number of signal samples. The detection algorithm consists of the following steps: frequency filtering, zero crossing detection and parameter reading. Filtering of the input signal is aimed at obtaining a signal consisting of a single tonal component. Zero crossing detection allows the elimination of multiple random zero crossings, which do not occur in a pure sine wave signal. The frequency is based on the frequency of transitions through zero, the amplitude is the largest value of the signal in the analysed time interval, and the initial phase is derived from the moment at which the transition through zero occurs. The obtained parameters were used to synthesise a compensation signal in an active tonal component reduction algorithm. The results of the algorithm confirmed the high efficiency of the method.

3:20 PM 02-Aug-2021 **IN21_2246.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2246

Sound power and sound energy measurements using an ellipsoidal measurement surface

Edward Zechmann

To support purchasing low noise products, sound power and sound energy measurements of sufficient quality need to be routinely made by consumers on a global scale. Sound power measurements using ISO 3744, 3745, and 3746 are conducted in a free field using an acoustic far-field approximation of the intensity integrated over an enveloping measurement surface. Sound power and sound energy measurements generally use a hemispherical, parallelepiped, or cylindrical measurement surface. Those measurement surfaces have limitations and assume that the measurement points lie on the measurement surface often in preferred positions. An alternative approach is to choose microphone positions that optimally satisfy the assumptions of the measurement. The measurement surface should then be fit to the chosen microphone positions. Regression methodologies are available for fitting ellipsoids. The number of microphone positions can be as few as three to fit an ellipsoid. An ellipsoidal measurement surfaces can abut zero, one, two, or three orthogonal reflecting planes. Correction equations for the microphone locations and the angle errors for the microphone orientation and wave propagation direction are shown. This paper will present simulations of sound power, sound energy, and corrections for environmental reflections for ISO 3745 and other measurement surfaces.

3:40 PM 02-Aug-2021 **IN21_3510.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3510

Experimental determination of the acoustical effects of face masks on speech effort

Noah Schumaker, Andrew Barnard

The COVID-19 pandemic has led to a global trend in mask wearing. This study investigates how wearing face masks influence the output levels of the human vocal range. Masks were equipped onto a test fixture to evaluate acoustic insertion loss over whole-octave bands important for vocal transmission. With the exception of face shield, tested masks showed less than 2 dB of insertion loss at frequencies less than 2 kHz and up to 5 dB of attenuation at frequencies above 2 kHz. The face shield showed insertion loss of more than 10 dB in the 4 and 8 kHz octave bands.

Session: 13.13 The Future of Building Acoustics Measurements and Modelling
Channel 2

4:20 PM 02-Aug-2021 **IN21_1781.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1781

Formulation and evaluation of a composite acoustic objective incorporating air-borne and structure-borne transmission loss for optimization of building components

Jonathan Broyles, Micah R. Shepherd, Nathan C. Brown

Technological advancements in computational building modeling have enabled designers to conduct many simulations at both the building and component levels. With the evolution of parametric modeling at the early stage of building design, designers can evaluate multiple design options and identify the best performing solutions. However, to conduct design space exploration or optimization, an objective function is needed to evaluate a design's performance. While defined objectives exist for building design considerations such as sustainability, energy usage, and structural performance there is not a single, encompassing objective that can accurately assess acoustic performance for optimization. This paper proposes the development of a novel acoustic objective function that encompasses sound transmission when designing floors, walls, or other acoustic barriers. The composite function will incorporate both air-borne and structure-borne sound simultaneously to determine the appropriate percentages for the formulation of the composite function. The results of the composite acoustic function for multiple floor constructions will be compared for the determination of a final acoustic transmission composite function. This study will detail why the implementation of a composite acoustic function is valuable for design optimization for sound transmission, what the limitations of this method are, and future applications of a composite acoustic function.

4:40 PM 02-Aug-2021 **IN21_1908.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1908

Analytical model of the diffuse sound transmission loss of finite double panel structures

Javier Vazquez Torre, Jonas Brunskog, Vicente Cutanda Henriquez

An analytical model for the forced sound transmission loss of finite single-leaf walls using a variational technique was previously developed and validated. As the double panel is one of the most used structures in building acoustics, the aim of this paper is to extend the analytical model to consider double panel structures. Analytical formulas for the forced part of the airborne sound insulation of finite sized double panel structures are derived using a variational technique based on the integral-differential equation of the fluid loaded panels. The formulas are valid in the entire audible frequency range. The results are compared to alternative analytical models and measurements, with reasonable agreement.

5:00 PM 02-Aug-2021 **IN21_1384.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1384

Acoustic design tools for estimation of sound insulation performance of wood wall and floor assemblies

Cheng Qian, Lin Hu, Christian Dagenais, Sylvain Gagnon

The National Building Code of Canada 2015 stipulates the minimum requirements of the airborne sound insulation transmission through common interior walls and ceiling/floor assemblies. The required minimum Apparent Sound Transmission Class (ASTC) is 47 in Canada, whereas the Impact Insulation Class (IIC) for floors is recommended to be higher than 55. For many years, significant efforts were made to develop sound insulation prediction models or tools to predict the sound insulation performance of wall and floor/ceiling assemblies at the design phase in order to meet the requirements and the recommendations made by codes. However, today few models can provide a reliable acoustics design tool. In this document, three prediction tools thought to be practically useful are presented and evaluated. Between these three prediction tools, one is an analytical model of the Insul software while the other two are empirical models developed by the National Research Council of Canada and the American Wood Council. This paper compared the STC and IIC ratings of wood wall and floor assemblies estimated by these three models and verified them by the measured STC and IIC ratings. This work aims at providing an idea for readers to choose a suitable design tool to proceed with their acoustic designs.

5:20 PM 02-Aug-2021 **IN21_2619.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2619

A Sound Insulation Prediction Model for Floor Structures in Wooden Buildings Using Neural Networks Approach

Mohamad Bader Eddin, Sylvain Menard, Delphine Bard, Jean-Luc Kouyoumji, Nikolas-Georgios Vardaxis

Recently, machine learning and its applications have gained a large attraction in different fields. Accurate predictions in building acoustics is vital especially in the design stage. This paper presents a sound insulation prediction model based on Artificial Neural Networks (ANNs) to estimate acoustic performance for airborne and impact sound insulation of floor structures. At an initial stage, the prediction model was developed and tested for a small amount of data, specifically 67 measurement curves in one third octave bands. The results indicate that the model can predict the weighted airborne sound insulation for various floors with an error around 1 dB, while the accuracy decreases for the impact sound especially for complex floor configurations due to large error deviations in high frequency bands between the real and estimated values. The model also shows a very good accuracy in predicting the airborne and impact sound insulation curves in the low frequencies, which are of higher interest usually in building acoustics.

5:40 PM 02-Aug-2021 **IN21_1757.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1757

An explicit time-domain FEM for acoustic simulation in rooms with frequency-dependent impedance boundary: Comparison of performance in 2D simulation with frequency-domain FEM

Takumi Yoshida, Takeshi Okuzono, Yui Sugimoto, Kimihiro Sakagami

Accurate boundary modelings that address the frequency-dependent sound absorption characteristics of various sound absorbers are crucial for wave-based room acoustic simulation. In time-domain simulations, however, a computationally demanding convolution appears in frequency-dependent impedance boundary conditions. The present paper proposes a room acoustic solver with a fourth-order accurate explicit

TD-FEM, incorporating a frequency-dependent absorbing boundary condition efficiently using a recursive convolution method, namely the auxiliary differential equation (ADE) method. Its performance against the fourth-order accurate frequency-domain FEM is examined via 2D real-scale room acoustic problems, solving a sound propagation in an office room up to 4.5 kHz. Firstly, we describe briefly the formulation of the proposed room acoustics solver based on the explicit TD-FEM. Then, the discretization error property of the proposed method is evaluated via an impedance tube problem, including a frequency-dependent impedance boundary of porous sound absorber. Finally, the accuracy and efficiency of the proposed method are demonstrated with the comparison of frequency-domain FEM solver, which uses a sparse direct solver for the solution of the linear system at each frequency. Results showed the proposed method can perform an acoustic simulation with significantly low computational costs compared to the frequency-domain solver while keeping an acceptable level of accuracy.

Session: 13.01 Acoustic Regulations and Classification for Buildings, Part 1
Channel 2

7:20 PM 02-Aug-2021 **IN21_2531.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2531

Audibility of emergency broadcasting sound in a mechanical room in an office building

Jeongho Jeong

Fire alarm and emergency broadcasting sound are important in fire and disaster situations. For the clear presentation of the fire alarm and emergency broadcasting sound to occupants of buildings, some guidelines and requirements were established. In NFPA 72 and BS standard, a specific alarm sound level for alarm sound of residential facilities was proposed and Speech Transmission Index(STI) was regulated for the emergency broadcasting system. In the fire and disaster situation, one of the important facility is a mechanical and electrical system to maintain water and electricity supply. To maintain this function in the buildings, clear presentation of emergency broadcasting sound to the workers in the mechanical and electrical room is crucial for the emergency operation of the system. In this study, the noise level in the mechanical rooms and electricity facilities of more than 40 years old office building were measured. Also, audibility and room acoustic properties such as reverberation time and STIwas simulated using Odeon 12. In order to deliver emergency broadcasting sound more clearly, sound absorption material and a soundproof chamber for noisy devices are needed. Also, the emergency broadcasting system in noisy facilities should be improved to produce the broadcasting sound louder and clearer.

7:40 PM 02-Aug-2021 **IN21_3054.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3054

Brazilian BIM Objects Technical Standard: a first approach on Acoustics parameters

Paola Weitbrecht, Carolina Monteiro, Cecilia Jardim

The Building Information Modeling (BIM) has increased worldwide as a new approach on the building design, construction, and facilities management. Given this panorama, the Brazilian Government enforced a regulation in 2019, Decreto 9983, which outlines a roadmap for the BIM implementation in the Brazilian construction ecosystem. As one of its guidelines is to publish the necessary technical standards, a special committee, ABNT CEE 134, was hosted at the Brazilian organization for Technical Standardization with a dedicated WG for establishing BIM objects parameters. In the framework of the WG, a subgroup on Acoustics analysis aimed to deal on how to incorporate acoustic requirements to the BIM Object. In this paper, the authors describe the development of this feature, unprecedented so far. The approach adopted for incorporating acoustic requirements into BIM objects at the Brazilian BIM Standard aimed to facilitate the workflow of acoustic consulting, while adapting it to the limitations imposed by the existing software and the construction market culture in Brazil. This paper also provides some guidelines on how this issue could be addressed in future standards revisions.

8:00 PM 02-Aug-2021 **IN21_3063.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3063

The Brazilian performance standard revision. Sumary and next steps

Marcos Holtz, Davi Akkerman, Carolina Monteiro

In 2019, the Brazilian Standard NBR 15575: 2013 start a periodical revision process. This standard presents performance criteria for dwellings, such as acoustic, thermal, lighting, durability, etc. During this first enforcement period, some requirements result in divergent interpretations, e.g. difficulties to define the noise class, proposed as a subjective criteria. Technical groups were created to analyze the current text and propose modifications to solve these issues. This article presents an overview of the mains issues related to the acoustic requirements found in the standard. A summary of the proposals is presented, which went through a national ballot.

8:20 PM 02-Aug-2021 **IN21_3169.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3169

Impact sound transmission: experiments of control at the receiver room

Davi Akkerman, Paola Weitbrecht, Mariana Shieko, Marcel Borin, Leonardo Jacomussi

Considering Impact sound level requirements accomplishment in Brazil, floating floors are still considered as an inviable solution for building companies due to the implications in the total cost of building, mainly for social housing. Alternative and sometimes cheaper solutions are those undertaken in the receiver room. However, the lack of laboratory and field tests on the acoustic performance of this type of system is still a barrier for acoustic designing in Brazil. The aim of this paper is to study and validate different constructive solutions developed jointly with building companies for improving the impact sound insulation performance on the receiving room of new Brazilian housing constructions.

8:40 PM 02-Aug-2021 **IN21_3236.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3236

A proposal for standard methods and criteria for the assessment of residential noise complaints

Mihkel Toome, Steve Meszaros

Acoustical consultants often receive inquiries regarding noise complaints, particularly from occupants of multi-unit residential buildings. The noise complaints are typically regarding building services noise, other transient noises caused by the building or building elements, or due to noise from neighbours. While guidelines with respect to “acceptable” noise intrusion and levels for some sources exist, often the guideline criteria are not applicable, and the assessment must be based on proposed criteria by the acoustical consultant. This can leave uncertainty and ambiguity in terms of what is and what is not a valid noise complaint. The development of a standard procedure and criteria for the assessment of noise complaints would be a significant undertaking, but would be invaluable to acoustical engineers, multi-unit residential strata/condominium/co-op board members, property management, and the general public. This paper reviews relevant literature, outlines the major components for consideration in the development of a standard procedure and criteria, and will put forth a recommended framework for a standard approach.

Session: 08.01 Vehicle Noise and Vibration, Part 1
Channel 3

6:00 AM 02-Aug-2021 **IN21_1718.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1718

NEMO project: acoustic detection of vehicle engine speed

Truls Svenn Berge, Viggo Henriksen

As part of the EU Horizon2020 project NEMO, SINTEF has developed an algorithm to detect the engine speed of passing vehicles. Some road vehicles can emit abnormal high noise levels or high levels of exhaust gases in urban conditions. The high noise level can be related to aggressive driving (high acceleration and high engine speed), to a modified or malfunctioning exhaust system, or to other vehicle defects. It is well-known that many motorcycles or mopeds often are equipped with non-original exhaust mufflers, giving high noise levels that can be a nuisance to the community. In the NEMO project, the detecting of so-called high emitters (HE) is essential to reduce the impact of such vehicles on the environment and public health. To enable to categorize HE vehicle based on the driving behaviour, it is necessary to detect both acceleration and corresponding engine speed. The paper describes the principle of the algorithm developed and results from testing on vehicles, including a motorcycle. This test shows that it is feasible to estimate the engine speed, also when the vehicle is accelerating, if the number of cylinders is available for the estimation. Further testing of the algorithm is planned within the NEMO project.

6:20 AM 02-Aug-2021 **IN21_2505.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2505

Modeling and analysis for dynamic behavior of elevator traction system under the braking of safety gear

Xiaolong Ma, Peng Zhang, Ni Li, XI Shi, Huaiwu Zou

In the emergency case when the elevator car is over speeding in the downward direction, the traction car will be stopped rapidly by the braking of safety gear. However, the counterweight and the traction sheave are still moving, which maybe induces the collision between the counterweight and the traction sheave, the slip and off-track between the traction sheave and the rope. Therefore, a two sides mass-spring-damping rope model was proposed in this paper to investigate the dynamic behavior of elevator traction system under the braking of safety gear. In this model, the interaction between the car and the counterweight on both sides of the traction sheave was introduced. Meanwhile, the slip behavior and various constraints between the rope and traction sheave were respected in this model. Especially, the rope slack and the rope length change were considered to approach the mechanical properties of real rope. Furthermore, a numerical scheme based on Newmark- method was applied to solve the proposed dynamic model. Then the impacts of the braking force on the dynamic behavior of elevator traction system under different working conditions were deeply studied. Results showed the braking force of the safety gear, the speed and the acceleration of the traction sheave had great influences on the bounce of the counterweight. In fact, the braking performance, the vibrations of the car, rope and counterweight could be well analyzed based on this model, which is key for the realization of the steady and safe braking of traction elevator.

6:40 AM 02-Aug-2021 **IN21_2477.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2477

Experimental study on cushioning behaviors of foam with different skin-liked covers

Heye Xiao, Focai Yuan, Xudong Zhang, Chizhen Xu, Jie Zhou

Periodic structures were used in foams to improve their cushioning ability in previous studies, which are usually constructed by additive manufacturing methods with high cost. To improve cushioning property of the foam materials at a low cost, foams with skin covers are proposed in this paper to provide a new idea for a structural design that is inspired by the composition of animal skins. The foam without covers and covered with three different skin types, including square shape, circle shape, and Pearlfish skin, are investigated in this study. The stiffness and acceleration responses of these structures are measured by static loading and dropping test respectively, which are used to evaluate their static and dynamic cushion properties. Based on the tested results, it demonstrated that the cover skins could improve the stiffness of the foam materials and decrease acceleration response of mass fixing on them in dropping test at 0.4 m and 0.5 m. The enhancement for cushion ability of the proposed structure in this paper is proved experimentally.

7:00 AM 02-Aug-2021 **IN21_2109.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2109

Impact of a tunnel on the TL of a vehicle floor in bare and trimmed conditions and investigation on the most suitable simplified geometry able to better represent such impact

Federico Di Marco

NVH engineers are faced with the challenge of designing trim parts for vehicle interior and exterior, like inner dash insulators, carpets, underbody shields or engine encapsulations, which can be made with very different Bills of Materials (BOMs) including among others foams, felts or heavier layers. The measurables commonly used to rank various solutions are Transmission Loss (TL) and absorption. Depending on the numerical analysis method, different approaches may be considered for the evaluation of the TL of an automotive component. In particular, in Statistical Energy Analysis (SEA), automotive components are modeled as an assembly of panels having a simple shape, e.g. flat panels and/or panels with single or double curvature. Furthermore, in SEA the trim is normally modeled by means of the Transfer Matrix Method (TMM), which is essentially a 2-dimensional methodology. This paper intends to analyze in some depth the level of approximation that these practices bring with themselves, specifically in relation to the modelling of an automotive floor.
More in detail, the aim of the paper is first to investigate what impact has the presence of the tunnel on the TL of a vehicle floor in bare and trimmed conditions and then to evaluate if the presence of the tunnel can be better modeled by using a semi-cylinder or three flat plates welded together in a trapezoidal shape, both shapes considered as a reasonable simplification of the actual geometry of a typical tunnel.
The analysis is carried out at simulation level using FE. To investigate both air bone noise and structure borne noise transmission, two types of excitations are used: a diffuse acoustic pressure field applied to the entire floor surface and an imposed displacement applied to the edge of the floor surface. Furthermore, 3 different kind of trims are taken into consideration in order to analyze if and how the tunnel modeling strategy may influence the evaluation of the trim effectiveness.

7:20 AM 02-Aug-2021 **IN21_1689.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1689

Method for localisation of sound sources and aggregation to an acoustic centre

Yannik Weber, Matthias Behrendt, Tobias Gohlke, Albert Albers

Preliminary work by the IPEK - Institute of Product Engineering at KIT has shown that the simulated pass-by measurement for exterior noise homologation of vehicles has relevant optimization potential: the measurement can be carried out in smaller halls and with a smaller measurement setup than required by the norm and thus with less construction cost and effort. A prerequisite for this however is the scaling of the entire setup. For the scaling in turn, the sound sources of the vehicle must be combined to a single point sound source - the acoustic centre. Previous approaches for conventional drives assume a static centre in the front part of the vehicle. For complex drive topologies, e.g. hybrid drives, and unsteady driving conditions, however, this assumption is not valid anymore. Therefore, with the help of an acoustic camera, a method for localizing the dominant sound sources of the vehicle and a software-based application for summarizing them to an acoustic centre were developed. The method is able to take into account stationary, unsteady and sudden events in the calculation of the acoustic centre, which is moved as a result. Using substitute sound sources and two vehicles, the method and the used measurement technology were examined and verified for their applicability.

Session: 09.01 Porous Materials
Channel 3

8:20 AM 02-Aug-2021 **IN21_2493.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2493

Acoustic characterization of membranes attached to sound absorbing base materials

Juan Carlos Rodríguez Vercher, Jesús Alba, Romina del Rey

The use of membranes attached to sound absorbing materials, with the aim of modifying its absorption properties, is quite a usual practice in acoustic conditioning applications. The behavior of the final composition formed by the sound absorbing base material and the attached membrane can serve to characterize the effect of the membrane, if the properties of the base material are known. This can be of great interest for several reasons. Firstly, the difficulty to characterize the materials separately, due to the thinness of the membranes. Secondly, the effect of the binding method used between the absorbing material and the membrane (glue, seams, etc.) can modify the properties of the membrane. This work presents a model that enables us to determine the acoustic impedance of the membranes from an initial analysis of the base material and a second analysis of the composition formed by the base material with the membrane. These analyses are carried out in an impedance tube by following the ISO 10534-2 standard and the results obtained allow modeling the attached membrane effect.

8:40 AM 02-Aug-2021 **IN21_2495.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2495

Indirect determination of airflow resistance of textiles with reference samples

Juan Carlos Rodríguez Vercher, Romina del Rey, Jesús Alba

Airflow resistance is a non-acoustic parameter of great relevance in the acoustic characterization of porous materials. It is used in several sound absorbing material prediction models and it is also a control parameter for acoustic conditioning and insulation in different building solutions. The ISO 9053 standard defines several methods to obtain it, using both direct measurements and indirect techniques. However, both procedures may involve problems related to the placement of the textile samples in the tube or to the stability of the samples during testing. In this work, the use of reference materials to stabilize the measurement of thin materials is proposed. Airflow resistance results obtained for different materials in an impedance tube are presented. The tests have been carried out by following the Ingard & Dear method, as an indirect technique accepted by the standard. Several material compositions with a wide range of airflow resistance values have been analyzed with different reference materials.

Session: 05.01 Aircraft Interior Noise
Channel 3

11:00 AM 02-Aug-2021 **IN21_2671.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2671

Design, development and testing of digital MEMS pressure sensor array for full-scale vibroacoustic measurements

Pankaj Joshi, Frank Khelfa, Hendrik Lehmkuhl, Patrick Cordes, Patrick Naujoks, Thorsten Scharowsky, Kay Kochan

This manuscript addresses design, development, and application of micro-electro-mechanical systems (MEMS) based digital pressure sensor array for vibroacoustic measurements. These vibroacoustic measurements were conducted on a A320 type single aisle aircraft demonstrator subjected to broadband as well as tonal excitations. Cabin noise levels were measured with both condenser microphones as well as digital MEMS pressure sensor array. The measured cabin noise shows strong qualitative as well as quantitative agreement between both type of measurement devises for full scale cabin noise measurements inside an aircraft demonstrator. The observed strong agreement is valid for both single wall (fuselage with thermal insulation) and double wall (fuselage with thermal insulation and trim panel) cabin noise measurements. Such strong agreement within 1.0 dB tolerance is significantly motivating for further development of reliable but low-cost MEMS based measurement devises and corresponding efficient data post-processing algorithms for full scale vibroacoustic measurements in general. Additionally, it is also demonstrated that the large number of MEMS based digital pressure sensors can be used in areas where the physical space constraints are high. This demonstration shows strong potential to derive additional vibroacoustic indicator for the development and the testing of future noise control solutions in a non-traditional way.

11:20 AM 02-Aug-2021 **IN21_3228.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3228

Noise measurements in the AS 350 helicopter under the specific operating conditions of SAR mission

Felipe Gelain, Stephan Paul

The AS 350 helicopter is a small and versatile helicopter used in many countries by private and public operators. In some countries the model is also often used for SAR missions. In the Brazilian public rescue services, AS 350 helicopters account for around 80 percent of the whole fleet. SAR missions often require operating conditions different from those for usual passenger transport. This includes flying and hovering with open doors or at low altitudes and low speeds.

Noise exposure during SAR missions is of concern not only for the crew but also for the passengers, i.e. injured patients or newborn. While very important, data on acoustic conditions in SAR aircraft are scarce and do not exist for the AS 350 yet. Therefore, to investigate the noise in the AS 350 during SAR specific operating conditions different aircraft of the same model were equipped with recording equipment (microphone and SQuadriga II stand-alone front end) and flown in the specific operating conditions of SAR missions. Recordings were analyzed using not only 1/n-octave and or FFT analysis, but also variable frequency resolution Fourier analysis for better low frequency analysis and psychoacoustic models available in ArtemiS Suite v12. Results show how noise characteristics vary depending on the operation of the aircraft, and which operating conditions are the most critical and should be avoided. The data can be used by SAR operators to build noise optimized mission profiles for critical missions, such as transportation of newborn and maintaining operational safety.

11:40 AM 02-Aug-2021 **IN21_2334.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2334

Influence of mobility completeness and source behavior on the robust-ness of Transfer Path Analysis and Source Characterization methods: A numerical study.

Simon Prenant, Thomas Padois, Thomas Dupont, Olivier Doutres

Structure borne noise is considered a major contribution to the noise generated inside aircrafts. In order to analyze it, engineering methods have been developed such as Transfer Path Analysis (TPA) and Source Characterisation (SC). These methods are based on active and passive properties of the source and the receiving structure being coupled or decoupled. The theoretical formulation requires mobility according to all Degrees Of Freedom (DOFs) and rotational DOFs represent a challenge for experimental application. To fulfill the mobility matrix, indirect method have been developed and specific sensors have been proposed, resulting in a more complex experimental set-up and an increase in measurement uncertainties. The necessity of assessing the full matrix completeness is thus still questionable. The robustness of these methods with respect to the matrix completeness and the source behavior is investigated numerically in this work. A numerical model has been developed to simulate vibrating sources with simple or complex vibratory behavior and to assess the mobility matrices for any completenesses. Velocity on the receiving structure is used as a target indicator. The influence of source behavior and completeness are discussed and the results show that the required mobility completeness depends on the source behavior.

12:00 PM 02-Aug-2021 **IN21_1382.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1382

Prediction and Improvement of Aircraft Cabin Acoustics using Statistical Energy Analysis and Sound Quality Evaluation

Nurkan Turkdogru Gurun, Jonathan Chen, Frederick Ward, Matthew Wilcox, Zhiming Luo

Aircraft interior acoustic design is a key influencer for cabin comfort. An essential part of the design is optimization of acoustic insulation systems under weight restrictions to create a pleasant environment for human ear. Considering the complexity of aircraft geometry, noise sources, and transfer paths, computational prediction techniques become invaluable tools for increasing the accuracy in material selection

while reducing design time and costs. In this study, a procedure that integrates sound quality evaluation with Statistical Energy Analysis (SEA) to design aircraft acoustic insulation systems is described. SEA is employed to predict the cabin sound pressure levels of a narrow body aircraft insulated with sound absorption and vibration damping materials. Aircraft cabin including under-floor sections is modelled based on 3D airframe and VIP style interior design and the model is validated with flight test data. Transfer functions obtained from SEA model for selected transfer paths are utilized to filter the noise signal recorded with a binaural recording system during flight. Sound quality metrics are computed in order to map perceptive response. An iterative process is introduced to improve acoustic design by investigating the effects of different sound insulation systems and room absorption values on noise levels and sound quality metrics.

12:20 PM 02-Aug-2021 **IN21_1882.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1882

Aircraft interior acoustics - background noise contamination

Ramana Kappagantu, Manuel Etchessahar, Edgar Matas, Koen Vansant

Aircraft interior noise is an important factor to be considered for cabin comfort. In a cruising condition this noise source is mostly broadband in nature and is coming from the exterior, primarily the turbulent boundary layer (TBL) of the flow around the moving aircraft. Capturing this noise to a high frequency is critical for designing the sound packaging. Also, this becomes important in the design of public announcement (PA) system for the aircraft cabin, i.e. the correct placement of speakers. One of the metrics used for this acoustic design is speech transmission index. Deterministic techniques like finite or boundary element techniques for low frequencies and ray tracing method to reach higher frequencies are better suited for getting the narrow band responses. On the other hand, to characterize the background noise due to the TBL loads, statistical energy analysis (SEA) route is pursued. In this paper the authors combine different techniques to capture the background noise and use them with PA sources and eventually capture the sound perceived at points of interest. The articulation metrics are compared for different operating conditions of the aircraft. In the presentation attempts will be made to play the auralized sounds.

12:40 PM 02-Aug-2021 **IN21_2417.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2417

Vibro-acoustic modeling of aircraft structures using Finite Element- informed Statistical Energy Analysis

abderrazak mejdi, Luca Alimonti, Bryce Gardner

This paper addresses the problem of predicting the structure born and airborne sound transmission in aircraft using Statistical Energy Analysis (SEA). Often analytical formulations are used to approximate the SEA parameters. In the present prediction method, a finite element (FE)-informed SEA approach is employed. To compute the coupling coefficient, the structure is represented with a repetition of unit cell and an FE model of the unit cell is assigned to evaluate the direct field dynamic stiffness matrix of the SEA subsystems at the connections. An efficient strategy is employed to determine the equivalent material properties of the FE model. Thus, a two-dimensional unit cells of different constructions such as composite, sandwich, visco-elastic laminate and ribbed section sections can be used. To evaluate the equivalent properties of multilayers structures, each layer is assumed as thick laminate with orthotropic orientation. Moreover, rotational inertia and transversal shearing, membrane and bending deformations are accounted for. First order shear deformation theory is employed. The developed approach handles symmetrical layouts of unlimited number of transversal compressible or incompressible layers. The accuracy of this modeling approach is confirmed through comparison to alternate validated theoretical approaches. Representative examples of spacecraft structural response and interior noise predictions for typical load cases are shown and the use of SEA models as a tool for guiding construction of complex structures to meet acoustic performance targets and optimize designs are presented. Conclusions about the application and advantages of this approach is presented.

Session: 05.02 Airframe Noise
Channel 3

2:00 PM 02-Aug-2021 **IN21_2326.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2326

Trailing-edge noise reduction of a wing by a surface modification

Varun Bharadwaj Ananthan, R.A.D. Akkermans, Dragan Kozulovic

There is an increased emphasis on reducing airframe noise in the last decades. Airframe noise is sound generated by the interaction of a turbulent flow with the aircraft geometry, and significantly contributes to the overall noise production during the landing phase. One examples of airframe noise is the noise generated at a wing's trailing edge, i.e., trailing-edge noise. In this contribution, we numerically explore the local application of riblets for the purpose of trailing-edge noise reduction. Two configurations are studied: i) a clean NACA0012 wing section as a reference, and ii) the same configuration with riblets installed at the wing's aft part. The numerical investigation follows a hybrid computational aeroacoustics approach, where the time-average flow is studied by means of RANS. Noise sources are generated by means of a stochastic approach called Fast Random Particle Mesh method. The results show a deceleration of the flow behind the riblets. Furthermore, the turbulent kinetic energy indicates increased unsteadiness behind the riblets which is shifted away from the wall due to the presence of the riblets. Lastly, the sound sources are investigated by means of the 3D Lamb-vector, which indicates a slight reduction in magnitude near the trailing edge.

2:20 PM 02-Aug-2021 **IN21_1890.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1890

Aeroacustic and aerodynamic investigating of a new airfoil trailing-edge noise-suppressing design

Yehia Salama, Joana Rocha

In this work, a new noise suppressing airfoil trailing-edge design, termed "finned serrations", is presented and numerically evaluated. This brand-new approach consists of the superposition of two different noise suppressing morphological features inspired by the wings of the owl.

Embedded Large Eddy Simulations are employed in tandem with the Ffowcs WilliamsHawkings model to predict and analyze the design aerodynamics and aeroacoustics and compare the obtained output to that of a flat trailing-edge airfoil. Finned serrations are shown to combine the effects of having finlets and serrations. Because of the bluntness of the serration roots, the airfoil is subject to vortex shedding, while the flow is generally decorrelated in the spanwise direction, thanks to the channeling effect of the finlets. The turbulent kinetic energy distribution close to the airfoil trailing-edge surface is also significantly altered, as the more energetic eddies are convected away from the airfoil surface. Lastly, mixing across the airfoil surface is improved, and the average size of the turbulent coherent structures near the airfoil trailing-edge is reduced. The presented results suggest that the coupling of different noise-suppressing mechanisms is a promising path to explore, with the goal of coming up with new, quieter
trailing-edge configurations.

2:40 PM 02-Aug-2021 **IN21_3202.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3202

Aeroacoustic analysis of slat tones

Hasan Kamliya Jawahar, Syamir Alihan Showkat Ali, Mahdi Azarpeyvand

Experimental measurements were carried out to assess the aeroacoustic characteristics of a 30P30N high-lift device, with particular attention to slat tonal noise. Three different types of slat modifications, namely slat cove filler, serrated slat cusp, and slat finlets have been experimentally examined. The results are presented for an angle of attack of $\alpha = 18$ at a free-stream velocity of U = 30 m/s, which corresponds to a chord-based Reynolds number of Re = 7 x 10. The unsteady surface pressure near the slat region and far-field noise were made simultaneously to gain a deeper understanding of the slat noise generation mechanisms. The nature of the low-frequency broadband hump and the slat tones were investigated using higher-order statistical approaches for the baseline 30P30N and modified slat configurations. Continuous wavelet transform of the unsteady surface pressure fluctuations along with secondary wavelet transform of the broadband hump and tones were carried out to analyze the intermittent events induced by the tone generating resonant mechanisms. Stochastic analysis of the wavelet coefficient modulus of the surface pressure fluctuations was also carried out to demonstrate the inherent differences of different tonal frequencies. An understanding into the nature of the noise generated from the slat will help design the new generation of quite high-lift devices.

3:00 PM 02-Aug-2021 **IN21_1610.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1610

High Lift Device Modifications for Reducing Airport Noise – A Review

Daryoush Allaei, Benjamin Reydel, James Rall

Aircraft noise has been one of the top environmental issues at and near airports across the country because of its negative impact on communities. The growth of the nation's air transportation system is restricted predominantly due to regulations on limiting aircraft noise generated around airports. Reducing aircraft noise will lead to wider community acceptance of new or larger airports, lower airline operating costs by reducing noise quota fees, and increase air traffic growth through operating more flights.
One of the most significant contributors to aircraft noise, structural vibrations caused by air flow across its frame, are high lift devices. A review of high lift devices, such as flaps, and methods to reduce their noise levels will be presented. Solution reviews will focus on reducing flap trailing-edge scattering and flap side-edge vortices.

3:20 PM 02-Aug-2021 **IN21_2783.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2783

Parametric optimization of aircraft arrival trajectories for aviation noise mitigation using BADA4 performance model

Ameya Behere, Tejas Puranik, Michelle Kirby, Dimitri Mavris

Successful mitigation of aviation noise is a key enabler for sustainable aviation growth. A key focus of this effort is the noise arising from aircraft arrival operations. Arrival operations are characterized by the use of high-lift devices, deployment of landing gear, and low thrust levels, which results in the airframe being the major component of noise. In order to optimize for arrival noise, management of the flap schedule and gear deployment is crucial. This research aims to create an optimization framework for evaluating various aircraft trajectories in terms of their noise impact. A parametric representation of the aircraft arrival trajectory will be created to allow for the variation of aircraft's flap schedule. The Federal Aviation Administration's Aviation Environmental Design Tool will be used to simulate the aircraft trajectory and performance, and to compute the noise metrics. Specifically, the latest performance model from EUROCONTROL called "Base of Aircraft Data – Family 4" will be used. This performance model contains higher fidelity modeling of aircraft aerodynamics and other characteristics which allows for better parametric variation.

Session: 05.05 Improving Tools for Subsonic Aircraft Noise Prediction
Channel 3

4:20 PM 02-Aug-2021 **IN21_2043.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2043

Next generation aircraft noise-mapping

Ulf Tengzelius, Anders Johansson, Mats Åbom, Karl Bolin

At CSA, Centre for Sustainable Aviation at KTH Stockholm, several projects have run during the last 4 years. One outcome from this research is the SAFT-program for prediction of aircraft noise contours (noise-mapping) and time-histories in receiving points on ground.
SAFT is a versatile and comprehensive tool already including several computational methods such as standard ECACdoc.29 method and more accurate time-stepping simulation-based representations of aircraft sound sources (frequency and direction dependent). The program allows

for input of “general aircraft trajectory input” in the sense that either the trajectory data of concern is fitted to the current pre-defined formats or SAFT is easily updated to read a “new” format.
Among the pre-defined formats of current version is csv-files prepared from OpenSky Historical database. From these kinds of data thrust and other noise-predictor variables are extracted and applied for noise-mapping.
Moreover, SAFT allows for studies of aggregated air-traffic in defined areas as well as of single event flight-trajectories. And for these almost any metric (L, L, L, L, …) might be extracted together with differences in dB, “Delta-dB”, between any two scenarios or individual flights. Could be routing, runway-use, individual flight procedures etc. Anticipated future implementations involve drone trajectories and sound-source representations.

4:40 PM 02-Aug-2021 **IN21_2723.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2723

Empirical estimation of engine-integration noise for high bypass ra-tio turbofan engines

Incheol Lee, Yingzhe Zhang, Dakai Lin

To investigate the impact of installation on jet noise from modern high-bypass-ratio turbofan engines, a model-scale noise experiment with a jet propulsion system and a fuselage model in scale was conducted in the anechoic wind tunnel of ONERA, CEPRA 19. Two area ratios (an area of the secondary nozzle over an area of the primary nozzle), 5 and 7, and various airframe configurations such as wing positions relative to the tip of the engine nacelle and flap angles, were considered. Based on the analysis of experimental data, an empirical model for the prediction of engine installation noise was proposed. The model comprises two components: one is the interaction be-tween the jet and the pressure side of the wing, and the other is the interaction between the jet and the flap tip. The interaction between the jet and the pressure side of the wing contributes to the noise at the low frequencies (≤ 1.5 kHz), and the interaction between the jet and the flap tip con-tributes to the noise at the high frequencies. The proposed model showed a good agreement with the experimental data.

5:00 PM 02-Aug-2021 **IN21_2352.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2352

Improving single flyover noise prediction for subsonic aircraft

Oleksandr Zaporozhets, Alexandras Jagniatinskis

Current ICAO Doc 9911 provides the algorithm to calculate aircraft noise levels for any kind of airport flight scenario. The essential difference exists between the measured and calculated sound levels, especially for single flight noise events. Doc 9911 recommends using this method for equivalent sound levels L and noise indices L first of all. A number of national noise regulations still require for single noise event assessment. An article analyzes a number of reasons to explain the inaccuracy of noise event calculations. For example, the differences between calculated balanced flight parameters (thrust and velocity first of all) and supervised in real flights may influence the accuracy first of all. Statistical data was gathered to make more general view on these differences and some proposal to use them in calculations has being proved.
Also, the assumptions of the ICAO Doc 9911 method may contribute to the inaccuracy of calculations. Among them are the homogeneous atmosphere for sound propagation, generalized for overall fleet noise directivity pattern, etc. Ground effect model defines the values for aircraft absent in operation currently. The first assumption provides a conflict with flight path calculations for varied atmosphere parameters with height over the surface.

5:20 PM 02-Aug-2021 **IN21_2855.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2855

Subtraction Analysis for Predicting the Propagation Effects of Aircraft Noise

Yiming Wang, Kai Ming Li

In 2013, the Federal Aviation Administration and Volpe National Transportation System Center conducted a series of acoustic measurements with a propeller driven aircraft operating in the regions near Houston, Texas. The recorded data on octave band sound levels, aircraft locations, temperature and wind speed profiles were used in the current study to quantify the uncertainties for predicting the propagation effects of aircraft noise. Use of the Aviation Environmental Design Tool (AEDT) was explored for its accuracy and validity in real world scenarios offered by the dataset. The sound exposure level (SEL) data for each section of a flight path was used instead of the time history data for reducing the directivity effect of the sound source due to the change in its relative positions with the receivers. A subtraction-based method was introduced to analyze the propagation effect in which the SELs between two receiver locations were compared. The use of the subtraction method reduces the possible influences of the sound power variations along the flight paths. The measured data for a spiral and a level flight event were presented and the AEDT predictions on the propagation effects were examined in this paper.

5:40 PM 02-Aug-2021 **IN21_2842.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2842

Advanced procedure noise model validation using Seattle International Airport noise monitor networks

Ara Mahseredjian, Jacqueline Thomas, R. John Hansman

Advanced operational flight procedures that utilize modifications to thrust, airspeed, altitude, and configuration can be implemented to mitigate noise impacts for communities surrounding airports. Evaluating and designing such procedures requires accurate modeling of the aircraft performance, source noise, and atmospheric propagation of the source noise to the ground. Modeling frameworks to assess advanced procedures have been developed but must be validated to ensure their results are reasonable. This paper presents validation of such noise models using a network of ground noise monitoring data at Seattle-Tacoma International airport and ADS-B operational radar flight profiles from the OpenSky database. Modeled noise from operational flights of several aircraft types are shown to be consistent with noise monitor data when reasonable flap settings and atmospheric corrections for the actual weather at the time of flight are used. Discrepancies that exist between the modeled and measured noise results are identified to determine where current noise modeling methods must be improved to accurately represent all relevant noise sources.

6:00 PM 02-Aug-2021 **IN21_2846.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2846

Validation of the aviation environmental design tool's noise model using high fidelity weather

Ana Gabrielian, Tejas Puranik, Mayank Bendarkar, Michelle Kirby, Dimitri Marvis

To enable sustainable aviation growth, mitigation of environmental effects must be developed in parallel. To further this effort, these effects are modeled using capabilities such as the Aviation Environmental Design Tool (AEDT), a program that is able to model aircraft performance, fuel burn, emissions, and noise. Past and current projects are performed with the intent of improving the accuracy of the models within AEDT to capture various real-world effects. This paper targets the sensitivity of the noise prediction and propagation by varying multiple assumptions within AEDT. To validate the noise capabilities, multiple streams of real-world data will be used to accurately model actual flights to and from SFO airport. This data includes High-Fidelity weather data, detailed flight performance characteristics from airline flight data records and noise monitoring data obtained from stations around the airport. The results from this study are expected to offer recommendations and help users prioritize and more accurately quantify community noise exposure using AEDT.

6:20 PM 02-Aug-2021 **IN21_3008.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3008

Noise shielding surrogate models using dynamic artificial neural networks

Francesco Centracchio, Lorenzo Burghignoli, Giorgio Palma, Ilaria Cioffi, Umberto Iemma

The optimal design methodologies in aeronautics are known to be constrained by the computational burden required by direct simulations. Due to this reason, the development of efficient metamodelling techniques represents nowadays an imperative need for the designers. In fact, surrogate models has been demonstrated to significantly reduce the number of high-fidelity evaluations, thus alleviating the computing effort. Over the last years, the aeronautical designers community has switched from a design approach predominantly based on direct simulations to an extensive use of metamodels. Recently, to further improve the efficiency, several dynamic approaches based on parameters self-tuning have been developed to support the metamodel construction. This work deals with the use of surrogate models based on Artificial Neural Network for the noise shielding of unconventional aircraft configurations. Here, the insertion loss field of the a Blended Wing Body is reproduced by means of advanced machine learning techniques. The relevant framework is the calculation of the noise emitted by innovative aircraft configurations by means of suitable corrections of existing well-assessed noise prediction tools. The self-tuning algorithm has demonstrated to be accurate and efficient, and the observed performance discloses the possibility to implement numerical strategies for the reliable and robust unconventional aircraft optimal design

Session: 20.08 Vibroacoustics for Medical Solutions
Channel 3

7:00 PM 02-Aug-2021 **IN21_2745.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2745

Moving object detection and tracking based on Doppler ultrasound

Hyeong Geun Jo

Fetal health monitoring during pregnancy has become a necessary procedure. Fetal heart rate (FHR) monitoring can determine fetal development or presence of heart disease and evaluate fetal well-being. The FHR measurement uses typically an acoustic probe-based Doppler ultrasound.

Doppler ultrasound method transmits a continuous wave signal to the abdomen of a pregnant woman to receive a reflected signal from the fetal heart. Periodic displacement of the heart tissue produces the Doppler effect and the phase change of the reflected wave is proportional to the velocity of the fetal heart. The reflected signal is modulated into a phase signal and the received signal is demodulated to detect the heart rate. The current clinician system consists of a single probe and requires the probe to be manipulated to the optimal position to measure FHR. The system is highly dependent on trained diagnostic experts. The movement of the pregnant woman and the fetus leads to the misaligned acoustic beam which degrades the reliability of the measurement.

This work presents a detection and tracking system using a Doppler signal to compensate for the target's movement. The system is implemented by integrating multi-channel probes interfaced to a Doppler signal converter with a 2-degree of freedom (DOF) motor device. This work describes the characteristics of two key components: Doppler signals of multi-channel probes according to the direction of the acoustic beam and the algorithm with a 2-DOF tracking system.

7:20 PM 02-Aug-2021 **IN21_3046.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3046

Cough monitoring and pneumonia diagnosis algorithm through analysis of respiratory system-based vibro-acoustic signals and AI technology

Youngbeen Chung, Narae Kim, Donggeun Lee, Sang-Heon Kim, Junhong Park

In case of pneumonia often accompanied by serious complications, sometimes lead to death, early diagnosis and continuous monitoring can greatly reduce the dangerousness. Moreover, the COVID-19 pandemic has demonstrated the need for new diagnostic tools that can minimize medical personnel engagement while avoiding equipment being exposed to afflicted patients. In this study, we developed cough monitoring algorithm by detecting the vibrations of human body. The acceleration response at each part of body was measured to determine propagation characteristics of vibration when cough occurs. And it was confirmed that the monitoring accuracy was improved when use the vibration signal compared to the case of using only acoustic signal. After that, we analyzed the perceived cough in terms of psych-acoustical and sound-energy aspects. For the characteristic features derived by quantifying the results of analysis, the data augmentation process was applied, and finally AI-based pneumonia diagnosis algorithm was constructed. To estimate the performance of algorithm, the accuracy of pneumonia determination

in new cough cases was verified. It showed the higher value than the accuracy of pulmonologists with only cough sounds. Therefore, developed algorithm that perform continuous cough monitoring and reliable pneumonia diagnosis can be used as an effective supplementary tool for early diagnosis and prognosis of pneumonia.

7:40 PM 02-Aug-2021 **IN21_3138.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3138

Study for the interaction between the medium in the middle ear and vibro-acoustic transmission

Jeon Jonghoon, Jonghoon Jeon, Kyunglae Gu, Junhong Park

This study presented a quantitative evaluation index related to sound response for diagnosis of middle ear condition. The signal transmission paths for human perception of sound are divided into bone conduction and air conduction, respectively, depending on the path through which vibration and sound are transmitted. The components of auditory system that can affect the sound signal variability include temporal bone, ear canal, eardrum, and middle ear cavity. The specific acoustic impedances were obtained through simple geometric model of the auditory components, and the sound transmission mechanism was implemented through the outer-middle ear circuit model. The frequency range corresponding to the resonance characteristics of each components were calculated. The response difference for the medium of middle ear was confirmed by deriving frequency response function between the input sound and the output sound in the frequency domain through the transfer function method. The reliability of the algorithm was confirmed through the ROC curve, and individual evaluation indexes were derived according to the priority factor between classification accuracy and error rate.

8:00 PM 02-Aug-2021 **IN21_3144.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3144

Intraocular Pressure Estimation Method Based on Vibration Propagation Characteristics According to Structure Contact

Kim Deukha, Seongwook Jeon, Won June Lee, Junhong Park

Intraocular pressure (IOP) measurement is one of the basic tests performed in ophthalmology and is known to be an important risk factor for the development and progression of glaucoma. Measurement of IOP is important for assessing response to treatment and monitoring the progression of the disease in glaucoma. In this study, we investigate a method for measuring IOP using the characteristics of vibration propagation generated when the structure is in contact with the eyeball. The response was measured using an accelerometer and a force sensitive resistor to determine the correlation between the IOP. Experiment was performed using ex-vivo porcine eyes. To control the IOP, a needle of the infusion line connected with the water bottle was inserted into the porcine eyes through the limbus. A cross correlation analysis between the accelerometer and the force sensitive resistor was performed to derive a vibration factor that indicate the change in IOP. In order to analyze the degree of influence of biological tissues such as the eyelid, silicon was placed between the structure and the eyeball. The Long Short-Term Memory (LSTM) deep learning algorithm was used to predict IOP based on the vibration factor.

8:20 PM 02-Aug-2021 **IN21_1919.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1919

Photoacoustic medical imaging demonstration using a pulsed LED

Leah Burge, Lauryn McKenna, Murray Korman

This demonstration of photoacoustics involves a focused light-emitting diode (LED) pulse (620 nm wavelength) which illuminates an optically absorbing target. The rapid expansion generates an ultrasonic pulse detected by an immersion transducer. An LED is a cost-effective alternative to the traditional neodymium-doped Yttrium-Aluminum Garnet (Nd:YAG) laser and laser diode- that is most effective in near-infrared. The LED is driven by a home-made MOSFET driver capable of 100 A pulses. Focused pulses illuminate a horizontal 1.2 mm capillary tube filled with Fast Green Dye. A highly-diffuse Teflon cylindrical cavity (9 cm tall, 6 cm diam) contains the mounted capillary tube. A 2.25 MHz immersion transducer with four low-noise amplifier gain blocks (combined 86 decibel gain, 0.5- 30 MHz bandwidth), detects a time-averaged signal from over 1000 trials. Comparisons are made using India ink. Earlier, T. J. Allen and P. C. Beard used 35 percent hematocrit blood in a capillary tube at a 620 nm wavelength demonstrating the feasibility of photoacoustic medical imaging of vascular systems under the skin or shallow-tissue cancerous tumors (using tomography) as an alternative to radioactive medical imaging. Our work precedes a photoacoustic tomography demonstration using three targets in an open acrylic tank.

8:40 PM 02-Aug-2021 **IN21_3134.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3134

Non-invasive Fetal heartbeat detection using vibration sensing system

Wanseung Kim, Jonghoon Jeon, Jeongkyu Hoh, Junhong Park

Monitoring the fetal heartbeat is essential for obtaining information about fetal condition during pregnancy. By measuring the maternal uterine contractions, the movement of the fetus, and the fetal heart rate, the state of the fetus is detected and taking appropriate measures prevent fetal health abnormality. The NST method is used to obtain the fetal heart rate. The ECG method is useful to observe heart rhythm. In this study, a system that can detect fetal heartbeat signals using vibration sensors is proposed. For vibration measurement, a band-type device with a sensor was proposed. The band was wrapped around the mother's stomach to sensing signals generated by the mother’s body. In order to extract the fetal heartbeat signal, appropriate signal processing for denoising is performed. Processed signal was divided into several IMFs using the CEEMD method. The maternal heartbeat signal and fetal heartbeat signal were separated from the IMF. Through frequency analysis, the characteristics of each signal make clear

Session: 20.06 UAVs and the Future of Urban Soundscape
Channel 5

6:00 AM 02-Aug-2021 **IN21_2509.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2509

A Hybrid and Efficient Low-noise assessment Platform for Urban aerial mobility (HELPU)

Siyang Zhong, Peng Zhou, Yi Fang, Xin Zhang

Urban aerial mobility (UAM) is a promising approach to improve the traffic situation in gigantic cities, which, however, may encounter significant noise pollution issues. An integrated research platform, which is being established at HKUST, to include noise generation, long-distance propagation, and perception at the observers is timely to assess the environmental impact of UAM noise and to develop low-noise designs and flight planning. A high-quality test rig in the anechoic aerodynamic facility at HKUST is employed to measure the propeller aeroacoustics and aerodynamics, and to enable the innovative noise control device and design studies. The measurements and high-fidelity simulations using an in-house computational aeroacoustics solver can lead to comprehensive databases to facilitate and validate the development of physics-oriented noise prediction models. Also, high-efficient implementation of the boundary element method is conducted to account for the noise scattering due to the fuselage and then to evaluate the impact of UAM layout on the directivity patterns, which will then be efficiently projected to the far-field observers using the advanced Gaussian beam tracing with the effects due to moving source, atmospheric attenuation, and refraction, complex boundary absorption and reflection incorporated. Low-noise flight planning is then be made accordingly.

6:20 AM 02-Aug-2021 **IN21_2256.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2256

Perception of noise from small quadcopter UAVs

Justine Hui, Michael Kingan, Yusuke Hioka, Gian Schmid,, George Dodd, Kim Dirks, Shaun Edlin, Sean Mascarenhas, Young-min Shim

This paper presents the results of a study evaluating the human perception of the noise produced by small quadcopter UAVs. The study utilised recordings of the noise produced by several different quadcopter UAVs in hover and in constant-speed flight at a fixed altitude. These recordings were made using an eigenmic system. The recordings were reproduced using a 3D sound reproduction system located in the large anechoic chamber at the University of Auckland. Human subjects were asked to rate the annoyance of the recordings. The responses of the test subjects are presented and these are compared with objective metrics to assess suitable metrics for quantifying the impact of noise from these vehicles on humans.

6:40 AM 02-Aug-2021 **IN21_2457.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2457

Performance evaluation on multi-channel Wiener filter based speech enhancement for unmanned aerial vehicles recordings

Yameizhen Li, Benjamin Yen, Yusuke Hioka, Yusuke Hioka

Recording speech from unmanned aerial vehicles has been attracting interest due to its broad application including filming, search and rescue, and surveillance. One of the challenges in this problem is the quality of the speech recorded due to contamination by various interfering noise. In particular, noise contamination due to those radiated by the unmanned aerial vehicles rotors significantly impacts the overall quality of the audio recordings. Multi-channel Wiener filter has been a commonly used technique for speech enhancement because of its robustness under practical setup. Existing studies have also utilised such techniques in speech enhancement for unmanned aerial vehicle recordings, such as the well-known beamformer with postfiltering framework. However, many variants of the multi-channel Wiener filter have also been developed over recent years such as the speech distortion weighted multi-channel Wiener filter. To address these recent advancements, in this study we compare the performance of these variants of techniques. In particular, we explore the benefits these techniques may bring forth in the setting of audio recordings from an unmanned aerial vehicle.

7:00 AM 02-Aug-2021 **IN21_2160.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2160

Visual and audio perception study on drone aircraft and similar sounds in an Urban Air Mobility setting

Roalt Aalmoes, Naomi Sieben

Urban Air Mobility (UAM) is a novel aerospace concept involving drones and Personal Air Vehicles (PAVs) operating in a densely populated urban environment. Most of such vehicles will be electric-powered and rotor-based, creating a distinct sound in the proposed setting of a city. Public acceptability, partially due to noise impact, is a valid concern for the introduction of UAM. To evaluate human perception and noise annoyance of these vehicles, a study is set up that comprises audio-only and combined audio-visual stimuli of hovering and fly-over events using a Virtual Reality experiment. For both types of stimuli, two ambient environments, recorded with synchronized spherical video and ambisonics audio, are provided as background: a louder urban street environment, and a quieter urban street environment. In addition to the drone sounds, more familiar sounds are also evaluated, namely a helicopter and a lawnmower sound, with and without a visualisation. Test subjects are asked about their noise sensitivity according to a shortened Weinstein scale, and their attitude towards drones using a separate questionnaire at the end of the experiment.

7:20 AM 02-Aug-2021 **IN21_2045.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2045

Sound, noise, annoyance? Information as a means to strengthen the public acceptance of civil drones

Hinnerk Eissfeldt, Albert End

Civil drones are becoming ever more present in public perception. Ranging from parcel delivery to wildlife protection and from precision farming to law enforcement, many applications are said to have market-changing potential. Against this background, nations and institutions

around the world are trying to keep up with the dynamic technological developments by means of rules and regulations. Since all parties involved expect a strong increase in both the number of drones and the range of their uses, there is a rising interest in the public acceptance of these vehicles. Widespread acceptance can promote the dissemination of new technologies. Conversely, citizens' concerns about the use of drones in their daily environment may pose barriers to the further proliferation of civil drones, especially in urban areas. The psychoacoustic properties of the vehicles have repeatedly been discussed as being one such limiting factor. This paper discusses results of a representative national study on the social acceptance of civil drones, taking a closer look at effects of information about drones as potential means to foster public acceptance. The findings underline the role of well planned information campaigns as well as community engagement in managing the contribution of drones in future urban soundscapes.

Session: 13.16 The Future of Office Privacy & Sound Masking
Channel 5

7:40 AM 02-Aug-2021 **IN21_2713.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2713

Creating a sound-designed sound masking signal for open-plan offices that is both pleasant and has a positive impact on cognitive performance.

Benjamin Johannes Mueller, Mariella Laubengeiger, Noemi Martin, Philip Leistner

In open-plan offices, sound masking is often used to lower speech intelligibility and raise cognitive performance of the employees by reducing the irrelevant speech effect. Classic sound masking methods use speakers built into the ceiling of the office to increase the overall background noise level in the office and reduce speech intelligibility. However, the emergence of activity based offices is increasing the need for personalized sound masking methods that are no longer used globally in the office, but can be controlled by each employee individually depending on their activity and, for example, played back through headphones during activities that require particularly intense concentration. The playback of a classical sound-masking noise (e.g. a simple pink noise filtered by -5 dB per octave) via headphones is effective, but not pleasant. For this reason, a new sound-designed masking signal was developed in the present study, which consists of slowly fluctuating binaural harmonic components, as well as atmospheric sounds like water sounds and masking noise. A listening test with a cognitive task and a survey after each test condition showed that the developed signal had a similar positive effect on cognitive performance as a classical masking noise, but was rated as significantly more pleasant.

8:00 AM 02-Aug-2021 **IN21_2168.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2168

Field study for the evaluation of the acoustic quality of open-plan offices

Patrick Chevret, Thomas Bonzom, Lucas Lenne, Laurent Brocolini, Julien Marchand

Even if the global health crisis is currently changing the work organisation in offices in the service industry, the problem of noise in open plan offices remains a major challenge with regard to occupational health and well-being. Since 2012, the French National Research and Safety Institute for the Prevention of Occupational Accidents and Diseases (INRS) has been carrying out acoustic surveys in French open-plan offices by measuring both some usual indicators of empty offices (Tr, D2S, Lp4m, rc, Lp) and also the ambient noise levels in activity. In addition, GABO questionnaires have been proposed to employees to assess their perception of the noise environment. So far, 50 open spaces were evaluated, with more or less data collected depending on the situation encountered. Approximately 1,400 employees have already answered the questionnaire. All of the sites visited cover the entire set of activities described by the ISO 22955 standard. An analysis of the links between the acoustic parameters and the perception of employees was carried out. This analysis provides additional information to the studies on the choice of acoustic descriptors and on the use of sound masking systems that aim to control background noise to reduce noise disturbance due to intelligible conversations.

8:20 AM 02-Aug-2021 **IN21_3328.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3328

Impact of Partition types on Architecture design studios acoustical environment

Hany Hossam Eldien, Umaru Bongwirnso

Working in Architecture design studios environment requires various activities. Interaction, communication and meetings could affect the speech intelligibility and the speech privacy conditions. Students Areas with a more silent environment are needed with a minimized level of distraction from surrounding activities, while teamwork and discussion areas with a high level of interaction need a good speech intelligibility. One of the more important elements which can improve the open spaces acoustical conditions is the partitions between workstations.The main purpose of this work is to evaluate the acoustical performance of four partitions types in open plan offices; 1.10m two sides partition height, 1,50m front side partitions, 1,50m one side partitions and 1.50 two sides partitions. This Study was conducted in the College of Architecture, Imam Abdulrhman Bin Faisal University, KSA. Based on ISO 3382-3, Speech Transmission Index, STI in the nearest workstation, Distraction distance rD, privacy distance rP, A-weighted background noise level L,A,B and A-weighted SPL of speech at 4 metres L,A,S,4m have been measured. It was found that the best results can be obtained by 1.50m front side and 1.50m two sides partitions.

8:40 AM 02-Aug-2021 **IN21_1813.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1813

Biophilic Sound Masking Systems: Promoting Acoustical Comfort in Workspaces

Ethan Salter, Dylan Mills

Promoting speech privacy and acoustical comfort in office buildings has always been an important consideration for designers, owners, and occupants. Acoustical comfort has many degrees, including reduction of stress, enhancing focus, and reducing distractions. It can also create a more pleasurable and relaxing environment.

Concurrently, the sustainable and green design movements have evolved the “language” of design and building to include a more holistic understanding of occupant comfort. This includes the materials and systems that occupants interface with and use. Additionally, interior environmental quality considerations, including noise, are incorporated into green building rating systems such as WELL, LEED, CHPS, and others. However, it is not merely about providing a slightly better or more efficient system, but also understanding on a deeper level the effects of a building’s environment on people’s health. One aspect of this is the concept of “biophilia,” where designers look to natural systems and materials for inspiration. The interior acoustical environment is a significant part of that.
Electronic sound masking systems have been used in office environments for decades, and their efficacy, when appropriately designed and installed, has been proven repeatedly. What has been changing in recent years is the concept of biophilic sound masking systems, which do not merely broadcast broadband noise (AKA pink noise or "white" noise) in a space. These systems can broadcast “natural” sounds such as running water, animals, wind, etc. that are not only pleasing and soothing, but also effective in sound masking.
This paper will describe biophilia in general how it relates to the interior noise environment, and related design considerations. In addition, the paper includes a case study of an office building project that employed a sound masking system with biophilic capabilities.

9:00 AM 02-Aug-2021 **IN21_3199.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3199

Spatial uniformity tolerances for sound masking systems in open-plan offices

Roderick Mackenzie, Roderick Mackenzie, Farideh Zarei, Vincent Le Men

Electronic sound masking systems raise the ambient sound level in offices to a controlled minimum sound level in order to increase speech privacy and reduce distractions. Sound masking systems are calibrated to provide the most uniform sound field achievable, as a spatially non-uniform masking sound field could result in occupant perception and uneven speech privacy conditions. Tolerances for acceptable spatial uniformity vary between specifiers, and may be based on different evaluation methods using only a few discrete measurement points to represent an entire office space. However, the actual uniformity of a masking sound field across an office, and the parameters influencing it, has not been widely investigated. Thus, this study aims to investigate the masking sound uniformity in a typical open-plan office space using fine-grid measurements conforming to measurement method of ASTM E1573-18. Percentages of measured locations where the sound pressure levels were within specified tolerances (with increments of 0.5 dB) were calculated using the measured 1/3 octave band levels. The research also utilized geometric acoustical simulations to investigate how physical office parameters (number of loudspeakers, partition heights, ceiling absorption, and diffusion characteristics) affect the sound field uniformity of the sound masking system.

Session: 13.14 Building System Noise & Vibration Control
Channel 5

11:00 AM 02-Aug-2021 **IN21_2948.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2948

Proacustica Handbook: noise and vibration control in building installations

Jose Nepomuceno, Priscila Wunderlich

Proacústica is a nonprofit entity created in 2010 to congregate companies and professionals willing to leverage the development of acoustics in Brazil. Three technical committees (TCs): Environmental Acoustics, Building Acoustics, and Room Acoustics, contribute to the drafting of laws, standards, production of technical content, and integration between different players of the market.
By 2021, the Room Acoustics TC incorporated three Working Groups: Special Rooms, Schools and Noise Control and Vibration Control – the last one dedicated to the Proacustica Handbook: Noise and Vibration Control In Building Installations. The purpose of this publication is to describe the step-by-step measures to implement noise and vibration control strategies in buildings.
These strategies are aimed at the particularities of the Brazilian market at the moment and also a way to improve how M/E/P equipment manufacturers, installers, designers, and acoustic consultants approach the subject from the design to the construction,
Important technical discussions among participants included: the use of sound pressure versus sound power data for equipment; the sound rating for diffusers, VAVs, and other ductwork devices; vibration isolation guidelines, among other topics.
This paper presents the Handbook structure, relevant discussions, and recommendations to be published as a final document by the end of 2021.

11:20 AM 02-Aug-2021 **IN21_1612.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1612

Uncertainty of sound power measurements of a reference sound source using the AHRI Standard 230 sound intensity method

Curtis Eichelberger, Paul Bauch

The uncertainty of determining the sound power of HVAC equipment using the AHRI Standard 230 sound intensity measurement method is presented. Measurements of six different reference sound sources (RSS) at four different laboratories, by nineteen different individuals with four different instrumentation systems are presented. From 2004 through 2020, these measurements were performed as part of a training program at Johnson Controls HVAC test laboratories to qualify technicians and engineers on the use of sound intensity instrumentation. The results illustrate the reproducibility of sound intensity measurements using the scanning method of AHRI Standard 230.

11:40 AM 02-Aug-2021 **IN21_2958.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2958

Post-occupancy HVAC survey: What can be learned form 1,800 measurements

Jeff Fullerton, Alexander Maurer

After opening a new multi-family residential complex, the association was asked to perform a comprehensive survey of the sound from their HVAC systems. The survey sought to quantify the sound levels from every HVAC diffuser, grille, and register that served the residences and

common spaces. The effort required access into over 250 residences typically measuring between 3 and 5 locations in each residence, and as many as 7 to 9 locations in penthouse residences. While the heat pump systems serving the residences were similar models, their capacities varied depending on the square footage and solar exposure of the residence. The variations in the sound levels of these systems and from the central ventilation were significant. This presentation will highlight what was learned from the survey.

Session: 13.15 Acoustic Performance of Operable & Demountable Partitions
Channel 5

12:00 PM 02-Aug-2021 **IN21_2407.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2407

Operable partitions – a life of experiences, observations, and testing plus comments on standards

Noral Stewart

Experiences testing operable partitions since 1986 will be reviewed including typical performance and various problems observed with both the partitions and surrounding structures. ASTM standards E557 on proper building preparation for an operable partition and E336 for the measurement of field performance will be discussed, including the 2005 revision of E336 as it affects evaluation of operable partitions.

12:20 PM 02-Aug-2021 **IN21_2413.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2413

Field measurements of demountable and pre-fab walls

Basel Jurdy, Michael Yantis

Flexibility of enclosed office walls is important to technology companies. In healthcare, prefab walls have advantages from a cost and efficiency standpoint. Demountable office walls allow facilities to rearrange spaces to accommodate changing team sizes, types and locations. Prefab walls save construction time and allow for maintenance efficiency and cost. A decade of noise reduction measurements of several manufacturers' demountable and pre-fab walls is presented. Early issues that reduced the in-field performance have largely been improved but some issues remain and are common amongst all manufacturers. The most notable is the connection between the wall and the acoustic tile ceiling. Highest performing demountable walls from a decade ago tested to the high 20's or low 30's NIC. Recent test showed results between mid 30's and high 30's. Pre-fab wall testing between patient rooms demonstrated that the FGI separation criteria can be met with partial and no bulkhead closure above the ceiling

12:40 PM 02-Aug-2021 **IN21_2917.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2917

Operable walls: where the rubber meets the mullion

Brandon Cudequest

The architecture that surrounds an operable wall often determines its acoustical success. There are standard guides for detailing operable walls; however, these offer a rigid take on design aesthetics. Abstracting these principles into general goals, the designer can accommodate a variety of architectural styles. The surrounding construction should act as a safety net by providing labyrinths when seals fail or by blocking problematic flanking paths. The architecture should also ease system operation allowing users to deploy the operable wall with minimal fail rate. This paper compares several off-the-shelf and custom systems, highlighting the importance of construction details and coordination and their impact on the installed product performance. The architecture can only support these systems to a degree and the designer should select an operable system that works within the given conditions. By comparing design trends in operable walls from an acoustical consultant standpoint, this paper will spotlight architecturally harmonious systems as well as several system features to be aware of when evaluating options.

1:00 PM 02-Aug-2021 **IN21_2974.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2974

Acoustical performance of horizontal-sliding-panel operable partition walls

Jim Borzym

Field measurements of airborne sound transmission loss were made on several operable partitions of the horizontal-sliding-panel type between conference rooms. Apparent Sound Transmission Class (ASTC) and Noise Isolation Class (NIC) ratings were computed. Very significant deviation of field-measured sound transmission ratings and manufacturers' Sound Transmission Class (STC) ratings were found. Clients were not satisfied by actual sound isolating performance. Transmission of voice was clearly audible. Some deficiencies of field conditions were found. Some deficiencies of partition installation were found. Modifications were made; acoustical performance did not change significantly.

Workshop: Introduction to Active Noise Control, Part 1
Channel 6

7:00 AM 02-Aug-2021 **Oral Only**

Introduction to Active Noise Control and New Challenges, Part 1

Mingsian Bai, Jordan Cheer, Woo-Seng Gan, Yoshinobu Kajikawa, Yangfan Liu, Scott Sommerfeldt, Yongjie Zhuang

In the recent decade, research and applications of active noise control (ANC) have attracted more attention than ever before, mainly due to the fast improvement in the on-chip computing power and the reduction in cost of signal processing hardware, as well as the general public's increasing concerns on health and comfort when using engineered products. Many recent studies focus on expanding the spatial region that can be controlled by an ANC system, extending the effective frequency range to a wider bandwidth as well as exploring ANC applications in

various acoustic environments and engineered products. This presents many new challenges in many aspects of ANC including signal processing, control theory, transducer design/deployment, physical acoustics and vibration, etc.
In this workshop, an introductory presentation is given first providing a brief background on ANC and overviewing fundamental theories and principles on which active noise control is based. This is then followed by six focused talks given by world leading researchers in this area. Each talk presents recent studies on a specific topic related to current technical challenges in active noise control. The topics covered in those talks include global ANC based on optimal array beamforming theory, expansion of the control region by sensing acoustic energy density and vibration spatial gradients, extension of the control frequency limit using motion tracking techniques, ANC in the built environments, an ANC-based personal audio technique for public spaces, and efficient multi-channel ANC filter design formulation for controller stability and robustness.

Workshop: Introduction to Active Noise Control, Part 2
Channel 5

2:00 PM 02-Aug-2021 **Oral Only**

Introduction to Active Noise Control and New Challenges, Part 2

Mingsian Bai, Jordan Cheer, Woo-Seng Gan, Yoshinobu Kajikawa, Yangfan Liu, Scott Sommerfeldt, Yongjie Zhuang

In the recent decade, research and applications of active noise control (ANC) have attracted more attention than ever before, mainly due to the fast improvement in the on-chip computing power and the reduction in cost of signal processing hardware, as well as the general public's increasing concerns on health and comfort when using engineered products. Many recent studies focus on expanding the spatial region that can be controlled by an ANC system, extending the effective frequency range to a wider bandwidth as well as exploring ANC applications in various acoustic environments and engineered products. This presents many new challenges in many aspects of ANC including signal processing, control theory, transducer design/deployment, physical acoustics and vibration, etc.
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Session: 09.02 Acoustic Metamaterials, Part 1
Channel 6

6:00 AM 02-Aug-2021 **IN21_2962.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2962

Enhancement of sound absorption in a band frequency using thin porous layer-lined metasurfaces

Joong Seok Lee, Jun Hyeong Park, Pyung Sik Ma, Shin Young Kim, Yoon Young Kim

When a porous layer is installed on a hard wall, sound absorption performance is mainly determined by thickness of the layer. Although material parameters of porous materials are strongly dependent on frequencies, the thickness limitation related to the quarter wavelength of incident sound wave has been a key factor in the treatment of porous layers for noise reduction. This implies that a thicker porous layer is required to absorb lower-frequency sound effectively. To overcome the thickness limitation, metaporous layers, which are named as a compound of sound absorbing porous layers with the concept of metamaterials have received much attentions for alternative implementations of porous layers. Recently, we proposed a new type of metaporous layer for enhancing sound absorption performance in a specified broad frequency band. The proposed metaporous layer is constructed with a thin porous layer backed by a reactive metasurface consisting of an array of bent channels. Formation of sound absorption band is directly determined by the characteristics of scattered sound field from the proposed metaporous layer. Analytical and numerical investigations show that the metasurface is considerably responsible for the enhanced sound absorption in the proposed metaporous layer, while sound dissipation occurs only in the thin porous layer.

6:20 AM 02-Aug-2021 **IN21_2491.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2491

The study of ultrasonic layer-matched to penetrate bone

Lianchun Li, Haijun Wu, Haijun Wu, Weikang Jiang

Acoustic metamaterial layer-matched was designed to enhance ultrasound penetration through bones. The conventional ultrasound layer-matched, known as coupling agent, can only enhance the transmittance of ultrasound to soft biological media, such as cartilage and muscle, but cannot penetrate hard media, i.e. bone. An ultrasound layer-matched based on the impedance matching principle is presented to make ultrasound penetrate bone, which parameters are designed by acoustic metamaterial equivalent parameter technique. The ultrasound layer-matched is fabricated by 3D printing which can correct the aberrations of the bone. Some configurations are investigated by numerical simulation as well as experiments in the anechoic chamber. In particular, a bone matching layer can be designed optimally for the definite thickness of the bone and the definite operating frequency of the ultrasound probe, which enhanced ultrasound to penetrate both of the layer-matched and the bone with no echo. The results of experiments and simulations show that the proposed ultrasound layer-matched metamaterial can enhance the transmission efficiency of ultrasound to penetrate some hard biological media bones.

6:40 AM 02-Aug-2021 **IN21_2465.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2465

Design of a metamaterial-based muffler for a target frequency range

Byunghun An, Jinwoo Lee

This work proposes an acoustic metamaterial-based muffler that effectively blocks a transmission noise for a target frequency range. Since the acoustic metamaterial-based muffler consists of arrayed unit cells, its noise attenuation performance is strongly affected by the internal layout of the unit cell. The wave transmission characteristics of an acoustic metamaterial is explained by the effective bulk modulus and dispersion curve of an unit cell. Therefore, the internal layout of the unit cell should be optimally designed so that its band gap should include the target frequency range of a muffler. To the end, an acoustical size optimization problem is formulated to design a unit cell of the muffler and is solved for a given design requirement. The noise blocking frequency range of the unit cell is characterized by the bandgap in its dispersion curve during the optimization process. The wave transmission characteristics of the metamaterial muffler is validated experimentally.

Session: 09.02 Acoustic Metamaterials, Part 2
Channel 6

11:00 AM 02-Aug-2021 **IN21_2913.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2913

Inverse metacluster design using generative modeling for minimal scattering response

Peter Lai, Feruza Amirkulova

Metamaterials are subwavelength-sized artificial structures with the ability to manipulate incident waves in such a way that affects how the energy propagates throughout the medium. In acoustics, particularly placed scattering elements can reduce the total scattering cross section (TSCS) response. We propose a method to inversely design acoustic metamaterial configurations using deep learning and generative modeling. Using our proprietary multiple scattering solver with MATLAB optimization toolbox, we generate a dataset of optimal configurations with minimized TSCS within a discrete range of wavenumbers. We use this dataset to train a Conditional Wasserstein Generative Adversarial Network (cWGAN) to generate similar metacluster designs corresponding to specified input TSCS. To improve the coordinate recognition ability of the cWGAN, we include the novel CoordConv layer in the generator and critic. After training, the cWGAN can produce a variety of optimal configurations given an expected TSCS. Evaluating TSCS of generated configurations shows that the model is capable of proposing scatterer configurations that are comparable or better than the dataset within the optimized range.

11:20 AM 02-Aug-2021 **IN21_2567.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2567

Optimization of metamaterials with complex neck shapes for aircraft cabin noise improvement

Tenon Charly Kone, Sebastian Ghinet, Raymond Panneton, Anant Grewa

More frequently, recent low-frequency noise control techniques commonly implemented in aerospace and ground transportation as well as in building applications are based on acoustic metamaterial concepts. The technologies proposed in the literature, using layered porous materials with embedded Helmholtz resonators (HR), exhibited considerable potential when tuned at tonal, multi-tonal or narrow frequency bands. Our recent investigations have shown that the acoustical performance of these metamaterials can be further improved by the use of resonators with complex shaped necks. These necks can be designed and optimized to minimize the HR resonance frequencies (small form factor) and maximize the sound transmission loss (STL) performance.
This paper presents the developed design optimization method for HRs with complex neck shapes recessed within the HR cavity. The HRs were embedded in a layer of porous material. The implemented approach was based on the transfer matrix methods (TMM) in series and in parallel coupled to a multi-objective optimization. Complex optimum neck shapes were obtained allowing for a shift towards the low frequencies of the resonator resonance with a good STL performance. Moreover the STL calculated using the TMM approach were observed to be in excellent agreement with the finite element method numerical results.

11:40 AM 02-Aug-2021 **IN21_2569.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2569

Multi-tonal low frequency noise control using Helmholtz resonators with complex cavity designs for aircraft cabin noise improvement

Tenon Charly Kone, Sebastian Ghinet, Raymond Panneton, Thomas Dupont, Anant Grewal

The noise control at multiple tonal frequencies simultaneously, in the low frequency range, is a challenge for aerospace, ground transportation and building industries. In the past few decades, various low frequency noise control solutions based on acoustic metamaterial designs have been presented in the literature. These solutions showed promising performance and are considered a better alternative to conventional sound insulation materials. In the present investigation, it was noticed that subdividing the cavity of a Helmholtz resonator allowed the control of multi-tonal noise at several resonance frequencies simultaneously and a shift of the resonance peaks towards the low frequencies.
This paper proposes concepts of Helmholtz resonators with subdivided cavities to improve the sound transmission loss (STL) performance and simultaneously control the noise at several tonal frequencies. HRs with cylindrical shaped cavities were embedded in a layer of porous material. The STL of the metamaterial noise insulation configuration was predicted using serial and parallel assemblies of transfer matrices (TMM) incorporating a thermo-viscous-acoustic approach to accurately account for the viscous and thermal losses of acoustic wave propagation within the metamaterial. The STL calculated using the proposed TMM approach were observed to be in excellent agreement with the finite element method (FEM) numerical results.

12:00 PM 02-Aug-2021 **IN21_2207.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2207

An integrated toolchain for the design of aeroacoustic metamaterials: the AERIALIST H2020 project.

Umberto Iemma

The project AERIALIST (AdvancEd aicRaft-noIse-AlLeviation devIceS using meTamaterials), funded within the Breakthrough Innovation topic of the H2020 program, has closed its activity on May 2020. The objective of the project was the disclosure of the potential of metamaterials in developing disruptive devices for the mitigation of aircraft noise, in order to contribute to the identification of the breakthrough technologies targeted at the achievement of the noise reduction targets foreseen by the ACARE Flightpath 2050. Although targeted to low TRL, AERIALIST has been focused on the development of an integrated toolchain capable to address the entire design loop, from the early conception to the numerical and experimental proof of concept, up to the final design and manufacturing. The toolchain was founded onto four pillars: i) the extension of the acoustic metamaterial theory to aeroacoustics; ii) the exploitation of the latest additive manufacturing technologies; iii) the wind-tunnel assessment of the selected concepts; iv) the identification of a development roadmap towards higher TRL. After three years of activity, the project has attained all its objectives. The present paper is a review of the main outcomes of the project, their application potential and relevance to the ACARE objectives.

12:20 PM 02-Aug-2021 **IN21_2759.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2759

Controlling the amount of acoustic absorption by using clusters of hard cylinders

Vicente Cutanda Henriquez, José Sánchez-Dehesa

The viscothermal absorption of a cluster of hard cylinders periodically arranged in air is directly related with the filling fraction of the underlying lattice. In this work, we present a comprehensive study of the viscous absorption of clusters with circular external shape. The study has been performed by using a homogenization theory in which the clusters have been represented by a single fluid-like cylinder with effective parameters. The validity of the homogenization approach has been supported with numerical experiments in which the viscosity of the actual cluster is calculated with an improved version of the boundary element method. The simulations have been performed by embedding the clusters in a multimode impedance tube. For example, for a circular cluster containing 817 hard cylinders distributed in a hexagonal lattice with filling ratio of 0.836, the absorptive factor calculated with the homogenization approach is 41.5%, which underestimates by about 1% the value obtained with the complete cluster.

12:40 PM 02-Aug-2021 **IN21_3078.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3078

Experimental and numerical investigations of ventilated acoustic metamaterial based in-parallel arrangement of Helmholtz resonator for façade screen

Denilson Ramos, Luís Godinho, Paulo Amado-Mendes, Paulo Mareze

Understanding urban noise as a serious environmental problem in urban centers, the development and application of noise control strategies have demanded a recent effort by several researches. In this case, the development of acoustic metamaterial artificially designed to manipulate the wave phenomena has become a recent topic, aiming at optimized responses, and enables the development of subwavelength devices with potential application in passive ventilation and noise mitigation, providing better environmental conditions in buildings. The present paper intends to contribute to the knowledge in this field by investigating the concept of an acoustic metamaterial with negative bulk modulus based in a parallel arrangement of Helmholtz Resonators. Experimental and numerical investigations are carried out to determine the acoustic potential of the proposed meta structure in terms of sound absorption and sound transmission loss. The developed concept exhibits significant benefits in the properties of sound transmission loss, and seems a potential application for noise control at specific frequency bands (mainly at low to middle frequency) in building façades.

1:00 PM 02-Aug-2021 **IN21_2573.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2573

Broadband noise mitigation using coupled Helmholtz resonators: a numerical study

Mariia Krasikova, Anton Melnikov, Sergei Krasikov, Yuri Baloshin, David Powell, Andrey Bogdanov

In this work we investigate a periodic structure in the frequency range from 20 Hz to 5500 Hz designed for broadband noise insulation. The considered unit cell consists of a simple structure: a pair of polymer pipes with slits carved along the axes, representing two coupled Helmholtz resonators. In order to develop a design with a broad band gap, we analyze the eigenmodes of the infinite two-dimensional structure considering their symmetry and interaction. This analysis is supported by parametric optimization of the resonator geometry. The obtained band diagram is compared with numerically determined transmission coefficient of a finite structure based on the same unit cell. The number of unit cells of the finite structure is chosen to be sufficient for demonstration of insulating properties and stop band formation. Furthermore, we analyze how the transmission coefficient is linked to the pressure field distribution inside the resonators. Owing to the simplicity of the geometry, the obtained results may become a basis for development of budget-friendly passive systems for broadband noise insulation within the audible range of frequencies.

1:40 PM 02-Aug-2021 **IN21_2431.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2431

Design of acoustic cloak using generative modeling and gradient-based optimization

Linwei Zhuo, Feruza Amirkulova

Metamaterials are engineered composites that can achieved electromagnetic and mechanical properties that do not exist in natural materials by rearranging their structures. Due to the complexity of the objective functions, it is difficult to find the globally optimized solutions in metameterial design. This talk outlines a gradient-based optimization with generative networks that can search for the globally optimized cloaking devices over a wide range of parameters. The GLO-Net[1] model was developed originally for one-dimensional nano-photonic

metagratings is generalized in this work to design two-dimensional broadband acoustic cloaking devices by perturbing positions of each scatterer in planar configuration of cylindrical scatterers. Such optimized cloaking devices can efficiently suppress the total scattering cross section to the minimum at certain parameters over range of wavenumbers. During training each iteration, a generative model generates a batch of metamaterials and compute the total scattering cross section and its gradients using an in-house built multiple scattering MATLAB solver. To evaluate our approach, we compare our obtained results with fmincon in MATLAB.

Reference:
[1] Jiaqi Jiang and Jonathan A. Fan. Simulator-based training of generative neural networks for the inverse design of metasurfaces. Nanophotonics, 9(5):1059–1069, nov 2019.

2:00 PM 02-Aug-2021 **IN21_1775.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1775

Band structure and defect states in acoustic phononic crystals using expansion and micro-perforated chamber mufflers

Adriano Mitsuo Goto, Victor Gustavo Ramos Costa Dos Santos, José Maria Campos Dos Santos

The expansion and the micro-perforated chamber mufflers are acoustic silencers designed to attenuate the sound propagation at duct systems. These silencers can show interesting phononic crystals behavior when set periodically. The concept of phononic crystals still is an emerging topic in vibration and sound control. The periodic arrangement of acoustic silencers can provide a significant enhancement of the sound absorption due to the “wave filtering” property where the wave cannot propagate at certain frequency ranges, called stopbands or bandgaps. However, these properties may be affected by defects, like the break of the periodicity due to manufacturing errors. For the present work, the influence of some defects on the acoustic efficiency is investigated numerically for expansion and micro-perforated chamber mufflers. A direct and efficient approach is used to obtain the transfer and dynamic stiffness matrices. Simulated examples are used to calculate the forced response, transmission loss, and dispersion diagram, which are verified by other methods.

Session: 09.08 New Generation Materials
Channel 6

2:40 PM 02-Aug-2021 **IN21_2074.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2074

A design framework for absorption and diffusion panels with sustainable materials

Jonathan Dessi-Olive, Timothy Hsu

Architectural acoustics has not traditionally had unified design methods that specify acoustical performance, visual appearance, and sustainable material selection, leading to underperforming products that contribute to a waste stream of petro-chemical foam and fiberglass materials. The evolution of design, materials, and manufacturing techniques in recent years has created new opportunities to reimagine acoustic diffusers and absorbers. Previous work by the authors have demonstrated a unifying framework for design and collaboration in architectural acoustics. The framework uses visually-driven computational design method inspired by shape grammars that generate a wide range of acoustic phase grating diffuser arrays that display unique visual and performative qualities. Simulation and evaluation metrics to assess the complexity of each design are rated in terms of their diffusion and absorption coefficients and a visual aesthetic coefficient. This paper extends the framework to include digital fabrication protocols and sustainable material specifications – including the use of fungi-based materials. Built prototypes demonstrate an expanded acoustic design space that gives acousticians the potential to create custom diffuser shapes with precise acoustical response. The innovative combination of computational design methods and sustainable fabrication protocols will be discussed, and the acoustic properties of arrays will be evaluated and compared to simulations of corresponding designs.

3:00 PM 02-Aug-2021 **IN21_3086.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3086

Nonlocal acoustic metasurface absorber for ultra-broadband sound absorption

Yifan Zhu, Badreddine Assouar

Classical designs of acoustic meta-absorber usually have a trade-off between bandwidth, efficiency and thickness. Here, we introduce the concept of nonlocal acoustic metasurface absorber by using a bridge structure connecting resonating unit cells to improve the performances of the meta-absorber. By utilizing the coupling effect between the adjacent unit cells, ultra-broadband sound absorption is achieved with deep-wavelength thickness. The physical mechanism of the nonlocal acoustic metasurface absorber is investigated by developing analytical models. We theoretically and numerically study the nonlocal metasurface with connecting bridge and the traditional metasurface without bridge. The nonlocality can introduce three specific effects: 1. Optimizing of effective acoustic impedances. 2. Shift of Fabry–Perot resonant frequencies. 3. Strengthening of the coupling effects between adjacent unit cells. These effects help to improve the bandwidth and the efficiency of the acoustic meta-absorber. We numerically and experimentally achieve an averaged absorption coefficient larger than 0.9 within the ultra-broadband bandwidth from about 600 Hz to 2600 Hz, with a sample thickness of 6.8 cm, , /9 for the lowest frequency. Our finding demonstrates the advantage of non-local acoustic metasurface to conceive subwavelength sound meta-absorber.

3:20 PM 02-Aug-2021 **IN21_1458.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1458

Acoustic space filling curve metamaterials for grazing flow in Jet engine inlets

Jennifer Glover, Dan O'Boy

Acoustic metamaterials research has grown exponentially in the past 10 years driven by the advances in manufacturing and an increased understanding of damaging environment noise. 2020 was the first noise reduction target as set by Advisory Council for Aircraft Research and Innovation in Europe with a relative 50% decrease. This was missed by current Jet engine noise control technology; however, metamaterials

offer an encouraging alternative. Space Filling Curves (SFC) have the potential to provide a lightweight, thin, high performance acoustic liner. SFC have a history in mathematical geometry dating back to the 1890's but are a comparatively new addition to acoustics. They are designed with a sub-wavelength curled cross-section creating a maze-like pattern which slows acoustic wave propagation through the liner enabling characteristics such as negative refraction and low frequency attenuation. This paper contains a comparison of some of the most promising SFC metamaterial acoustic liner designs, in terms of the fundamental theory of the design category and a discussion of the reflection, absorption and transmission characteristics in terms of a grazing flow conditions. Computer simulation and impedance tube based experimental testing compares the designs. The paper concludes with future application for aeroacoustics with particular focus on the engine inlet.

3:40 PM 02-Aug-2021 **IN21_2320.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2320

Diffraction in phase gradient acoustic metagratings: multiple reflection and integer parity design

Mohammad Uzair, Xiao Li, Yangyang Fu, Chen Shen

Diffraction occurs when acoustic waves are incident on periodic structures such as graded metasurfaces. While numerous interesting diffraction phenomena have been observed and demonstrated, the underlying mechanism of diffraction in these structures is often overlooked. Here we provide a generic explanation of diffraction in phase gradient acoustic metagratings and relate high-order diffractions to multiple reflections in the unit cells. As such, we reveal that the number of unit cells within the metagrating plays a dominant role in determining the diffraction patterns. It is also found that the integer parity of the metagrating leads to anomalous reflection and refraction with high efficiency. The theory is verified by numerical simulations and experiments on planar metagratings and provides a powerful mechanism to manipulate acoustic waves. We further extend the theory to cylindrical waveguides for the control of sound vortices via topological charge in azimuthal metagratings. The relevance of the theory in achieving asymmetric wave control and high absorption is also discussed and verified both numerically and experimentally.

4:00 PM 02-Aug-2021 **IN21_2437.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2437

Predicting acoustic performance of high surface area particle stacks with a poro-elastic model

Zhuang Mo, Guochenhao Song, J. Stuart Bolton, Seungkyu Lee, Yongbeom Seo

Because of the high sound absorption they offer at low frequencies, there is a growing interest in high surface area particles and how they might be applied in noise control. Therefore, a model that can accurately predict the acoustic behavior of this type of materials will be useful in relevant applications. A poro-elastic model based on a combination of Biot theory and an existing rigid model of granular activated carbon (GAC) is introduced in the current work. The input parameters for this model consist of a certain number of properties that are known by measurement, and a set of values obtained by matching the model prediction with acoustic measurements. Measured absorption coefficients and surface impedance of stacks of several types of different activated carbon particles are shown in this paper. A fitting procedure that determines the unknown parameters is also described. It is shown that the model is able to predict the acoustic behavior of the particle stacks, and especially to capture the frame resonances at low frequencies, thus, validating the proposed model. Beyond the activated carbon used in the present tests, it is reasonable to generalize this model to stacks of other high surface area particles.

Session: 09.00 Acoustic Materials - Aerospace Applications
Channel 6

4:40 PM 02-Aug-2021 **IN21_2126.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2126

The challenges and successes of passive acoustic treatments on the International Space Station

Holly Smith-Dalenberg, Christopher S. Allen, Jose G. Limardo-Rodriguez

Habitable space environments pose unique challenges to the selection of passive acoustic treatments used to mitigate noise. On the International Space Station, strict regulations regarding flammability, particulate release, and off-gassing must be considered during material selection, resulting in the exclusion of many common acoustic treatments used in ground-based applications. The Johnson Space Center Acoustics Office has identified a small subset of acoustic absorption and barrier materials that meet these stringent requirements, and has developed numerous treatments for noise mitigation, including duct-wrapping and liners, acoustic absorption and barrier blankets, and mufflers. The Acoustics Office utilizes impedance and transmission loss tubes to optimize the layering of acoustic materials for these treatments while observing restrictive volume and mass limits. Future acoustic mitigation development will focus on moisture and microbial-resistant materials and treatments that can be utilized in enclosed spaces that require higher scrutiny in regards to cleanliness, such as waste management bays and surfaces surrounding exercise equipment or galleys.

5:00 PM 02-Aug-2021 **IN21_1568.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1568

Development of acoustic mufflers for cabin noise reduction in Orion spacecraft

Indranil Dandaroy, S. Reynold Chu, Jeffrey Dornak, Christopher S. Allen

Controlling cabin acoustic noise levels in the Crew Module (CM) of the Orion spacecraft is critical for adequate speech intelligibility, avoid fatigue, and prevent any possibility of temporary and permanent hearing loss to the crew. The primary source of cabin noise for the on-orbit phase of the mission is from the Environmental Control and Life Support System (ECLSS) which recycles and conditions breathing air and maintains cabin pressurization through its ducting network and components. Unfortunately, as a side effect, noise from the ECLSS fans propagates through theses ducts and emanate into the cabin habitable volume via the ECLSS inlet and outlets. To mitigate excessive duct-borne noise, two ECLSS mufflers have been designed to provide significant acoustic transmission loss (TL) so that the cabin noise requirements can be met. Each muffler is meant to be installed in the ducting of the ECLSS air inlet and outlet sides, respectively. Packaging constraints and tight

volume requirements necessitated the mufflers to be of complex geometry and compatible with the bends of the ECLSS duct layout. To design and characterize the acoustic performance of the inlet and outlet mufflers, computational acoustic models were developed using the Finite Element Method (FEM) with software. Characterization of the acoustic material and perforations in the mufflers were addressed with poro-elastic theory. Once the mufflers were designed on paper and its TL predicted, prototypes of these mufflers were created using additive manufacturing. The muffler prototypes were subsequently tested for acoustic TL in the laboratory with various configurations of acoustic materials. Comparing the analytical predictions to the test performance yielded excellent correlation for acoustic TL and demonstrated significant broadband noise attenuation. The ECLSS mufflers are currently scheduled to be installed on the Artemis II CM of the Orion spacecraft and will provide significant cabin comfort to crew during the mission.

5:20 PM 02-Aug-2021 **IN21_1886.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1886

A review of variable-impedance acoustic liner concepts developed at NASA

Michael Jones

This paper presents results attained in the NASA Langley Research Center test rigs using concepts for which the impedance varies over the surface of the liner. These liners are typically designed for significant sound absorption over a wide frequency range, but it is also possible to tune the design to achieve increased absorption at selected frequencies. A brief review is provided regarding a number of variable-impedance concepts. The first is a modified version of a conventional two-layer liner, in which the embedded septum location and acoustic properties are different for adjacent core chambers. Two concepts employ core chambers with different lengths, one with bent chambers to allow packaging within a limited volume, and the other with shared inlet ports to reduce the surface porosity. The last employs a perforated facesheet in which the hole diameter and porosity are varied over the surface of the liner. Data acquired in the NASA normal incidence and grazing flow impedance tubes are used to demonstrate the capabilities of these concepts. Impedance prediction models are also presented for comparison with these measured data.

Session: 09.02 Acoustic Metamaterials, Part 3
Channel 6

6:00 PM 02-Aug-2021 **IN21_3472.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3472

Adjustable sound insulation frequency band through the combination of membrane-type acoustic metamaterial array

Xiang Wu, TengLong Jiang, JianWang Shao, GuoMing Deng, Chang Jin

Membrane-type acoustic metamaterials are thin films or plates composed of periodic units with small additional mass. A large number of studies have shown that these metamaterials exhibit tunable anti-resonance, and their transmission loss values are much higher than the corresponding quality laws. At present, most researches on membrane-type acoustic metamaterials focus on the unit cell, and the sound insulation frequency band can only be adjusted by adjusting the structural parameters and material parameters. In this paper, two kinds of acoustic metamaterials with different structures are designed, which are the center placement of the mass and the eccentric placement of the mass.The two structures have different sound insulation characteristics. By designing different array combinations of acoustic metamaterials, the sound insulation peaks of different frequency bands are obtained. This paper studies the corresponding combination law, and effectively realizes the adjustable sound insulation frequency band.

6:20 PM 02-Aug-2021 **IN21_2182.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2182

Sound reflection of acoustic porous metasurfaces under uniform mean flow

Renhao Qu, Jingwen Guo, Yi Fang, Siyang Zhong

Acoustic metasurfaces are artificial 2D structures with a sub-wavelength thickness that can realize some exotic properties such as non-trivial refraction, broadband and low frequency absorption. However, most relevant studies are still in a static medium, hindering their realistic applications in aviation, where background flow exists. To address it, the effects of mean flow on the acoustic performance of metasurfaces, which is designed based on the generalized Snell's law (GSL) to achieve anomalous reflections, are systemically studied. Firstly, an analytical model of GSL taking the effect of background uniform mean flow into account is built, in which the wavenumbers of both incident and reflected waves are corrected. Then, taking an acoustic porous metasurface for instance, the effectiveness of the derived model is validated by numerical simulations. Results reveal that the reflected waves are deflected in the presence of background flow. The critical incident angle, at which the incident sound wave is converted to surface wave, decreases with the increasing flow velocity. Since the converted surface wave can only propagate along the metasurface, there is little sound energy radiated into far field, which is benefit for the noise attenuation in the presence of flow.

6:40 PM 02-Aug-2021 **IN21_2162.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2162

Tunable frequency bandgaps in elastic metamaterials with internal contacts

Eunho Kim, Guenil Kim, Kyeong Min Cho, Yeongtae Jang

We design an elastic metamaterial with internal contacts and study the tunable frequency band structure of the metamaterial. It is well-known that the frequency band of granule structures consisting of particles changes depending on the system's compression because of the nonlinearity of the contact between particles. We adopt this efficient tunning mechanism, i.e., contact, in the design of continuum type elastic metamaterials. We first design a unit cell structure showing internal contacts under compression and fabricate it using a 3D printer. We

numerically and experimentally identify that the unit cell's stiffness suddenly increases when the internal contact happens. This sudden change of the stiffness induces a change of frequency characteristics of the structure. Here, we demonstrate that internal contacts are useful for designing various frequency bandgaps and tuning them efficiently.

Session: 09.06 Sound Absorption Measurements, Part 1
Channel 6

7:20 PM 02-Aug-2021 **IN21_2729.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2729

Trial applications at gymnasiums of in-situ sound absorption measurement method by ensemble averaging technique

Toru Otsuru, Reiji Tomiku, Noriko Okamoto, Siwat Lawanwadeekul

The authors have been published a series of papers on a measurement method for sound absorption characteristics of materials using ensemble averaging technique, i.e., EA method. The papers' results included measurement mechanisms, measurement uncertainty, and so on. Herein, to examine adaptability, especially in in-situ conditions, the EA method is applied to measure absorption characteristics of materials installed in two gymnasiums. A glass-wool panel with the dimension of 0.5 m by 0.5 m by 0.05 m and with the density of 32 kg m^-3 was brought around and measured to check the measurement consistency. Several measurements were conducted during badminton plays were undergoing. Measured sound absorption coefficients revealed that most results agree well with those measured in reverberation rooms. Certain improvement is necessary for the specimen brought to the in-situ measurement to keep the consistency. The inconsistency is considered to originate from unstable conditions between the specimen and floor.

7:40 PM 02-Aug-2021 **IN21_3158.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3158

Finite element sound field analysis on measurement of absorption coefficient in a reverberation room - Relationships between inclination of walls and measurement results-

Reiji Tomiku, Noriko Okamoto, Toru Otsuru, Shun Iwamoto, Shoma Suzuki

The absorption coefficients in a reverberation room are most representative measure for evaluating absorption performance of architectural materials. However, it is well known that measurement results of the coefficient vary according to a room shape of the measurement and area of the specimen. Numerical analyses based on wave acoustics are effective tools to investigate these factors on absorption coefficient measurement in reverberation room. In this study, sound fields for the measurement of absorption coefficient in reverberation room are analyzed by time domain finite element method (TDFEM). This study shows effectiveness of the analysis for investigation on causes of variation in the measurement results and improvement methods of the measurement. First, some measurement sound fields for absorption coefficient in reverberation rooms the walls of which are incline or decline are analyzed by the TDFEM. Next, reverberation times in each sound fields are calculated from the results obtained by TDFEM and the absorption coefficients are evaluated from the reverberation time of the room with and without specimen. Finally, the relationships among room shape, degree of inclination of the wall, the sound absorption coefficient of the specimen, frequencies and the measurement absorption coefficient are investigated.

8:00 PM 02-Aug-2021 **IN21_3163.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3163

Calculation of statistical absorption coefficient using ensemble averaged surface normal impedance of material

Noriko Okamoto, Toru Otsru, Reiji Tomiku, Masahiro Masuda, Arisa Tabaru

To predict and control the indoor sound field, it is important to comprehend sound absorption characteristics of building materials. In the previous studies, the authors have proposed an in-situ sound absorption measurement method of materials using ensemble averaging technique, namely EA method. The method yields a simple and efficient in-situ measurement of surface normal impedance of materials at random-incidence. In this paper, the authors calculate the statistical absorption coefficient using the surface normal impedance of material by the EA method to obtain random incidence absorption coefficient. At first, the procedure of calculating the statistical absorption coefficient from the normal impedance by EA method is described. Next, the sound absorption characteristics for five kinds of materials are measured by the EA method and the reverberation room method. Finally, the statistical absorption coefficients are calculated from results obtained by the EA method and are compared with absorption coefficients by the reverberation room method.

8:20 PM 02-Aug-2021 **IN21_2324.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2324

A flow and acoustic facility for characterization of liner and meta-acoustic surfaces under grazing flow condition

Wei Yi, Jingwen Guo, Yi Fan, Renhao Qu, Siyang Zhong, Xin Zhang

The Hong Kong University of Science and Technology (HKUST) has designed and assembled a new facility, a grazing flow tube, for aeroacoustic characteristics measurement of acoustic liners, e.g. transmission loss, impedance, etc., under a high-speed grazing flow. The cross-section of the test section of the tube has a dimension of 50 mm × 50 mm, and the grazing flow speed can be up to 0.3 Ma. A settling chamber, a long-enough flow development section and a multi-stage anechoic termination are adopted to ensure the high-quality flow field and acoustic field. This paper presents the detailed designs of the key components of the facility, as well as the calibrations of the velocity profile in a series of cross-section surfaces of the duct along the streamwise direction and sound pressure distributions in the axial and circumferential directions. Pitot tube, Hotwire and PIV are used to obtain the flow field measurement results. The overall performance of the diagnostic facility is verified

by comparing the impedance results of acoustic liners acquired from an impedance tube under the static condition and the theoretical variation of axial wavenumber with Ma number under the grazing flow.

8:40 PM 02-Aug-2021 **IN21_2262.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2262

Measurement of sound absorption coefficient in a reverberant room using probability density function of damping constant

Kosuke Goto, Takehiko Nakagawa, Yoshinari Yamada

The measurement method of the sound absorption coefficient in a reverberation room is standardized in ISO 354. However, the measurement accuracy often deteriorates at low frequencies. This paper proposes a method that improves the measurement accuracy of the sound absorption coefficient at low frequencies. It calculates the sound absorption coefficient using reverberation time (RT) that is derived from the distribution of a damping constant for a sinusoidal input. The measured values by the proposed method were compared with those by the ISO 354 method. As a result, the proposed method reduces the spatial variability of RT and gives a better agreement with the statistical absorption coefficient that is calculated by a transfer matrix model at low frequencies.

Session: 14.07 Outdoor Noise Propagation
Channel 7

6:00 AM 02-Aug-2021 **IN21_2679.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2679

A study on variations in excess attenuation due to ground surface and meteorological conditions based on a long-term outdoor sound propagation experiment

Takatoshi Yokota, Koichi Makino, Genki Iizumi, Takuya Tsutsumi

From the winter of 2018, outdoor sound propagation experiments (maximum horizontal range: 300 m) have been repeatedly conducted three times a day on weekdays at a glider airfield in Hokkaido, Japan. The ground condition of the experimental field is grass-covered in summer and snow-covered in winter. In each experiment, impulse responses have been measured by time-stretched pulse method and excess attenuation has been obtained at receiving points. Meteorological data at the field has been also measured. Based on the data of excess attenuation collected under various meteorological conditions over a long period, variation in sound propagation characteristics due to the differences in ground surface condition and meteorological condition has been investigated. The numerical analysis based on the GFPE method has been also carried out with changing the parameter of meteorological condition and ground surface condition. By comparing the results with the experimental data, the prediction method of the variations in excess attenuation has been also investigated.

6:20 AM 02-Aug-2021 **IN21_3165.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3165

A comparison of the ground excess attenuation model in Harmonoise with finite-difference time-domain solutions under grounds with mixed types

Yusaku Koshiba, Takuya Oshima

Total noise exposure is calculated for the evaluation of health effects caused by environmental noise. For the calculation, computationally drawn noise maps are used. In the computation process, sound propagation over ground surface with mixed types should be calculated for better accuracy. One engineering model that allows such calculation is the ground excess attenuation model of the Harmonoise model. However, the applicability of the model to such complex grounds remains unclear. In this study, a 40m-length ground surface with a discontinuity in flow resistivity is defined. By moving the discontinuity position, sound propagation from a point source and a receiver at each end is calculated using the model and a numerical method. The numerical method is the finite-difference time-domain method with porous medium modeling that has been proven to be accurate. It is found from the numerical results that in higher frequencies the excess attenuations in terms of the discontinuity position have fluctuations. The fluctuations are found to correspond to the interference by diffraction path difference passing the discontinuity. In contrast, the model results exhibit smooth transition from an extremity of single flow resistivity surface to another. A simple model of such diffraction needs to be developed.

6:40 AM 02-Aug-2021 **IN21_2170.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2170

Landscape depressions can create silent zones in noise polluted parks

Timothy Van Renterghem, Pieter Thomas, Dick Botteldooren

Excessive road traffic noise exposure in (sub)urban parks hinders its restorative function and will negatively impact the number of visitors. Especially in such green environments, noise abatements by natural means, well integrated in the landscape, are the most desired solutions. Although dense vegetation bordering the park or raised berms could come first in mind, local landscape depressions are typically underused. In this work, a case-study of a small suburban park, squeezed in between two major arterial roads, is analyzed. The spatially dependent road traffic noise exposure in the park is assessed in detail by mobile sound pressure level measurements. Local reductions of up to 6-7 dBA are found at landscape depressions of only a few meters deep. It can therefore be concluded that this is an efficient measure and should be added to the environmental noise control toolbox for noise polluted parks.

7:00 AM 02-Aug-2021 **IN21_2405.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2405

Ground Attenuation Factor Based on Measurements

Dan Lin, Andrew Eng

Assumptions made on the ground types between sound sources and receivers can significantly impact the accuracy of environmental outdoor noise prediction. A guideline is provided in ISO 9613-2 and the value of ground factor ranges from 0 to 1, depending on the coverage of porous ground. For example, a ground absorption factor of 1 is suggested for grass ground covers. However, it is unclear if the suggested values are validated. The purpose of this study is to determine the sound absorption of different types of ground by measurements. Field noise measurements were made using an omnidirectional loudspeaker and two microphones on three different types of ground in a quiet neighborhood. One microphone was located 3ft from the loudspeaker to record near field sound levels in 1/3 and 1 octave bands every second. The other microphone was located a few hundred feet away to record far field sound in the same fashion as the near field microphone. The types of ground tested were concrete, grass, and grass with trees. Based on the measurement data, it was found that grass and trees absorb high frequency sound well and a ground factor of 1 may be used for 500Hz and up when using ISO 9613-2 methodology. However, at lower frequencies (125 Hz octave band and below), grassy ground reflects sound the same as concrete surfaces. Trees absorb more low frequency sound than grass, but less than ISO 9613-2 suggested.

7:20 AM 02-Aug-2021 **IN21_2130.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2130

Accurate noise modeling for petrochemical plants – impact of compressor Piping

Arindam Ghosh

Compressor piping is a dominant noise source in petrochemical plants with large centrifugal compressors. Acoustic insulation is used on compressor suction, discharge and recycle lines as a measure to mitigate noise radiating from compressor piping. This paper will demonstrate using case studies the importance of acoustic insulation on compressor piping as the primary and most cost effective noise control method for both community and in-plant noise. Case studies include the predicted and measured noise levels obtained during post startup noise surveys. This paper will also illustrate that to obtain good agreement with measured noise levels it is imperative to accurately model the piping sources following the actual piping layout and account for distance attenuation. A cost-benefit analysis of using complete compressor houses and/or acoustic blankets will be presented along with the efficacy of various types of acoustic insulation including elastomeric foam and aerogel based insulation systems. Different acoustic requirements for hot and cold insulation systems will also be presented.

7:40 AM 02-Aug-2021 **IN21_2070.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2070

Open source acoustic model development for natural and protected environments

Adwait Ambaskar, Victor Sparrow

Natural quiet and the sounds of nature are important natural resources and experiencing them is an important aspect of outdoor recreation experiences. Anthropogenic sound can negatively impact these resources and diminish the benefits realized from outdoor recreation. On public lands where many types of recreation share trails and landscapes, the sounds produced by some types of recreation (e.g., motorized recreation) can negatively impact the experiences of others. To effectively manage public resources including natural soundscapes and recreation opportunities, public land and recreation managers need an understanding of the effects of recreation-caused sounds like those associated with motorized recreation. Acoustic models for recreation and protected areas provide an essential tool to help in predicting sound levels generated by these anthropogenic sources and can aid in studying the extent of potential recreation conflicts, while providing a definite direction to mitigate such conflicts. An open source outdoor sound propagation model integrated with Geographic Information Systems (GIS) lays out a good foundation for mapping visitor experience affected by sound sources like gas compressors and motorized recreation sounds. The results thus produced present a preliminary version of an outdoor sound propagation tool, to assist parks and state forest services in making important management decisions to refine visitor experience.

Session: 11.06 Wind Turbine Noise

Channel 7

8:00 AM 02-Aug-2021 **IN21_1125.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1125

Experimental study of particle dampers applied to wind turbine blades to reduce low-frequency sound emission

Braj Bhushan Prasad, Fabian Duvigneau, Daniel Juhre, Elmar Woschke

Sound emission from an onshore wind turbine is one of the significant hurdles to use wind energy to its full potential. The vibration caused by the generator is transmitted to the blades, which radiates the sound to the surrounding. The purpose of this experimental study is to present a passive vibration reduction concept, which is based on the high damping properties of granular materials. The efficiency of this concept will be investigated using a laser scanning vibrometer device. For the experimental purpose in the laboratory, small-scale replicas inspired by the original configurations are used as reference geometries for the wind turbine generator and the blades. Vibrations of the prototype, with and without granular material filling, will be determined and compared with each other. The influence of the amount of granular material inside the structure is also investigated. Apart from this, different types of granular filling are examined with respect to their efficiency in reducing the amplitude of vibration of the structure while being as light as possible in order to design a lightweight solution, which increases the overall mass of the wind turbine marginally.

8:20 AM 02-Aug-2021 **IN21_2449.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2449

Attenuation of Torsional Vibration in the Drivetrain of a Wind Turbine using a Centrifugal Pendulum Absorber

Hyeongill Lee, Youkyung Han, Byeongil Kim

The drivetrain of wind turbines consists of many complicated rotary elements such as planetary gear, parallel gear train, bearing etc. The drivetrain of the wind turbine are studied with many different modeling techniques in several works. However, the things come to complicated when considering a complete drivetrain of a wind turbine. In this study, the transfer matrix method will be utilized to analyze the torsional vibration of a sample wind turbine drivetrain. Each element in the drivetain of the sample wind turbine is modeled with a specific transfer matrix and the matrix for the whole drivetrain is derived by serial multiplications of individual matrices. Dynamic characteristics of the drivetrain are investigated with derived matrix. Then, the application of a centrifugal pendulum absorber(CPA) to the drivetrain to attenuate the torsional vibration in the system is studied. The transfer matrix for the CPA introduced in the previous study is used to determine the optimal configuration and location of the CPA. The CPA shows good performance on the torsion vibration reduction for the drivetrain of the sample wind turbine.

8:40 AM 02-Aug-2021 **IN21_2589.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2589

Amplitude modulations increase annoyance due to wind turbine noise immission

Christoph Pörschmann, Stephan Großarth, Johannes M. Arend, Sebastian Schmitter, Dirk Schreckenberg, Klaus Wunder

Current literature suggests that annoyance of wind turbine noise is strongly affected by amplitude modulations (AM). A survey was carried out at five German residential study sites near wind turbines with a total of about 500 residents to study the effects of AM in more detail. Annoyance, disturbances, and the perception of wind turbine noise characteristics, including AM, were assessed. For each participant, address-related exposure to rating levels of wind turbines was estimated. Further, we carried out headphone-based listening experiments with participants from three of the five study areas and with non-exposed participants from another 'control' location. In the listening experiments, perceived annoyance was rated for varying AM and for different A-weighted sound pressure levels for a total number of 79 subjects. As expected, the results show an increase in annoyance with sound pressure level. Furthermore, annoyance increased significantly with the extent of amplitude modulations. Interestingly, annoyance showed a strong rise as soon as amplitude modulations became audible in the signal and this rise was hardly affected by the sound pressure level. In our contribution, we present comparisons of the results of the survey and the listening experiments.

Session: 14.03 Noise Barriers
Channel 7

11:00 AM 02-Aug-2021 **IN21_2485.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2485

Characterizing noise barriers: SOPRANOISE half-term progress report

Jean-Pierre Clairbois, Massimo Garai, Wolfram Bartolomaeus, Michael Chudalla, Fabio Strigari, Marco Conter, Andreas Fuchs

SOPRANOISE targets simplified assessment of the in-situ intrinsic acoustic performances of road / railway noise barriers. This paper presents its half-term progress. The research is divided in 5 Work Packages, the scientific ones being WP2 to WP5.WP2 is about establishing a state of art (SoA) of the intrinsic performances characterization: it is now finished and presented in 2 other papers by Conter and Fuchs. WP3 is about in-situ inspection tools: based on a review / questionnaire, an inspection protocol has been developed allowing simplified assessments mainly based on visual inspections and characterization of possible defects; WP3 is now in its final testing phase. WP4 is about designing a brand new "quick and safe methods" that could take place "in between" the inspection tools and the standardized EN1793-5 and 6; the research and development phases of WP4 are now finished, while its validation along highways is now scheduled. Finally, WP5 is about the use of noise barriers in the European market and the final report: a synthesis on the physical behavior of noise barriers and the physical significance of the test methods has been done, as well a SoA on the effective use of noise barriers; the results will be presented.

11:20 AM 02-Aug-2021 **IN21_2302.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2302

SOPRANOISE – update and analysis of noise barrier database including new current results

Marco Conter, Andreas Fuchs, Paul Reiter

In the frame of the SOPRANOISE project (funded by CEDR in the Transnational Road Research Programme 2018) work package 2 focused first on providing theoretical and practical background information on measurement of the acoustic performance of noise barriers due to a state-of-the-art regarding correlations and possible trends between diffuse (EN 1793-1, EN 1793-2) and direct sound field methods (EN 1793-5, EN 1793-6). After that, the objective of this research was to extend and update the database of the European noise barrier market developed during the QUIESST project, including more detailed analyses on single-number ratings as well as third-octave band measurement results. The data collected and the analysis performed show relevant facts and figures about acoustic performances of noise barriers measured under diffuse and direct sound field conditions, together with a better understanding of the respective significance, similarities and differences of these standardized methods, improving data analysis and correlations between these methods. This paper gives a general overview of the data collected, summarising the main results of the statistical analyses performed. Overall results and comparisons between results of

measurements performed under diffuse and under direct sound field conditions are shown. Finally, conclusions and possible outlook of the research are presented.

11:40 AM 02-Aug-2021 **IN21_1324.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1324

Insertion loss (IL) of finite sound barriers of different contours – An introduction to geometrical solutions in 3-D space

Giora Rosenhouse

The design of finite sound barriers noise sources and control points requires calculations beyond those that are used when the Maekawa formula is applied, since the problem involves polygon sd barriers located in various possible orientations in 3D space. We present here some means that are linked to basic mathematical geometrical tools. Those means are relatively simple, as compared to the physical formulation of the relevant diffraction solutions for sound barriers (e.g. Rosenhouse, 2019, 2020). Such calculations can apply algebraic, trigonometric or vector analysis and their combinations to define the geometries of barrier IL. This approach includes the location of the sources and control points, which are essential as data for finding IL and other issues of environmental acoustics. We will show solutions including results of IL for a common rectangular barrier, as compared to IL of a barrier with a sloped top and side, among other possibilities.

12:00 PM 02-Aug-2021 **IN21_2310.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2310

Additional noise reduction with diffracting elements on barriers using numerical and standard calculation methods

Frits van der Eerden, Rafal Kurylek, Sandra Blaak, Erik Salomons, Tessel Van der Laan, Willem Jan van Vliet

The noise reduction of a (low) barrier can be enhanced by using an additional element with quarter-wavelength resonators with varying depths. A so-called Whiswall or WHIStop deflects sound upwards for specific frequencies. Measurements for a 1.1 meter high Whiswall and for a 1.1m barrier are compared in a separate paper. The enhanced barrier effect is measured at a short distance behind the barrier, for several situations. In this paper these measurements are compared with the results of a numerical finite element model (FEM) to validate this model. Next, the noise reduction is calculated at long ranges, up to 600 meters, for different point-to-point scenarios representative for road and rail traffic. A numerical parabolic equation method (PE) is coupled to the FEM model and a representative downwind condition is taken into account. The results at longer distance are used to design an engineering method for the enhanced barrier effect that can be used in standard noise calculation models, such as the Dutch national calculation model (SRM2) or the ISO 9613-2 standard.

12:20 PM 02-Aug-2021 **IN21_2194.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2194

Additional noise reduction with diffracting elements on barriers: experimental testing

Wout Schwanen, Mark Mertens, Ysbrand Wijnant, Willem Jan van Vliet

The noise reduction of a (low) noise barrier can be enhanced by using an additional element with quarter-wavelength resonators with varying depths. The so-called WHISwall or WHIStop deflects sound upwards for specific frequencies creating an additional sound reduction. Different experiments on the WHISwall and WHIStop are performed as input for model validation. The development and validation of the model are described in a separate paper. In this paper the measurement campaign and its results are presented.
We performed measurements on two setups. The first setup consists of a 1.1 meter high WHISwall, a 1.1m high noise barrier and a reference section (without noise measure). Measurements have been conducted with both an artificial sound source and pass by measurements with light and heavy motor vehicles. In a second test setup, the WHIStop was placed on top of a 4 meter high noise barrier and the diffraction was determined according the European standard EN 1793-4.

12:40 PM 02-Aug-2021 **IN21_1846.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1846

A FEM/Kirchhoff-Helmholtz integral model for noise diffractors on low height noise barriers

Ysbrand Wijnant, Judith L. Rochat, Bart Willems, Wout Schwanen

So-called noise diffractors are a novel way to reduce traffic noise. As opposed to blocking or absorbing noise, diffractors bend noise in an upward direction, creating a shadow zone of reduced noise levels behind the diffractor. The diffraction is most effectively induced by quarter-wavelength resonators. The resonators can be placed in the ground but can also be mounted on top of a (low height) noise barrier, which provides additional reduction.
In this paper, we describe a finite element/Helmholtz integral model for a diffractor mounted on a low height noise barrier. The finite element model is used to calculate the scattered acoustic field in the proximity of the diffractor for a noise source sufficiently far away from the diffractor. The acoustic pressure and particle velocity on the outer boundary of the finite element domain are subsequently used in the Kirchhoff-Helmholtz integral formulation to evaluate the acoustic field in the far field. The major benefit of this approach is a large reduction of the model size and reduced calculation times. This allows us to assess the reduction values at different barrier heights, larger distance from source to diffractor and larger distances from diffractor to evaluation points, with an example shown for highway traffic noise.

Session: 14.00/14.01/14.04 Environmental Noise
Channel 7

2:00 PM 02-Aug-2021 **IN21_2280.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2280

Merging science education, citizen science and general population noise exposure data collection in the battle against noise pollution

Luc Dekoninck

Science, Technology, Engineering, Mathematics in education is commonly referred to as STEM. The last decades illustrate that our society is transferring into an ever accelerating technological environment. In parallel, the general public became an important driving force in collecting citizen science data to trigger legislative pressure and impact on policy makers to accelerate the improvement of their quality of life. That practice is currently extending into the environmental impact of noise related quality of life. This publication suggests to merge those educational STEM goals, citizen science monitoring and the need for population based noise monitoring data for efficient policy support. The presented educational project can be regarded as a proof-of-concept and can be repeated in different schools and classes every year. This approach has the potential to acquire abundant noise monitoring data and provides an unbiased population sampling dataset by design. This population driven involvement allows to assess real-life and long-term noise policy impact and could become a fundamental pillar in achieving the overall societal goal of improving noise related environmental quality of life.

2:20 PM 02-Aug-2021 **IN21_2615.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2615

The uncertainty in the acoustic annoyance evaluatiom

Mário Mateus, Manuel Carlos Gameiro da Silva

The coexistence of a mixed use, in a significant part of the buildings, with a part being used for housing purposes and another part for economic activities (commercial, services, etc.) creates situations that are frequently a reason for complaints due to acoustic annoyance. In Portugal, the assessment of this type of discomfort is carried out through sound measurements, comparing the value of the difference between the total sound and the residual sound with the legal limits set in national legislation. This comparison is made without considering the uncertainty value of that difference. If the value of uncertainty is not depicted when declaring compliance in test reports, the level of risk associated with the decision rule (such as false accept and statistical assumptions) can take values between 2.5% and 50%. This risk assumes the highest value when the obtained difference is equal to the established limit value. This paper presents a formulation that allows obtaining the value of the uncertainty for that difference, based on the Monte Carlo simulation method. The estimation of the uncertainty value led to physically more plausible values, when compared to those normally obtained with the usual formulation based on the propagation of uncertainty law.

2:40 PM 02-Aug-2021 **IN21_2645.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2645

Noise Control and its relationship with the UN Sustainable Development Goals

Eoin King

This paper considers noise and its control in the context of the United Nations Sustainable Development Goals (SDGs). Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality, and social equity, and the UN SDGs describe the major development challenges in these pursuits. The SDG Framework comprises 17 broad goals, that cover a wide range of issues including poverty, hunger, health, education, gender equality, clean water, clean energy, sustainable cities and communities, climate, responsible consumption, and production, amongst others. Although noise and its management are not clearly identified in any of the 17 goals, this paper posits that noise is an issue cross-cutting through almost all of the goals. Through the lens of the SDGs, this paper summarizes how a failure to adequately address noise presents a significant challenge to the realization of sustainable development.
This paper considers noise and its control, in the context of the United Nations Sustainable Development Goals (SDGs). Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality and social equity, and the UN SDGs describe the major development challenges in these pursuits. The SDG Framework comprises of 17 broad goals, that cover a wide range of issues including poverty, hunger, health, education, gender equality, clean water, clean energy, sustainable cities and communities, climate, responsible consumption and production, amongst others. Although noise and its management are not clearly identified in any of the 17 goals, this paper posits that noise is an issue cross-cutting through almost all of the goals. Through the lens of the SDGs, this paper summarizes how a failure to address noise presents a significant challenge to the realization of these goals.

3:00 PM 02-Aug-2021 **IN21_2603.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2603

The interplay of tourism and noise: A literature review

Lisa-Marie Wadle, Noemi Martin

Tourism is an important economic factor for countries, cities and individual beings. However, tourism also has an impact on the environment, e.g. in terms of noise. This does not only constitute a burden for locals but also effects tourists whose goal, among others, commonly is to rest during their holidays. A literature review was conducted covering the last ten years (2011-2021) and will be updated until the conference. The terms or and noise as well as synonyms and related terms were used in the search string. The search results in over 400 documents which were reduced based on their fit to the area of research interest and a practical screening. The overview gained by reviewing the literature indicates the most common noise sources with relation to tourism. Furthermore, several studies were found which analyse the consequences for locals and how they react to and deal with the noise. Some of the studies focused on measures taken on noise reduction like reducing the noise source itself, developing new methods to measure or visualize noise as well as structural measures. Based on this review, future research areas were identified.

3:20 PM 02-Aug-2021 **IN21_2826.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2826

Long Term Ambient Sound Level Survey

Henk de Haan, Virgini Senden

A 32 month long nighttime ambient sound level survey was conducted between from April 2017 and December 2019, inclusive. Sound level data was recorded at three locations within approximately 600 m of one another. Weather data was collected at one site. The measurement locations were at the edge of the city, where the suburbs make way for the countryside. Two noise monitoring stations were located near the back yards of detached houses. The third station was located in a more rural setting. This paper will look at trends in the nighttime ambient sound level (e.g. summertime vs wintertime), and try to establish the minimal duration of a measurement program for generating reliable results.

3:40 PM 02-Aug-2021 **IN21_2966.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2966

Assessing the Potential for Noise Complaints due to Backyard Chickens

Charles Moritz

During the past decade, there has been tremendous growth in the popularity of backyard chickens in urban and suburban locations throughout the United States. While there are many advantages to raising chickens, their introduction has not gone without controversy. Noise has been a common concern during discussions of municipal ordnances and a common complaint against flock owners. There is very little data on the sound levels produced by chickens in the technical literature. What data is published is not appropriate for predicting sound levels at owners' property lines. In addition, the non-technical literature, social media, newspaper stories, etc. abounds with misinformation. To determine the sound power of various chicken breeds, the author has been measuring sound levels from birds in his flock. This data can then be compared to the sound level from other typical back yard sound sources, existing community annoyance prediction models, and records of noise complaints.

4:00 PM 02-Aug-2021 **IN21_2581.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2581

Bibliographic review of socio economic effects of environmental noise for public policies in Chile

Alexis Campos, Felipe Raimann Arias, Pablo Gonzáles Padilla

The Ministry of Environment of Chile is currently updating the public policies that regulate noise mainly from industrial sources. For this reason, a background record of studies that describe the benefits and socioeconomic effects of noise in the population is needed. Through a bibliographic review it was possible to identify a variety of benefits and effects in the economy, health and social ambit, as well as new investigation lines that take in consideration the mental health and non favorable socioeconomic conditions (economic inequality, racial and ethnic problems). The different works analyzed include the recent systematic reviews for the elaboration of the "Environmental noise guidelines for the European Region" of the World Health Organization, a series of works mainly of European origin and two Latin American economic studies.

Finally, due to the low regulation in Latin American countries regarding noise, it is possible that these problems are greater than those reported in developed countries and therefore their study is of interest to create or apply other public policies in the region to a greater extent.

Session: 14.05 Noise Mapping

Channel 7

6:00 PM 02-Aug-2021 **IN21_2591.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2591

Acoustic Prediction Modeling and Sound Mapping of public transport users' exposure at a bus stop.

Dayane Cristina Lima Estercio, Paulo Fernando Soares

The objective of this research is to develop a mathematical model to predict the road traffic noise level at the bus stop, to assess the level of noise that users of these urban facilities are exposed daily. To help assess the exposure and the environmental impact, sound mapping will be performed using the IMMI software. In the model, the calculation of direct paths and specular reflections and diffuse was adopted. The study was applied in three sections in the city of Maringá, Brazil. At each point, the user was simulated standing and sitting. The sound source was positioned on the axis of each strip, every five meters. In total, 5124 readings of source positions were evaluated in 84 measured points. For the validation, the Anderson-Kurze, Kang, Yang and Zhang, Bistafa and Naish model were applied, and then the t-Student test were applied. The results showed a correspondence between the developed model, the data of the measurements and the reference models in the range of 25 Hz to 10000 Hz, there was a greater variance between the models applied in the high frequencies. It is concluded that the model was able to estimate the sound level of the stretches evaluated.

6:20 PM 02-Aug-2021 **IN21_3069.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3069

A closer look at rail methodology in the BTS National Transportation Noise Map

Amanda Rapoza, Meghan Shumway, Gary Baker, Peter Wilke

In 2017, the Bureau of Transportation Statistics released the inaugural national, multi-modal transportation noise map prototype. The noise modeling and mapping effort was envisioned as a way to facilitate the geographic tracking of national trends and provide insight into transportation noise-related questions as changes occur over time - changes between modes, types of vehicles within modes and the geographic shifts of populations. How do changes in aircraft technology change the transportation noise landscape? Does increased high speed rail availability affect highway-related noise? How does a population shift away from urban centers affect the soundscape? The inaugural model included aviation and highway sources. The first update, released in November 2020, includes passenger rail-related noise in addition to aviation and highway sources. Operations in this new mode include commuter rail mainline, high-speed electric, light rail, heavy rail and

streetcars, along with commuter rail horns at highway-rail grade crossings. The data for this noise map were modeled based on USDOT methods, with adjustments and simplifications to model on a national scale. This paper focuses on the modeling methods and geospatial approach used to develop the passenger rail noise data layer.

6:40 PM 02-Aug-2021 **IN21_1616.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1616

Route survey research of US military aircraft at Futenma Air Base and Kadena Air Base in Okinawa Prefecture

Takeshi Tokashiki

Currently, about 186.09 km2 of US military bases are located in Okinawa Prefecture, accounting for about 10.4% of the prefecture's land area, and about 70% of US military bases nationwide are concentrated. Many of the US military bases are located in or near urban areas, and have an impact on the city planning of related municipalities. Among them, the aircraft noise problem is serious, and noise exceeding 100 dB (value observed in the residential area at the measurement point) such as takeoff and landing noise and engine adjustment noise is generated on a daily basis, which greatly deteriorates the living environment of the local residents. It is a factor. In response to this, the national government has taken measures such as soundproofing work.
In this study, the subjects were Kadena Air Base and Futenma Air Base, and continuous measurements were made around the bases to investigate the surrounding sound environment.

Session: 20.01 Artificial Intelligence for Noise and Vibration Control, Part 1
Channel 7

7:40 PM 02-Aug-2021 **IN21_2397.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2397

Experimental force reconstruction on plates of arbitrary shape using neural networks

Tyler Dare

Measuring the forces that excite a structure into vibration is an important tool in modeling the system and investigating ways to reduce the vibration. However, determining the forces that have been applied to a vibrating structure can be a challenging inverse problem, even when the structure is instrumented with a large number of sensors. Previously, an artificial neural network was developed to identify the location of an impulsive force on a rectangular plate. In this research, the techniques were extended to plates of arbitrary shape. The principal challenge of arbitrary shapes is that some combinations of network outputs (x- and y-coordinates) are invalid. For example, for a plate with a hole in the middle, the network should not output that the force was applied in the center of the hole. Different methods of accommodating arbitrary shapes were investigated, including output space quantization and selecting the closest valid region.

8:00 PM 02-Aug-2021 **IN21_2479.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2479

Generative Adversarial Neural Network for Unsupervised Bearing Fault Detection

Gyuwon Kim, Seungchul Lee

Detecting bearing faults in advance is critical for mechanical and electrical systems to prevent economic loss and safety hazards. As part of the recent interest in artificial intelligence, deep learning (DL)-based principles have gained much attention in intelligent fault diagnostics and have mainly been developed in a supervised manner. While these works have shown promising results, several technical setbacks are inherent in a supervised learning setting. Data imbalance is a critical problem as faulty data is scarce in many cases, data labeling is tedious, and unseen cases of faults cannot be detected in a supervised framework. Herein, a generative adversarial network (GAN) is proposed to achieve unsupervised bearing fault diagnostics by utilizing only the normal data. The proposed method first adopts the short-time Fourier transform (STFT) to convert the 1-D vibration signals into 2-D time-frequency representations to use as the input to our (DL) framework. Subsequently, a GAN-based latent mapping is constructed using only the normal data, and faulty signals are detected using an anomaly metric comprised of a discriminator error and an image reconstruction error. The performance of our method is verified using a classic rotating machinery dataset (Case Western Reserve bearing dataset), and the experimental results demonstrate that our method can not only detect the faults but can also cluster the faults in the latent space with high accuracy.

8:20 PM 02-Aug-2021 **IN21_2415.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2415

A machine learning-based methodology for computational aeroacoustics predictions of multi-propeller drones

Cesar Legendre, Cesar Legendre, Vincent Ficat-Andrieu, Athanasios Poulos, Yoshitaka Nakashima, Wataru Kobayashi, Gaku Minorikawa

The rapid progress in technological developments of small Unmanned Aircraft Systems (sUAS) or simply "drones" has produced a significant proliferation of this technology. From multinational businesses to drone enthusiasts, such a technology can offer a wide range of possibilities, i.e., commercial services, security, and environmental applications, while placing new demands in the already-congested civil airspace. Noise emission is a key factor that is being addressed with high-fidelity computational fluid dynamics (CFD) and aeroacoustics (CAA) techniques. However, due to uncertainties of flow conditions, wide ranges of propellers' speed variations, and different payload requirements, a complete numerical prediction varying such parameters is unfeasible. In this study, a machine learning-based approach is proposed in combination with high-fidelity CFD and CAA techniques to predict drone noise emission given a wide variation of payloads or propellers' speeds. The transient CFD computations are calculated using a time-marching LES simulation with a WALE sub-grid scale. In contrast, the acoustic propagation is predicted using a finite element method in the frequency domain. Finally, the machine learning strategy is presented in the context of fulfilling two goals: (i) real-time noise prediction of drone systems; and (ii) determination of propeller's rotation speeds leading to a noise prediction matching experimental data.

8:40 PM 02-Aug-2021 **IN21_1490.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1490

Combination of gated recurrent unit and Network in Network for underwater acoustic target recognition

Shuang Yang, Xiangyang Zeng

Underwater acoustic target recognition is an important part of underwater acoustic signal processing and an important technical support for underwater acoustic information acquisition and underwater acoustic information confrontation. Taking into account that the gated recurrent unit (GRU) has an internal feedback mechanism that can reflect the temporal correlation of underwater acoustic target features, a model with gated recurrent unit and Network in Network (NIN) is proposed to recognize underwater acoustic targets in this paper. The proposed model introduces NIN to compress the hidden states of GRU while retaining the original timing characteristics of underwater acoustic target features. The higher recognition rate and faster calculation speed of the proposed model are demonstrated with experiments for raw underwater acoustic signals comparing with the multi-layer stacked GRU model.

Session: 17.03 Psychoacoustic Noise Evaluation: Basics & Applications, Part 1
Channel 8

6:00 AM 02-Aug-2021 **IN21_1304.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1304

Application of loudness level to temporally varying sounds

Sonoko Kuwano, Seiichiro Namba

Most of the environmental noises are temporally varying and include various frequency components. Various methods for evaluating the environmental noises have been proposed. Among them, the method for calculating loudness level was first standardized in 1975 as ISO 532, including Stevens' and Zwicker's methods. Unfortunately, these methods can only be applied to steady state sounds. On the other hand, Aeq (Equivalent Continuous A-weight Sound Pressure Level) is standardized for the evaluation of level fluctuating environmental sounds as ISO 1996. In , the energy mean and A-weighting are used for averaging temporal fluctuation and frequency weighting, respectively. The present authors with their colleagues have conducted many psychological experiments using artificial sounds and actual sounds since 1970's and have being introduced that p (Loudness-based Method), which is a combination of ISO 532 for frequency weighting and ISO 1996 for temporal level fluctuation, is a good method for evaluating various kinds of environmental sounds. ISO 532-1 (Zwicker's method) has been revised including the temporal fluctuation into consideration in 2017, in which p has been adopted as a note. The merit of p will be introduced in this paper presenting many examples.

6:20 AM 02-Aug-2021 **IN21_2062.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2062

Pitch strength and annoyance of acoustic analogs of flutter echo – a pilot study

Anne Balant, Heather Lai, Vayda M. Wilson

The impetus for this pilot study was the observation of flutter echoes on the aisle of a church with a barrel-vaulted ceiling. When source and receiver height were comparable, the flutter echoes consisted of a 39-msec repeating pattern of three short pulses that persisted for reverberation times of up to 5 sec. The disruptive quality of these echoes perceptually was striking. It was hypothesized that the perception of a sequence of rapidly alternating periodicity pitches might be the source of this disruptive quality. A pilot study was conducted to assess the perceived pitch, pitch strength, and annoyance of isochronous and anisochronous synthetic pulse trains involving up to three different inter-pulse intervals per pattern. Intervals of the anisochronous pulse trains were controlled to create harmonic and inharmonic relationships among the intervals, which ranged from 5-20 msec. Twelve adult college students participated in the study remotely via videoconferencing due to social distancing requirements. A modified category scaling method was used. Participants positioned a slider on a graphical user interface to reflect their ratings of pitch strength and annoyance and used a slider to adjust the frequency of a reference tone for pitch matching. Results and implications for further research will be presented.

6:40 AM 02-Aug-2021 **IN21_2701.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2701

Impressions and interpretations of vehicle horn sounds with acoustic characteristics of speech

Masayuki Takada, Kanji Goto

In Japan, vehicle horns have been used as a means of communication between drivers, and frequently aroused psychological negative reactions in hearers. If horn sounds have acoustic features of speech, they possibly help communication between drivers, and improve hearers' negative impressions. To investigate such hypotheses, psychoacoustical experiments were conducted using synthesized horn sounds with acoustic characteristics of Japanese speech "abunai", which implies a dangerous situation. Spectral features and temporal envelopes were extracted from the speech stimulus and the similar one with swapped syllables, and were reflected in horn sounds. Two experiments were carried out to examine the effects of acoustic characteristics of horn sounds on the perceived quality and interpretations of the intention behind another driver's horn use. Stimuli with spectral characteristics of the speech and those of swapped syllables were evaluated as being less unpleasant and more safe than the original horn sound. On the other hand, many responses of 'caution' and 'danger' were obtained for the stimulus with spectral characteristics of the speech. Results suggested that the horn sound with spectral characteristics of the speech improved from the original horn sound in the perceived quality, and correctly communicated the intention behind another driver's horn use.

7:00 AM 02-Aug-2021 **IN21_3252.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3252

Effects of speed and road condition on annoyance caused by motorcycle noise emission

Omid Samani, Anna Martius, M. Ercan Altinsoy

Recently much attention has been drawn to the noise emission of two-wheelers and motorcycles. Considering the high levels of noise pollution and annoyance caused by motorcycles, it is necessary to evaluate the contribution of their noise emission to the overall traffic noise. Furthermore, this emission must be included in traffic noise studies and noise maps. In order to have a clear understanding of the noise characteristics of this vehicle category, extensive studies are required. This paper aims to investigate the effects of speed and road condition on annoyance caused by motorcycle noise emission. For this purpose, noise measurements are carried out for various engine speeds, and road conditions. These stimuli are used later in a perceptual experiment to realize the effect of each parameter on the caused annoyance. Stimuli are reproduced in the laboratory where participants can determine their annoyance toward each stimulus. Finally, based on the outcome of the perceptual experiment and analysis of psychoacoustic parameters, a conclusion is drawn to clarify how annoyance and noise emission alter in response to the changes in speed and road condition.

7:40 AM 02-Aug-2021 **IN21_2777.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2777

Equivalent sound level as a predictor for road traffic noise annoyance assessment

Jan Felcyn, Anna Preis

Noise annoyance can be rated either in situ or in laboratory conditions. Regarding the , many papers indicate that only 30% of the variance in people's answers can be explained by sound level values.
This value increases when a single type of noise is presented to participants in lab. However, the relationship between time structure of the noise stimulus and annoyance rating is still ambiguous.
In this study road traffic noise stimuli with different time structure at three different sound levels were created. Moreover, the psychoacoustical characteristics of them were also computed.
The calculated data was compared with results of the listening test in which participants rated each stimulus on the numerical ICBEN scale. Analysis showed that loudness and sound level are the dominant factors, they correlate quite well (~70%) with people's ratings. However, the different time structure of the road traffic noise at the same sound level did not evoke significantly different noise annoyance ratings.
Since there are no standards available for loudness measurement, the sound level for the same type of noise remains the simplest factor to reliably predict its impact on people regarding noise annoyance.

8:00 AM 02-Aug-2021 **IN21_1435.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1435

Experimental investigation on acoustics and efficiency of rotor configurations for electric aerial vehicles

Ronja König, André Gerlach, Henry Schmidt, Eike Stumpf

Aerial vehicles based on distributed electric propulsion systems have gained great interest. Their rotors however create loud and annoying sound, what obstructs market success. Variations in rotor configuration can be observed on emerging concepts, whereby the main varied parameters are blade radius, number of blades and blade distribution.
The focus of this paper is to identify how these parameters can be chosen to optimize efficiency and acoustics, including psychoacoustic metrics and sound quality of single rotors while hovering. Results from experimental investigations done in a hover-test-bench are presented. Rectangular, symmetric blades are used. Experiments are done varying blade radius (61mm to 126 mm), number of blades (2 to 8) and blade distribution (equal and unequal angles). Acoustic measurements are analyzed regarding microphone position, sound pressure level, spectral characteristics, psychoacoustic metrics and selected sound quality models.
Results show, that variations in blade radius, number of blades and blade distribution can improve efficiency and acoustics. Influence of these parameters on the acoustic signature at constant rotational speed and at constant thrust is discussed. Conclusions for optimized rotor design at aerial vehicles are derived and supplemented by resulting boundary conditions like building space and weight.

8:20 AM 02-Aug-2021 **IN21_2830.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2830

Temporal integration of partial loudness of helicopter-like sounds

Josef Schlittenlacher, Brian C. J. Moore, Brian C. J. Moore

When developing new vehicles that are to be operated in existing background noise, such as electric vertical take-off and landing aircraft (eVTOLs) in cities, a sound design goal should be to minimize the loudness in the given background noise. Rotorcraft sounds are characterised by their pulses, and the choice of rotor size and number allows to vary the temporal characteristics. We asked participants to compare the loudness of pulse trains with pulse durations of 1, 2, 5, 10 and 20 ms and a pulse rate of 20 Hz in a two-interval, two-alternatives forced choice task and a 1-up/1-down procedure. Street noise was presented simultaneously with the pulse trains, and had the same root-mean-square (RMS) level as the fixed reference pulse train of about 65 dB SPL. First results indicate that the sounds with a short pulse duration need considerably less RMS level to result in the same loudness as a long pulse duration, i.e. the partial loudness of shorter pulses is higher at the same equivalent sound pressure level.

8:40 AM 02-Aug-2021 **IN21_2180.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2180

Exposure to industrial noise: impacts on cognitive performance

Luiz Henrique Mesa Casa Pereira, Björn Knöfel, Jan Troge, Welf-Guntram Drossel, Marcel Klein, Jörn Hübelt

Research on the relation between exposure to noise and cognitive performance inside industrial environments is not as broad as on office environments. For a better understanding of the specific industrial noise problems, participants performed arithmetic tests inside a hemi anechoic room while they were exposed to sounds of five typical industrial noise sources. The subjects also classified how annoying they

perceived the noise signals. The effect of noise on the arithmetic test's performance was larger on accuracy than on velocity, which was verified using a Student t-test. Spectral-temporal characteristics – especially high frequency content and strong low frequency modulation – appear to relate better with lower performance on the test than high sound levels. Subjects that evaluated noise as more annoying performed worse in a final arithmetic test (under silence) after being exposed to the noises, indicating a possible cumulative effect of noise on performance. The findings provide a better insight in the cognitive behavior of people who are exposed to industrial noise. Hence, the study will proceed with the specific noise analysis of single industrial workplaces.

Session: 17.03 Psychoacoustic Noise Evaluation: Basics & Applications, Part 2
Channel 8

11:00 AM 02-Aug-2021 **IN21_2487.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2487

Improvement of sound atmosphere in the compartment of construc-tion machine

Takeo Hashimoto, Shigeko Hatano

Noise inside the compartment of construction machine makes the operator feel annoyed and exhausted due to the unwanted component of noise. This paper deals with the treatment of sound inside the compartment of construction machine to make the sound atmosphere desirable for the operator. The main cause of annoyance due to the exposure of noise is the peaky engine order components. This paper provides the method to reduce annoyance for the operator inside by the reduction of peaky components.

11:20 AM 02-Aug-2021 **IN21_2727.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2727

Research on commercial vehicle sound quality objective evaluation

Kun Qian, Zhichao Hou, Ruixue Liu, Dengke Sun, Rongkang Luo

With the increasing demand of users for the acoustical comfort of commercial vehicles, the sound quality has become one of the important indicators of comfort evaluation. The research focuses on the objective evaluation method of the subjective perception of the sound quality in commercial vehicle. The interior noises of commercial vehicle with an inline six diesel engine are measured. The five psychoacoustic parameters (loudness, roughness, sharpness, fluctuation strength, tonality and articulation index) are applied to the evaluation and analysis of the interior noises of the commercial vehicle. Using psychoacoustic parameters to evaluate the noises in commercial vehicle, it is of great significance for the analysis and control of the noises in commercial vehicle. The research results provide a theoretical basis for guiding the sound quality design and development of commercial vehicles.

11:40 AM 02-Aug-2021 **IN21_1686.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1686

Loudspeaker-based sound reproduction for evaluating noise transmission into the car cabin

Matthieu Kuntz, Gregor-Johannes Müller, Peter Kalinke, Bernhard U. Seeber

Virtual and laboratory-based design techniques can accelerate the development process over conventional prototype-and-field-test procedures. In car acoustics, the transmission of outside airborne noise into the cabin needs to be understood and managed. Here, we evaluate the accuracy of sound field recording and reproduction techniques for investigating the transmission of airborne noise into the driver's cabin of a car. Reference measurements of a real sound field, generated by a truck with idling engine to create a realistic scenario, were carried out in a semi-anechoic chamber. The reference sound field was recorded inside and around a test car. Additionally, a spatial recording of the reference sound field was carried out and used to reproduce the reference sound field over a loudspeaker array in a different, fully anechoic chamber, where the sound field was again measured inside and around the same test car. A comparison of the measured loudness inside the test car shows that this key parameter for sound quality could be reproduced rather faithfully over a loudspeaker array in a controlled testing facility.

12:00 PM 02-Aug-2021 **IN21_1484.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1484

Development of a metric for predicting people's responses to gusting wind noise in automobiles

Daniel Carr, Patricia Davies

Automobile manufacturers are trying to improve the interior noise environment in their cars. A more thorough understanding of how people perceive the noise is an important step towards this goal. The focus of the current research is on modeling the acceptability of time-varying wind noises containing gusts. A listening test was designed containing sounds that were simulated on the computer, based on pre-defined airflow profiles. The time-varying noises in the test follow one of two simple gusting scenarios. The primary scenario contained two segments of steady wind flanking a series of consecutive equal-strength gusts. The number, duration, and strength of the gusts were varied between sounds. This was done to examine general trends of acceptability with modulation rate, modulation depth, and duration. The second scenario contained two gusts of equal or unequal strength, occurring either without a break or separated by a time gap. This was done to examine the relationship between people's reactions to the individual gusts in a pattern and their reactions to the whole pattern. A small number of steady-wind noises were included for reference. Terms in an acceptability model containing a previously proposed gusting metric were estimated. Possible refinements to the metric and model are discussed.

12:20 PM 02-Aug-2021 **IN21_1630.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1630

Psycho-acoustic evaluation of the automotive acoustic comfort using vibro-acoustic prediction methods

Valentin Miqueau, Etienne Parizet, Sylvain Germes

In the automotive industry, the acoustic comfort is considered as a selling point of utmost importance. To help the OEMs improve the acoustic comfort in cars, as a one-tier supplier of automotive glazing, Saint-Gobain is currently working on the acoustic comfort within the cabin in order to propose the right set of glazing consistent with the OEMs' specifications.
The characterization of the acoustic comfort mostly relies on physical demonstrators required for carrying out the relevant measurements. It is however not available early in the project phase, delaying the subjective analysis late in the development phase. To have the opportunity to develop effective solutions, the acoustic comfort has to be investigated as early as possible in the design process.
Saint-Gobain is thus currently developing relevant acoustic models in order to predict the mid-high frequency airborne interior noise generated by the wind excitations. The subjective acoustic comfort has then to be assessed using the predicted interior sound pressure levels converted into audio soundtracks for the auralization purposes.
In this paper, we briefly present the Statistical Energy Analysis model developed by Saint-Gobain. The psychoacoustic methodology deployed to evaluate its reliability for the subjective evaluation of the automotive acoustic comfort is detailed.

12:40 PM 02-Aug-2021 **IN21_2096.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2096

Relationships between prior experience with fan noise and fan noise ratings in laboratory listening tests

Stephan Töpken, Steven van de Par

In the assessment of noise annoyance and sound quality, judgments made in the laboratory can be influenced by the prior experience that a participant had with the specific type of sound under test. In field tests for noise annoyance, prior experience and individual noise sensitivity are often part of the data collection but they are not always reported for sound quality evaluations in the laboratory. In this paper, data from listening tests dealing with the perception of fan noise was re-analyzed with respect to the individual prior experience participants had with fan noise in their life. The answers to a short questionnaire showed that the prior experience of the participants with fan sounds was quite different. For the investigated 30 fan sounds, five categories of every-day situations could be identified, in which fan sounds had been most commonly heard by the participants. The frequency how often fan sounds had been heard and the overall annoyance by fan sounds in daily life differed considerably between the participants. However, the exploration of the present data did not reveal a strong link between the individual prior experience and the results of the listening tests when averaged across participants with same ratings.

1:00 PM 02-Aug-2021 **IN21_2100.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2100

Loudness- and preference-equivalent levels of fan sounds at different absolute levels

Eike Claaßen, Stephan Töpken, Steven van de Par

In daily life, fans are a common and often unwanted noise source. The sound pressure level in dB(A) is often not sufficient to characterize their unpleasantness and level adjustments would be needed to compensate this shortcoming.
In this study, listening experiments were conducted to determine loudness- and preference-equivalent levels of 19 different fan noise stimuli. For this purpose, the level of each stimulus was varied with an adaptive procedure until it was equally loud (loudness task), or equally preferred (preference task) as a common reference noise with a fixed level of 75 dB(A).
This study repeats an earlier similar study, with a lower reference level of 60 dB(A) and using a larger set of stimuli. The present results are in broad agreement with the results of the prior study, supporting the stability of the matching procedure. Apparently, level adjustments (penalties) derived from such experiments do not change when stimulus levels are increased by 15 dB.
Based on the new results, an existing model developed with a 60 dB(A) reference, can be expanded to also predict preferences for sound sources up to 75 dB(A). Further experiments with a reference level of 45 dB(A) will complement the data to lower levels.

Session: 17.04 Sell & Buy Quiet
Channel 8

2:00 PM 02-Aug-2021 **IN21_2027.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2027

Sell and Buy Quiet – the extended concept to reduce noise (at work and at home)

Fabian Heisterkamp, Johanna Bengtsson Ryberg, Jean Jacques, Alwin Verdaasdonk

Despite progress in legislation, e.g. laws requiring employers to assess and address the noise risk for their workers, and in the use of new technologies, e.g. battery powered tools or gardening equipment, noise-induced hearing loss remains a problem even today. The NOise MAchinery Directive (NOMAD) Task Force of the European Member States cooperating in market surveillance has raised the awareness of many relevant stakeholders regarding the need for cooperation between manufacturers of products emitting noise and their users. A promising means to deal with the noise problem is to make possible and effective a real competition towards quieter machines and equipment, so that market forces drive the technological development. To that end, we introduce the concept of Selling and Buying Quiet and address the issues hindering its application. These became evident during NOMAD Phase 2, in particular at NOMAD Workshop 2 in 2019. The issues comprise general aspects, e.g. education on proper determination of noise emissions by manufacturers and use of noise information by machine users, as well as specific problems with existing EU legislation. Finally, we provide ideas and set goals to improve the situation, so that Buying and Selling Quiet will become a reality.

2:20 PM 02-Aug-2021 **IN21_2240.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2240

"Buy Quiet" with the added benefit of considering all safety, health, and cost factors

Edward Zechmann

Approximately 22 million U.S. workers are exposed to hazardous workplace noise. The industries with the highest prevalence of self-reported occupational HL were Mining (61%), Construction (51%) and Manufacturing (47%). "Buy Quiet" is the most strategic way to reduce noise exposure. However, there are other safety, health, and cost factors that significantly influence a purchasing decision for equipment. A more holistic approach is needed. The safety requirements procurement standard (SAE AS6228) has extensive guidance for evaluating all the safety, health, and cost factors influencing a purchasing decision for equipment. The factors are systematically incorporated into a five-year life cycle score. Unfortunately, this standard is underutilized. Publication of SAE AIR6916 and one-page guidance for each tool type will help to address the underutilization. SAE AIR6916 provides simplified guidance for using the AS6228 standard. One-page guidance documents with example evaluations of life cycle scores will make it easier for additional tools to be evaluated in a consistent and comparable manner. Working with retailers and online shopping websites is needed to make the life-cycle score information more easily accessible and easy to use for making purchasing decisions. Additional efforts are aimed at making the life-cycle score methodology routinely utilized and adaptable to new applications.

2:40 PM 02-Aug-2021 **IN21_1448.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1448

How to make sell and buy quiet a reality in Britain

Tao Wu, Paul Brereton, Jacqueline Patel

Hearing loss caused by excessive exposure to noise at work remains reportedly widespread. Purchase of quieter machinery is an efficient method of reducing both occupational noise exposure and the need to manage risk from noise, but it requires reliable noise information. Machinery supplied in Britain must have noise risk minimized and, where noise continues to present a risk, be supplied with data making clear the potential for noise risk, enabling identification of lower noise models and indicating methods of controlling that risk. In 2012 a pre-market surveillance exercise reported 80% non-compliance with these legal requirements and found it highly unlikely that buyers and users of machinery could make reliable decisions based on the noise data provided with machines. This paper considers the prospect of Sell and Buy Quiet becoming a reality in Britain through: restoring stakeholder confidence in noise data; establishing incentives for stakeholder action; making low noise machinery identifiable; clarifying and simplifying noise legislation; and improving some noise test codes.

3:00 PM 02-Aug-2021 **IN21_2623.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2623

Societal obstacles to Selling and Buying Quiet

David Nelson

The desire for a quieter environment, office, or workplace is nearly universal. The technology exists to accurately measure noise emission and estimate the health, functional, and financial impacts on hearing conservation, speech interference, and residential or workplace comfort. Several useful methods for labelling of noise emission have been proposed over the years. Government regulations for certain classes of equipment are already in place in some countries. Why then after several decades of concerted effort is "Selling and Buying Quiet" not commonplace? It may be that the fault lies neither with the quality of the engineering work nor the existence or lack of regulation. Instead, a complex of societal factors including confusion, misinformation, denial, and cognitive dissonance effectively undercut any program. This paper will discuss the societal factors opposing the success of "Selling and Buying Quiet", as experienced by the author, along with some possible approaches for increasing the recognition of noise control engineering in the future.

Session: 17.03 Psychoacoustic Noise Evaluation: Basics & Applications, Part 3
Channel 8

6:20 PM 02-Aug-2021 **IN21_2041.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2041

An experiment on the feeling of separation when multiple aircraft noises are overlapped

Makoto Morinaga, Takanori Matsui, Sonoko Kuwano, Seiichiro Namba

In order to calculate the A-weighted single event sound exposure level () of aircraft noise, the following method is described in the manual for aircraft noise measurement in Japan. Firstly a time-section, which is the range between two points where the noise level is 10 dB lower than the maximum noise level (), should be identified, and secondly the energy within the section is integrated. This method can easily be applied to the single event noises. When multiple aircraft noises are overlapped simultaneously, there are cases where cannot be calculated adequately by this method. In such cases, it is required to record the number of aircraft noises in the field measurements. However, even in the case of manned measurement, it is not easy to separate sound sources just by listening to the sound. A pilot study of the psychoacoustic experiment was conducted using the stimuli where multiple aircraft noises were overlapped in order to find what condition is needed so that multiple aircraft noises were separately perceived. It was suggested that a considerable time interval was needed so that people felt the separation between aircraft noises only with auditory information.

6:40 PM 02-Aug-2021 **IN21_1478.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1478

Study on psychological evaluation model of a good conversation in knowledge creative activity by multiple people

Sohei Tsujimura, Motoki Yairi, Takayoshi Okita, Mayu Nidaira

In recent years, Japanese companies are focusing on enhancing the knowledge creative activities of office workers, and the way of working in the office is shifting from the conventional divisional routine work to collaborative and creative work. On the other hand, office spaces are becoming quiet, and the number of extremely quiet them with noise levels below 40 dB is increasing. Previous studies have reported that a sound environment that is too quiet gives the worker the impression that it is difficult to have a conversation, further accumulation of research results is desired for the construction of a sound environment that enhances knowledge creative activities. Therefore, in this study, focusing on the relationship between sound environment and intellectual productivity, we investigated a sound environment suitable for knowledge creation activities by multiple people. Psychoacoustic experiments were conducted to examine the effects of sound pressure level (signal-to-noise ratio), type of sound and reverberation time of meeting room on the impression of “good conversation”. Furthermore, using the psychological evaluation data of the experimental participants, the causal model of psychological evaluation of “good conversation” was examined by multiple regression analysis, and the psychological factors that contribute to the impression of it was clarified.

7:00 PM 02-Aug-2021 **IN21_1900.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1900

Impact of COVID-19 on the sound environment in a dental office - a case study

Tomomi Yamada, Kazunori Nozaki, Sonoko Kuwano, Mikako Hayashi

As of February 2021, COVID-19 has not yet converged globally. Careful countermeasures are required for protecting infection of COVID-19 at dental clinics. Virus particles in saliva are likely to spread outside during dental treatment. Dental staffs must use a variety of personal protective equipment (PPE). In addition, the frequency of using dental aerosol suction devices in the dental office has increased dramatically, and the sound environment in the clinic has changed after taking the measures against COVID-19. In this study, we will report the measurement results of the changes in the sound environment during dental treatment that were perceived by dental healthcare professionals and patients.

Session: 16.00/16.01/16.04 Noise and Health, Part 1
Channel 8

7:40 PM 02-Aug-2021 **IN21_2451.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2451

Using noise control principles when evaluating the acoustic impacts of face coverings during the coronavirus pandemic

Richard Ruhala, Laura Ruhala

Several different combinations of face masks and shields are evaluated for their acoustic performance using a head and torso simulator (HATS). The HATS is used as a controlled and repeatable artificial sound source using white noise in a classroom environment. Sound pressure levels at octave band frequencies due to the face coverings are evaluated at a location of 2.0 meters from the HATS which is within the direct field to reduce the room acoustical effects. The problem is modeled as a barrier separating a source and receiver using fundamental noise control principles. Fabric material properties are used such as thickness, density, stiffness, and damping. The results are compared with experimental tests. The face shield with clear plastic barrier produces a resonance in the 1000 Hz octave band. Analytical models of cavity resonances, standing wave resonances, or plate resonances are calculated and compared with the experimental resonance. The speech interference level is used to determine the frequency content that is most likely to cause hearing difficulties and compared with A-weighted differences between the unmasked condition and masked.

8:00 PM 02-Aug-2021 **IN21_3020.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3020

Medical debates and musical interpretations of vibroacoustic disease in Vieques, Puerto Rico

Alejandra Bronfman

In 2001 the band Cornucopia (Puerto Rican musicians Jorge Castro and Claudio Chea) released an album called “Vibroacústica”. The title refers to a disease that allegedly afflicts people who have been exposed to loud noise over long periods of time. The vibrations thicken the walls of the heart, so the theory goes, and damage the immune, gastrointestinal, and neurological systems. This is noise as toxin, entering and sickening the body. The album takes the disease as its point of departure, and using location recordings of the coast of Puerto Rico, analog synthetic manipulations and digital processing, both recreates and protests the noise and its impact on human beings in Vieques, Puerto Rico, which was the target of bombing practice for over sixty years. This paper argues that the album subverts the idea of the preservation of a soundscape and instead reinterprets the sonic violence of occupation with the tweets, chirps and burbles of its soundtracks.

8:20 PM 02-Aug-2021 **IN21_3128.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3128

Change in the self-reported health status of residents associated with the reduced aircraft noise around Tan Son Nhat Airport after the epidemic outbreak

Bach Lien Trieu, Tran Thi Hong Nhung Nguyen, Thu Lan Nguyen, Makoto Morinaga, Yasuhiro Hiraguri, Takashi Yano, Yosiaki Sasazawa

The change in the self-reported health status of residents associated with the reduced aircraft noise around Tan Son Nhat airport (TSN) after the epidemic outbreak in early 2020 was investigated in three stages. Stage 1 is pre-outbreak when the airport was operating at its highest capacity. Phases 2 and 3 are three months and six months after the stop of international flight operation implemented in March 2020. Data on the residents' health status was obtained from face-to-face interviews. The questionnaire items were composed of Noise annoyance questions using the 11-point ICBEN scale, the Total Health Index, Health and lifestyle questionnaire, Depression Scale revised questionnaire, and questionnaires to identify insomnia, hypertension, and hearing loss. Other factors related to living conditions such as education, income, or housing were also collected as health adjustment factors. The noise levels of phases 2 and 3 were estimated by updating the noise contour map of phase 1 using the TSN airport's operation data in corresponding periods in 2020. This study provided evidence relating to variation of the residents' health status due to the noise situation change.

8:40 PM 02-Aug-2021 **IN21_2513.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2513

Relationship between noise-induced annoyance and age based on data of previous literatures

Ke Ni, Yu Huang

Many studies have investigated subjective responses to noise, but few concerned about the influence of age on the annoyance (discomfort) caused by noise. It is difficult to get a quantitative model featuring the relationship between noise-induced annoyance and age from one or several laboratory studies due to relatively small samples and limited age groups. This paper investigated recent studies (published after the year 2000) on noise-induced annoyance by the literature review method. We classified the studies according to their employed noise types and summarized the quantified subjective values and the ranges of age. The quantitative values of annoyance obtained from variable rating scales were transferred to a uniform scale and normalized. A probability density function then figured out the corresponding annoyance of a certain age under the small sample -distribution assumption. A predicting model of noise-induced annoyance from the age of 7–55 was proposed, which fitted previous data well.

Session: Poster Q&A Session 1
Poster Session

8:00 AM 02-Aug-2021 **IN21_2635.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2635

Passive control of the flow-induced noise from a rectangular cylinder using porous walls

Reon Nishikawa

A noise reducing technique for the flow-induced noise using a porous material was studied experimentally and numerically. In the experiment, flow-induced noises emitted from three types of rectangular cylinders were measured in a low-noise wind tunnel. One cylinder was made of four aluminum plates and others were made of two or three aluminum plates. Measurement results show that the frequency of the distinct tonal noise was different among three cylinders, that frequency was higher for using porous material. It was also found that the sound pressure lelvel of the noise was also different and that of the cylinder using two porous material plates was 25 dB smaller at maximum. Velocity field of the wake of cylinders were examined by the PIV measurement and that showed that time and space scale of separated vortices around cylinder were smaller for using two porous material plates. It is assumed that the change of aerodynamic sound was caused by that change in velocity field. In the numerical simulation, we could simulate changes of the emitted noise and the wake of the cylinder by applying the slip boundary condition of the velocity to the wall of the cylinder.

8:00 AM 02-Aug-2021 **IN21_1456.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1456

The theoretical analysis and simulation of acoustic absorber for nonlinear shunted loudspeaker

Wenjiang Wang, Xianhui Li, Junjuan Zhao, Peng Zhang, Xinyun Li, Liying Zhu, Yueyue Wang

In this paper, a nonlinear electroacoustic absorber based on a tunable loudspeaker is proposed to broaden its sound absorption bandwidth. The main mechanism is a nonlinear circuit is coupled at loudspeaker's terminal. A series of theoretical analysis and simulation work are carried out in this paper. The equivalent model is composed of a linear term describing the loudspeaker and a nonlinear term of a coupled Duffing-van Der Pol bistable circuit. The invariant manifold method is used to solve different time scales. The analysis and simulation results show that the nonlinear circuit can widen the frequency bandwidth of the structure.

8:00 AM 02-Aug-2021 **IN21_1702.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1702

Study on sound absorption characteristics of cubic nonlinear sound absorption structure

Congshuang Jiang, Xianhui Li, Min Yang, Weimin Xiao

Traditional sound-absorbing materials such as porous materials and fiber materials can not achieve effective sound absorption at low frequency. The working frequency band of resonant sound-absorbing structure is narrow, and that of nonlinear sound-absorbing structure is wide, but it usually needs a higher excitation level to work. The nonlinear active control of the resonant absorption structure can achieve and control the nonlinear behavior of the absorption structure under the weak excitation level, especially the cubic nonlinear absorption

mechanism can increase the optimal absorption bandwidth and the maximum absorption coefficient at the same time. In this paper, theoretical and numerical methods are used to analyze the sound absorption characteristics of the active control cubic nonlinear sound absorption structure. The nonlinear modes of the cubic nonlinear sound absorption structure and the periodic mechanical response under harmonic excitation are studied, and the stability of the structure is analyzed. Numerical simulation with Runge Kutta method is used to study the variation of sound absorption performance of cubic nonlinear structure with its structural parameters, which will help to optimize the structural parameters and further improve the sound absorption performance.

8:00 AM 02-Aug-2021 **IN21_2705.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2705

Background Noise Removal Technique using Deep Learning Segmentation Network without Segmentation Map

Hyunsuk Huh, Seungchul Lee

Audio data acquired at industrial manufacturing sites often include unexpected background noise. Since the performance of data-driven models can be worse by background noise. Therefore, it is important to get rid of unwanted background noise. There are two main techniques for noise canceling in a traditional manner. One is Active Noise Canceling (ANC), which generates an inverted phase of the sound that we want to remove. The other is Passive Noise Canceling (PNC), which physically blocks the noise. However, these methods require large device size and expensive cost. Thus, we propose a deep learning-based noise canceling method. This technique was developed using audio imaging technique and deep learning segmentation network. However, the proposed model only needs the information on whether the audio contains noise or not. In other words, unlike the general segmentation technique, a pixel-wise ground truth segmentation map is not required for this method. We demonstrate to evaluate the separation using pump sound of MIMII dataset, which is open-source dataset.

8:00 AM 02-Aug-2021 **IN21_3146.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3146

Structural vibration design of a pod structure including an optical system of a fighter aircraft

Taeyoung Yoon, Jaemyung Cho, Sungsoo Na, Seongho Yoon

Structural vibration design of a pod structure including an optical system installed on a fighter aircraft is very significant in improving accuracy of targeting system to the target objects. To reduce and isolate the vibration generated during the flight, it is crucial to properly design the rubber mount between the pod and the aircraft. In this study, free vibration analysis of the pod is conducted through finite element analysis (FEA) and experiments. Correlations are performed with reasonably acceptable accuracy about the natural frequencies, mode shapes, and frequency response functions obtained by FEA and experiment. Then to optimize the structural dynamics of the pod, three variables are considered, which are mass of the dummies, the numbers of and positions of rubber mounts, and hyperelastic property of rubber mounts. In addition, the position of the pod on the fighter is analysed by FEM to estimate the possibility of further enhancement of its structural dynamics. Finally, forced vibration was undertaken using random signals of a shaker with 1Grms, 2Grms and 2.65Grms considering the test standard. It is found out that frequency responses of the pod are sensitive below 100 Hz to the values of the excitation signals. It is thus indeed to design appropriately the rubber mounts to improve structural dynamics of the pod, which results in the accuracy of targeting system.

8:00 AM 02-Aug-2021 **IN21_1614.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1614

Simulation research on low frequency sound absorption of monostable metamaterials

Tuo Xing, Xianhui Li, Xiaoling Gai, Zenong Cai, Xiwen Guan

The monostable acoustic metamaterial is realized by placing a flexible panel with a magnetic proof mass in a symmetric magnetic field. The theoretical model of monostable metamaterials has been proposed. The method of finite element simulation is used to verify the theoretical model. The magnetic force of the symmetrical magnetic field is simplified as the relationship between force and displacement, acting on the mass. The simulation results show that as the external magnetic force increases, the peak sound absorption shifts to low frequencies. The theoretical and finite element simulation results are in good agreement.

8:00 AM 02-Aug-2021 **IN21_1803.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1803

Numerical feasibility study for transverse vibration control of rotating shaft with a neural network-based tracking algorithm

Dongwoo Hong, Hyeongill Lee, Youkyung Han, Byeongil Kim

Rotary elements have been applied to a variety of mechanical systems such as pumped-storage hydroelectricity and nuclear power plant. Due to their vibration problems occurred by misalignment, bent, and unbalance, a sharp decline efficiency of system and malfunction can be caused and furthermore, the rotor may be damaged. In order to control the rotor vibration actively, active vibration control using the magnetic bearing and piezo actuator is being vigorously studied to improve operating conditions of rotary devices. This research accomplished numerical simulations of active vibration control for an unbalanced rotor system using the active bearing system applying piezo actuators. Overall rotor system is modeled using energy method and an active bearing model with two actuators placed in both x- and y-direction is developed using lumped parameter method. For implementing active control scheme through the active bearing system, a signal tracking algorithm based on neural network is developed and utilized to the rotor system. The active bearing system shows good performance on transverse vibration reduction for rotating systems.

8:00 AM 02-Aug-2021 **IN21_1620.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1620

Phase calibration method for microphone array based on multiple sound sources

Bo Jiang, XiaoQin Liu, Xing Wu

In the microphone array, the phase error of each microphone causes a deviation in sound source localization. At present, there is a lack of effective methods for phase error calibration of the entire microphone array. In order to solve this problem, a phase mismatch calculation method based on multiple sound sources is proposed. This method requires collecting data from multiple sound sources in turn, and constructing a nonlinear equation setthrough the signal delay and the geometric relationship between the microphones and the sound source positions. The phase mismatch of each microphone can be solved from the nonlinear equation set. Taking the single frequency signal as an example, the feasibility of the method is verified by experiments in a semi-anechoic chamber. The phase mismatches are compared with the calibration results of exchanging microphone. The difference of the phase error values measured by the two methods is small. The experiment also shows that the accuracy of sound source localization by beamforming is improved. The method is efficient for phase error calibration of arrays with a large number of microphones.

8:00 AM 02-Aug-2021 **IN21_1785.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1785

Effect of fiber cross-section on the transport and acoustic properties of fibrous materials

Sung Soo Yang, Ju Hyun Jeon, Yeon June Kang

Fibrous materials can efficiently dissipate acoustic energy, and their intrinsic properties are determined by fiber geometries (microscale). In this study, the effect of cross-sections of fibers on the transport and acoustic properties of fibrous materials was investigated. First, fibers of various cross-sections were modeled by adjusting their open porosity. The representative elementary volumes of fiber structures were generated to describe the periodic unit-cell structures. Next, the transport properties (such as static airflow resistivity, high-frequency limit of the dynamic tortuosity, viscous characteristic length, thermal characteristic length, and static thermal permeability) of fibrous materials were calculated by solving numerical problems using the finite element method. These properties of fibrous materials with complex cross-sections were compared with those with circular cross-sections. Finally, the sound absorption coefficients were predicted using the Johnson-Champoux-Allard-Lafarge (JCAL) model and rigid frame approximation, and the differences in sound-absorbing behavior were analyzed. This study can provide insights into the design of lightweight fibrous materials while maintaining optimal sound absorption performance.

8:00 AM 02-Aug-2021 **IN21_1856.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1856

Sub-array equalization technique for the parametric array loudspeaker to reduce nonlinear distortion

Chi Zhang, Jing Ren, Chuang Shi

The parametric array loudspeaker (PAL) is a directional loudspeaker which uses the nonlinear acoustic effect, namely the parametric array, to produce an audio beam from narrow ultrasonic beams. The PAL can efficiently deliver audible information, without generating noise to the surroundings. One significant drawback of the PAL is the nonlinear distortion. Therefore, many sophisticated methods have been proposed to preprocess the input signal of the PAL. However, those methods usually request a flat frequency response of the ultrasonic transducer array (UTA). In the past, equalization has been tried out for the whole UTA, but the performance was sometimes not satisfactory due to the inconsistent productions of ultrasonic transducers. This paper proposes to group the ultrasonic transducers by their impedances. Several sub-arrays are thereafter formed and equalized individually. The comparison results demonstrate that the propose sub-array equalization technique can suppress the nonlinear distortion of the PAL more effectively than the previous method.

8:00 AM 02-Aug-2021 **IN21_1894.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1894

Virtual bass preprocessing and carrier frequency optimization for the parametric array loudspeaker

Shengqi Tao, Jing Ren, Chuang Shi

The parametric array loudspeaker (PAL) is a novel type of loudspeaker that can project a directional sound beam. It is usually used in creating personal sound zone and projecting private messages to a targeted audience. However, the PAL has a very poor low-frequency response due to the inherent nonlinear acoustic principle generating sound from ultrasound in air. A psychoacoustic signal processing method known as the virtual bass (VB) has been proved to be an effective method to improve the bass quality of consumer electronics with miniature or flat loudspeaker unit. This paper proposes the VB processing based on the phase vocoder (PV) for the bass enhancement of the PAL that adopts a vestigial sideband modulation method. The harmonics generated by the VB processing are presented in the partial sideband, while the audio input without the bass component is embedded in the full sideband. A measure, namely the in-band peak flatness, is thereafter proposed in this paper to determine the optimal carrier frequency, given a practical uneven frequency response of the ultrasonic transducer. The subjective testing results validate that the proposed VB processing together with the optimal carrier frequency can finally realize the improvement of bass sound quality of the PAL.

8:00 AM 02-Aug-2021 **IN21_2647.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2647

Measurement of very high frequency (VHF) sound in our daily experiences

Koki Harusawa, Yumi Inamura, Masaaki Hiroe, Hideyuki Hasegawa, Kentaro Nakamura, Mari Ueda

Recently, it is frequently reported that very high frequency (VHF) sounds are emitted from daily necessaries such as home electric appliances. Although we measured VHF sounds from home electric appliances in our previous study, the origins of such VHF sounds have not yet been identified. In the present study, we tried to identify the VHF sound source in each home electric appliance using a “sound camera”, which visualizes the spatial distribution of the sound intensity using a microphone array. The sound camera visualized the location of the sound source at frequencies from 2 to 52 kHz with a field of view of 63 degrees. The sound camera elucidated that the VHF sounds were emitted from the

power source of a LET light, the ventilation duct of an electric fan, and the body of an IH cooker. Their frequency characteristics were dependent on the sound source, i.e., combinations of pure tones in the LED light and distributing in a wide frequency range in the electric fan.

8:00 AM 02-Aug-2021 **IN21_2673.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2673

Non-linear beamformer with long short-term memory network

Mitsunori Mizumachi, Ryotarou Oka

Acoustic beamforming with a microphone array enables spatial filtering in a wide frequency range. It is a challenging issue to sharpen the main-lobe in the lower frequency region with a small-scale microphone array, of which the number and spacing of microphones are small. A neural network-based non-linear beamformer achieves a breakthrough in sharpening the main-lobe. The non-linear beamforming works well for the narrowband signals but is weak in wideband beamforming. The non-linear beamforming with the long short-term memory is proposed to deal with wideband speech signals. The long short-term memory network is trained in the recurrent neural network architecture with the sequence of audio data such as speech signals. The performance of the proposed beamformer is confirmed using a small-scale 8-ch MEMS microphone array, where eight microphones are linearly arranged with the neighboring spacing of 10 mm, under a real environment. The beam-pattern of the proposed non-linear beamformer succeeds in sharpening the main-lobe although the linear delay-and-sum beamformer could not achieve frequency selectivity. The feasibility of the proposed beamformer is also confirmed in speech enhancement.

8:00 AM 02-Aug-2021 **IN21_2747.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2747

An improved voice activity detection method based on spectral features and neural network

Liu Ting, Luo Xinwei

The recognition accuracy of speech signal and noise signal is greatly affected under low signal-to-noise ratio. The neural network with parameters obtained from the training set can achieve good results in the existing data, but is poor for the samples with different the environmental noises. This method firstly extracts the features based on the physical characteristics of the speech signal, which have good robustness. It takes the 3-second data as samples, judges whether there is speech component in the data under low signal-to-noise ratios, and gives a decision tag for the data. If a reasonable trajectory which is like the trajectory of speech is found, it is judged that there is a speech segment in the 3-second data. Then, the dynamic double threshold processing is used for preliminary detection, and then the global double threshold value is obtained by K-means clustering. Finally, the detection results are obtained by sequential decision. This method has the advantages of low complexity, strong robustness, and adaptability to multi-national languages. The experimental results show that the performance of the method is better than that of traditional methods under various signal-to-noise ratios, and it has good adaptability to multi language.

8:00 AM 02-Aug-2021 **IN21_2919.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2919

Estimation of otoacoustic emission and excitation force of bone conduction actuator by combined lumped parameter model

Akiko Fujise

In sound presentation system using actuators which excite the surface of the pinna or head, both otoacoustic emission and vibration transmission inside the body contribute to the perception of the sound. The contribution of these pathways is affected by both the location of the excitation and mechanical characteristic of the actuator, leaving the optimal output level of the actuator to mask environmental sound or to present information yet to be estimated. This study, therefore, proposes a simplified model which combines an acoustic equivalent circuit of ear canal and a mechanical equivalent circuit of the tissues of the head. The model enables to estimate both otoacoustic emission component directly corresponding with the loudness for air conducted sound and the component of the transmission inside the head which requires the measurement of the loudness level individually by each excitation location. As the preliminary investigation preceding the establishment of the proposed model towards the human, these two components were calculated using the known parameter values for artificial ear and artificial mastoid. The results indicate that the stiffness of the excited soft tissue and the type of the actuator strongly affect the cutoff frequencies, resonances, and anti-resonances observed within the audible range.

8:00 AM 02-Aug-2021 **IN21_1576.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1576

Two-dimensional finite difference-time domain analysis of focus boom noise with velocity disturbance in the atmosphere

Takao Tsuchiya, Masashi Kanamori

In this paper, two-dimensional linear sound wave analysis in the stratified atmosphere with temperature gradient and velocity disturbance is numerically applied to the analysis and prediction of focus boom noise. Focus boom occurs when a supersonic transport accelerates or ascent or descent maneuvers at supersonic speed. Its overpressure is typically more than three times greater than that of a cruise sonic boom. As a result, supersonic transports in future commercial operation are likely to face restrictions on their flight conditions. The compact-explicit finite difference-time domain method is applied to the analysis of two-dimensional linear sound wave propagation. Some numerical experiments are carried out for the case of acceleration. As a result, it is shown that the complex wavefront is accurately analyzed by the FDTD method compared with the ray tracing method. It is also shown that a noise disturbed by velocity disturbance in the atmosphere reaches the ground over a wider area than the focus boom in the no disturbance case.

8:00 AM 02-Aug-2021 **IN21_1960.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1960

Field Test Research on Environmental Noise Characteristics in the Throat Area of Metro Depot

Lei He, Ruixiang Song, Jie Yang, Yubin Wu, Yanan Wu

Environmental noise pollution is the primary environmental problem faced by the superstructure of metro depots. The throat area of depot is prone to high wheel-rail impact noise due to the use of seam lines, multiple joints, turnouts and small radius curves. The noise exerts through fire and ventilation openings on the side walls, which may cause high annoyance to the residents in the superstructures both on the upper cover and surrounding areas. In this paper, a field test was condected on the environmental noise in the throat area of metro depot. The noise of the trackside and adjacent open space were recorded, and the time-frequency domain characteristics and statistical characteristics and attenuation law of the noise generated by train operation in the throat area were analyzed. The research results have certain guiding significance for the prediction and control of noise in the throat area of the depot.

8:00 AM 02-Aug-2021 **IN21_1428.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1428

The Analysis and Optimization of the Exhaust Manifold Flow-induced the Interior Abnormal Noise under the Vehicle Acceleration Condition

Jun Zhang, Yongjiang Xu, Hao Song

The Exhaust manifold is an important engine part. With the increasingly strict national emission regulations, a large number of stainless steel integrated exhaust manifold are used in the automobile, but the design and verification of exhaust manifold NVH performance are generally inadequate. In this paper, considering the abnormal noise of a vehicle under the condition of full acceleration, the investigation and analysis process of noise problems are described in detail. The Mechanism of exhaust manifold flow-induced noise and the corresponding engineering measures are proposed, and the effectiveness of the optimization scheme is verified by comparing measurement results and the vehicle subjective assessment, which has important engineering reference value for improving the development level of NVH performance of exhaust manifold.

8:00 AM 02-Aug-2021 **IN21_1921.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1921

Detection and identification of illegal-modified private cars through frequency band analysis

Hok Man Joyce Chow, Sau Cheong Cheung, Kit Wing Cheng, Chee Kwan Lee, Terence Tsang, Hin-long Ng

Post-purchase-illegal-modification of road vehicles' exhaust systems by vehicle fanatics for loudness has caused an upsurge in nuisances to local residences when driven and rallied during late night and early mornings. Traditional enforcement measures rely on setting up roadblocks by the Police at rallying hotspots. These measures involve the judgement of individual police officer and can be subjective. With the aid of noise monitoring equipment, the accuracy and efficiency of on-site exhaust system-modified vehicle detection can be enhanced. Since the sound profile of a single-vehicle exhaust cannot be captured by simple roadside noise level measurements alone, segregation and analysis of the noise spectrum are employed to identify vehicles with modified exhaust systems. The paper presents the findings of investigating the feasibility and accuracy of off-the-shelf devices for detecting vehicles fitted with modified exhaust systems, with private cars being the primary target. A pilot test by roadside noise monitoring has been conducted with a sound level meter and an acoustic camera and revealed an on-site accuracy of up to 75%. Data collected during the tests were further used to explore the applicability of integrating artificial intelligence with traditional noise monitoring devices.

8:00 AM 02-Aug-2021 **IN21_2533.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2533

On the resonance sound generated in a vehicle cabin moving at low speed due to breaking force

Zhe Li, Ryo Kiyotaki, Osamu Terashima, Vinay Poddar, Takashi Murakami

To improve the comfortability in a vehicle cabin, unwanted noise which is recognized as an allophone generated from automobile wheels was experimentally studied to investigate its generation mechanism and to develop its reduction countermeasures. In this experiment, simultaneous measurements of sound pressure and vibrational acceleration of the wheel surface were performed. Then, frequency analysis, vibrational modal analysis and operational transfer path analysis were performed by using measured data. The results show that this kind of noise started in a low frequency first and then became higher. Furthermore, the high-frequency noise was mainly generated by vibrational acceleration at its center and near the rim when the wheel spoke gets close to the brake caliper. The high-frequency noise is around 250Hz, 750Hz, 1000Hz and 1250Hz, and the wheel spoke easily gets vibration and resonance mainly from around 750Hz and 1000Hz. Vibration at 750Hz occurs on the side of the wheel spoke in the rotation direction, while vibration at 1000Hz occurs at the midpoint of the wheel spoke. The closer to the brake caliper, louder noise was generated at the wheel spoke.

8:00 AM 02-Aug-2021 **IN21_2992.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2992

A study on the effects of compression of the felt on flow resistance and acoustic characteristics

Yoon-sang Yang, Seung Lee

The sound absorbing materials used to reduce automobile interior noise are classified into Felt and PU Foam. Felt are widely used not only in internal combustion engine vehicles but also in Electric Vehicles because they are eco-friendly materials that can be recycled and relatively light. Automotive interior parts manufacture materials in various thicknesses depending on the shape of matched parts. The pressed material changes the density, flow resistance and affects the overall NVH performance of the vehicle. In this study we worked to confirm changes in flow resistance, sound absorption coefficient and sound transmission loss performance among acoustic characteristics based on the compress ratio

of Felt. It was confirmed that the larger the compression of Felt, the larger the flow resistance value, thereby affecting the acoustic characteristic impedance, sound absorption coefficient and sound transmission loss.

8:00 AM 02-Aug-2021 **IN21_3289.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3289

Influence of automobile sealing rib structure on sound insulation performance and optimization of section parameters

Xian Wu, TengLong Jiang, JianWang Shao, GuoMing Deng, Meng Zhao

The door sealing strip plays an important role in the sound insulation of the car, and its sound insulation performance has a great influence on the sound quality and comfort of the vehicle. The sound insulation performance of the seal can be analyzed by Finite Element-Statistic Energy Analysismodel. There are great differences in the cross-section of the door sealing strip system at different positions, which leads to the difference of sound insulation. Therefore, it is very important to study the sound insulation performance of the sealing strip by studying the parameters of different sections. This paper explores the influence of the structure of automobile sealing rib on the sound insulation performance. Taking the sound power of the receiving end of the sealing strip as the index, the orthogonal optimization test is carried out for the simplified section shape of the door seal strip: the wall thickness of the sealing strip, the height of the sealing strip and the rib length. The optimal combination of a set of sealing strip sections is established, and the sound insulation performance of the sealing strip is improved.

Session: 06.02 Road Noise Treatment
Channel 1

6:00 AM 03-Aug-2021 **IN21_2260.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2260

Comparison of Noise Reduction Performance Evaluation Methods for Low-Noise Pavement in Korea- Part Ⅲ

Byungchae Kim, Hyunjin Kim, Wonuk Kang

In Korea, road noise is assessed as a measurement method of exterior noise emitted by road vehicle for management standards by the National Institute of Environmental Sciences.
In this method, the noise felt at the actual pickup point is measured as LAeq (the roadside equivalent noise level).
Recently, to clarify the standard for measuring noise on low-noise pavements, the CPX (ISO11819-2; Close-proximity method) was first introduced in the Porous Pavement Guidelines of the Ministry of Land, Infrastructure and Transport.
According to ISO, the CPX adopts the side microphone as a mandatory measurement location, and the rear optional.
The side location has been a mandatory due to its high correlation with SPB (ISO 11819-1, Statistical Pass-by method).
However, according to our previous study on the correlation evaluation between L and CPX rear microphone noise level, both noise reduction effect was about 9-12 dB(A) showed a high correlation in Korea where heavy road traffic is common.
The following study aims to show the consistent correlation between the L and CPX rear noise level.
Furthermore, it is intended to be helpful in selecting the location of the CPX microphone that can most effectively represent the actual noise on the low-noise pavement in Korea.

6:20 AM 03-Aug-2021 **IN21_2268.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2268

Noise reduction of Parallel barrier integrated with compact flexible panel device

Yat Sze Choy, Wang Zhibo, Yang Waiping

Erection of parallel barriers to control environmental noise such as traffic noise and construction noise is commonly seen in community. Owing to the formation of multiple reflection waves between the parallel barriers, their performance may be worse than a single barrier. To improve the performance of parallel barriers, a small piece of flush-mounted panels backed by a slender cavity in an otherwise rigid wall of barriers is proposed. With the excitation of the incident wave from a sound source inside parallel barriers, the flexible panel vibrates and sound is radiated out to undergo acoustics interference with sound field between the parallel barriers so that the sound intensity in this space and diffraction wave at the barrier top edge is reduced over a broadband in the low-frequency regime. The use of the panel provides flexibility in controlling range of stopband with high insertion loss by varying mass and bending stiffness. A semi-analytical model for dealing with vibroacoustic coupling between the open cavity and vibrating panel in a two-dimensional configuration is established in order to understand the sound suppression mechanism within the shadow zone. With the optimal structural properties of the panel, the extra averaged insertion loss of about 5dB in the frequencies ranging from 50 to 1000 Hz is reached for the parallel barrier.

6:40 AM 03-Aug-2021 **IN21_2383.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2383

Empirical study on the correlation between measurement methods under diffuse and direct sound field conditions for determining sound absorption and airborne sound insulation properties of noise barriers

Andreas Fuchs, Reinhard Wehr, Marco Conter

In the frame of the SOPRANOISE project (funded by CEDR in the Transnational Road Research Programme 2018) the database of the European noise barrier market developed during the QUIESST project was updated with newly acquired data. This database gives the opportunity for an empirical study on the correlation between the different measurement methods for the acoustic properties of noise barriers (according to the EN 1793 series) to further investigate the interrelationships between these methods by using single-number ratings and third-octave band data. First a correlation of the measurement methods for sound absorption under diffuse field conditions (EN 1793-1) and sound reflection under direct sound field conditions (EN 1793-5) is presented. Secondly, a correlation of the measurement methods for airborne sound insulation

under diffuse field conditions (EN 1793-2) and airborne sound insulation under direct sound field conditions (EN 1793-6) is shown. While for airborne sound insulation a distinct correlation is found due to the wide data range, for sound absorption no robust correlation can be found.

7:00 AM 03-Aug-2021 **IN21_2105.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2105

Confusion in the evaluation of sound barriers under harmonized standard

Pavel Rubáš

After the obligatory introduction of the declaration of uncertainty in EN 1793-2:2018, the B categories shall not be used to prevent further confusion. Contrary to the updated standard, B categories remain a ubiquitous contractual criterion in the Czech Republic. Contractors continue to request insulation category B3 products determined according to the cancelled EN 1793-2:1997. The current standard only specifies a test method for determining the intrinsic airborne sound insulation performance of noise barriers designed for tunnel roads, deep trenches or covered spaces. EN 1793-6:2018 shall be used for barriers designed for non-reverberant conditions. Notified bodies involved in barriers testing should exercise care and analyze whether supporting test standards in the cancelled but still harmonized EN 14388:2005 can be used or whether the latest testing procedures will be considered. A guidance document is vital because the situation is becoming increasingly confusing. Common rules should be established across the EU to prevent invalid contractual requirements concerning B3 category barriers designed for non-reverberant conditions. The paper analyzes the current unsatisfactory situation, discusses the application of single number rating involving uncertainties, and proposes decision rules for logical and illogical contractual requirements.

7:20 AM 03-Aug-2021 **IN21_2066.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2066

Corn plants as temporary acoustic barrier to limit the effects of noise pollution

Gino Iannace, Virginia Puyana-Romero, Giuseppe Ciaburro

Corn is a cereal imported into Europe from the Americas and is used for human and animal feed, but there are also industrial uses such as the production of ethanol, as a fuel for heating homes or to produce starch. Corn grows in the summer in areas where there is water. Corn is grown in many regions of the world and its production exceeds that of any other cereal in quantity. The corn plant can reach up to three meters in height, with a stem diameter of a few centimeters and with dense leaves longer than 30 cm and 10 cm wide. There are noisy activities where it is necessary to attenuate the noise produced to limit the effects of noise pollution. Some activities use temporary barriers depending on the processing cycle adopted. If noisy work is carried out during the summer season, corn rows of adequate width can be used as an acoustic barrier. In this paper, the possibility of using corn plants as an acoustic barrier is investigated. The acoustic measurements of the noise attenuation of corn rows of adequate width are described. Using a semi-spherical source placed on the ground, the acoustic attenuation due to the corn plants arranged in several rows for different distances from the sound source to the receiver was measured.

7:40 AM 03-Aug-2021 **IN21_2421.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2421

Control of low frequency noise from an environmental test facility

Malcolm Smith, Erika Quaranta

Environmental test chambers are used in the automotive industry to verify the resilience of vehicles. In just a few hours it is possible to take a car from mid-winter in the artic, via a high mountain range, to mid-summer in a desert. Powerful ventilation systems are used to change the temperature, pressure and humidity of the air in the chamber, and the variable speed blowers are a major source of low frequency noise, which can cause significant disturbance at neighbouring properties if there are gaps in silencer performance. This paper details a study to assess the attenuation requirements for a system to meet a standard criterion for low frequency far-field noise levels, and to select a reactive silencer system to achieve that specification under all circumstances. The system used standard silencer components where possible, but needed to take account of long pipe runs through the facility, with tailpipe resonances being a particular issue, and was further constrained by space and loading limits for the building. Design layouts were verified using the Actran FE code, taking account of interactions with existing silencers and transfer functions to the far-field, in order to have very high confidence of a successful outcome.

8:00 AM 03-Aug-2021 **IN21_1783.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1783

The Performance of a Low Berm in Reducing Traffic Noise

Paul Donavan, Carrie Janello

Traffic noise measurements were made behind a low, earth berm and in an adjacent open field to estimate insertion loss. The traffic was comprised of a mix of light vehicles, heavy trucks, and some medium trucks. The berm had a height of 1.65 meters above the roadway and began at the outside shoulder of a four-lane highway along U.S. Highway 101 in Northern California. Two microphone positions were located on the far side of the berm at distances of 28 and 40 meters from the center of the near lane of vehicular traffic. Away from the berm, a microphone was placed in an open field at 28 meters from the highway at a site upstream of the berm. The difference between the open location and those behind the berm were 11.6 and 9.9 dB for the 28- and 40-meter locations, respectively. The reductions obtained with the berm are compared to double edge diffraction theory and acoustic scale model results from the literature. The results of this study are reviewed in this paper and a comparison to FHWA Traffic Noise Model results is presented.

Session: Keynote Lecture
Channel 1

9:00 AM 03-Aug-2021 **Oral Only**

Efforts for reducing the impact of aircraft noise at Japan and worldwide airports and a suggestion for the improvement to the next generation

Naoaki Shinohara

10:00 AM 03-Aug-2021 **Oral Only**

Challenges in modeling sound packages: A short history and future trends of the sound propagation in poro-elastic media

François-Xavier Bécot

Session: 02.03 Numerical Methods in Vibro-Acoustics, Part 1
Channel 1

11:00 AM 03-Aug-2021 **IN21_1712.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1712

Vibrational energy distribution in plate excited with random white noise

Tyrode Victor, Nicolas Totaro, Laurent Maxit, Alain Le Bot

In Statistical Energy Analysis (SEA) and more generally in all statistical theories of sound and vibration, the establishment of diffuse field in subsystems is one of the most important assumption. Diffuse field is a special state of vibration for which the vibrational energy is homogeneously and isotropically distributed. For subsystems excited with a random white noise, the vibration tends to become diffuse when the number of modes is large and the damping sufficiently light. However even under these conditions, the so-called coherent backscattering enhancement (CBE) observed for certain symmetric subsystems may impede diffusivity. In this study, CBE is observed numerically and experimentally for various geometries of subsystem. Also, it is shown that asymmetric boundary conditions leads to reduce or even vanish the CBE. Theoretical and numerical simulations with the ray tracing method are provided to support the discussion.

11:20 AM 03-Aug-2021 **IN21_2186.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2186

Subtractive modeling using the reverse condensed transfer function method: influence of the numerical errors

Florent Dumortier, Laurent Maxit, Valentin Meyer

Decoupling procedures based on substructuring methods allow to predict the vibroacoustic behaviour of a given system by removing a part of an original system that can be easily modelled. The reverse Condensed Transfer Function (rCTF) method has been developed to decouple acoustical or mechanical subsystems that are coupled along lines or surfaces. From the so-called condensed transfer functions (CTFs) of the original system and of the removing part, the behaviour of the system of interest can be predicted. The theoretical framework as well as a numerical validation have been recently published. In the present paper, we focus on the influence of numerical errors on the results of the rCTF method, when the CTFs are calculated using numerical models for the original system and/or the removed part. The rCTF method is applied to a test case consisting in the scattering problem of a rigid sphere in an infinite water domain and impacted by an acoustic plane wave. Discrete green formulation and finite element method are used to estimate the CTFs. Numerical results will be presented in order to evaluate the sensitivity of the method to model errors and the potential promises and limitations of the method will be highlighted.

11:40 AM 03-Aug-2021 **IN21_2535.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2535

Development of a hybrid SmEdA/SEA model for predicting the power exchanged between low and high modal density subsystems

Guang Zhu, Laurent Maxit, Nicolas Totaro, Alain Le Bot

Statistical modal Energy distribution Analysis (SmEdA) was developed from classical Statistical Energy Analysis (SEA). It allows computing power flow between coupled subsystems from the deterministic modes of uncoupled subsystems without assuming the SEA modal energy equipartition. SmEdA is well adapted in mid-frequency when the subsystems have not a very high modal density. However, for some systems e.g. the plate-cavity system, one subsystem can exhibit a low modal density while the other one a high one. The goal of the paper is then to propose an extension of SmEdA formulation that allows describing one subsystem by its deterministic modes, and the other one as a diffuse field statistically supposing modal energy equipartition. The uncertain subsystem is then characterized by sets of natural frequencies and mode shapes constructed based on Gaussian Orthogonal Ensemble matrix and the cross-spectrum density of a diffuse field, respectively. This formulation permits not only the computation of mean noise response but also the variance generated by the uncertainties and furthermore without bringing in much computation. It is demonstrated that the obtained analytical results from the proposed hybrid SmEdA/SEA are consistent with numerical results computed by FEM with an appropriate degree of uncertainty.

12:00 PM 03-Aug-2021 **IN21_1740.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1740

Solving linear systems from dynamical energy analysis - using and reusing preconditioners

Martin Richter, Gregor Tanner, Bruno Carpentieri, David Chappell

Dynamical energy analysis (DEA) is a computational method to address high-frequency vibro-acoustics in terms of ray densities. It has been used to describe wave equations governing structure-borne sound in two-dimensional shell elements as well as three-dimensional electrodynamics. To describe either of those problems, the wave equation is reformulated as a propagation of boundary densities. These densities are expressed by finite dimensional approximations. All use-cases have in common that they describe the resulting linear problem using a very large matrix which is block-sparse, often real-valued, but non-symmetric. In order to efficiently use DEA, it is therefore important to also address the performance of solving the corresponding linear system. We will cover three aspects in order to reduce the computational time: The use of preconditioners, properly chosen initial conditions, and choice of iterative solvers. Especially the aspect of potentially reusing preconditioners for different input parameters is investigated.

12:20 PM 03-Aug-2021 **IN21_1906.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1906

•Finite element method and dynamical energy analysis in vibro-acoustics - A comparative study

Sebastian Zettel, René Winter, Marco Norambuena, Marc Böswald, Martin Richter, Gregor Tanner

Future aircraft concepts utilizing innovative lightweight structures and novel propulsion concepts are a necessity for long term sustainable air travel. These concepts pose new challenges for the vibro-acoustic assessment of cabin structures and the associated noise impact on passengers. Finite Element (FE) models derived from aircraft pre-design data are not optimized for use in acoustic analyses, i.e. the mesh is too coarse to provide meaningful results while setting up Statistical Energy Analysis models for this specific purpose is adding another time-consuming step. A possible alternative, Discrete Energy Analysis (DEA), is evaluated. This method allows to calculate the acoustic behavior of thin-walled structures in higher frequency ranges simply using existing FE meshes. In this paper an experimental lightweight aluminum structure and its respective FE model is investigated for a frequency range up to 5000 Hz. A comparison in terms of vibrational energy between DEA, FE and measurement results are presented. Finally, a lower-bound frequency range is identified in which DEA and FEM correlate and thus allow a substitution for further simulations at higher frequencies.

Session: 01.03 Experiments in Flow-Induced Noise & Vibration
Channel 1

1:40 PM 03-Aug-2021 **IN21_2851.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2851

Acoustical analysis of sound generated by synthetic jet actuators

Song Wang, Rayane Ait Oubahou, Zixin He, Anthony Mickalauskas, David Menicovich, Luc Mongeau

Piezoelectrically driven synthetic jet actuators (SJA) are useful in various applications such as flow control, heat transfer and camera lens cleaning. This paper aims to better understand the fundamental sound generation mechanisms of synthetic jet actuators and investigate methods for the noise reduction and vibration control. The SJAs tested in this paper are driven by sinusoidal signals at frequencies ranging between 100 and 600 Hz, and can produce pulsated air jets at high velocity, up to 100 m/s. The sound generated by these devices, generally tonal and rich in harmonics, was modeled as the superposition of two monopoles associated with the breathing mode of the diaphragm and of the pulsated jet. Component analyses showed that the two monopoles cancelled each other partially depending on their amplitudes and phase relationship. A computational aeroacoustic model of the SJAs was built using PowerFLOW, a computation fluid dynamic simulation software. Simulation results were compared with jet velocities measured with a hot-wire anemometer and flow patterns were analyzed. Active and passive control methods were investigated, and a sound quality analysis was performed in order to reduce the overall radiated sound power and improve sound quality.

2:00 PM 03-Aug-2021 **IN21_2072.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2072

"The answer is blowin' in the wind" - case study of a perforated roof screen

Anthony Nash

A recently-completed building was fitted with a roof screen fabricated from perforated sheet metal panels having "U"-shaped upturned flanges. When wind impinges on the panels, complex tone clusters are generated, leading to complaints from the occupants. The unusual character of the tonal spectrum is reminiscent of a film sound effect intended to simulate a hovering extraterrestrial spacecraft. After some preliminary (but inconclusive) field investigations, it was decided to test samples of the perforated panel in a large commercial wind tunnel where the speed and angle of the airstream could be controlled. Tones generated in the tunnel were found to occur in groups or clusters — these are most pronounced when the airstream's angle of incidence is close to grazing. Gradually increasing airspeed caused the frequency of the tones to "jump" from one cluster to the next higher cluster. The physical principles of the tone-generating mechanism are not fully understood; however, it appears that structural resonances in the panel flanges are excited by air flowing over the perforate. Some form of a positive structural-acoustical feedback loop is involved since a) the frequencies within each tone cluster are quite stable and, b) damping the panel flanges extinguishes the tones.

2:20 PM 03-Aug-2021 **IN21_2711.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2711

An experimental investigation of turbulent flow over a two-dimensional obstacle on a flat plate

Shivam Sundeep, Xin Zhang, Siyang Zhong, Huanxian Bu

Aeroacoustic and aerodynamic characteristics of the turbulent boundary layer encountering a large obstacle are experimentally investigated in this paper. Two-dimensional obstacles with a square and a semi-circular cross-section mounted on a flat plate are studied in wind tunnel tests, with particular interests in the shear layer characteristics, wall pressure fluctuations, and far-field noise induced by the obstacles. Synchronized measurements of the far-field noise and the wall pressure fluctuations were conducted using microphone arrays in the far-field and flush-mounted in the plate, respectively. Additionally, the streamwise and wall-normal velocity fluctuations behind the obstacle were measured using the X-wire probe. The measured velocity profiles, spectra, and wall pressure spectra are compared, showing that the rectangular obstacle has a significant impact on both the turbulent flow and far-field noise. The large-scale vortical structures shed from the obstacles can be identified in the wall pressure spectra, the streamwise velocity spectra, and the wall pressure coherence analysis. Within the shear layer, the pairing of vortices occurs and the frequency of the broadband peak in the velocity spectra decreases as the shear layer grows downstream. Further eddy convective velocities of large-scale vortical structures inside the shear layer were analyzed based on the wall pressure fluctuations.

2:40 PM 03-Aug-2021 **IN21_2719.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2719

Empirical prediction of flight effect on subsonic coaxial-jet noise by introducing an adjusted flight velocity term

Incheol Lee

The effect of forward flight on jet noise is difficult to quantify through flyover tests since only the total noise is measured in a full-scale flyover test, and the contribution of the jet noise is difficult and sometimes nearly impossible to identify. Thus, most studies on the flight effect have been carried out through model-scale experiments with a single-stream jet simulator in a free jet facility. In this paper, the effect of forward flight was captured by using an adjusted flight velocity term (αV) to describe jet velocity in a new prediction of coaxial-jet noise. The new jet noise prediction method assumes that there are three components: primary, secondary, and mixed components with no filter functions. The coefficient α is determined by a thorough investigation of the model-scale data gained from an experiment in the anechoic wind tunnel of ONERA. The value of α is 1 for the primary component, 0.5 for the secondary component, and a linear function of the angle for the mixed component. The simple adjustment of the flight velocity successfully embodied the effect of forward flight at all angles, with no separate velocity exponent or an additional term.

Session: 02.07 Vibro-Acoustics of Metamaterials
Channel 1

3:20 PM 03-Aug-2021 **IN21_2052.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2052

(Generalized) Bloch mode synthesis for the fast dispersion curve calculation of 3D periodic metamaterials

Vanessa Cool, Lucas Van Belle, Claus Claeys, Elke Deckers, Wim Desmet

Metamaterials, i.e. artificial structures with unconventional properties, have shown to be highly potential lightweight and compact solutions for the attenuation of noise and vibrations in targeted frequency ranges, called stop bands. In order to analyze the performance of these metamaterials, their stop band behavior is typically predicted by means of dispersion curves, which describe the wave propagation in the corresponding infinite periodic structure. The input for these calculations is usually a finite element model of the corresponding unit cell. Most common in literature are 2D plane metamaterials, which often consist of a plate host structure with periodically added masses or resonators. In recent literature, however, full 3D metamaterials are encountered which are periodic in all three directions and which enable complete, omnidirectional stop bands. Although these 3D metamaterials have favorable vibro-acoustic characteristics, the computational cost to analyze them quickly increases with unit cell model size. Model order reduction techniques are important enablers to overcome this problem. In this work, the Bloch Mode Synthesis (BMS) and generalized BMS (GBMS) reduction techniques are extended from 2D to 3D periodic structures. Through several verifications, it is demonstrated that dispersion curve calculation times can be strongly reduced, while accurate stop band predictions are maintained.

3:40 PM 03-Aug-2021 **IN21_1842.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1842

Predicting robust complete and full band gaps in three-dimensional frame structures

Luiz Henrique Marra da Silva Ribeiro

Vibration can cause structural damage in dynamic systems when not designed properly. Recently, several approaches are emerging in structural dynamics as possible alternatives for passive vibration and noise control, such as phononic crystals and metamaterials. In this work, a three-dimensional frame that presents intersection of longitudinal, flexural and torsional band gaps is investigated. For periodic structures, the Irreducible Brillion Zone (IBZ) gives information for any possible angle of propagation of a wave. The manufacturing process induces variability along each three-dimensional frame element. The present study verifies the robustness of the band gaps of the three-dimensional structure against spatially varying geometry and mechanical properties. The spatial random fields are modeled using the expansion optimal linear estimator (EOLE). Bayesian statistics is used to infer on the stochastic response simulated using the Monte Carlo method combined with the EOLE. The three-dimensional frame is modeled via Euler-Bernoulli beam and ordinary shaft theories as well as with Timoshenko and Saint-Venant theories. It is shown that the three-dimensional frame structure exhibits a complete (for all waves) and full (throughout the IBZ) robust band gap against the proposed variability. Both models are able to predict this robust band gap.

4:00 PM 03-Aug-2021 **IN21_2344.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2344

Resonant metamaterial designs for a broadband mitigation of flow-induced vibrations

Felipe Alves Pires, Luca Sangiuliano, Noé Geraldo Rocha de Melo Filho, Hervé Denayer, Elke Deckers, Wim Desmet, Claus Claeys

Resonant metamaterials have recently emerged as lightweight and performant noise and vibration solutions for the hard-to-address low-frequency ranges. These engineered materials are made by an assembly of resonant elements onto a host structure. Their interaction leads to tuneable frequency ranges, known as stop bands, in which they can outperform classical noise control measures. However, these stop bands have a limited frequency range effect. To broaden the noise and vibration performance also outside the stop band, this paper presents a design approach for a finite resonant metamaterial plate. Two regularly spaced grids of resonant elements are both added to a plate. In the first grid, the resonant elements are tuned to the same nominal frequency and stop band behaviour is achieved. In the second grid, the tuned frequency of each resonant element is found through an optimisation procedure, with the goal of minimising the dynamic response of the plate outside the stop band. To speed up the optimisation, model order reduction and a dynamic sub-structuring method are employed. The performance of this finite resonant metamaterial plate design is validated by evaluating its vibration response due to a broadband grazing flow excitation and comparing it to a plate with equivalent mass additions.

4:20 PM 03-Aug-2021 **IN21_2571.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2571

Metamaterial plate with an arrangement of different resonators

Giovanna Pisicchio Zanoni, Alberto Luiz Serpa

Local resonant metamaterials have been widely studied for vibration suppression in the last 20 years. They produce band gaps, which are frequency regions where the wave is not allowed to propagate. They are an alternative to reduce vibration levels at lower frequencies when compared to phononic crystals, which require larger periodic cells to create band gaps at lower frequencies. The most common configuration for a local resonant metamaterial is a periodic cell of a known structure with one attached resonator. In this study, a plate with a periodic cell using two different resonators is analyzed. Some configurations of mass and stiffness for the two resonators will be discussed to pursue the best compromise between a wider band gap and a more considerable vibration attenuation. The dispersion relation for the proposed metamaterial unit cell will be calculated using the Wave Finite Element Method to evaluate these configurations. The frequency response function for a finite structure with the proposed arrangement will also be calculated using the Finite Element Method to compare the results.

4:40 PM 03-Aug-2021 **IN21_2098.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2098

Phononic crystal sandwich for broadband and low frequency acoustic insulation under diffuse field

Natacha Aberkane-Gauthier, Miguel Moleròn, Damien Lecoq, Clément Lagarrigue, Charles Pézerat, Vincente Romero-García

Light and thin structures exhibiting high sound insulation over a wide frequency range are a major industrial concern, especially in the transport and building sectors. Phononic crystals constitute promising solutions to solve this issue due to their particular dispersion properties. In this work, we build a system consisting of a well-known sandwich panel comprising a soft elastic core layer hosting periodically arranged rigid inclusions. Diffuse field measurements show a huge improvement of the Transmission Loss compared to the system without inclusions. In fact, for this kind of panel, the structured core enables Bragg band-gap opening for guided slow propagating waves leading to low frequency and broadband enhancement of the Transmission Loss. Using a 3cm-thick material we are able to improve the response from 300 Hz on ($\lambda/38$ in air). We then develop a finite elements model to achieve a precise description and understanding of the problem. We also propose a numerical tool to analyze the system's band-structures from a vibroacoustic point of view. It proves very useful for the further development of practical solutions.

Session: 03.02 - Modeling & Numerical Simulation, Part 2
Channel 2

6:00 AM 03-Aug-2021 **IN21_3124.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3124

Efficient prediction of construction equipment exterior and cabin interior noise over broad frequency range using novel SEA method

Hiromitsu Emoto, Taisei Yamaguchi, Hiroki Suganuma, Atsushi Kawano

Statistical Energy Analysis (SEA) is commonly used for the prediction of interior cabin noise from construction equipment such as excavators, dump trucks, or graders. While traditional SEA method is computationally efficient and effective for the prediction of total radiated noise, it isn't suitable for prediction of sound diffraction around machinery and evaluation of spatial variations in sound field. As a result, prediction of cabin airborne interior noise transmission using SEA method typically requires experimental measurements in order to estimate incident sound field over the exterior boundary of the cab which makes it unsuitable for use in early stage design where test data isn't available. A novel SEA method that accounts for spatial gradients in the reverberant field has been developed and is introduced in this paper. It's usage for prediction of both exterior and cab interior noise over broad frequency range is demonstrated along with experimental validation for construction equipment under operating conditions.

6:20 AM 03-Aug-2021 **IN21_1660.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1660

An isogeometric formulation of locally-conformal perfectly matched layer for acoustic scattering problems

Yongzhen Mi, Xiang Yu

This paper presents an isogeometric formulation of the locally-conformal perfectly matched layer (PML) for time-harmonic acoustic scattering problems. The new formulation is a generalization of the conventional locally-conformal PML, in which the NURBS patch supporting the PML domain is transformed from real space to complex space. This is achieved by complex coordinate stretching, based on a stretching vector field indicating the directions in which incident sound waves are absorbed. The performance of the isogeometric PML formulation is discussed through several acoustic scattering problems, spanning from one to three dimensions. It is found that the proposed method presents superior computational accuracy, high geometric adaptivity, and good robustness against challenging geometric features. The geometry-preserving ability inherent in the isogeometric framework could bring extra benefits by eliminating geometric errors that are unavoidable in the conventional PML. Meanwhile, these properties are not sensitive to the location of the sound source or the depth of the PML domain.

6:40 AM 03-Aug-2021 **IN21_1708.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1708

3D shape optimization of loudspeakers

Peter Risby Andersen, Vicente Cutanda Henríquez, Niels Aage, Junghwan Kook

Improving the performance of loudspeaker units and cabinet designs traditionally relies on a combination of trial and error, sometimes based on a lumped parameter modelling approach. During the last decades, however, large-scale numerical simulations are playing a growing role as a means of improving performance of complex engineering devices such as loudspeakers. However, a numerical model still relies on the experience of the operating engineer to make the appropriate design changes. This can be a difficult task. The use of numerical simulations combined with optimization has a huge potential for further guiding the design process of advanced industrial products where intuition alone is not sufficient. Nevertheless, broadband acoustic simulations are still very time consuming.
In this work, we explore the efficiency of a newly proposed semi-analytical adjoint sensitivity approach based on the boundary element method in combination with a lumped parameter model. The sensitivity analysis is used to shape optimize the cabinet of a loudspeaker using free form deformation. The objective of the optimization is to improve frequency responses and directivity patterns.

7:00 AM 03-Aug-2021 **IN21_2909.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2909

The effect of bamboo clip dimension and position towards the frequency spectrum of a vibrating inhomogeneous bundengan string

Indraswari Kusumaningtyas, Ayrton Fithiadi Sedjati, Asadulloh Julda Hifzhuddin, Gea Oswah Fatah Parikesit

Bundengan is a traditional musical instrument from Indonesia. One of its unique features is the ability to produce sound imitating the gamelan, a percussive metallophone. This is generated by plucking on the bundengan strings, which have small bamboo clips attached to them. In this work, the effect of the clip dimension and position on the frequency spectrum of the vibrating string is analysed by means of computer simulation and experiment. The string was modelled using Scilab, taking into account the transversal and rotational vibration of the string and bamboo clip, including air drag force. The height to diameter ratio of the clip can be varied in the model. Furthermore, we set up a bundengan string on a sonometer with no resonator, attached specially made bamboo clips on it, and measured the sound frequency spectrum of the vibrating string. The results showed that increasing the height to diameter ratio of the clip decreased the overtone frequencies of the string. It was also found that the fundamental frequency of the string decreased, but its overtones increased, when the clip is shifted towards the middle of the string. The frequency spectrum from the simulation corresponds well to that from the experiment.

7:20 AM 03-Aug-2021 **IN21_1763.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1763

Bubble curtain modelling: analytical prediction of piling noise mitigation

Marco Huisman, Louis Lederwasch, René Smidt Lützen

In order to mitigate underwater noise caused by pile driving, bubble curtains are widely used during offshore constructions. These form an impedance barrier to the acoustic pressure wave, and the resulting attenuation on the interface of water to bubbly water is the main driver behind the insertion loss that can be achieved. A secondary effect is energy absorption by bubble resonance; however, normal bubble sizes are such that the resonance frequency is considerably higher than the peak in the piling noise spectrum, rendering the resonance contribution to the overall insertion loss relatively small. The broadband insertion loss and sound level reduction spectra of bubble curtains are mainly determined on an empirical basis, comparing actual project data and noise monitoring results across sites. Although several efforts have been made to capture the noise mitigation by bubble curtains in numerical models, there is no straight-forward integrated modelling method available to quantify the influence of individual design and operational parameters. Using a number of assumptions and simplifications, this paper presents an analytical model for the frequency-dependent and broadband insertion loss achieved by bubble curtains, that combines both impedance and resonance effects.

7:40 AM 03-Aug-2021 **IN21_2879.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2879

Using simulation to predict reverberation room performance: Validation and parameter study

Jared Schmal, David Herrin, Jennifer Shaw, Charlie Moritz, Alexis Talbot, Nikhil Ghaisas

Predicting the behavior of a reverberation room is inherently challenging and often puzzling. Many still rely on a time-consuming trial-and-error approach when designing the interior and placing diffusers to achieve a diffuse field. An accurate finite element simulation of a reverberation room would enable design ideas and modifications to be tested without any downtime of the physical room. Room modifications of interest are diffuser geometry, material, size, and placement, and the addition of tuned absorbers. For a simulation to be capable of such a task, each

surface would need to accurately emulate the material specific behaviors occurring in the room. A finite element simulation in Actran VI was tuned to reflect the real-world low-frequency behavior of the reverberation room at Blachford Acoustics located in West Chicago, IL. A detailed analysis of the process and methods used to create and verify the model are discussed. This is followed by a simple parameter study to look at some modifications of interest.

Session: 02.08 Machine Learning Approaches in Vibro-Acoustics
Channel 2

8:00 AM 03-Aug-2021 **IN21_2294.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2294

Optimizing the acoustic properties of a meta-material using machine learning techniques

Alessandro Casaburo, Dario Magliacano, Giuseppe Petrone, Francesco Franco, Sergio De Rosa

The scope of this work is to consolidate research dealing with vibroacoustics of periodic media. This investigation aims at developing and validating tools for the design of global vibroacoustic treatments based on foam cores with embedded periodic patterns, which allow passive control of acoustic paths in layered concepts. Firstly, a numerical test campaign is carried out by considering some solid (but still non-perfectly rigid) inclusions in a 3D-modeled porous structure; this causes the excitation of additional acoustic modes due to the periodic nature of the meta-core itself. Then, some design guidelines are provided in order to predict several possible sets of characteristic parameters (i.e. inclusion geometry, elastic and foam properties) that, constrained by the imposition of mass and thickness of the acoustic package, may satisfy the target functions (i.e. the frequency at which the first Transmission Loss peak appears, together with its amplitude). Results are obtained through the implementation of machine learning algorithms, which may constitute a good basis in order to perform preliminary design considerations that could be interesting for further generalizations.

8:20 AM 03-Aug-2021 **IN21_2342.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2342

Explainable machine learning: A case study on impedance tube measurements

Merten Stender, Mathies Wedler, Norbert Hoffmann, Christian Adams

Machine learning (ML) techniques allow for finding hidden patterns and signatures in data. Currently, these methods are gaining increased interest in engineering in general and in vibroacoustics in particular. Although ML methods are successfully applied, it is hardly understood how these black box-type methods make their decisions. Explainable machine learning aims at overcoming this issue by deepening the understanding of the decision-making process through perturbation-based model diagnosis. This paper introduces machine learning methods and reviews recent techniques for explainability and interpretability. These methods are exemplified on sound absorption coefficient spectra of one sound absorbing foam material measured in an impedance tube. Variances of the absorption coefficient measurements as a function of the specimen thickness and the operator are modeled by univariate and multivariate machine learning models. In order to identify the driving patterns, i.e. how and in which frequency regime the measurements are affected by the setup specifications, Shapley additive explanations are derived for the ML models. It is demonstrated how explaining machine learning models can be used to discover and express complicated relations in experimental data, thereby paving the way to novel knowledge discovery strategies in evidence-based modeling.

8:40 AM 03-Aug-2021 **IN21_2094.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2094

Deep learning-enhanced single point sound source localization for spherical microphone array

Soo Young Lee, Jiho Chang, Seungchul Lee

In this contribution, we present a high-resolution and accurate sound source localization via a deep learning framework. While the spherical microphone arrays can be utilized to produce omnidirectional beams, it is widely known that the conventional spherical harmonics beamforming (SHB) has a limit in terms of its spatial resolution. To accomplish the sound source localization with high resolution and preciseness, we propose a convolutional neural network (CNN)-based source localization model as a way of a data-driven approach. We first present a novel way to define the source distribution map that can spatially represent the single point source's position and strength. By utilizing paired dataset with spherical harmonics beamforming maps and our proposed high-resolution maps, we develop a fully convolutional neural network based on the encoder-decoder structure for establishing the image-to-image transformation model. Both quantitative and qualitative results are demonstrated to evaluate the powerfulness of the proposed data-driven source localization model.

Session: 02.03 Numerical Methods in Vibro-Acoustics, Part 2
Channel 2

2:00 PM 03-Aug-2021 **IN21_1002.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1002

Tutorial on Acoustic Fluid Loading of Structures

Stephen Hambric

Any vibrating structure is loaded by the fluid surrounding it. Whether air, water, or something else, the fluid loading adds a spatially distributed resistance (in phase with the vibration) and reactance (out of phase with the vibration) over the structural surfaces. The resistance absorbs energy, and damps structural vibrations. The reactance is either mass-like, effectively adding to the structural density, reducing resonance frequencies and vibration amplitudes; or stiffness-like, increasing resonance frequencies. Usually, mass-like reactance is caused by fluids external to a structure, and stiffness-like reactance is caused by enclosed volumes of fluids. This tutorial uses analytic methods to compare and contrast external and internal fluid loading on a flat rectangular plate and demonstrates the effects of fluid loading on plate vibration and

radiated sound. The well-known stiffening effect of the internal Helmholtz resonance is demonstrated for a thin panel and a shallow entrained cavity. The differences between heavy (water) and light (air) external fluid loading are also demonstrated, with significant reductions in resonance frequencies and peak vibration amplitudes for water loading.

2:20 PM 03-Aug-2021 **IN21_2643.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2643

Computing Radiated Sound Power using Quadratic Power Transfer Vector (QPTV)

Rajendra Gunda, Sandeep Vijayakar

Pressure Acoustic Transfer Functions or Vectors (PATVs) relate the surface velocity of a structure to the sound pressure level at a field point in the surrounding fluid. These functions depend only on the structure geometry, properties of the fluid medium (sound speed and characteristic density), the excitation frequency and the location of the field point, but are independent of the surface velocity values themselves. Once the pressure acoustic transfer function is computed between a structure and a specified field point, we can compute pressure at this point for any boundary velocity distribution by simply multiplying the forcing function (surface velocity) with the acoustic transfer function. These PATVs are usually computed by application of the Reciprocity Principle, and their computation is well understood.
In this work, we present a novel way to compute the Velocity Acoustic Transfer Vector (VATV) which is a relation between the surface velocity of the structure and fluid particle velocity at a field point. To our knowledge, the computation of the VATV is completely new and has not been published in earlier works.
By combining the PATVs and VATVs at a number of field points surrounding the structure, we obtain the Quadratic Power Transfer Vector (QPTV) that allows us to compute the sound power radiated by a structure for ANY surface velocity distribution. This allows rapid computation of the sound power for an arbitrary surface velocity distributions and is useful in designing quiet structures by minimizing the sound power radiated.

2:40 PM 03-Aug-2021 **IN21_2236.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2236

A hybrid method for broadband vibroacoustic simulations

Jared Miller, Scott D. Sommerfeldt, Jonathan D. Blotter, David C. Copley

Many methods for simulating acoustic responses of vibrating systems are only suitable for limited frequency ranges, providing either an accurate low frequency or high frequency response. A hybrid method is presented to combine a low frequency modal response and a high frequency statistical energy response to obtain a unified broadband response. The method is designed to produce an auralizable response. An experimental setup is used to validate the method. Listening tests are conducted to assess the realism of the auralizations compared to measurements. The listening tests confirm that the method is able to produce realistic auralizations, subject to a few limitations.

3:00 PM 03-Aug-2021 **IN21_3044.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3044

SEA model for structural acoustic coupling by means of periodic finite element models of the structural subsystems

Luca Alimonti, Abderrazak Mejdi, Andrea Parrinello

Statistical Energy Analysis (SEA) often relies on simplified analytical models to compute the parameters required to build the power balance equations of a coupled vibro-acoustic system. However, the vibro-acoustic of modern structural components, such as thick sandwich composites, ribbed panels, isogrids and metamaterials, is often too complex to be amenable to analytical developments without introducing further approximations. To overcome this limitation, a more general numerical approach is considered. It was shown in previous publications that, under the assumption that the structure is made of repetitions of a representative unit cell, a detailed Finite Element (FE) model of the unit cell can be used within a general and accurate numerical SEA framework. In this work, such framework is extended to account for structural-acoustic coupling. Resonant as well as non-resonant acoustic and structural paths are formulated. The effect of any acoustic treatment applied to coupling areas is considered by means of a Generalized Transfer Matrix (TM) approach. Moreover, the formulation employs a definition of pressure loads based on the wavenumber-frequency spectrum, hence allowing for general sources to be fully represented without simplifications. Validations cases are presented to show the effectiveness and generality of the approach.

3:20 PM 03-Aug-2021 **IN21_2791.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2791

Power balance analysis of nonperiodic structural components from a model converted from FEM to SEA.

Mathias Hinz, Júlio Apolinário Cordioli, Luca Alimonti, Bryce Gardner

Using Statistical Energy Analysis (SEA) to characterize the power flow within a vibroacoustic system is a challenging task when the subsystems have irregular shape and complex construction. Retrieving analytical solutions for the ordinary SEA parameters is nearly impractical without restricting simplifications and periodicity is usually not exploitable due to the lack of repetition patterns. A promising option to perform the power balance for such cases is to filter part of the information contained in a Finite Element Method (FEM) model of the system, in order to convert it into a SEA model. In this paper, the Lorentzian Frequency Average and the Nonparametric Random Matrix Theory are applied to randomize the dynamic stiffness matrix of the FEM components from a system of industrial application. The obtained direct field dynamic stiffness matrices are employed along the diffuse field reciprocity relationship as a general framework to determine the energetic content of each component. The results obtained with this procedure are evaluated against the ones from classical SEA and Monte Carlo techniques.

Session: 05.04 Urban Air Mobility Community Noise, Part 1
Channel 3

6:00 AM 03-Aug-2021 **IN21_2541.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2541

Simulation of multi-rotor powered urban aerial mobility noise for environmental assessment

Qichen Tan, Haoyu Bian, Siyang Zhong, Xin Zhang

The operation of the rapidly growing unmanned aerial vehicles (UAV) and the promising urban aerial mobility (UAM) could have a significant noise impact on the environment. In this work, we developed a cloud-based noise simulator to efficiently assess the environmental impact of UAM and UAV. The noise sources and long-distance propagation are computed by the propeller noise prediction models and an advanced Gaussian beam tracing method, respectively, in local high-performance computers. Users can define the working conditions and vehicle layer through a platform with a user-friendly graphical interface. In addition, the noise level distribution at the observers of interest such as the buildings can be visualized. By employing advanced interpolation methods or autonomous learning algorithms, the computations are efficiently accelerated such that the noise distributions are simultaneously displayed during flights of the vehicles. To better measure the noise impact on human perception, various noise metrics will be output for further analysis. By conducting the virtual flights using the simulator, the noise impact in each flight state and atmospheric condition of different vehicles can be predicted, which will then facilitate the low-noise flights for both UAV and UAM.

6:20 AM 03-Aug-2021 **IN21_2203.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2203

Techniques for adaptive metamodelling of propeller arrays far-field noise

Umberto Iemma, Caterina Poggi, Monica Rossetti, Giovanni Bernardini

The fast development of Urban-Air-Mobility as well as the constant growth of the air transport have made the acoustic pollution abatement a crucial requirement for the aviation industries in order to comply with the increasingly demanding constraints for the community acceptance. The aeroacoustic characterization of arrays of electrically-powered propellers is one of the most challenging issues. The vast majority of the UAM concepts under development adopt propulsion systems based on multiple propellers, for which reliable and cost-efficient aeroacoustic models are still lacking. The present paper proposes the development of surrogate models for the description of acoustic emission of multi-propeller configurations. The numerical investigation focuses on surrogate models able to take into account the effects of the propeller blade geometry (e.g., chord and twist distributions) and global propeller-array geometric parameters (e.g., propellers clearance) on acoustic performances of the whole system. An innovative Artificial Neural Network adaptive metamodelling technique is applied on a numerical database obtained through a boundary integral formulation for the solution of incompressible potential flows around lifting/thrusting bodies, followed by the application of the Farassat 1A boundary integral formulation for the noise field evaluation.

6:40 AM 03-Aug-2021 **IN21_2278.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2278

Noise prediction for urban air taxi operation

Mark Koehler, Frank Baader, Peter Brandstätt

Solutions to escape crowded streets are increasingly taking up new forms of mobility. This also includes air taxis or VTOLs. In addition to passenger traffic, suggestions, such as parcel delivery by drones, are also regularly part of future visions. Air taxis pose additional safety requirements due to the transport of people and they also represent a major potential source of noise. A challenge that urban planners, pollution control officers and decision-makers have to face. Using the concrete example of an urban landing place for air taxis at the main train station in the city of Ingolstadt, possible problems, issues related to noise protection and their legal basis were examined. This presentation is a summary of the projects results. The examinations include the creation of noise mapping in order to simulate the impact to the already existing noise situation. Those were based on current flight noise regulations with necessary alterations regarding VTOLs. Because air taxi noise is expected to be more annoying than regular traffic noise, the possible application of flight noise indexes such as the “Frankfurt flight noise index FFI 2.0” shall be reviewed. Based on the results of the previous examinations, possible noise protection measures shall be developed.

7:00 AM 03-Aug-2021 **IN21_1638.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1638

ATEFA – A first German approach on UAM community noise and air-taxi certification

Michael Bauer, Daniel Redmann, Lis Weilandt

Urban air mobility (UAM) includes larger air taxis, driven by multiple distributed propellers or fans, installed in a fixed configuration or as tilted wings/engines. These novel electric air vehicles will always generate tonal and broadband noise, in some cases with components from a specific installation situation. In any case, noise will propagate to the ground, into high populated areas of large cities or into their urban environment, individually depending on the operational situation of air taxi use. Some of the populated areas, where no significant noise from air traffic has been observed so far, will be exposed to this new type of aircraft noise. ATEFA, as the first German national funded research project on UAM community noise, aims to provide first answers. Three selected air taxi concepts, strongly differing acoustically from each other, will be technically described and their noise emissions will be modeled and predicted. Air taxi operations will be simulated by generic traffic scenarios in a selected area of southern Germany, and community noise near vertiports, but also “en-route” along the flight paths, will be computed. Beside this, noise certification aspects will be assessed regarding metrics and procedures and compared to a light low-noise helicopter as reference aircraft.

7:20 AM 03-Aug-2021 **IN21_1333.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1333

Community noise from urban air mobility (UAM) and its control by traffic management

Michael Bauer

The awareness about UAM is amplified by steadily growing numbers of air taxi concepts being announced. In general environmentally friendly by electric propulsion, community noise and en-route noise are still prominent open questions. Several studies for larger UAM aircraft, describing the acoustic characteristics of a variety of potential air taxi concepts, have been performed by the author. Due to the abovementioned multitude of different vehicle concepts and their multiple operational conditions, each of them shows individual sound characteristics. Therefore, further investigations of noise created by air taxi fleets appear to be crucial. Understanding of community noise around vertiports and along air taxi routes will strongly depend on those fleets. In this paper, acoustically different air taxi systems are composing different sets of air taxi fleets, used for air traffic noise simulations. The simulations start with baseline scenarios of equally represented taxi systems on fixed flight paths with several flight levels in a certain air lane. The final fleets are consisting of random air taxi composition with randomly populated flight paths. The results, based on common noise metrics and changes in the number of affected residents, could provide a first indication how to reduce community noise by future UAM traffic management.

Session: 08.03 Tire Noise, Part 1
Channel 3

7:40 AM 03-Aug-2021 **IN21_2964.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2964

Artificial Neural Network Model for Road Pavement Classification using Features of Tire-Pavement Noise and Road Surface Images

Seo Il Chang, Bo Kyeong Kim, Jae Kwan Lee

Artificial neural network models were developed to classify road pavement types into the transverse-tined, the longitudinal-tined, NGCS(Next Generation Concrete Surface), Diamond Grinding, and Stone Mastic Asphalt by utilizing tire-pavement noise and road surface images. Tire-pavement noise data were collected by OBSI(On-Board Sound Intensity) method, and analyzed to obtain sound intensity level, sound pressure level, and sound quality indices. Road surface image data was analyzed through image feature extraction algorithms of Hough transformation and HOG(Histogram of gradient). The important features among the acoustic and image characteristics were selected by a random forest model. The acoustic features selected by the random forest algorithm are the overall sound intensity level of 400~5kHz 1/3-octave bands, the sound intensities (W/m2) of 800~2kHz 1/3-octave bands, loudness, fluctuation strength and tonality. The image features selected are the number of longitudinal lines extracted from Hough transform algorithm and HOG of the central cell. The two groups of the selected features were applied separately or together to an artificial neural network model to find classification performance. The classification accuracy rates of the models using acoustic features only, image features only and both acoustic and image features combined were 90.8%, 88.8%, and 97.3%, respectively.

8:00 AM 03-Aug-2021 **IN21_1822.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1822

Advanced design of Close-Proximity (CPX) trailer enclosure acoustics on tyre/road noise measurement

Dongfang Li, Dong Fang Li, Randolph Chi Kin Leung

The PolyU Mark II Twin-wheeled CPX trailer was developed for the measurement of tyre/road noise in Hong Kong urban environment according to a standard methodology (ISO/CD 11819-2) - the Close-Proximity (CPX) method. Numerical simulations of the acoustics of PolyU Mark II CPX enclosure were conducted and a good agreement between numerical and experimental results was obtained. In order to extend the capacity of the Mark II CPX trailer and enhance the acoustic performance within the enclosure for future tyre/road noise studies, the validated numerical simulations were carried on to design the next generation of the PolyU CPX system. Through analyzing the acoustic performance within the enclosures of different dimensions and the distributions of sound pressure level (SPL) inside the anechoic chamber, the geometry of the PolyU Mark III CPX enclosure was finally determined. With newly designed enhanced interior wall absorption, the new PolyU Mark III CPX enclosure design was delivered into numerical simulations for acoustic analysis. Fewer room modes and high uniformity of SPL distributions were observed within the new enclosure design. The PolyU Mark III CPX enclosure was fabricated based on the corresponding dimensions and the specific absorption layers. Great consistency was achieved between the numerical and measured results of the Mark III CPX enclosure. In addition, the PolyU Mark III CPX enclosure shows an improved acoustic property with a lower background noise level during road tests than Mark II CPX enclosure. The outcome of this study firmly establishes the feasibility of designing advanced CPX enclosure with numerical simulations with results that can be realized in realistic CPX measurement.

8:20 AM 03-Aug-2021 **IN21_1830.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1830

Temperature influence on tire/road noise measurements: recently collected data and discussion of various issues related to standard testing procedures

Erik Bühlmann, Felix Schlatter, Ulf Sandberg

Air, road, and tire temperatures substantially affect tire/road noise emission. For measuring purposes, one would like to normalize measurements to a reference temperature by means of a reliable correction procedure. Current studies show that temperature effects remain an important source of uncertainty in tire/road noise measurements and tire testing, even after applying the correction terms provided in the various standards. This seems to be the case for the measurement methods used in OBSI, CPX, SPB, and various regulations or directives based on ECE R117. This paper examines a new dataset consisting of 7.5 million temperature measurements aimed at contributing to a better

understanding of temperature effects and the ways they relate to air, road, and tire temperatures. It is assumed that tire temperatures are the most relevant for noise corrections; therefore, special studies are made for how tire temperatures relate to air and road (test surface) temperatures. A profound analysis is provided on how these relationships vary over different day times, seasons, and climatic regions. Based on this analysis, the authors provide suggestions for improvement of temperature normalization in current tire/road noise and tire testing standards. Special considerations are devoted to measurements on test tracks having ISO 10844 reference surfaces.

8:40 AM 03-Aug-2021 **IN21_2031.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2031

Why do clogged porous asphalt pavements give better traffic noise reduction than a dense-graded asphalt pavement?

Ulf Sandberg

In Europe, porous asphalt concrete pavements (PAC) are commonly used to reduce traffic noise. Especially the double-layer type (DPAC) provides substantial traffic noise reduction. Unfortunately, PAC pavements compared to dense asphalt pavements have reduced acoustic longevity; the main reason being clogging of the pores and voids, sometimes also more ravelling.
The dense-graded pavements considered here are stone mastic asphalts (SMA, in the US known as stone matrix asphalt) which often have surface macrotexture of the same size as the PAC. The main difference is that the PAC has accessible pores/voids providing sound absorption, while the SMA has practically no porosity.
One would expect that when the pores in the PAC have become clogged while ravelling is not yet substantial, that the noise property of the PAC would approach that of the SMA. But experimental studies suggest that even when PAC:s are effectively clogged, they retain a certain noise reduction compared to SMA:s.
This paper examines this feature of clogged PAC versus SMA and reasons for this unexpected property, for a few Swedish DPAC pavements compared to SMA pavements, with due consideration of possible difference in maximum aggregate size and macrotexture as represented by mean profile depth (MPD) and grading curves.

9:00 AM 03-Aug-2021 **IN21_2365.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2365

Monitoring trends in road surface impact on rolling noise emissions

Dick Botteldooren, Wout Van Hauwermeiren, Karlo Filipan, Bert De Coensel

Road surfaces degrade over time due to heavy traffic and weather conditions, which negatively influences both driving comfort and acoustic properties. In addition, the lifetime of a road surface can be increased by performing cost-effective incremental maintenance and this maintenance becomes more expensive when the damages are more severe (cracks, potholes). Current methods such as CPX are performed in a standardized way (using designated equipment and tightly controlled measurement conditions), however budget constraints limit frequent monitoring of surfaces. Therefore, continuous monitoring using ordinary passenger vehicles could be helpful to observe trends in rolling noise emissions and road evenness. Hence, we deployed designated sensor boxes in a number of vehicles that are on the road for other purposes. In addition, advances in calibration of different devices using de-noising autoencoders alleviate the effect of various measurement conditions such as driving speed, braking, accelerating, and temperature. As our innovative methodology has now been on the road for several years, trend analysis becomes possible.

9:20 AM 03-Aug-2021 **IN21_1431.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1431

Uncertainty in the standardized method "Characterization of the acoustic properties of road surfaces" by CEN TC227 WG5

Gijsjan van Blokland, Luc Goubert

TC227 of CEN has developed a method to determine the effect of the road pavement on the sound emission of road vehicles. The proposed methods can be applied to define the acoustic label value of a generic or proprietary pavement type, to check compliance of a pavement with the specifications for that pavement type and to monitor the development of the acoustic properties over the lifetime of the product. With the procedure one can additionally derive the coefficients for the pavement correc tion in the noise emission formulae for road vehicles in the CNOSSOS-EU calculation model. The application of the method exhibits a limited accuracy. The paper investigates the sources of uncertainty of the standardized method and combine the contributions into a single overall uncertainty according to the procedures laid down in Guide 98-3 of ISO. The uncertainty is determined for each of the listed application areas. From the uncertainty analysis the major contributions are identified. Improvement of the method shall focus on only these contributions.

Session: 05.04 Urban Air Mobility Community Noise, Part 2
Channel 3

11:00 AM 03-Aug-2021 **IN21_2555.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2555

Towards predicting noise-power-distance curves for propeller and rotor powered aircraft

Daniel Amargianitakis, Rodney H. Self, Antonio J. Torija, Anderson R. Proença

Propeller and rotor based propulsion systems are the dominating choice of power delivery system in the upcoming Urban Air Mobility market. Fully electric air-taxis (car sized vehicles with Vertical Take-off and Landing, VTOL, capabilities) concepts are using the benefits of the scalable properties of electric motors to distribute propulsor units all over the airframe. The large variety of concepts and configurations of these vehicles poses a serious issue in predicting noise generated on the ground. The need for a high-level model to aid in acoustic decision making is evident. Through the demonstrated methodology of computationally deriving Noise – Power – Distance curves for conventional turbo fan

aircraft, this paper delivers the capability of dealing with propeller propulsion systems and the associated propeller tonal noise sources to generate the NPDs and therefore noise exposure maps. The aims can be broken down into two objectives: a) demonstrate the capabilities of the proposed propeller harmonics noise scaling laws to calculate noise variation from a baseline scenario and b) incorporate the scaling components into the larger capability of producing noise exposure contours, by the means of computationally deriving NPD curves for propeller powered aircraft. Preliminary NPD curves for General Aviation sized propeller power aircraft are generated and discussed.

11:20 AM 03-Aug-2021 **IN21_1570.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1570

An investigation into the impact of unmanned aerial vehicles on soundscape perception in urban and rural environments

Rory Nicholls, Antonio Torija Martinez

It is predicted that urban air mobility, including the use of small to medium sized unmanned aerial vehicle (UAV) delivery systems, will be introduced into cities across the globe within the next 15 years. It is known, however, that noise is one of the main limiting factors for the wider adoption of these vehicles. Neither the metrics nor the methods used for conventional aircraft seem to be optimal for this novel source of noise. This research will aid in developing suitable psychoacoustic methodologies and metrics, specifically designed to quantify community noise impact of these vehicles. This paper describes a psychoacoustic experiment used to gather participant responses to UAV sound recordings, both isolated and with typical background noise in a diversity of soundscapes. Results from this psychoacoustic experiment will be used to correlate perceptions of UAV noise with objective sound quality metrics, and build new regression relationships that could describe the impact of a given UAV on the perception of soundscape environments. Future extension to the research may include evaluating the differences in psychoacoustic responses when introducing more accurate reproduction methods, such as virtual reality systems, and how these could be incorporated into a standardised human response measurement procedure.

11:40 AM 03-Aug-2021 **IN21_1482.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1482

Community noise assessment of urban air mobility vehicle operations using the FAA Aviation Environmental Design Tool

Stephen Rizzi, Menachem Rafaelof

In contrast to most commercial air traffic today, vehicles serving the urban air mobility (UAM) market are anticipated to operate in communities close to the public at large. The approved model for assessing environmental impact of air traffic actions in the United States, the Federal Aviation Administration's Aviation Environmental Design Tool (AEDT), does not support analysis of such operations due to a combined lack of a UAM aircraft performance model and aircraft noise data. This paper discusses the initial development of a method to assess the acoustic impact of UAM fleet operations on the community using AEDT and demonstrates its use for representative UAM operations. In particular, methods were developed using fixed-point flight profiles and user-supplied noise data in a manner that avoids unwanted behavior in AEDT. A set of 32 routes in the Dallas-Ft. Worth area were assessed for single and multiple (fleet) operations for two concept vehicles.

12:00 PM 03-Aug-2021 **IN21_1488.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1488

The AIRNOISE-UAM tool and verification with FAA aviation environmental design tool

Jinhua Li, Jinhua Li, Yun Zheng, Menachem Rafaelof, Stephen Rizzi

Noise disruption is expected to be a significant factor for public acceptance of urban air mobility vehicle operations. Today the noise exposure caused by fixed-wing aircraft and/or helicopters operating from airports can be predicted using the Federal Aviation Administration's Aviation Environmental Design Tool (AEDT) software. The noise at the receiver is calculated by interpolating and/or extrapolating noise data as a function of power and distance, named Noise-Power-Distance (NPD) data, for each vehicle type in the AEDT database. The noise data at the receiver fully accounts for atmospheric propagation and includes several adjustments including those for vehicle speed, lateral attenuation, and noise fraction. Urban air mobility will introduce a new class of vehicles named electric Vertical Take-Off and Landing (eVTOL). In this paper, a new tool named "AIRNOISE-UAM" has been developed together with new NPD data named "Gen-1 NPD" to predict noise exposure caused by eVTOL aircraft operations. The predicted noise exposure results from individual flight segments and integrated scenarios are verified with those from AEDT.

12:20 PM 03-Aug-2021 **IN21_1650.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1650

Comparison of two community noise models applied to a NASA urban air mobility concept vehicle

Juliet Page, Stephen A. Rizzi, Rui Cheng

Predictions of community noise exposure from the NASA urban air mobility (UAM) concept vehicles have been conducted for representative operations using the FAA Aviation Environmental Design Tool (AEDT) in order to demonstrate modeling tool interoperability and assess applicability, capabilities and limitations of integrated noise modeling tools. To both quantify limitations and highlight other capabilities, a comparative analysis is performed using a time simulation method, in particular, using the Volpe Advanced Acoustic Model (AAM). Starting with the same source noise model, the 3D directivity of a UAM concept vehicle is predicted in terms of aeroacoustic pressure time histories at a sphere of observers near the vehicle. In addition to distilling those data to a set of noise-power-distance data for input to AEDT, the data are processed preserving directivity, into narrowband, one-twelfth and one-third octave bands for input to AAM. Results from AEDT and AAM modeling are provided for a variety of metrics to demonstrate the effect that source noise and propagation modeling fidelity have on predicted results at receptors over a study area.

Session: 07.01 Railroad and Ground-Borne Noise, Part 1
Channel 3

7:00 PM 03-Aug-2021 **IN21_2242.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2242

Rail noise grade separation alternative analysis case study

Paul Burge, Jim Cowan

The San Francisco Bay Area has an existing commuter rail system that brings commuters from southern regional communities into the downtown city center. One of the communities served by commuter rail service is the City of Palo Alto, CA, which includes four active grade crossings, each requiring train horn sounding for each train event. The City wished to evaluate various options to eliminate the noise generated from horn soundings by creating road/rail grade separations at each existing grade crossing and other possible noise and vibration control elements. The alternatives included crossing closures, rail bed trenching, viaducts, roadway underpasses, and tunnels. A noise and vibration study was undertaken to provide an analysis of which alternatives would provide better reductions in noise and vibration in the surrounding community. The study included an assessment of existing noise levels and predicted future noise and vibration levels for construction and operation of each proposed alternative using current established noise and vibration methodology. The results of this study included comparisons of the noise and vibration associated with each of the of the proposed alternatives that could be used in conjunction with other studies considering cost, traffic, safety, aesthetics and other factors to select an overall preferred alternative.

7:20 PM 03-Aug-2021 **IN21_2381.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2381

A case study on the noise effects of elevating existing train tracks

Joelle Suits

When modeling rail noise on an elevated track, there are several adjustments that need to be considered relative to modeling at-grade operations. These adjustments include the effects of re-radiated noise from the track and support structure, reduced ground attenuation due to an elevated noise source and a reduction in the potential for shielding from adjacent rows of buildings. These adjustments are built into the model as a part of the design of a project. This case study examines a unique situation where a project involved elevating existing at-grade tracks to eliminate a bottleneck related to an at-grade crossing of two perpendicular train tracks. The project elevated one main track over the other and shifted the track closer to noise sensitive receivers. The US Federal Transit Administration and Federal Railroad Administration guidance, which were used to assess noise impacts, produced unexpected results during the initial assessment due mainly to the assumptions regarding the changes in shielding and ground attenuation with the elevated structure. This presentation will discuss the initial assumptions used in the project, the limitations of the model relative to changes in shielding and ground attenuation, and the solutions that were implemented to obtain reasonable results for the impact assessment.

7:40 PM 03-Aug-2021 **IN21_3031.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3031

Cancer research lab, a challenging micro-vibration design

Siddharth Mahajan, Ahmad Bayat, Michael Georgalis

A donated land to three universities near a river bank, in an urban setting prompted the universities to commission a state-of-the-art cancer research lab for a prominent scientist. The site ambient vibration was measured around 2000 micro-inches/sec due to nearby highways, light-rail system, and long-term construction staging area, among others. The research lab requirements were dictated by high-end Scanning Electron Microscopes, Transmission Electron Microscopes, etc. The vibration specification for these tools demanded the environment to perform at or below 50 micro-inches/sec, a factor of 40 reduction. Typically, we desire the site ambient to lie below the vibration criterion with some margin to allow for contribution from building MEP sources. This unusual site condition presented on the surface, an impossible design challenge. We developed a multi-pronged design approach that took advantage of the soil condition at the site and designed a specialized foundation for the lab floor, and supplemented it with improvement on the tool-based isolation system by implementing an active isolation system. The final result was that the 40x site vibration was reduced to below lab vibration criterion curve of 50 micro-inches/sec. To our knowledge, the structural and foundation system of this lab is one-of-a-kind in the world.

8:00 PM 03-Aug-2021 **IN21_2503.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2503

Effect of sound source movement at low Mach number on radiated noise level

Yusuke Makino, Yasushi Takano

Change in A-weighted sound pressure level or Noise level of radiated sound due to sound sources moving at low Mach number at the same speed along a straight track is discussed in this paper. When a sound source move, frequency and amplitude modulation is observed in the radiated sound field. Without their modulation, the noise level at a receiving point is determined only by distance and A-weighted sound power level of each sources. Solution of modulated frequency and amplitude of radiated sound can be obtained by using the Duhamel's efficient calculation. The modulated frequency and amplitude increase for approaching sources and decrease for receding sources. The difference of maximum noise level, and the equivalent sound level during the sources passing-by, with or without considering the modulation, increases monotonically with respect to source velocity, and independent of distance from the track. This difference increases as dominant frequency band of the sources decreases due to A-weighting below 1 kHz.

8:20 PM 03-Aug-2021 **IN21_1582.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1582

Use of a transient SEA for calculation of structure-borne interior noise in trains from an induction motor controlled by multi-mode PWM

Yosuke Tanabe, Takashi Yoshizawa, Shinji Sugimoto, Takafumi Hara

This paper presents a transient SEA (Statistical Energy Analysis) approach to predict the structure-borne interior noise in trains from an induction motor controlled by multi-mode PWM (Pulse Width Modulation). Most of the induction motors installed in trains are controlled by multi-mode PWM, which switches between asynchronous and synchronous modes according to the speed to reduce switching losses. This control causes the electromagnetic forces of PWM harmonics to change, resulting in a transient interior noise depending on the vehicle's speed. In this paper, we model the bogie using FEM to calculate the transmission of the electromagnetic forces to the vehicle body through traction bars and dampers. Next, we model the vehicle body using a transient SEA to calculate transient energy in a 1/3 octave band excited by the transmitted electromagnetic forces. Finally, we restore the waveform of interior noise by applying the appropriate phase to the transient energy to auralize the analysis result. We obtained reasonable agreement by comparing the analysis results of the interior noise with the actual measurements.

8:40 PM 03-Aug-2021 **IN21_1476.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1476

Realizing a Self-powered Real-time Monitoring System on High-speed Trains

S.K. Lai, C. Wang, L.H. Zhang, Y.Q. Ni

The development of the worldwide high-speed rail network is expanding at a rapid pace, imposing great challenges on the operation safety. Recent advances in wireless communications and information technology can integrate the Internet of Things and cloud computing to form a real-time monitoring platform of high-speed trains. To realize this system, a sustainable power source is indispensable. In this case, an ideal solution is to deploy a vibration-based energy harvester instead of batteries for the electrical supply of wireless sensors/devices, as vibrations induced by rail/wheel contact forces and vehicle dynamics are an abundant energy source. To address this challenge, a multi-stable, broadband and tri-hybrid energy harvesting technique was recently proposed, which can work well under low-frequency, low-amplitude, and time-varying ambient sources. In this work, we will introduce our idea, following the recently proposed energy harvester and the dynamic responses of a train vehicle, to design a self-sustained sensing system on trains. Supported by this self-powered system, accelerometers and microphones deployed on an in-service train (in axle boxes/bogie frames) can measure vibration and noise data directly. The correlation of the vibration and noise data can then be analyzed simultaneously to identify the dynamic behavior (e.g., wheel defects) of a moving train.

Session: 01.02 Computational Methods in Flow-Induced Noise & Vibration, Part 3
Channel 4

6:00 AM 03-Aug-2021 **IN21_1410.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1410

A numerical investigation of flow-induced cavity noise control

Zhenan Song, Daoqing Chang, Hongling Sun

The influence of the multiple ultrasound transmitting units and the steady injecting water or suck-ing water on the shear layer oscillation and noise by flow-induced cavity is numerically investi-gated in this paper. The ultrasound transmitting units and the steady injecting water or sucking water are located upstream of the leading edge of the cavity. The flow field near the cavity is com-puted based on the large eddy simulation method (LES). The calculation and analysis results show that the peak amplitude of noise can be reduced by the steady injecting water at the leading edge of the opening. And within a specific range of flow rates, the greater the injecting rate is, the more obvious the peak amplitude of noise decreases

6:20 AM 03-Aug-2021 **IN21_1791.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1791

A method to predict the flow-induced noise of an open cavity of a complex geometry

Tingsheng Zhong, Cheng Yang

Shear flow past a cavity involves a complex fluid dynamic process. Of vital importance is the occurrence of self-sustained oscillations that give rise to tones and the amplitudes of which may be further amplified if the hydrodynamic mode is coupled with the cavity mode. Extensive efforts have been made to investigate the mechanisms of such a simple yet compelling system as well as to predict the noise generated, while most of them are focused on geometry of rectangular shape. For an irregular shaped cavity, numerical methods are usually used which are computationally expensive. A method is developed to predict the tones generated by the shear flow past an open cavity of a complex geometry. In view of the feedback process involved within the system, a describing-function method decomposing the system into a non-linear part and a linear part is used. The linear description function is established by the patch mobility method where the transfer function between patches is extracted from finite element results, while the nonlinear description function is established based on the vortex sound theory. The proposed method showed a superb computation efficiency over CFD method and its accuracy was justified by comparing with the results of public literature.

6:40 AM 03-Aug-2021 **IN21_1498.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1498

Validation setup for the investigation of aeroacoustic and vibroacoustic sound emission of confined turbulent flows

Paul Maurerlehner, Stefan Schoder, Sebastian Floss, Johannes Tieber, Helfried Steiner, Günter Brenn, Manfred Kaltenbacher

Confined flows induce sound at certain flow conditions, which can be annoying in electric vehicles due to the absence of combustion noise. Noise in internal flow may occur due to unfavorable flow-guiding geometries caused by the complex packaging required in engine compartments of modern vehicles. The flow-induced sound is emitted at duct openings (e.g., ventilation inside the passenger cabin). It also originates from the vibroacoustic emissions of the flow-guiding structure excited by the flow.
We propose a modular validation procedure for aeroacoustic simulations of confined flows. The experimental setup includes the vibroacoustic emission of the involved flow-guiding structure. The test rig consists of a sensor system, a high-pressure blower, modular pipe sections, and absorbers, which decouple the system from blower noise and avoid acoustic reflections at the pipe exit. A sufficiently long straight inlet section ensures fully developed flow conditions entering the investigated region. For capturing the vibroacoustic sound radiation of the flow-guiding structure, the measurement object and the surrounding microphones are encapsulated in a wooden box, lined with micro-perforated plates. Measurement results of a straight pipe and a pipe with a half-moon-shaped orifice are presented. Additionally, the sound generation is reproduced by Lighthill's aeroacoustic analogy applying a hybrid approach.

7:00 AM 03-Aug-2021 **IN21_3035.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3035

Numerical study on the contribution of surface and volume components of flow-induced noise in baffle silencers

Bartosz Chmielewski, Iván Herrero-Durá, Paweł Nieradka

Baffle silencers are a well-known solution for noise mitigation in industrial applications. One of the issues concerning these devices is the flow-inducted noise produced when a non-laminar flow of the medium in the duct occurs. These situations occur, for example, in dedusting installations or exhaust systems with the high-speed flow (large Reynolds number of the turbulence and small Mach number). This kind of installation has a complex shape that causes a turbulent flow in the medium. Installing a baffle silencer in these conditions causes additional noise. This noise cannot be predicted by using a standard approach with equations for laminar flow conditions. This paper presents the first step of the research in this field. The first step is to find a relation between CFD simulations' results and self-noise of the baffle silencer. In this work, we use the formulation proposed by Proudman in 1952 to calculate the sound power generated by the flow. The formulation is based on the turbulent kinetic energy k and dissipation rate ε of the flow, which is calculated by CFD simulations. The resulting sound power level needs to be calibrated. The calibration method is developed and presented. The aim of this research is to design an experimental setup.

Session: 01.05 Aero & Hydro-Acoustics
Channel 4

7:20 AM 03-Aug-2021 **IN21_1290.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1290

Broadband force spectrum of a pump-jet under inflow turbulence

Shuaikang Shi, Huang Xiuchang, Rao zhiqiang, Hua hongxing

To clarify the characteristics of unsteady force spectrum of a pump-jet running under inflow turbulent,the turbulence grid and Fourier synthesis method is employed to produce incoming turbulence with spatial flow structure and temporal fluctuation, which is combined with LES (large eddy simulation) to obtain broadband unsteady force spectrum of the pump-jet. The results show that the proposed method could obtain the unsteady force broadband spectrum for duct, stator and rotor. The unsteady force broadband spectrum of the pump-jet is composed of the "hump" around the blade passing frequency and its multiples, the characteristic line spectrum at the stator blade passing frequency and shaft frequency of adjacent stator multiples. With the number of blades increasing, the "hump" becomes more obvious, the characteristic peak changes periodically and reaches the minimum when the number of blades is the number of rotors. Due to the use of the stator and duct, the amplitude of the unsteady force broadband spectrum of the pump-jet is higher than propeller, but the "hump" is not as obvious as propeller. The research is helpful to clarify the unsteady force characteristics of pump-jet induced by turbulence, and provide ideas for the vibration and noise reduction of pump-jet.

7:40 AM 03-Aug-2021 **IN21_1958.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1958

Numerical investigation into effects of gas concentration and bubble collapse on tip vortex cavitation noise of NACA16-020 wing

Garam Ku, Cheolung Cheong, Hanshin Seol, Hongseok Jeong

In this study, the effects of gas concentration and bubble collapse on tip vortex cavitation noise of NACA16-020 wings are investigated using coupled Eulerian-Lagrangian method based on sequential application of Reynolds averaged Navier-Stokes (RANS) solver, bubble dynamics model and acoustic analogy. The bubble dynamics model used in the preceding study (Ku et al., 2020) is modified by including the gas pressure terms and the bubble collapse model, which depends on the timing and threshold of bubble collapse, the number, initial radius and location of divided bubbles. The validity of the modified bubble dynamics model is confirmed through its application to a benchmark problem where single bubble is triggered by laser. Then, the coupled Eulerian-Lagrangian method based on the modified bubble dynamic model is applied for the prediction of tip-vortex cavitation noise of NACA16-020 wing. The predicted results of the tip vortex pattern and acoustic pressure spectrum are compared with the measured results, which shows closer agreements between two results than those in the previous study.

8:00 AM 03-Aug-2021 **IN21_2258.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2258

Numerical Study of Airfoil Tonal Noise Reduction using Segmented Elastic Panel Configuration

Arif Muhammad Irsalan, Garret C. Y. Lam, Randolph C. K. Leung

In this paper, a novel passive method for airfoil tonal noise reduction is proposed using a configuration of two segmented elastic panels mounted on the airfoil. Numerical investigation using perturbation evolution method is carried out at a low Reynolds number based on airfoil chord of 5x10 and an angle of attack of 5. The passive method of employing a single panel has shown promising tonal noise reduction capabilities where the resonating panel located just ahead of the sharp growth of boundary layer instability within the airfoil separation bubble provided the strongest reduction of instabilities and noise reduction up to 3 dB has been achieved. The idea is extended in the present study by employing a two-panel configuration based on the localized flow characteristics over the airfoil surface. Five different panel configurations are designed and their effectiveness in terms of tonal noise reduction is evaluated and compared with baseline configuration. The azimuth and spectral analyses indicate the different extent of noise reduction for each configuration and even noise amplification in one of them. A significant noise reduction up to 8 dB is observed for the optimum configuration indicating the effectiveness of this novel method for devices operating at low Reynolds number.

8:20 AM 03-Aug-2021 **IN21_2695.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2695

The multi-functional rotor aerodynamic and aeroacoustic test platform at HKUST

Han Wu, Chuntai Zheng, Peng Zhou, Ryu Fattah, Xin Zhang, Guocheng Zhou, Bao Chen

This paper describes the multi-functional rotor noise and aerodynamics test platform at the Hong Kong University of Science and Technology (HKUST). To investigate the noise characteristics of propellers with aerodynamic flows, the test rig is installed in the 2.5×2 (m) low-speed and low-noise wind tunnel in the Aerodynamic and Acoustic Facility (AAF) at HKUST. The wind tunnel can facilitate flow from 0 to 40 m/s. The test rig is assembled in a turntable on the ceiling of the tunnel wall, which enables the testing range of pitch angle can vary from 0° (axial flow) to 90° (parallel flow), with an accuracy of 0.1°. The noise produced by the rotor is measured by a set of wall-mounted surface microphones. Semi-empirical calibration is conducted to quantify the noise reflection by the tunnel walls. A low-noise struct has been designed and manufactured to locate a set of far-field microphones equipped with nosecone, to improve the quality of acoustic measurement inside the flow. In addition, a synchronized system is developed to conduct the phase-locking Particle Image Velocimetry (PIV) measurement on the rotor, to study the flow pattern to better understand the noise generation mechanism.

8:40 AM 03-Aug-2021 **IN21_2697.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2697

Experimental assessment of the noise characteristics of propellers for commercial drones

Han Wu, Peng Zhou, Siyang Zhong, Xin Zhang, Kunyu Luo

Multi-copters or drones are engaged in a wide range of industrial applications for their flexibility, safety and low-cost. The noise emission is becoming an issue with the expanding applications, among which the propellers that drive the drones are the major sources of noise. In this work, the noise characteristics of small-scale propellers is experimentally investigated using the advanced rotor aerodynamics and aeroacoustics test platform in an anechoic chamber at the Hong Kong University of Science and Technology (HKUST). The study will focus on the representative off-the-shelf propellers. The rotor noise will be measured by a linear array with 20 microphones, and the aerodynamic forces will be acquired by using the high-accuracy load cells. The dependence of both the tonal and broadband noise radiation with the thrust and rotation speed at various conditions will be tested. The study will enhance our understanding of the noise features of the multi-rotor powered drones, and will provide us with a better understanding of the status of the drone noise impact on the environment.

Session: 06.01 Road and Transportation Noise, Part 1
Channel 4

11:00 AM 03-Aug-2021 **IN21_2725.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2725

Assessing traffic noise in teh City of Sharjah using prediction models

Hussein Elmehdi

Noise originated from traffic on inner-city roads has been recognized as a major issue that has negative effects that go beyond annoyance and adverse health effects on people living near such roads. In this paper, we report the results of employing mathematical models for assessing traffic noise levels near roads in the City of Sharjah, UAE. Our field measurements indicated high noise levels near inter-city roads including roads in residential areas. To further investigate this, measured noise levels arising from principle traffic noise parameters were re-examined using published mathematical models with the objective of validating the acoustic noise levels generated by traffic noise of mixed composition, traffic flow rate and distance from the source. The main sound levels, namely the statistical equivalent sound levels (Leq): L10, L50 and L90 were used in the mathematical predictive models, to calculate the day time sound levels and correlated it with in situ measurements. We have examined 10 linear regression models, reported in the literature, five of which were found to provide strong correlation and were validated for predicting noise arising from traffic. The models are recommended for calculating mixed traffic noise levels and its effects on people living near these inter-city roads.

11:20 AM 03-Aug-2021 **IN21_3010.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3010

The influence of link characteristics on road traffic noise mapping by using Big Data

Gaetano Licitra, Antonino Moro, Luca Teti, Lara Ginevra Del Pizzo

This paper describes a new method developed within the BEEP project (Big data for Environmental and occupational EPidemiology) to estimate road traffic flows and to improve the truthfulness of noise maps for agglomerations through Big Data treatment. This new approach, based on data provided by Google API, acquires information regarding travel time to estimate traffic volumes using link delay functions. To achieve this goal, an appropriate experimental plan was designed to simultaneously collect travel times by Google Application Programming Interface (API) and traffic volumes on site. The experimental survey, carried out in the cities of Rome and Pisa, involved different types of road links with traffic lights or roundabouts and different number of lanes. The influence of link characteristics on the correlation between travel time and traffic flow was analysed. The method developed was used in a small area of the city of Rome, and noise maps derived by Big Data were compared to noise maps produced via conventional means.

11:40 AM 03-Aug-2021 **IN21_1342.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1342

A case study of noise pollution levels during the restrictions period due to COVID-19.

David Montes-González, Juan Miguel Barrigón-Morillas, Ana Cristina Bejarano-Quintas, Manuel Parejo-Pizarro, Guillermo Rey-Gozalo, Rosendo Vílchez Gómez, Pedro Atanasio-Moraga

The pandemic of coronavirus disease (COVID-19) led to the need for drastic control measures around the world to reduce the impact on the health of the population. The confinement of people in their homes resulted in a significant reduction in human activity at every level (economic, social, industrial, etc.), which was reflected in a decrease in environmental pollution levels. Studying the evolution of parameters, such as the level of environmental noise caused by vehicle traffic in urban environments, makes it possible to assess the impact of this type of measure. This paper presents a case study of the acoustic situation in Cáceres (Spain) during the restriction period by means of long-term acoustic measurements at various points of the city.

12:00 PM 03-Aug-2021 **IN21_1925.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1925

NEMO project: developing a N-RSD (Noise Remote Sensing Device) to identify high noise emitters in the road traffic flow

Maximilian Ertsey-Bayer, Nikolas Kirchhoff, Sonia Alves, Bert Peeters, Viggo Henriksen, Truls Berge

NEMO (Noise and Emissions MOnitoring and Radical mitigation) is a research project aiming at developing an autonomous system to detect noise and air pollutant emissions from individual vehicles within the traffic flow. The objective is to identify high emitters within the normal traffic. For noise, a high emitter is a vehicle that is either in a poor or modified condition (e.g., with an illegal or malfunctioning exhaust) or that is driven in a noisy way (fast acceleration, high engine speed in low gear, etc.). A vehicle that has been type approved, is well maintained, and is driven under normal conditions is never a high-emitter vehicle, even if it is subjectively perceived as annoying. A Noise Remote Sensing Device (N-RSD) is being developed. This device will capture, for each individual vehicle, the driving conditions (vehicle speed, acceleration, engine speed and load) and the single-event noise levels and spectral characteristics. The noise levels will be normalized to comparable driving conditions and fed into a classification model. The classification model will then be able to identify the high emitters vehicles. When finished, the NEMO system will allow cities and road authorities to reduce annoyance and health impacts from noisy and polluting vehicles, for instance by raising awareness among drivers or by restricting access to low emission zones.

12:20 PM 03-Aug-2021 **IN21_2304.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2304

Implementing auralized CPB sounds on a pedestrian simulator

Francisco Soares, Frederico Pereira, Emanuel Silva, Carlos Silva, Emanuel Sousa, Elisabete Freitas

Recently, several studies on pedestrian safety and particularly those addressing pedestrian crossing behaviour and decision-making, have been performed using virtual reality systems. The use of simulators to assess pedestrian behaviour is conditioned by the feeling of presence and immersion, for which the sound is a determining factor. This paper presents an implementation procedure in which tyre-road noise samples are auralized and presented as auditory stimuli in a virtual environment, for assessing pedestrian crossing decision-making. The auditory samples obtained through the Close Proximity (CPX) method and subsequently auralized to represent Controlled Pass-By (CPB) sounds reproduce the sounds of a vehicle approaching a crosswalk. The auralized sounds together with the presentation of visual stimuli composed an experiment which was carried out with 30 participants. Safety indicators, as the time-to-passage at the moment that participants decided to cross a virtual crosswalk and the minimum time-to-collision were registered and compared with data obtained in real-world road crossings. A comparison with real world data points to a close alignment between results obtained in virtual and real environments, indicating a good suitability of the approach for studying pedestrian crossing behaviour.

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Analyzing transportation noise during the pandemic.

Josh Curley, Kody Snow

The COVID-19 pandemic has introduced new challenges in the approach to many types of projects in the field of acoustical consulting. An important one being the impact on how transportation noise studies are conducted, in particular on-site noise measurements and subsequent computer modeling. The pandemic has affected roadway, railway, and aircraft travel, and consequently the noise generated by these transportation noise sources. This raises questions about the methods used to determine existing and future transportation noise impact upon

residential sites. After a year into the pandemic, it appears that postponing an analysis is no longer feasible and that the need for an adaptable method of analysis is required to meet jurisdictional transportation noise analysis requirements.
How should these studies be completed during this time in which it is highly likely that roadway, railway, and aircraft volumes are not what they were pre-pandemic? How or even should on-site noise measurements be taken? Will the local jurisdictions accept the studies completed during the pandemic? When will roadway, railway, and airport volumes be back to pre-pandemic levels, or will they ever be back to that volume? Will there be a significant impact on noise? This paper will follow the process used to complete transportation noise studies during the pandemic, which involved creatively adapting known methods to address these new questions while working closely with local jurisdictions, providing the education and guidance needed for them to comfortably review studies so that the transportation noise component of site approval does not slow down residential projects.

1:00 PM 03-Aug-2021 **IN21_1840.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1840

Automate TNM Input Process Using Python

Ronald Ying, Nish Patel

Since 2004, we have been using TNM 2.5 to analyze the noise impacts from traffic. The decades-old Graphical User Interface (GUI) is inadequate to handle large scale projects with hundreds of receptors and roadways. TNM 3.0 has a vastly better user interface, but its import function is still buggy as of early 2021. Therefore, we have developed an interim solution to automate massive input using ESRI ArcGIS software and Python's third-party packages such as Pandas, PyAutoGUI, and subprocess. This process is used to automate building barrier input and roadway/traffic inputs in the old TNM 2.5 user interface.

Session: 06.01 Road and Transportation Noise, Part 2
Channel 4

7:00 PM 03-Aug-2021 **IN21_2980.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2980

Influence of vehicle source directivity in Japanese and European outdoor sound prediction models under a semi-finite thick barrier configuration

Takuya Oshima, Fumiya Takeda, Yumi Kurosaka

The Japanese ASJ RTN-Model 2018, European Harmonoise and CNOSSOS-EU outdoor sound prediction models are respectively known to have symmetric, asymmetric and omnidirectional sound emission directivities along front-back direction of the source vehicle. However, the influence of such difference in directivities to final predicted sound levels has not been investigated much. In this study, the influence is investigated using the ASJ Model and the Harmonoise under a configuration of semi-finite thick barrier along a source road. The configuration is an idealization of Japanese roadside buildings that have gaps in between, unlike European buildings that continuously extend over a whole urban block. Under the configuration, distribution of A-weighted sound levels around the end face of the barrier are computed with and without source directivity taken into account by each model. It is found from the results that the source directivity of the ASJ model makes little difference in the noise level distribution. In contrast, the source directivity of Harmonoise is found to make differences of 0.5-0.8 dB at right behind the barrier depending on vehicle running direction. However, a combined effect of source directivity and reflection at the end face is found to be negligible.

7:20 PM 03-Aug-2021 **IN21_2663.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2663

Extensive study of receiver point interpolation methods for drawing estimated road traffic noise maps in Japanese city blocks.

Yudai Yamashiro, Akiko Sugahara, Yasuhiro Hiraguri, Kazunori Harada, Takuya Oshima, Yoshinori Saito, Satoshi Atobe

There are various issues need to be addressed when drawing estimated road traffic noise maps in Japan. One of them is there is a trade-off between computational load and estimation accuracy due to the number of sound receiver points on the building facades where the noise exposure is evaluated. An interpolation to generate receiver points on facades as post-processing of a computation made on relatively coarse receiver points can be a solution to achieve compromise between computational load and estimation accuracy.
In this study, estimated noise maps are drawn in nine real city blocks in Japan with different land-use areas by placing sound receiving points with intervals of 1m, 5m and 10m. The map of the 1m interval is used as the reference noise levels. The maps of the 5m and 10m intervals are interpolated to the 1m interval using 29 interpolation methods.
The optimal combination of the interval of sound receiving points and the interpolation method are found based on error of the interpolated maps compared to the reference map.

7:40 PM 03-Aug-2021 **IN21_3130.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3130

Road traffic noise mapping based on aerial photographs - sound power level determination of road vehicles

Shinichi Sakamoto, Taiki Fukuda, Miki Yonemura, Hyojin Lee

As the first step to obtain a city urban area noise map of road traffic noise, sound power levels of vehicles on the roads should be accurately estimated over a wide area. In Japan, ASJ RTN-Model 2018 was proposed as the representative road traffic noise prediction model, and by using the model sound power level of a vehicle can be determined if the vehicle type, traveling speed, and driving mode are known. As such data on urban road network, the Ministry of Land, Infrastructure and Transport of Japan publishes the road traffic census including road traffic

volume and travel speed of major roads in Japan. The data, however, is limited to major roads and there is no data on minor roads. In this study, to estimate noise condition and situation on arbitrary road, a method for estimating the traveling speed and the traffic volume of vehicles on the road from aerial photographs was examined. Road traffic noise levels along several roads in Tokyo were analyzed by the proposed method and the validity of the calculation results were verified by comparing with short-time measurement results obtained along the target roads.

8:00 PM 03-Aug-2021 **IN21_2659.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2659

Methodology of estimating the number of inhabitants to assess the population exposure to environmental noise in Japan

Shota Suda, Akiko Sugahara, Yasuhiro Hiraguri, Kazunori Harada, Takuya Oshima, Yoshinori Saito, Satoshi Atobe

Population exposure has been used in the risk assessment process for environmental noise. The number of inhabitants is essential data for the evaluation of population exposure. However, such data is not opened to the public to prevent privacy violation. There are several existing methods for the estimation of the number of habitants, but only with limited accuracy. The purpose of this study is to propose a more accurate method for estimating the number of inhabitants using web scraping techniques and numerical maps issued by the Geospatial Information Authority of Japan. The number of inhabitants is estimated from the number of households and the census. The number of households is calculated based on the total number of housing that is extracted from using web scraping techniques. The proposed method is found to present a better accuracy of the number of inhabitants for the detached houses while the estimation for apartment houses should be still improved.

8:20 PM 03-Aug-2021 **IN21_2248.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2248

Field measurement of reverberation time and average absorption of one high-rise building room by road traffic noise penetrating facade

Jiping Zhang, Zheming Wang, Heng Ma, Weike Wang

The facade insulation (FI) is one choice for Road traffic noise (RTN) at a high-rise accommodation building nearby a motor road. The weakness of FI is from window, so the window insulation (WI) is also a prioritized descriptor. ISO16283-3 states a field method to measure FI using RTN. However, in room acoustics, besides FI, reverberation time (RBT) or indoor average sound absorption (IASB) are another two un-ignorable descriptors. When the value of IASB is small, the indoor noise is not only contributed from penetrating façade RTN, but also supplemented by the residual sound from high reverberation field, weakening FI. As a parallel to ISO16283-3, this paper suggests an engineering method to measure RBT and IASB of one high-rise building room close to a motor road by penetrating façade RTN. It can supply a convenient tool for the field measurement of RBT and IASB with RTN. At the end, we made a field measurement of RBT, IASB, and WI at a hotel room nearby a viaduct in Hangzhou of China, assistant to adjust RBT or IASB and WI so as to improve the sound quality of the hotel. Further, the method can extend to the lines of rail, aviation, and shipping.

8:40 PM 03-Aug-2021 **IN21_1505.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1505

Determination of passenger car noise equivalent for mid-sized cities in India

Adarsh Yadav, Manoranjan Parida, Brind Kumar

The heterogeneity in traffic flow composition increases the complexity of road traffic noise analysis for mid-sized in India. This study aims to determine a passenger car noise equivalent (PCNE) with respect to the average traffic stream speed that represents the number of a particular vehicle category with reference to an identified vehicle based on their noise emission characteristics. In the present study, vehicles are classified as bus, truck, light commercial vehicles (minibus, minitruck), three-wheelers (vikram-rickshaw), two-wheelers (bike/scooter), car, e-rickshaw and auto-rickshaw, and tractor-trailer. Car is taken as a reference vehicle for estimation of PCNE in our study due to its high percentage in traffic stream. Data has been collected on both bituminous and concrete pavement in Kanpur city, India, to analyze the differential effect of pavement on the noise level. As per this study, tractors-trailers, trucks, three-wheelers, and buses had a higher PCNE value, while two-wheelers and cars had almost similar PCNE value. A comparative analysis of PCNE value at concrete pavement is also conducted by considering car running on the bituminous pavement as reference vehicle. The study suggests to employ PCNE value in traffic noise analysis as it converts the divergent traffic volume in terms of the car.

Session: 20.01 Artificial Intelligence for Noise and Vibration Control, Part 2
Channel 5

6:00 AM 03-Aug-2021 **IN21_1864.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1864

Sound Field Reconstruction in Rooms with Deep Generative Models

Xenofon Karakonstantis, Efren Fernandez Grande

The characterization of Room Impulse Responses (RIR) over an extended region in a room by means of measurements requires dense spatial with many microphones. This can often become intractable and time consuming in practice. Well established reconstruction methods such as plane wave regression show that the sound field in a room can be reconstructed from sparsely distributed measurements. However, these reconstructions usually rely on assuming physical sparsity (i.e. few waves compose the sound field) or trait in the measured sound field, making the models less generalizable and problem specific. In this paper we introduce a method to reconstruct a sound field in an enclosure with the use of a Generative Adversarial Network (GAN), which s new variants of the data distributions that it is trained upon. The goal of the proposed

GAN model is to estimate the underlying distribution of plane waves in any source free region, and map these distributions from a stochastic, latent representation. A GAN is trained on a large number of synthesized sound fields represented by a random wave field and then tested on both simulated and real data sets, of lightly damped and reverberant rooms.

6:20 AM 03-Aug-2021 **IN21_1492.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1492

Deep Learning-based Health Indicator for Better Bearing RUL Prediction

Taewan Kim, Seungchul Lee

The prognostic performance of data-driven approaches closely depends on the features extracted from the measurement. For a high level of prognostic performance, features must be carefully designed to represent the machine's health state well and are generally obtained by signal processing techniques. These features are themselves used as health indicators (HI) or used to construct HIs. However, many conventional HIs are heavily relying on the type of machine components and expert domain knowledge. To solve these drawbacks, we propose a fully data-driven method, that is, the adversarial autoencoder-based health indicator (AAE-HI) for remaining useful life (RUL) prediction. Accelerated degradation tests of bearings collected from PRONOSTIA were used to validate the proposed AAE-HI method. It is shown that our proposed AAE-HI can autonomously find monotonicity and trendability of features, which will capture the degradation progression from the measurement. Therefore, the performance of AAE-HI in RUL prediction is promising compared with other conventional HIs.

6:40 AM 03-Aug-2021 **IN21_2373.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2373

Partial discharge monitoring using deep neural networks with acoustic emission

Saichand Gourishetti, David Johnson, Sara Werner, András Kátai

The occurrence of partial discharge (PD) indicates failures in electrical equipment. Depending on the equipment and operating conditions, each type of PD has its own acoustic characteristics and a wide frequency spectrum. To detect PD, electrical equipment is often monitored using various sensors, such as microphones, ultrasonic, and transient-earth voltage, whose signals are then analyzed manually by experts using signal processing techniques. This process requires significant expertise and time, both of which are costly. Advancements in machine learning, aim to address this issue by automatically learning a representation of the signal, minimizing the need for expert analysis. To this end, we propose a deep learning-based solution for the automatic detection of PD using airborne sound emission in the audible to the ultrasonic range. As input to our proposed model, we evaluate common time-frequency representations of the acoustic signal, such as short-time Fourier, continuous wavelet transform and Mel spectrograms. The extracted spectrum from the PD signal pulses is used to train and evaluate the proposed deep neural network models for the detection of different types of PD. Compared to the manual process, the automatic solution is seen as beneficial for maintenance processes and measurement technology.

7:00 AM 03-Aug-2021 **IN21_11598.pdf** **DOI:** https://doi.org/10.3397/IN-2021-11598

A neural network based noise suppression method for transient noise control with low-complexity computation

Yiya Hao, Shuai Cheng, Gong Chen, Yaobin Chen, Liang Ruan

Over the decades, the noise-suppression (NS) methods for speech enhancement (SE) have been widely utilized, including the conventional signal processing methods and the deep neural networks (DNN) methods. Although stationary-noise can be suppressed successfully using conventional or DNN methods, it is significantly challenging while suppressing the non-stationary noise, especially the transient noise. Compared to conventional NS methods, DNN NS methods may work more effectively under non-stationary noises by learning the noises' temporal-frequency characteristics. However, most DNN methods are challenging to be implemented on mobile devices due to their heavy computation complexity. Indeed, even a few low-complexity DNN methods are proposed for real-time purposes, the robustness and the generalization degrade for different types of noise. This paper proposes a single channel DNN-based NS method for transient noise with low computation complexity. The proposed method enhanced the signal-to-noise ratio (SNR) while minimizing the speech's distortion, resulting in a superior improvement of the speech quality over different noise types, including transient noise.

Session: 20.13 Education in Acoustics

Channel 5

7:20 AM 03-Aug-2021 **IN21_1618.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1618

Artificial and Practical Intelligence. Hannah Arendts Ethics in "Vita activa or On active Life"

Monika Gatt

Hannah Arendt's work "Vita Activa and The Human Condition" is considered one of the most im-portant ethical and moral writings of our time. The philosopher understands practical life as an in-escapable human condition, as condicio humana. Practical philosophy, which includes ethics and morality, is situated between work and society. There, technology finds its application. Meanwhile technology's influence has gained the ability to shape culture, as artificial intelligence (Al) and transhumanism show. This influence has come to be viewed increasingly critically by scientists, who see it as often violating human boundaries.

In the ethical evaluation of a course of action oriented on technology, we follow a traditionally Aristotelian distinction between poesis (greek) and praxis (greek). With poesis we mean an instru-mental, purposeful production process, which is realized through implementation and completed in the finished product. With praxis we define human activity, or communal work.

Arendt interprets the technical processes of conception and work as creativity. As homo Jaber, the "tool-maker", we want to make the world more beautiful and useful. As animal laborans, we want to make our lives easier and longer.

Today, many of us try to orient ourselves in our everyday lives through technology, such as voice-controlled software. However, in order orient ourselves in the world, it is not technology that is nec-essary, but rather human intelligence and practical action.
This paper illuminates Arendt's interpretation of the human condition as practical action, and em-phasizes the lessons it provides for ethical education in acoustic engineeringHannah Arendt's work "Vita activa or On Active Life" is considered one of the most important ethical and moral writings of our time. The philosopher understands practical life as an inescapable human condition, as condicio humana (Latin). Practical philosophy, which includes ethics and morality, is situated between work and society. There technology finds application, meanwhile technology has culturally shaping influence, as the transhumanism shows. This influence is increasingly viewed critically by scientists, human boundaries are often violated.
In the ethical evaluation of an action directed at technology, we distinguish traditionally Aristotelian between poesis (Gr.) and praxis (Gr.). With poesis we mean an instrumental, purposeful production process, which is realized in implementation and completed in the finished product, with praxis we define human action, the common work.
Arendt interprets the technical process of conception and work as creativity. As Homo faber, we want to make the world more beautiful and useful, or as Animal laborans, we want to make our lives easier and longer.
However, today we try to orient ourselves in everyday life through technology, such as voice- controlled software. But, so that we can orient ourselves in the world, not only technology is necessary, but especially intelligence and practical action.
The lecture shows the conditio humana of practical action and which consequences can be derived from it.

7:40 AM 03-Aug-2021 **IN21_2653.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2653

Auditory training system for improvement of auditory perception ability in blind soccer.

Mari Ueda

Blind soccer is a sport designed for people with visual impairment. All players (except the goalkeepers) are people with visual impairment but not limited to complete vision loss (i.e. without any ability to see; blind in both eyes) . Considering the various degrees of the disability, all players put on an eye mask for a complete vision blockage so they just rely on their audio sensation for the location of the ball and the goals to drift, shoot, and defend as a game with a high degree of movement. Different from conventional soccer games, the ball makes a sound in which the callers at the back of the shooting goal provide audio guidance in order to make the game highly dependent on audio information. However, the ability to recognize and locate rely solely on training and personal experience of individual players that essential audio information of the game has never been analyzed in a scientific manner and theories about distance positioning is especially inadequate. Hence, this study aims to utilize the audio sensation for better game performance. First, we focus on the distance attenuation feature when the ball spins, which is followed by a description about an audio training system for distance positioning from sounds.

8:00 AM 03-Aug-2021 **IN21_2617.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2617

Learning effect of active learning coursework in engineering acoustics course

Yusuke Hioka, Michael Kingan, George Dodd, George Dodd

This paper reports the learning effect achieved by a newly developed coursework for an engineering acoustics course offered to fourth year and postgraduate engineering students at the University of Auckland, New Zealand. The course teaches fundamental knowledge that acoustical engineers need and which underpins a variety of sub-disciplines in acoustics including: fundamental physics of wave propagation, building and room acoustics, electro-acoustics, audio signal processing, and the psychology of hearing. The coursework incorporated practical active learning activities and was developed in order to help students gain understanding of complex concepts related to the room acoustics measurement and analysis. The coursework also has the goal of providing students with an introduction to some of the practical tasks which are typical of a practising acoustical engineering in New Zealand.
The learning effect was measured by comparing students' performance in a quiz that was run before students commenced working on the coursework and that in the final examination and by investigating common mistakes students made in the report which was the required deliverable of the coursework. Overall, the new coursework successfully improved students' understanding of the material which it covered.

8:20 AM 03-Aug-2021 **IN21_1115.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1115

COVID Teaching of acoustics and noise control: Lab in a box for experiments at home

Stephen Dance

In June 2020 with the advent of COVID emergency plans were put in place to deliver the Masters course in Environmental and Architectural Acoustics totally on-line. This was necessary as although the acoustics laboratory is large, it was deemed to be unsafe for face-to-face teaching due to a complete lack of ventilation in the anechoic and reverberation chambers. Hence, it was necessary to create an alternative. It was decided that a “lab in a box” supported by on-line demonstrations and pre-recorded films would create the best alternative experience for the students. The “lab in a box” allowing the demonstrations to be replicated at home or in the garden. The results showed that the students gained from more independence, increased flexibility in deliver achieving very similar marks. This has opened up the possibility of increasing student numbers by reusing these alternative teaching strategies.

8:40 AM 03-Aug-2021 **IN21_1691.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1691

Case study - lesson plan for noise control engineering concepts for use in ABET accredited engineering programs

Lily Wang, Bryan Beamer, Keegan J. Moore, Katie Krainc

ABET accreditation is an internationally recognized system ensuring consistency and quality in engineering education programs. As a part of ABET accreditation, there is no set requirement for any general engineering program to include noise control engineering concepts in their

curricula. However, one of the seven student outcomes that each ABET accredited engineering program must document is their students' "ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare…" Controlling noise is a fundamental strategy for protecting workers from occupational noise and the public from the harmful effects of environmental noise. In this presentation, a case study is presented which focuses on the development and execution of a noise control lesson plan designed to meet ABET requirements. The lesson plan not only promotes the understanding and practice of noise control engineering techniques but also is designed to help engineering programs demonstrate ABET student outcomes related to consideration of safety and health.

Session: 20.01 Artificial Intelligence for Noise and Vibration Control, Part 3
Channel 5

11:00 AM 03-Aug-2021 **IN21_3186.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3186

Learning-based estimation of individual absorption profiles from a single room impulse response with known positions of source, sensor and surfaces

Stéphane Dilungana, Antoine Deleforge, Cédric Foy, Sylvain Faisan

In situ estimation of the individual absorption profiles of a room remains a challenging problem in building acoustics. This work is aimed at studying the feasibility of this estimation in a shoebox room of fixed and known geometry, using a room impulse response measured from a source and sensor at fixed and known positions. This problem is tackled using supervised learning. Three neural network architectures are compared. Simulated training and validation sets featuring various types of perturbations (surface diffusion, geometrical errors and additive white Gaussian noise) are generated. An extensive empirical simulated study is carried out to determine the influence of these perturbations on the performances of learned models, and to determine which components of the room impulse response are most useful for absorption coefficients prediction. Trained models are shown to yield errors significantly smaller than those of a naive mean estimator on every simulated datasets, including those featuring realistic perturbation levels. Our study outlines the benefit of using convolutional neural network layers, especially when geometrical errors exist. It also reveals that early acoustic echoes are the most salient feature of room impulse responses for absorption coefficient prediction under a fixed geometry.

11:20 AM 03-Aug-2021 **IN21_2375.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2375

Investigating the influence of microphone mismatch for acoustic traffic monitoring

Saichand Gourishetti, Jakob Abeßer, Sascha Grollmisch, András Kátai

The development of robust acoustic traffic monitoring (ATM) algorithms based on machine learning faces several challenges. The biggest challenge is to collect and annotate large high-quality datasets for algorithm training and evaluation. Such a dataset must reflect a broad variety of vehicle sounds since their emitted acoustic noise patterns depend on a variety of factors such as engine noises at different speeds and road conditions. Additionally, the characteristics of the employed microphones have a strong influence on the data. If microphones with different directionality and frequency responses are used during the model development and the final deployment phase, a data mismatch is caused, which can have a deteriorating effect on the performance of machine learning algorithms. In this paper, the influence of mismatched recording locations and microphone characteristics on the proposed ATM system is investigated. To evaluate these effects, we implement state-of-the-art convolutional neural networks to detect passing vehicles, classify their type, and estimate their speed and direction of movement. The evaluated models perform well on low- and high-quality recordings at different locations when using the same recording device for training and testing. However, the results indicate that microphone mismatch causes several issues, which need to be carefully addressed.

11:40 AM 03-Aug-2021 **IN21_2463.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2463

Investigating the relationship between train speed and ground vibrations using random forest machine learning models

Gerrit Jan Dijkgraaf, F.L.H. Klein Schaarsberg, A.C. de Niet, H. Zandberg

In the Netherlands, concerned citizens have proposed reducing train speed as an effective measure to mitigate annoyance caused by railway-induced vibrations. In the present study the relationship between train speed and other influencing parameters (e.g. axle load, wheel roughness), and ground vibrations was investigated using measurements, at different locations, of ground vibrations caused by the passage of regular freight trains and a test train at different speeds. Measurements have been analysed using multivariate regression models and a random decision forest model. The prevailing uncertainties have also been measured using normalized mean deviation between the model predicted value and the actual value. A comparison of results demonstrates that a 'trained and tested' random forest model has certain predictive advantages: i) mean deviation between predicted and actual value is found to be the lowest with random forest model; ii) the random forest model considers all available parameters in the dataset, thus simulating the real situation more closely. However, the model is very location-specific and must therefore be used with caution. In general it is observed that a decrease in train speed results in the reduction of measured vibration levels.

12:00 PM 03-Aug-2021 **IN21_2907.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2907

Scalable Machine Learning Approach to Classifying Transportation Noise at Two Urban Sites in Greater Boston, Massachusetts

Tiange Wang, Ruijie Jiang, YuLun (Elain) Lin, Kyle Monahan, Douglas Leaffer, Stephen Doroff, Brian Tracey

The goal of this study was to characterize transportation noise by vehicle class in two urban communities, to inform studies of transport noise and ultra-fine particulates. Data were collected from April to September 2016 (150 days) of continuous recording in each urban community using high-resolution microphones. Training data was created for airplanes, trucks/buses, and train events by manual listening and extraction of audio files. Digital signal processing using STFT and Hanning windowing was performed in MATLAB, creating audio spectrograms with varying frequency: log vs linear frequency scales, and 4K vs 20K max frequency. For each of the four spectrogram sets, a neural net model using PyTorch was trained via a compute cluster. Initial results for a multi-class model provide an accuracy of 85%. Comparison between a selection of frequency scales and expanding to longer time periods is ongoing. Validation with airport transport logs and local bus and train schedules will be presented.

Session: 13.08 Acoustics in Indoor Spaces, Part 1
Channel 5

12:40 PM 03-Aug-2021 **IN21_2637.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2637

Development and application of an integrated virtual thermal-acoustic manikin design used inside an office space

Eusebio Conceição, Mª Ines Conceição, Mª Manuela Lúcio, João Gomes

In this study an integrated virtual thermal-acoustic manikin design used inside ventilated and occupied office spaces is developed and applicated. The component of the virtual thermal manikin evaluates the internal airflow and occupants' thermal, thermo-physiology and clothing systems and calculates the thermal comfort and the indoor air quality levels. The component of the virtual binaural manikin evaluates the direct and indirect sound and calculates the reverberation time. The space geometry with complex topology is developed using a Computer Aid Design (CAD), while the occupants' geometry is made using geometric equations. The grid generation, in the surrounding space surfaces and around the external occupants' surfaces geometry, is used to calculate the radiative heat exchanges and the sound propagation. In this study, performed in an office room occupied by eight persons and equipped with personalized ventilation system, the thermal comfort level, the air quality level and the space reverberation time is evaluated and discussed. In accordance with the obtained results the values are, in general, in accordance the actual standards.

1:00 PM 03-Aug-2021 **IN21_1888.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1888

Studying acoustical capacity and quality of verbal communication in occupied restaurants

Jared Paine, Lily M. Wang

Sound level data and occupancy data has been logged in five restaurants by the research team at the University of Nebraska – Lincoln. Sound levels and Occupancy at 10 second intervals were documented over time periods of two to four hours during active business hours. Noise levels were logged with dosimeters distributed throughout each restaurant, and occupancy was obtained from images recorded by infrared cameras. Previous analyses of this data have focused on average sound levels and statistical metrics, such as L10 and L90 values. This presentation focuses on each restaurant's Acoustical Capacity and Quality of Verbal Communication, as introduced by Rindel (2012). Acoustical Capacity is a metric describing the maximum number of persons for reasonable communication in a space, calculated from the unoccupied reverberation time and the volume of the space. Quality of Verbal Communication is a metric describing the ease with which persons in the space can communicate at a singular point in time, depending on the reverberation time, the volume of the space, and the number of occupants in the space.

1:20 PM 03-Aug-2021 **IN21_2132.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2132

Room acoustics criteria and measurements of lobbies and atria for various building types

Ted Pyper, Matt Whitney, David Porter, David Porter

The lobby or atrium for a building may serve many purposes -- entryway, welcome area, circulation zone, and architectural point of interest. Increasingly, lobbies and atria serve more and more functions: gathering area, presentation area, music and event space, study area, and dining, among other uses. Since variable acoustics in lobby spaces are not typically feasible or desirable, the acoustical design of lobby spaces must strike a balance for the variety of events planned for the space.

Working with design teams and owners to understand the needs of each space, acoustical design criteria evolve based on project-specific needs and previous experience. In this presentation, lobbies are considered for various building types, including education facilities, student commons, museums, and performing arts buildings. In addition to studies of existing spaces and modeling of buildings in design, this presentation expands on the authors' previous efforts by documenting the measured reverberation and background noise in several lobbies and atria after the completion of design and construction.

1:40 PM 03-Aug-2021 **IN21_2595.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2595

Occupant noise exposure in a fitness classroom setting

Madeline Didier, Gina Jarta

Fitness facilities characteristically place an emphasis on the health and wellness of their occupants. Very loud amplified speech and music in group fitness rooms creates energetic spaces at the expense of the health and wellness of participants' hearing. The authors measured spectral sound pressure levels from fitness programs and occupants in over 20 group fitness classes (cycling, dance, strength training, and yoga) at facilities throughout the United States. Measurements occurred over durations varying from 10 minutes to a full hour. Variables considered include class type and the athletic club where the classroom is located. This paper discusses the overall findings from these noise surveys with an emphasis on noise exposure and statistical levels. This paper also includes a discussion of noise management and recommendations for best management practices to help achieve energetic spaces that are protective of hearing health and wellness.

2:00 PM 03-Aug-2021 **IN21_2952.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2952

Measurement survey using acoustic measurement network and sound environment evaluation system by experience sampling

Kengo Togashi, Kazunori Harada, Kazunori Harada, Yasuhiro Nagasawa, Yasuhiro Hiraguri, Kentaro Suga, Aya Onoe

The use of open-plan offices is increasing as they are effective in improving intellectual productivity by fostering a communication among workers. Previous research on the relationship between the indoor sound environment and intellectual productivity has mostly reported the impact of the sound environment on the tasks that individuals work on. However, there has been no research on the impact of sound environment on office spaces where multiple workers are actually working. In this study, we developed a system that can analyze the individual characteristics of workers in relation to the sound environment by simultaneously measuring their evaluation to the sound environment and the sound environment of the office. The system collected workers' evaluation of their impressions to the sound environment through a regular questionnaire using the experience sampling method. At the same time, it measured the sound environment of the office with multiple small measurement devices. The obtained sound environment evaluation data and the acoustic data of the office were stored in a single database. Finally, this system was run in a working environment to evaluate the sound environment on a trial basis.

Session: 13.03 Ventilation-Enabling Sound Insulation Devices, Part 1
Channel 5

2:40 PM 03-Aug-2021 **IN21_2176.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2176

Assessing a parallel baffle splitter, an experimental and numerical study on insertion loss and pressure drop

Juan Escudero, Héctor Fuentes

HVAC systems are composed of different noise sources and paths. The non-attenuated propagation of noise through the system has detrimental effects on acoustic comfort of people inside the premises. To mitigate the propagated noise, parallel baffle splitters are used which reduce the transmitted noise through acoustic coatings. Different methods have been developed to predict the insertion loss of those elements, however, if the input data is not well known these models can lead to deviated results. On the other hand, the use of splitter in HVAC systems produces pressure drop which can damage the equipment used if that is not well predicted. Different models are available in the literature, which relates dimensional features and design velocity to estimate the pressure drop coefficient. However, models can give overestimated results. In this work an experimental rig was implemented to assess a splitter installed inside of a test duct. Measurements were performed to estimate insertion loss and pressure drop coefficient, following the guidelines exposed on the ISO 7235 standard. The results were compared with analytic methods. Finally, a numerical method analysis of the test rig was performed, showing the correlation between these results and the experimental data.

3:00 PM 03-Aug-2021 **IN21_2361.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2361

Soundproof Window - Natural Ventilation

Vinícius Ávila Ferreira

Expansion of brasilians cities worsen noise pollution in these places, forcing people to maintain their doors and windows closed. Domestic environment enclosing lead to necessity of air conditioning system, however the frequent use of the equipment may cause many health problems, such as respiratory difficulties and spread of diseases , not to mention high costs with energy. Considering these facts, there is the need of soundproofing windows with air supply , that allows passage of air without noise passage, guarantee a well-ventilated environment, with thermic and acoustic comfort without the use of acclimatisation systems . we have developed two prototypes with significant opening that allows air supply (passage) (0,35m2) and noise reduction (Rw+Ctr) reaching 8 to 10 dB. In the first study, we considered people inhabiting really noisy surrounding areas, who has already installed a regular window. In this particular case, we developed a soundproofing window air supply that can be installed over the existing one. A second study considered new constructions to focus the environment where the person sleeps and then elaborate a soundproofing window air supply for bedrooms.
Keywors: soundproofing windows, air supply, sound insulation. noise pollution

3:20 PM 03-Aug-2021 **IN21_1866.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1866

Noise reduction of plenum window with add-in dual staggered sound scatterer arrays

Xiaolong LI, Shiu Keung Tang, Shiu-Keung, Tang

In present study, a 1:4 scaled down model was used to explore the noise reduction across the plenum window with add-in dual staggered scatterer arrays (sonic-crystal). Reverberation time inside the model space was measured firstly to eliminate the effect of the possible reverberation variation on the sound transmission loss of the plenum window. Two sonic-crystal arrays, the two-by-two and two-by-three scatterer arrangements, were adopted for measurement. A total of four arrays was thus tested after the staggering. Computational simulation was conducted for the sound field inside the plenum chamber to study the noise reduction mechanism of the present window system. Results show that the noise reduction of the plenum window was improved by varying degrees due to the placement of the dual staggered sonic-crystal. The Installation of the dual staggered sonic-crystal increased the sound energy reflections out of the plenum window inlet and decreased the sound energy that passed through the plenum window cavity. At the same time, the resonances inside the window cavity also contributed to the sound transmission loss of the plenum window. The noise reduction across the plenum window was enhanced. The improvement was between ~2 to ~2.7 dBA.

3:40 PM 03-Aug-2021 **IN21_2871.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2871

The effect of aspect ratio on the inerstion loss of lined ducts

Caoyang Li, David Herrin

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbook provides tabulated information that can be used to determine the insertion loss of a variety of lined and unlined ducts. However, the tabulated cross-sections are primarily for square ducts. Not surprisingly, there is a need for information on the insertion loss of ducts having different aspect ratio cross-sections. Hence, the insertion loss for large aspect ratio cross-sections are investigated using a previously validated finite element simulation approach. A coupled structural-acoustic finite element analysis is performed, and data is compared to measurement results from the literature for a few configurations. An analysis campaign is then performed which better explains the effect of aspect ratio on duct insertion loss.

Session: 13.12 Case Studies in Building Acoustics
Channel 5

5:20 PM 03-Aug-2021 **IN21_1987.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1987

Acoustic study in a main avenue and its effects in classrooms and offices of a university in Mexico City

Antonio Bautista Kuri, Antonio Bautista Kuri

This study presents the results of a detailed acoustic investigation, systematized and with adequate equipment to the current regulations, carried out in an avenue of intense vehicular traffic located in front of a recently built architectural complex, based on concrete, aluminum, glass, and other materials, called the Postgraduate Unit, belonging to the National Autonomous University of Mexico. These measurements show that, in the initial design of the buildings, the most current knowledge about exterior-interior sound insulation through their facades was not considered. The data collected and the interviews conducted reveal that the Sound Pressure Levels rise, altering the Interior Acoustic Comfort, necessary for the performance of daily academic, administrative and research activities, resulting in permanent inconveniences for users, in addition to the saturation of areas, lack of adequate spaces and excessive unscheduled expenses. Paradoxically, empty spaces are observed in areas with high Sound Pressure Levels, which means that there is a certain level of architectural failure.

5:40 PM 03-Aug-2021 **IN21_1622.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1622

Review of acoustically related design factors for three recent Los Angeles area music studios.

Michael Brown

The design of a professional-quality music recording studios involves a specific set of challenges, namely the need to provide high levels of sound isolation, rigorous noise and vibration control for building support systems, and the provision of acoustically appropriate room finishes. The optimization of design solutions for each of these challenges depends upon project-specific requirements, including aesthetic objectives, base building constraints and the musical genres being recorded. This paper reviews how these challenges were successfully addressed in three recent Los Angeles area music recording/broadcast studio projects. Projects reviewed include a recording studio at University of California, Los Angeles, where challenges included the need to accommodate all musical genres, from jazz, to orchestra, to drum ensembles. The two other studios were both for broadcast organizations: KCRW, an influential NPR-affiliated music-orientated radio station and for the commercial radio broadcaster SiriusXM. The paper includes discussion of why and how various acoustical techniques were utilized, including use of “floating” construction and live room variable acoustics. Solutions for successfully incorporating significant areas of glazing into live rooms and accommodation of audiences are also discussed, along with the various acoustical room finishes that were applied.

6:00 PM 03-Aug-2021 **IN21_2391.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2391

Case Study: Floating Jack-Up Slabs for Multi-Story Cinema in Manhattan

Bradlay Hunt, Florian Sassmannshausen

A review of a uniquely designed floated jack-up concrete slab to isolate fourteen movie theaters on multiple floors within a multi-use building. The jack-up boxes were engineered and custom tailored to increase airborne sound transmission loss performance while achieving a very high vibration isolation efficiency specified. Field test results were obtained to validate the floating jack-up concrete's acoustical performance.

6:20 PM 03-Aug-2021 **IN21_2425.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2425

A case study in the measurement of door sound isolation with ASTM test standards

Christopher Ono, Todd Beiler, Devin Clausen

The use of the door transmission class rating in lieu of the apparent sound transmission class rating has yet to gain traction within building codes and specified project requirements. This paper presents a case study involving performance requirement testing conducted at a university's media facility, in which sound insulation properties were a critical design and construction focus. Both test methods described in ASTM E2964 and ASTM E336 were performed where a door was the test partition. Door transmission class ratings were presented in comparison to apparent sound transmission class ratings for the same partition. Testing was performed in a variety of situations, including scenarios both inside and outside of the minimum requirements of testing standards. Our analysis considers the effectiveness of the recently adopted ASTM E2964 in comparison to the methods of the ASTM E336. We also consider some of the subtle differences between the two test methods and how they may impact the testing of certain adjacencies.

6:40 PM 03-Aug-2021 **IN21_3238.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3238

Noise Control design for a Ventilation Fan - Case Study

Jonathan Bonnett, Carmel Cuschieri, Joseph M. Cuschieri

A ventilation system was design and installed for a multi story garage. The ventilation system system had a vertical concrete shaft with the ventilation fan located on the top floor at street level. The ventilation fan is separated from the outside by a set of metal louvers. Adjacent to the louvers is an open pedestrian area. The exhaust fan as installed had an inline duct silencer but this was insufficient in terms of providing the desired noise mitigation. The project desire was not to make changes to the fan or its inline silencer or the external louvers so an alternative noise mitigation option had to be explored. Based on the provided sound power characteristics of the fan, the exterior noise levels as calculated matched the expected levels coming out of the metal louvers. The interior of the ventilation shaft is bare concrete with the fan installed though a hole in the concrete top floor. The predominate noise was the very high reverberation inside the ventilation shaft. The owner of the property made an attempt at installing noise absorption but this was not sufficient. Based on the field data the sound levels with the preliminary absorption solution matched expectation, but further noise reduction was required. A complete sound absorption on the walls of the concrete ventilation shaft noise mitigation solution was design, and the expected levels predicted to show that significant noise reductions can be obtained by a comprehensive noise absorption solution. The noise mitigation solution was implemented and exterior sound level measurements performed at the completion of the project. The measured sound levels outside of the metal louvers were in very good agreement with the predicted levels. Based on the success of this first noise mitigation solution, noise mitigation for a second ventilation system is not being considered.

7:00 PM 03-Aug-2021 **IN21_1832.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1832

Countermeasures against floor impact sound by heavy impact source of a box floor structure in a reinforced concrete wall construction testing device

Ryuta Tomita, Kyoko Abe

We have performed experimental examinations for the purpose of proposing a floor finishing structure with superior effects in terms of combating heavy-weight floor impact sound. We have developed a box floor with ease of construction and excellent heavy-weight floor impact sound insulation performance and examined its effect with a 1200 × 1200 mm test piece connected to inter-noise 2020. The box floor has a floor finishing structure with anti-vibration and sound insulation measures aimed at improving measures against heavy-weight floor impact sound. We herein report the results of a basic examination on the reduction of the transmitted heavy-weight floor impact sound of a box floor structure in a reinforced concrete wall construction testing device when the area is further expanded to about 10 m^2. As a result, with the air layer under the box floor open, the floor impact sound level was reduced by 9 dB in the 63-Hz band compared to the bare surface. In addition, with the air layer at the bottom of the BOX floor sealed, the floor impact sound level was reduced by 5 dB in the 63-Hz band compared to the bare surface.

7:20 PM 03-Aug-2021 **IN21_1336.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1336

The measurements of crowd noise in a large waiting hall of ShenYang Station in China

Hongshan Liu, Hui Ma, Chao Wang, Chao Wang

This study aims to explore the characteristics and distribution of crowd noise in large space and on-site measurements of crowd noise were conducted in the waiting hall in the ShenYang Railway Station, which is the largest station in Northeast China. Photos and videos were also recorded to obtain the number and the status of the passengers. The results showed that the A-weighted crowd noise in ShenYang station was between 55dB and 80dB and the number of passengers was between 2,000 and 3,000 at peak hours. Although passengers rarely talked, it was found that both the noise level and number of passengers fluctuated rapidly in time domain, and there was a strong linear correlation between the crowd noise level and the number of passengers. The spatial distribution of crowd noise was relatively uniform at peak hours, and the crowd noise in the seating area on both sides was slightly higher than that in the central traffic area in other hours. This study is helpful for the noise control and acoustic design in the extra-large space with large crowd.

7:40 PM 03-Aug-2021 **IN21_2226.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2226

Are online meetings noisier than conventional meetings?

Nicholas Boulter, Jim White

Design of sound insulation in office meeting rooms is typically based on 'normal' speech levels, but anecdotal evidence suggests that raised speech levels may be common where video/teleconferencing (VC/TC) is in use. If this is the case, then partitions in meeting rooms may be under-designed. In order to gain an understanding of the real-world occupational noise levels that exist in VC/TC enabled meeting rooms, long-term noise monitoring was conducted in multiple offices across the globe and matched to records of VC/TC use. Correlations uncovered include a link between VC/TC use and increased Lp, and higher speech Lw in larger meeting rooms.

Session: 13.16 The Future of Office Privacy & Sound Masking

Channel 5

8:20 PM 03-Aug-2021 **IN21_2990.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2990

Just noticeable difference of sound pressure level of speech in open-plan office

Haram Lee, Haram Lee, Hyunin Jo, Jin Yong Jeon

In this study, the general sound environment characteristics of open-plan office (OPO) were investigated, and just noticeable difference (JND) of sound pressure level of speech at a distance of 4 m (Lp,A,S,4m) suggested in ISO 3382-3 was suggested. First, in order to understand the sound environment characteristics of OPO, one minute sound sources recorded in 8 offices were collected and physical and psychological acoustic characteristics were analyzed. A total of 30 office workers were subject to subjective evaluation on 8 sound sources, and they were asked to respond to questionnaires related to annoyance, work satisfaction, and speech privacy. Next, to investigate the JND, two computer simulation models identical to those of the actual OPO were implemented, and sound sources each having six different Lp,A,S,4m values were generated through the change of the sound absorption coefficient of the interior finish. The JND of Lp,A,S,4m was presented by performing paired comparison for the same subjects. It is expected that the JND of Lp,A,S,4m proposed in this study can be used for the sound environment rating of OPO.

8:40 PM 03-Aug-2021 **IN21_3215.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3215

The effect of sound masking on employees' acoustic comfort and performance in open-plan offices in Canada

Roderick Mackenzie, Roderick Mackenzie, Joonhee Lee, Vincent Le Men, Farideh Zarei

Sound masking systems are commonly used in open-plan offices to generate a controlled minimum level of background sound, in order to decrease the signal-to-noise ratio of intrusive speech and blend out transient office noise. However, a question in the acoustical design of offices is whether the self-generated noise of occupants may alone be sufficient to provide the background sound level conditions necessary to achieve similar levels of speech privacy and acoustic comfort as sound masking systems. This study examines the relationship between occupant-perceived speech privacy and acoustic comfort under three different acoustic scenarios (no masking, controlled 42 dBA, and 47 dBA masking sound levels). The study was conducted pre-COVID-19 in two separate open-plan offices located in Quebec, Canada that at the time were close to full occupancy. Employees completed subjective questionnaires before and after each change in conditions, focusing on how the sound environment impacted their comfort and work performance during the study. Statistical results show that the occupants were significantly more satisfied during the two sound masking conditions in comparison to the no-masking condition, where only the occupant-generated and exterior/mechanical system noise was present as the background sound. Implications for open-plan offices with lower occupancy conditions post-COVID-19 are discussed.

Session: 15.05 Soundscape Evaluations

Channel 7

6:00 AM 03-Aug-2021 **IN21_3048.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3048

The effects of aural and visual factors on appropriateness ratings of residential spaces in an urban city.

Johann Kay Ann Tan, Siu-Kit Lau, Yoshimi Hasegawa

This study investigates the aural and visual factors that influence appropriateness perception in soundscape evaluations in residential spaces, where people may spend most of their time in. Appropriateness in soundscape is derived from the expectation of sound sources in a specific environment, place or function heard by a listener. Appropriateness of soundscapes in 30 locations in an urban residential environment is investigated with varying landscape, visual and aural elements through a questionnaire. Participants experienced the soundscape in-situ and were asked to evaluate the appropriateness of soundscape as well as the dominance of specific sound sources such as traffic, human activities and birdsongs in the residential space. The effect of type of traffic on appropriateness is also investigated. A strong relationship is found between appropriateness and affective soundscape qualities such as pleasantness, highlighting the importance of considering appropriateness in soundscape research. In audio-visual combination of specific elements and the partial correlation with appropriateness, specific aural sound sources are found to correlate uniquely to appropriateness while controlling for relevant visual elements, whereas visual elements became redundant in its partial correlation to appropriateness. Residents' perception of appropriateness is found to likely be more dependent on the individual visual elements rather than the overall landscape.

This study investigates the factors that influences appropriateness perceptual in soundscape evaluations in residential spaces, where people may spend most of their time in. Appropriateness in soundscape is derived from the expectation of sound sources in a specific environment, place or function and heard by a listener. The appropriateness of soundscapes of 30 locations in an urban residential environment is

investigated with varying visual (greenery, building, waterbody) and aural elements through a questionnaire approach. Participants experienced the soundscape in-situ and were asked to evaluate the appropriateness of soundscape as well as the dominance of specific sound sources such as traffic, human activities and birdsongs in a residential space. The type of traffic is also investigated to explore the effect of traffic load on appropriateness.

6:20 AM 03-Aug-2021 **IN21_2001.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2001

Which aspects of soundscape can the soundscape attributes measure?

Koji Nagahata

The eight perceptual attributes for soundscape assessment provided in ISO/TS 12913-2: 2018 are widely used in recent soundscape studies. Several studies across the language showed that the basic structure of the soundscape appraisal two-dimension space obtained from the attributes are robust. However, this robustness of the basic structure only means the robustness of the linguistic structure of the eight perceptual attributes, and never means those attributes cover the whole human perception of the soundscapes. Some studies suggest there are some appraisal scales which cannot be expressed in the two-dimensional appraisal space. This study discusses which aspects of soundscape can the soundscape attributes measure.

6:40 AM 03-Aug-2021 **IN21_2138.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2138

Do visual and audio experiences affect overall satisfaction and restorative potential of the soundscape for different visiting duration in urban blue space?

Ying Qi, Xingyue Fang, Tian Gao, Ling Qiu

People could have a relatively great visiting experience in blue space no matter from visual or audio perspectives. However, blue space gained less attention in previous soundscape researches. More and more studies have proved the effect of visual and audio experience on visiting satisfaction or even the restorative potential of the soundscape. This study conducted an on-site survey in different blue spaces in Xi'an, China to explore how the visual, audio, and overall visiting satisfaction and the restorative potential of soundscape interacted in blue space. Furthermore, the relationships among them were also explored in different visiting duration. The results suggested that (1) Visual satisfaction didn't change over time while the soundscape satisfaction, overall satisfaction, and soundscape restoration peaked when people had stayed for 1 to 3 hours. (2) For four dimensions of soundscape restoration, Fascination peaked in 30 minutes to 1 hour, and Capability peaked in 30min-3h while Being-away and Extent remained constant. (3) As for overall satisfaction and soundscape restoration, the vision mainly contributed to them in the first 1 hour, while the hearing mainly contributed during 1 to 3 hours of experience. (4) As for POS (perceived occurrences) of sound sources, people could hear more natural sounds and human sounds in 30min-3h than in the first 30min. This study emphasized the importance of soundscape function in the planning and designing of urban blue space.

7:00 AM 03-Aug-2021 **IN21_3118.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3118

Psychoacoustic evaluation of soundscapes by means of repeated measurements

Andre Fiebig

Research on soundscape explore facets of how acoustic environments affect human perception in context. By means of psychoacoustic parameters the sound character of acoustic environments can be described comprehensively as those parameters play an important role with respect to manifold auditory sensations. Although there seems to be a consensus of the benefit of psychoacoustics for soundscape evaluations and the ISO/TS 12913-2 particularly requests to give consideration to psychoacoustic indicators in soundscape investigations rather little is known about the relationships between psychoacoustic quantities and significant soundscape dimensions. Numerous investigations aimed to establish links between psychoacoustics and soundscape appraisal, but the gained results were often not suited for generalization. Moreover, it is rather unclear how urban locations vary in their sound character over longer periods and how the level of variation drives soundscape assessments. In order to establish an understanding of potential psychoacoustic characterization of urban locations for soundscape evaluations, repeated measurements of different locations are analyzed and the general behavior of psychoacoustic quantities derived. Based on these investigations it is intended to expand knowledge on the usefulness of psychoacoustics from the perspective of the soundscape approach.

Session: 15.06 Soundscape and its Application
Channel 7

7:40 AM 03-Aug-2021 **IN21_1654.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1654

Soundscape composition analysis combined with acoustics and musicology: a case study on the music piece of Daybreaking

Zhanjie Ju, Zhiyong Deng, Xushan Xue, Aili Liu

With its own unique musical vocabulary oundscape composition has been unprecedently developed all over the world. The analysis of music s from the perspective of acoustics has its own advantages that cannot be replaced by the traditional musicology. Based on music named Dayb for a hope to overcome COVID-19, this paper analyzes the acoustic elements of , frequency spectrum and waveform. Combined with the traditional musicology, it can show that the undulation of waveform has associated with the formal structure and the visualization of music. The frequency spectrum shows that as the climax of the piece, the sound has a high energy in the range of 300-1000Hz, which is one of the extremely sensitive frequency ranges for human. The composer not only skillfully integrates the chanting of monks with the complex environmental sounds, but also reflects the innovative composition skills. The change of from weak to strong or contrarily is also in line with

the emotional expression, that is, the core idea of moving from nature to nature. Since soundscape c retains more information, it is easier to immerse the audience in the listening process and appreciate the beautiful hope rather than the difficulty of understanding it.

8:00 AM 03-Aug-2021 **IN21_2976.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2976

Soundscape assessment of non-acoustic factors for effective stakeholder engagement in airport expansion projects in the UK

Lisa Lavia, Caroline Brown, Lisa Lavia

Effective soundscape planning, in accordance with the ISO soundscape standard series, is predicated on accurately assessing the human response to sound in context. ccurately assess the human response for this purpose requires the identification of context specific non-acoustic factors (NAFs). In particular, the NAF of stakeholders' perceived control over sound from developments directly impacts the effectiveness of engagement in planning processes. However, what constitutes perceived control can vary widely, including stakeholders' experiences, perceptions and requirements in context. Perceived control affect quality of life and therefore it is a factor in sustainable planning and development processes. This primarily qualitative constructivist grounded theory study investigates the NAFs comprising stakeholders' perceived control and the impact on effective engagement in the context of planning and soundscape management for airport expansion projects in the UK. The initial stages of this research included participant observation and 1:1 interviews. Preliminary findings indicate context specific discrete aspects regarding communication quality (as distinct from quantity) as intrinsic to developing, supporting and maintaining perceived control amongst stakeholders. This research builds on existing soundscape and noise and health findings to develop a conceptual framework for effective stakeholder engagement for standardised soundscape design and planning in the built environment.

8:20 AM 03-Aug-2021 **IN21_2755.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2755

A research on assessment of soundscape in urban area by means of Caption Evaluation Method: effects of context on evaluation of soundscape

Takeshi Akita, Masahiro Tomioka, Hanui Yu, Naoko Sano, Ayako Matsuo

Caption Evaluation Method is a technique that was developed in Japan to learn about the reason of evaluation of landscape. The investigative method is a formalized one and can show the element of landscape that a person focused on when he made an evaluation of the landscape, and the reason why he made a good or bad evaluation on it. In the present research, Caption Evaluation Method is applied to the survey of soundscape in urban area. Twenty-one subjects were instructed to walk along the predetermined route, and to take a picture and make evaluation of soundscape when they found out sound that attracted their attention. They rated the sound as good, bad or normal, and they reported the character and impression of it by formalized questionnaire. As a result, one hundred fifty-seven sound elements were obtained. They were classified under the proposed way in the previous research. Results show that traffic noise is assessed bad by almost all the people because of its noisy character, but sound from information display system receives different assessment among people. It is supposed that evaluation of not so noisy sound can be easily affected by the context in a person's mind.

8:40 AM 03-Aug-2021 **IN21_2891.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2891

Physiological and psychological responses to soundscapes and their connections using machine learning

Ming Yang, Christian Laufs

Acoustic environment has significant impacts on humans' feelings and emotions, cognitive performance, and behaviours. It evokes both physiological and psychological responses, which in the long term affect physical and mental health. It has been long believed that physiological and psychological responses are interconnected, yet their correlations are complex and may vary among conditions and studies. This present research study explores the physiological and psychological responses at the exposure to acoustic environment in a short period of time, and examines whether the physiological responses are able to predict the psychological responses. In this research, the physiological and psychological responses of subjects to a set of soundscapes are collected in a laboratory setting, by respectively continuous physiological measurements and self-report ratings on subjective experiences. The connections between the physiological and psychological responses are examined using machine learning methods. The results show the connections between physiological and psychological responses to soundscape. To a certain degree, it is able to predict the psychological responses from the measured physiological responses.

Session: 14.08 Noise Monitoring
Channel 7

11:00 AM 03-Aug-2021 **IN21_2035.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2035

ConvTasNet-based anomalous noise separation for intelligent noise monitoring

Han Li, Kean Chen, Bernhard U. Seeber

Noise pollution has become a growing concern in public health. The availability of low-cost wireless acoustic sensor networks permits continuous monitoring of noise. However, real acoustic scenes are composed of irrelevant sources (anomalous noise) that overlap with monitored noise, causing biased evaluation and controversy. One classical scene is selected in our study. For road traffic noise assessment, other possible non-traffic noise (e.g., speech, thunder) should be excluded to obtain a reliable evaluation. Because anomalous noise is diverse, occasional, and unpredictable in real-life scenes, removing it from the mixture is a challenge. We explore a fully convolutional time-domain audio separation network (ConvTasNet) for arbitrary sound separation. ConvTasNet is trained by a large dataset, including environmental sounds, speech, and music over 150 hours. After training, the scale-invariant signal-to-distortion ratio (SI-SDR) is improved by 11.40 dB on

average for an independent test dataset. ConvTasNet is next applied to anomalous noise separation of traffic noise scenes. We mix traffic noise and anomalous noise at random SNR between -10 dB to 0 dB. Separation is especially effective for salient and long-term anomalous noise, which smooth the overall sound pressure level curve over time. Results emphasize the importance of anomalous noise separation for reliable evaluation.

11:20 AM 03-Aug-2021 **IN21_2316.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2316

Exploiting data from the NoiseCapture application for environmental noise measurements with a smartphone

Judicaël Picaut, Erwan Bocher, Gwendall Petit, Nicolas Fortin

NoiseCapture is a smartphone application initially developed as part of a participative approach for environmental noise mapping. After more than 3 years, the database produced from all over the world contributions is considerable (more than 77k contributors, nearly 300k tracks representing about 72 million 1-second measurements, in nearly 200 countries). Beyond the initial objective, other uses of the application have emerged: individually by users for their own needs, by associations of people in charge of the fight against noise pollution, within the framework of educational activities, by researchers for the realization of their own research, by communities to address the subject of noise pollution. As these new applications emerged, the development team of NoiseCapture was led to extend the possibilities of exploitation of these data. Thus, in this paper, we present different possibilities for a user to perform his own data analysis, namely: a local export of data from the smartphone, access to raw data and pre-processed data from the NoiseCapture server, access to formatted GIS layers from OGC standard service. All these methods are enabled thanks to the open source ecosystem, such as Python libraries, R software suite and GIS tools.

11:40 AM 03-Aug-2021 **IN21_3018.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3018

Accurate and controled vehicle pass-by noise emission quantification in real life traffic

Lucille Pinel Lamotte, Fabien Lepercque, Valentin Baron

Noise emission from individual vehicle largely contributes to city pollution and has serious health impact. The standards towards vehicle manufactures consists in pass-by testing with specific acceleration conditions which are not representative of all real driving. For the 2015/996 EU directive, the vehicle source model is inspired of the preceding pass-by standard with derived data represented the propulsion and rolling noise sources. Anyhow, those sources are underestimated due to driving behavior, aged and modified vehicle, road surface, meteorological conditions… The true data collection of vehicle pass-by would be interesting. Moreover, some of the countries are reflecting on how to fight against those extremely noisy vehicle exceeding noise limit with efficient monitoring systems. This paper presents an innovative tool able to detect, identify and quantify the noise emission of individual pass-by vehicle in real life traffic. It is based on the combination of array and video processing. Compared to the state of the art and thanks to MEMs technology, the system is optimized and designed to quantify the individual noise vehicle emission regarding standard with controlled measurement and accurate processing. If the conditions are not respected to properly qualify the pass-by regarding the system limits, the data are ignored. It aims at constructing large and accurate database useful to determine average noise levels and/or acceptable noise limits per vehicle category.

12:00 PM 03-Aug-2021 **IN21_2350.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2350

Audio recording analysis in an urban park of the city of Milan (Italy)

Roberto Benocci, Roberto Benocci, Alessandro Bisceglie, Fabio Angelini, H. Eduardo Roman, Giovanni Zambon

A noise monitoring campaign has been performed in an urban park of Milan (Italy) called Parco Nord. The area of study is a large peri-urban park in the northern part of the city, characterized by wooded land rich in biodiversity and exposed to different sources and degrees of anthropogenic disturbances, such as road traffic noise and artificial light.
The acoustic environment is rather complex due to the contemporary presence of different noise sources, leading to the difficult task of discriminating them in audio data. Due to these multifactorial characteristics, we evaluated different eco-acoustic indices in the attempt to derive a methodology to evaluate the potential of sound ecology indicators to discriminate the different types of sounds present in medium-large urban parks. Time series of about two-week recordings have been transformed into eco-acoustics indices and statistically analysed. The results show a redistribution of recordings into each cluster associated with different sound components and different period of the day. This allowed the identification of different degree of biophonic and/or anthropogenic activities throughout the day.

12:20 PM 03-Aug-2021 **IN21_1672.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1672

Applicability of MEMS microphones for environmental sound level monitoring

James Oatley, Craig Storey

This paper explores the challenges associated with the integration of MEMS microphone technology into IEC 61672 classified or type-approved environmental sound level monitors. A comparison is drawn between MEMS microphones and electret condenser capsule microphones to highlight key performance differences within the technologies, and a basic integration method for both technologies is suggested. A review of the IEC 61672 and type-approval standards is conducted against the suggested integration method for a MEMS microphone; key shortcomings are reported and objectively reviewed. Development trends for MEMS microphones are explored, providing key insights into the progression of the technology against electret condenser capsule microphones. Furthermore, the evolution of environmental sound level monitoring systems is explored with a key focus on networked and sound localisation technology. The importance of MEMS microphones within the evolution of environmental sound level monitoring systems is presented alongside key arguments for the practical suitability of MEMS technology over electret condenser capsule technology.

Session: 14.18 Drone Noise in Communities
Channel 7

2:00 PM 03-Aug-2021 **IN21_1848.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1848

'Attack of the Drones' Exploration of Sound Power Levels Emitted and the Impact Drone's could have upon Rural Areas, Roxwell, Essex, UK

Josephine Nixon, Stephen Dance

This study considers the acoustic emission from a DJi Phantom 4 commercial drone using different rotor blades. Measurements were taken from a hovering drone with four commercial product blade configurations. Measurements were taken in accordance with (BS) EN ISO 3745: 2009 'Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Precision methods for anechoic rooms and hemi-anechoic rooms'. The aim of the project was to consider the sound characteristics emitted, specifically tonality and to determine the distance a drone could be heard from, with the different blade configurations, in a rural setting. By considering the different blade configurations within a rural setting, the role drones have within society is considered.

2:20 PM 03-Aug-2021 **IN21_1694.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1694

Community Acceptance of Drone Noise

Erich Thalheimer

Within the next five years, small package delivery drones and larger human passenger drones will become the next mode of transportation to fill our environment with noise. They are already being used in test markets around the world to gauge community acceptance of the concept; none the least of which being the noise generated by these drones. In fact, along with safety, noise is the prime concern for gaining acceptance and regulatory approval for widespread use of drones. Title 14 CFR Part 36 contains FAA's current certification requirements for drone flyover noise at the source. But what about receiver noise criteria? This paper will describe some of the prototype drones in use today, the major manufacturers and drone delivery services already well into development, and the current federal regulatory setting for community noise in the United States for various modes of transportation. The paper concludes with a recommended noise criteria approach, for FAA to consider adopting, that would provide a balance between the drone manufacturers' need to produce noise with the community's need for peace and quiet.

2:40 PM 03-Aug-2021 **IN21_1652.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1652

Community noise from a drone delivery distribution center: challenges and options

Jacob Poling

As drone package delivery services are expanded, community noise will be an issue that every operator will need to consider. Drones represent a unique new community noise source that will operate and be perceived differently than traditional aircraft and ground transportation vehicles. It is also likely that some early implementations of drone delivery services by major retailers will operate out of existing distribution centers, which may not be ideally located from a noise perspective. This study considers potential drone delivery noise in the community surrounding an existing distribution center, assuming the facility were to be utilized as the hub of a future drone package delivery service. The predicted noise levels from drone deliveries are compared to typical community noise limits, and potential alternative noise metrics for assessing annoyance from drone noise in communities are discussed. Options to reduce community noise from drone deliveries by altering flight altitude and speed, utilizing different flight path routing strategies, and taking advantage of the potential masking of drones by existing roadway noise are considered.

3:00 PM 03-Aug-2021 **IN21_2222.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2222

Examination of spectral content, peak frequency relationships, and annoyance for unmanned aerial vehicle operations

Judy Rochat, Herb Singleton, Keith Yoerg

Unmanned aerial vehicles (UAVs) can be used for many purposes, servicing delivery, recreational, utility inspection, and film industries, among others. For some applications, use of UAVs can expose communities to a type of noise not currently experienced, with current noise sources typically related to transportation operations (e.g., aircraft, rail, road noise sources) and home activities (e.g., air conditioning units, lawn care). As such, it is important to understand the type of noise communities will experience with UAV operations. For this paper, a UAV flyover event and hover event are examined in terms of spectral content and the relationship of peak frequencies. In addition, the peak frequencies and relationships are discussed in terms of those typically associated with annoyance.

Session: 15.00 Soundscapes, General, Part 1
Channel 7

6:40 PM 03-Aug-2021 **IN21_2084.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2084

Development of a feedback interface for in-situ soundscape evaluation

Furi Andi Karnapi, Bhan Lam, Trevor Wong, Kenneth Ooi, Zhen-Ting Ong, Woon-Seng Gan, Jooyoung Hong, Samuel Yeong

Studies involving subjective evaluation require feedback from human participants to assess the performance of a system or an environment. A participant is typically presented with a set of metrics to be observed and they present their assessment accordingly. Investigator-led in-situ soundscape evaluation in ISO 12913-2 collects perceptual responses along with other acoustical and locale information. This is a labor intensive and time-consuming processes. To alleviate and complement investigator-led evaluations, a portable and compact feedback system with an e-ink display and capacitive buttons was designed, and is undergoing field tests to address the aforementioned requirements. The system employs a low-cost, low-power microcontroller unit (MCU) with necessary hardware interfaces to enable capacitive sensing. Capacitive buttons provide an intuitive interface and avoid the inherent wear and tear of mechanical buttons. This digitized feedback interface affords the flexibility to synchronize (wired or wirelessly) with a playback system to evaluate an augmented soundscape, and is suitable for both supervised and unsupervised subjective assessments.

7:00 PM 03-Aug-2021 **IN21_2086.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2086

Assessment of inter-IC sound microelectromechanical systems microphones for soundscape reporting

Trevor Wong, Bhan Lam, Furi Andi Karnapi, Kenneth Ooi, Woon-Seng Gan

Acoustic parameters obtained from calibrated acoustic equipment are part of the minimum soundscape reporting requirements as stated in Annex A of ISO 12913-2. To dynamically monitor the acoustic environment of a large area, a large network of acoustic sensors could be deployed, albeit at significant cost. Micro-Electro-Mechanical Systems (MEMS) microphones offer compact, low-cost and high-performance alternatives to traditional analog microphones. In particular, the use of Inter-IC Sound (IS) communication allows MEMS microphones to be conveniently used in concert with I2S output interfaces for sound actuation. The performance of several IS MEMS Microphones was compared to that of an IEC 61094-4:1996 WS2F microphone in an anechoic chamber and a series of digital filters was designed to compensate for the differences in frequency response. The noise floor, compensated frequency response, acoustic parameter accuracy of IS MEMS were evaluated and recommendations regarding the suitability of the IS MEMS were provided.

7:20 PM 03-Aug-2021 **IN21_3156.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3156

The influence of the community soundscape on Neighbourhood social cohesion(for example, the Dong'an family area in Harbin, China)

Wei Zhao, Jingrui Li, Xun Zhu

With the improvement of the living standards of Chinese urban residents, the residential acoustic environment of the community as a place of life for people urgently needs to be improved. Taking the Dong'an family area in Harbin as an example, through on-site questionnaire surveys and mathematical-statistical analysis, the related relationships and influencing factors of the overall perception of the acoustic environment, the social cohesion of the neighborhood, and the benefits of physical and mental health are studied. The results show that the perception of the soundscape in historical and cultural blocks is closely related to factors such as sound source, sound pressure level, building layout, and social factors of residents; the perception of the soundscape in the green space of the block has a significant positive impact on neighborhood relationships, and neighborhood relationships are healthier. Benefits have a significant positive impact; soundscape perception and health benefits have a significant correlation, and indirectly have a beneficial impact on mental health by promoting neighbor relationships.

7:40 PM 03-Aug-2021 **IN21_2244.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2244

An objective evaluation method and experiment on the impact of road traffic noise on the soundscape: The case of West Lake

Jiping Zhang, Jiping Zhang

A positively judged soundscape generally includes both natural and social/cultural sounds in the sonic environment. Road traffic noise (RTN) is a major source of sound that may impact the both, such as the case of West Lake. Many studies examine soundscapes contexts with RTN based on physical descriptors, and subjective social scientific assessments by their descriptors mainly using onsite questionnaires to develop an understanding of the situation. By application of an objective evaluation method borrowed from speech intelligibility measurement techniques defined as the signal-to-noise-ratio-loss in the presence of RTN, research of the correlation between background RTN and environmental soundscape is developed by a self contained and evident proof derivation, proposed an objective evaluation method for protecting the soundscape from RTN, and presented the design and performance of an experiment to verify the method at two roads where RTN is propagated a distance into two roadside urban parks at West Lake. Our goal is the assessment and protection of the environmental soundscape from RTN using a convenient objective evaluation method that supplements cumbersome subjective investigations, provides an early warning concerning the RTN impact to the soundscape, and a tool how to improve the soundscape within the RTN impacted areas.

8:00 PM 03-Aug-2021 **IN21_3261.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3261

Efforts to improve the unique sound of Indonesian cities

Christina E. Mediastika, Anugrah S. Sudarsono, Sentagi S. Utami, Isnen Fitri, Rizka Drastiani, M.I. Ririk Winandari, Akbar Rahman, Asniawaty Kusno, N.W. Meidayanti MustikaYuliana B. Mberu

As a large country with thousands of ethnic groups and cultures, it is hoped that every city in Indonesia will have its uniqueness. However, preliminary data collected from 10 major cities in Indonesia shows no uniqueness. The most visited public places in these cities, i.e. parks and squares, which are generally associated with natural sounds, are dominated by human and traffic noise. Surprisingly, a noisy acoustic environment is not considered a nuisance. The study reported here looks for reasons why people ignore the noise. An online questionnaire developed using a 5-point Likert scale was distributed to collect data due to the Covid-19 pandemic. Five hundred and ninety-five respondents participated in the survey. ANOVA and Kruskal Wallis test were run to identify differences between soundscape dimensions and differences in soundscape attribute ratings, respectively. The data shows that Indonesians visit public places for communal or social activities, which are triggered by the attractiveness of the places and the types of activities they can participate in. It is the reason why noise is not considered a nuisance. Pleasantness and eventfulness are the two dominant soundscape dimensions found in this study. In the Indonesian context, pleasure correlates with events. Eventfulness is associated with the number of people and their activities in public places. However, in most of the cities surveyed, eventfulness scores were low when they were unable to engage in the events held in public places. They visit public places based on the attractiveness of the place and the activities, and they feel comfortable in noisy public places when they can be involved in the activity. Once people become attached to communal activities in public places, the pleasantness dimension also exists. Thus, two things need to be considered to improve the acoustic environment of cities in Indonesia. First is by reducing traffic noise to increase the dimensions of eventfulness by using attractive attractions in public places. Second is to investigate the types of attractions that are of interest, if possible, is to restore local culture with its unique sound to build a unique city soundscape. In this study, participants identified the uniqueness of sounds in public places by using sounds that could not be classified as unique such as the voice of and the music played by street vendors.

8:20 PM 03-Aug-2021 **IN21_2290.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2290

Soundscape restoration model based on psycho-physiological response with audio-visual interaction in natural environment

Hyun In Jo, Jin Yong Jeon

In this study, a soundscape restoration model was proposed in terms of audio-visual interaction based on psycho-physiological response by natural soundscape experience. To this end, audio-visual stimuli were collected in 6 sites of 2 types of natural environment (greenery and water) and 3 sites of urban environment (as control), and a laboratory evaluation environment was implemented using virtual reality technology. Sixty subjects participated in the experiment for two days, and the individual's health status, personality and temperament, and sensitivity were investigated before the evaluation. In the experiment on the first day, a stress test (mental arithmetic) was performed before the stimulation experience, and questionnaires related to psychological recovery was answered after the stimulation experience. In all the experimental procedures, physiological responses such as heart rate, electroencephalogram (EEG), and eye-tracking were measured so that before/during/after response from experience could be compared. In the experiment on the second day, they were asked to respond to a questionnaire related to the soundscape and landscape of environment. Finally, the relationship between the audio-visual environment (soundscape and landscape perception) and the psycho-physiological response was investigated using structural equation model, and based on this, design guidelines for healthy urban city were proposed.

8:40 PM 03-Aug-2021 **IN21_3150.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3150

Research on the Relationship between Acoustic Environment Perception and Landscape Evaluation in Historic Districts——A Case Study of Central Street in Harbin

Wei Zhao, Qingxuan Rui, Xun Zhu

Historical blocks are important material and cultural heritages in the city, and the inheritance of urban culture is affected by its acoustic environment. This article selects Central Street as the research object to study the relationship between its acoustic environment perception and landscape evaluation. The method of field investigation combined with questionnaire survey was adopted. The results show that the pleasure and richness of the soundscape have a positive impact on the satisfaction of the landscape. Under a certain sound intensity, music and broadcast sounds can increase the pleasure of the soundscape, but at excessively high sound intensity, it reduces the pleasure of the soundscape; traffic sounds and construction sounds have a negative impact on the pleasure of the soundscape . At the same time, the elderly have a higher evaluation of the soundscape and landscape perception. This research can be used in the soundscape construction of historic districts and provide a certain reference value for the subsequent renovation and reconstruction of historic districts and improving their integrity.

Session: 17.01/17.02/17.08 Perception, Part 1
Channel 8

6:00 AM 03-Aug-2021 **IN21_2885.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2885

Frequency dependence of vertical whole-body vibration perception - is your car rattling or humming?

Anna Schwendicke, M. Ercan Altinsoy

Humans perceive whole-body vibration in many daily life situations. Often they are exposed to whole-body vibration in combination with acoustic events. Sound and vibration usually stems from the same source, for example concerts or travelling in vehicles, such as automobile, aircrafts, or ships. While we can describe acoustic stimuli using psychoacoustic descriptors such as loudness or timbre, the description human perception of whole body vibration frequently has been reduced to comfort or quality in the past. Unlike loudness or timbre, comfort and quality are dependent on the overall context. Especially in vehicles expectations might differ lot between different vehicle classes. Previous studies have evaluated a large range of suitable descriptors for whole-body vibrations that are independent of context. They suggest that certain descriptors are driven to a large extend by the frequency content of the vibration. This study systematically investigates the influence of frequency content on the perception of whole-body vibration varying frequency content and intensity of the vibrations. The results verify the frequency dependence of specific descriptors and identify the respective frequency ranges.

6:20 AM 03-Aug-2021 **IN21_2006.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2006

Influence of steering vibration on vehicle speed recognition and comfortableness in cabin.

Eiji Yoshioka, Shin Itou, Junji Yoshida

In recent years, electric vehicles are becoming more popular. This transition makes interior noise and vibration smaller according to the engine rest and makes interior more comfortable. On the other hand, this reduction has a possibility to decrease important information for drivers. In this study, we focused on the steering vibration as the vehicle speed information and investigated the influence on the comfortableness in cabin for the compatibility through subjective evaluation test using a simple driving simulator. In the test, vehicle speed controlling task was given to the participants without speed meter at acceleration conditions. In addition, subjective evaluation about the comfortability to the presented sound and vibration was conducted after the speed recognition test. As the presented steering vibration, the following four patterns were prepared. 1: internal combustion engine noise and vibration with road and wind noise (background noise), 2: electric-powered vehicle noise without vibration (background noise without vibration), 3: tire vibration with background noise, 4: motor vibration with background noise. As the result, the steering vibration of internal combustion engine or motor was found to be suitable stimuli for compatibility between the speed recognition performance and the comfortability in cabin.

6:40 AM 03-Aug-2021 **IN21_2107.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2107

Perception thresholds for whole-body vibrations on an airplane seat

Louis Krause, Stephan Töpken, Steven van de Par

The comfort during a flight on an aircraft is important for passengers. Like many other physical factors, vibrations of the airplane may negatively affect comfort. To understand the impact of vibration on comfort, it is important to know in which way the vibrations transmitted through the seat affects the perception of whole-body-vibrations. In this study, perception thresholds for vertical sinusoidal whole-body vibrations with frequencies between 20 Hz and 75 Hz were determined on a vibration platform with a typical economy class aircraft seat bench. Acceleration levels were recorded with accelerometers placed at the right rear seat rail and inside a seat cushion between the seat surface and the participant. The results show a distinct frequency dependency of the detection thresholds when measured at the seat rail. When taking the difference between the two measurement positions into account and describing the thresholds by the acceleration levels at the seat cushion, the determined perception thresholds are nearly frequency independent up to 50 Hz. This finding is in good agreement with literature data suggesting that the specific experimental setup does not play a big role in this frequency range. Differences above 50 Hz might be explained by the additional armrests in the present study.

Session: 17.05/17.07 Sound Quality and Consumer Product Noise
Channel 8

7:20 AM 03-Aug-2021 **IN21_1745.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1745

Understanding the relationship between onomatopoeic expressions and sound quality for rotary switch operating sounds

Toru Miyairi, Takeshi Shirasaka, Hisato Shimomura, Takeshi Toi

In our daily lives, we often use onomatopoeia to convey images of products. However, the correspondence between onomatopoeia and physical quantities is not clear. To apply onomatopoeia to product design, we focused on the relationship between the sound symbolism of onomatopoeia and product sound quality. The target of the evaluation was the operation sound of the rotary switch. A subjective evaluation experiment was conducted in which participants were asked to free answer to the impressions associated with the operation sounds using onomatopoeic expressions. The obtained onomatopoeia was then analyzed by quantitative text analysis using mora as the unit of analysis. The results showed the voiced consonants appeared more frequently in the louder operation sounds. In addition, the vowel /o/ appeared more frequently in sounds with low sharpness, and the vowel /i/ appeared more frequently in sounds with high sharpness. Since these trends are

similar to other studies on sound symbolism, this study shows the possibility of using onomatopoeia in product design by utilizing sound symbolism.

7:40 AM 03-Aug-2021 **IN21_2238.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2238

Parameter study of Variation noise in outdoor of air conditioner

Minkyu KIM, Byoungha Ahn, Simwon Chin

In the outdoor unit of a room air conditioner, the main factors that made it possible to vary the ability of cooling and heating are the development of BLDC motors, advances in inverter technology, and the development of refrigerant volume control technology. The main reason for this change in cooling and heating capacity is that it is possible to change the RPS of compressors. As the range of the compressor's RPS expands, so does the range of response to load variations. This is mainly based on the capacity of the high-pressure refrigerant produced by the compressor.
When the compressor rotates at high speed or low speed, the difference in noise occurs depending on the difference in rotational speed. Of course, fans and motors also contribute to noise fluctuations, but the overall governing factor is the greater contribution of refrigerant from compressors and compressors. The refrigerant flows into the cycle configured in the outdoor unit and varies in speed and flow rate depending on the amount of refrigerant. This results in vibration and noise appearing in the form of radiations, resonances, solid sounds, resonances, and so on. There are several factors that can cause vibration or noise changes depending on the flow velocity and flow rate.
In this paper, we selected reactance of compressor motors, mufflers directly connected to compressor discharge ports and accumulator at compressor inlet where fluid vibrations occur the most.
First of all, reactance of motor responds quickly to load fluctuations and has a large instantaneous torque to instantaneous load fluctuations. The muffler, which is directly connected to the compressor discharge port, is the first Cavity where high-pressure gas meets, and can evaluate the concentration of kinetic energy that generates noise and improve the collection center to reduce fluctuating noise. The Accumulator is the part with the lowest temperature of refrigerant gas entering the compressor, and the rapid change in the flow path causes the most fluid to generate vibration and radiation of the structure. For this reason, we select three elements first.
In this paper, we specifically describe the background of selecting three elements of an air conditioning outdoor unit for the variability of noise over RPS changes. We demonstrate that these factors can review the feasibility of the experiment, explain the results of the analysis, and possibility of reduce the variation noise.

8:00 AM 03-Aug-2021 **IN21_1767.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1767

MOSQITO: an open-source and free toolbox for sound quality metrics in the industry and education

Roberto San Millán-Castillo, Eduardo Latorre-Iglesias, Martin Glesser, Salomé Wanty, Daniel Jiménez-Caminero, José María Álvarez-Jimeno

Sound quality metrics provide an objective assessment of the psychoacoustics of sounds. A wide range of metrics has been already standardised while others remain as active research topics. Calculation algorithms are available in commercial equipment or Matlab scripts. However, they may not present available data on general documentation and validation procedures. Moreover, the use of these tools might be unaffordable for some students and independent researchers. In recent years, the scientific and technical community has been developing uncountable open-source software projects in several knowledge fields. The permission to use, study, modify, improve and distribute open-source software make it extremely valuable. It encourages collaboration and sharing, and thus transparency and continuous improvement of the coding. Modular Sound Quality Integrated Toolbox (MOSQITO) project relies on one of the most popular high-level and free programming languages: Python. The main objective of MOSQITO is to provide a unified and modular framework of key sound quality and psychoacoustics metrics, free and open-source, which supports reproducible testing. Moreover, open-source projects can be efficient learning tools at University degrees. This paper presents the current structure of the toolbox from a technical point of view. Besides, it discusses open-source development contributions to graduates training.

8:20 AM 03-Aug-2021 **IN21_1968.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1968

Sound quality evaluation for luxury refrigerator door closing sound

Kanta Imamori, Atsuya Yoshiga, Junji Yoshida

In this study, we carried out subjective evaluation tests employing 19 refrigerator door closing sounds to quantify the luxury feeling. By applying factor analysis to the subjective evaluation results, the sound quality of the refrigerator door closing sound was found to be expressed by the following two factors: overall loudness and the pitch of the sound. Subsequently, luxury feeling evaluation model was obtained through multiple regression analysis. As the result, the luxury feeling of the door closing sound was evaluated to be high when the sound was softer and had lower pitch. Then, we prepared several luxury door closing sounds according to the obtained evaluation model through a filter processing and conducted subjective evaluation tests again to verify the evaluation model. The result shows that the amplitude increased sound at low frequency band under 100 Hz, which was calculated to be high luxury by the evaluation model, was actually evaluated as the best among the presented sounds through the subjective test. And the luxury sound quality evaluation method was confirmed to be useful to quantify and estimate the sound quality of the refrigerator door closing sound.

8:40 AM 03-Aug-2021 **IN21_1884.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1884

Digitalizing sound in your personal space

Ramana Kappagantu, Karl Karlson, Koen Vansant

Design specifications for appliances are usually in the context of standard acoustic rooms like anechoic (full or hemi) and sometimes reverberant. However in the world of infotainment industry the devices are operated in your personal space - a generic environment like that

of a living room and they continuously interact with other devices in real time. One has to take into account the scattering and absorption of sound from different surfaces and how they constructively and destructively interfere in generating a signature sound for the room and the devices. This environmental impact increases the design space significantly and makes it impractical to consider physical prototyping and testing. Simulating the acoustic behavior of the devices in a room environment has been attempted in the past and were successful only for lower frequency ranges or for smaller rooms. High end Multipole BEM and FEM Adaptive Order technologies have emerged in the recent past and together with parallel cloud computing make the modeling of generic room environment more feasible, up to a few kHz given adept hardware setup. A different, more asymptotic method like Ray Tracing provides a real breakthrough here and enables taking on the full audible frequency range and large rooms, in at least one order of magnitude faster solving times compared to the more conventional FEM and BEM method, which further supports optimization possibilities for different configurations in reasonable time.

Session: 16.00/16.01/16.04 Noise and Health, Part 2
Channel 8

11:00 AM 03-Aug-2021 **IN21_3088.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3088

Health effects related to wind turbine sound: A review

Irene van Kamp, Frits van den Berg

Worldwide questions about health effects play a role in local debates about windfarms. A review was prepared for the Swiss Federal Office for the Environment of the literature published since 2017 about the health-effects of wind turbine sound. Scientific literature was collected on the effect on annoyance, sleep disturbance, cardiovascular disease and metabolism. Also, visual annoyance and other non–acoustic factors, such as appraisal of the local decision making process were investigated. Annoyance came forward as a consequence of wind turbine sound: the louder the receiver sound level, the stronger the annoyance response. For other health effects, results of scientific research are inconsistent. Effect are not a consequence of the sound levels, but rather related to the residents' annoyance. The literature did not show that infrasound or low frequency sound leads to other effects when compared to sound at higher frequencies. Evidence shows that residents experience less annoyance when they participate in the siting process. By being able to take part in the siting and in balancing costs and benefits, residents experience less annoyance. It is therefore important to take worries of local residents seriously and involve them in the process of planning and the siting of wind turbines.

11:20 AM 03-Aug-2021 **IN21_2188.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2188

The test bench for the assessment of the impact of wind turbine noise on human performance

Dariusz Pleban, Grzegorz Szczepański, Jan Radosz, Łukasz Kapica

Among the factors related to the operation of wind farms, wind turbine noise has to be seen as a source of annoyance for both people living and working near wind farms. A method and a test bench to conduct noise annoyance tests of different types of wind turbine noise in laboratory conditions have been developed. The test bench is based on a multi-channel sound reproducing system using the DANTE network (in which digital acoustic signals are broadcast over Ethernet) and is compiled in the acoustic test chamber. The test bench consists of 19 speakers, including 17 Avantone MixCube studio monitors and 2 LS600 woofers. During the tests a study subject is assessed in terms of efficiency and performance using a computer-based ALS test from the Vienna Test System. The paper describes the test method, the test bench and the results of the pilot studies carried out to assess the impact of wind turbine noise on human performance.

11:40 AM 03-Aug-2021 **IN21_2761.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2761

Annoyance from community and neighborhood noise during the COVID-19 lockdown in Serbia: a pilot study

Katarina Paunovic, Branko Jakovljević, Radmila Mirčić

We present a pilot study on noise perception and annoyance related to community and neighborhood noise sources during the COVID-19 lockdown in Serbia, enforced from March 15 to May 6, 2020. The online anonymous survey was conducted using social network platforms. Respondents from all over the country, aged 15 to 75 years took part in the study. All participants worked or studied from their homes during the investigated period. Overall, during the lockdown, participants perceived less noise from the major community sources, such as road traffic, air traffic, and construction works on the streets; at the same time, they perceived more noise from their neighbors, such as noise from electrical appliances and elevators inside the buildings, as well as noise from humans (music, voices, steps) and animals. In addition, respondents more often perceived "new" community sounds, such as birds, church bells, and emergency vehicles. They found the sirens of emergency vehicles and noise from their neighbors most annoying at that time. Many participants changed their behavior and attitudes toward noise during the lockdown. Every sixth participant complained about neighborhood noise. This study points to the need for the improvement of the acoustic environment at home in the future.

12:00 PM 03-Aug-2021 **IN21_2019.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2019

Health impact assessment of road traffic noise in the EU in 2020-2035

Erik Salomons, Michael Dittrich

The negative health effects of road traffic noise in the EU are analyzed over the period 2020-2035. For a baseline scenario, with autonomous traffic growth and fleet development, it is found that the EU health burden in 2030 is equivalent to the loss of 1.7 million 'healthy life years'. Various noise abatement scenarios are analyzed, with noise solutions such as quiet road surfaces, quiet tyres, and electric vehicles. The health benefits of the scenarios are calculated as health-burden differences from the baseline scenario. The calculation methodology is based on the

noise exposure distributions reported in 2017 by EU member states, for urban agglomerations and for major roads. Changes in noise exposure are calculated with EU model Cnossos for vehicle emission, considering different types of roads (residential streets, main roads, motorways,…). The monetized health benefits are used as input for a cost-benefit analysis of the scenarios over the period 2020-2035. For quiet tyres, for example, high health benefits and low costs are found, resulting in a high cost-to-benefit ratio. This work was part of a study for the European Commision, exploring different options for reducing the EU health burden caused by noise from road, rail, and air traffic.

12:20 PM 03-Aug-2021 **IN21_2282.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2282

Cardiovascular mortality and transportation noise: a prospective Swiss cohort study

Danielle Vienneau, Benjamin Flückiger, Apolline Saucy, Louise Tangermann, Beat Schäffer, Jean Marc Wunderli, Martin Röösli

Transportation noise from road, rail and air traffic can be detrimental to health and wellbeing. Previous studies, including our own, have shown death from specific cardiovascular diseases (CVD) to be associated with these exposures. Now, with 15 years of follow-up, integrated address history and noise exposure data for multiple years corresponding to census decades, we conducted an extended analysis of the Swiss National Cohort. Mean exposure in 5-year periods were calculated, and three virtual sub-cohorts were defined (2001-2006, etc.) in addition to the full cohort (2001-2015). Multi-pollutant (Lden_road, Lden_rail, Lden_air), time dependent Cox proportional hazards models were applied to 4.14 million adults and adjusted for potential confounders and PM2.5. During the 15-year follow-up, there were 277,506 CVD and 34,200 myocardial infarction (MI) deaths. In the full cohort, there was an increased risk of death for road traffic (1.029 [1.024−1.034] CVD; 1.043 [1.029−1.058] MI per 10dB), railway (1.013 [1.010−1.017] CVD; 1.020 [1.010−1.030] MI) and aircraft noise (1.040 [1.020−1.060] MI). For road traffic noise, Hazard ratios (HR) were higher in males vs. females and in younger vs. older age groups. HRs were also remarkably consistent with our previous analysis with follow-up until 2008, and were relatively similar across the three virtual sub-cohorts.

12:40 PM 03-Aug-2021 **IN21_2359.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2359

Road traffic noise disease burden estimates for a model study of varying urban morphology cases

Jens Forssén, Andreas Gustafson, Meta Berghauser Pont, Marie Haeger-Eugensson, Niklas Rosholm

For a model set of 31 different building morphologies in an urban setting, road traffic noise exposure has been calculated and analysed. For five of the building morphologies also vegetation surfaces on facades and roofs were studied. Facade exposures were analysed for both smaller (single-sided) flats and larger (floor-through) flats, considering the direct exposure from the roads as well as the non-direct exposure at noise-shielded positions like inner yards, applying a noise mapping software in combination with a prediction model for the non-direct exposure. Using noise indicators Lden and Lnight, the disease burden, in terms of DALY (Disability-Adjusted Life Years) per person, was estimated and analysed, via predictions of annoyance and sleep disturbance. The resulting effects of varying the building morphology and adding vegetation are shown and discussed, including effects of a bonus model for flats having additional facade elements with lower noise exposure.

1:00 PM 03-Aug-2021 **IN21_2340.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2340

Integrating environmental noise considerations into public policy: the case of Ireland

Jon Paul Faulkner, Enda Murphy

European Commission Directive (EU) 2020/367 describes how harmful effects from environmental noise exposure are to be calculated for ischemic heart disease (IHD), high annoyance (HA), and high sleep disturbance (HSD) for road, rail, and aircraft noise under the Environmental Noise Directive's (END) strategic noise mapping process. It represents a major development in understanding the extent of exposure from transport-based environmental noise given it is a legal requirement for all EU member states from the 2022 reporting round. It also has the potential to accelerate the development of stronger noise-health policies across the EU. While this development is to be welcomed, there are a number of basic noise-health policy applications that first need to be implemented in the Irish case if the noise-health situation is be accurately assessed and if public health is to be adequately protected. In order to address this requirement the following paper presents concrete policy and practice recommendations as well as an evaluation of the current application of noise management policy in Ireland which is administered to protect the public from the harmful effects of environmental noise. This paper provides guidance on how noise-health considerations can be integrated into key relevant areas of Irish policy including healthcare, the environment, transportation, and planning.

1:20 PM 03-Aug-2021 **IN21_2354.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2354

Association between noise annoyance and mental health outcomes – an evidence review

Xiangpu Gong, Benjamin Fenech, Claire Blackmore, John Gulliver, Anna Hansell

To date, most reviews on noise and mental health have focused on noise exposure. However, a number of studies found associations between mental health and noise annoyance, but not with exposure. A literature search was carried out in PubMed and Web of Science databases. We also hand-searched conference proceedings and references in other systematic reviews on noise exposure and annoyance/mental health. We identified 25 articles through the databases searches that satisfied the inclusion criteria; existing literature reviews provided two additional publications. The majority of identified studies used either a 5-point (n=15) or 11-point scale (n=5) to measure noise annoyance. The sources of noise annoyance mainly come from traffic (n=18 or 67%), and neighbourhood (n=4 or 15%). For mental health outcomes, 20 (74%), 2 (7%) and 2 (7%) articles used validated questionnaires, self-reported use of anxiolytics/antidepressants, or self-reported diagnosis of mental disease, respectively, to assess mental health. Six articles differentiated between depression and anxiety disorder while 19 focused on general mental health. Results from these studies overall point to an adverse association of noise annoyance (high noise annoyance in particular) with depression, anxiety or general mental problem, either measured by self-reported diagnosis, self-reported medicine use or questionnaires.

Session: 17.01/17.02/17.08 Perception, Part 2
Channel 8

7:20 PM 03-Aug-2021 **IN21_2547.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2547

Differences in perceived loudness between men and women: A cross-cultural comparison among Japanese, Chinese, and Malaysians

Mariko Tsuruta-Hamamura, Kumi Nakada, Ryoga Kikuchi, Naoki Watanabe

Previously, we investigated gender difference in loudness perception among Japanese and Chinese. Among Chinese, female participants tended to assigned higher loudness scores than did males for the same sound. That difference was also evident when a ratio scale, such as magnitude estimation, was used to evaluate loudness. However, among Japanese, that difference was not clearly observed when the ratio scale was applied. To examine factors affecting gender differences in loudness perception, we conducted the same rating experiments among Malaysian males and females. We found that a rating experiment using the verbal interval scale showed that the female Malaysian participants tended to rate the same sounds as louder than did males. In one test, we measured the limit of sound pressure level that would be perceived as soft or as loud: we observed the above gender differences with the lowest limit of loud sound. However, that gender difference did not emerge in the rating experiments using the ratio scale. The tendency we recorded among Malaysians was the same as Japanese. Thus, differences in judging loudness between males and females may actually reflect differences in the use of verbal expressions rather than differences in perception.

7:40 PM 03-Aug-2021 **IN21_3052.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3052

Evaluation of recognition performance of guidance direction present-ing by sequential emitting sound in evacuation guidance system

Tetsuya Miyoshi

Providing guidance using light and sound source to support prompt evacuation during a disaster is an important issue. The final purpose of our research is to propose and develop an evacuation guidance system using a sound source that are emitted along a predetermined evacuation path sequentially. In this paper, we report the results of analysis and discussion about the identification performance of human being for the emitting sound source in several empirical conditions as the basic study of our research goal. We conducted two experiments under the conditions combining of these factors, in which subjects identified emitting sounds in two cases that the sound stimuli were emitting in straight lines and in right-angle lines. From the experimental results, it was shown that the accuracy rate of identification of the emitting sound was improved when the vocal phase was used as the sound source and when the emitting time interval was extended. The results about identification the sequence of sound also demonstrated that the performance became lower as the sound stimuli emitting farther from subjects in a straight line, and also the response time became longer in case that the sequence order from back to front than the other direction.

8:00 PM 03-Aug-2021 **IN21_2148.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2148

Spatial release from masking in varying spatial acoustic under higher order ambisonic-based sound reproduction system

C. T. Justine Hui, Yusuke Hioka, Catherine I. Watson, Hinako Masuda

A previous study found that spatial release from masking (SRM) could be observed under virtual reverberant environments using a first order Ambisonic-based sound reproduction system, however, poor localisation accuracy made it difficult to examine effect of varying reverberation time on SRM. The present study follows on using higher order Ambisonics (HOA) to examine how benefits from SRM vary in different spatial acoustics. Subjective speech intelligibility was measured where four room acoustics:reverberation time (RT)= 0.7 s (clarity (C50)= 16 dB, 7 dB); RT= 1.8 s (C50= 8 dB, 2 dB) were simulated via a third order Ambisonic system with a 16 channel spherical loudspeaker array. The masker was played from 8 azimuthal angles (0, +-45, +-90, +-135, 180 degrees) while the target speech was played from 0 degree. The listeners are deemed to benefit from SRM if their intelligibility scores were higher when the masker comes from a different angle than that of the target. We found while listeners could benefit from SRM at C50 = 16 dB and 8 dB, the benefit starts to diminish at C50 = 7 dB, and listeners could no longer benefit from SRM at C50 = 2 dB.

8:20 PM 03-Aug-2021 **IN21_2134.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2134

Head related transfer function measurements of common PPE

Megan Ewers, Sam Kincaid, Marco Beltman

Due to COVID 19, personal protective equipment (PPE) is now used in everyday life. Such PPE affects communication and perception. This paper provides an overview of the impact of PPE on Head Related Transfer Functions (HRTF's). Spatial acoustic effects of common PPE on human hearing can be documented to improve and inform field worker safety and communication. After a general description of the measurement process and required tools, we focus on a few methods which contribute significantly to the accuracy and analysis of PPE-based HRTF data. The dedicated setup allows measuring a full 360 degree map in automated fashion. It includes a special ring setup with 25 speakers, and a precise turn table that is used to adjust the angle of the device under test with respect to the ring. Binaural measurements were performed on a set of common PPE items on a Head And Torso Simulator (HATS) system, including hard hats, safety glasses, hearing protection, and various face masks. An overview of the data is presented.

8:40 PM 03-Aug-2021 **IN21_1771.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1771

Psycho-physiological evaluations of low-level impulsive sounds produced by air conditioners

Yoshiharu Soeta, Ei Onogawa

Air conditioners are widely used in buildings to maintain thermal comfort for long time. Air conditioners produce sounds during operation, and air conditioners are regarded as one of the main noise sources in buildings. Most sounds produced by the air conditioner do not fluctuate over time and sound quality of the steady sounds produced by the air conditioner have been evaluated. However, air conditioners sometimes produce low-level and impulsive sounds. Customers criticizes such sounds are annoying when they sleep and they spend time quietly in the living room. The aim of this study was to determine the factors that significantly influence the psycho-physiological response to the low-level impulsive sounds produced by air conditioners. We assessed the A-weighted equivalent continuous sound pressure level (LAeq) and factors extracted from the autocorrelation function (ACF). Subjective loudness, sharpness, annoyance, and electroencephalography (EEG) were evaluated. Multiple regression analyses were performed using a linear combination of LAeq, the ACF factors, and their standard deviations. The results indicated that LAeq, the delay time of the first maximum peak, the width of the first decay of the ACF, and the magnitude and width of the IACF could predict psycho-physiological responses to air conditioner sounds.

Session: 07.01 Railroad and Ground-Borne Noise, Part 2

Channel 1

6:00 AM 04-Aug-2021 **IN21_3136.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3136

Noise Reduction by Rail Damper Tunable for Individual Rails in Curve

Wilson Ho, Ghazaleh Soltanieh, Wylong Wang

Tuned mass rail dampers are cost effective for the mitigation of the airborne noise and vibration with the ability to be tuned for individual site. TMDs have been developed and installed at a single rail in a curve tunnel and achieve more than 4dB(A) noise reduction in many cases. According to the on-site noise reduction performance during damper installation, half, one, two or three dampers can be installed at each spacing between two baseplates. TMDs with only half-installation provides more than 10dB reduction at vertical pin-pin resonance (~1kHz). With the standard installation, they provide the strong damping to half the corrugation growth rate. The stick-slip phenomena which causes the corrugation will be affected by the damping effect from TMDs. On the other hand, they can also be tuned to the low-frequency (p2 resonance) for grandborne noise control. The high reduction of the grand borne noise proved our claim for effectiveness of the TMDs besides many other studies on the other parameters like the type of the baseplates or the soil types. According to the test results TMDs achieve strong performance in different range of the frequencies.

6:20 AM 04-Aug-2021 **IN21_2834.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2834

DISC BRAKE SQUEAL ANALYSIS USING NONLINEAR MATHEMATICAL MODEL

Akif Yavuz, Osman Taha Sen

Many academics have examined the disc brake squeal problem with experimental, analytical, and computational techniques, but there is as yet no method to completely understand disc brake squeal. This problem is not fully understood because a nonlinear problem. A mathematical model was created to understand the relationship between brake disc and pad thought to cause the squeal phenomenon. For this study, two degree of freedom model is adopted where the disc and the pad are modeled. The model represents pad and disc as single degree of freedom systems that are connected together through a sliding friction interface. This friction interface is defined by the dynamic friction model. Using this model, linear and nonlinear analyzes were performed. The stability of the system under varying parameters was examined with the linear analysis. Nonlinear analysis was performed to provide more detailed information about the nonlinear behavior of the system. This analysis can provide information on the size of a limit cycle in phase space and hence whether a particular instability is a problem. The results indicate that with the decrease in the ratio of disc to pad stiffness and disc to pad mass, the system is more unstable and squeal noise may occur.

6:40 AM 04-Aug-2021 **IN21_2853.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2853

The effect of two trains passing at the same time on the ground borne vibration level

Carel Ostendorf

When predicting the ground borne vibration level, it is assumed that only one train passes so the predicted vibration level is caused by a single train. When there is one track for every direction of the train, it is possible that two trains will pass each other on a specific location at the same time. What influence do these two trains have on the vibration level compared to the vibration level of a single train passing that same location?

For this study ground borne vibration levels have been measured on two locations in The Netherlands using a 3 by 3 grid, 25 meters apart, on a distance of 25, 50 and 75 meters of the track. During the 4 weeks measuring time, all the trains have been captured on video. All the double train situations have been marked. The corresponding vibration level Vmax (according to the Dutch SBR B guideline) has been determined for both the single trains and the double trains and compared to each other. In the analysis, the type of trains passing each other and the distance of the receiver to the track, has been taken into account when determining the difference in vibration level.

7:00 AM 04-Aug-2021 **IN21_3000.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3000

Methods for the assessment of low-frequency noise from mining activities in the Netherlands

Jelle Assink, Rosan Nusselder, Kim White, Olivier den Ouden, Erik de Graaff, Edwin Nieuwenhuizen

According to the World Health Organisation, noise ranks among the environmental stressors with the highest impact on public health. The contribution of low-frequency noise (LFN) is not well-understood and deserves more research attention from several perspectives, that include epidemiology, acoustics as well as civil engineering. The attribution of symptoms to LFN is increasing due to a growth in public awareness and the expansion of industrial installations and traffic. In the Netherlands, numbers of LFN-related complaints are rising. Several of those have been attributed to the mining industry. However, an effective methodology for the assessment of such complaints is not yet available.
In this presentation, methods are defined to assess LFN from mining activities in the Netherlands, focusing on the extraction, processing, transportation and storage of gas, salt and geothermal heat. Through a literature review and interviews with domain experts, methodologies have been derived with regards to 1) the prediction of LFN generation at the source, 2) observational techniques and 3) potential impacts on health. A broad low-frequency band is considered, spanning from the often-discarded infrasonic frequencies to up to 200 Hz. Based on this study's results, recommendations are given for establishing a standard procedure to assess LFN produced by mining activities.

7:20 AM 04-Aug-2021 **IN21_2785.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2785

Vibration source properties of cargo trains: free field vibration and trackside measurement analysis

Eliam Vlijm

Annoyance caused by railway operations has gained increasing attention in the Netherlands. This has led to a multimillion research project into different aspects of train passages as a source of vibration. The project is initiated by the Dutch railway operator ProRail. In advance of this project a study has been performed on vibration signals at free field caused by cargo train passages at four different sites. The signals have been compared to trackside measurements. The trackside measurements consist of fibre optic measurements of the rail deflection at pre-installed locations different from the free field vibration measurement sites. Different vibration level indicators have been studied like train speed, axle loads and wheel roughness indicators and their correlation with vibration levels. Vibration levels are defined in several ways, a frequency weighted running mean square value (so-called Veffmax), a 2-second RMS level (unweighted) and levels per frequency band. Special attention is given to the variation in time of the measured vibration signals during the train passage to see whether 'bad quality' wheel passages can be identified. The results give valuable input for a future case study in which wheel quality and its influence on vibration levels will be studied further.

7:40 AM 04-Aug-2021 **IN21_2385.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2385

Development of a dynamic model of the axisymmetric railway wheel for sound radiation prediction

Víctor Andrés, Jose Martínez-Casas, Javier Carballeira, Francisco Denia

In this work, a vibroacoustic model is developed to predict the dynamic response and sound radiation of an axisymmetric railway wheel under a non-axisymmetric excitation. To do this, first, the energy equation of the wheel is analytically integrated along the circumferential direction after an expansion of its response as Fourier series. Then, the vibrational dynamics of the three-dimensional wheel is solved through a set of two-dimensional problems which come from that integration. Subsequently, the three-dimensional sound radiation of the railway wheel is calculated from the solution of the aforementioned two-dimensional problems by means of analytical relations based on the harmonic distribution of the dynamics in the circumferential coordinate. Additionally, the wheel rotation is introduced in the model using an eulerian approach, in order to consider the associated gyroscopic and inertial effects. The proposed model presents a greater computational efficiency compared to full three-dimensional methodologies, without compromising the precision of the results. This allows the implementation of the sound radiation calculation in optimization algorithms with the aim of achieving quieter designs of railway wheels.

Session: Keynote Lecture
Channel 1

9:00 AM 04-Aug-2021 **Oral Only**

Environmental noise in cities: Lessons learned and what is next

Jorge Arenas

10:00 AM 04-Aug-2021 **Oral Only**

Applications of acoustical oceanography

Megan Ballard

Session: 02.06 Nonlinear Vibro-Acoustics
Channel 1

11:00 AM 04-Aug-2021 **IN21_2192.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2192

Variation in vibro-acoustic noise due to the defects in an automotive drum brake

Ananthapadmanabhan Ramesh, Sundar Sriram

Drum brakes are significant contributors to noise and vibration in automobiles causing discomfort to the passengers. The vibration and hence the resulting noise increase due to various inherent defects in the drum brake, such as asymmetry. This work aims to quantify the variation in the vibro-acoustic noise due to several common defects in the drum brake using an integrated non-linear vibration analytical model and a numerical acoustic model. The sources of vibro-acoustic noise sources such as contact and reaction forces are predicted using a four-degree-of-freedom non-linear contact mechanics based analytical model. A finite element based acoustic model of the drum brake is utilized to predict the force to the sound pressure transfer function in the drum brake. Product of the transfer functions and the forces gives the corresponding sound pressure level from which the overall sound pressure levels are estimated. The variation in the overall sound pressure levels due to different drum brake defects is evaluated by introducing defects to the analytical model. The results show that the overall sound pressure level is a strong function of the defects. It is envisioned that the current work will help in the development of effective health monitoring systems.

11:20 AM 04-Aug-2021 **IN21_1836.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1836

Comparison of noise generated from simplex and duplex configurations of drum brake using non-linear vibro-acoustic models

Akash Yella, Sriram Sundar

The drum brakes used on the rear wheels of automobiles have various configurations. These contribute to the differences in kinematic (geometry) and dynamic (contact, friction) aspects, eventually leading to significantly different vibration and acoustic response. This work attempts to estimate the difference in the vibro-acoustic noise generated by the drum brake's simplex and duplex variants using a combination of non-linear analytical vibration models and a numerical acoustic model. Four degrees-of-freedom lumped parameter models developed for the simplex and the duplex configurations with conformal contact predict the contact and reaction forces during braking. These forces act as the sources for the finite element based acoustic models developed for the two configurations to obtain the sound pressure to force transfer functions. The sound pressure levels are estimated by the product of the predicted forces with the respective transfer functions in the frequency domain. The sound pressure levels of the simplex and duplex drum brakes are quantitatively compared under different braking conditions, and the results are presented. It is expected that this vibro-acoustic analysis will help in designing quieter drum brakes.

11:40 AM 04-Aug-2021 **IN21_1858.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1858

Development of experimental vibro-acoustic transfer function for a system with combined rolling-sliding motion

Kumar Milind Rewanand Shripad, Sriram Sundar

Combined rolling-sliding contact is present in popular non-linear systems such as cam-follower, gears, clutches, and brakes. These systems produce significant noise due to complex contact between the components during operation. The noise generated is a strong function of the contact parameters and excitation to the system. The objective of this study is to develop a transfer function to quantify the vibro-acoustic noise for various contact conditions. Acceleration, reaction forces, and acoustic pressure measurements are made on a cam-follower setup with combined rolling-sliding contact. Experiments are performed under different conditions of friction, lubrication, load, and speed. Contact forces are back-calculated using the kinematics. The transfer function relating the acoustic pressure to different forces is estimated. It is observed that the contact parameters govern the transfer function and hence the vibro-acoustic systems. The developed transfer function is useful in designing better sub-systems with combined rolling-sliding contact to reduce noise exposure, as a direct technique to relate the contact parameters to the noise does not exist. This study can be extended to other complex systems such as gears and clutches.

12:00 PM 04-Aug-2021 **IN21_3080.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3080

Development of a Unique Experimental System Investigating Vibroacoustic Characteristic of Geared Transmission Systems

Umut Murat Gök, Osman Taha Sen

Gearboxes are widely using in industry, especially in automotive transmission systems. In actual technology level, different component-based quality control methods are applied for the quality control of powertrains but test systems, designed for assembled products, are based on subjective evaluations and scalar measurement of total sound pressure. These systems, especially operating in industrial conditions where background noise is effective, cannot meet the technical requirements. In this paper, the development of a unique experimental platform, capable of testing the powertrain under real operating conditions (torque, rotational speeds), and the experimental results are explained. In the system where transmission error, noise and vibration measurements are carried out, defective samples were determined according to statistical evaluations and errors were classified. In future studies, using the ability to calculate mechanical efficiency based on measurements, the correlation between deviations in mechanical efficiency and transmission error will be examined.

12:20 PM 04-Aug-2021 **IN21_1795.pdf** **DOI:** https://doi.org/10.3397/IN-1795-3080

Vibration level induced by the friction of two rough surfaces weakly loaded

Modeste Assemien, Alain Le Bot

This paper presents an experiment to measure the vibration level generated when a light solid slides over a dry and rough surface. The experimental set-up is based on linear constant motion with speed range from 1 to 1000 mm/sec. The aim is to study the evolution of the vibration level as a function of the sliding speed and the friction area. Measurements show that the vibration level is a logarithmic increasing function of the sliding speed with a transient velocity. It is also observed that two regimes exist for the evolution of vibration level versus apparent contact area. On the one hand the vibration level is proportional to the friction area, but on the other hand this level is constant.

Session: 02.04 Uncertainty and Variability in Vibro-Acoustics

Channel 1

12:40 PM 04-Aug-2021 **IN21_2844.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2844

Welding distortion generated uncertainties in the vibrational behavior of a ladder-like structure

David Sipos, Marcell Ferenc Treszkai, Daniel Feszty

Recent developments in acoustic simulation methods allowed engineers to assess the vibroacoustic behavior of various type of structures within a virtual environment, thus allowing the replacement of prototype-based development with simulations. However, there are some factors, that cannot be considered in simulations in advance. In the present study, the effect of the distortions generated due to welding on a ladder-like structure equipped with flat plates was investigated. The measured acceleration frequency response functions were compared to finite element simulation results. The measured responses differed significantly from the simulation, even in the low frequency range, where the global modes were not expected to be altered or vanished. Investigation of the simulated results revealed that the additional modes were related to the vibration of the plates, which were assumed to be flat, instead of considering the warping caused by the welding process. After measuring the approximate deformation of the plates, an updated simulation model was made, introducing an approximate curvature in them. The results obtained with the updated simulation model performed much better in the low frequency range as well as in the third octave-averaged frequency bands up 1200 Hz. The sensitivity of the warping was also systematically evaluated.

1:00 PM 04-Aug-2021 **IN21_1670.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1670

Comparison of quadrature and regression based generalized polynomial chaos expansions for structural acoustics

Gage Walters, Andrew Wixom, Sheri Martinelli

This work performs a direct comparison between generalized polynomial chaos (GPC) expansion techniques applied to structural acoustic problems. Broadly, the GPC techniques are grouped in two categories: , where the stochastic sampling is predetermined according to a quadrature rule; and , where an arbitrary selection of points is used as long as they are a representative sample of the random input. As a baseline comparison, Monte Carlo type simulations are also performed although they take many more sampling points. The test problems considered include both canonical and more applied cases that exemplify the features and types of calculations commonly arising in vibrations and acoustics. A range of different numbers of random input variables are considered. The primary point of comparison between the methods is the number of sampling points they require to generate an accurate GPC expansion. This is due to the general consideration that the most expensive part of a GPC analysis is evaluating the deterministic problem of interest; thus the method with the fewest sampling points will often be the fastest. Accuracy of each GPC expansion is judged using several metrics including basic statistical moments as well as features of the actual reconstructed probability density function.

1:20 PM 04-Aug-2021 **IN21_2211.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2211

Variance Quantification of Different Additive Manufacturing Processes for Acoustic Meta Materials

Manuel Bopp, Arn Joerger, Matthias Behrendt, Albert Albers

Many concepts for acoustic meta materials rely on additive manufacturing techniques. Depending on the production process and material of choice, different levels of precision and repeatability can be achieved. In addition, different materials have different mechanical properties, many of which are frequency dependent and cannot easily be measured directly. In this contribution the authors have designed different resonator elements, which have been manufactured utilizing Fused Filament Fabrication with ABSplus and PLA, as well as PolyJet Fabrication with VeroWhitePlus.

All structures are computed in FEA to obtain the calculated Eigenfrequencies and mode shapes, with the respective literature values for each material. Furthermore, the dynamic behavior of multiple instances of each structure is measured utilizing a 3D-Laser-Scanning Vibrometer under shaker excitation, to obtain the actual Eigenfrequencies and mode shapes. The results are then analyzed in regards to variance between different print instances, and in regards to accordance between measured and calculated results. Based on previous work and this analysis the parameters of the FEA models are updated to improve the result quality.

1:40 PM 04-Aug-2021 **IN21_2543.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2543

Assessment of digital image correlation vibrometry in the presence of thermal flow disturbance

Kenji Homma, Paul R. Braunwart, Patrick L. Clavette

Digital Image Correlation (DIC) is an image-based method for measuring displacement and/or stain on the surface of a structure. When coupled with a stereo pair of highspeed cameras, DIC can also capture three-dimensional dynamic deformation of a structure under vibratory loading. However, high frequency and small amplitude displacement typically associated with structural vibrations mean that extra care is required during measurement and data processing. It becomes more challenging when thermal disturbances are present in the optical path, for example

from a heated air flow, which introduces extraneous noise due to disturbances in the refractive index. In the present study, a simple composite plate was vibrated under a shaker excitation and stereo DIC measurements were performed. The obtained vibratory displacement results were compared against accelerometers and a laser Doppler vibrometer. Heated air flow was introduced in front of the plate to observe the effects of thermal disturbances on the DIC measurements. Although the contributions from the thermal disturbances were clearly visible in the DIC displacement data, it was shown that the vibratory deflections of the structure could still be extracted by post processing of the DIC data.

Session: 04.03 Spatial Audio, Part 1
Channel 1

2:20 PM 04-Aug-2021 **IN21_1751.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1751

3-D sound field reproduction with reverberation control on surround sound system by combining parametric and electro-dynamic loudspeakers

Yuna Harada, Kenta Iwai, Masato Nakayama, Takanobu Nishiura

Recently, with the development of video technology, 3-D sound field reproduction systems that can provide a high presence have attracted attention. Conventional systems with electro-dynamic loudspeakers have a problem that the sound image lacks sharpness when constructing a narrow sound image. To solve this problem, we utilize a parametric array loudspeaker which has sharp directivity by the straightness of ultrasounds. Parametric array loudspeakers can produce sharper sound images due to the sharper directivity and lower reverberation compared with electro-dynamic loudspeakers. However, it is difficult to represent reverberation by parametric array loudspeakers. In this paper, we propose a method for 3-D sound field reproduction to achieve both the sharp images and reverberation presence by combing parametric array loudspeakers and electro-dynamic loudspeakers in surround sound system. In the proposed method, sharp sound images are rendered by parametric array loudspeakers and the reverberation presence is provided by electro-dynamic loudspeakers, emitting reverberation signals synthesized with a reverberation control filter. The reverberation control filter is adaptively designed to reproduce the reverberation time and the direct-to-reverberation ratio of the target sound field in other environments. The experimental results show that the proposed method can achieve the reproducing the sharp sound image with some reverberation presence.

2:40 PM 04-Aug-2021 **IN21_2820.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2820

Regularized spherical harmonics-domain spatial active noise cancellation in a reverberant room

Shoken Kaneko, Nirupam Roy, Nail Gumerov, Ramani Duraiswami

Active Noise Cancellation (ANC) at a target area in an open space, as opposed to cancellation in the ears through headphones, can lead to future applications. For instance, a personal acoustic environment in an airplane seat or inside a car, or a quiet zone in a noisy shared workspace can be possible using such open-space ANC without any uncomfortable on-body audio equipment. Recent advancements reinforce the practicality of such systems. However, regularization of the cancellation signal has been a crucial challenge in open-space ANC as it causes amplification of noise at locations away from the target area. This work presents a spherical harmonics-domain feed-forward spatial ANC method with a room-wide global cost function to address this issue. This room-wide global cost function is used for optimizing the set of regularization hyperparameters, while at run time only local information captured by a microphone array surrounding the target listening zone is required. Numerical experiments applying the proposed method in a simulated reverberant room show the effectiveness of the proposed method in creating a specific zone of silence with low to moderate noise amplification in the rest of the room.

3:00 PM 04-Aug-2021 **IN21_2956.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2956

Head tracker using webcam for auralization

William D'Andrea Fonseca, Davi Rocha Carvalho, Jacob Hollebon, Paulo Henrique Mareze, Filippo Maria Fazi

Binaural rendering is a technique that seeks to generate virtual auditory environments that replicate the natural listening experience, including the three-dimensional perception of spatialized sound sources. As such, real-time knowledge of the listener's position, or more specifically, their head and ear orientations allow the transfer of movement from the real world to virtual spaces, which consequently enables a richer immersion and interaction with the virtual scene. This study presents the use of a simple laptop integrated camera (webcam) as a head tracker sensor, disregarding the necessity to mount any hardware to the listener's head. The software was built on top of a state-of-the-art face landmark detection model, from Google's MediaPipe library for Python. Manipulations to the coordinate system are performed, in order to translate the origin from the camera to the center of the subject's head and adequately extract rotation matrices and Euler angles. Low-latency communication is enabled via User Datagram Protocol (UDP), allowing the head tracker to run in parallel and asynchronous with the main application. Empirical experiments have demonstrated reasonable accuracy and quick response, indicating suitability to real-time applications that do not necessarily require methodical precision.

3:20 PM 04-Aug-2021 **IN21_2190.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2190

Precision of inertial measurement unit sensors in head-tracking systems used for binaural synthesis

Kristian Jambrosic, Vedran Planinec, Marko Horvat, Peter Francek

Binaural synthesis is the most used sound system for diverse virtual and augmented reality systems nowadays, given its simplicity of implementation and the need of using only two audio channels. It is widely used in computer games, auralization and even audio production. To achieve the most natural sound field recreation, systems used for binaural synthesis must include a head-tracking sensor to dynamically calculate the binaural signal for the head orientation at any given moment. This is done by inertial measurement unit (IMU) sensors, specifically

the triaxial accelerometers, gyroscopes, and magnetometers. Simpler systems, e.g., Arduino or other embedded systems, provide only raw sensor data, and the orientation is calculated by a processing unit. Other, more complex systems such as smartphones or VR headsets already calculate their position from the raw data using complex sensor integration algorithms. In this paper, a measurement procedure for measuring the precision of IMU sensors is presented. The need of absolute orientation calibration is addressed, and challenges of sensor data drift are discussed. Measurement results for simple embedded systems and complex systems found in smartphones are presented, and an estimation of IMU sensor quality for binaural synthesis is made.

Session: 02.02 Inverse Approaches in Vibro-Acoustics
Channel 2

6:00 AM 04-Aug-2021 **IN21_2565.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2565

Effect of junction type on the vibroacoustic response of a system of plates

Marcell Treszkai, Daniel Feszty

Modelling of junctions is one of the most challenging tasks in vibroacoustics, especially for Statistical Energy Analysis (SEA), where the results heavily depend on the damping (DLF) and coupling loss factors (CLF). Also, it is an interesting question to determine that to what extent does the DLF or CLF contribute to the overall vibroacoustic characteristics of a structure? The aim of this paper is to investigate via measurements and SEA simulations the effect of the ratio of DLF and CLF on the response of a system for various junctions, such as riveting, bolting, line and point welding, between two steel plates. Loss matrices are determined experimentally by the Power Injection Method in the 200-1600 Hz frequency range. The simulation was performed in the ESI VA One software by using its analytical CLF formulations and compared to experimental data. For the reference case, a bended plate structure was considered, representing an ideal junction between two subsystems. This was equipped with damping foils to ensure the same weight and then compared to the results from other joints. Results showed that increasing the CLF could be more effective than focusing on increasing the DLF.

6:20 AM 04-Aug-2021 **IN21_1696.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1696

Traveling-wave control of the bending wave in a beam for high quality sound radiation

Ki-Ho Lee, Jeong-Guon Ih, Donghyun Jung

The bending wave generated by the actuator exciting a panel can be controlled to be in the traveling wave form void the structural resonances, which deteriorates the radiated sound if the panel is used as a speaker. Although such traveling-wave control method (TCM) yields a wider effective frequency range than the modal control method, the requirement of using many actuators is the practical problem yet. If a beam is employed instead of a plate as a panel speaker, the number of actuators can be reduced despite a smaller radiating surface than a plate. This study adopts three actuators for the beam control using TCM. An actuator excites the beam in the middle position, and the two actuators near the two edges are used to suppress the reflected waves from the boundaries. The control result shows that the driving-point mobility of the primary actuator is converted into that of an infinite beam, which means that the boundaries are changed into anechoic ones and the structural resonances are eliminated. Accordingly, the beam radiates a smooth sound spectrum without sharp peaks and troughs related to the resonant responses. Effects of material and dimension in determining the effective frequency range are also explored.

6:40 AM 04-Aug-2021 **IN21_2655.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2655

Computation analysis of regularization methods and parameter selection for acoustics radiation modes source reconstruction of vibrating plates

Luis Corral, Pablo E. Román

Source localization and power estimation is a topic of great interest in acoustics and vibration. Acoustic source radiation modes reconstruction is a method of particular interest. Solutions leads to determinate sound/vibration power and surface velocity distribution from sparse acoustics samples. It has been shown that the quality of the results depends on Tikhonov regularization parameter. This inverse method is based on the radiation resistance matrix and we show that a single instruction multiple threads computing approach for graphics processing unit device exhibit better speed performance than common approaches to achieve the solution. We compare four regularization and three estimating methods for regularization parameters. We use a similarity measure to the simulated cases in three frequencies. Tikhonov regularization exhibits best reconstruction results. However, truncated singular vector decomposition also shows good performance with the advantage of not using a regularization parameter. Graphics processing unit implementation reduce reconstruction's computing time at least in a half.

7:00 AM 04-Aug-2021 **IN21_1966.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1966

Vehicle interior noise and vibration prediction by combination analyses of Component and Operational TPA

Takuma Tanioka, Junji Yoshida

In this study, we propose an analytical method consisting of Operational TPA (OTPA) and Component TPA (CTPA) to predict the vehicle interior noise and vibration without the vehicle operational test in case the noise source such as engine was modified. In the proposed method, the blocked force of the noise source was obtained at a test bench and the vibration at the source attachment point on the vehicle was calculated by CTPA. After then, the response point signal (interior noise / vibration) is estimated from several reference point signals including the calculated vibration by OTPA. For the verification of this method, a simple vehicle model which is composed of four tires and a motor was prepared in addition to a test bench. OTPA was firstly applied to the vehicle model to analyze the contribution from tires and a motor to the body vibration (response point). The blocked force of a modified motor was obtained by CTPA at the test bench and the force was used to

predict the response point by OTPA. Finally, the estimated interior vibration was compared with the actual measured response point vibration when the motor was replaced on the vehicle model and the accuracy was verified.

Session: 02.03 Numerical Methods in Vibro-Acoustics, Part 3
Channel 2

7:40 AM 04-Aug-2021 **IN21_2721.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2721

The vibrational response of a fluid-loaded baffled plate near a free surface

Jamie Kha

An analytical model to predict the vibrational response of a simply supported rectangular plate embedded in an infinite baffle with an upper free surface under heavy fluid loading and excited by a point force is presented. The equations of motion of a thin plate are solved using------ modal decomposition technique by employing admissible functions for an in-vacuo plate and by directly solving the Helmholtz equation for acoustic waves in a fluid. The vibrational response for a flat plate in an infinite baffle and unbounded domain (semi-infinite domain) using analytical formulation available in literature is initially computed. These results are then compared against present results to observe the effect of a free surface. Predictions from analytical models are validated by comparison with results obtained by numerical models. The proposed analytical approach presents a novel formulation to describe a fluid-loaded flat plate in a waveguide and an efficient method for predicting its vibrational response.

8:00 AM 04-Aug-2021 **IN21_3986.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3986

Study on target energy transfer of 3D acoustic cavity - plate coupling system with the membrane nonlinear energy sink

Jinmeng Yang, JianWang Shao, GuoMing Deng, Xian Wu

The target energy transfer (TET) between a membrane nonlinear energy sink (NES) and the acoustic medium inside a rectangular cavity is studied. The acoustic medium is interacted with a plate and multi-order modes coupling of the 2 structure is considered. Based on the modal expansion approach, with Green's function, Helmholtz equation and the boundary conditions of the acoustic medium and the plate, the coupling coefficient matrix of the mode of 2 structures is derived. The equations of the membrane NES, multi-order modes of the acoustic medium and multi-order modes of the plate are established, and numerical analysis is used to investigate the TET phenomenon. The results show that in condition of a single-point excitation to the plate, under a certain range of excitation levels, the membrane can be seen as a kind of NES, and the energy in the acoustic medium can be unidirectionally transmitted to the membrane NES and attenuated, reducing the sound pressure level in the cavity. At the same time, it is found that the NES can suppress multi-order sound pressure of the acoustic medium at the same time, and realize the control of cascaded resonance noise.

8:20 AM 04-Aug-2021 **IN21_2164.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2164

Joint modeling for the analytical estimation of dynamic behaviors of beam-coupled structures

Hansol Park, Yeon June Kang, Hee Soo Pyo

In this study, analytical method is applied for the estimation of dynamic behaviors of beam-coupled structures. Mathematical expressions are given with terms of shape factors, material information and assembly angles of each sub-component. Based on Euler-Bernoulli beam theory, entire formulation is built with compatibility of system dynamics. The coupled structures are divided into two types, point coupling and mass coupling, related with the properties of coupling points. Point coupling is commonly used assumption that two sub-components are combined with lumped spring or damping, and mass coupling has undeformable rigid joint which has mass and inertia like welded structures. Dynamic properties of coupled structures are predicted in forms of frequency response functions and spectral responses about given forces. The verification process is conducted for assessing the accuracy of the estimation formula by using modal frequencies and mode shapes of beam-coupled structures. Extracted modal parameters from experimental modal analysis and finite element method are adopted as reference values for verification.

8:40 AM 04-Aug-2021 **IN21_1634.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1634

Predicting vibration transmission across junctions using diffuse field reciprocity

Wannes Stalmans, Cédric Van hoorickx, Edwin Reynders

Predicting the sound insulation of an engineering system is a complex problem since not only the direct path through a separating element but also the flanking transmission paths can largely influence the sound insulation of the system. When conventionally analyzing flanking transmission, a diffuse field is assumed in the walls and floors, which are modelled as plates. The junction connecting the walls and floors is assumed to be of infinite extent and the transmission of vibration across the junction is calculated by integrating over all possible angles of incidence. Due to the limitations of the conventional approach, a new approach based on diffuse field reciprocity is proposed. The diffuse field reciprocity relationship relates the vibration transmission to the direct field of a diffuse subsystem to the direct field dynamic stiffness of the subsystem, i.e., the dynamic stiffness of the equivalent infinite subsystem as observed at the junction. The direct field dynamic stiffness matrices of thin, isotropic, elastic plates can be analytically derived. For more complex walls or floors a possible approach is to calculate the

direct field dynamic stiffness using finite elements and perfectly matched layers. The perfectly matched layer surrounding the finite element model absorbs the wave propagating outwards from the bounded domain, thus simulating an infinite subsystem.

9:00 AM 04-Aug-2021 **IN21_1636.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1636

Impact sound prediction of finite floor structures with the modal transfer matrix method

Jasper Vastiau, Cédric Van hoorickx, Edwin Reynders

The transfer matrix method (TMM) is commonly employed for wave propagation analysis in layered media of fluid, elastic and porous nature. Up to now it has been used extensively to analyze airborne sound transmission and sound absorption. Its use for impact sound transmission has been investigated to a limited extent, i.e. for thick homogeneous elastic plates of infinite extent and for specific receiver points. This contribution aims to broaden the scope such that the global impact sound, radiated by finite floor structures containing elastic, fluid and/or porous layers, can be analyzed in a more robust way than previously available in literature. A disadvantage of the conventional TMM is that only floors of infinite extent can be implemented. It is possible to remove this drawback using a spatial windowing technique. Furthermore, the modal behavior of the floor is approximately taken into account by projecting the impact force onto the mode shapes and only allowing for the propagation of those waves, corresponding to modal wavenumbers, in the structure. Predictions of the radiated sound power are made for various bare floors and floating floor systems of both infinite and finite extent.

Session: 04.00 Signal Processing, Measurements, Sound Reproduction, Diagnostics for Noise and Vibration Engineering, General, Part 3
Channel 3

6:00 AM 04-Aug-2021 **IN21_1037.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1037

Research on Optimization method of power flow of cylindrical shell stiffener based on BESO

Xiaoyan Teng, Zhihua Yan, Xudong Jiang, Qiang Li

In order to establish a method for topological optimization of the power flow response of a cylindrical shell stiffener structure based on BESO, this paper will combine the BESO topology optimization theoretical and the power flow response theory , and take the overall minimization of the power flow of the cylindrical shell stiffener structure as the optimization goal. Then an iterative optimization algorithm for the layout of the stiffener structure on the cylindrical shell surface can be established.
The plate-beam coupling structure is used to simulate the cylindrical shell stiffener structure, a finite element model of the cylindrical shell stiffened is established and solved to obtain the power flow sensitivity of the finite element. This is used as an iterative criterion for the layout of the stiffener on the surface of the cylindrical shell structure optimize. Through the analysis of numerical examples, it is obtained that the optimization of the rib layout can better reduce the overall power flow response of the structure, which also verifies the feasibility of the optimization method.

6:20 AM 04-Aug-2021 **IN21_2804.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2804

A study of the effects of structural delamination location on delamina-tion detection using a non-linear chaotic oscillator method

Xuan Li, Dunant Halim, Xiaoling Liu

This work aims to investigate the effects of structural delamination location on the effectiveness of delamination assessment using a vibration-based non-linear chaotic oscillator method. The change in structural vibration characteristics due to delamination at different structural locations can pose a challenge for accurate delamination detection due to the possible weak changes in the measured vibration signal and the existence of noise that can corrupt the signal. Thus in this work, a chaotic oscillator method was used due to its sensitivity to relatively small changes in measured vibration signal and robustness to measurement noise. The effects of vibration sensing location on the sensitivity in detecting the location of delamination was also investigated in this work. The Lyapunov Exponent was used in conjunction with the chaotic oscillator as a damage index, for the purpose of defining an effective measure to locate the delamination damage in a laminated structure. The correlation between the damage index and vibration sensing location for different delamination locations was investigated for a laminated beam structure, with a method for finding an optimal location for vibration sensors proposed. It was found that a vibration sensor placed in selected structural regions can provide an increased level of sensitivity in detecting certain delamination locations. The results from this work also demonstrated the effectiveness of the developed method in determining an optimal placement for vibration sensors for delamination detection.

6:40 AM 04-Aug-2021 **IN21_2806.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2806

Assessment of delamination location in composite laminates based on a chaotic oscillator method

Xuan Li, Dunant Halim, Xiaoling Liu

The work aims to study the assessment of delamination location in composite laminates using vibration measurement with a chaotic oscillator method. Delamination is a type of damage that commonly occurs in composite laminates, which can cause a severe degradation of their material properties. The traditional vibration-based methods can encounter difficulties in detecting and locating these delamination-type damages especially when the size of delamination is relatively small and there is a significant level of noise in its vibration measurement. With this particular consideration, a vibration-based method using a non-linear chaotic oscillator was used in this study due to its sensitivity to the change in vibration signal characteristics. A numerical model of composite laminates with delamination damage under harmonic excitation was developed and the vibration signal obtained from composite laminates was processed using the chaotic oscillator method. A feature named

Lyapunov Exponent (LE) was used as a delamination damage index to describe the characteristics of the chaotic oscillator for cases with delamination at varying structural locations. The effects of delamination locations on the developed damage index were analyzed in this work. The results showed that there was a strong correlation between the delamination location and the LE feature, even for the case with a relatively high level of measurement noise. The results demonstrated the effectiveness of the method to identify delamination in composite laminates, which has also the potential to be used to detect other types of damages.

7:00 AM 04-Aug-2021 **IN21_2537.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2537

Novel features for the detection of bearing faults in railway vehicles

Matthias Kreuzer, Alexander Schmidt, Walter Kellermann

In this paper, we address the challenging problem of detecting bearing faults from vibration signals. For this, several time- and frequency domain features have been proposed. However, these proposed features are usually evaluated on data originating from relatively simple scenarios and a significant performance loss can be observed if more realistic scenarios are considered. To overcome this, we introduce Mel Frequency Cepstral Coefficients (MFCCs) and features extracted from the Amplitude Modulation Spetrogram (AMS) as features for the detection of bearing faults. Both AMS and MFCCs were originally introduced in the context of audio signal processing but it is demonstrated that a significantly improved classification performance can be obtained using the proposed features. Furthermore, the data imbalance problem that is prevailing in the context of bearing fault detection, meaning that typically much more data from healthy bearings than from damaged bearings is available. Therefore, we propose to train a One-class SVM with data from healthy bearings only. Bearing faults are then classified by the detection of outliers. Our approach is evaluated with data measured in a highly challenging scenario comprising a state-of-the-art commuter railway engine which is supplied by an industrial power converter and attached to a gear and load.

7:20 AM 04-Aug-2021 **IN21_2403.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2403

Influence of the bolt size on the source of damping in automotive joints

Shaan Sanjeev, Dan J. O'Boy, Paul Cunningham, Steve Fisher

Experimental tests are carried out on automotive bolted joints to study the influence of the bolt size on the source of damping during dynamic loading. Aluminium beams and five different bolt sizes are chosen and used to assemble single-lap joints under strictly controlled experiments. Measurements are taken to estimate the energy loss during forced excitation and to identify the source of damping in jointed structures, and an analogous monolithic solid beam is also used during the experimental investigation to isolate the joint effects and compare the data gathered. The dynamic response of the jointed structure exposed to forced excitation is captured under free-free boundary conditions. The motion of the assembled structure is identified by carrying out a finite element analysis.

Session: 04.02 Signal Identification and Source Separation
Channel 3

7:40 AM 04-Aug-2021 **IN21_11599.pdf** **DOI:** https://doi.org/10.3397/IN-2021-11599

A real-time music detection method based on convolutional neural network using Mel-spectrogram and spectral flux

Yiya Hao, Yaobin Chen, Weiwei Zhang, Gong Chen, Liang Ruan

Audio processing, including speech enhancement system, improves speech intelligibility and quality in real-time communication (RTC) such as online meetings and online education. However, such processing, primarily noise suppression and automatic gain control, is harmful to music quality when the captured signal is music instead of speech. A music detector can solve the issue above by switching off the speech processing when the music is detected. In RTC scenarios, the music detector should be low-complexity and cover various situations, including different types of music, background noises, and other acoustical environments. In this paper, a real-time music detection method with low-computation complexity is proposed, based on a convolutional neural network (CNN) using Mel-spectrogram and spectral flux as input features. The proposed method achieves overall 90.63% accuracy under different music types (classical music, instruments solos, singing-songs, etc.), speech languages (English and Mandarin), and noise types. The proposed method is constructed on a lightweight CNN model with a small feature size, which guarantees real-time processing.

8:00 AM 04-Aug-2021 **IN21_2205.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2205

CNN-based multi-class multi-label classification of sound scenes in the context of wind turbine sound emission measurements

Nils Poschadel, Christian Gill, Stephan Preihs, Jürgen Peissig

Within the scope of the interdisciplinary project WEA-Akzeptanz, measurements of the sound emission of wind turbines were carried out at the Leibniz University Hannover. Due to the environment there are interfering components (e. g. traffic, birdsong, wind, rain, ...) in the recorded signals. Depending on the subsequent signal processing and analysis, it may be necessary to identify sections with the raw sound of a wind turbine, recordings with the purest possible background noise or even a specific combination of interfering noises. Due to the amount of data, a manual classification of the audio signals is usually not feasible and an automated classification becomes necessary. In this paper, we extend our previously proposed multi-class single-label classification model to a multi-class multi-label model, which reflects the real-world acoustic conditions around wind turbines more accurately and allows for finer-grained evaluations. We first provide a short overview of the data acquisition and the dataset. We then briefly summarize our previous approach, extend it to a multi-class multi-label formulation, and analyze

the trained convolutional neural network regarding different metrics. All in all, the model delivers very reliable classification results with an overall example-based F1-score of about 80 % for a multi-label classification of 12 classes.

8:20 AM 04-Aug-2021 **IN21_1753.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1753

Speech extraction with RGB-intensity gradient on rolling-shutter video

Tsubasa Yoshizawa, Atsushi Yoshida, Kenta Iwai, Takanobu Nishiura

Recent studies have been proposed to extract speech from the captured video of objects vibrating by sound waves. Among them, from the viewpoint of equipment cost, the method of extracting speech from the video captured by rolling-shutter cameras, which are widely used in consumer digital single-lens reflex cameras, has been attracting attention. The conventional method with the rolling-shutter video uses a grayscale video for processing based on phase images. However, a grayscale video has a smaller dynamic range than an RGB video, and thus the speech extraction accuracy of the conventional method degrades. Therefore, this paper proposes a speech extraction method based on RGB-intensity gradients on an RGB video to improve speech extraction accuracy. The proposed method extracts the speech by calculating the similarity of R, G, and B intensity gradients, and using these three intensity gradients expands the dynamic range. The experimental results on the quality and intelligibility of the extracted speech show our proposed method outperforms the conventional method.

8:40 AM 04-Aug-2021 **IN21_2599.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2599

Subjective hearing sensation of process variations at a milling machine. How reliable will chatter marks be detected?

Florian Trautmann, Björn Knöfel, Welf-Guntram Drossel, Jan Troge, Markus Freund, Lars Penter, Damian Anders

Intuition enables experienced machine operators to detect production errors and to identify their specific sources. A prominent example in machining are chatter marks caused by machining vibrations. The operator's assessment, if the process runs stable or not, is not exclusively based on technical parameters such as rotation frequency, tool diameter, or the number of teeth. Because the human ear is a powerful feature extraction and classification device, this study investigates to what degree the hearing sensation influences the operators decision making. A steel machining process with a design of experiments (DOE)-based variation of process parameters was conducted on a milling machine. Microphone and acceleration sensors recorded machining vibrations and machine operators documented their hearing sensation via survey sheet. In order to obtain the optimal dataset for calculating various psychoacoustic characteristics, a principle component analysis was conducted. The subsequent correlation analysis of all sensor data and the operator information suggest that psychoacoustic characteristics such as tonality and loudness are very good indicators of the process quality perceived by the operator. The results support the application of psychoacoustic technology for machine and process monitoring.

Session: 08.05 Transmission and Drivetrain Noise

Channel 4

6:00 AM 04-Aug-2021 **IN21_1860.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1860

A study on the development and application of program for planetary gear design considering planetary gear noise and efficiency

Hyun Ku Lee, Moo Suk Kim, Sa Man Hong, Dong Kyu Yoo, Ahmet Kahraman, Jonny Harianto

In general, gear mechanical loss is associated with the friction of the lubricating contact surface of the gear and bearing that transmit the power, and a no-load spin loss which is load independent occurs due to gear rotation and the interaction of the bearing component with the lubricating element. In order to minimize planetary gear loss, it is desirable to design by checking the efficiency at the concept design stage. However, a design technique that considers the noise and efficiency of a planetary gear set simultaneously has not been achieved so far. In this paper, a program called 'pRMC with EHL' to check together the efficiency and noise that affected by gear specifications has been developed. By using developed program, planetary gear sets specifications have been designed. And through the experimental evaluation, automatic transmission efficiency could be reduced by 0.3% in combination fuel consumption mode and the planetary gear vibration could be also reduced by 10 dB than former design. Through this designing verification and input parameter correlation, a new planetary gear set designing process has been come up with successfully at the concept design stage.

6:20 AM 04-Aug-2021 **IN21_2140.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2140

Performance of a friction ring DVA for vibration control of a flywheel

Xiaodong He, Xiuchang Huang, Xiuchang Huang, Hongxing Hua

A flexible ring DVA with friction contact interfaces (essentially a viscoelastic-friction DVA) is proposed to suppress vibration of a flywheel, two other cases are also studied, i.e., viscoelastic DVA and friction DVA. Based on an equivalent 3 degrees of freedom (DOFs) dynamic model, displacement response of the flywheel-DVA are obtained by using harmonic balance method (HBM). It is shown that all three types of DVA can suppress vibration of the flywheel effectively, bandwidth of the viscoelastic-friction DVA is enlarged due to the existence of friction interface. Performances of the DVA are evaluated by analyzing the displacement responses and forces (i.e., spring force, damping force and friction force). It is shown that the frequency corresponding to the turning point on the response curve is the critical frequency at which dynamic vibration absorption takes place, and it is also the frequency at which the friction force begins to take effect. In the process of emergence and disappearance of the dynamic vibration absorption, the friction force plays a role similar to a

6:40 AM 04-Aug-2021 **IN21_1799.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1799

Low excitation spur gears with variable tip diameter

Joshua Götz, Sebastian Sepp, Michael Otto, Karsten Stahl

One important source of noise in drive trains are transmissions. In numerous applications, it is necessary to use helical instead of spur gear stages due to increased noise requirements. Besides a superior excitation behaviour, helical gears also show additional disadvantageous effects (e.g. axial forces and tilting moments), which have to be taken into account in the design process. Thus, a low noise spur gear stage could simplify design and meet the requirements of modern mechanical drive trains.
The authors explore the possibility of combining the low noise properties of helical gears with the advantageous mechanical properties of spur gears by using spur gears with variable tip diameter along the tooth width. This allows the adjustment of the total length of active lines of action at the beginning and end of contact and acts as a mesh stiffness modification. For this reason, several spur gear designs are experimentally investigated and compared with regard to their excitation behaviour.
The experiments are performed on a back-to-back test rig and include quasi-static transmission error measurements under load as well as dynamic torsional vibration measurements. The results show a significant improvement of the excitation behaviour for spur gears with variable tip diameter.

7:00 AM 04-Aug-2021 **IN21_1876.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1876

Acoustical behavior of loss-optimized involute gears

Sebastian Sepp, Joshua Goetz, Karsten Stahl

The progressing electrification of vehicle drive systems focuses more and more on efficient high-speed concepts. Increasing the motor speed leads to a higher power density of the electrified power train and thereby to an increased range for battery electric vehicles. The high rotational speeds cause new challenges in designing gearboxes regarding the efficiency and the acoustical behavior. Most present gearings in conventional vehicles are designed with high tooth depths to ensure low noise excitation behavior combined with the best possible efficiency. By changing the gear geometry to smaller tooth depths with higher pressure angles, it is possible to further decrease gear losses. However, the loss-optimized gear geometry must not jeopardize the beneficial acoustical behavior. In theoretical studies, the acoustical behavior of loss-optimized gears are investigated and compared to gearings designed according to the state of the art. Design calculations of the excitations of all ideal gears without deviations are on similar levels. However, application of such gear geometries faces severe challenges because the sensitivity to manufacturing deviations may be high. In this paper, simulation results and test results between low-NVH gears and loss-optimized gears are documented and analyzed.

7:20 AM 04-Aug-2021 **IN21_1852.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1852

Vibrational Monitoring of Nested Planetary Geartrain with Unground Pinion

Jianxiong Feng, Yangfan Liu, Kai Ming Li

The nested planetary gear train, which has two integrated single-stage planetary gearsets, is one of the newly developed compound gear train that has been successfully applied to the automobile transmissions. In the current study, a certain type of gear fault in the nested gear train, ungrounded pinion, is investigated using a non-destructive approach monitoring its vibration levels. A novel experimental test stand with open and vertical setup has been designed to collect the vibrational data by mounting the accelerometer directly to the gear clutches. Each of the two layers of the compound gear was tested separately. The measured vibrational data were processed with several signal processing techniques, which includes (a) frequency spectrum analysis, (b) time synchronous averaging (TSA) and (c) modulation sideband analysis. The experimental results show that the existence of the ungrounded pinion can be identified with the frequency spectrum analysis of the vibrational data. In addition, the modulation sidebands are also modeled using a modified version of the traditional technique of physical signal modeling. It is shown that the relative phase of the planet and the meshing vibration strength changed by the unground gear is the critical factor for determining the modulation sideband behavior. In addition, the location of the ungrounded pinion can also be determined by the time history processed by TSA.

7:40 AM 04-Aug-2021 **IN21_2377.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2377

An experimental methodology to study engine gear rattle problems

Ata Donmez, Ahmet Kahraman

Gear induced noise represents a major part of overall automotive drivetrain noise. Gear rattle noise is caused by strongly nonlinear dynamic behavior of the gear pair, primarily due to external torque of speed fluctuations under lightly loaded conditions. Such loading conditions cannot be generated by using the conventional gear dynamics test set-ups that employ power recirculating gearbox arrangements or conventional electric motors. In this paper, a new test set-up is introduced to emulate the actual torque/velocity fluctuations of the input and/or output members of a gear train through three-phase synchronous servo-motors. In addition to establishing backlash boundaries, a pair of absolute encoders are used to measure the relative motions of the gears as well as their impacts along the drive and coast sides flanks or gears. Torsional vibratory behavior of a gear pair is presented at different backlash values under several input/output fluctuation conditions along with the companion sound pressure measurements.

Session: 10.01 Underwater and Maritime Acoustics
Channel 4

8:00 AM 04-Aug-2021 **IN21_1820.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1820

Underwater acoustic target classification based on u-shaped network

lingzhi xue, Xue Lingzhi, Zeng Xiangyang

Target recognition is a key task and a difficult technique in underwater acoustic signal processing. One of the most challenging problem is that the label information of the underwater acoustic samples is scarce or missing. To solve the problem, this paper presents a local skip connection u-shaped architecture network(U-Net)based on the convolutional neural network(CNN).To this end, the network architecture is designed cleverly to generate a contracting path and an expansive path to achieve the extraction of different scale features. More importantly, a local skip connection mechanism is proposed to optimize classification rates by reusing former feature maps in contracting path. The experimental results of the measured dataset demonstrate the recognition accuracy of the model is better than that of deep belief network(DBN) and generative adversarial network(GAN) networks.Further research on three kinds of network by visualization method shows that the proposed network can learn more effective feature information with limited samples.

8:20 AM 04-Aug-2021 **IN21_2411.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2411

Acoustic survey at Genova (Italy) Aquarium aiming at characterizing the acoustic of tropical marine environment

Giovanni Zambon, Alessandro Bisceglie, Chiara Confalonieri, Silvia Lavorano, Roberto Benocci

An acoustics survey has been performed at Genova (Italy) Aquarium aiming at characterizing the acoustic environment of tropical underwater habitats. Mid-term (5-7 days) and short-term measurements (10-20 min) within different fish tanks containing tropical habitats have been chosen for a preliminary analysis. Eco-acoustic indices and statistical-related acoustic indices have been applied to derive information on the population activity and determine the bio-acoustic richness. Such approach will be used to compare environments with different degree of disturbance and derive information on the environmental quality of both artificial and natural habitats

8:40 AM 04-Aug-2021 **IN21_2060.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2060

Ferry M/V Kramer noise mitigation

Michael Bahtiarian

The Motor Vessel (M/V) Edward V. Kramer is an aluminum vessel that operates as a small passenger ferry, which is owned and operated by the Department of Homeland Security (DHS) and used to transport DHS personnel and materials to Plum Island, NY. It was placed in service in 2018 and right from the start the sound levels inside the Main Deck compartment were found to be excessive. The original vessel specification included a noise limit of 75 dBA in the Main Deck Passenger Lounge and measured levels were as high as 87 dBA. A ship survey of sound and vibration was performed. Noise predictions to determine the controlling sound paths was also performed based on engine sound and vibration source levels. Recommendations for mitigation were presented and carried out by another shipyard. Mitigation included vibration isolation of the main engines and sound attenuation improvements to the Main Deck Passenger Lounge. After completion of the modifications, another survey was performed in 2021 and results show a reduction by as much as 11 dB in the Main Deck Passenger lounge. Noise estimation methods and details on the noise control treatments are given in the paper.

Session: 08.01 Vehicle Noise and Vibration, Part 2
Channel 4

2:00 PM 04-Aug-2021 **IN21_1642.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1642

An adjustable bearing seat stiffness element for targeted vibration influencing

Carolin Sturm, Andreas Lindenmann, Thomas Gwosch, Sven Matthiesen

In order to be able to influence the dynamic system behavior in a targeted manner, parameters such as stiffness in the technical system must be adjustable. In high-speed powertrains, the stiffness of the bearing seat, in particular, has an influence on the dynamic characteristics. As part of our research, we developed an adjustable bearing seat stiffness element. The focus of research was on an adjustable, scalable element with a small design space and the same properties over the perimeter. We characterized it statically with the help of a universal testing machine and dynamically using a shaker system. The results are compared with theoretical approaches. The results show that the stiffness is almost linearly adjustable in the load range of 0-100N. The results indicate that the developed element can be used to adjust desired stiffness and thus to influence vibrations in a targeted manner. The findings can be used in the design of high-speed powertrains e.g. in serial products or test benches.

2:20 PM 04-Aug-2021 **IN21_2561.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2561

Test bench development and validation for blocked force measurements in six degree of freedom

Martin Burkhardt, Eric Hensel, Welf-Guntram Drossel

For transfer path analysis (TPA) methods, the description of the source is essential. The possibilities of source characterization are as different as the TPA methods. For the classical methods, the source is considered in the installed state with feedback from the receiver structure, while for component-based TPA the source is described without feedback from the coupled structure. In addition to TPA, source characterization is also used in the product development process for evaluation or comparisons. Also in these cases, the source must be characterized without

feedback from the test structure, which can generally be realized by measuring free velocities or blocked forces. Because of the need of external load to reach the components operating point, force measurements are often used.
However, the realization of a reactionless test setup for the measurement of forces poses some challenges. The paper presents a setup that can be used to perform a direct force measurement at a point in six degrees of freedom. The necessary boundary conditions to approximate the idealized blocked force assumption are discussed, the calculation of the blocked force in six degrees of freedom is presented, the structural dynamic response at a reference point is calculated and compared with operational measurements.

2:40 PM 04-Aug-2021 **IN21_2501.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2501

OTPA method-based contribution analysis of components on the vibration of fuel cell in fuel cell vehicles

Zequn Nan, Matthias Behrendt, Mengting Lu, Manuel Petersen, Albert Albers

Due to the introduction of auxiliary components in fuel cell vehicle powertrains and absence of internal combustion engine, the vibration sources and transfer paths are very different from conventional vehicles. These vibrations interact on the output performance of the fuel cell system. Therefore, it is necessary to investigate the vibration characteristics of the fuel cell system under vehicle operating conditions. IPEK conducted vehicle measurements regarding different driving manoeuvres and environments. In order to quantitatively evaluate contributions of each vibration source on the total vibration of fuel cell, frequency-domain contribution was investigated based on Operational Transfer Path Analysis method with the singular value decomposition as well as principal component. The results of vibration in Z-direction in the vehicle coordinate system show that the hydrogen pump dominantly contributes to the vibration of fuel cell in a wide range of frequency in the majority of the driving manoeuvres. However, the results vary in various driving manoeuvres, environments and frequencies. The Paper will discuss in detail the vibrational contributions in X-, Y- and Z-direction.

3:00 PM 04-Aug-2021 **IN21_2865.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2865

Development of disc spring stack containment methods for vibration isolation

Paul Gilmore, Umesh Gandhi

Cone disc springs exhibit quasi-zero stiffness behavior that is useful in isolating objects from low frequency vibrations. However, the stroke of a single disc spring is too low for most applications, and springs are stacked to increase the displacement. A method to contain the isolator stack then becomes critical for practical uses. Many challenges in developing these containment methods have been identified and can be collectively described as how to appropriately contain the stack without affecting isolation performance. In this work, three designs are considered: a retaining ring design, tube and shaft design, and zero poisson ratio sleeve design. Disc spring stacks with containment method are built, and load-deflection curves are measured and compared with standalone stacks. Under quasi-static compression testing, each containment method has minimal effect on the standalone stack load-deflection curve. However, significant differences in isolation performance are observed in vibration testing and found to depend on characteristics such as lateral stability, lateral strength, and degrees of freedom. Lastly, advantages, disadvantages, and appropriate applications for each containment method are summarized. The conclusions of this work are that containment method is an important variable in the application of disc spring isolators and robust, versatile containment designs have been demonstrated.

3:20 PM 04-Aug-2021 **IN21_1917.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1917

Silencer for high-frequency turbocharger compressor noise via an acoustic straightener

Pranav Sriganesh, Rick Dehner, Ahmet Selamet

Decades of successful research and development on automotive silencers for engine breathing systems have brought about significant reductions in emitted engine noise. A majority of this research has pursued airborne noise at relatively low frequencies, which typically involve plane wave propagation. However, with the increasing demand for downsized turbocharged engines in passenger cars, high-frequency compressor noise has become a challenge in engine induction systems. Elevated frequencies promote multi-dimensional wave propagation rendering at times conventional silencer treatments ineffective due to the underlying assumption of one-dimensional wave propagation in their design. The present work focuses on developing a high-frequency silencer that targets tonal noise at the blade-pass frequency within the compressor inlet duct for a wide range of rotational speeds. The approach features a novel “acoustic straightener” that creates exclusive plane wave propagation near the silencing elements. An analytical treatment is combined with a three-dimensional acoustic finite element method to guide the early design process. The effects of mean flow and nonlinearities on acoustics are then captured by three-dimensional computational fluid dynamics simulations. The configuration developed by the current computational effort will set the stage for further refinement through future experiments.

3:40 PM 04-Aug-2021 **IN21_2184.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2184

Innovative elastomeric shear leg mount concepts for quasi-zero stiffness isolation

Luke Fredette, Rajendra Singh

Passive vibration isolation may be a cost-effective solution to isolate a supported system containing a source and/or receiver from the supporting structure. The standard linear theory suggests a low-stiffness joint to create a mobility mismatch in the transmission path, but this solution may lead to large amplitude motions in the supported system. To achieve both motion control and isolation with the same mount and without compromising either objective, an innovative, nonlinear mount concept is proposed. Taking advantage of geometric nonlinearity for large displacements, a quasi-zero stiffness is generated by exploiting the interaction between the nonlinear mechanisms that govern the motion of a number of inclined shear legs. For example, a three-regime stiffness profile is created, including a medium-stiffness preload regime, a quasi-zero stiffness isolation regime, and a high-stiffness motion control regime. This concept offers significant benefits compared with a

more conventional compromise approach in that low-amplitude vibrations are exceptionally isolated while large amplitude transient motions are controlled. Illustrative computational examples will be presented to support the underlying linear and nonlinear design principles. Limiting cases will be discussed as well.

Session: 08.03 Tire Noise, Part 2
Channel 4

7:20 PM 04-Aug-2021 **IN21_2455.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2455

Comparison of roadwheel and roadway noise generated by a mono-pitch tire tread

Richard Ruhala, Courtney Burroughs, Laura Ruhala

Tire-pavement interaction noise (TPIN, aka tire-road noise or tyre-road noise) is most efficiently measured in acoustically controlled laboratories with large diameter roadwheels (drums) that have surface treatments which replicate some pavement properties, especially when comparing the acoustic performance of different tires. However, it is not clear how closely the roadwheel replicates the road surface, including differences that include road curvature and mechanical impedance of pavements. On the other hand, measuring on a moving vehicle with a microphone array presents it own set of challenges. In this study, a Nearfield Acoustical Holography (NAH) method is used to measure tire/pavement interaction noise on roadways and roadwheels with similar smooth pavement and rough pavement properties. Sound intensity fields, overall sound power levels, and sound pressure levels are reconstructed very close to the tire surface. An experimental passenger car tire with a mono-pitch tread is used in this study. The experimental tire has three circumferential grooves and 64 equally spaced transverse grooves cut into the tread. Differences in sound fields and levels between roadway and roadwheel test conditions for this tire are shown.

7:40 PM 04-Aug-2021 **IN21_3224.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3224

Experimental Observations in Tire Cavity Resonance and Interactions with Periodic Noise Components

Kiran Patil, Jordan Schimmoeller, James Jagodinski, Sterling McBride

Tire cavity resonance is one of the major sources of tire-related in-cabin noise and vibration. It has gained more attention in recent years with the growth of the electric vehicle market. This is due to the absence of masking noise from the internal combustion engine and powertrain. Thus, the mitigation of this issue has become a critical task for tire and vehicle manufacturers. The excited cavity resonant frequency in an unloaded condition is typically between 170 – 220 Hz. However, multiple studies have shown that loading the tire will result in two dominant resonances transmitted into the cavity. Their corresponding mode shapes are typically described in terms of the direction of their characteristic acoustic pressure variation i.e., fore-aft cavity mode and vertical cavity mode. As the tire's rotational speed increases, in-cabin measurements show that the tire cavity resonant frequencies separate from each other. Further, interactions with the periodic component of tire noise at certain speeds are also observed. These periodic components can be attributed to tire non-uniformities and tread pattern related excitation. This interaction is perceived as tonal noise inside the vehicle cabin at discrete speeds. This work presents experimental results summarizing these findings.

8:00 PM 04-Aug-2021 **IN21_2889.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2889

Simulation of the frequency split of the fundamental air cavity mode of a loaded and rolling tire by using steady-state transport analysis

Won Hong Choi, J. Stuart Bolton

It has been found that when a tire deforms due to loading, the fundamental air cavity mode splits into two due to the break in geometrical symmetry. The result is the creation of fore-aft and vertical acoustic modes near 200 Hz for typical passenger car tires. When those modes couple with structural, circumferential modes having similar natural frequencies, the oscillatory force transmitted to the suspension can be expected to increase, hence causing increased interior noise levels. Further, when the tire rotates, the frequency split is enlarged owing to the Doppler effect resulting from the airflow within the tire cavity. The current research is focused on determining the influence of rotation speed on the frequency split by using FE simulation. In particular, the analysis was performed by using steady-state transport analysis which enables vibroacoustic analysis in a moving frame attached to tire in the frequency domain. The details of the modeling are described and results are given for a tire under different rotation speeds, presented in terms of dispersion curves that illustrate the interaction between structural and acoustical modes. The results are compared to those for static tires and tires spinning without translational velocity to highlight the effects of rolling.

8:20 PM 04-Aug-2021 **IN21_2609.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2609

A multibody dynamic model for predicting operational load spectra of dual clutch transmissions

Murat Inalpolat, Enes Timur Ozdemir, Bahadir Sarikaya, Hyun Ku Lee

In this paper, a generalized nonlinear time-varying multibody dynamic model of dual clutch transmissions (DCT) is presented. The model consists of clutches, shafts, gears and synchronizers, and can be used to model any DCT architecture. A nonlinear clutch model is used to determine the transmitted power to the transmission at any speed and clutch temperature. The clutch can be a single- or multi-plate clutch and can operate in a wet or dry-clutch configuration. A combined kinematic and powerflow simulation enables calculation of gear, shaft, bearing and clutch quasi-static loads as well as gear mesh frequencies following a duty cycle as the input. For the corresponding Linear-Time-Invariant (LTI) system model, natural frequencies and mode shapes are obtained by solving the eigenvalue problem. The modal summation technique is used to determine the steady state forced vibration response of the system. For the corresponding NTV system, Newmark's time-step marching

based integration is used to determine both the steady state and transient forced vibration response of the system. The DCT model is exercised using a common transmission architecture operating at several different operating conditions. The resulting impact of changing operational conditions on gear and bearing loads as well as dynamic transmission error spectra are demonstrated.

8:40 PM 04-Aug-2021 **IN21_1706.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1706

Design and simulation of Helmholtz resonator assembly used to attenuate tire acoustic cavity resonance noise

Wei Zhao, Xiandong Liu, Yingchun Shan, Tian He

Tire acoustic cavity resonance noise (TACRN) is a typical annoying lower-frequency interior noise of a passenger car. The widely used attenuating method of attaching the porous sound absorption material in tire cavity can reduce TACRN effectively, but causes the increase of tire-wheel assembly weight and cost, also the poor durability. Additionally, the Helmholtz resonator (HR) is also used in the wheel of some cars although having only narrow effective band. The existing investigation shows that the frequency of TACRN varies with the car speed and load and also has the split characteristics. The change of TACRN frequency causes a certain difficulty to suppress TACRN effectively. Aiming at this problem, in this paper, TACRN frequency range of a specific tire cavity under different operating conditions is first calculated and analyzed. Then, for a specific aluminum alloy wheel, a HR assembly including several HRs is designed to make the natural frequencies of HR assembly cover the TACRN frequencies. Finally, the reduction effect of TACRN is simulated and evaluated by comparing the sound fields in tire cavity with/without HR assembly under same volume velocity sound source. This work is helpful for attenuating TACRN effectively under the changing operating conditions.

Session: 12.00 Active Noise Control, General
Channel 6

6:00 AM 04-Aug-2021 **IN21_1824.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1824

Optimal ANC System Arrangement Based on Complete System Analyses Applying COSMOL Multiphysics and Matlab

Miqing Wang, Shulin Wen, Woon-Seng Gan, Shulin Wen

In real active noise control system implementation, the arrangement of secondary sources and error microphones have significant effect on the performance of the system. Analytical and experimental ways are usually combined to determine the best system layout. In this paper, we use COSMOL Multiphysics to accurately model the acoustic environment in enclosures with the real measured dimensions and parameters. Matlab is adopted to simulate the basic active noise control algorithms. The combined simulation results are used to decide the optimal system layout of the real ANC system. Experiments are conducted on a real ANC system with EVAL-21489-EZLITE from ADI to validate the analyzed and simulation results.

6:20 AM 04-Aug-2021 **IN21_1962.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1962

Acoustic analysis of snoring sound from different microphones

Yuhe Yao, Jiecheng Zhu, Shaowei Guo, Wei Liu, Li Ding, Jianxin Peng

Snoring is a common symptom of obstructive sleep apnea-hypopnea syndrome. The results show that there are obvious differences for most microphones in terms of the data distribution of features in the time and frequency domain. The results of snoring analysis from different recordings devices would be totally divergent. In view of this, when developing snoring analysis devices based user selected microphones (i.e. smartphone) recorded, we should take into account the discrepancy between different microphones.

6:40 AM 04-Aug-2021 **IN21_1755.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1755

Multi-channel feedforward active noise control system for reducing snore noise with snore noise-term detection

Koki Nakamura, Kenta Iwai, Takanobu Nishiura

In this paper, a multi-channel feedforward active noise control system for reducing snore noise with noise-term detection is proposed. The snore noise consists of a noise-term and a silent-term, and it is difficult to reduce the snore noise by the active noise control system. Since the conventional multi-channel feedforward active noise control system updates the noise control filters even in the silent-term, the conventional active noise control system updates the noise control filters unnecessarily. Therefore, the proposed multi-channel feedforward active noise control system introduces threshold processing to update the noise control filters only in the noise-term. Owing to this process, it is possible to reduce the update count of the noise control filters. Simulation results show that the proposed active noise control system can reduce the snore noise as same as the conventional active noise control system and can reduce the update count of the noise control filters compared to the conventional active noise control system.

7:00 AM 04-Aug-2021 **IN21_1472.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1472

Global feedforward active noise control using a linearly constrained loudspeaker beamformer and a sensor interpolation approach

Yi-Cheng Hsu, Mingsian R. Bai, Ma, Chenghung

The key issue of three-dimensional active noise control (3D ANC) problems is that global control is generally difficult, given limited number of discrete sensors. In this paper, feedforward multi-channel ANC approach is proposed to circumvent this difficulty. In view of the model-

matching principle and multiple secondary sources, an underdetermined multi-channel inverse filtering (UMIF) system is formulated. With this UMIF system as a design constraint, a cost function is introduced to minimize the noise energy at a large number of control points. This linearly constrained minimum variance (LCMV) proves effective in broadening the controlled area in a 3D space. Optimal deployment of control points and the regularization terms of LCMV approach are also examined. To implement the proposed ANC system in a non-freefield environment, sensor interpolation can be used to find the frequency response between control points and loudspeakers, with plane wave decomposition and some room response measurements. The proposed ANC system has been implemented on a six-element linear loudspeaker array. Simulation and experiment results have demonstrated that the propose approach has yielded significant noise reduction performance in a large control area.

7:20 AM 04-Aug-2021 **IN21_2306.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2306

Active noise control for open windows

Shahin Sohrabi, Peter Svensson, Teresa Pàmies Gómez, Jordi Romeu Garbi

Over the last decades, the applications of the active noise control system are broadened. In this study, the active noise control is modeled to reduce the noise pass through an open window. The objective is to define a suitable location for the control sources and error microphones to achieve more noise level reduction at the other side of the window. The performances of the active noise control system are calculated for two different arrangements: (1) the control sources on the edge of the opening and (2) the control sources distributed on the surface of the window. Furthermore, two cost functions are considered to model the noise control system including the minimization of the total squared pressure at cancellation points and the minimization of sound intensity at the surface of the aperture.

7:40 AM 04-Aug-2021 **IN21_2393.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2393

A compact active structural acoustic control method for minimizing radiated sound power

Scott Sommerfeldt

Active structural acoustic control is an active control method that controls a vibrating structure in a manner that reduces the sound power radiated from the structure. Such methods focus on attenuating some metric that results in attenuated sound power, while not necessarily minimizing the structural vibration. The work reported here outlines the weighted sum of spatial gradients (WSSG) control metric as a method to attenuate structural radiation. The WSSG method utilizes a compact error sensor that is able to measure the acceleration and the acceleration gradients at the sensor location. These vibration signals are combined into the WSSG metric in a manner that is closely related to the radiated sound power, such that minimizing the WSSG also results in a minimization of the sound power. The connection between WSSG and acoustic radiation modes will be highlighted. Computational and experimental results for both flat plates and cylindrical shells will be presented, indicating that the WSSG method can achieve near optimal attenuation of the radiated sound power with a minimum number of sensors.

Session: 12.02 Smart Materials
Channel 6

8:00 AM 04-Aug-2021 **IN21_1769.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1769

Designing a tuned-shunt electrodynamic metamaterial in the presence of uncertainties

Lawrence Singleton, Jordan Cheer, Stephen Daley

Resonant structural vibrations are a common source of disruptive noise, and suppressing these vibrations is often the most direct way to reduce the noise levels. Elastic metamaterials (EMMs) consist of distributed resonant substructures, at a scale which is small compared to the wavelength of vibration. This allows these materials to be used in applications where space is limited, and more traditional vibration suppression techniques would be impractical. Tuned resonators can be designed through selection of geometry or material properties, but an alternative approach, which requires significantly less prototyping, is through the use of shunted electrodynamic inertial actuators. In this paper, a novel electrodynamic metamaterial (EDMM) is proposed consisting of an array of mass-produced inertial actuators, each connected to a tuned shunt impedance. It is considered impractical to measure the dynamic and electrical parameters of a large number of actuators, and so the effect of uncertainties in the actuators is investigated on both the performance and the stability of the EDMM.

8:20 AM 04-Aug-2021 **IN21_3110.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3110

Wave-based control for nonreciprocal acoustics using a planar array of secondary sources

Joe Tan

There has been significant interest in the design of nonreciprocal acoustic devices that allow acoustic waves to be perfectly transmitted in one direction, whilst the acoustic waves propagating in the opposite direction are blocked or reflected. Previously proposed nonreciprocal acoustic devices have broken the symmetry of transmission by introducing nonlinearities or resonant cavities. However, these nonreciprocal acoustic devices typically have limitations, such as signal distortions and the bandwidth over which nonreciprocal behaviour can be achieved is narrow. This paper will investigate how active control can be used to minimise the transmitted and reflected waves independently to achieve nonreciprocal sound transmission and absorption using a planar array of secondary sources in a two-dimensional environment. The advantage of the proposed active control system is that it is fully adaptable, which means that the directivity of nonreciprocal behaviour can also be reversed. The performance of the proposed wave-based active control system is investigated for a range of angles of incidence and its performance limitations are explored.

Session: 09.06 Sound Absorption Measurements, Part 2
Channel 6

11:00 AM 04-Aug-2021 **IN21_2120.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2120

Numerical study of the impact of reverberation room design and test parameters on sound absorption measurements

Paul Didier, Cédric Van hoorickx, Edwin Reynders

The measurement of sound absorption in reverberation rooms following the ISO 354:2003 standard relies on Sabine's equation to derive absorption coefficients from reverberation times. This equation assumes perfect diffusivity, i.e. the sound field is composed of many statistically independent plane waves with uniformly distributed spatial phases, themselves uncorrelated to the corresponding amplitudes. In this work, both existing and fictitious reverberation rooms are numerically modelled using the finite element method. Finite porous absorbers are introduced in the rooms as equivalent fluid models. Standardized sound absorption measurement are simulated in the rooms through the determination of reverberation times. The respective effects of the sample size, sample placement, source positioning, and presence of finite panel diffusers are investigated. The resulting absorption coefficients are then confronted to the theoretical values in a perfectly diffuse sound field, that interacts with a baffled, finite-sized absorber, as obtained with a hybrid deterministic-statistical energy analysis model. The process notably underlines the strong, yet often disregarded, beneficial effect of panel diffusers at low frequencies in highly regularly-shaped rooms. Another conclusion of this work is that reverberation room design represents a crucial factor that can influence sound absorption measurements at low frequencies.

11:20 AM 04-Aug-2021 **IN21_2118.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2118

An optimization method for reverberation room design

Paul Didier, Cédric Van hoorickx, Edwin Reynders

The ISO 354:2003 standard relating to sound absorption measurements is currently under revision to improve the reproducibility of the procedure it describes. Round robin tests conducted across various reverberation rooms indeed revealed significant disparities between sound absorption measurements of the same sample. One of the reasons is that, at low frequencies, the sound field in a single laboratory cannot be considered fully diffuse. However, the average sound field across different laboratories may be considered diffuse if the interaction between the finite sample and the diffuse field is duly accounted for and the direct field close to the absorber is disregarded. In this work, a method is developed for optimizing reverberation room design such that measured absorption values are as close as possible to ensemble average diffuse values. The reverberation room is modelled using the finite element method and standardized measurements of an absorptive sample are simulated. The distance between resulting absorption coefficients and diffuse target values is minimized in an optimization procedure having the geometrical characteristics of the model as input parameters. The results are anticipated to participate to the revised ISO 354 as guidelines for the construction of new reverberation rooms or the improvement of existing ones.

11:40 AM 04-Aug-2021 **IN21_2575.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2575

Loudspeaker configuration in reverberation rooms for sound absorption measurement using room mode determination

Niels Peter Moos, Cheol-Ho Jeong, Mads Bolberg, Rasmus Stahlfest Holck Skov

For Sabine absorption coefficient measurements in reverberation rooms, it is preferable to excite as many room modes as possible. But the number of excited room modes is significantly affected by many factors, among which one dominating factor is the loudspeaker location particularly at frequencies below the Schroeder frequency. In turn, this could significantly influence the statistical absorption coefficient obtained according to ISO 354. Therefore, this study aims to investigate the impact of loudspeaker configurations on the excitation of room modes. Frequency response functions are measured using a broad band steady state noise signal using four sound sources at various locations, and the numbers of excited room modes in the one-third octave bands are quantified and compared against those by Green's function simulations. A procedure for determining favorable loudspeaker positions based on the excited room modes is proposed, which can be a useful input to the working group of the ISO 354 standard.

12:00 PM 04-Aug-2021 **IN21_2810.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2810

High-frequency acoustic impedance tube based on MEMS microphones

Roman Schlieper, Song Li, Jürgen Peissig, Stephan Preihs

Acoustic impedance tubes are commonly used to measure a test specimen's acoustic characteristics, such as reflection factor, absorption coefficient, or acoustic impedance, in combination with one or two condenser measurement microphones according to associated standards. In the development process of an impedance tube, the microphone diaphragm's size has an important role in the measurement quality. On the one hand, the microphone diameter has to be large enough to ensure the possibility of measuring at low sound pressure levels (SPLs), but on the other hand, the size of the microphone diaphragm should be small in order not to influence the sound propagation through the impedance tube due to the microphone coupling. Micro-Electro-Mechanical Systems (MEMS) microphones are recently widely applied in various acoustic applications due to their small size and high sensitivity. This paper proposes the development of an acoustic impedance tube equipped with 16 MEMS microphones and an inner diameter of 8 mm with an operating frequency range between 60 Hz and 16 kHz. The bottom port MEMS microphones are connected via a 1 mm hole to the tube. The system evaluation is based on standard test specimens like empty probe adapters, rigid termination, and porous absorbers.

12:20 PM 04-Aug-2021 **IN21_2103.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2103

How small-scale variation in mineral wool products effect random incidence sound absorption

Mads Bolberg

Mineral wool products are produced by creating a spray of fibres, that is collected and made into slabs. This randomized spray can lead to small variations across a slab. Nevertheless, mineral wool slabs are often treated in acoustics as locally reacting perfectly homogeneous, isotropic materials. This means that small-scale characterisations are extrapolated to large-scale without considering the impact from possible variations in a large-scale setup. The question is how the small-scale characterisations should be used for large-scale setups with this in mind.
Three products with the same thickness and density, but with significantly different specific airflow resistances were selected for random incidence sound absorption tests. The products were all specially made ceiling tiles and measurements were conducted in E200 setup according to ISO 354:2003. The tiles were gradually exchanged in a random fashion, so measurement results were obtained using a combination of tiles with different specific airflow resistances.
Results showed a surprisingly linear relation between the sound absorption and the average specific airflow resistance of tiles used in the measurements. The results point to that variations in products must be observed, but also that small variations in specific airflow resistance in standardized products are insignificant.

12:40 PM 04-Aug-2021 **IN21_3197.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3197

Diffusion equation modelling for energy flow analysis in reverberation chambers

Ryan Hao, Ning Xiang

Noise is a growing concern in the built environment. Sound absorbers are a viable option for noise treatment. However, the characterization of their absorption coefficient in standardized measurement chambers still show challenges for high accuracy as required in practice. In recent years, experimental analysis has shown that assumptions of diffuse sound fields made in well-known reverberation chambers are unfulfilled. Specifically, that sound intensities in chamber-based measurement methods are presumed to be isotropic or diffuse. Diffusion equation models have shown dramatic changes in energy flow in the presence of highly absorptive materials under test. This has been attributed to well-documented inconsistencies reported from reverberation chamber measurements across different laboratories. This work will demonstrate that the diffusion equation model is proving to be a computationally efficient and viable method for predicting sound energy flows, garnering an increasing amount of interest from the acoustical community.

Session: 09.09 Acoustic Material Design, Part 1
Channel 6

1:20 PM 04-Aug-2021 **IN21_3332.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3332

Experimental Investigation of Mean Flow Profile Effects on Impedance Eduction

Victor Kopiev, NIkolay Ostrikov, Stanislav Denisov, MIkhail Yakovets, Maxim Ipatov

The results of experimental and computational studies of the three-dimensional mean flow velocity profile influence on the impedance eduction are presented. In order to measure the three-dimensional velocity profile, the TsAGIâ€™s â€œInterferometer with flowâ€ facility was upgraded so that additional holes were made in one cross section of the rectangular duct. As a result, it became possible to measure the longitudinal flow velocity in this cross section along 6 lines using a Pitot tube or a hot wire anemometer. The full three-dimensional velocity profile is determined by interpolating the values measured.Experimental results of the velocity profile for various experiment conditions are presented. Based on the numerical solution of the three-dimensional Pridmore-Brown equation by means of Finite Element Method and the gradient descent method, the problem of impedance eduction are investigated. The influence of the flow velocity profile and the form of functional on the obtained impedance values are discussed. The impedance values educted by means of this approach are compared with the impedance values obtained using two-dimensional impedance eduction methods, which didnâ€™t taking into account the three-dimensional non homogeneity of the flow velocity field.

1:40 PM 04-Aug-2021 **IN21_1308.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1308

Design and optimization of acoustic liners with a shear grazing flow: OPAL software platform applications

Remi Roncen, Pierre Vuillemin, Patricia Klotz, Frank Simon, Fabien Méry, Delphine Sebbane, Estelle Piot

In the context of noise reduction in diverse applications where a shear grazing flow is present (i.e., engine nacelle, jet pump, landing gear), improved acoustic liner solutions are being sought. This is particularly true in the low-frequency regime, where space constraints currently limit the efficiency of classic liner technology.
To perform the required multi-objective optimization of complex meta-surface liner candidates, a software platform called OPAL was developed. Its first goal is to allow the user to assemble a large panel of parallel/serial assembly of unit acoustic elements, including the recent concept of LEONAR materials. Then, the physical properties of this liner can be optimized, relatively to given weighted objectives (noise reduction, total size of the sample, weight), for a given configuration. Alternatively, properties such as the different impedances of liner unit surfaces can be optimized.
To accelerate the process, different nested levels of optimization are considered, from 0D analytical coarse designs in order to reduce the parameter space, up to 2D plan or axisymmetric high-order Discontinuous Galerkin resolution of the Linearized Euler Equations.
The presentation will focus on the different aspects of liner design considered in OPAL, and present an application on different samples made for a small scale aeroacoustic bench.

2:00 PM 04-Aug-2021 **IN21_1496.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1496

Design and optimization of acoustic liners with a shear grazing flow: OPAL software platform description

Frank Simon, R. Roncen, P. Vuillemin, P. Klotz, Fabien Méry, E. Piot

In the context of aircraft noise reduction in varied applications where a cold or hot shear grazing flow is present (i.e., engine nacelle, combustion chamber, jet pump, landing gear), improved acoustic liner solutions are being sought. This is particularly true in the low-frequency regime, where space constraints limit the efficiency of conventional liner technology. Therefore, liner design must take into account the dimensional and phenomenological characteristics of constituent materials, assembly specifications and industrial requirements involving multiphysical phenomena.

To perform the single/multi-objective optimization of complex meta-surface liner candidates, a software platform coined OPAL (OPtimisation of Acoustic Liners) was developed. Its first goal is to allow the user to assemble a large panel of parallel/serial elementary acoustic layers along a given duct. Then, the physical properties of this liner can be optimized, relatively to weighted objectives, for a given flow and frequency range: impedance target, maximum absorption coefficient or transmission loss with a total sample size and weight...

The presentation will focus on the different elementary bricks and assembly of a problem (from 0D analytical coarse designs in order to reduce the parameter space, up to 2D plan or axisymmetric high-order Discontinuous Galerkin simulations of the Linearized Euler Equations).

2:20 PM 04-Aug-2021 **IN21_2521.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2521

Influence of the Poisson's ratio on the efficiency of viscoelastic damping treatments

Lucie Rouleau, Isadora Ruas Henriques, Jean-François Deü

An efficient way of mitigating noise and vibration is to embed viscoelastic patches into the host structure. Viscoelastic properties are of significant importance in determining the performance of the passive damping treatment. The behaviour of homogeneous isotropic materials is described by two elastic constants (generally the Young modulus and the Poisson ratio, or the shear and bulk moduli), which are frequency- and temperature-dependent in the case of viscoelastic materials. In practice, the Poisson's ratio is often considered as independent of temperature and frequency.

One goal of this work is to numerically evaluate the validity of this assumption and its limitations (frequency range, thickness of the viscoelastic layer). To this end, a thermo-mechanical characterization of a viscoelastic material is carried out by dynamic measurements of the complex shear and bulk moduli, allowing the indirect measurement of the frequency- and temperature-dependent Poisson's ratio.

Moreover, the measurements of the Poisson's ratio (direct or indirect) can lead to considerable uncertainties. For instance, large discrepancies have been observed when characterizing the Poisson's ratio of polymer foams. Another goal of this work is to investigate the influence of those uncertainties on the dynamic response of a damped structure.

2:40 PM 04-Aug-2021 **IN21_3027.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3027

Towards fully controlled anisotropy in cellular porous media: an overview

Mathieu Gaborit, Huina Mao, Romain Rumpler, Peter Göransson

In the recent years, our team has been working to identify key aspects of anisotropy on porous media. More than just characterising their anisotropic properties, we’re interested in generating cellular media with completely designed anisotropic properties. The results of these studies have partly been published and more are to come. In this presentation, we’ll present an overview of this work and it ultimately ties to acoustics. We will introduce the key findings,discussed specific results that can be achieved and provide context and details related to the strategy developed to address the tasks.

3:00 PM 04-Aug-2021 **IN21_2217.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2217

Sound absorption of polydisperse heterogeneous porous composites

Gabriel Núñez, Rodolfo Venegas, Tomasz G. Zielinski, François-Xavier Bécot

Sound absorption of polydisperse heterogeneous porous composites is investigated in this paper. The wave equation in polydisperse heterogeneous porous composites is upscaled by using the two-scale method of homogenisation, which allows the material to be modeled as an equivalent fluid with atypical effective parameters. This upscaled model is numerically validated and demonstrates that the dissipation of sound in polydisperse heterogeneous porous composites is due to visco-thermal dissipation in the composite constituents and multiple pressure diffusion in the polydisperse heterogeneous inclusions. Analytical and semi-analytical models are developed for the acoustical effective parameters of polydisperse heterogeneous porous composites with canonical geometry (e.g. porous matrix with cylindrical and spherical inclusions) and with complex geometries. Furthermore, by comparing the sound absorption coefficient of a hard-backed composite layer with that of layers made from the composite constituents alone, it is demonstrated that embedding polydisperse heterogeneous inclusions in a porous matrix can provide a practical way for significantly increasing low frequency sound absorption. The results of this work are expected to serve as a model for the rational design of novel acoustic materials with enhanced sound absorption properties.

Session: 09.07 Low Frequency Noise Control
Channel 6

6:20 PM 04-Aug-2021 **IN21_2215.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2215

Low-frequency noise control using layered granular aerogel and limp porous media

Yutong Xue, Amrutha Dasyam, J. Stuart Bolton, Bhisham Sharma

The acoustic absorption of granular aerogel layers with a granule sizes in the range of 2 to 40 μm is dominated by narrow-banded, high absorption regions in the low-frequency range and by reduced absorption values at higher frequencies. In this paper, we investigate the possibility of developing new, low-frequency noise reduction materials by layering granular aerogels with traditional porous sound absorbing materials such as glass fibers. The acoustic behavior of the layered configurations is predicted using the arbitrary coefficient method, wherein the granular aerogel layers are modeled as an equivalent poro-elastic material while the fibrous media and membrane are modeled as limp media. The analytical predictions are verified using experimental measurements conducted using the normal incidence, two-microphone impedance tube method. Our results show that layered configurations including granular aerogels, fibrous materials, and limp membranes provide enhanced sound absorption properties that can be tuned for specific noise control applications over a broad frequency range.

6:40 PM 04-Aug-2021 **IN21_1807.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1807

Low frequency vibration suppression of a moderate thick cabin structure by multiple piezoelectric patches shunted with RL-double negative capacitance circuits

Zhiwei Zheng, Feng Li, Xiuchang Huang, Zhiwei Su, Hongxing Hua

Multiple piezoelectric patches shunted with RL-double negative capacitances circuits, which are bonded on the bulkhead, are proposed to control the resonant response of multiple low frequency modes of a moderate thick cabin structure. Dynamic modeling of the electromechanical coupling system of the cabin structure and the piezoelectric shunt circuit is established by employing the three-dimensional finite element. Optimum tuning strategy is based on the trial and error method. It is shown that the proposed approach is effective in enhancing the generalized electromechanical coupling coefficient and controlling the low frequency modes that exhibits coupled deformation of the bulkhead and cabin structure.

7:00 PM 04-Aug-2021 **IN21_3171.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3171

Theoretical and numerical study of nonlinear acoustic absorbers for low frequency noise control

Min Yang, Xianhui Li, Zenong Cai, Junjuan Zhao, Peng Zhang, Yunan Liu

In this paper, the sound absorption characteristics of cubic nonlinear sound-absorbing structures are analyzed by theoretical and numerical methods. The slow flow equations of the system are derived by using complexification averaging method, and the nonlinear equations which describe the steady- state response are obtained. The resulting equations are verified by comparing the results which respectively obtained from complexification-averaging method and Runge-Kutta method. It is helpful to optimize the structural parameters and further improve the sound absorption performance to study the variation of the sound absorption performance of cubic nonlinear structure with its structural parameters.

Session: 12.01 Algorithms and Hardware for Active Noise Control
Channel 6

7:20 PM 04-Aug-2021 **IN21_1736.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1736

A conjugate gradient least square based method for sound field control

Pierangelo Libianchi, Finn T. Agerkvist, Elena Shabalina

In sound field control, a set of control sources is used to match the pressure field generated by noise sources but with opposite phase to reduce the total sound pressure level in a defined area commonly referred to as dark zone. This is usually an ill-posed problem. The approach presented here employs a subspace iterative method where the number of iterations acts as the regularization parameter and controls unwanted side radiation, i.e. side lobes. More iterations lead to less regularization and more side lobes. The number of iterations is controlled by problem-specific stopping criteria. Simulations show the increase of lobing with increased number of iterations. The solutions are analysed through projections on the basis provided by the source strength modes corresponding to the right singular vector of the transfer function matrix. These projections show how higher order pressure modes (left singular vectors) become dominant with larger number of iterations. Furthermore, an active-set type method provides the constraints on the amplitude of the solution which is not possible with the conjugate gradient least square algorithm alone.

7:40 PM 04-Aug-2021 **IN21_1995.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1995

Active noise control without secondary path modeling: algorithm and implementation

Xing Ren, Hongwei Zhang

Active noise control (ANC) has been intensively studied for decades. The most classical ANC algorithm should be the filtered-x least mean square (FxLMS) algorithm, which needs the model of the secondary path to work. Thus, the residual error of the ANC system is closely related to the preciseness of the secondary path model. In many applications, the secondary path is often time-varying. Therefore, off-line identification of the secondary path is not applicable. However, on-line identification often requires an additional white noise as a stimulating signal of the secondary path, which will deteriorate the final noise reduction effect. This paper proposes an improved artificial bee colony (ABC)

algorithm for ANC system, which does not require identification of the secondary path. In order to guarantee the convergence of the algorithm and accelerate the convergence speed, this paper introduces a variable forgetting factor into the fitness function, and improves the traditional ABC algorithm by integrating LMS algorithm into the ABC algorithm. A single channel ANC system equipped with an FPGA hardware platform is set up in an anechoic chamber, and experiments show that the proposed algorithm can produce a satisfactory noise reduction effect without modeling the secondary path.

8:00 PM 04-Aug-2021 **IN21_2793.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2793

Simplified fast transversal filter algorithms for multichannel active noise control

Lei Wang, Kean Chen, Jian Xu, Wang Qi

In recent years, more attention has been paid to the performance of algorithm in active noise control (ANC). Compared with filtered-x LMS (FxLMS) algorithm based on stochastic gradient descent, filtered-x RLS (FXRLS) algorithm has faster convergence speed and better tracking performance at the cost of high computational complexity. In order to reduce the computation, fast transversal filter (FTF) algorithm can be used in ANC system. In this paper, simplified multi-channel FXFTF algorithms are presented, and the convergence speed and noise reduction performance of different multichannel algorithms are simulated and compared, and the numerical stability of the algorithms are analyzed.

8:20 PM 04-Aug-2021 **IN21_2254.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2254

Active Noise Control Algorithm with Saturated Actuator

Hakjun Lee, Youngjin Park

Active noise control system has received its attention in various technical field such as headphone, motor vehicle, etc. Meanwhile, filtered-x least mean square (FxLMS) algorithm is conventional linear algorithm used in active noise control system. It assumes that acoustic path from the noise source and control source to target area are linear. However, in actual system, the secondary path including a D/A converter, an amplifier, and an actuator may exhibits nonlinear distortion like saturation effects. To cope with this nonlinear effects, functional link artificial neural network (FLANN) has been proposed. FLANN uses nonlinear function expansion filter with FxLMS based control algorithm to control the nonlinear effect. In this paper, noise reduction performance and convergence speed are improved by modifying the conventional FLANN algorithm by decoupling the linear and nonlinear part of noise signal.

8:40 PM 04-Aug-2021 **IN21_2004.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2004

Implementation of coherence-based-selection multi-channel wireless ANC in headphone

Xiaoyi Shen, Dongyuan Shi, Woon-Seng Gan, Santi Peksi

Active noise control (ANC) headphone is widely used to attenuate the noise around human' s ear. The microphone mounted on the conventional ANC headphones collected the mixed reference signals when more than one noise sources are often present in the surrounding. In this case, the uncorrelated noise sources involved in the mixed reference usually deteriorate the noise reduction performance of the ANC headphones. To solve this problem, wireless microphones are proposed to install close to each potential noise source in the environment. The microphones pick up the clean reference signals and transmit them to the ANC controller embedded in the headphones with time-advance wirelessly. Every reference signal selected by a coherence-based-selection algorithm is provided individual control filter in each ear. Each control filter updated by using a single clean reference offers better noise reduction performance for ANC headphones. Furthermore, numerical simulations and real-time experiment results in this paper demonstrate the improvement of the proposed method compared with conventional ANC headphones.

Session: 15.00 Soundscapes, General, Part 2
Channel 7

6:00 AM 04-Aug-2021 **IN21_3291.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3291

Noise perception assessment in urban green spaces using soundwalk approach

Omid Samani, Verena Zapf, M. Ercan Altinsoy

Urban green spaces are intended to provide citizens with calm environments free of annoying city noises. This requires a thorough understanding of noise emission and related exposure to sounds in green spaces. This research investigates noise perception in various spots in an urban green space. For this purpose, the study has been conducted in the grand garden of the city of Dresden. The garden covers 1.8 square kilometers of various landscapes, including water streams, park railways, fountains, bridges, roads for bicycles and pedestrians etc. Noise perception was investigated at eleven spots with emphasis on four noise types: nature noise, human noise, traffic noise, and technical noise. In parallel, audio-visual recordings were conducted for each spot to identify the connection between the perceptual measures and the psychoacoustic parameters. These spots are categorized based on the resulting perception and psychoacoustic parameters. In addition, the visual effect of each spot on final perception is investigated. Eventually, annoyance for each spot is identified based on the corresponding participants' perception and is associated with the relevant psychoacoustic parameters.

6:20 AM 04-Aug-2021 **IN21_3295.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3295

Sound evaluation of urban spaces in the central area of São Paulo

Ranny Michalski, Giovanna Milani Caparroz, Laís de Gusmão Coutinho

The present work evaluates noise conditions to which people are subject in the central region of São Paulo city. Strategic points were chosen for sound assessment, considering quantitative and qualitative aspects. Different occupancy profiles, height of buildings, constructive density, number of empty spaces, width of the roads and capacity of vehicle flow, were selected. In addition to acoustic measurements, an evaluation of the profile and flow of the vehicles has been made, to serve as input for simulation in a computational model of urban environmental noise and noise mapping of selected areas. The concept of soundscape was approached with the characterization of local sound sources and their sound perception. Questionnaires were applied for subjective assessment and the profile of the interviewees was also characterized. This attitude is important because it leads to an understanding of who exactly is exposed and affected by certain sound levels, and how the same sound level can generate different perceptions. This sensibility while approaching the subject makes people stop being just numbers and more human strategies are adopted for urban planning. At the end, an image was produced to summarize the overall analysis performed.

6:40 AM 04-Aug-2021 **IN21_3120.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3120

Relational analysis in soundscape preservation

Pamela Jordan

Given the musical origins of soundscape studies, soundscape preservation might suggest the need to protect specific features—such as prominent soundmarks or long-standing natural sounds—to maintain a sonic environment's composition. However, the identification of a soundscape primarily by its discrete elements misses the importance of relational longevity. A relational lens of identification can distinguish a soundscape's effects on visitors rather than simply the presence of specific components, placing human perception candidly at the center of consideration. For instance, an urban courtyard might no longer echo with hand-drawn carts from the street, yet visitors continue to experience a distanced connection with evolving traffic sounds – here the sonic-spatial relationship persists rather than sonic elements being frozen in time. This paper will discuss longevity in the relationships connecting use, architectural space, and sonic character. The discussion draws from architectural analysis, soundwalking, and psychoacoustic research in exploring soundscape preservation within the orbit of heritage conservation more broadly. Case studies focus on a variety of historic contexts, including a military installation, medieval church, and factory landscape, highlighting the limitations of a compositional soundscape reading, the fundamental role of transit through a soundscape for visitors, and the potentials for relational analysis in soundscape preservation efforts.

Session: 15.15 Exposure-Response Functions for Community Noise and the Effect of Non-Acoustic Factors
Channel 7

7:20 AM 04-Aug-2021 **IN21_2972.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2972

Effects of the reduction of aircraft noise emission due to the travel restriction during the COVID-19 pandemic at residential areas around Tan Son Nhat Airport

Thulan Nguyen, Tran Thi Hong Nhung Nguyen, Bach Lien Trieu, Makoto Morinaga, Yasuhiro Hiraguri, Takashi Yano, Yosiaki Sasazawa

The travel restrictions caused by the epidemic outbreak in early 2020 worldwide have caused many changes in all aspects of life, especially in the acoustic environment. This study examines the impact of this environmental change at Tan Son Nhat International Airport (TSN), the largest airport in Vietnam, by comparing the situations before and after the airport stopped operating all international flights in March 2020. The after-the-change survey was conducted in 2 phases, June and September 2020, three months and six months after the stop decision. The number of flights observed in August 2019 was 728; this number is 413 and 299 for the two surveys in 2020. The range of noise levels estimated for 12 sites around TSN decreased from 63-81 dB in 2019 to 32-67 dB in June 2020 and 33-69 dB in September 2020. At the same aircraft noise level, the percentage of highly annoyed (% HA) and the percentage of insomnia (%ISM) in the 2020 survey are higher than those in the 2019 survey. The comparison results of reaction to noise before and after the TSN's noise change indicated an increase in negative responses to noise might happen in the increased noise and reduced noise situation.

7:40 AM 04-Aug-2021 **IN21_1296.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1296

Annoyance due to road traffic noise: an attempt to describe the effects of non-acoustic factors

Truls Gjestland

The annoyance response is traditionally presented as the percentage of people highly annoyed as a function of the noise exposure, DNL, or similar. It is, however, a well-known fact that the noise level per se only explains about one-third of the variance of the annoyance response. An analysis based on the Community Tolerance Level, CTL, quantifies the combined effect of all non-acoustic factors, but does not explain the effect of each individual one. The paper is an attempt to separately quantify the effect of different non-acoustic factors.

8:00 AM 04-Aug-2021 **IN21_2047.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2047

The impact of COVID-19 lockdown on the noise pollution: case study in the city of Skopje

Simona Domazetovska, Maja Anachkova, Viktor Gavriloski, Ankica Sokolikj, Sandra Stojkovska

The lockdown that the city of Skopje has suffered during the months of April to June 2020 in order to control the spread of COVID-19 has significantly changed the acoustic environment in the urban parts of the city. The absence of vehicles, people on the streets and closed

restaurants has led to a noise reduction captured by the low-cost wireless sensor network in the City of Skopje. The analysis carried out in this paper show reduction in noise pollution strongly correlated with the population's activity and behavior to the new circumstances. Overall, the sound pressure levels vary around 65 dB; however, some extreme decrease can be noticed, especially during the quarantine weekends. Also, the noise levels were compared between the same time periods during the year of 2019 and 2020, where it can be perceived reduction in the sound level for 36,5% for the day-evening-night noise level indicator (L). Significant variations occur for the indicators L, L, and L, especially during the lockdown weekends.

8:20 AM 04-Aug-2021 **IN21_1997.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1997

Shooting noise annoyance in communities around German military training areas

Dirk Schreckenberg, Stephan Großarth

Shooting noise is characterized as impulsive, intermittent sound with high energy and low frequencies. Studies have shown that for given average sound levels shooting noise is regarded as more annoying than transportation noise, particularly road traffic noise. In comparison to transportation noise, responses to shooting noise are less frequently studied. The latest published German studies on community responses to shooting noise were conducted in the 1980ies and 1990ies. The study presented in this contribution aims to provide new data on shooting noise responses in communities around military training areas. Annoyance responses were collected using a survey with 1043 residents living around three military training sites in Germany. For the address of each resident, on the basis of shooting training in the year 2019 the average continuous sound levels and the sound exposure levels for day and night-time with the frequency weightings A, C, and Z was estimated for grid cells of 250 x 250 m. Results on the exposure-response relationship between these noise metrics and the percentage of highly annoyed persons (%HA) are presented. Among others, the results indicate, that non-acoustic factors, particularly attitudes related to the source have a strong impact on the annoyance.

8:40 AM 04-Aug-2021 **IN21_2563.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2563

Monte Carlo method for uncertainty evaluation of noise annoyance prevalence

Ricardo Luís d'Avila Villela

When a decision-making process relies on the information provided by a measurement or simulation result, the right decision demands a good quality result, in other words, a low uncertainty result. In order to establish public policies for environmental noise control, it is essential to identify the impact of each type of noise pollution (e.g. road, aircraft and rail transportation noise) on the population affected. One of the noise impact metrics that can be used is the number of highly noise annoyed people in a region whose estimated value is obtained from the corresponding exposure-response function and noise and population density maps. However, an estimated value of the noise impact metric with high uncertainty makes it difficult to realize the actual severity of the problem and its priority in relation to other public health issues. In this work, a Monte Carlo simulation method is used to assess the uncertainty of a noise impact metric result, namely the number of people highly disturbed by road noise in a city. This article also presents a sensitivity analysis of uncertainty sources that allows quantification of the main uncertainty components, which supports improvements in noise impact metric results.

Session: 15.03 Soundscapes in Urban Planning and Architecture
Channel 7

11:00 AM 04-Aug-2021 **IN21_2651.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2651

An investigation on the methods of noise countermeasures for safeguarding Intangible Cultural Property- Attempt of noise compatibility planning rooted in the local community -

Mari Ueda

In the Ogino area of Atsugi City, where the Kanagawa Institute of Technology is located, Japanese drums are being practiced and the arts are inherited in order to perform at events such as Japanese festivals. It may be reported. Therefore, in Atsugi City, when the main purpose is to practice Japanese drums, the practice place is restricted, such as not being able to obtain permission to use the facilities of the city. In order to solve such a problem, we performed acoustic measurement of Japanese drums and clarified their acoustic characteristics. It was confirmed that the sound near the drum due to the repellent impact of the Nagado daiko has a lot of energy even in the low frequency component of 200 Hz or less, and the magnitude of the radiated sound SEL increases as the sound is hit harder. It is also difficult for local governments to take physical noise countermeasures for membranophones from a cost perspective. Therefore, the ultimate goal of this research was to obtain a solution to the noise problem by social measures to continue the succession activities of traditional musical instruments such as Japanese drums, which are difficult to take measures against physical noise. Launched and operated a website to understand the current state of noise complaints and to collect the voices of local residents regarding the sound of drums according to the lifestyle and situation of each individual as part of the Noise Compatibility Planning attempt. We built the system.

11:20 AM 04-Aug-2021 **IN21_2998.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2998

Soundscape related to emotional evoke in memorial open places

Wei Zhao, Hongyu Li, Xun Zhu

As a type of landscape with special cultural connotation and symbolic significance, commemorative places carry people's emotional sustenance for the memorial subject. Based on the special cultural and spiritual connotation of commemorative landscape, it is different from other landscape types in terms of soundscape perception. This paper takes Nanjing Sun Yat-sen Mausoleum and the square in front of Yuhuatai

Martyrs Cemetery as examples to conduct a comparative study. Through field questionnaire surveys, data such as basic information, environmental evaluation, and emotional arousal evaluation of subjects are obtained. The results show that (1) the matching degree of the audiovisual landscape affects the acoustic environment satisfaction and environmental satisfaction, and shows a positive correlation. (2) The sound environment evaluation such as the sense of ritual and solemnity is positively correlated with the satisfaction of the soundscape. (3) The degree of arousal of voice and emotion is positively correlated with the sense of ritual, solemnity, mission, responsibility, admiration, and meaning. Researching the soundscape perception of commemorative places from the perspective of emotional arousal will help build a soundscape environment with a more memorable atmosphere, arouse individual emotions, and achieve better memorial and educational significance, so as to expand the related research of soundscape.

11:40 AM 04-Aug-2021 **IN21_2789.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2789

The relevance of psychoacoustic percentiles for the description of morphological characteristics in urban areas

Daniel de la Prida, Margret Sibylle Engel, Janina Fels, Antonio Pedrero

Research over the last decade has explored the relevance of psychoacoustic indicators such as Loudness (N), Sharpness (S), Roughness (R) and Fluctuation Strength (FS) for the description of the perceptual construct of soundscapes. Furthermore, the recent ISO 12913-2 standard, published in 2018, recommends their use for the quantitative assessment of soundscapes. However, usually, investigations on soundscapes are using averages of the psychoacoustic indicators, and little research has evaluated the relevance of percentiles for the perceptual description of physical environments in terms of geometrical features, prevailing noise sources, temporal and meteorological variables, etc.
This study aims to verify whether psychoacoustic percentiles can representatively describe the geometrical features of different urban sonic environments. For this purpose, recordings were taken in Aachen and Madrid in different days and seasons, at 14 certain locations in each town. In addition, morphological data was collected of the sites.
A Principal Component Analysis (PCA), conducted on psychoacoustic percentiles (i.e., P1, P5, P10, P50, P90, P95, P99) of N, S, R and FS and geometrical features (road, pedestrian sidewalk and propagation path widths, as well as building heights), showed well-defined components, highlighting the fact that some percentiles can describe specific geometrical features of the urban sonic environments.

12:00 PM 04-Aug-2021 **IN21_1761.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1761

An interdisciplinary sound classification framework for environmental sound design

Kivanc Kitapci, Dogukan Ozdemir

One of the objectives of architectural design is to create multi-sensory environments. The users are under the influence of a wide variety and intense perceptual data flow when users experience a designed space. Architects and environmental designers should not ignore the sense of hearing, one of the most important of the five primitive senses that allow us to experience the physical environment within the framework of creative thinking from the first stage of the design process. Today, auditory analysis of spaces has been studied under architectural acoustics, soundscapes, multi-sensory interactions, and sense of place. However, the current sound design methods implemented in the film and video game industries and industrial design have not been used in architectural design practices. Sound design is the art and application of making soundtracks in various disciplines and it involves recognizing, acquiring, or developing of auditory components. This research aims to establish a holistic architectural sound design framework based on the previous sound classification and taxonomic models found in the literature. The proposed sound design framework will help the architects and environmental designers classify the sound elements in the built environment and provide holistic environmental sound design guidelines depending on the spaces' functions and context.

Session: 14.06 Urban Sound Planning
Channel 7

12:40 PM 04-Aug-2021 **IN21_1834.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1834

Relation between soundscape and spatial configuration in different urban contexts

Benameur Okba, Valerio Cutini, Francesco Leccese, Giacomo Salvadori, Noureddine Zemmouri

During the last decade, the problem of noise pollution has continued to increase in Europe as well as in under-developed countries. This issue is stressed in city centers, owing to the abundance of residential activities, vehicle traffic and multiple services. This study investigates the relationship between urban spatial configuration and environment soundscape in two different areas: Pisa historic center, Italy and Biskra downtown, Algeria, using the potential of Space Syntax theory in predicting noise levels distribution. For this analysis, thirty stations of measurements were held in each area during day time using a Sound Level Meter. A Noise map was modeled using the interpolation tool provided by a Geographic Information System program, while the collected data were correlated with the Angular Segment Analysis variables. The findings reveal a close relationship between the sound levels obtained and Space Syntax theory global and local indexes such as Normalized Choice and Integration, which signifies the ability of the approach in describing the sound phenomenon in different urban contexts.

1:00 PM 04-Aug-2021 **IN21_2296.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2296

Further investigation on pockets of quiet within historical city centres: the case of widenings

Massimiliano Okba, Roxana Adina Toma, Luigi Maffei

Making available quiet zones for the urban population is a key factor to offer them the possibility to have restorative experiences and relief from stressful city life. Although these zones are often associated with vast green parks, the latter are usually located outside or far from cities' centres. Moreover, if we consider the case of historical city centres, they are almost absent.
In previous research, we have focused on searching for alternative quiet spaces that inhabitants and tourists could use as a temporary refuge from urban noise and chaos.

In these studies, we have shown that thanks to their acoustics peculiarities and several other non-acoustic characteristics, the cloisters and the courts of historic buildings have a high potential to induce restoration. Nevertheless, among the narrow streets of the historic cities centres, the widenings can also provide a small contribution to a temporary restoration of people.
This paper investigates the restorative potentiality of these further spaces and compares the outcomes carried out from binaural recordings and in situ interviews with those of cloisters and courts of historic buildings within the ancient city centre of Naples.

1:20 PM 04-Aug-2021 **IN21_3553.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3553

Acoustic balance between highway and metro: a case study of Dos Hermanas

Gabriel Piza, Gabriel Piza, José Ancela

With the Directive 2002/49 of the European Parliament, commitments are established for the control of noise pollution for member countries. Based on such determination, an important tool for the noise pollution control is the noise map, which represents an area or its population exposed to different ranges of noise. The same Directive defines that environmental noise is influenced by different sources, including transport routes such as road traffic and the subway. This study evaluates the acoustic balance between the Sevilla metro and the A-376 highway traffic. For such assessment, different mobility scenarios have been developed and all of them have been evaluated using noise maps. A residential block in Dos Hermanas, a town in Sevilla province, has been taken as a case study. According to the evaluated scenarios, the population affected by high level noises decreases as the metro is more used than the highway.

1:40 PM 04-Aug-2021 **IN21_2939.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2939

Air-cooled chiller screening noise analysis with preliminary building project information

Mark Storm

For Inter-noise 2018, the author submitted a paper proposing techniques to derive reasonable preliminary estimates of building project stationary noise emission levels from sparse but available data that may seem unrelated to noise or vibration such as gross square footage (GSF), expected occupancy, and land use or function. Results from these predictions would be used to support or refine established buffer distances between exposed outdoor heating, ventilating, and air-conditioning (HVAC) system noise sources and nearby noise-sensitive receptors, helping planners tasked with ambitious infill or growth goals better fit building projects into complicated campus development puzzles. This paper provides supplemental guidance by linking the same preliminary building project GSF, occupancy, and function information to estimates of cooling load (expressed as refrigeration tonnage) and thus an additional HVAC consideration not discussed in the author's previous study. When such refrigeration relies upon air-cooled condensers installed outdoors on building rooftops or at grade, substantial noise sources are introduced to the environment. Thus, this new study shares data and methodology to help expand the value and utility of the previous work and potentially provide more comprehensive building HVAC noise estimates for use by building developers and planners.

Session: 17.06 Information Technology Noise
Channel 8

6:00 AM 04-Aug-2021 **IN21_1698.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1698

Round-robin testing on Sound power level measurement for Reference Sound Source and Office printer

Kohei Shimoda

Round-robin testing for two samples, Reference Sound Source in accordance with ISO 6926 and Office printer with electrophotographic engine, were executed by seven testing laboratories in Japan on 2020. All tests were executed with parallelepiped measurement surface in hemi anechoic chamber in accordance with testing standard for engineering-grade sound power determination, ISO 3744:2010. The results show that sample standard deviation for RSS is better than printer. Standard deviations for overall A-weighted sound power level for two samples are better than combined standard uncertainties calculated with reference example of standard deviations in ISO 3744 (1.5 dB for Reference Sound Source as standard deviation of operating/mounting condition is negligibly small, 1.6 dB for printer as stable operating/mounting condition 0.5 dB). This paper also indicates tips for those who would conduct round-robin testing to obtain valid results by obviating incorrect operations and malfunctions of printers or similar equipment from the experience of some round-robin tests.

6:20 AM 04-Aug-2021 **IN21_1700.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1700

Statistical assessment of A-weighted sound power level for printer with electrophotographic engine

Kohei Shimoda

Statistical distribution and statistical upper limit (the value which 93.5 % of the batch of new equipment are expected to lie) of A-weighted sound power level for one office printer were experimentally estimated from 10 new samples picked up from market. The printer is capable of A4-size printing with electrophotographic engine which corresponds Annex C.16 Page printers in ECMA-74 17th (2019). A-weighted sound power level for continuous printing mode was determined in accordance with noise test code for ITTE (Information Technology and Telecommunications Equipment such as printers and personal computers), ISO 7779:2018 and ECMA-74 Annex C. Sample standard distribution of production of overall A-weighted sound power level (determined from 100-10000 Hz one-third-octave band) is 0.25 dB, whereas individual one-third-octave band has larger distribution. The value obtained is better than reference distribution 1.32 dB set in ISO 9296:2017 which states estimation of statistical upper limit value of the batch of equipment for ITTE.

6:40 AM 04-Aug-2021 **IN21_2174.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2174

Application of psychoacoustic analyses according to ECMA-418-2

Julian Becker, Roland Sottek, Thiago Lobato

Assessing and assuring sound quality has become a very important task for product design. Customers expect product sounds without disturbing noises. This is a challenge because spectro-temporal noise patterns (such as tonal sounds or modulated signals that generate a roughness sensation) must be taken into account, in addition to frequency-weighted values like dB(A) and loudness. If the sound of a technical product exhibits these characteristics, it is most likely perceived as having poor quality.
The new standard ECMA-418-2 describes methods for the automatic quantification of tonal sounds and modulated sounds, which generate a sensation of roughness. The methods are based on a psychoacoustic hearing model and thus emulate human perception very closely.
This paper describes the application of these methods. Several examples show how these parameters can be used for sound engineering and how to interpret the results.

7:00 AM 04-Aug-2021 **IN21_2172.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2172

High-resolution spectral analysis (HSA) vs. discrete fourier transform (DFT)

Roland Sottek, Thiago Lobato

The Discrete Fourier Transform (DFT) is the standard technique for performing spectral analysis. It is used in the form of the well-known fast implementation (FFT) in almost all areas that deal with signal processing. However, the DFT algorithm has some limitations in terms of its resolution in time and frequency: the higher the time resolution, the lower the frequency resolution, and vice versa. The product of time (analysis duration) and analysis bandwidth (frequency resolution) is a constant. DFT results depend on the analysis window used (type and duration), although the physical signal properties do not change. The High-Resolution Spectral Analysis (HSA) method, published at the ASST '90, considers the window influence through spectral deconvolution and thus leads to a much lower time-bandwidth product, correlating better with human perception. Recently, variants of the HSA have been used for a psychoacoustic standard (roughness). Additionally, HSA is planned for a new model of fluctuation strength. This paper describes the improvements made to the HSA algorithm as well as its robustness against noise, and compares application results for both methods: HSA and DFT.

7:20 AM 04-Aug-2021 **IN21_2921.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2921

New ECMA 74 operating conditions for personal computers and workstations

Willem Beltman, Seth Bard, Travis North, Charles Oppenheimer, Paul Waters, Andrew Wiltzius, Sean Zimmerman

Annex C in ECMA 74 outlines the operating conditions for personal computers and workstations during acoustic testing. In practice, the way systems are used and designed changes over time. After InterNoise 2018 in Chicago, a special IT industry workgroup was formed with the goal to update this section in Annex C to better reflect current workloads during use. This paper outlines the new operating conditions that were developed by this workgroup. It describes the different operating modes to be measured, and how to set and document power and performance parameters during the acoustic measurements. In addition to the standard idle condition, it includes operating conditions selected from the following usage scenarios: 1) web browsing, 2) office productivity, 3) media content creation, and 4) power user/gaming.

Session: 16.03 Occupational Noise & Health
Channel 8

11:00 AM 04-Aug-2021 **IN21_3002.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3002

A comparison of standardized methods for sound attenuation test of hearing protectors

Sakae Yokoyama

In order to prevent hearing impairment due to occupational noise, it is essential to wear hearing protectors such as earplugs and earmuffs, especially in an extremely noisy environment. The method of measuring their sound attenuation is defined by international standards such as ISO and IEC, and standards such as ANSI, BS, AS/NZS, JIS et.. Although most standards recommend subjective methods where the thresholds of hearing shall be measured once with open ears and once with the hearing protector in place for each subject, measurement and evaluation methods are not unified internationally. In Japan, in April 2020, the old product standard was abolished in consideration of international consistency, and a new method standard was established with the ISO standard as the corresponding international standard for the first time in about 40 years. In this study, we compared the measurement methods and evaluation methods according to the standards for sound attenuation tests of hearing protectors.

11:20 AM 04-Aug-2021 **IN21_1720.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1720

Pilot studies of noise annoyance in relation to time, amplitude and frequency characteristics of sound

Jan Radosz

Noise is any unwanted sound that may be disruptive or harmful to health or increase the risk of an accident at work. Noise as a stressor can contribute to the development of various types of diseases, cause distraction, make work difficult and reduce its efficiency. Aim of the pilot studies was to asses noise annoyance in relation to time, amplitude and frequency characteristics of sound in typical office environment. The Vienna Test System was used for this purpose. Virtual office acoustic environments were developed with different psychoacoustic parameters, but with a constant A-weighted sound pressure level of 55 dB - environment with conversations, environment with office equipment (computers, printers, telephones), environment D with all office noise sources together. The reference environment was a quiet office room with no additional noise sources. Recorded real noise sources were transferred to a virtual 3D sound environment and converted into binaural

sound, which was then played back on headphones. During the exposure to each of the acoustic environments, the subjects performed the ALS test (work performance series) and then assessed the given environment using a questionnaire. The tested acoustic environments were assessed in the range from not at all annoying to very annoying. On average, environments with office noise were rated as moderately annoying. However, subjective feelings of the respondents were not reflected in the results of psychological tests.

11:40 AM 04-Aug-2021 **IN21_2733.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2733

How well does Spain manage occupational noise and vibration risks?

Rafael Sánchez-Guardamino Elorriaga, María José García Tomás

From the analysis of Spanish national statistics on occupational diseases notification during the period 2009 – 2018, a prospective study on the level of compliance with the national implementation of both European Union directives 2003/10/CE and 2002/44/CE respectively, is undertaken. Research is developed by Occupational Health and Safety National Institute in liaison with Spanish autonomous regional governments. Questionnaires were designed by technical personal from the national Institute in order to collect relevant information. These questionnaires were fulfilled in situ by specialized and qualified civil servants from several autonomous regions. Up to 566 companies take part of the study from different economical activities, in which outstanding noise and/or vibration risk is present. The study conclude in relation to preventive management of noise that, both there are serious deficiencies in the characterization of the exposure, and it also entails a very low effectiveness in reducing risk. As far as vibration risk management is concerned, a deficient specific legal regulatory implementation is found. As a result, of such conclusions, an action plan is being designed to improve working conditions by means of assuring the compliance with legislation.

12:00 PM 04-Aug-2021 **IN21_1728.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1728

Priorities for occupational noise in Britain

Chris Steel, Paul Brereton

Regulation of occupational exposure to noise in Britain for 50 years has reduced risk. However, statistics from around the globe (and in Britain alone) suggest that the range in harm is between around zero and more than 1 in 4 workers exposed to high noise. The uncertainty in statistics and the potential high incidence and prevalence of harm justifies investigation. In Britain, we will investigate the current risk of occupational hearing loss and the effectiveness of current noise control measures. We propose to gather data during inspections of industries that are known to have high levels of workplace noise. Finding high incidence of hearing damage will indicate a failure of immediate management of risk and likely result in enforcement action. We propose to review employers' control of noise propagation in the workplace through use and maintenance of noise controls supplied with machines and supplemented with acoustic barriers and noise havens. We propose to review suppliers design and build of noise control into their products and their reported noise emissions for noisiest typical use. We are looking to benefit from the experience of our global counterparts before finalising our plans.

12:20 PM 04-Aug-2021 **IN21_1910.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1910

Evaluating worker noise exposure levels in the presence of complex noise

William Murphy, Wei Qiu, Meibian Zhang

Recent research into the assessment of worker noise exposure has demonstrated that the combination of impulsive noise and continuous noise creates an additional risk of developing noise-induced hearing loss (NIHL). Zhang et al (2021) demonstrated that workers exposed to non-Gaussian noise accumulated NIHL at a faster rate over their careers than worker exposed to Gaussian noise. The kurtosis statistic of the sound pressure distribution provides a means to adjust the estimated risk of hearing loss between exposure groups exposed to different types of noise. This paper will review the results from our recent studies of kurtosis and exposure level. Some unanswered questions involve the selection of a suitable sample length to estimate kurtosis, the selection of a compensation factor to apply, and understanding the differences exhibited in short (less than 10 years) and long-term exposures and kurtosis.

12:40 PM 04-Aug-2021 **IN21_2219.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2219

Status - International Space Station (ISS) Crewmembers' Noise Exposures

Jose Limardo, Christopher S. Allen, Richard W. Danielson, Andrew J. Boone

Environmental noise in space vehicles, caused by onboard equipment and crew activities, has generated concerns for crew health and safety since early U.S. space missions. The International Space Station (ISS) provides a unique environment where acoustic conditions can be monitored while crewmembers from the U.S. and their international partners work and live for as long as 6 to 12 consecutive months. This review of acoustic dosimetry data collected to date reveals that the noise exposure limits of NASA's stringent noise constraint flight rule have been exceeded in 41% of these dosimetry measurements since ISS Increment 17 (2008), with undefined impacts to crew. These measurements do not take into account the effects of hearing protection devices worn by the crew. The purpose of this paper is to provide an update on ISS noise exposure monitoring approaches and hearing conservation strategies that include acoustic dosimetry data collected since the ISS Increment 55 mission (April 2018). Future directions and recommendations for the ISS noise exposure monitoring program will also be presented, including research initiatives aimed at better defining the impact of ISS noise on crew health and performance.

1:00 PM 04-Aug-2021 **IN21_2877.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2877

The evolution of quiet lawn mowers and their impact on community noise and hearing conservation

Leslie Blomberg, Dave Trezza

Noise measurements of more than 600 lawn mowers were made at 25 feet and at the operator's ear between 2004 and 2021. These data are presented and compared with the measurement of more than 60 mowers in 1973 by the US EPA. With the exception of electric lawn mowers, very little progress has been made quieting lawn mowers. Electric lawn mowers are significantly quieter than gas mowers. Recently, with improvements in battery technology, the performance of electric mowers has improved significantly. There are currently electric push, self-propelled, and ride-on mowers with comparable performance to gas powered mowers. Finally, the impacts of lawn mower noise on community noise and hearing conservation are discussed.

1:20 PM 04-Aug-2021 **IN21_2925.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2925

Hearing protection and communication in high noise environments using vibration sensing and neural network voice transformation

Willem Beltman, Hector Cordourier, Paulo Lopez Meyer

In the United States alone, there are more than 9 million workers who are exposed to high levels of noise (> 85 dBA) that require hearing protection. Not only is there a risk of hearing damage due to these high noise levels, but it also prevents communication between people, leading to significant safety risks, including people not using hearing protection because of the desire to communicate. Workers in such high noise environments typically also wear safety glasses. This paper outlines an integrated system with safety glasses, hearing protection, and communication elements, using vibration sensing technology and a neural network based voice transformation routine. Data was collected to train the neural network based voice transformation. Recordings were made under various representative noise conditions, with some well exceeding sound pressure levels of 93 dBA, and Signal to Noise Ratios were extracted. In addition, experiments were conducted according to a modified ITU P.835 approach to determine intelligibility, naturalness and overall quality. The results demonstrate that with this approach, speech can be clearly understood in such high noise environments with this approach.

Workshop: 08.01 Identifying the Most Successful Methods of Hearing Conservation in High Noise Industry – and Where We Can Improve
Channel 8

2:00 PM 04-Aug-2021 **Oral Only**

Identifying the most successful methods of hearing conservation in high noise industry – and where we can improve

Amanda Azman, Paul Brereton

This workshop will be a round-table review of practical implementation of hearing conservation methods and standards. The actions expected of employers in the U.S., Britain and other participating countries will be presented. Discussion of the various elements of a successful hearing conservation program will take place (noise measurement, quieter machinery, controlling noise propagation, hearing protection, audiometric testing, training, etc.). Workshop delegates will jointly consider the successes and challenges of different approaches. The workshop organizers will produce a short report on good practice to reduce the incidence and progression of occupational hearing damage. There will be a takeaway message for practical hearing conservation program implementation – what works well, what works with effort, what doesn't work and what might become possible in the near future.

Session: Poster Q&A Session 2
Poster Session

1:20 PM 02-Aug-2021 **IN21_1369.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1369

Analysis of the interaction of Helmholtz resonators in periodic acoustic metamaterials depending on its orientation with the acoustic source.

David Ramírez, Sergio Castiñeira-Ibáñez, Jose Maria Bravo-Plana-Sala, Juan Vicente Sánchez-Pérez, Rubén Picó

Acoustic screens based on sonic crystals constitute one of the most promising technological bets of recent years in the field of environmental acoustics. Sonic crystals are defined as new materials formed by arrays of acoustic scatterers embedded in air. The design of these screens is made using powerful simulation models that provide reliable results without the need of expensive experimental testing.
This project applies the finite elements method in order to analise an acoustic barrier that includes (Helmholtz) resonators in its scatterers, and studies the interference of the sonic crystal with the effect of the Helmholtz resonator, depending on its orientation with the acoustic source.

12:00 PM 04-Aug-2021 **IN21_2717.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2717

Calculation tool NoBel for sound propagation assessment of noise from gasturbines on the ground

Oleksandr Zaporozhets, Sergii Karpenko, Larisa Levchenko

Gas turbine engines of aviation type are the basic element of gas-pumping stations of the pipelines around in the world. They produce harmful noise and the protection zone around the gas-pumping station must provide the safe distance to residence in its vicinity. Due to Ukrainian legal requirements for the stationary (not movable) noise sources the sound pressure levels in octave bands must be used as limits for protection of the population complementarily to equivalent and maximum sound levels at day and night periods.
A new calculation tool was designed to assess the effects during sound wave propagation from stationary noise sources like gas-turbine installations, as for homogeneous atmosphere, so as for real meteorological and topographical conditions. The tool provides the possibility to predict the conditions of maximum noise exposure at point of noise control. For homogeneous atmosphere the divergence, air absorption, ground surface reflection and acoustic screens contribute to propagation effects mostly. Their formulation in accordance with current knowledge provides more accurate sound levels assessment with differences ± 2 dBA at the boundaries of protection zone in comparison with existing national legal requirements of noise protection calculations.
In real atmosphere temperature and wind (in direction and speed) vary with altitude over the ground surface always. These real conditions provide the dependence of sound speed with altitude, and in consequence the refraction of sound waves. For specific conditions of positive sound refraction the tool predicts the sound levels at the receiver up to 10 dBA higher, at negative sound refraction – on 5-7 less than in homogeneous atmosphere for legal protection distances. Tool NoBel is appropriate to be used for specific airport stationary noise scenarios, like for aircraft engine run-ups after their maintenance or repair.

12:00 PM 04-Aug-2021 **IN21_2049.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2049

Noise emission of combustion engines and road vehicles – a historical review

Bruno Spessert, Martin Fischer

This paper deals with the historical development of the noise emission of cars, trucks and their petrol and diesel engines; it focus on the European Union and the time period between 1910 and 2020.
Combustion engines were and are important noise sources of road vehicles. Until around 1970 engine noise levels were increased strongly by higher speeds, by higher cylinder pressures and especially for truck engines by the introduction of the diesel combustion process.
The noise emission was mainly caused by the drive train until the 1960ies for cars and until the 1970ies for trucks. Since then the development of acoustically more advantageous engines was forced by noise regulations and simultaneously enabled by technical advancements. As a consequence of the acoustical optimization of the engines the tire/road noise became dominant.
Despite of the technical advancements the road noise stress of the population is still much too high. Therefor the necessary short-term reduction of noise stress has to be realized by regulatory measures.

12:00 PM 04-Aug-2021 **IN21_3188.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3188

Influence of different materials used for 3D printing in miniature speaker enclosure development

Bartlomiej Chojnacki, Jan Pawlik, Tadeusz Kamisinski

Additive manufacturing techniques are commonly used in industry and mechanical prototyping. The past years brought rapid growth in this technology development, also in the speaker cabinets manufacturing industry. We observe numerous DIY projects on the market based on the 3D printed cabinet parts; however, this technology also offers novel options that should be investigated and documented. In the current state of the art, the basic properties and construction aspects for speaker acoustic performance is not provided as the 3d printing technique is usually treated as the tool for other projects' development. This paper will provide a detailed comparison of the most common 3D printing materials used in FDM techno9logy, such as PLA, TPE, PET-G, and others with different mechanical properties. Example enclosure for a loudspeaker of 37 mm diameter will be printed in different shapes and compared for frequency and sensitivity differences. The results will be discussed, investigating the possible use of different than traditional rigid plastic enclosures and new options using complicated geometry shapes possibly to manufacture with 3D printing techniques.

12:00 PM 04-Aug-2021 **IN21_1777.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1777

Are on board comfort classes noise and vibration levels really suitable?

Luigi Bregant, Flavia D'Agostin, Martina Lorenzino

In shipbuilding industry, comfort is a relevant issue both for crew members and passengers. A comfortable environment enables crew members to perform accurately their tasks and it is an effective factor contributing to the satisfaction of passengers. Noise and vibration, as environmental parameters, play an important role in subjects' comfort. Naval Classification Societies established series of noise/vibration comfort level criteria, which, however, did not take into account some aspects: 1) noise/vibration recordings are carried out during time periods shorter than the exposure time of passengers; 2) the subjective mood is not investigated. In the present study, we studied comfort perception by measuring heart rate variability and mood. We exposed participants to four levels of acoustic noise [from 45 to 55 dB(A)] and three levels of vibration (1.5, 1.8, 2 mm/s) inside a full-scale mock-up of a cruise ship cabin. We found that the increase of noise/vibration intensity determines an increase of heart rate variability and negative mood. However, changes in comfort responses did not occur for the noise/vibration comfort thresholds identified by the Classification Societies. Our results evidence the importance to include psychophysiological measure of comfort when defining comfort criteria on board.

12:00 PM 04-Aug-2021 **IN21_1991.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1991

Evaluation of floating floors performances using the reception plate method

Fabio Serpilli, Valter Lori, Samantha Di Loreto

This paper concerns the development and experimental validation of a simplified method to evaluate the performances of materials for floating floors. The method is based on the reception plate theory. The porpouse is to evaluate the impact sound pressure level reduction ΔL by the differences of the sound power level ΔP measured on the reception plate with and without the acoustic material. The results are compared with the values measured in accordance with ISO 10140 standards.

12:00 PM 04-Aug-2021 **IN21_1999.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1999

The acoustics of a medieval room

Silvana Sukaj, Ilaria Lombardi, Amelia Trematerra

Rooms inside old castles are used for various kinds of events such as conferences, exhibitions, music concerts. In this way, the rooms become the cultural center of the cities in which they are located. These rooms have large ceilings and the walls are plastered. The walls must remain without coverings for historical and artistic reasons, so the walls cannot be covered with elements that can absorb sound. The acoustic conditions are not satisfactory due to the presence of excessive reverberation time, which negatively affects speech understanding. In this paper, acoustic measurements are reported inside a representative room inside a medieval castle. The room is used for conferences and various events. The acoustic measurements were performed with the impulse response technique and the average values of the T30 is equal to 3.5 seconds, the average value of D50 is equal to 0.2. The room has an insufficient condition for good speech listening and therefore presents conditions of poor speech understanding. With the aid of software for architectural acoustics, it is possible to estimate the amount of sound-absorbing material to be inserted in the room to obtain optimal conditions for listening to speech. Since this is an environment with historical and artistic characteristics and therefore it is not possible to cover the walls with suitable sound-absorbing materials, a solution has been studied with semi-rigid panels which, installed on some supports, can be easily removed at the end of the events.

12:00 PM 04-Aug-2021 **IN21_2577.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2577

Use of masks inside the classrooms

Silvana Sukaj, Amelia Trematerra, Giuseppe Ciaburro, Gino Iannace

To counter the transmission of Covid -19 it is mandatory to wear face masks. Medical face masks (surgical or other medical devices) are used to control the spread of infection by reducing the airborne dispersion of the viral load-carrying saliva droplets emitted from the mouth when talking, sneezing or coughing. The use of the mask can cause fatigue, difficulty in breathing and reduced speech understanding. In school classrooms, the use of masks makes verbal communication very difficult by reducing speech understanding and this can affect both the learning level of pupils and cause vocal dysfunctions in teachers who incur an overload of the speech apparatus. To investigate the effects of using the mask in learning environments, tests were carried out with pupils of a primary school. The students were given dictations by a teacher according to two configurations: with and without a mask. Subsequently, the texts written by the children were analyzed to assess the presence of possible errors in the understanding of the dictation administered with and without a mask.

12:00 PM 04-Aug-2021 **IN21_2312.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2312

Influence of green space design on individual noise perception

Verena Zapf

Especially in urban areas, green spaces are important recreational destinations, yet they are often exposed to high levels of traffic noise. Therefore, it should be investigated to what extent the design of green spaces affects the perception of noise within the green spaces. For this purpose, four soundwalks with a total of 34 participants were conducted in the Großer Garten in Dresden, Germany. A range of acoustic and perceptual properties were measured and examined. Furthermore, the green space was characterised with regard to its vegetative design and the visibility of the noise sources, as well as evaluated by the participants with respect to visual impression and appropriateness. The statistical evaluation has shown that the visual impression, the appropriateness and the masking of the noise sources correlate significantly with the perceived loudness and pleasantness - but not with the eventfulness. With regard to vegetation, it was found that the diversity of vegetation correlates significantly with all three parameters of individual noise perception, whereas the quantity of vegetation does not. Thus, it can be said that appealing design, masking of the noise sources and diversity of vegetation reduce individual noise perception and therefore increase the recreational value.

12:00 PM 04-Aug-2021 **IN21_2822.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2822

Noise and errors in hospitals

Silvester Siegmann

“Noise in hospitals” is a theme in specialist literature since decades. “Safety of patients” is a theme which is increasingly noticed internationally since the American report „To err is human“ was published at the turn of millennium. In an hospital in Germany the influence of level-oriented characteristics in the operating room on errors was investigated. We used generalized linear mixed models (GLMM). Model 1: First we entered the factors “objective measured noise” (noise measured in dBA), “subjective evaluated noise”, sensitivity to noise (‘are you sensitive to noise?’, 1–5). Model 2: In a second step we entered the factors occupation (1: physician vs. 2: nursing staff), age and sex (1: male, 2: female). In model 1 objective noise became a significant predictor and for the subjective evaluated noise a trend can be seen. With more silence – objective and subjective – the less near mistakes the respondents mentioned. In model 2, which shows better fit indices, again the objective noise became

significant, but the effect of subjective evaluated noise was no longer significant, instead noise sensitivity showed significant associations with near mistakes, again corresponding to the outcomes for the mistakes more sensitive and younger respondents rather admitted near mistakes.

12:00 PM 04-Aug-2021 **IN21_2318.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2318

Physical and perceptual dimensions of open urban spaces in Biskra, Algeria

Luigi Maffei, Samiha Boucherit, Djihed Berkouk, Djihed Berkouk

The sound dimension is a constitutive element of the architectural, urban, and environmental projects of open spaces. In combination with other physical stimuli, such as vision, thermoigrometric conditions, odors, the sound can contribute to fulfill the expectation and it can improve the well being of the citizens who are the users of these spaces. Many researches attempted to find out correlation between quantitative multisensorial physical features of open spaces and subjective qualitative evaluation by users. In many cases these attempts were successful, however few researches considered specifically special categories such as older citizens or visually impaired citizens.
In order to receive information to make the sensory urban architecture approach more inclusive as possible, in this preliminary study several relevant urban sites such as gardens, main streets and open markets in the city of the Biskra in Algeria have been characterized in terms of physical properties and in these sites, through specific surveys, the response of users was collected. Among the users, different categories of citizens with specific needs were contemplated for the subjective assessment.

12:00 PM 04-Aug-2021 **IN21_2338.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2338

Noise control engineering on neonatal incubators

Christian Adams, Regine Stutz, Elisabeth Kaiser, Michelle Bous, Sybelle Goedicke-Firtz, Franziska Hornberger, Michael Zemlin

Neonatal incubators provide suitable environmental conditions for premature newborns and allow for medical treatment such as medication and monitoring of vital functions such as blood pressure. The incubator includes several system components such as a control system, an oxygen supply, a scale or flaps and drawers for patient care and storage of medical material, respectively. These system components generate noise such as monitoring alarms, noise of the oxygen supply, or noise due to opening and closing of flaps during medical treatments. The noise leads to a significantly increased sound exposure inside the incubator. Increased sound exposure is known to cause distress and to increase the risk of acute or chronic diseases in the preterm neonate. This paper presents acoustic measurements on an incubator in a neonatal intensive care unit. Several vibration and acoustic measurements are performed inside the incubator as well as in the surrounding environment in order to characterize typical acoustic scenes from everyday life on the neonatal intensive care unit. Based on the measurement results, the scenes are categorized in terms of sound exposure. This forms the basis for a future design for acoustics of the incubator.

12:00 PM 04-Aug-2021 **IN21_2657.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2657

Elastic wave propagation in metamaterial rods with periodic shunted piezo-patches

Edson J.P. de Miranda Jr., Edilson D. Nobrega, Leopoldo P.R. de Oliveira, José M.C. Dos Santos

The wave propagation attenuation in low frequencies by using piezoelectric elastic metamaterials has been developed in recent years. These piezoelectric structures exhibit abnormal properties, different from those found in nature, through the artificial design of the topology or exploring the shunt circuit parameters. In this study, the wave propagation in a 1-D elastic metamaterial rod with periodic arrays of shunted piezo-patches is investigated. This piezoelectric metamaterial rod is capable of filtering the propagation of longitudinal elastic waves over a specified range of frequency, called band gaps. The complex dispersion diagrams are obtained by the extended plane wave expansion (EPWE) and wave finite element (WFE) approaches. The comparison between these methods shows good agreement. The Bragg-type and locally resonant band gaps are opened up. The shunt circuits influence significantly the propagating and the evanescent modes. The results can be used for elastic wave attenuation using piezoelectric periodic structures.

12:00 PM 04-Aug-2021 **IN21_2284.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2284

An innovative X-shaped vibration isolation mount with tunable quasi-zero-stiffness property

Jing Bian, Xingjian Jing, Yishen Tian

Passive vibration isolation is always preferable in many engineering practices. To this aim, an innovative, compact, and passive vibration isolation mount is studied in this paper. The novel mount is adjustable to different payloads due to a special oblique and tunable stiffness mechanism, and of high vibration isolation performance with a wider quasi-zero-stiffness range due to the deliberate employment of negative stiffness of the X-shaped structure. The X-shaped structure has been well studied recently due to its excellent nonlinear stiffness and damping properties. In this study, by using of the negative stiffness property within the X-shaped structure, the X-shaped mount (X-mount) can have an obviously larger vibration displacement range which maintains the quasi-zero-stiffness property. A special oblique spring is thus introduced such that the overall equivalent stiffness can be much easily adjusted. Systematic parametric study is conducted to reveal the critical design parameters and their relationship with vibration isolation performance. A prototype and experimental validations are implemented to validate the theoretical results. It is believed that the X-mount would provide an innovative technical upgrade to many existing vibration isolation mounts in various engineering practices and it could also be the first prototyped mount which can offer adjustable quasi-zero stiffness conveniently.

12:00 PM 04-Aug-2021 **IN21_1838.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1838

Acoustic characterization of Zea Mays culm fibers (corn) and Musa X Paradisiacal (banana) stem fibers in proportion 50% - 50%.

Yesika Alvarez Ruiz, José Alcides Ruiz

The following research arises as a proposal to the implementation of Zea Mays culm fibers and Musa X Paradisiaca stem fibers in proportion 50% - 50% for the development of a new eco-material with acoustic properties, the objective was to measure the absorption coefficient based on the international standard ISO 10534-1 Determination of the acoustic absorption coefficient and acoustic impedance in impedance tubes. Using the impedance tube to identify the minimums and maximums needed to perform the computational procedure in the MATLAB software tool, and finally obtain the sound absorption coefficients of the material. The measurement process is supported by the implementation of the impedance tube, having all its consideration and previous measures that support the veracity of the data taken through this process, in addition to the fact that background noise measurements were made in order to pass these values to ensure reliable results in the measurement, performed with a class 1 sound level meter; The fibers analyzed had a range between 0.8136 and 0.9225 absorption coefficient in the bands of 1000, 2000 and 4000 Hz, testing the effectiveness in their implementation as an acoustic barrier.

Keywords: absorption, eco-material, fibers, barrier, acoustics.

12:00 PM 04-Aug-2021 **IN21_1132.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1132

Analysis of the acoustical environment of classrooms in three brazilian public schools through measurements and 3d simulation

Fernanda Horst Andrade, Rodrigo Scoczynski Ribeiro, Manuel Teixeira Braz César

The present study analyses the outdoor and indoor sound pressure levels (SPL) and the reverberation time (RT) measured in three Brazilian public classrooms. For the SPL, a sound level analyzer (class II) was used, and for the RT it was used a smartphone for the measurements. The sound sources were the impulses of bursting balloons and the data was processed in a MatLab toolbox (ITA-Toolbox). The classrooms were also simulated in an open source modeling software (I-SIMPA), using ray-tracing principles. Based on the results of the simulations, supported by the low-cost measurements, it was observed that the classroom didn’t reach the national standards for classroom acoustics. Some improvements were designed with sustainable materials in order to reach the lower limits of the standards using the same room acoustics software. It was observed that the low-cost measurements helped on the diagnosis of classroom’s acoustic issues which was also verified in the 3D simulation. This procedure showed itself as a cheap solution for classroom acoustic designs.

12:00 PM 04-Aug-2021 **IN21_3232.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3232

Influence of microclimatic elements on sound propagation in Amazonian cities: The case of urban noise in Belem.

Vânia Raposo de Moura dos Santos, Gustavo Melo

Many studies have shown that microclimatic elements influence the sound propagation in cities, and can contribute to increasing or decreasing the urban noise. This paper aims to discuss the relationship between main microclimatic elements - air temperature, air humidity, atmospheric pressure and winds - and the noise caused by road traffic in an Amazonian urban environment, in order to emphasize the importance of urban planning instruments be adapted to the specific microclimatic conditions, promoting the improvement of the urban environment from more efficient building strategies for controlling the sound pollution. For this, it’s used as basis a theoretical framework on the topic, meteorological data from Brazil's National Institute of Meteorology and illustrative maps of the city of Belem. It was found that the temperature, humidity and atmospheric pressure, for this microclimate, do not collaborate for reducing road traffic noise, leaving this responsibility to the winds (air ventilation) and the way they behave within the built urban mass.

KEYS
Urban noise - Urban Microclimate - Amazonian environment

12:00 PM 04-Aug-2021 **IN21_2064.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2064

A novel corpus developed to evaluate the impact of hospital noise on speech intelligibility

Sydney Perry, Tessa Bent, Erica Ryherd, Melissa Baese-Berk

Hospital noise often exceeds recommended sound levels set by health organizations leading to reductions in speech intelligibility and communication breakdowns between doctors and patients. However, quantifying the impact of hospital noise on intelligibility has been limited by stimuli employed in prior studies, which did not include medically related terminology. To address this gap, a corpus of medically related sentences was developed. Word frequency, word familiarity, and sentence predictability, factors known to impact intelligibility of speech, were quantified. Nearly 700 words were selected from the Merriam-Webster Medical Dictionary. Word frequency was taken from Lexique, a 51-million-word corpus of American subtitles (Brysbaert & New, 2009). Word familiarity was rated by 41 monolingual listeners. The words were then used to construct 200 sentences. To determine sentence predictability, the sentences were presented to 48 participants with one word missing; their task was to fill in the missing word. Three 40 item sentence sets with different familiarity / frequency types (low/low, high/low, high/high) were selected, all with low predictability levels. These sentences and 40 standard speech perception sentences were recorded by two male and two female talkers. This corpus can be used to assess how hospital noise impacts intelligibility across listener populations.

Session: 08.04 Vehicle Sound Design and Simulation
Channel 1

6:00 AM 05-Aug-2021 **IN21_2250.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2250

Auralization of electric vehicle's interior noise SEA simulation

Eunsoo Jo, Ki Sang Chae, Dong Chul Park, Wookeun Song, Moonju Hwangf

Statistical Energy Analysis (SEA) has become an essential step to minimize the vehicle interior noise level. The outcome of SEA is typically 1/3 octave spectrum, and consequently it is difficult to understand the subjective effect of interior noise. This study investigated two approaches to achieve the binaural synthesis of SEA results. One is directly from the SEA 1/3 octave result and the measured coherence function. The other makes use of Source Path Contribution (SPC) to estimate the time signals on the exterior panels and subsequently applies the SEA results as a set of Finite Impulse Response (FIR) functions. Both approaches seem to result in realistic binaural signals as well as the correctly scaled sound pressure levels at the receivers. The one using SPC results can generate the input data for an NVH driving simulator by decomposing the harmonics and the masking noises. This means that the SEA result can be experienced by driving the simulated vehicle freely.

6:20 AM 05-Aug-2021 **IN21_2154.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2154

Acceleration sound design for vehicles using distortion products

Yu Aburagi, Natsuki Yamagiwa, Noriyuki Tanimoto, Shunsuke Ishimitsu, Mitsunori Matsumoto, Yasuki Murakami

When considering the acoustic design of automobiles, low-frequency sounds can increase the excitement levels for users. However, there are several problems accompany an increase in the low-frequency levels of an engine sound. For example, it is difficult to create a balance between silence and excitement when a sound's different order components are changed. It is also difficult to generate heavy bass engine sounds in practical scenarios. Thus, the application of distortion products in the auditory system of the cochlea is considered. Distortion products are perceived when two or more sounds with slightly different frequencies are played simultaneously. This study was conducted to examine the possibility of achieving powerful engine sounds using distortion products. At first, the relationship between different combinations of complex sounds and the pitch perception of distortion products was investigated. As a second step, the application of distortion products to the acceleration sound was also considered. The results suggested the possibility of synthesizing a low-frequency component using distortion products inside a cochlea.

6:40 AM 05-Aug-2021 **IN21_2629.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2629

Perceptual Difference on HVAC Sound Quality between Electric and Conventional Vehicles

Katsuya Yamauchi, Minori Dan, Federico Cioffi, Luigi Maffei, Massimiliano Masullo

The heating, ventilation and air-conditioning (HVAC) system is one of the most critical sources in in-vehicle noise environment, especially when cars are moving at low speed or at lower engine rotation. With the transition to electric vehicles (EV) from internal combustion engine vehicles (ICEV), the contribution of powertrain becomes lower on the background noise inside car cabins. The authors have been conducting a collaborative research on HVAC sound quality inside car cabins. In this paper the results of a subjective evaluation of HVAC sound quality were presented, that attempted to compare the perceptual differences among the two groups, i.e. EVs and ICEVs. The result revealed the difference in the noise perception among the two types of vehicles especially softer air flow rate conditions.

7:00 AM 05-Aug-2021 **IN21_1805.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1805

Design of an In-cabin Personal Audio Zone System Using an Optimized Acoustic-Contrast-Control-Pressure-Matching Algorithm

Zhe Zhang, Junjie Wu, Junjie Wu, Minghui Yang, Yonggang Leng

This paper presents the design of an in-cabin personal audio zone (PAZ) system that enables the driver and one rear-row passenger to listen to different audio programs with acceptable mutual disturbance. The system is designed predicated on a modified acoustic-contrast-control-pressure-matching (ACC-PM) algorithm, which is optimized using the genetic algorithm (GA) to find out the optimum tradeoff between performance indices including the acoustic contrast (AC) and error performance (Err) and the numerical stability of the algorithm. Comparison with the traditional ACC-PM algorithm reveals an increased contrast and improved reproduction quality. In addition, perhaps more importantly, the numerical stability of the optimized algorithm is substantially enhanced, making it possible to involve more loudspeakers into the PAZ system to achieve an even better sound compartmentalization performance.

7:40 AM 05-Aug-2021 **IN21_1874.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1874

Suggestive Sound Design – How to use Active Interior Sound Design to improve traffic safety

Manuel Petersen, Marc Etri, Matthias Behrendt, Albert Albers, Manuel Spekker, Tim Jonathan Lefringhausen

Active sound design becomes an important addition to the newest generation of premium class electrical vehicles to enhance the emotionality of the driving experience. Musicological research indicates that emotions are altered by certain harmonic sets of pitches, whereas results in traffic psychology show that emotions can influence the driving behavior. Despite these findings, there is no research done on how changes to an active vehicle sound could influence the driving behavior.
In this paper, we describe an approach for a suggestive sound design. It's based on the hypothesis, that the chosen safety distance by a driver could be altered by changing the inherent dissonance of an active interior vehicle sound based on the current safety distance. The suggestive sound design is based on an additive synthesizer utilizing the Shepard-Risset glissando. The sound can be controlled by external signals e.g. CAN signals from real or virtual vehicles.

To verify this hypothesis, a driving simulator was built in which the driving experience with a suggestive sound and the resulting driving behavior can be validated through subject studies within an immersive and reproducible virtual reality environment.
The research aims at improving road safety by influencing the driver through changes in the interior vehicle sound.

8:00 AM 05-Aug-2021 **IN21_2601.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2601

An analytical model for predicting noise radiated by switch reluctance electric motors

Murat Inalpolat, Bahadir Sarikaya, Enes Timur Ozdemir, Hyun Ku Lee

Switch reluctance motors (SRM) have become a prominent alternative for electric vehicles in recent years due to their simple, high power density architecture and cost-effective manufacturability. Despite its potential, NVH problems have been one of the biggest challenges for SRM's implementation. Vibration and noise generated by the SRM are mainly caused by phase switching related torque ripple, unbalanced electromagnetic forces from air gap variations and lamination problems. Our proposed model is an analytical noise radiation prediction model which relates geometrical, material and electrical design inputs to radiated sound power. The electromagnetic part of the model is nonlinear with saturation and provides back-emf and flux linkage by receiving design inputs. The computed magnetic energy, radial and tangential rotor forces are utilized as excitation sources to a continuous shell dynamic model to obtain the steady-state vibration response. Finally, surface velocities obtained from the shell model are used to calculate sound power. Utilizing a shell structure provides axial, radial and tangential information on the casing by considering the effect of magneto-restrictive forces of laminations, torque ripples and unbalanced electromagnetic forces. The effect of air gap, lamination error, and stator and rotor geometry on sound radiation are studied through an example case study.

8:20 AM 05-Aug-2021 **IN21_2605.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2605

A dynamic shell model for diagnostics of rotating machinery under periodic excitation

Murat Inalpolat, Enes Timur Ozdemir

In this paper, a generalized dynamic model of a shell structure has been developed and utilized for diagnostics purposes. The dynamic model is three-dimensional, includes the effects of rotary inertia and shear deformation, and can handle moving loads in radial, tangential and axial directions. The model is utilized to determine in-plane radial displacements of the shell structure under concentrated radial loads for different boundary conditions. The periodic loads are constructed using harmonics obtained through the Fourier series expansion method. The modal expansion technique is implemented for calculation of the steady state forced response of the shell structure. A simplified acoustic radiation model is also implemented in conjunction with the dynamic shell model to predict the noise radiated from a rotating circular cylindrical shell structure under different kinematic, loading and boundary conditions. Moreover, forced vibration response and acoustic radiation predicted will be employed to reveal patterns in the signals that can potentially be used for diagnostics of rotating machinery applications. The shell model is derived using a comprehensive approach and thus can be used to model prevalent engineering applications ranging from electric motors to gears and bearings.

Session: Plenary Lecture
Channel 1

9:00 AM 05-Aug-2021 **Oral Only**

Aircraft noise reduction achievements and future challenges

Pascale Neple

Special Session: Technology for a Quieter America and a Quieter World
Channel 1

11:00 AM 05-Aug-2021 **IN21_2545.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2545

Progress on consumer and industrial product noise control and technology transfer: summaries of the 2015 and 2016 TQA workshops

George Maling, Adnan Akay, Eric W. Wood

Progress on consumer and industrial products noise reduction, was a Technology for a Quieter America (TQA) workshop and International INCE symposium hosted by the National Academy of Engineering (NAE) held in October 2015 . The workshop consisted of two major parts, consumer products at home and commercial and industrial products. The former included appliances, waste disposers, leaf blowers, Information Technology Equipment and automotive interior noise. The second half of the workshop included such industrial products as air moving devices, industrial power generation equipment generator sets, compressor noise, transformer noise and valve plus gear noise. It also included national and international noise emission standards for consumer and industrial products. The technology transfer workshop was hosted by NAE in October 2016. The workshop covered four areas; an overview of technology transfer in the United States, government programs, technology transfer from universities, and panel discussions on a variety of topics. Government agencies which participated included NASA, the National Science Foundation, the Small Business Administration, the Federal Aviation Administration, the Office of Naval Research (ONR), and the Naval Research Laboratory.

11:20 AM 05-Aug-2021 **IN21_2551.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2551

Commercial aviation, a new era: summary of the 2017 TQA workshop

Gregg Fleming

More environmentally friendly aircraft designs, particularly with regard to noise, was a Technology for a Quieter America (TQA) workshop hosted by the National Academy of Engineering (NAE) held in May 2017. This workshop titled "Commercial Aviation: A New Era", centered on the importance of commercial aviation to the U.S. economy, and what it will take for the U.S. to maintain global leadership in the aviation sector, including a forward-looking topic on more environmentally friendly aircraft designs. A principal focus of the workshop was the necessary step-changes in aircraft engineering technology that must be addressed with the development and testing of flight demonstrators together with significantly increased funding of public-private partnerships. Government agencies which participated included NASA, the Federal Aviation Administration, and the Department of Housing and Urban Development (HUD). There was also substantial participation from the aviation industry, airports, airlines, non-government organizations and academia.

11:40 AM 05-Aug-2021 **IN21_2611.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2611

Noisy motorcycles and barriers and quieter pavements for traffic noise abatement: summaries of two TQA workshops

Paul Donavan

In the Technology for a Quieter America report, motorcycles were mentioned three times, once in terms of standard test methods and twice in relation to community noise. In New York City, motorcycles placed in the top 10 bothersome noise sources identified by residents. Although there are regulated levels that manufacturers must meet, complaints about in-service motorcycle noise persist. To address this issue, a round table meeting was held in August 2012 with a broad spectrum of participants representing manufacturers, regulators, and other interested, knowledgeable engineers. In preparation of the TQA report, a workshop entitled Cost-Benefit Analysis (CBA) for Noise Control found that CBA was being applied in the area of traffic noise mitigation in regard to the use of barriers and/or quieter pavement. To address the particular CBA issues for this topic, a workshop was held in January 2014 with state and federal transportation officials and the research team responsible for the National Cooperative Highway Research Program NCHRP Report 738, Evaluating Pavement Strategies and Barriers for Noise Mitigation. The findings of these two meetings are summarized in this paper.

12:00 PM 05-Aug-2021 **IN21_2707.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2707

Noise control engineering education: recommendations from the 2019 TQA workshop

Adnan Akay

This paper summarizes recommendations about noise control engineering education made in a special session on noise control engineering education at NOISE-CON 2019 in San Diego and during an National Academy of Engineering (NAE)-hosted workshop under the auspices of the Technology of Quieter America (TQA) program. Speakers in both the special session and at the workshop represented industry, academe, and government emphasizing the need for more noise control engineers, the expertise required, and the areas in which they are needed. The ensuing discussions, summarized in two published reports, also point to the new technologies that affect noise control engineering education.

12:20 PM 05-Aug-2021 **IN21_2893.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2893

TQA-1: The 2010 NAE Technology for a Quieter America (TQA) report and ten years of workshops

Eric Wood, George Maling, George C. Jr. Maling

The Technology for a Quieter America project began in February, 2005 with a request from the project office of the National Academy of Engineering to produce a consensus report on the state of the technology in noise control engineering. A committee was appointed and a series of workshops on the various TQA topics were held. The TQA report was published by the National Academies Press in 2010. After the report was completed, it became clear that additional studies on specific topics covered in the TQA report would be valuable. These were not to be traditional consensus studies but workshops organized on an ad hoc basis and approved by the NAE project office. The first workshop was in 2012 on noise from motorcycles and the most recent workshop held in 2020 was on aerial mobility which included drones and air taxis. In all, ten reports have been published and are available as public information documents from the Institute of Noise Control Engineering. In 2016, the National Academy of Engineering formalized the process for development of workshops in the form of member-initiated activities. There is currently a formal process for the submission and approval of proposed projects.

12:40 PM 05-Aug-2021 **IN21_2899.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2899

Unmanned air systems (UAS/UAV) (drone) and aerial mobility: summaries of the 2018 and 2020 TQA workshops

Robert Hellweg, Gregg G. Fleming

Unmanned air system (UAS/UAV) noise and urban mobility noise were the subject of two National Academy of Engineering (NAE) hosted workshops under the auspices of the Technology of Quieter America (TQA) program. Both workshops were organized by the INCE Foundation in cooperation with the U.S. National Aeronautics and Space Administration (NASA) and the U.S. Federal Aviation Administration (FAA). The first workshop "UAS and UAV (Drone): Noise Emissions and Noise Control Engineering Technology" was held in Washington, DC in December, 2018. manufacturers, users, U.S. government agencies, universities, consultants and professional societies. The second was an e-workshop "Aerial Mobility: Noise Issues and Technology" in December, 2020. Participants at each workshop included representatives from manufacturers (US and international), users, U.S. government agencies, academia, consultants, professional societies, and law firms. Topics included:

modelling, testing, psychoacoustics, community impact, noise reduction strategies, measurement techniques, and uses of both UAS/UAVs and aerial mobility.

1:00 PM 05-Aug-2021 **IN21_2911.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2911

Protecting national park soundscapes: summary of the 2012 NAE workshop

Gregg Fleming, Karen Trevino, Robert D. Hellweg

After reviewing the 2010 National Academy of Engineering (NAE) report "Technology for a Quieter America", the National Park Service (NPS) asked the NAE to undertake a consensus study on the importance of quiet to both visitors and wildlife in its hundreds of properties. The aim of the workshop was to provide best practices to assist NPS park managers, contractors, and concessionaires in protecting park soundscapes. The workshop was hosted by the NPS in Fort Collins, Colorado in October 2012 and was attended by twenty-four participants including park personnel and noise control specialists from government, academia, industry and consulting firms. The NAE report published in cooperation with the NPS and the Volpe National Transportation Systems Center identified seventeen cost-effective actions for reducing noise in our national parks. This paper describes and summarizes the issues raised at the workshop and those recommendations.

1:20 PM 05-Aug-2021 **IN21_3033.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3033

Reducing employee noise exposure in manufacturing: a review of the 2014 workshop

William Murphy

In 2014, the Institute for Noise Control Engineering (INCE) Foundation, the Noise Control Foundation and the National Institute for Occupational Safety and Health organized a meeting of industry, government, and academic experts to discuss "Reducing Noise Exposures in the Manufacturing: Best Practices, Innovative Techniques, and the Workplace of the Future." This presentation will review the content of the recommendations for hearing loss prevention programs, successful implementations for noise control engineering, and new techniques to predict noise exposures in the workplace. Efforts to develop Buy Quiet programs and to promote the Safe-in-Sound Excellence in Hearing Loss Prevention and Innovation will be reviewed.

Workshop: I-INCE Young Professionals
Channel 1

2:00 PM 05-Aug-2021 **Oral Only**

I-INCE Young Professional Workshop

Patricia Davies, Taha Sen

Young Professionals Workshop & I-INCE Young Professionals and Latin American Young Professionals Awards Events. Awards presented by I-INCE President Robert Bernhard.

Session: 04.01 Acoustic Holography, Beamforming and Array Techniques
Channel 2

6:00 AM 05-Aug-2021 **IN21_3095.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3095

Sensor placement for sound field reconstruction in enclosures.

Samuel A. Verburg, Efren Fernandez-Grande

Sampling spatio-temporal acoustic fields is a challenging problem since it demands a large number of sensors. Typically, to characterize the pressure field inside an enclosure, the number of measurements required increases linearly with frequency and cubically with volume, becoming an intractable problem for rooms of moderate size even at low and mid frequencies. Sparse representation techniques, such as Compressed Sensing, rely on the sparsity of natural signals in certain representation domain to drastically reduce the number of measurements needed to sample such signals. In this study, we optimize the placement of sensors inside an enclosure in order to reduce the measurements required for a given reconstruction accuracy. The proposed methodology selects a sparse set of sensor positions from predefined grid via the QR factorization of the sensing matrix. Numerical results show an effective reduction in the required number of measurements when their positions are optimized, in contrast to standard random positioning. Unlike the majority of existing approaches, we study the placement problem for wide-band acoustic fields.

6:20 AM 05-Aug-2021 **IN21_1898.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1898

Optimization of underdetermined hologram points in reconstructing the vibro-acoustic source field based on ESM

Laixu Jiang, Jeong-Guon Ih

The distribution of measurement points is important in reconstructing the vibro-acoustic source field using the near-field acoustical holography (NAH) based on the equivalent source method (ESM). Because too close measurement impose a limit in the implementation of ESM, an optimal arrangement of the hologram data is needed to enable a longer distance measurement although the points are still within the near field. In this work, the optimal measurement positions are determined by adopting the method that assures the independence among the measuring positions as far as possible. Singular value decomposition of the transfer matrix is employed in the loop-iteration calculation fashion, in which

the candidate measuring point affecting the increase of singularity is eliminated at each iteration step. Comparison is made with the uniformly distributed hologram points, the monopole version of ESM model, and the patch holography method. The test results reveal that the acoustic field of sound sources can be reconstructed meaningfully from the optimized hologram points of underdetermined condition. Under the predetermined reconstruction accuracy, the test results varying the hologram distance show that it is possible to realize the underdetermined far-distance measurement than the usual NAH.

6:40 AM 05-Aug-2021 **IN21_2144.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2144

A new technology for locating very low frequency and negative signal-to-noise ratio sound sources

Yazhong Lu, Sean Wu, Zeyu Yuan, Wen He

This paper presents a new technology that enables one to locate multiple sound sources with very a large dynamic range simultaneously, including very low frequency and negative signal-to-noise ration sound sources in a non-ideal environment, where there are random background noise and unknown interfering signals. In particular, spatial resolution of source localization is frequency independent. In other words, spatial resolution remains very high at very low as well as at very high frequencies. The underlying principle of this new technology is a hybrid methodology that includes a passive SODAR (nic etection nd anging), advanced signal processing and least-squares minimization. Using this technology, engineers will be able to visualize sound sources in both real time and post processing in an adversary test environment. Live videos of sound sources localization inside a crowd machine shop are shown, where there are unknown background noise, unspecified sound reflections and reverberation, and interfering signals.

7:00 AM 05-Aug-2021 **IN21_1797.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1797

Sound field projection system using optical see-through head mounted display

Atsuto Inoue, Wataru Teraoka, Yasuhiro Oikawa, Takahiro Sato, Masahito Kobayashi

There are various ways to grasp the spatial and temporal structures of sound field. Sound field visualization is an effective technique to understand spatial sound information. For example, acoustical holography, optical methods, and beam-forming have been proposed and studied.
In recent years, augmented reality (AR) technology has rapidly developed and is now more familiar. Many sensors, display devices, and ICT technologies have been implemented in AR equipment, which enable interaction between real and virtual worlds.
In this paper, we propose an AR display system, which displays the results obtained by the beam-forming method. The system consists of 16ch microphone array, real-time sound field visualization system and optical see-through head mounted display (OST-HMD). Real-time sound field visualization system analyses sound signals recorded by 16ch microphone array by beam-forming method. Processed sound pressures data are sent to OST-HMD by using transmission control protocol (TCP), and colormap is projected on real world. Settings property of real-time sound field visualization system can be changed by using virtual user interface (UI) and TCP. In addition, multi-users can experience the system by sharing sound pressures and settings property data. Using this system, users wearing OST-HMD can observe sound field information intuitively.

7:40 AM 05-Aug-2021 **IN21_3084.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3084

Deconvoluting acoustic beamforming maps with a deep neural network

Wagner Gonçalves Pinto, Michaël Bauerheim, Hélène Parisot-Dupuis

Localization and quantification of noise sources is an important scientific and industrial problem, the use of phased arrays of microphones being the standard techniques in many applications. Non-physical artifacts appears on the output due to the nature of the method, thus, a supplementary step known as deconvolution is often performed. The use of data-driven machine learning can be a candidate to solve such problem. Neural networks can be extremely advantageous since no hypothesis concerning the environment or the characteristics of the sources are necessary, different from classical deconvolution techniques. Information on the acoustic propagation is implicitly extracted from pairs of source-output maps. On this work, a convolutional neural network is trained to deconvolute the beamforming map obtained from synthetic data simulating the response of an array of microphones. Quality of the estimation and the computational cost are compared to those of classical deconvolution methods (DAMAS, CLEAN-SC). Constraints associated with the size of the dataset used for training the neural network are also investigated and presented.

8:00 AM 05-Aug-2021 **IN21_2439.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2439

A basic study on estimating location of sound source by using distributed acoustic measurement network

Itsuki Ikemi, Kazunori Harada, Akiko Sugahara, Yasuhiro Hiraguri

The sounds from childcare facilities are often a cause of noise problems with neighbors, however since the sound power levels of children's play and other sounds in child-care facilities have not become clear, evaluation methods have not been established, making countermeasures difficult. In order to evaluate the noise, it is necessary to model the location of the sound source and the sound power level. We have been developing a sound source identification system that uses multiple Raspberry Pi-based recording devices to estimate the location of a sound source and sound power levels. By using GPS for time synchronization, the system can be distributed and placed without connecting cables, which is expected to expand the measurement area significantly. As a method of estimation, the arrival time difference is calculated by cross-correlation from the signals input to each recording device, and the sound source location is estimated from the calculated arrival time difference and the location information of the device. The effectiveness of this system was verified in an anechoic room and outdoor fields.

8:20 AM 05-Aug-2021 **IN21_2288.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2288

MEMS microphone intensity array for cabin noise measurements

Carsten Spehr, Daniel Ernst, Hans-Georg Raumer

Aircraft cabin noise measurements in flight are used toto quantify the noise level, and to identify the entry point of acoustic energy into the cabin. Sound intensity probes are the state-of-the-art measurement technique for this task. During measurements, additional sound absorbing material is used to ease the rather harsh acoustic measurement environment inside the cabin.
In order to decrease the expensive in-flight measurement time, an intensity array approach was chosen. This intensity probe consists of 512 MEMS-Microphones. Depending on the frequency, these microphones can be combined as an array of hundreds of 3D- intensity probes. The acoustic velocity is estimated using a high order 3D finite difference stencil. At low frequencies, a larger spacing is used to reduce the requirement of accurate phase match of the microphone sensors.
Measurements were conducted in the ground-based Dornier 728 cabin noise simulation as well as in-flight.

8:40 AM 05-Aug-2021 **IN21_2709.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2709

Demonstration of a unified approach to beamforming

Christof Puhle

In this paper, we discuss a unification of several well-known frequency domain beamforming methods into one working principle. The methods under consideration include Functional Beamforming, Asymptotic Beamforming, Adaptive Beamforming and - as a natural limiting case - Standard Beamforming. Common to most of these methods is the underlying eigenvalue decomposition of the cross-spectral matrix. Introducing a weighted power mean (also called weighted Hölder mean) in terms of these eigenvalues for every map point, each of the above methods is represented by a certain power p. Because of the latter, this unified approach will be called Power Beamforming throughout this paper. Going from the limiting case p=1 of Standard Beamforming to lower power values results in the attenuation of side lobes and sharpening of the main lobes in the corresponding beamforming map. We demonstrate this effect using simulations and several real-world measurements.

Session: 13.02 Impact and Structure-Borne Noise, Part 1

Channel 2

11:00 AM 05-Aug-2021 **IN21_2274.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2274

Thickness-resonance waves in underlays of floating screed

Charlotte Crispin, Wuyts Debby, Dijckmans Arne

The prediction of the reduction of impact sound pressure level ΔL according to annex C of the standard ISO 12354-2 gives an acceptable estimation of the floating floor's performance for thin resilient layers. However, the performance is often largely overestimated for thick resilient layers or for resilient layers combined with thermal layers. One reason for this is that the simplified model doesn't account for the thickness resonances in the underlays which can greatly affect ΔL. This is confirmed by comparing finite element and transfer matrix method simulations with experimental results. This paper establishes the mechanisms leading to the development of these resonance waves and provides some guidelines to estimate their negative effects on the ΔL.

11:20 AM 05-Aug-2021 **IN21_1113.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1113

Impact sound pressure values - Field measurements for different configurations of concrete slabs on the ground

Bernt Mikal Larsen

The presentation will summarize and discuss values of field measured normalized impact sound pressure level L'n,w measured sideways with different configurations of concrete slabs on ground within buildings. All results are adjusted to receiving room volume of 100 m3 and with thickness of concrete slab 80-100 mm. Measurement on continuous concrete slab on expanded polystyrene gives L'n,w between adjoining rooms of 74 dB. Different principles of splitting have been investigated to evaluate the effect on L'n,w. The configuration where only the concrete slab is split (and with a plastic film between the concrete base and the upper layer of expanded polystyrene), gives L'n,w of approximately 66 dB which is 8 dB lower than for a continuous bare concrete slab. When both the concrete slab and the upper layer of expanded polystyrene are split, measurements show L'n,w of 58-61 dB for the case of no flooring, which is 13-16 dB lower than for a continuous concrete slab (no split). When both concrete slab and all layers of polystyrene are split down to continuous foundation measurements show L'n,w of 55 dB. The situation with concrete slab and all layers of polystyrene split and with no foundation beneath gives L'n,w of 46 dB. Consequences for airborne sound and R'w will be discussed as well for the above mentioned configurations.

11:40 AM 05-Aug-2021 **IN21_2111.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2111

Robust prediction metrics for structure-borne noise in timber buildings

Ola Flodén, Peter Persson

This paper presents an investigation of prediction metrics for structure-borne noise in timber buildings, based on the vibration response of the structure. The purpose of the study is to derive a robust measure for predicting structure-borne noise in timber buildings based solely on the vibration response; a measure with a known correlation to the actual acoustic response. Such a measure is useful for establishing simplified numerical prediction models, and for making robust assessments of different design alternatives. The procedure has previously been applied to automotive applications with a valuable outcome for the industry.

The vibration and sound pressure responses in a room of a multi-storey building are calculated using the finite element method. As excitation, a harmonic unit point load (20-300 Hz) located at another storey of the building is used. Based on the structural and acoustic response fields, scalar values are calculated by performing spatial and frequency domain averaging and summations. Various methods for calculating scalar values from the vibration response are investigated. The correlation between the vibration scalar values and the acoustic scalar values are presented.

12:00 PM 05-Aug-2021 **IN21_2840.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2840

Vibration transmission across fractured beam-to-column junctions of reinforced concrete

Marios Filippoupolitis, Carl Hopkins

To detect human survivors trapped in buildings after earthquakes by using structure-borne sound it is necessary to have knowledge of vibration transmission in collapsed and fragmented reinforced-concrete buildings. In this paper, Statistical Energy Analysis (SEA) is used to model the vibration transmission in seismic damaged reinforced concrete beam-to-column junctions where the connection between the beam and the column is made only via the steel reinforcement. An ensemble of 30 randomly damaged beam-to-column junctions was generated using a Monte Carlo simulation with FEM. Experimental SEA (ESEA) is then considered with two or three subsystems to determine the CLFs between the beam and the column with either bending modes or the combination of all mode types. It is shown that bending modes dominate the dynamic response and that the uncertainty of predicting the CLFs using FEM with ESEA is sufficiently low that it should be feasible to estimate the coupling even when the exact angle between the beam and the column is unknown. In addition, the use of two rather than three subsystems for the junction significantly decreases the number of negative coupling loss factors with ESEA.

12:20 PM 05-Aug-2021 **IN21_1644.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1644

Measuring force and impedance for the tapping machine

Sunit Girdhar, Andrew R. Barnard, John LoVerde, Wayland Dong

The standard tapping machine used for the ASTM and ISO tests does not require the test engineer to measure the input force in the system, instead, just relies on measuring the sound pressure level (SPL) output. However, the input force depends on the assembly itself being tested. The input force levels are lower for lightweight assemblies like hardwood floors as compared to heavyweight assemblies like concrete. Without knowledge of this input force, the output SPL levels cannot and should not be compared using the IIC (Impact Insulation Class) rating. In this work, we measured the input force levels for the same tapping machine on different floors. We also measured the floor impedance for different assemblies and their comparison is also shown. This work shows the importance of measuring input forces for the standard floor-ceiling assembly impact tests

Session: 04.03 Spatial Audio, Part 2
Channel 3

6:00 AM 05-Aug-2021 **IN21_1438.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1438

Sound field reproduction using multilayer equivalent source method

Xi Hong, Xiangyang Zeng, DU Bokai

Sound field reproduction aims to create or reproduce a desired sound environment, where both the audio content and the spatial property of the sound field are preserved. For a practical reproduction system which is usually placed in a real ‘listening room’, acoustic transfer function measurement of the loudspeaker array is a time consuming work. The equivalent source method is an option to interpolate loudspeaker array acoustic transfer functions over the target region in reverberant sound field and has been implemented in the preceding researches. However, the selection of the optimized distances of the equivalent sources remains a challenging problem, especially considering the complex acoustic environment in reverberant room. In this work, we apply a multilayer equivalent source method. A simulation is conducted in virtual listening rooms with different reverberation conditions to investigate the reproduction performance of the proposed method. The comparison with the conventional single layer equivalent source method is provided.

6:20 AM 05-Aug-2021 **IN21_1442.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1442

A two-zone sound field reproduction based on the region energy control

Bokai Du, Xiangyang Zeng, Haitao Wang

Multizone sound field reproduction aims to create different acoustical environments in regions without physical isolation. For a real reproduction system, it is always expected to improve system performance and reduce measurement effort. In this paper, a two-zone sound field reproduction is investigated with a proposed region control method. Conventional multipoint method only controls sound field at limited number of measurement points. However, the proposed method tries to control the sound field energy over the whole region. Considering the system’s diverse work environment, different interpolation methods are applied in the proposed method. Simulations are conducted under free field and reverberation condition in order to deeply compare with conventional method and another harmonic domain method. Simulation results show that the proposed method achieves better performance than the conventional multipoint method in free field and reverberant environment. On the other hand, the region control method proposed in this paper is free from microphone array geometry requirement, which means the method is more convenient for the practical application.

6:40 AM 05-Aug-2021 **IN21_2150.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2150

Comparative study of loudspeaker position optimization techniques for multizone sound field reproduction

Sipei Zhao, Sipei Zhao, Qiaoxi Zhu, Ian Burnett

Mutlizone sound field reproduction aims to generate personal sound zones in a shared space with multiple loudspeakers. Conventionally, loudspeakers are placed to form a regular pattern such as circular, arc or linear array, which are empirical rather than optimal mainly for the convenience of physical placement. Recently, several algorithms have been proposed to select a fixed number of loudspeaker locations from a large set of candidate positions, such as the sparse regularization methods (i.e. Lasso and Elastic Net), the Constrained Match Pursuit method, the Gram-Schmidt Orthogonalization method . Most of these methods were investigated for single-zone rather than mulit-zone sound field reproduction based on the pressure matching techniques. This paper compares the performance of the state-of-the-art techniques for loudspeaker position optimization in a multizone sound field reproduction system in terms of reproduction error, acoustic contrast and array effort. Both single tone and broadband sound signals are used and the effect of the distance between the bright and dark zones on the performance of the algorithms are investigated.

7:00 AM 05-Aug-2021 **IN21_1749.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1749

Upper hemisphere sound image control with horizontal-arranged loudspeakers based on parametric head-related transfer functions

Syumpei Miura, Kenta Iwai, Yoshiharu Soeta, Takanobu Nishiura

The 22.2 multichannel sound system has been developed for an ultra high-definition television system. This system consists of twenty two loudspeakers and two sub-woofers called low frequency effects, and can reproduce three-dimensional sound image appropriate to the ultra high-definition television system. However, this system has a problem of high cost to install. On the other hand, the multichannel sound system with horizontal-arranged loudspeakers has lower cost to install than full scale one. However, this system cannot reproduce an upper sound image. Therefore, in this paper, we propose the upper sound image control with horizontal-arranged loudspeakers based on the parametric head-related transfer functions. The proposed method generates binaural signals to control the sound image elevationally based on the parametric head-related transfer functions in the median plane. Also, the proposed system uses the interaural level difference to control the sound image of binaural signals azimuthally. Finally, the proposed method generates output signals for horizontal-arranged loudspeakers from binaural signals by designing a multichannel inverse system based on multi-input / output inverse theorem. The experimental results show that the proposed method can control the sound image to elevation angle with the same accuracy as binaural lreproduction.
The 22.2 multichannel sound system has been developed for an ultra high-definition television system. This system consists of twenty loudspeakers and two sub-woofers called low frequency effects, and can reproduce three-dimensional sound image appropriate to the ultra high-definition television system. However, this system has a problem of high cost to install. On the other hand, the multichannel sound system with horizontal-arranged loudspeakers has lower cost to install than full scale one. However, this system cannot reproduce an upper sound image. Therefore, in this paper, we propose the upper sound image control with horizontal-arranged loudspeakers based on the parametric head-related transfer functions. The proposed method generates binaural signals to control the sound image elevationally based on the parametric head-related transfer functions in the median plane. Also, the proposed system uses the interaural level difference to control the sound image of binaural signals azimuthally. Finally, the proposed method generates output signals for horizontal-arranged loudspeakers from binaural signals by designing a multichannel inverse system based on multi-input / output inverse theorem. The experimental results show that the proposed method can control the sound image to elevation angle with the same accuracy as binaural reproduction.

Session: 02.01 Acoustic Black Holes
Channel 3

7:20 AM 05-Aug-2021 **IN21_1664.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1664

Wavenumber domain analysis of full-band energy harvesting and damping dissipation characteristics of plate embedded with heterogeneous ABH array

Yue Bao, Haoming Liang, Xiandong Liu, Yingchun Shan, Tian He

The Acoustic Black Hole (ABH) structure has been developed as a promising approach for passive vibration attenuation and noise control. The basic theory of ABH effect hinges on the geometry thickness gradual decreasing according to the power law. This feature of structure reduces flexural wave speed, resulting in “trapping” flexural wave into ABH indentation to achieve energy focalizing. In this work, the FE model of a plate embedded with ABH indentation and damp structure is established and excited by a series of harmonic forces respectively. The characteristics of energy distribution in this plate in full frequency band are investigated by the power flow method and wavenumber domain analysis. By transforming the spatial vibratory energy into wavenumber domain, the ABH effect is analyzed and compared with a uniform panel. Meanwhile, the dissipation effect of vibration and sound radiation energy has been studied with addition of damping material. Furthermore, the energy harvesting and dissipation performances of a plate embedded with heterogeneous ABH array are investigated in order to demonstrate the influence of ABH structure parameters and configuration. The research will be beneficial for the vibration energy control in full frequency band.

7:40 AM 05-Aug-2021 **IN21_1656.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1656

Optimization of Damping Configurations in a Plate Embedded with ABH Array

Haoming Liang, Yue Bao, Xiandong Liu, Yingchun Shan, Tian He

Owing to its broadband and lightweight features, the Acoustic Black Hole (ABH) effect has attracted increasing interests in the structural dynamics and vibration-acoustic communities in recent years. And damping material is essential to achieve effective ABH phenomena. To explore effective vibration and noise control in thin-walled structures such as vehicle body panel using ABH effect, aiming at the plate embedded with two-dimensional ABH array, this paper investigates the coupling between ABH structure and damping material. First, the energy dissipation mechanism of viscoelastic damping material is analyzed to obtain the deformation characteristic that leads to effective energy dissipation. Next, the bending deflection of a plate with a single ABH under harmonic excitation is investigated, and the damping material configuration is optimized to obtain an optimal vibration suppression. Finally, the above-mentioned configuration is applied to a plate embedded with the ABH array and compared with the conventional damping arranging method. And the advantages of this damping material configuration scheme in vibration and noise control are investigated and summarized. This paper provides a reference for the damping material configuration and optimization of the thin plates embedded with ABHs.

8:00 AM 05-Aug-2021 **IN21_1632.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1632

Effects of annular acoustic black holes on sound radiated by cylindrical shells

Oriol Guasch, Jie Deng

While most acoustic black hole (ABH) designs are intended to reduce vibrations in beams and plates, annular ABHs have been recently proposed for cylindrical shells. The key to achieve the ABH effect in a structure consists in embedding an indentation on it such that it slows down incident waves and concentrates their energy at the center of the ABH. There, it can be typically dissipated by means of a viscoelastic layer. Many studies exist on the vibration of structures with ABH indentations but only a few address the topic of sound radiation. In this work, we evaluate the impact that an annular ABH has on the sound radiated by a baffled cylindrical shell. The vibration of the cylinder is computed using Gaussian basis functions in the Rayleigh-Ritz method. Once determined the surface velocity of the ABH cylinder, a Green's function approach is employed to obtain its surface acoustic pressure and then the sound power level, radiation efficiency and supersonic intensity. The dependency of the latter on the ranges determined by the ring and critical frequencies is analyzed for the case of a thick acoustic shell. Beyond the critical frequency, supersonic flexural waves entering the ABH become subsonic, substantially reducing the radiation efficiency and therefore, the emitted sound. Further reduction is achieved once passed the ring frequency.

8:20 AM 05-Aug-2021 **IN21_1560.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1560

Sound absorption based on Micro-perforated panels and Acoustic Black Hole principle

Xiaoqi Zhang, Li Cheng

Acoustic black holes (ABHs) have been so far investigated mainly for bending wave ma-nipulation in mechanical structures such as beams or plates. The investigations on ABHs for sound wave manipulation, referred to as Sonic black holes (SBHs) are scarce. Existing SBH structure for sound reduction in air is typically formed by putting a set of rings inside a duct wall with decreasing inner radius according to a power law. As such, the structure is very complex and difficult to be practically realized, which hampers the practical application of SBHs for sound reduction. This study explores the possibilities of achieving SBH effects using other types of structural configurations. In particular, micro-perforated panels are proposed to be introduced into the conventional SBH structure, and the simulation results show that the new formed SBH structure is simpler in configuration in terms of number of rings and more efficient in terms of sound energy trapping and dissipation.

8:40 AM 05-Aug-2021 **IN21_1801.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1801

A semi-analytical method for the vibration of cylindrical shells with embedded acoustic black holes

Jie Deng, Oriol Guasch, Laurent Maxit, Ling Zheng

Embedding acoustic black holes (ABHs) on beams and plates has revealed as an appealing passive method for noise and vibration reduction. However, most ABH designs to date only concern straight beams and flat plates, while cylindrical structures are commonly found in the aeronautical and naval sectors. In this work, we suggest a semi-analytical method to compute the vibration field of a cylinder with an ABH indentation. We also show the ABH efficiency in terms of shell vibration reduction. It is proposed to resort to Gaussian basis functions in the framework of the Rayleigh-Ritz method, to reproduce the ABH cylinder vibration field. The ABH shell displacements in the three directions are decomposed in terms of Gaussian functions, which can be dilated and translated analogously to what is done with wavelet transforms. The functions are also forced to satisfy the continuity periodic conditions in the shell circumferential direction. The Gaussian expansion method (GEM) results in high precision at a low computational cost. The suggested semi-analytical method is validated against a detailed finite element (FEM) model. Modal frequencies and modal shapes are recovered very accurately. Besides, the mean square velocity of the annular ABH shell under point external excitation is compared to that of a uniform shell, in the 50-1000 Hz frequency range. Noticeable vibration reduction is achieved.

Session: 13.01 Acoustic Regulations and Classification for Buildings, Part 2
Channel 3

11:00 AM 05-Aug-2021 **IN21_2228.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2228

Neighbour noise in multi-storey housing – Annoyance and potential health effects

Birgit Rasmussen, Ola Ekholm

Neighbour and traffic noise annoyance questions have been included in the Danish Health and Morbidity Surveys since year 2000. Noise annoyance was assessed by asking the respondents about noise annoyance from neighbours and traffic, respectively, in their home during the past two weeks. For people in multi-storey housing, neighbour noise annoyance was significantly higher than annoyance from traffic. The latest survey was performed in 2017; 3893 respondents living in multi-storey houses completed the self-administered questionnaire, 36% reported being very/slightly bothered by neighbour noise and 22% by traffic noise.
Additional studies were carried out aiming at analyzing associations between neighbour noise annoyance and physical/mental health symptoms such as pain in various body parts, headache, fatigue, depression and anxiety and furthermore with getting enough sleep to feel rested. Noise annoyance from neighbours was strongly associated with all these health/sleep outcomes. Similar associations were observed for traffic noise. Although causality cannot be established in this cross-sectional study, it is concluded that neighbour noise annoyance is strongly associated with various physical/mental health symptoms and with not getting enough sleep to feel rested.
The results highlight that health effects of neighbour noise might be as serious as for traffic noise and should have more attention.

11:20 AM 05-Aug-2021 **IN21_2230.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2230

Acoustic regulations for hospital bedrooms – Comparison between selected countries in Europe

Birgit Rasmussen, Teresa Carrascal Garcia, Simone Secchi

Regulatory acoustic requirements for hospitals exist in several countries in Europe, but many countries have either insufficient regulatory limits or only recommendations. The main purpose of limit values is to ensure optimal acoustic conditions for patients under treatment and for personnel for the various tasks taking place in many different rooms, e.g. bedrooms, examination and treatment rooms, corridors, stairwells, waiting and reception areas, canteens, offices, all with different acoustic needs. In addition, some rooms require special considerations like psychiatric rooms and noisy MR-scanning rooms. The extent of limit values varies considerably between countries. Some specify a few, others several criteria. The findings from a comparative study carried out in selected countries in various geographical parts of Europe show a diversity of acoustic descriptors and limit values. The paper includes examples of criteria for reverberation time, airborne and impact sound insulation, noise from traffic and from service equipment. The discrepancies between countries are discussed, aiming at potential learning and implementation of optimized limits for more room types. In addition to regulations or guidelines, some countries have hospitals included in national acoustic classification schemes with different acoustic quality levels. Indications of such classification criteria will be included in the paper.

11:40 AM 05-Aug-2021 **IN21_1556.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1556

Perception of the Home Environment. The 2019 Study

Ric Van Poll

RIVM conducted a questionnaire study into residents' perception of the living environment. This includes monitoring data on residents perception of sounds, vibrations, odours, and safety risks in the neighbourhood. In 2019, 2259 residents of the Netherlands aged 16 years and older participated in this survey. The 2019 data show that the degree of satisfaction with the home environment was fairly high and the same as it was during the previous survey in 2016. Road traffic is an important source of severe annoyance (10.4%) and severe sleep disturbance (5,9%). Mopeds and motorbikes in particular cause severe noise annoyance (10.6%). Compared to 2016, more people experience severe annoyance from the sound of vans. Road traffic also causes nuisance due to the vibrations that it causes (3.9%). Neighbours are a source of noise annoyance (9.0%) and the most important source of severe odour annoyance. The latter primarily involves odours from fireplaces (5.3%), fire pits, and barbecues (5.0%). Activities by neighbours also cause severe annoyance due to vibrations. It also turns out that people living in the vicinity of a 'higher-risk activity', such as heavy industry, are more frequently (severely) concerned about their own safety. Results of the 2020 Study will presented as well.

12:00 PM 05-Aug-2021 **IN21_1904.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1904

Dutch building code regulates noise limits for outside placed heat pumps

Wim Beentjes, Theo Campmans

To reduce CO-emission, Air/Water and Air/Air heat pumps are increasingly used in the Netherlands. Due to several noise complaints, the Dutch government decided that legal regulations were necessary to restrict outside noise. The legislation process consisted of three phases.
Determination of noise limits on neighbouring plot boundaries, based on a comparison with existing noise regulations for small companies in a defined quiet living environment. Creation of rules for ground-bound dwellings and for apartments.
Determination of the legal noise measurement procedure of installed heat pumps, such as defining working conditions and how to deal with tonality.

Developing a design tool for simple situations. This tool calculates the sound attenuations between the heat pump and all relevant receiver positions. The smallest attenuation determines the allowed sound power level of the heat pump. This is key information for appropriate selection of heat pumps. For complex situations, special calculation is still needed.

12:20 PM 05-Aug-2021 **IN21_2943.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2943

An overview of room acoustics requirements in North American, nonresidential, building standards

Gary Madaras

In the United States and elsewhere in North America, acoustics requirements for nonresidential buildings in Federal acts, codes, official standards and unofficial guidelines and rating systems tend to be voluntary, grass-roots and bottom-up instead of being mandatory, top-down or governmentally mandated. This relates to the governmental viewpoint that noise is merely a nuisance, not a health risk as viewed in other parts of the world. Existing requirements associated with noise control – whether they are related to environmental/community noise, transmission of transportation noise through the building envelope or occupant noise through the interior construction assemblies or minimizing noise from building services – are more prevalent in these standards. Requirements for good room acoustics related to sound absorption, speech intelligibility and distraction-free and comfortable interiors that promote human health and well-being are appearing in more standards and being updated to have more stringent values. Much improvement is still needed in older standards that do not have regular revision cycles and open, public, review periods. An overview of the types of room acoustics metrics used, their evolving values, advantages/disadvantages and the research behind them will be provided. Recommendations for future advancements will be offered.

Session: 05.03 Airport Community Noise, Part 1

Channel 4

6:00 AM 05-Aug-2021 **IN21_2330.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2330

Study on aircraft noise directivity of behind the start of takeoff roll

Toshiyasu Nakazawa, Naoaki Shinohara

This paper discusses aircraft noise directivity behind the start of takeoff roll. Aircraft noise has the radiation directivity because of aircraft engine mount position and the engine noise directivity. Thus, lateral noise directivity correction is recommended in airport noise calculation guidelines such as ECAC Doc.29 and ICAO Doc9911. In these guidelines, the directivity of flyover noise and the directivity at the start of takeoff roll on ground are prepared separately. A 90-degree dipole model is used for the directivity of the flyover noise, and another similar directivity is used for the directivity behind the start of takeoff roll. It is necessary to properly evaluate the directivity behind the takeoff roll because it has a large contribution to noise calculation of the vicinity of the airport. Therefore, we measured aircraft noise behind the start of takeoff roll with sound level meters placed half-concentrically around Narita Airport in Japan. From these measurement results, various types of aircraft noise directivity behind the takeoff roll are examined and considered the effects of weather conditions such as wind direction. Finally the differences from existing models are compared.

6:20 AM 05-Aug-2021 **IN21_2753.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2753

Sound arrival direction and acoustic scene analysis for the monitoring of airport noise

Keishi Sakoda, Ichro Yamada, Kenji Shinohara

The authors have developed a sound direction detection method based on the cross-correlation method and applied it to automatic monitoring of aircraft noise and identification of sound sources. As aircraft performance improves, noise decreases, and people are interested in and dissatisfied with low-level noise aircraft, especially in urban areas where environmental noise and aircraft noise combine to complicate the acoustic environment. Therefore, it is necessary to monitor and to measure not only aircraft noise but also environmental noise. Since our surveillance is aircraft noise, it is important to analyze noise exposure from acoustic information rather than trucks or images.
In this report, we will look back on the development process of this sound direction detection technology, show examples of helicopters and application examples of acoustic scene analysis to high-altitude aircraft, and consider the latest situation realized as acoustic environment monitoring. We believe that this analysis will make it easier to understand the noise exposure situation at the noise monitoring station. It also describes the future outlook for this method.

6:40 AM 05-Aug-2021 **IN21_2984.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2984

Daily fluctuations in aircraft noise exposure around civil airports and military airfields in Japan

Koichi Makino, Naoaki Shinohara

In Japan, yearly average of (day-evening-night sound level) as cumulative noise index has been adopted in national noise guideline of "Environmental Quality Standards for Aircraft Noise." Daily flight movements at civil airports are almost stable because of scheduled airline flight. On the other, daily total flight movements at military airfields greatly change day to day because of training flights, etc. Thus, noise exposure around the airport may change significantly from day to day due to change of flight movement. This paper shows examples of fluctuations, frequency distribution and deviation of daily using aircraft noise monitoring data around civil airports and military airfields. In the case of civil airports, standard deviation of daily was less than 5 dB at the monitoring stations where the yearly average of were about 55 dB or more. However, the standard deviation of daily increased 10 dB or more in some cases at points where yearly average of less than 55 dB. Furthermore, in the case of military airfields, the standard deviation of daily were 5 dB or more for all monitoring stations.

7:00 AM 05-Aug-2021 **IN21_1668.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1668

Evaluation method of military aircraft noise using AI analysis of aircraft images

Etsushi Fujita, Taichi Higashioka, Manabu Sugiura, Osamu Kohashi

In recent aircraft noise survey in Japan, noise data is associated with each aircraft by flight log or by radio information including transponder signals. Especially, above Tokyo metropolitan area, flight tracks are tangled extremely each other, therefore assessments from various perspectives such as departure / arrival airport, used runway, aircraft model, and operator have been demanded for determining noise policies. However, for military aircrafts, it is not easy to identify their information with the same way as commercial aircrafts, because their flight logs are not disclosed and many of them do not emit transponder signals like commercial aircrafts. Therefore, manned 24 hours survey around air bases have been necessary to obtain flight information of military aircrafts. In this paper, we propose an AI-based analysis using captured aircraft images for obtaining actual flight data of military aircrafts. In the past trials, we could determine the takeoff/landing time and the aircraft model by the above method. Associating these information and noise data measured at monitoring stations, details of noise characteristics around the air base can be clearly grasped. Advanced analysis of the causes of noise impact will lead effective and concrete countermeasures.

7:20 AM 05-Aug-2021 **IN21_1765.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1765

Noise assessment of taxibotted versus conventional taxiing operations using a phased microphone array

Bieke von den Hoff, Mirjam Snellen, Dick G. Simons

In sustainable aviation the focus is mostly applied to the greenhouse gas emissions during flight. However airports have an increasing interest in reducing emissions during ground operations such as taxiing for example to improve the local air quality. Amsterdam Airport Schiphol started a pilot for sustainable taxiing with a pilot-controlled hybrid-electric aircraft towing vehicle called TaxiBot in 2020. The COVID-19 pandemic created an opportunity for extensive operational testing on a near-empty airport. Due to the low background noise levels in this situation, also a noise assessment of taxiing with the TaxiBot versus conventional two-engine taxiing was performed. This assessment can be used to evaluate the noise levels to which ground workers or neighbouring communities are exposed due to TaxiBot operations.
For the noise measurements a phased microphone array was used, which allowed not only for a noise level and directionality assessment, but also for noise source identification. This paper compares the noise emissions and noise sources between a taxibotted and conventional taxiing operation. The results show that a taxibotted taxiing operation produces significantly lower noise levels. Additionally, acoustic imaging shows that the TaxiBot engine is the main noise source for a taxibotted pass-by manoeuvre.

Session: 05.03 Airport Community Noise, Part 2
Channel 4

11:00 AM 05-Aug-2021 **IN21_1742.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1742

Sound source modelling by nonnegative matrix factorization for virtual reality applications

Christian Dreier, Michael Vorländer

Auralization is a suitable method for subjective noise evaluation of virtual prototypes. A basic requirement is the accurate modelling of the sound sources. This includes a dynamic and parametric description at multiple operating conditions. In the case of wave propagation including flow, such as aircraft or vehicle noise, aeroacoustics or fluid dynamics simulations are practically limited to the acoustic near field due to high computational costs. Especially challenging are simulations of rotating systems, such as fan noise radiation. For better applicability, the proposed method is based on in-situ recordings of flyovers. The processing chain compensates for source position and movement as well as atmospheric and soil damping effects on recorded data. The compensated source signal is decomposed into partial sources in spectro-temporal domain with nonnegative matrix factorization (NMF) and can optionally be enhanced by physically-based source information. The format of the source model obtained is ready to use for dynamic sound synthesis in real-time virtual reality applications.

11:20 AM 05-Aug-2021 **IN21_1564.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1564

Virtual reality simulated aircraft flyovers: Influence of the landscape on the overall pleasantness of the environment.

Romain Dedieu, Catherine Lavandier, Roalt Aalmoes, Henk Lania, Ingrid Legriffon, Isabelle Boullet, Umberto Iemma

To give residents better understanding of the impact of future airport scenarios, a virtual reality application with sound simulation will be tested in the frame of the European ANIMA project. The set-up has been evaluated in laboratory before being used in real situation. This paper presents the laboratory experiment whose aim is to assess the application's relevance for simulating flyovers. Although the perceptual experiment is designed to test the influence of aircraft vision crossed with aircraft sound, this paper focusses only on the impact of the landscape where the flyovers are observed. Two landscapes (park and buildings) are presented to 60 participants, in balanced order, with 12 audio-visual stimuli in both landscapes. Participants had to rate four differential semantic scales. Globally there is no influence of the landscape on the overall pleasantness, but when looking at the individual answers, it appears that three groups of participants can be discriminated. The majority of people do not change their pleasantness ratings in both landscapes, but some participants prefer experiencing the flyovers in the park landscape because it is visually more pleasant, and others prefer the opposite because it is more annoying to be submitted to aircraft noise in a green park landscape.

11:40 AM 05-Aug-2021 **IN21_1494.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1494

Operational noise optimization of aircraft approaches – Initial findings

Bengt Moberg, Anders Johansson, Johan Rignér, Per Näsman

As the pilots slow the aircraft down and extend flaps and landing gear in preparation for landing the characteristics of the aircraft as a noise source changes. In the OPNOP project, the possibility to use this variation in noise generation to minimize noise at a specified location is examined. Such analysis requires an increased understanding about aircraft noise generation as the aircraft changes configuration and speed during the approach, where theoretical models available can be overly simplistic and of little use for this purpose. Using flight data from 113 actual Airbus A321 flights, and corresponding noise measurements on the ground, this study reports on the initial findings forming the foundation on which further analysis will be conducted. Intermediary findings relate to: a comparison between models and actual measurements, the distance variability to the runway for various flap selections and extension of the landing gear as well as a comparison between flight data and on-ground noise measurements. Captured data suggest that it should be possible to use speed and configuration recommendations to reduce noise over selected approach areas. Future research will include scenario generation and incorporate flight data from an earlier study to increase validity.

12:00 PM 05-Aug-2021 **IN21_2023.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2023

Exemplification case studies as a focus for the implementation of best practices related to aircraft noise management at airports

Barbara Ohlenforst, N.E. Burtea, G. Heyes, S. Jeram, O. Konovalova, O. Zaporozhets, B. Peerlings, R. Aalmoes

The current study presents the analysis of seven airport exemplification case studies undertaken in the European project “Aviation Noise Impact Management through Novel Approaches – ANIMA”. Best practices related to aircraft noise management at airports in individual airport contexts were implemented and evaluated. Case studies on communication and community engagement in airport noise management were investigated at Heathrow (Great Britain), Ljubljana (Slovenia) and Rotterdam The Hague (The Netherlands) airports. For Zaporizhzhia (Ukraine) and Iasi (Romania) airports, the implementation of interventions related to land use planning was examined. The interdependencies between noise and emissions were studied for Cluj (Romania) and Catania (Italy) airports. All case studies were performed under the scope of the corresponding national legislation and guidelines. Individual characteristics of airport operations were taken into account. The case studies were aligned with expectations and priorities of all involved stakeholders, such as representatives of airport operators, local communities, civil aviation authorities and policy makers. The efficacy of the noise management case studies is assessed in terms of: the capacity to negotiate consensus outcomes, the extent to which noise impact reductions were achieved; and the participants’ satisfaction with the process and outcomes. Experience gained from these studies will be used to distill best practices for future intervention.

12:20 PM 05-Aug-2021 **IN21_3210.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3210

Development of Fly Neighborly helicopter model specific operational noise abatement guidance from acoustic flight test data

Juliet Page, Amanda Rapoza, Eric Jacobs

Improved helicopter noise abatement guidance has been developed based on acoustic test data acquired by NASA, FAA and Volpe in support of the Helicopter Association International (HAI)’s Fly Neighborly Program. This higher fidelity material was developed to supplement previous training programs based on pilot and operator feedback. The manner of presentation allows pilots to readily interpret the directional noise emission of their vehicle at different operating conditions. Flight path, airspeed, approach descent rate, and deceleration rate can be assessed to optimize flight patterns both during the pre-flight planning stage and in real time during flight operations in response to local conditions and events. The resultant sound directivity would be displayed as colored noise exposure contours overlaid onto a map of the area in the vicinity of the helicopter.

New Fly Neighborly training modules have been developed utilizing directional operational noise plots based on Volpe’s Advanced Acoustic Model (AAM) modeling with empirical sound sphere data from dedicated US Government helicopter flight tests. This paper will describe the acoustic analyses and will present the updated noise guidance for the AS350, AS365, AW139, Bell 205, Bell 206, Bell 407, R-44, R-66 and S-76D helicopters.

Session: 05.03 Airport Community Noise, Part 3
Channel 4

2:00 PM 05-Aug-2021 **IN21_1586.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1586

Aircraft noise management

Francesca Remigi, Daniele Sepulcri, Shanti Wisniewska, Kalil Nayer Nouri

Several studies predict an increase up to 40% in traffic flights by the 2040. Airport noise control is a complicated procedure which creates an interesting blend of science, politics, and money. Accordingly, in many communities where airport noise is perceived as a significant problem, a noise control program is sometimes viewed as a continual process, rather than a discrete solution which will come to an end at some point in time.This work is an overview in the existing European low framework and the noise abatement procedure put in place to manage the aircraft noise.

2:20 PM 05-Aug-2021 **IN21_1722.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1722

Enhancing noise management strategy: recommendations from the strategy literature.

Graeme Heyes

Airports are required to manage noise impact owing to their requirement to obtain a social license to operate, and to comply with legislation such as the ICAO Balanced Approach and Environmental Noise Directive. Research has however shown that noise management actions and interventions often take a techno-centric approach, are implemented in silos, and that their success beyond noise metrics is rarely evaluated. Moreover, the success of Noise Action Plans in driving long-term noise management outcomes has also been critiqued at a number of levels. In the context of this background, this paper outlines the case for more strategic approaches to noise management and, drawing on the academic strategic literature, outlines approaches to developing such strategies that can be followed by airports. The aim of such approaches is to complement existing noise management guidance by providing step-processes that can aid airports in developing robust, repeatable, evaluable, and successful noise management strategies that are consistent with wider airport strategy and that are sympathetic to the needs of airport residents.

2:40 PM 05-Aug-2021 **IN21_3300.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3300

US Federal Aviation Administration Neighborhood Environmental Survey: study design and survey methodology

Eric Jodts, Jean Opsomer

As part of the agency's broader noise research program, the Federal Aviation Administration (FAA) has undertaken a multi-year research effort to quantify the impacts of aircraft noise exposure on communities around commercial service airports in the United States (U.S.). The overall goal of the study was to produce an updated and nationally representative civil aircraft dose-response curve; providing the relationship between annoyance and aircraft noise exposure around U.S. airport communities. To meet this goal, the FAA sponsored a research team to help design and conduct a national survey, known as the Neighborhood Environmental Survey (NES).

Residents from households around 20 airports were selected for participation in the survey; the detailed sampling process is covered in another paper.

Two survey instruments were administered to adult residents within the NES: a mail questionnaire and a follow-up telephone interview for the mail respondents. The mail survey was administered to samples of individuals in the selected airport communities in six separate "waves" over a 12-month period starting in October 2015. All mail survey respondents were invited to complete a follow-up telephone interview, which asked detailed questions on several areas including respondents' opinions on noise, exposure to aircraft noise, relationship to the airport, concerns about aircraft operations, views on airport community relations, among others.

Analysis of the survey responses on annoyance levels and the associated DNL was used to estimate dose-response curves for each individual airport and a national dose-response curve. The national dose-response curve created from the mail questionnaire shows considerably more people are highly annoyed by aircraft noise at a given noise exposure level compared to historical FICON data.

This paper provides a detailed discussion of the survey design and methodology. Additional information describing the motivation to conduct the NES and how its findings will help inform ongoing work to address aircraft noise concerns; and the noise methodology are provided in companion papers.

3:00 PM 05-Aug-2021 **IN21_3302.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3302

U.S. Federal Aviation Administration Neighborhood Environmental Survey: Study Motivation and Results

Sean Doyle, Donald Scata, James Hileman

As part of the agency's broader noise research program, the Federal Aviation Administration (FAA) has undertaken a multi-year research effort to quantify the impacts of aircraft noise exposure on communities around commercial service airports in the United States (U.S.). The overall goal of the study was to produce an updated and nationally representative civil aircraft dose-response curve; providing the relationship between annoyance and aircraft noise exposure around U.S. airport communities. To meet this goal, the FAA sponsored a research team to help design and conduct a national survey, known as the Neighborhood Environmental Survey (NES).

By assessing the results of the NES through both internal review and input from public comment, the FAA seeks to better inform its noise research priorities and noise policies.

This paper will outline the FAA's motivation to conduct the NES as well as how its findings will help inform ongoing work to address aircraft noise concerns. Additional information describing the noise methodology and survey methodology are provided in companion papers.

3:20 PM 05-Aug-2021 **IN21_3304.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3304

U.S. Federal Aviation Administration Neighborhood Environmental Survey: Noise Methodology

Joseph Czech, Mary Ellen Eagan

As part of the agency's broader noise research program, the Federal Aviation Administration (FAA) has undertaken a multi-year research effort to quantify the impacts of aircraft noise exposure on communities around commercial service airports in the United States (U.S.). The overall goal of the study was to produce an updated and nationally representative civil aircraft dose-response curve; providing the relationship between annoyance and aircraft noise exposure around U.S. airport communities. To meet this goal, the FAA sponsored a research team to help design and conduct a national survey, known as the Neighborhood Environmental Survey (NES).

A multi-stage and statistically rigorous process was used to select a representative sample of US airports, including a balanced sampling frame that included six factors: geographic distribution, temperature, day-night split, operational tempo, fleet mis, and population density.

The research team computed Day-Night Average Sound Levels (DNL) for the 20 airports in two waves: first for survey respondent selection, and then for pairing with respondent locations to create the dose response curve. Analysis of the responses and the associated DNL was used to generate dose-response curves for each individual airport and a national dose-response curve showing the percent "Highly Annoyed" for a

given noise level. The National dose-response curve created from the mail questionnaire shows considerably more people are highly annoyed by aircraft noise at a given noise exposure level compared to historical FICON data.
This paper presents the airport selection and noise modeling process used to support the creation of the National dose-response curve. Additional information describing the motivation to conduct the NES and how its findings will help inform ongoing work to address aircraft noise concerns; and the survey methodology are provided in companion papers.

Session: 08.06 Electric, Hybrid and Alternative Powertrains
Channel 4

6:20 PM 05-Aug-2021 **IN21_1373.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1373

Measurement and Analysis of Torque Ripple in Inverter Driven Electric Machines

Mitchell Marks

Torque ripple in electric machines can create both noise and vibration. While torque ripple is often well understood theoretically, it is much more difficult to accurately predict and measure. Often torque ripple is measured as a function of magnets and slot interaction at extremely low speed, but this can only be extrapolated to understand its implications for noise and vibration and is not useful for understanding torque response during dynamic scenarios like a change in load. The slow speed method of measurement also neglects possible switching effects on the torque profile. This paper will explore challenges in measuring the different sources of torque ripple and give an alternative method to measure torque ripple at higher speeds and also dynamically. This will include best practices and examples.

6:40 PM 05-Aug-2021 **IN21_2124.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2124

Eccentricity Effects on NVH Performance of Interior Permanent Magnets Machines for Hybrid and Electric Vehicles

Peng Zhang, Song He, Michael C. Muir, G. S. J. Gautam

For the hybrid electric vehicles (HEVs) and electric vehicles (EVs) applications, the electric machine drive unit system provides the main noise source, especially in the presence of faults. Eccentricity is one of the most common faults, which is mainly caused by the motors' package design and assembling process. There are four main types of eccentricity for motors: static offset, dynamic offset, static tilt and dynamic tilt, which are presented and analyzed. Both two-dimensional (2D) and 3-dimentional (3D) finite element analysis (FEA) are utilized in the electromagnetic field analysis for an Interior Permanent Magnet (IPM) motor. The corresponding methodologies for the mesh and force mapping to the mechanical FEA for the NVH analysis are presented. The NVH test shows that both 2D and 3D FEA can provide reasonable accuracy for the motor eccentricity fault analysis. The 2D FEA is the most common method used in the design optimization and early performance prediction for electrical. For the 3D FEA, due to the high requirement for the computer hardware and computation capability, it is usually used in the final validation for electrical machines' performance. The sensitivity of motor performance versus the airgap heights and eccentricities are studied.

7:00 PM 05-Aug-2021 **IN21_2399.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2399

Application of Blocked Force Methodology in NVH development of Electrical Machines

Keyu Chen, Marcus Hartwig

To determine excitation forces of electrical machines from measurements, Transfer Path Analysis is commonly used. Transfer Path Analysis yields input forces indirectly utilizing measured responses and transfer functions. When conducting transfer function measurement, it is recommended that the source of excitation is mechanically isolated from the receiver structure. However, in practice this is difficult to achieve without affecting the transfer path itself.
The concept of the Blocked Force method introduces blocked forces which are independent of the receiver structure, thus allowing measurement of transfer functions without isolating the source.
In this research, a stator / rotor assembly is considered as the source. This assembly is bolted to a test-housing, considered as the receiver. Blocked forces are determined at the mounting locations between stator and test-canister. The correctness of the calculated blocked forces is verified by comparing the predicted and measured responses at selected target points which were not used for determining the blocked forces.

7:20 PM 05-Aug-2021 **IN21_2409.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2409

Automated Material Parameter Calibration for an Electric Motor Stator

Hasan Pasha, Gil Jun Lee, Henry Zhang, Steve Hale, Santosh Kottalgi

For accurate prediction of E-motor noise and vibration performance at the design stage, it is important to model the E-Motor stator structural behavior with high fidelity. Orthotropic material properties have been widely used in practice to simulate laminated steel in the stator. In these models, material constants are calibrated to match natural frequencies of critical modes such as oval/triangle/square modes. Typically, identifying accurate material properties is a manual, time-consuming process, involving lots of trial and error. This study presents an automated workflow to calibrate the material properties for the stator with Ansys Mechanical and optiSLang. The developed workflow can track natural frequencies and corresponding mode shapes of critical modes, and adjust material constants automatically to find best material parameters for the given frequencies. It can rotate the mode shapes and find the orientation that gives best match to the measurements based on modal assurance criteria (MAC). This workflow has shown a good correlation between simulation and test in terms of natural frequencies and

corresponding mode shapes for the stator of a switched reluctance motor (SRM). Such an automated workflow enables the fast, efficient material calibration process, therefore accurate electric powertrain NVH simulations.

8:00 PM 05-Aug-2021 **IN21_2631.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2631

Measurement and Assessment on Environmental Noise Impact of Electric Vehicles in Accelerating Condition

Katsuya Yamauchi, Jo Yoshino

Noise emission from the vehicles propelled by electric system (such as pure electric and hybrid electric vehicles, EVs) is usually lower than the conventional internal combustion engine vehicles. Some previous studies have been shown the difference in A-weighted sound power level of EVs from the conventional ones. The difference is not dramatically large, i.e. less than 4 dB when the cars running at constant speed of 20 km/h. In this paper, we present the additional measurement results of sound power level of EVs in accelerating condition. Because when the cars in accelerating condition, the difference of propulsion systems becomes more significant on noise emission. The results are shown as regression model of sound power level depending on the vehicle speed. Moreover, the environmental noise impact of growing population of EVs is assessed through a prediction of at a case of intersection.

8:20 PM 05-Aug-2021 **IN21_2779.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2779

An influence of characteristics of amplitude fluctuation on detectability of alert sound of electric powered vehicles

Nozomiko Yasui, Masanobu Miura, Tetsuya Shimamura

The motor sound on electric powered vehicle is quiet at low speeds. Thus, pedestrians have difficulty detecting the vehicles approaching them under urban noise. Although the vehicles were designed to play an alert sound to solve this problem, it has not been solved yet. Our previous studies found that characteristics of amplitude fluctuation, fluctuation frequency, non-periodic fluctuation and amplitude envelope, are effective to make them detect approaching vehicles. However, those studies were investigated under only a specific actual environment, weren't examined validity of detectability in those studies. Here, this paper investigates under another actual environment, examine the validity. Investigations were carried out by using synthesized complex sounds which were designed to have periodic and non-periodic amplitude fluctuations. Those complex sounds have characteristics of amplitude fluctuations in gasoline powered vehicle. Amplitude envelopes such as modulation wave in amplitude-modulated sound were set for deviations for time and amplitude, and amplitude-modulated complex sounds were synthesized using sine wave, sawtooth wave, and rectangle wave. Then, their effects on detectability by pedestrians were assessed in another actual environment. The results found that amplitude fluctuation enhances the ability with which people detect approaching electric powered vehicles in case of some complex sound.

8:40 PM 05-Aug-2021 **IN21_3148.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3148

Design and performance exploration of a cymbal piezoelectric energy harvester under the excitation of power transformer vibration

Xishan Jiang, Xu Lu, Jing Zheng

With the rapid application of internet of things technology and wireless sensor in transformer station, the demand for stable and reliable power source becoming increasingly stronger. Power transformer operates with high energy density vibration, which provides a suitable energy source for health monitoring sensors. A cymbal piezoelectric transducer is designed to harvest the energy of vibration, which is made of cymbal end cap and piezoelectric ceramic to convert mechanical energy to electricity. Also, the power circuit is designed to realize the transmission and storage of electric energy. Then, the performance of the cymbal piezoelectric energy harvester is explored by FEM and experiment. The influence of mechanical vibration characteristics on the charging power of piezoelectric transducer is studied, including amplitude, frequency and preload. The experimental results show that the cymbal piezoelectric energy harvester can provides stable and reliable power, which allows the possibility of large-scale application of wireless sensor in transformer station. The present work provides a new design concept for developing the novel cymbal harvesters used in large-sized vibratory equipment, such as power transformer, to harvest vibration energy.

Session: 13.08 Acoustics in Indoor Spaces, Part 2
Channel 5

6:00 AM 05-Aug-2021 **IN21_2703.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2703

Re-evaluation acoustic quality in lecture halls using G and C50: University of Sharjah Case Study

Hussein Elmehdi, Monica Sanjinez

In our previous studies, we focused on the common approach of measuring Reverberation Time (RT) for assessing acoustic quality in various types of lecture halls at the University of Sharjah (United Arab Emirates). The absorbing surfaces at the lecture halls at the University of Sharjah are limited to one surface (hanging ceiling), which has been shown in the literature to affect the accuracy in the description of the acoustic response as a result of the introduced uncertainty in the measured reverberation times. Because of these reasons, it has been highlighted in the literature that RT is considered not a good predictor of acoustic quality, namely speech intelligibility, in the lecture halls. Therefore, additional acoustic parameters need to be measured of calculated to accurately predict the acoustic response in lecture halls, especially speech intelligibility during activities that takes place within the lecture hall. The focus of our current research is to extend our precious work on RT to calculate additional acoustic parameters, namely the acoustic strength, G, and the speech clarity, C. Our goal is to investigate the practical use of G and C to describe acoustic response in the examined lecture halls. In addition to special variations with frequency, we will examine the

effects source position, room dimensions at different locations within the lecture hall. The measurements were conducted in the same lecture halls under the same conditions including the acoustic absorbers and sound diffusers, which have shown to influence measured acoustic parameters. The results were compared to standards for the purpose of providing recommendations for range of acoustic parameters to support adequate speech communication during various teaching and learning activities in lecture halls.

6:20 AM 05-Aug-2021 **IN21_1624.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1624

Numerical study in sound absorption ability of curtain in random incidence condition

Zenong Cai, Xianhui Li, Xiaoling Gai, Tuo Xing, Fang Wang, Xiwen Guan, Zenong Cai

Woven fabric can provide variety application scenarios in acoustic field as flexible and light features. Folded curtain can be made from fabric, which is a good application example of woven fabric in noise control as sound adjuster in multi-function halls. Many geometric parameters can affect the sound absorption ability of folded curtain, such as folding shape, folding depth, the average distance of air cavity and folding period, etc. However, in random incidence condition, the relationship of geometry parameters and sound absorption ability is not clear in previous works. To obtain this relationship, Finite Element Method is used in this work. Because of the different folded shape, the contribution fractions of different angles are changed by the different geometry parameters. A series of three dimensional models is established with different geometric conditions. Different angles of incidence plain sound waves are introduced in three dimensional models. Numerical results show the detailed contribution fractions of different angles. A new formula that can predict sound absorption ability of folded curtain in random incidence condition can be gained.

6:40 AM 05-Aug-2021 **IN21_2197.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2197

Noise and acoustics in complicated rooms with the sound particle method

Thomas Judd, Stefan Weigand, Jochen Schaal

The analysis of noise and acoustics in indoor spaces is often performed with geometrical methods from the ray-tracing family, such as the sound particle method. In general, these offer an acceptable balance between physical accuracy and computational effort, but models with large numbers of objects and high levels of detail can lead to long waits for results. In this paper, we consider methods to assist with the efficient analysis of such situations in the context of the sound particle diffraction model. A modern open-plan office and a large cathedral are used as example projects. We look at space partitioning strategies, adaptive placement of receivers in the form of mesh noise maps, and graphics-card-style hardware acceleration techniques, along with iterative modelling methods. The role of geometrical detail in the context of uncertainties in the input data, such as absorption and scattering coefficients, is also studied. From this, we offer a range of recommendations regarding the level-of-detail in acoustic modelling, including consideration of issues such as seating, tables, and curved surfaces.

7:00 AM 05-Aug-2021 **IN21_2166.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2166

The effects of different ceiling structures and plan typologies on acoustical conditions of historical mosques

Fatma Yelkenci Sert, Özgül Yılmaz Karaman, Özgül Yilmaz Karaman

Mosque is a building type used by Muslim people consists of speech and music rituals. Good acoustical condition in mosques is an important issue to provide desired acoustical environment for prayers and Imams during different worship rituals. Prayers need to feel individuality in praying and the sense of unity in recitation of the Quran, hymns. Worship activities need a high level of speech intelligibility and to satisfy prayers in the spiritual aspects which make people feel closed to the God.

In the context of study, six historical mosques in Turkey, with different types of cover structures and plan typologies, are designated as study areas. The present study contains two methods which the first one is collecting acoustical data by measurements and the second consists of mathematical modelling software program. The purpose of study to investigate effects of different plan typology and ceiling structures on acoustical characteristics in mosques with similar volume. Also, distribution of acoustical parameters and the suitability of the values obtained through acoustic simulations and measurements to the recommended values are aimed to be investigated. As a result of the investigations, it was concluded that the objective acoustic parameters of mosques changed according to the geometric parameter properties.

7:20 AM 05-Aug-2021 **IN21_1972.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1972

Does the wall sound different? Variable acoustics in rehearsal rooms using small resonator structures in an acoustic panel.

Björn Knöfel, Paula van Brummelen, Tobias Behrens, Hartmut Schirmer

The wall listens different? Variable acoustics in rehearsal rooms using small volume structures in an acoustic panel.

Session: 13.03 Ventilation-Enabling Sound Insulation Devices, Part 2
Channel 5

8:00 AM 05-Aug-2021 **IN21_1976.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1976

Numerical simulation of air inlets sound insulation

Julien Puig

Breathing healthy air at home requires efficient ventilation which is generally achieved by mechanically controlled ventilation systems. However, the installation of air inlets, at the top of windows, reduces sound insulation. Actually, laboratory tests must be processed by manufacturers to measure the SRI (sound reduction index), which is calculated from the difference between the source and receiving sound power levels in the one-third octave band.

The addition of melamine, a widely used porous material with interesting acoustic properties, slightly decreases the transmitted noise through air inlets, but the sound reduction remains far from that of a window without any inlet at all. Moreover, experimental settings induce uncertainties, particularly when low frequencies are involved.
Numerical simulation is thus an interesting alternative for studying air inlets' vibro-acoustic behaviour. Many parameters can be considered without the need to carry out new experiments, thus greatly reducing financial costs. Calculations must be computationally efficient to enable an optimization approach. To this end, the proposed numerical model is based on the patch transfer function method which is a substructuring approach. Here, each subsystem of complex geometries is discretized by finite elements while porous materials are modelled using an equivalent fluid or localized impedance.

8:20 AM 05-Aug-2021 **IN21_3050.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3050

Noise reduction of enhanced acoustic balconies on a high-rise building block

SK Tang, Rudolf YC Lee

A new device called 'enhanced acoustic balcony' is installed in a new housing estate in Hong Kong. It is intended to help reduce the impact of traffic noise on the residents. This balcony is basically an enlarged form of a plenum window and with three openings. Apart from the outdoor air inlet, there is the balcony door and a side-hung window on the interior balcony wall for natural ventilation of the indoor space. Sound absorption of NRC 0.7 is installed on the balcony ceiling and its sidewall facing the incoming traffic noise and an inclined panel is installed outside the balcony to provide noise screening. A site measurement of its noise reduction is carried out in the present study in a newly completed housing block. A 28 m long loudspeaker array is used as the sound source. The indoor noise levels are measured according to ISO standard. The results show that the difference between indoor and outdoor noise levels in the presence of this balcony form varies over a relatively narrow range between 10 to 13 dBA for an elevation angle from 25 to 60 deg. There is a weak increase of the noise level difference with elevation angle.

8:40 AM 05-Aug-2021 **IN21_3208.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3208

Aerodynamic and acoustical effects caused by placing two prefabricated duct silencers in series

Karl Peterman

It once was not uncommon to find ductborne noise control designs and recommendations that would attempt to provide high sound attenuation values, especially for problematic lower frequencies, by using a pair of prefabricated duct silencers in series with one another, sometimes immediately adjacent but typically separated by some distance. Similarly, heating, ventilating, and air-conditioning (HVAC) duct silencers are occasionally required to accommodate fire dampers or access sections that effectively break up the silencer along its length, creating an empty gap between the noise-attenuating internal elements. Typical published performance characteristics of prefabricated duct silencers do not include effects from the use of additional silencers nearby and little information is available in common duct design and application literature. This paper will present information from a series of tests of various silencers in different configurations and spacings in an aero-acoustic test facility that will help describe the effects on insertion loss, generated noise, and pressure drop.

Session: 13.06 Performance Hall and Auditorium Acoustics
Channel 5

11:00 AM 05-Aug-2021 **IN21_1640.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1640

Acoustical modelling of a Swedish 13th century church ruin, and its use for musical production.

Sebastian Holm

Visby is an old hanseatic town on the island of Gotland in Sweden. The town has a large number of old church ruins, one of which goes by the name of St. Lars. The church is believed to be a 13-century orthodox church, and abandoned in the 16 century, all that is left today are the stone walls and parts of the inner ceiling vaults. Through collaboration with the local museum, St.Lars has now been measured and 3D-modelled by the author, Sebastian Holm from Efterklang, who is also a part-time musician. The model has been fitted with what is assumed to be an historically accurate ceiling structure and materials as well as windows, doors, various furnishings and a make-up stage. With acoustical modelling and auralisations made in Odeon, various source and receiver positions has been tested for acoustical qualities, and the impulse responses are now used for musical production for the medieval band known as Patrask. The mixing process uses the impulse response from left and right side of the stage to produce a stereo reverb, and the results are compared to auralisations of the music made with Odeon. The overall process is discussed, with links to the music itself.

11:20 AM 05-Aug-2021 **IN21_2445.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2445

Concert hall: acoustic design comparing analytical results and ray tracing

Karina Sá, Raquel Rossatto Rocha, Bárbara Fengler

With the intention of designing architecture for music and inspired by music, the J.C. Martins Concert Hall was created with 1008 seats and an approximate volume of 49400 ft³. Among all the architectural aspects considered, such as strategic location analyzed from the mass plan, study of volumetries, acoustics is the highlight due to its importance and complexity of the project. The Concert Hall is the object of the present study, the purpose of the article is to compare the simulated results in the EASE software with the analytical results of the reverberation time calculated by the Sabine and Eyering equations for the Concert Hall. Acoustic parameters such as reverberation time, clarity, among others, were simulated to verify the acoustic quality of the room in question. With that, it was possible to analyze and discuss the limitations of the analytical method and the simulations. Even so, the results were satisfactory to reach the adequated indexes of the acoustic parameters.

11:40 AM 05-Aug-2021 **IN21_2058.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2058

Big Acoustics in Small Spaces - Achieving HS Auditorium Design Goals with Space Constraints

Robert Tanen, Alexander M. Aquila

When designing a high school auditorium there are several factors that determine the outcome of the final construction. Prior to establishing acoustical design goals, the restrictions outlined from the design team typically start at budget and may extend to the size of the box in which the auditorium is to fit. A fluent balance between design restrictions and internal acoustical goals is critical to create a successful end-product. This case study shows the actions taken to increase the volume, provide custom diffusion, and isolate an auditorium from mechanical sources directly above the space. Furthermore, critical acoustical metrics such as loudness, spaciousness, ITDG, intimacy, reverberation time, clarity, etc., were analyzed in design and measured post construction. Results, based on ISO 3382-1 testing are provided, as are the noise control measures implemented to achieve the established set of design criteria. The overall intent of this case study presentation is to exhibit how goals across each design team discipline can be met, through sometimes unwilling compromise, ultimately producing a rewarding end-result for acousticians, architects, engineers, and ownership.

12:00 PM 05-Aug-2021 **IN21_2515.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2515

Reuse of coffee waste and paper cups for acoustical panel applications in architectural studios

Ece Sel, İpek Düzova, Anıl Ege Şireli, Beyza Yazıcı, Zühre Sü Gül

This study has been initiated with an aim of enhancing the acoustical comfort levels in the architectural studios of Bilkent University in Ankara. Initial assessment of the studios by field tests indicated very long reverberation times, supporting the complaints by the students and instructors. In order to be applied in studio environment, acoustical panels are developed out of recycled materials. The increasing coffee demand and consumption of our era have motivated the reuse of both paper cups and coffee waste. The end-product is composed of two layers. The outer layer is out of recycled coffee cups, placed in different arrangements in terms of orientation, size, and spacing. The backing layer is a panel of compressed and kiln-dried coffee grains and tea leaves. The coffee/tea residues are adhered together by using natural binders. In order to determine the best possible alternative of the waste materials with the highest sound absorption performance, different density variations have been explored. Both impedance tube tests and acoustical field measurements are utilized during the process of research and development. Considering the increasing demand for green technology, the layered panel system is proposing cost minimized, environmentally friendly, and biodegradable solutions with improved acoustical and aesthetical values.

Session: 13.02 Impact and Structure-Borne Noise, Part 2
Channel 5

1:00 PM 05-Aug-2021 **IN21_2080.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2080

Isolating an above grade MRI from traffic induced vibration

James Moore, Kaolin Kinsey

MRI installations require that ambient floor vibration levels not exceed limits defined by the manufacturer. In this study, vibration measurements for a second-floor installation exceeded the allowed levels. A road adjacent to the building experienced heavy traffic and was in poor condition with potholes and asphalt patches. The second-floor exhibited resonances in the same 8-15Hz frequency range as ground-borne vibration due to traffic close to the building. The MRI comes supplied with resilient pads that effectively isolate above 20 Hz. For isolation of the floor resonances excited by vehicular traffic, an additional stage of isolation pads was designed that lowered the system resonance frequency of the MRI on the floor to 6.5Hz. The added pads, with greater thickness and softer material, raised concerns of the MRI collapsing sideways like a thin, tall column above its critical buckling load. Lateral snubbers were incorporated where their compressive stiffness constrained the rails laterally and a low shear stiffness did not significantly increase the system resonance frequency. Vibration measured on the MRI after installation showed the novel system provided effective isolation of traffic induced vibration, satisfying vibration requirements for the MRI. Model predictions of MRI vibration relative to floor vibration agreed well with measurements.

1:20 PM 05-Aug-2021 **IN21_2033.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2033

Simplified parametric modeling to predict vibration attenuation provided by on-grade slabs

Steven Lank, Hal Amick, Hal Amick

When measured vibration amplitudes at the proposed site for a highly sensitive facility exceed the maximum allowable for the sensitive equipment, mitigation measures must be integrated into the design that will reduce the vibration amplitudes to meet the requirements. Past studies have shown that thick concrete slabs supported on a well-engineered subgrade can effectively reduce ground borne vibrations at certain frequencies. Predicting the vibration performance of a new slab-on-grade can be a significant challenge, however, as the performance is highly dependent upon the site soil conditions and nature of the vibration sources impacting the location, as well as structural characteristics. Large and detailed three-dimensional finite element analysis models of the site conditions and proposed structure are often used for this type of assessment, however development of such a model requires significant time and cost to develop accurately. This presentation discusses a proposed an alternative simplified parametric modeling technique using two-dimensional plane strain modeling. This technique can be utilized in combination with real-world data to predict the relative benefit of various slab thicknesses and design features such as structural breaks. The paper will include multiple comparisons between predicted results using this methodology and field measurement results.

1:40 PM 05-Aug-2021 **IN21_2068.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2068

Effectiveness of neoprene pad vibration isolators at high frequencies

Jerry Lilly

The natural frequency, dynamic stiffness, and insertion loss of commercially available neoprene pad vibration isolators have been measured in a simple, single degree of freedom system over a wide range of pad loadings out to a maximum frequency of 10 kHz. The results reveal that dynamic stiffness can vary significantly with pad loading as well as the durometer of the material. It will also be shown that insertion loss follows the theoretical single degree of freedom curve only out to a frequency that is about 5 to 10 times the natural frequency, depending upon the pad durometer rating. Above that frequency wave resonances in the material cause the insertion loss to deteriorate significantly out to a frequency near 1 kHz, above which the insertion loss maintains a relatively constant value, again depending upon the pad durometer rating. In some instances the insertion loss values can approach 0 dB or even become negative at specific frequencies in the frequency region that is 10 to 20 times the natural frequency of the system.

2:00 PM 05-Aug-2021 **IN21_2549.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2549

Effect of stud material and structural properties on the transmission loss of partitions

Wayland Dong, John LoVerde, Benjamin Shafer, Lin Hu

A common light frame wall design is gypsum wall board (GWB) cladding on each side of a row of studs. Steel studs are available in a variety of metal thicknesses and designs, and wood studs can be solid lumber or engineered wood composite studs with a variety of structural properties. Most published laboratory testing on these walls uses only a small subset of the available stud types, and the acoustical effect of changes to the stud parameters is not well understood. The authors and colleagues have performed several laboratory testing programs to systematically investigate the acoustical effects of stud properties, some of which were presented at Internoise 2020. This paper analyzes the effects of stud material and structural properties on third-octave transmission loss values and single-number ratings.

2:20 PM 05-Aug-2021 **IN21_2960.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2960

Subjective studies on impact sound in times of a pandemic -- a comparison between a laboratory study and an online listening test

Markus Mueller-Trapet, Iara Batista da Cunha, Jeffrey Mahn

The National Research Council Canada is currently investigating the perceived annoyance due to impact sound in multi-unit residential buildings (MURBs). The first part of a subjective laboratory study on a number of different floor/ceiling assemblies was completed with 26 participants just before the start of the Covid-19 pandemic in 2020. To evaluate the feasibility of carrying out a similar study without in-person attendance, the same stimuli from the laboratory study were used to create an online listening test. The online listening test was created in JavaScript and HTML5 to run on any internet browser. This paper will present the results of the online listening test and compare them to the laboratory study, focusing on the obvious drawbacks of an uncontrolled remote study such as the uncertainty due to the participants' headphones and listening environment. With an expectation that in-person studies will remain difficult to realize in the near future, this contribution provides evidence whether remote subjective listening tests are a viable alternative to controlled laboratory studies for impact sound.

2:40 PM 05-Aug-2021 **IN21_2796.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2796

Prediction of one-third-octave band sound and vibration levels from heavy-hard impacts

Matthew Golden, John LoVerde, Wayland Dong, Samantha Rawlings, Richard Silva

Noise and vibration due to dropping hard heavy weights is a common source of disturbance and complaint in residential, commercial, and mixed-use building types. The authors and others have worked on developing methodologies to accurately, repeatably, and conveniently measure heavy-hard impact noise and vibration in the field based on a standard weight drop. Separately, systems have been created to measure the force being injected into a building from heavy-hard impact. It has been shown that this force data can be used to successfully predict vibration levels in buildings if in-situ transfer functions are known. In this paper, the authors will present a novel one-third-octave band prediction method using the laboratory force data and a reference impact sheet to predict field performance without the need to measure transfer function. The method is evaluated using both noise and vibration measurements.

Session: 13.05 Sound Insulation Measurement
Channel 5

2:40 PM 05-Aug-2021 **IN21_2322.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2322

A review of techniques and errors involved in sound isolation testing

Jameson Dickman

Construction industry design standards are increasingly calling for new construction to be inspected and tested for compliance with design specifications after the project is built; otherwise known as the commissioning process. As part of this trend, owners, sensitive to the acoustics of their facilities, are seeking confirmation via measurements that their buildings meet sound isolation and background noise requirements, particularly when pursuing certifications under the US Green Building Council LEED standard, the WELL Building Standard, or other green building or wellness standards. In general, the error of sound isolation measurements is not officially established. This poses challenges to designers tasked with specifying assemblies and components to meet field verification requirements. This paper will briefly review current research and standards on the error of measurements such as Noise Isolation Class (NIC) and the Weighted Level Difference (D) and discuss

example design standards and guidelines which do or do not account for this error. It will also propose further research topics to better define the error in sound isolation measurements and best practices when establishing or designing to sound isolation criteria in new or renovated buildings.

3:00 PM 05-Aug-2021 **IN21_2553.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2553

Gauge repeatability and reproducibility study of airborne sound isolation measurements

Wayland Dong, Devin Wong, John LoVerde

A gauge repeatability and reproducibility study (GRR) uses analysis of variations (ANOVA) on an appropriately designed experiment to separate and quantify the components of the overall uncertainty. The authors have previously presented results of GRR studies of the measurement of airborne and impact insulation of floor-ceiling and demising wall assemblies in several apartment buildings, in which the uncertainty in the measurement method and the variability of the nominally-identical assemblies were compared. The results of two additional GRR studies on measurements of airborne noise isolation of wood stud demising walls are presented. The first study, like previous studies, evaluates the components of variance attributable to operator, repeatability, and part. The second study uses a fixed operator and part, and evaluates the variance due to loudspeaker type, position, and level on the measured noise reduction. The measurement standard (ASTM E336) gives limited guidance on the type and location of the loudspeaker used on the source side, and this study can inform whether changes in the standard with regards to the loudspeakers could reduce the uncertainty in measurement.

3:20 PM 05-Aug-2021 **IN21_2824.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2824

Interlaboratory and proficiency tests for buildings sound insulation field measurements in Brazil - 4th Edition 2020

Priscila da Silva Wunderlich, Carolina Monteiro, Juan de Frias Pierrard

Since 2013 ABNT NBR 15575:2013 entered into force in Brazil, a national technical standard that establishes acoustic requirements for dwellings, that can be verified by means of field measurements procedures performed according to specific ISO standards. Therefore, those requirements have fostered the acoustic field measurement market, and the number of laboratories has quickly increased across the county. ProAcústica - Brazilian Association for Acoustical Quality, a non-profit entity, aiming to improve the quality of the acoustics business in Brazil has organized in 2020 the fourth edition of the "Interlaboratory program of field measurements for building acoustics laboratories – INTERLAB Program". This consists of a fundamental tool for acoustic field laboratories to evaluate and verify the quality of their measurement results. This paper presents the methodologies and procedures used in the interlaboratory program, as well as the results of both the interlaboratory test and the proficiency carried out in São Paulo (Brazil) during 2017 by ProAcústica - Brazilian Association for Acoustical Quality. In this edition a total number of 25 laboratories have participated (32% more participants than the last edition in 2017) for different type of field tests: airborne sound insulation, airborne facade sound insulation, impact sound level, sound pressure level from service equipment in buildings, and reverberation time). The main objectives are the evaluation of the precision of the field test methods in the Brazilian market, and the analysis of the performance of the participating laboratories as a quality control tool.

3:40 PM 05-Aug-2021 **IN21_3307.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3307

Study of various wood stud partitions with various gypsum board and proprietary acoustical sound insulation products

Kristin Salenger

Wood stud construction is common in residential and hospitality buildings in some parts of the U.S.; however, there is a deficiency of field-tested sound insulation performance of partitions constructed with wood studs that are spaced closer than 16” on center. This study presents the sound isolation measurement results of a set of fifteen partitions within an existing facility that has been experiencing repeated complaints of poor acoustic privacy between horizontally adjacent spaces. The tested partition types varied between single stud, double stud, and single studs with resilient channel constructions. The walls had four materials of varying combinations applied, including 19/32” OSB, Type X gypsum board, proprietary enhanced gypsum board, and proprietary mass loaded vinyl. It was shown that the partition with enhanced gypsum board performed better than the same partition with Type X, the double stud partition performed lower than expected, and the addition of mass loaded vinyl to both double and single stud partitions did not affect the ASTC rating, among other findings.

Session: 13.00 Building Noise & Vibration and Architectural Acoustics, General
Channel 5

4:20 PM 05-Aug-2021 **IN21_2583.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2583

The impact of the cracks in the window

Vinícius Ávila Ferreira, Edison Claro de Moraes

When we talk about the acoustic insulation performance of a building facade, we know that its weakest link is the frame that makes it up. We soon know that great performance on the part of this component is necessary so that the facade assembly can obtain high levels of insulation. Although there are several lines and models of frames, each with two unique characteristics and varied acoustic performance, they have a similarity in their result curve. where at high frequencies it becomes a decisive point for your result. In this work, we will analyze the vulnerable points of a typology of mitering, focusing on its cracks and the impact that each one has on its result; as well as measures that can be taken so that the frame can acquire great acoustic performance, without changing the profile lines or glass thickness.

4:40 PM 05-Aug-2021 **IN21_2585.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2585

Impact of lamination on acoustic performance

Vinícius Ávila Ferreira

When we speak of laminated glass, it has several variations of lamination.
either increasing the number of laminations between glasses or the thickness of the lamination.
But how much does this really impact your acoustic performance?
In this work we will analyze different types of lamination and understand the difference in the performance curve of each one and how much this impacts on its result, whether global or at a certain frequency.

5:00 PM 05-Aug-2021 **IN21_2234.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2234

Acoustic decoupling for structural elements by affixed supports - inherent contradiction or perfect complement? Restrained vibration isolation supports - a critical review

Adam Wells, Patrick Carels

Restrained vibration isolation supports balance efficient isolation performance and stability for the supporting body under present loads. Necessary and beneficially for noise and vibration isolation applications with stringent stability requirements, such as full building isolation with potential uplift, interior partition sway bracing, curtain walls, elevator rail isolation, and mechanical vibration isolation, the performance of restrained vibration isolators are often misunderstood or oversimplified. This paper investigates the general vibration isolation theory used to create the analytical model for restrained isolation supports, intricacies of vibration isolation materials which may cause reality to diverge from well-known models, comparison of theory to laboratory testing, and a review of common uses/applications for these types of vibration isolation solutions, and recommendation to avoid undesired results from common pitfalls associated with restrained isolation supports implementation and installations.

5:40 PM 05-Aug-2021 **IN21_1648.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1648

Subjective and objective evaluation of the impact and airborne sound insulation of multi-unit residential buildings

Maedot S. Andargie, Marianne Touchie, William O'Brien

Multi-unit residential building (MURB) occupants often express dissatisfaction with their suites' acoustic conditions despite existing building acoustic standards and regulations as well as growing research on noise control and building acoustics. Reasons for this include the lack of proper characterization of acoustic comfort in MURBs and lack of comprehensive and stringent regulations. To better understand factors that impact acoustic comfort and explore strategies to improve the acoustic performance of MURBs, investigations of acoustic conditions were carried out. This work presents the results of the investigations which include subjective and objective evaluations of acoustic conditions in two MURBs. Impact sound insulation measurements using both a tapping machine and a rubber ball as well as 24-hour indoor noise monitoring were carried out in unoccupied suites. An online survey was then used to collect subjective assessments of the noise conditions in the buildings and the effects on occupants' comfort post occupancy. Results of the data analysis suggest that occupants are more sensitive to low-frequency impact sounds than mid- and high-frequency impact noise.

6:00 PM 05-Aug-2021 **IN21_2639.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2639

The effects of acoustical ceiling panel type and penetrations for services on vertical sound isolation inside buildings

Gary Madaras

Attenuation of sound transmitting between rooms oriented over one another inside buildings is studied. Transmission loss and sound transmission class were measured by an independent, accredited, acoustics laboratory with and without a variety of modular acoustic ceilings suspended under a baseline concrete floor structure. Ceiling panel material types include stone wool, fiberglass and mineral fiber. Ceilings were tested with and without the presence of service penetrations for supply air diffusers, return air grilles and light fixtures. Some ceilings were also scanned with a sound intensity probe and the resulting color sound maps are used as a supplemental method of evaluating both isolation and absorption performance of the individual components of the ceiling systems. Results show that while the effects of ceiling panel type on absorption performance, and thus room acoustics, is substantial, the material type and weight of the ceiling panels do not substantially affect the overall isolation performance of the floor-ceiling assembly.

6:20 PM 05-Aug-2021 **IN21_1892.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1892

Acoustical Conformance with FGI for Tenant Improvements in Outpatient, Medical Office or Clinic Facility Sound Isolation/Privacy Design

Jack B Evans, Edward Logsdon

Acoustical privacy and noise control design and implementation guidance is needed, regarding Facility Guidelines Institute (FGI) criteria for outpatient medical facilty tenant improvements (TI). TI in existing commercial buildings or medical office buildings may not have capital budgets or expected facility/lease life that hospitals enjoy. Full conformance to FGI criteria and guidelines may be limited; by economic feasibility and by constructability. Design professionals can use "good practice" space planning, demising assembly selection, and electronic sound masking to achieve appropriate acoustical privacy within reasonable capital expense budgets.
Consider FGI criteria for demising partition, ceiling, door and window selections plus infrastructure equipment and material selections that can provide cost-effective lightweight, common construction standards. The objectives are to protect the privacy of patient information and

provide quiet spaces, free of transient disturbance for clear speech communications. Continuous ambient sound increases speech privacy including speech transmitted from enclosed quiet spaces. Criteria for acoustics, speech privacy,continuous noise and masking exists in FGI. Temporal level changes (on/off, transients) and tonality (spectrum smoothness or balance) should be considered in basis-of-design (BoD). This paper will present design guidelines for selecting demising assemblies and supplemental sound masking for outpatient clinical spaces in commercial or medical office buildings.

Session: 13.02 Impact and Structure-Borne Noise, Part 3
Channel 5

7:20 PM 05-Aug-2021 **IN21_2523.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2523

Subjective responses between real impact sound and rubber ball im-pact sound

Jeongho Jeong

By the recent COVID-19 situation, people stay more time in their home and abatements on noise between neighbouring units are increasing. Heavy/soft impact sound is one of the major noise sources in high-rise apartment buildings. Standardized heavy/soft impact source is known for having the most similar physical and subjective characteristics with real impact sound such as a child running, jumping and an adult walking. The single number quantity on the rubber ball was standardized. A classification scheme for rubber ball impact sound needs to be standardized. Several studies on subjective responses were conducted on rubber ball impact sound in various situations. In this study, subjective responses on the rubber impact sound and real impact sound were compared. The subjective experiment was conducted in the listening chamber which is furnished similarly to the typical living room of Korean apartment buildings. In the experiment, rubber ball impact sounds recorded in the real apartment building and real impact sound recorded in the mock-up building were presented through a sub-woofer and multi-channel loudspeaker system. Subjective responses were collected with an 11 points SD scale.

7:40 PM 05-Aug-2021 **IN21_3006.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3006

Apparent impact sound insulation performance of cross laminated timber floors with floating concrete toppings

Jianhui Zhou, Zijian Zhao

Mass timber buildings are gaining increasing popularity as a sustainable alternative to concrete and steel structures. Mass timber panels, especially cross-laminated timber (CLT), are often used as floors due to their dry and fast construction. CLT has poor impact sound insulation performance due to its lightweight and relatively high bending stiffness. Floating concrete toppings are often applied to increase both the airborne and impact sound insulation performance. However, the impact sound insulation performance of floating concrete toppings on CLT structural floors is affected by both the concrete thickness and resilient interlayer. This study investigated the efficiency of both continuous and discrete floating floor assemblies through mock-up building tests using small-scale concrete toppings according to ASTM E1007-16. It was found that the improvements by continuous floating floor assemblies are dependent on the concrete thicknesses and dynamic stiffness of resilient interlayers. The improvements cannot be well predicted by the equations developed for concrete structural floors. The highest apparent impact sound insulation class (AIIC) achieved with continuous floating floor assemblies in this study was 53 dBA, while that of the discrete floating floor assemblies was up to 62 dBA. The discrete floating floor solution showed great potential for use in mass timber buildings due to the high performance with thinner concrete toppings.

8:00 PM 05-Aug-2021 **IN21_2088.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2088

Using Inverse Transient Statistical Energy Analysis to determine the transient power input from a heavy impact on floating floors

Susumu Hirakawa, Carl Hopkins

To aid design decision concerning heavy impacts on heavyweight floors, it is necessary to be able to predict Fast-time weighted maximum sound pressure levels (Lp,Fmax) in the receiving room. For excitation directly on the heavyweight floor this can be carried out using Transient Statistical Energy Analysis (TSEA) in a predictive mode. However, the performance of floating floors is not always possible to accurately predict hence an inverse approach to TSEA, referred to as ITSEA, has been developed to determine the transient power. This paper compares the prediction of the Lp,Fmax using TSEA with normalized transient power input determined by ITSEA with measurements conducted in two test chambers with and without floor small floor toppings. For one-third octave bands, the maximum difference in Lp,Fmax between measurement and TSEA ranged from 5.3 to 8.3dB and 6 to 7dB when using W`in,ForcePlate and W`in,ITSEA respectively. For octave bands, the maximum difference in Lp,Fmax between measurement and TSEA ranged from 2.1 to 7.5dB and 2 to 7dB when using W`in,ForcePlate and W`in,ITSEA respectively

8:20 PM 05-Aug-2021 **IN21_2298.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2298

Effect of ceiling and dry-type double floor on heavy-weight floor impact sound in concrete building and CLT building.

Takashi Yamauchi, Atsuo Hiramitsu, Susumu Hirakawa

The air layer between the interior finishes and the structure is used as piping and wiring space. In many cases, ceilings and dry-type double floors are commonly constructed in Japan. However, the effect of the air layer of ceilings and dry-type double floors on the heavy-weight floor impact sound insulation performance has not yet quantitatively investigated. Therefore, in this study, the same floor and ceiling structures were constructed for concrete and CLT buildings, and the heavy-weight floor impact sound was investigated. As results, it was confirmed that the reduction amount of the heavy-weight floor impact sound by the ceiling tended to be smaller in CLT buildings than in concrete buildings.

However, the trends were similar. Due to the dry-type double floor structure, the heavy-weight floor impact sound level was increased in concrete building and decreased in CLT building at 63 Hz in the octave band center frequency band. Therefore, it can be said that the dry-type double floor structure can be used to improve the heavy-weight floor impact sound performance in the CLT building.

8:40 PM 05-Aug-2021 **IN21_2693.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2693

Effect of different types of ceilings on floor impact sound insulation performance in CLT model building

Atsuo Hiramitsu, Susumu Hirakawa, Takahiro Tsuchimoto, Takashi Yamauchi

The floor impact noise generated in a building often causes problems among residents. The floor impact sound insulation performance of timber construction buildings is lower than that of concrete construction. However, due to the large supply of wood and the stress-relieving effects of wood, the use of wood is being promoted around the world. In Japan, the Act on the Promotion of the Utilization of Wood in Public Buildings was enforced to promote the use of CLT (Cross Laminated Timber) for the effective use of wood. We have been experimentally investigating the effect of floor finish structure in CLT model building. In this paper, we report the measurement results of the change in floor impact sound insulation performance when the suspended ceiling structure was changed. As results, it was confirmed that the effect of the sound-absorbing material in the ceiling cavity and the effect of the double-layer ceiling board were effective. In addition, it was clarified that the dry-type double floor structure with rubber vibration insulator on its legs is an effective floor finish structure for improvement of heavy and light weight floor impact sound insulation performances.

Session: 09.03 Microperforated Materials
Channel 6

6:00 AM 05-Aug-2021 **IN21_3116.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3116

Proposal of Acoustic Liners Combined with Fine-Perforated-Film

Yo Murata, Tatsuya Ishii, Shunji Enomoto, Hideshi Oinuma, Kenichiro Nagai, Junichi Oki, Hirofumi Daiguji

This paper deals with a resonant type liner panel with a special surface structure. A typical resonant type liner panel generally consists of a perforated face plate, cells, and a back rigid plate. One of the technical challenges of the acoustic liners applied to the future ultra-high bypass ratio engines is to increase the sound absorption efficiency under grazing conditions because the nacelle, covering of the engine, tends to reduce its length and the lined area. It is known that the sound absorption of the conventional liners tends to deteriorate as grazing flow increases. The authors introduced a special thin acoustically transparent film over the face plate of the acoustic liner. The film, a fine perforated film (FPF), is expected to prevent the interaction of the grazing flow with the opening of the liner face plate. An experimental result with a flow duct rig in JAXA confirmed that the proposed combination of the acoustic liner and the FPF improved the absorption in acoustic energy under grazing conditions, compared with the sole acoustic liner and simple treatment of the FPF.

6:20 AM 05-Aug-2021 **IN21_2470.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2470

Sound absorption of a finite flexible micro-perforated panel absorber back by a rigid air cavity filled with a fibrous porous material

Ho Yong Kim, Yeon June Kang

Back by a rigid cavity filled with a layer of porous layer, the sound absorption performance of a micro-perforated panel (MPP) can be enhanced in comparison with other resonance based sound absorbers. In this paper, a theoretical model of a finite flexible MPP back by a rigid air cavity filled with a fibrous porous material is developed to predict normal sound absorption coefficients. Displacements of MPP and sound pressure field in fibrous porous material and acoustic cavity are expressed using a series of modal functions, and the sound absorption coefficients of MPP system are obtained. Additionally, comparison of energy dissipation by MPP and fibrous material is performed to identify effects of a fibrous material on the sound absorption of a MPP. As expected, at anti-resonance frequency of an MPP, the fibrous material provide an alternative energy dissipation mechanism.

6:40 AM 05-Aug-2021 **IN21_2529.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2529

Experimental study of smart sound absorber using multimode electromechanical coupling control in the low-frequency range

Xiang Liu, Keming Wu, Lixi Huang, Keming Wu

To construct a smart sound absorber in the low-frequency range with a wide control band, a piezoelectric ceramic (PZT) shunted with multiple resonance circuit is attached onto a micro-perforated panel (MPP) to perform as a smart sound absorber. The absorption can be controlled by the shunt circuit parameters conveniently. This smart micro-perforated panel (MPP) is investigated experimentally to explore the feasibility and design procedure in practical use. Based on the coupling among the acoustical, electrical, and mechanical fields, the proposed broadband sound absorber can achieve good acoustic performance on subwavelength scales. The electrical response of the shunt circuit is tested with a Network Analyzer. The acoustic performance of the smart sound absorber is measured in an impedance tube with the two-microphone transfer function method. The experimental results validate that the shunt circuit can resonate with the PZT patch at multiple frequencies, and hence improve the sound absorption of the smart absorber at these frequencies.

7:00 AM 05-Aug-2021 **IN21_1129.pdf** **DOI:** https://doi.org/10.3397/IN-1129-2308

Ultralight micro-perforated sandwich panel with double-layer hierarchical square honeycomb core for broadband sound absorption

Wei He

The micro-perforated panel (MPP) has only one sound absorption peak, and the sound absorption performance is poor in the wide frequency range. Besides, the stiffness and strength of MPP are insufficient, so it can not bear the external load. In this study, double layers of hierarchical square honeycomb are placed within the air-back cavity of MPP to produce a sandwich structure. On the one hand, hierarchical honeycombs divide the air-back cavity into several sub-cavities. The perforations on the panel together with the sub-cavities form a series-parallel system of Helmholtz resonators. The sound absorption curve of the structure has multiple peaks and the half-absorption bandwidth is extensively widened. On the other hand, the hierarchical honeycomb with excellent load-bearing properties can strongly support the MPP to resist external loads. This new structure possesses both sound absorption and load bearing capabilities, and has practical application value in the noise reduction of high-speed trains and civil aircraft. Through theoretical and simulation analysis, the sound absorption performance of the structure is systematically studied and the influence of key parameters is quantified, providing guidance for the design of noise reduction materials.

Session: 09.04 Sound Absorbers and Diffusors

Channel 6

7:20 AM 05-Aug-2021 **IN21_2308.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2308

Numerical analysis of the transmission loss of dissipative mufflers with polygonal cross-section

Thomas Geyer, Christopher Mai, Anna-Sophia Henke

Dissipative mufflers are often used for the reduction of broadband noise transmitted in ducts. Many common calculation procedures for the transmission loss of such mufflers require conventional shapes like rectangular or circular cross-sectional areas. In an effort to analyze the effect of the cross-sectional area of dissipative mufflers on the resulting noise reduction, the transmission loss of axially uniform mufflers with polygonal cross-sectional areas was investigated using the finite element method. The mufflers are designed to have the same open area, and hence in a practical application would lead to a similar pressure drop. The results were compared to those obtained with the well known approximative method of Piening. Good agreement between simulation and estimation was found regarding basic trends at low frequencies, while notable differences were revealed regarding the maximum transmission loss.

7:40 AM 05-Aug-2021 **IN21_1444.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1444

Diffuse sound absorption modelling of complex finite absorbers using a hybrid deterministic-statistical energy analysis approach

Cédric Van hoorickx, Paul Didier, Edwin Reynders

This contribution presents a numerical approach to quantify the response of an absorber in a diffuse reverberation room. Conventionally, this is done by considering an infinite absorber coupled to an acoustic halfspace. It is, however, well known that the diffuse absorption coefficient for a finite absorber can be quite different due to what is referred to in literature as the edge effect. A finite size correction has been developed previously, but it is only applicable to homogeneous absorbers and is based on a computationally costly quintuple integration. This contribution presents an alternative approach in which a deterministic model, e.g. using the finite element or modal transfer matrix method, is coupled with a statistical model of the room using a hybrid deterministic-statistical energy analysis framework. With this framework, also the theoretical uncertainty on this diffuse sound absorption that is inherent in the diffuse field assumption can be quantified, i.e. the variance of sound absorption results that can be theoretically expected across an ensemble of reverberation rooms of the same volume. The methodology is numerically and experimentally validated for several absorber types.

8:00 AM 05-Aug-2021 **IN21_2056.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2056

Optimization of an absorbing surface with 2D Helmholtz resonators for reduced sensitivity to the incidence angle

Diana Maria Garza-Agudelo, Vicente Cutanda Henriquez, Cheol-Ho Jeong, Peter Risby Andersen

It has been shown in several recent publications that acoustic materials consisting of a combination of resonators tuned to different frequencies can render high absorption coefficient values over an extended frequency range while maintaining compactness. This makes them attractive solutions for applications in which low frequency sound control is needed, and/or when there are significant space constraints. Nevertheless, the acoustic performance of these surfaces varies with the angle at which a wave impinges on the surface. The changes in the absorption characteristics with the incidence angle occur both on the maximum absorption coefficient, and on the effective frequency bandwidth. Numerical optimization is a tool that can help realize designs with a large degree of geometrical freedom, and using this framework we have demonstrated an array of coupled 2D Helmholtz resonators that is less sensitive to changes in the incidence angle.

8:20 AM 05-Aug-2021 **IN21_2497.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2497

Estimation and experimental test of the sound-absorption coefficient of a pin-holder structure (Case of sound waves incidence upon the side surfaces of a group of cylinders)

Takamasa Sato, Shuichi Sakamoto, Isami Nitta, Shunsuke Unai, Takunari Isobe, Kenta Iizuka, Katsuhiko Tasaki

In this study, we conducted theoretical analyses and experiments related to the acoustic characteristics of the situation where sound waves are incident upon the side surfaces of a group of cylinders forming a pin-holder structure. The sound-absorption coefficient, entering its clearance between cylinders through the geometrical dimension of the clearance or the physical property of gas, was calculated. In the analytical model, the gap part of the pin-holder structure was divided into elements and approximated as a gap surrounded by two parallel planes. The characteristic impedance and propagation constant of the approximate gap were obtained and treated as one-dimensional transfer matrices; the sound-absorption coefficient was then calculated using the transfer-matrix method. The calculated value was compared to that obtained in an experiment with a sample prepared using a 3D printer; the sound-absorption coefficient was measured using a 2-microphone impedance-measuring tube. We attempted to make a simple yet accurate estimation of sound-absorption coefficient using these procedures. Our theoretical values displayed a similar tendency to that obtained by experiment.

8:40 AM 05-Aug-2021 **IN21_2731.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2731

An experimental study on acoustical performance of cross rib diffuser

Takumi Yoshida, Yasutaka Ueda, Norimasa Mori, Yumi Matano

The preset paper proposes a novel acoustic diffuser which we call cross rib diffuser (CRD) and investigates its acoustical performance in rooms experimentally. CRD consists of overlapping two one-dimensional periodic rib diffuser (OPRD) with different structural configurations. CRD can achieve high scattering coefficient with wider frequency band than OPRD. Moreover, unlike other diffusers with high scattering property such as metadiffuser and two-dimensional quadratic diffuser, CRD keeps simple and familiar design of OPRD suitable for use in various architectural spaces. In the paper, we firstly evaluated random-incidence scattering coefficient of CRD using 1/5 scaled reverberation room. Then, random-incidence absorption coefficient was measured in 1/1 reverberation room. Finally, an implementation experiment was conducted to examine applicability of CRD in improving acoustics in small meeting room with small absorption treatments. The results indicated that CRD reduced EDT and reverberation time, and increased D50 more than JND values. Additionally, CRD improved reverberation and speech intelligibility more significantly than OPRD with same installation area.

Session: 09.03 Microperforated Materials

Channel 6

11:00 AM 05-Aug-2021 **IN21_2489.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2489

Customized sound mitigation with micro-perforated panels

Manfred Kaltenbacher, Sebastian Floss

Micro-perforated panels in combination with an air-tight back volume constitute the micro-perforated absorber (MPA), an alternative means in the category of sound absorbing (meta)materials. In contrast to the conventional porous and fibrous materials, the MPA does not mitigate sound in broad frequency range, but rather has to be customized to a specific noise frequency range. In this contribution, we demonstrate the simulation framework based a genetically fitted equivalent fluid model. Application examples show the advantages and disadvantages of using MPAs in room
acoustic scenarios as well as with a background mean flow in ducts. The investigations found that the MPA's effectiveness strongly depends on the sound field characteristic. The MPP's surface roughness and back volume composition in-part significantly influence the efficiency of an adjacent turbo-machine.

11:20 AM 05-Aug-2021 **IN21_1402.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1402

Optimization of space-constrained micro-perforated absorbers by causality criteria

Teresa Bravo, Cedric Maury

The problem of space-constrained absorbers in the low frequency range constitutes an area of continuous research. Micro-perforated panels are advantageous because they can be tuned by a proper selection of their constitutive physical parameters including the diameter of the perforations and their separation distance, their thickness and the length of the backing cavity. However, such optimal selection is not straightforward, especially when considering multi-layer partitions. Current optimization algorithms are based on the maximization of the total absorption coefficient averaged over a frequency band, that requires a compromise between the bandwidth and the thickness of the control device. In this work, the problem is analysed on the basis of a causality criterion. This principle is generalized from its formulation in the field of electromagnetism to obtain a relation that correlates the thickness-to-bandwidth performance of a micro-perforated absorber to its total absorption coefficient. Using this relation, an optimization procedure is presented for the sequential selection of the optimal physical parameters for single-layer partitions. An excellent agreement has been found between the optimal values obtained by the causality criterion and those achieved by critical coupling conditions.

11:40 AM 05-Aug-2021 **IN21_1404.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1404

Enhanced modal matching method for perforated and micro-perforated partitions

Cédric Maury, Teresa Bravo

Perforated multilayer partitions are widely used in many problems for the aerospace and automotive industries and air-conditioning systems. Combinations of macro and micro-perforated perforations across the constitutive partition layers can provide different physical mechanisms for diverse control strategies depending on the problem requirements. However, there is a lack of unified numerical or analytical description able to provide accurate results over a broad frequency range for a wide range of diameter perforations ranging from supra-millimetric to sub-millimetric apertures. Furthermore, most of them do not account for the beneficial effects on the partition dissipation of the in-hole non-planar modes, albeit evanescent. In this work, an enhanced modal matching (EMM) method is presented that accounts for in-hole high-order modes as well as visco-thermal boundary layer effects inside the holes and over the outer surfaces surrounding the holes. The analytical results have been compared against effective models, numerical models and impedance tube measurements. They show good agreement for single and multi-layer partitions within the corresponding bandwidths of validity. Parametric studies have concluded that the panel thickness-to-hole diameter ratio is a key factor that plays a crucial role on the prominence of the in-hole radial modes and outer visco-thermal effects in the dissipation properties.

12:00 PM 05-Aug-2021 **IN21_2621.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2621

Broadband sound absorbers of multilayered micro-slit panels using Bayesian probabilistic inference

Michael Hoeft, Cameron J. Fackler, Ning Xiang

Micro-perforated panel absorbers can typically achieve either visual transparency or broadband absorption, but not both. This paper assesses the potential of Multilayer Micro-Slit panels to maintain both of these characteristics simultaneously. Micro-slit panels are similar to micro-perforated panels, and can similarly achieve high absorption coefficients without fibrous backing materials. The arrangement of slits are better suited to visual transparency than perforated holes because it provides more unobstructed panel per perforated area. However, these types of absorbers are limited to a narrow frequency bandwidth of effective absorption. By combining several panels into a multilayer assembly, broadband absorption becomes possible. The inherent complexity stemming from optimizing the parameters for multiple layers to meet a given design criteria necessitates the use of the Bayesian framework. This probabilistic method rapidly hones in on the best parameters of each individual layer so that the overall composite meets the design goal. Furthermore, Bayesian inference implemented cyclically alongside panel fabrication and testing allows for corrections of fabrication tolerances while assessing visual transparency.

Session: 09.05 Additive Manufacturing for Acoustic Applications
Channel 6

12:40 PM 05-Aug-2021 **IN21_2314.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2314

Optimization of 3D printed porous materials accounting for manufacturing defects

Jean Boulvert, Théo Cavalieri, Vicente Romero-García, Gwénaël Gabard, Jean-Philippe Groby

Open-cell materials are well-known for their low price, low weight, and broadband acoustic behavior. They form one of the most used class of acoustic treatments but suffer from a lack of versatility when made by conventional manufacturing processes. Recent advances in additive manufacturing allow to produce porous materials having a controlled microstructure. In this way, the design of treatments including porous materials is not limited to a catalog of existing media. The macroscopic behavior is governed by the micro-geometry of the porous medium, which can be estimated by numerical models. Then, acoustic treatments can be optimized numerically using predicting models and minimization algorithms. However, additive manufacturing induces defects often too complex to be accounted for numerically. In this presentation, a method allowing to obtain the parametric model of the intrinsic behavior of a 3D-printed porous material is presented. The corrected model is used in the optimization of several porous treatments; namely, graded porous materials, folded porous materials and metaporous surfaces. These treatments are versatile and display remarkable properties. They provide quasi-perfect absorption at several frequencies that can be out of reach of standard porous treatments in normal or oblique incidence. Experimental validations confirm the relevance of the proposed design processes.

1:00 PM 05-Aug-2021 **IN21_3177.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3177

3D printed multifunctional, load-bearing, low-frequency sound absorbers

William Johnston, Pulitha Godakawela Kankanamalage, Bhisham Sharma

Cellular porous materials are an attractive choice for lightweight structural design. However, though their open porous architecture is ideally suited for multifunctional applications, their use is typically limited by the pore sizes achievable by traditional as well as advanced fabrication processes. Here, we present an alternative route towards overcoming this pore size limitation by leveraging our recent success in printing fibrous structures. This is achieved by superimposing a fibrous network on a load-bearing, open-celled porous architecture. The multifunctional structure is 3D printed using a novel technique that enables us to simultaneously print a load-bearing scaffold and the necessary fibrous network. The acoustic properties of the printed structures are tested using a normal-incidence impedance tube method. Our results show that such structures can provide very high absorption at low frequencies while retaining the mechanical performance of the underlying architected structure.

1:20 PM 05-Aug-2021 **IN21_2683.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2683

Evaluation of additively manufactured stacks for thermo-acoustic devices

Samarjith Biswas, James M. Manimala, James M. Manimala

The thermo-acoustic effect provides a means to convert acoustic energy to heat and vice versa without the need for moving parts. This is especially useful to construct mechanically-simple and robust energy harvesting devices, although there are limitations to the power-to-volume ratio achievable. The mechanical and thermal properties as well as geometry of the porous stack that forms a set of acoustic waveguides in thermo-acoustic devices are key to its performance. In this study, we evaluate various additively manufactured polymer stacks against more conventional ceramic stacks using a benchtop thermos-acoustic refrigerator rig that uses air at ambient pressure as its working fluid. Influence of stack parameters such as material, length, location, porosity and pore geometry are examined using experiments and correlated to simulations using DeltaEC, a software tool based on Rott's linear approximation. Structure-performance relationships are established by extracting scaling laws for power-to-volume ratio and frequency-thermal gradient dependencies. It is found that additively manufactured stacks can deliver performance comparable to ceramic stacks while being more affordable and customizable for thermo-acoustic transduction applications.

Session: 12.03 Signal Processing for Active Control
Channel 6

2:00 PM 05-Aug-2021 **IN21_2808.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2808

Semi-adaptive active noise cancellation headphones

Song Li, Roman Schlieper, Jürgen Peissig

Active noise cancellation (ANC) headphones are becoming increasingly important as they can effectively attenuate perceived ambient noise. Fixed filters are commonly applied in commercially available ANC headphones due to their robustness. However, they are not capable of adapting to changes that occur in dynamic environments, resulting in degraded ANC performance. In contrast, adaptive filters are able to update the ANC filters to compensate for noise in dynamic environments, but large estimation errors can occur due to a sudden change in direction/type of noise or secondary path.

Some studies have suggested an ANC system by combining fixed and adaptive filters. Based on this mechanism, we propose a semi-adaptive ANC system in which the fixed and adaptive filters are weighted in real-time. Initially, the weighting for the fixed filter dominates the whole system to ensure the robustness of the ANC system. Then, the residual error provided by the adaptive filter is simulated and compared to the real measured one to determine the relative weighting between the fixed and adaptive filters. In this study, this approach is applied to a feedback ANC system. Simulation results show that our proposed approach achieves high noise attenuation performance while maintaining robustness with time-varying secondary paths.

2:20 PM 05-Aug-2021 **IN21_2128.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2128

Simulation of LMS based adaptive noise cancellation using Labview

Maja Anachkova, Simona Domazetovska, Zlatko Petreski, Viktor Gavriloski

The audio signals processed in the signal measurement systems are inevitably susceptible to unwanted noise which significantly affects the quality of the signal and the overall performance of the signal communication systems. Due to its' random and unpredictable nature, the amount of noise in signals has proven to be a significant issue in designing these systems and recently has been a trending research topic. In this regard, the active noise cancellation method has proven to be an effective technique for eliminating the noise effects on signal processing. The concept of active noise cancellation is based on the application of adaptive filters and algorithms proposed to reduce the signal corruption and distortion caused by the noise due to the principle of destructive interference. In this paper a simulation model of active noise reduction technique using the LMS (Least Mean Square) algorithm in Labview is presented. The purpose of the work is to investigate the noise cancellation effect on a recorded audio file in terms of analyzing the audio file before and after filtering out the noise by using the LMS algorithm and discuss the results thereof.

2:40 PM 05-Aug-2021 **IN21_1816.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1816

A constrained optimal hear-through filter design approach for earphones

Yongjie Zhuang, Yangfan Liu

The sound from environment will be altered after it transmits through headphones to the ear canal. A hear-though filter can be designed and implemented in the headphones to create a more natural hearing experience, i.e., offer a transparent mode for headphones. The design of hear-through filter is also required in some other applications, e.g., augmented reality audio. In this paper, a constrained hear-through filter design approach is proposed. It is firstly shown that the hear-through filter design problem can be formulated in a similar form to active noise control filter design in the frequency domain. One advantage of this design approach is that multiple practical constraints can be applied conveniently by formulating a constrained optimization problem. Then the constrained optimization problem for hear-through filter design is reformulated as cone programming problem which can be solved efficiently. The proposed design approach can also specify the desired delay of reproduced sound. The designed filter can be directly implemented in an active noise control system in the headphone such that the requirement for extra electronic components can be minimal.

Session: 09.01 Porous Materials
Channel 6

3:20 PM 05-Aug-2021 **IN21_1446.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1446

Characterization of multi-layer porous media in an impedance tube

Remi Roncen, Zine El Abiddine Fellah, Erick Ogam

A porous material is the combination of a solid phase and a fluid phase, with interactions and energy exchanges between phases giving rise to the dissipation of waves traveling through the porous medium. In air, mostly viscous effects and thermal effects are responsible for dissipation, in a way that strongly depends on the pore microstructure. To evaluate the intrinsic properties pertaining to this microstructure, inverse acoustic methods have been used in the past, typically using impedance tubes to observe the way a porous sample interacts with an acoustic field. The impedance tube is a widespread tool in the acoustic community and has proven to be efficient in retrieving, via an inverse method, porous material intrinsic properties such as the porosity or the tortuosity of a sample. In this work, a Bayesian representation of knowledge is taken, where information on a material property is encoded in a probability density function. When multi-layer materials are considered, classical inverse methods become ill-posed and it might become impossible to retrieve exactly each layer's intrinsic properties. This work presents two straightforward improvements that can be used in order to lift this ill-posedness and increase the precision with which material properties are obtained.

3:40 PM 05-Aug-2021 **IN21_2869.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2869

Simulations of poroelastic materials in a complex acoustic system using frequency-dependent parameters in the mid-frequency range

János Kun, Daniel Feszty, Dániel Feszty

Efficiency requirements prompt manufacturers to develop ever lighter acoustic packages in vehicles. Poroelastic materials are essential to achieve the desired interior noise level targets and thus the simulation of their effects is of utmost importance in NVH analyses. However, it is challenging to achieve good validation between finite element method (FEM) based simulation results and measurements in the mid-frequency range (400-1000 Hz). One possible reason could be the lack of using frequency-dependent Biot-paremeters describing the poroelastic materials (PEM) characteristics of trims. The present research aims to employ frequency-dependent Biot-parameters for the PEM materials to investigate the acoustic response of a scaled car-like steel structure composed of flat plates and U-section stiffeners enclosing an air cavity. Porous acoustic material is applied to the walls of the cavity. The focus of the study is to understand the effect of applying frequency-dependent Young's modulus and damping values for the PEM parameters in the 100-1000 Hz range. Simulation results obtained from ESI VPS FEM solver are compared with measurements, with particular focus on the interior sound pressure levels. The simulation methodology, including discretization techniques, structural damping and fluid damping applications are described in detail.

4:00 PM 05-Aug-2021 **IN21_2859.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2859

Investigation of frequency dependent mechanical properties of porous materials using dynamic mechanical analyzer and frequency-temperature superposition theory

Attila Schweighardt, Balazs Vehovszky

In acoustic design of engineering applications – such as in the acoustic analysis of passenger vehicles – poroelastic materials are of great importance. One of the most influencing properties in determining their noise-reduction potential is the storage modulus. The purpose of this study is to examine the frequency dependence of storage modulus of selected porous acoustic materials at least up to 1000 Hz. This is executed by using the combined use of dynamic mechanical analyzer and frequency-temperature superposition theory. All other methods for measuring the storage modulus fall short in determining frequency-dependence above 100 Hz: quasi-static mechanical analyzer is mostly used for determining an averaged constant value deduced from low-frequency measurements, while the usage of an electromagnetic shaker capable for high-frequency excitation may include effects of fluid motion inside the pores, thus significantly modifying the results. Frequency-temperature superposition enables to determine the storage modulus values in a wide frequency range, based on low-frequency measurements, where fluid-structure interaction is negligible. It was found that the modulus varied significantly up to and beyond 1000 Hz, and thus, acoustical characterization of these materials can be significantly improved using the proposed method. The work concludes with recommendations to improve the accuracy of the results.

Session: 09.09 Acoustic Material Design, Part 2
Channel 6

4:40 PM 05-Aug-2021 **IN21_2903.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2903

Compressed acoustic sealing foam optimization investigation using statistical approach

Mathieu Gontier, Barbara Romeyns

In industry segments such as automotive and industrial equipment the use of compressed porous materials is well known to improve the global acoustic performance of the complete system. Such porous materials should be designed in a specific way in order to reach a significant acoustic sealing performance at different compression rates.
Unfortunately, there are no standard measurement procedures nor predefined material characteristics that allow the selection of the right material with the optimal acoustic performance.

The main goal of this research is to link acoustic performance of compressed porous materials with intrinsic material characteristics using statistical techniques.

5:00 PM 05-Aug-2021 **IN21_2076.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2076

Multilayer treatment for subwavelength and broad absorption

Josué Costa Baptista, Edith Roland-Fotsing, Jacky Mardjano, Daniel Therriault, Annie Ross

Single layer optimized microchannels (268µm channels size) present high absorption at the quarter-wave resonance frequency (2460Hz for 30mm-thick treatment) but cannot provide significant absorption at lower frequencies. In this work, the absorption coefficient of multilayer treatments with 2, 5, 10- and 30-layers of channels with size varying from 50µm to 15mm was numerically optimized. The equivalent fluid wave number and characteristic impedance of each layer were predicted using the JCAL model. The Double-scale Asymptotic Method (DAM) was used to obtain the JCAL parameters. The multilayer treatment absorption was modelled with the Transfer Matrix Method (TMM). It was shown that multilayer treatments present superior absorption than single layer. For instance, bilayer treatment made of a 1mm-thick top layer (facing incident wave) of channels of 58µm and a 29mm-thick bottom layer of channels with 8.1mm provides perfect absorption around 1200Hz (i.e. 1260Hz below the quarter-wave resonance frequency of 30mm-thick single layer treatment). Alternatively, a 30-layer treatment with channels size varying from 100µm to 9.6mm provides absorption higher than 0.8 between 1350 and 6270Hz (i.e. 54% higher than single layer treatment with same thickness). These results pave the way to the fabrication of new multilayer treatments with interesting subwavelength and broadband absorption capabilities.

5:20 PM 05-Aug-2021 **IN21_2863.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2863

Modelling sound wave propagation through corrugated macro-geometry arrangement of porous material for combined heat sink and noise reduction applications

Harshavardhan Ronge, Shankar Krishnan, Sripriya Ramamoorthy

In convective air-cooled heat sink applications with space constraints, corrugated geometries can be used as in-duct sound absorbing structures offering lower duct-flow resistance than other geometries such as block-shape, wedge-shape geometries. Sound wave propagation through this geometry is presented using a simple 1-D acoustic model. Using the model, acoustic performance of corrugated sample is evaluated in terms of its transmission loss in dB. Thermal resistance and pressure drop values are also reported and compared with acoustic performance as function of number of corrugations and length of corrugated sample. A rectangular corrugated geometry has alternate inlet and outlet channels separated by porous walls. Sound propagation across this arrangement is modelled by extending prior model from literature with similar geometries. Prior model by Allam and Åbom (2005) is highly symmetric about the channels and porous walls are modelled by simple steady flow resistance equation. In current work, appropriate considerations are taken into account for the configuration of corrugated geometries suitable to general heat sink applications and sound wave propagation through porous walls is predicted by using Johnson-Champoux-Allard (jca) model. The porous walls at ends of the geometry are modelled as in acoustically series-parallel network combinations. Further, effect of heat sink temperature on sound wave propagation is also explored using the model.

Session: 11.00 Industrial Noise, General
Channel 6

7:40 PM 05-Aug-2021 **IN21_1868.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1868

Modeling Industrial Pipe Insulation Performance

Kevin Herreman

Reducing industrial noise emission utilizing jacketed pipe insulation is critical to reducing noise in industrial spaces. The ISO 15665 standard defines a testing process for measurement of the acoustical performance of installed and jacketed pipe insulation systems. However, the cost of testing per this standard, especially when using an external laboratory, can be very costly. That makes the development of a model to accurately estimate the performance of single, and multilayered, jacketed pipe insulation highly desirable. Utilizing a one-dimensional theoretical acoustic model along with empirical data, a model with sufficient accuracy to provide insertion loss results relative to the ISO 15665 standard was created. The creation and resulting functionality of the model for determining jacketed pipe insulation insertion loss and comparison of the resulting data to test results will be discussed herein.

8:00 PM 05-Aug-2021 **IN21_1870.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1870

Modeling Large Diameter Industrial Pipe Insulation Performance

Kevin Herreman

As previously presented, reducing industrial noise emission utilizing jacketed pipe insulation is critical to reducing noise in industrial spaces. The ISO 15665 standard defines a testing process for measurement of the acoustical performance of installed and jacketed pipe insulation systems. To provide a cost-effective method for evaluating various types of multilayered jacketed pipe insulation a model was developed. The model accurately estimates the performance of single, and multilayered, jacketed pipe insulation. Validating the use of the model to very large pipe diameters is highly desirable as the cost to test is significantly higher than testing the medium or small diameter pipe insulation. The estimated insertion loss result from the model is compared to validation testing results for large diameter jacketed pipe insulation are reported herein.

8:20 PM 05-Aug-2021 **IN21_3102.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3102

Machining and Fabrication Equipment in Workplaces

William Rosentel

Increasingly well-developed workplace acoustic standards have resulted in more consistent outcomes across projects and normalized occupant expectations of acoustic quality, enhancing productivity and satisfaction. Yet these standards are often not developed for or applied to R&D and manufacturing spaces that include traditional workplace room types and uses; design criteria is limited to OSHA-assessment for noise-at-work violations. Hybrid office buildings incorporating prototyping and maker spaces are common today and often contain high-noise equipment traditionally found in dedicated machine shops.

As these facilities are incorporated alongside traditional offices, noise and vibration levels generated by fabrication equipment should be accurately quantified to avoid compromised workplace acoustics. While sound data is available for most large construction equipment, available data for smaller fabrication machines typically found in machine shops is often non-standardized and difficult to obtain.

Field measurement of existing equipment installations can ground an acoustical analysis with real-world data and be highly valuable in evaluating potential noise and vibration impacts and applying cost-effective mitigation during design. This case study will present measurements obtained during a noise and vibration assessment of an existing machine shop located within an office building. The discussion will include limitations of the data and an assessment of potential for disruptions.

8:40 PM 05-Aug-2021 **IN21_1927.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1927

Power generator noise evaluation considering conversation audibility and improvement

Junji Yoshida, Yoshiki Nishimura, Senta Uegaki

Compact power generators are useful and convenient tools all over the world. The products are mainly set at around living space of human. Hence, the radiated noise should not disturb the human activities such as conversation. In this study, we then focused on the ease of conversation as the power generator noise performance and attempted to improve the performance. We firstly carried out subjective evaluate tests using recorded generator noise samples and reproduced Japanese syllables to evaluate the performance quantitatively from sound pressure of power generator noise. In the test, the participants answered the syllable they heard under the reproduced generator noise condition. And the correct answer rate of the presented syllable was calculated in each generator noise. The correct answer rate could be expressed well by using articulation index (AI) of each generator noise. Subsequently, the noise reduction target level of a portable generator satisfying the rate at 80% was set in each frequency band considering the influence of each frequency band on AI. Noise countermeasure was carried out to intake and exhaust parts having large contribution at the reduction target frequency bands. Finally, the noise could be decreased well and the AI cleared the target level.

Session: 15.01 Indoor Soundscapes

Channel 7

6:00 AM 05-Aug-2021 **IN21_2988.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2988

Effect of visual elements on Indoor soundscape perception in open-plan office

Beta Bayu Santika, Hyun In Joo, Jin Yong Jeon

This study examined the effect of changes in visual elements on spatial comfort and work productivity in the aspect of indoor soundscape perception in the open-plan office (OPO) sound environment. Various OPO visual stimuli were simulated using computer software (Unity 3D engine) to change the visual environment by varying variables such as worker density, window ratio, green ratio, and ceiling height. An interactive virtual reality environment was implemented to perform a specific task while experiencing the audio-visual stimuli combining the general OPO noise stimulus and the simulated OPO visual stimulus. Subjective evaluation was performed on a total of 30 subjects to evaluate indoor soundscape quality and work performance for each stimulus. Based on the results of this study, a pleasant OPO design guideline was proposed.

Keywords: Open-plan office, indoor soundscape, interactive VR test, spatial comfort

6:20 AM 05-Aug-2021 **IN21_2539.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2539

Soundscape evaluation to identify audio visual aspects in café for student's activities

Rizky Octaviani, Diandra Rizkiyani, Anugrah Sabdono Sudarsono, Sugeng Joko Sarwono

A café is a type of restaurant that typically serves coffee and tea, in addition to light refreshments such as baked goods or snacks. Nowadays, students also consider cafés as a social place to do various activities. The different activities might need a different environment. However, the existing studies regarding the soundscape in a café do not consider the different activities and only focus on the auditory aspects. In this study, the activities in a café and the important audio-visual aspects are identified. This information is beneficial to design appropriate cafés environment for different student activities. The data were collected using an online survey. The survey asked several pieces of information such as activity preference and audio-visual preference. The survey shows that the students' activities in a café are classified into four types: discussion-chatting (27%), group-studying (27%), eating drinking (20%), self-studying (16.5%), and others (9.6%). The survey also shows the five most important audio and visual aspects in a café: general noise (13.61%), dynamics (8.9%), the loudness of music (8.12%), color contrast (8.12%), and hubbub (7.85%).

6:40 AM 05-Aug-2021 **IN21_2015.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2015

Understanding the Effect of Geometric Forms on Indoor Soundscape Assessment: A Case Study in CSO Concert Halls in Ankara, Turkey

İlayda Erdoğu, Semiha Yılmazer

This study aims to compare the indoor soundscape of two concert halls with different geometric forms. The study included Presidential Symphony Orchestra (CSO) Concert Hall (CH) and CSO Grand Hall (GH) in Ankara, Turkey. CH was in shoebox form, and GH had vineyard form. Participants consisted of undergraduate students of the Interior Architecture and Environmental Design Department of Bilkent University. Twenty females and twenty males were selected between the ages of 20-25. They were randomly divided into two groups as CH and GH. An online listening test with the same music but different recordings of each hall was applied. Also, tests had the visuals of the relevant concert hall. The perceptual data was collected with the questionnaire from ISO/TS 12913 2 Method A. The results showed that the overall soundscape quality of GH was perceived as more positive than CH. The surrounding sound in GH was more eventful and pleasant than CH.

7:00 AM 05-Aug-2021 **IN21_2017.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2017

Exploring the Audio-Visual Interaction in a Dental Clinic Through the Restorative Environment

Zeynep Uğurlu, Semiha Yılmazer

The aim of this study is to examine the effects of audio-visual interaction in an indoor acoustic environment. The research focused on the waiting area of a dental clinic. The dental clinic is visited, and binaural audio-video recording is made. After, a listening task is given to the ten participants in three scenarios. Three experiment settings were designed for each scenario. The first experimental group was the control group who had the soundscape of the real environment; the second group, which is the audio group, only had the audial stimuli with the natural sound which is added to the real environment; and the third group, which is the audio-visual group, had both visual stimuli with an image of nature and audial stimuli. A listening task questionnaire and Perceived Restorativeness Soundscape Scale (PRSS) interpretation questionnaire were given to the participants. The results showed that the participants in the third group were found to perceive the indoor soundscape more positively than the other two groups.

7:20 AM 05-Aug-2021 **IN21_2021.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2021

Electroencephalogram (EEG) responses to indoor sound sources in wooden residential buildings

Alessia Frescura, Pyoung Jik Lee, Jeong-Ho Jeong, Yoshiharu Soeta

The present study aimed to explore relationships between physiological and subjective responses to indoor sounds. Specifically, The electroencephalograms (EEG) responses to neighbour sounds in wooden dwellings were investigated. Listening tests were performed to collect EEG data in distinct acoustics scenarios. Experimental work was carried out in a laboratory with a low background noise level. A series of impact and airborne sounds were presented through loudspeakers and subwoofer, while participants sat comfortably in the simulated living room wearing the EEG headset (B-alert X24 system). The impact sound sources were an adult walking and a child running recorded in a laboratory equipped with different floor configurations. Two airborne sounds (a live conversation and a piece of classical piano music) were digitally filtered to resemble good and poor sound insulation performances of vertical partitions. The experiment consisted of two sessions, namely, the evaluation of individual sounds and the evaluation of the combined noise sources. In the second session, pairs of an impact and an airborne sound were presented. During the listening test, electroencephalography alpha reactivity (α-EEG) and electroencephalography beta reactivity (β-EEG) were monitored. In addition, participants were asked to rate noise annoyance using an 11-point scale.

7:40 AM 05-Aug-2021 **IN21_1732.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1732

Understanding the effect of restorativeness in indoor soundscapes through a conceptual model

Cemre Orhan, Semiha Yilmazer

The soundscape is defined as the acoustic environment perceived or experienced by a person or people. Soundscape research, where human perception is at the center, has generally been conducted on unwanted sound sources to identify sounds' negative health effects. Therefore, wanted sound sources and their impact on being exposed to soundscapes that may induce positive outputs on health has been neglected. People tend to be in places that reduce stress and increase restoration. However, many indoor places cause stress in our daily lives and decrease the quality of living. This study aims to generate the conceptual model that would be used to identify what causes stress indoors and what can be done to transfer these spaces into restorative ones from the soundscape perspective. To generate a comprehensive model, by centering the soundscape framework of ISO, its constructs were combined with Attention Restorative Theory (ART), Stress Recovery Theory (SRT), and Biophilic Design approach into positive and negative relations based on their effects on health.

Session: 14.14 Community Noise
Channel 7

11:00 AM 05-Aug-2021 **IN21_1628.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1628

Design of noise barriers for the mitigation of construction noise

Heow Pueh Lee

Noise pollution is a major problem in many major cities in particular a small island state like Singapore with residential buildings very close to the major trunk roads and expressways. The problem is aggravated by the ongoing city redevelopment and construction of new mass rapid transit lines. Construction noise is therefore a common theme of public complaints and therefore there is an increased interest in the

development of more effective mitigation measure for construction noise. In this work, a Flat-tip jagged-edge profile was investigated and applied on the edge of a cantilever (slanted up for 45 degrees, facing the noise source) which was mounted at the top of a passive noise barrier. Besides the numerical simulations, the full sized prototypes were also experimentally tested on a construction sites with noise generated by a boring machine. Both numerical simulations and experimental results showed that this barrier with a slanted Flat-tip jagged cantilever would perform better than the traditional barrier having a Straight-edge cantilever of same height, with a maximum additional attenuation of 5.0 dBA experimentally obtained. The barrier with slanted Flat-tip jagged cantilever could also extend the shadow zone behind the barrier to higher levels of the building.

11:20 AM 05-Aug-2021 **IN21_3142.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3142

Managing Construction Noise in Hong Kong – Facing a New Decade with Confidence

Wilson Ho, Kin-Che Lam, Morgan CHENG, Max Yiu, Hannah Chin-wing Lo, Jamie Chi-ting Lai, Cheung-lam Wong

Hong Kong is a mature and busy metropolis with 7.5 million residents. Being constrained by limited land area for development, the cityscape of Hong Kong is primarily 3-dimensional in nature. The vast majority of the growing population is accommodated in closely packed high-rise residential towers. Similar to other major urban centres worldwide, Hong Kong citizens are affected by the virtually continuous construction activities expanding and renewing the city. The numerous construction sites are also bringing noise disturbance to some neighbourhoods. In 2020, the Hong Kong Environmental Protection Department completed a feasibility study on managing construction noise, including those associated with renovation of domestic premises. Part of the study was the conducting of face-to-face interviews of more than 5,000 households via a large scale public survey to gauge their views on construction noise disturbance, among others. This paper describes the current state and conditions of construction noise in Hong Kong, the issues and constraints, as well as challenges and opportunities. Highlights from the scientifically conducted public survey will be included to provide a robust and more comprehensive description of the prevailing situation.

11:40 AM 05-Aug-2021 **IN21_1826.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1826

Prediction of the variability of noise emissions from construction sites using Monte-Carlo simulation

Dave Davis, Craig Beyers

Noise emissions from construction sites are inherently unsteady. Noise emissions vary due to many causes, including the noise sources frequently changing in location, orientation, the types of activities they perform, and the acoustic shielding due to structures and/or terrain. The noise that arrives at receivers from construction site equipment can fluctuate over all time scales, from seconds to hours, days, months or years. Prediction of noise levels typically assumes either a “worst-case” approach in which all noise sources are assumed to be operating simultaneously, or by predicting an “energy-average” (Leq) level over a long time period. In the latter case, an energy-average (Leq) noise level is predicted at receivers, based on the anticipated percentage utilisation of the various noise sources on the construction site – that is, the fraction of time that each item of equipment is operating or not during the averaging time period. This paper presents a method that may be used to estimate the variability of noise emissions from the site and the corresponding noise immissions at receivers using the Monte-Carlo simulation method. Using this method, the expected minimum, maximum, percentiles and energy-average (Leq) noise immission levels at receivers can be predicted.

12:00 PM 05-Aug-2021 **IN21_1468.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1468

Gazex avalanche control system noise and vibration assessment

Paul Bollard

Bollard Acoustical Consultants, Inc. was retained by the Placer County Planning Dept. to quantify noise and vibration levels resulting from the Gazex avalanche control system usage during the winter of 2018-2019. The primary objective of the monitoring program was to obtain a statistically representative sample of noise and vibration data during Gazex usage for comparison against criteria for potential damage to structures and human hearing. During the survey period, 75 discrete discharges of Gazex cannons occurred. Each discharge was monitored at five fixed monitoring sites in the Alpine Meadows residential community. At the completion of the survey, 1,079 of the possible 1,125 possible data points of interest had successfully been captured. The results of the surveys indicated that, although noise and vibration levels generated by the Gazex system were elevated to the point of being considered highly annoying to local residents, criteria for damage to hearing and structures were not exceeded during the survey period.

12:20 PM 05-Aug-2021 **IN21_1880.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1880

Noise codes and acoustical design criteria for distribution facilities

Michael Conaway, Benjamin Mueller, Joseph Keefe

Distribution and warehouse-type facilities are routinely constructed all over the country and the world. On-site noise sources for this type of facility include heavy trucks, delivery vehicles, and rooftop HVAC equipment. Stationary noise is often more clearly regulated than mobile noise sources. To protect the public, appropriate criteria need to be established for all sources. Some jurisdictions have quantitative regulatory limits in place that may be used as design criteria while others may have less helpful qualitative code language or no noise code at all. A review of common metrics found throughout the U.S. is presented to understand code language that appropriately protects the public for specific sources. In addition, it is useful to analyze and discuss common criteria applied in the absence of quantitative code limits.

12:40 PM 05-Aug-2021 **IN21_1878.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1878

Montevideo, walkable city: pedestrianization of a large avenue during 2020 pandemic

Alice Elizabeth Gonzalez, Pablo Gianoli Kovar, Lady Carolina Ramírez, Micaela Luzardo Rivero

On March 13, 2020, the first cases of SARS-COVID19 were detected in Uruguay. During the first weeks of the pandemic, mobility was significantly reduced with the slogan "If you can, stay home"; it was not a mandatory but voluntary confinement. After a couple of months, there was a big drop in the number of people affected by the disease. Thus, the Municipality of Montevideo, betting on a more human and walkable city, defined that the main avenue of the city had a pedestrian section on Saturday afternoons. This resulted in a greater enjoyment of the city by its inhabitants, as they had more space to walk while maintaining safe distances between people. It was also possible to promote trading, since classically Ave. 18 de Julio is also a commercial stroll. Additionally, the sound pressure levels recorded by the Municipality's stationary sound level meters located at three points along the avenue, showed the reduction of environmental sound levels in pedestrian areas, improving the acoustic quality of the walk. In this paper, sound pressure levels on Saturday afternoons at different times of the year before, during and after the initial lockdown due to the COVID-19 pandemic, are compared and discussed.

Session: Poster Q&A Session 3

Poster Session

8:00 AM 05-Aug-2021 **IN21_1416.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1416

Optimum tuning of multiple piezoelectric patches shunted with series LR-negative capacitance circuits for broadband vibration control

Feng Li, Xiuchang Huang, zhiwei Zheng, Zhiwei Su, Hongxing Hua

To control the resonant response of multiple low order flexural modes of thin panel, multiple shunted piezoelectric patches are bonded on the structures, each is shunted with series LR-negative capacitances circuits and tuned to control the resonant response of one of these modes. A tuning strategy is proposed to obtain the optimal RL parameters based on the maximization of the time-averaged electric power dissipated by each shunt for a given negative capacitance. It is shown that the proposed approach is effective in controlling the broadband responses of the panel at low order flexural modes and minimizing the coupling between multiple modes and patches.

8:00 AM 05-Aug-2021 **IN21_1440.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1440

Effect of different magnets and iron-platelets on the low frequency performance of membrane sound absorber

Junjuan Zhao, Liying Zhu, Xinyun Li, Yueyue Wang, Wenjiang Wang, Xianhui Li, Yunan Liu

To achieve a compact design for low frequency tunable sound absorption, a membrane sound absorber (MSA) with nonlinear magnetic field is proposed in this paper. By employing a central iron platelet on the membrane, the MSA can be easily tuned by introducing a magnet at a distance from the platelet that can be adjusted. To investigate the low frequency properties of MSA with different magnets and iron-platelets, a series of impedance tube experiments are conducted in detail. The sample absorber has a rear cavity depth of 30 mm, three different magnets were used inside, tested results real that using a strong magnetic field can help broaden the frequency tuning range. Then, results from the MSA with five different sizes of iron plates tuned by one magnet show that the low-frequency tuning range moves to lower with the increase of the area of iron plates.

8:00 AM 05-Aug-2021 **IN21_1474.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1474

Influence of the acoustic structures placement on the measurements in a reverberation room

Yueyue Wang, Xianhui Li, Junjuan Zhao, Xingyun Li, Liying Zhu, Wenjiang Wang

Absorption coefficient is a signification index of acoustic structures, which is useful to determine acoustic treatment with a good sound-absorbing characteristic. To make the sound absorption of acoustic structures measured in a reverberation room more closely approximates the sound absorption that would be performed under the applicational condition, this paper studies the influence of different placements on the measurements in the reverberation room. In this paper, the absorption coefficients of micro-perforated membrane and micro-perforated stretch ceiling space sound absorbers are measured, which are placing in the middle of the reverberation room, close to the side walls of the reverberation room and in the corner of the reverberation room respectively. The experiments show that different placements of acoustic material in reverberation room have obvious effect on sound absorption above the 500Hz. It is more efficient to place materials in the middle of the reverberation room, while the absorption of being close to the side walls or in the corner of the reverberation room weakens. The results were agreed with the measurement of micro-perforated stretch ceiling space sound absorbers. It is useful to optimize the arrangement of acoustic materials and structures in controlling the building and rooms noise.

8:00 AM 05-Aug-2021 **IN21_1954.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1954

Development of Dash insulation with PU elastomer based sound insulation materials for increasing the sound insulation performances of electric vehicle noise derived from motor

Minji Yu, Jang-Seok Park

At present, fuel efficiency improvement technologies for example weight, engine efficiency improvement, design modification, and eco-friendly car are being proceed due to the tightened international regulations. Therefore, production of eco-friendly cars specially electric car has increased. Due to that, the main noise source has changed from engine to motor noise and road noise as it has been changed from engine cars that have led engine technology to eco-friendly cars. As the noise source has changed, it is necessary to manufacture sound

absorption/insulation structure for the noise characteristics generated by electric vehicles. In this work, the elastomer sheet was applied to the Dash outer as automotive terior parts for reducing engine noise. We applied the elastomer sheets for generation Dash outer layers (nonwooven/PU foam/nonwooven) to improve sound insulation properties. The elastomer sheet showed surface wetting between PU foam and elastomer sheets by optical microscopy. The acoustic properties were measured by APAMAT-II and BUCK tests.

8:00 AM 05-Aug-2021 **IN21_2689.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2689

Intelligibility of bone-conducted speech detected on the scalp

Satoshi Nanri, Taishi Shinobu, Sho Otsuka, Seiji Nakagawa

Bone-conduction microphones (BCMs) can detect speakers' voices with high signal-to-noise ratio even under extremely noisy environments like a machine factory or an engine room of a watercraft. BCMs are ordinarily attached to the front of the neck (larynx), therefore, it is sometimes accompanied by discomfort and esthetic problems. In order to solve such problems, we have been developing a novel BCM system built in a helmet, however, characteristics of bone-conducted speech detected on the scalp need to be clarified. In this study, mono-syllable articulations of bone-conducted speech detected at several locations on the head and neck were measured. Also, the speech transmission index (STI), objective measure of signal transmission quality, was calculated. The results indicated that the forehead and the vertex showed better articulation and STI than the mastoid process of the temporal bone, the mandibular condyle, and the occiput. In terms of the gender difference, the forehead and the vertex showed higher scores for the male voice, whereas the cheek showed the highest for the female voice. Additionally, the larynx showed lower scores than others. These results indicated that the attenuation of high-frequency components are smaller at the forehead and the vertex.

8:00 AM 05-Aug-2021 **IN21_1626.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1626

Underwater acoustic communication using nonlinear frequency modulation waveform with low side-lobe characteristics

Jeongha An, Hyoungin Ra, Changhyun Youn, Kiman Kim

In fluctuating underwater acoustic (UWA) communication, reducing the interference caused by multi-path propagation is important to get better performance. For this reason, Chirp Spread Spectrum (CSS), which has insensitive Doppler effect and having effective bandwidth, using Linear Frequency Modulation (LFM) waveform was used in UWA communication before. But LFM waveform has high auto-correlation function sidelobes it becomes interference and gets worse performance in reverberation environment.
This presentation proposes an UWA communication using Generalized Sinusoidal Frequency Modulation (GSFM) waveform which is generalized form of sinusoidal FM. GSFM waveform usually attains much higher spectral efficiency and lower peak-to-average power ratio than LFM while maintaining same bandwidth and pulse duration. GSFM waveform has various types and we use two GSFM pulses that is a Forward type in time-frequency domain and a time reversing type of Forward type in this presentation. Each type represents binary values '0' and '1', respectively. Each of pulses occupy same band of frequency and each of GSFM pulses have nearly orthogonality. Simulation results in various underwater channel environments with noise will be presented. A Bellhop-based underwater channel model is used for simulation. The proposed method will be analyzed compared to the conventional CSS method with LFM waveform.

8:00 AM 05-Aug-2021 **IN21_2737.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2737

Underwater Acoustic Target Recognition Based on Generative Adversarial Network Data Augmentation

Minghong Zhang, Xinwei Luo

Underwater acoustic target recognition is an important aspect of underwater acoustic research. In recent years, machine learning has been developed continuously, which is widely and effectively applied in underwater acoustic target recognition. In order to acquire good recognition results and reduce the problem of overfitting, Adequate data sets are essential. However, underwater acoustic samples are relatively rare, which has a certain impact on recognition accuracy.
In this paper, in addition of the traditional audio data augmentation method, a new method of data augmentation using generative adversarial network is proposed, which uses generator and discriminator to learn the characteristics of underwater acoustic samples, so as to generate reliable underwater acoustic signals to expand the training data set. The expanded data set is input into the deep neural network, and the transfer learning method is applied to further reduce the impact caused by small samples by fixing part of the pre-trained parameters. The experimental results show that the recognition result of this method is better than the general underwater acoustic recognition method, and the effectiveness of this method is verified.

8:00 AM 05-Aug-2021 **IN21_1902.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1902

Study on acoustic environment of canteens in South China University of Technology

Ziyu Zhou, Hongwei Wang

In order to understand the characteristics of the acoustic environment of University canteens, the canteens of South China University of Technology were selected as the research objects, and the acoustic parameters were measured on the spot and the questionnaire survey was conducted. The results show that the average sound pressure level of restaurants with smaller area is lower than that of restaurants with larger area, and the sound pressure level of dining space first increases rapidly, then increases slowly, and finally remains unchanged with the increase of the number of diners. In the aspect of restaurant acoustic environment satisfaction evaluation, the space with the smallest dining area has the highest acoustic environment satisfaction evaluation level, and the collision sound of tableware collection and table and chair moving has the highest correlation with the acoustic environment satisfaction evaluation. In terms of different types of noise sources, diners think that the

most disturbing noise for conversation is the voice of the surrounding people, followed by the collision of tables and chairs and the collection of tableware, and the least disturbing noise is the noise of air conditioning and kitchen equipment.

8:00 AM 05-Aug-2021 **IN21_1956.pdf** **DOI:** https://doi.org/10.3397/IN-2021-1956

Investigating acoustics and wave behaviour in cross-laminated timber panels

Chiaki Fenemore, Yi Yang, Michael Kingan, Brian Mace

Cross-laminated timber (CLT) is a timber product that is becoming increasingly popular in construction in NZ because of the ability to prefabricate panels off-site, as well as being lightweight and sustainable compared to other building materials. There is currently a lack of information on its acoustical properties, as the complex geometry through the thickness means it is difficult to model and predict sound transmission. The WFE (wave and finite element) method has been employed as it allows for a small segment of a material to be modelled using standard FE methods and can incorporate several material layers. It then requires finding the mass and stiffness matrices of the segment and post-processing them to determine the wave behaviour of the structure as a whole. The WFE method was used to model the sound transmission of several different CLT panels and these results were compared against measurements taken by the National Research Council Canada. In-house testing was also performed to obtain experimental wavenumbers, and these were also compared to wavenumbers produced by the WFE method.

8:00 AM 05-Aug-2021 **IN21_2039.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2039

Design and simulation of acoustics for the home theatre

Liying Zhu, Junjuan Zhao, Xianhui Li, Bin Zhang, Yueyue Wang, Wenjiang Wang, Yunan Liu

As a typical acoustics room, the sound quality of home theatre is an important standard to evaluate its design. Qualified acoustics design is the guarantee of good sound quality. The volume of home theatre is generally small, so the room size is similar to the low-frequency wavelength. Then the resonance will occur when the excitation of the sound source frequency acts on the natural resonance frequency of the room. At the same time, the secondary reflection of the room also interferes the direct sound emitted by the speaker, thus destroying the sound image. In order to solve the above problems, this paper took a home theatre as an example, analyzed the normal modes of the room by the theory of wave acoustics, and then made an acoustics design and simulation. The simulation results showed that the reverberation time was up to the relevant standards and the room acoustic quality environment was improved obviously after the acoustic design.

8:00 AM 05-Aug-2021 **IN21_2978.pdf** **DOI:** https://doi.org/10.3397/IN-2021-2978

Prediction and analysis of 220kV substation based on geometric acoustic simulation

Longxiang Zhang, Peng Chen, Haitao Sun

With the continuous improvement of people's living standards, the city has gradually formed a residential community with high residential density. In order to meet the power demand of the community, each new community basically needs to establish a supporting indoor substation according to the power load of the residents. Considering the residents' electricity habits, the electricity room of the supporting substation in the residential area works 24 hours a day, resulting in frequent noise nuisance incidents. Therefore, the detailed analysis of the indoor noise distribution and the radiated noise from the envelope surface of the substation has a positive significance for the reasonable control of substation noise. In this paper, the method of combining indoor and outdoor simulation is used to predict the 220 kV indoor substation noise. The indoor noise is simulated by Odeon software, and the outdoor noise is simulated by Cadna / a software, the two kinds of software are also based on the virtual sound source and sound ray tracking method of geometric acoustics. Firstly, the noise spectrum of each wall is calculated by Odeon software, and then the noise spectrum is interpolated and attenuated according to the sound insulation spectrum of the composite wall. The calculated spectrum is used as the plane source intensity for noise prediction in Cadna / a software, and finally the noise value of sensitive points at the boundary of substation can be predicted.

8:00 AM 05-Aug-2021 **IN21_3004.pdf** **DOI:** https://doi.org/10.3397/IN-2021-3004

Study on Sound Insulation Performance of Pressure Relief Wall of Transformer Chamber

Fabing Rong, Zhongjie Cheng, Peijie Liu

The problem of noise nuisance in indoor substation becomes more and more sensitive. The noise emission index of substation has become an important technical index of substation design. The noise control of indoor substation mainly adopts "auxiliary noise reduction technology" such as sound absorption, sound insulation and vibration isolation. The sound insulation performance of the pressure relief wall in the main transformer room of indoor substation is the key link of noise control. In order to reduce the noise interference, this paper selects the common sound insulation structure of the pressure relief wall, analyzes the main influencing factors of noise reduction, selects the sound insulation structure suitable for the pressure relief wall in the main transformer room of indoor substation, and tests the effectiveness of noise reduction of the sound insulation structure in the actual case. Based on the research results, the sound absorption structure in the main transformer room is arranged on the other indoor wall outside the pressure relief wall, and the pressure relief wall mainly considers the structure of sound insulation, which can effectively reduce the noise impact of the main transformer room.

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Noise impact assessment of onshore and offshore wind turbine

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Because of climate change and environmentally friendly energy policy in Korea, the demand for a new renewable energy development has been increased. Especially, the onshore and offshore wind turbines have played an important role in the power system for generating eco

friendly energy. However, in the stage of constructing and operating the onshore and offshore wind turbines, the aerodynamic and underwater noise effect on human and marine life becomes a prominent figure on a social issue, and it is necessary to prepare the assessment method of these noise impacts in order to prevent the influences on human and marine life in advance. Therefore, this paper is focused on suggesting the evaluation plans of the noise effect from the onshore and offshore wind turbines.

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Abnormal drone noise detection system based on the microphone array and self-supervised learning

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The drone noise mainly comes from its rotating blades, providing plentiful information of the status of the drone. In the production line, the abnormal sound detection system has the advantages of no contact and simple deployment and can help to locate the fault products at relatively low costs. Therefore, this paper develops an abnormal drone noise detection system based on the microphone array and self-supervised learning. The microphone array is a part of the data acquisition module to pick up the drone noise. There are eight microphones in the array, forming four differential microphone pairs. Each of them is pointing to a blade of the drone. A four-channel noise sample is recorded and then analyzed. It is worth noting that drone noise samples are extremely unbalanced, because abnormal samples are difficult to encounter. Hence, a self-supervised learning strategy is adopted by creating auxiliary classification tasks to fine tune representations of the normal drone noise samples. With the consideration of low-complexity, the trained neural network models can be finally deployed even on a Raspberry Pi system with no graphic cards.

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Subjective evaluation of the combining effect between the virtual bass and head related transfer functions

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Earphones are commonly equipped with miniature loudspeaker units, which cannot transmit enough power of low-frequency sound. Meanwhile, there is often only one loudspeaker unit employed on each side of the earphone, whereby the multi-channel spatial audio processing cannot be applied. Therefore, the combined usage of the virtual bass (VB) and head-related transfer functions (HRTFs) is necessary for an immersive listening experience with earphones. However, the combining effect of the VB and HRTFs has not been comprehensively reported. The VB is developed based on the missing fundamental effect, providing that the presence of harmonics can be perceived as their fundamental frequency, even if the fundamental frequency is not presented. HRTFs describe the transmission process of a sound propagating from the sound source to human ears. Monaural audio processed by a pair of HRTFs can be perceived by the listener as a sound source located in the direction associated with the HRTFs. This paper carries out subjective listening tests and their results reveal that the harmonics required by the VB should be generated in the same direction as the high-frequency sound. The bass quality is rarely distorted by the presence of HRTFs, but the localization accuracy is occasionally degraded by the VB.

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On the performance sound design of a stringed instrument by the control of the stiffness and mass of the component part

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This study investigates the difference of performance sounds of an electric guitar with a metal pickguard. The sounds of the open strings of the guitar are measured, showing that the damping time becomes shorter than that obtained with a commonly used plastic pickguard. Further, it was also found that the sounds of the 1 and 2 strings were distinct and those of the other strings were slightly suppressed when the metal pickguard was used. Therefore, the metal pickguard is effective in making sharp, clear, and distinct sounds. We changed the material of the pickguard from plastic to copper. In the experiments, simultaneous measurements of the vibrational acceleration of the peg, pickguard, and output voltage of the guitar with a constant plucking force of the strings were performed. It was found that the profile of the RMS value of the vibrational acceleration of the pickguard changed when the copper pickguard was used. Moreover, the vibrational modes of copper the pickguard were different than the others. In conclusion, it was determined that the sound quality is affected by the vibrational characteristics; thus, it can be adjusted by varying the means by which the pickguard is attached to the guitar body.

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Effects of degree of consonance and temporal pattern of the auditory signals on the auditory impression of warning

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Disaster alerts are usually accompanied by auditory signals at the beginning. It is to be desired that the auditory signal itself produces the sense of warning. Effects of (1) degree of consonance and (2) temporal pattern of the auditory signal on the auditory impression of warning were investigated using paired-comparison tests. In the both tests, sequences of 3 triads were used as stimuli. First, 7 types of stimuli were generated by varying the degree of consonance of the triad (frequency ratio of sinusoids was varied systematically from 2:3:4, 4:5:6, 6:7:8, 8:9:10, 10:11:12, 12:13:14 through to 14:15:16). Each subject showed changes of the auditory impression of warning depending on the degree of consonance, however, variation among subjects were observed. Second, 21 types of stimuli were generated in total by changing several temporal parameters (duration of the triad, interval between the triads, duty rate of the sequence). The results indicated that the auditory impression of warning increased as the duration of the triad increased the interval between the triads decreased.