Vol 38 No 4 July/August 2013

# ACOUSTICS BULLETIN


*in this issue…* **Measuring up: the new Jaguar F-type roars in at Acoustics 2013**

*plus…* How Marcos scooped the young person's award

Launch of IOA Good Practice Guide on wind turbine noise assessment

How spherical loudspeakers came into auralisation

Institute of **Acoustics**

## Contacts

**Editor:**
Charles Ellis

**Contributions, letters and information on new products to:**
Charles Ellis, Editor,
Institute of Acoustics,
3rd Floor St Peter's House,
45-49 Victoria Street, St Albans,
Hertfordshire, AL1 3WZ
tel: 01727 848195
e-mail: charles.ellis@ioa.org.uk

**Advertising:**
Enquiries to Dennis Baylis MIOA,
Peypouquet, 32320 Montesquiou, France
tel: 00 33 (0)5 62 70 99 25
e-mail: dennis.baylis@ioa.org.uk

**Published and produced by:**
The Institute of Acoustics,
3rd Floor St Peter's House,
45-49 Victoria Street, St Albans.

**Design and artwork by:**
oneagency.co London
81 Rivington Street
London, EC2A 3AY
e-mail: london@oneagency.co
web site: www.oneagency.co

**Printed by:**
Newnorth Print
College Street
Kempston
Bedford MK42 8NA



Annual subscription (6 issues) £120.00
Single copy £20.00



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**Front cover photograph:**
James Flitton of Campbell Associates (left) checks the sound of the new Jaguar F-type with Ashley Gillibrand of Jaguar Land Rover.

Institute of **Acoustics**

The Institute of Acoustics is the UK's professional body for those working in acoustics, noise and vibration. It was formed in 1974 from the amalgamation of the Acoustics Group of the Institute of Physics and the British Acoustical Society. The Institute of Acoustics is a nominated body of the Engineering Council, offering registration at Chartered and Incorporated Engineer levels.

The Institute has over 3000 members working in a diverse range of research, educational, governmental and industrial organisations. This multidisciplinary culture provides a productive environment for cross-fertilisation of ideas and initiatives. The range of interests of members within the world of acoustics is equally wide, embracing such aspects as aerodynamics, architectural acoustics, building acoustics, electroacoustics, engineering dynamics, noise and vibration, hearing, speech, physical acoustics, underwater acoustics, together with a variety of environmental aspects. The Institute is a Registered Charity no. 267026.

## Conference programme 2013

**2 July 2013**
Organised by the Musical Acoustics Group
**Acoustic challenges in quires and places where they sing**
*London*

**17 September 2013**
Organised by the Welsh Branch
**Noise management in Wales: an update**
*Cardiff*

**25 September 2013**
Organised by London Branch
**Uncertainty in the measurement, prediction and assessment of noise**
*London*

**29 October 2013**
Organised by the Environmental Noise Group
**The Wilson Report – 50 years on**
*London*

**12-14 November 2013**
Organised by the Electro-acoustics Group
**Reproduced Sound 2013**
Manchester

Please refer to **www.ioa.org.uk** for up-to-date information.

Dear Members

You will see in this Bulletin that in May the Institute published its *Good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise.* As I mentioned in my previous letter, its production for the Department of Energy and Climate Change has proved a somewhat controversial issue, with both members and non-members expressing unhappiness at the IOA's role and the GPG's content. Some members consider that by producing it the Institute has (wrongly in their opinion) "endorsed" ETSU, while others believe that the IOA should have addressed the issue of noise limits and are not happy with certain technical aspects of the document.

The Institute's remit, and the purpose of the document, is purely to provide a guide to technical matters relating to the application of the ETSU method. It was never intended that it should be a review of all issues relating to wind turbine noise such as its effects, or that it should investigate the correctness of the noise limits themselves. The Institute was asked by DECC to produce guidance as it has become apparent that the ETSU method is often not used correctly. Council was happy to do this as we have a responsibility to members and to the general public to ensure, if possible, that any standard methods for assessing noise are being correctly applied. It was not within the Institute's remit to challenge the underlying methodology or the noise limits of the existing ETSU method. However, we will keep our position regarding ETSU under review. Thanks are due to all those, both inside and outside the Institute, who responded to the consultation on the draft guidance. Richard Perkins, chairman of the working group which produced the GPG, will be writing to DECC to give them a summary of the consultation responses, which are available on the IOA website.

Wind farms are a comparatively new source of noise in this country. They were not included – or even, I think, imagined – as being a potential problem by the Wilson Committee whose report is 50 years old this year. As the article by Adam Lawrence explains, the main source of noise annoyance in the countryside in 1963 was the lawnmower, with chain saws and bird scarers also mentioned as causing problems. Revisiting the committee's report, it is amazing to see how comprehensive and detailed it is, covering all types of environmental, occupational, transportation and building noise, and how many of its recommendations are now accepted practice. It is also interesting to note, particularly when considering just how many topics were covered, that it was produced in under three years!

In May we also held the spring conference. It was good to see so many members there, representing all our different specialist groups. Delegates seemed to enjoy the fact that it was a multi-group meeting, although inevitably as always happens with multiple session meetings, the two papers that you really want to hear are always timetabled at the same time. There has been a lot of discussion recently about whether we should have full written papers, or whether, as often happens these days, delegates should just receive copies of the Powerpoint presentations. This meeting showed the importance of having full papers so that, if a presentation is missed, it is possible to read the written paper in the proceedings.

One of the great pleasures of being President is going to our conferences and meeting both old friends and new members. For new members particularly, it can be rather daunting to go to a conference and encounter a host of unfamiliar names and faces. So I would be really pleased if new members, and any of you I haven't met before, come and introduce yourselves. And can I ask other delegates to always look out for people who are on their own or seem a bit lost, and make a point of talking to them.

Bridget

Bridget Shield, President

# Delegates flock to Acoustics 2013 in Nottingham

## Seven parallel sessions marks new first for IOA

The Institute of Acoustics broke new ground in May when it held its first conference at the East Midlands Conference Centre, Nottingham. One hundred and sixty-eight delegates attended the event, which, in another first, featured seven parallel sessions.

After welcoming delegates, President Bridget Shield presented veteran IOA member Bob Peters with the RWB Stephens Medal in recognition of his outstanding contribution to research and education in a career that has spanned the best part of half a century.

Bob then entertained delegates by recapping some of the highlights of those 50 years in his medal lecture entitled Education Education Education – Acoustics Acoustics Acoustics. A full report of the award appears on page 16.

Below are summaries of the seven sessions provided by the organisers.

### Building Acoustics

***By Roger Kelly***

*'Zip-A-Dee-Doo-Dah Zip-A-Dee-Yeh My Oh My What A Wonderful Day'*

Well this was a truly surprising and wonderful day. From whether a cuckoo could constitute a noise nuisance from two miles away to the acoustic analysis of Kelvin's living room in Bridgend – and a lot of other stuff in between – I thoroughly enjoyed the day and was in full support of a one-day meeting with all the groups. The diversity and general buzz of the day was super enjoyable and I learned a lot to boot.

Anyway down to business:

After the very entertaining lecture by Bob Peters we began in the session with Stuart Colam (FISH Innovation) who talked about a new natural ventilation product called SoundScoop which uses a combination of porous and Helmholtz absorption to reduce sound between two spaces. The particular focus in this paper was on reducing low frequency noise from busy urban environments.

Next up was the Bickerdike Allen duo of Thomas Galikowski and David Trew who talked about the highs and lows of domestic sound insulation. Of particular interest to me was finding out about the Housing Health and Safety Rating System Regulations (HHSRS) – a bit of a mouthful I know. This was compared with the Occupant Equivalent Rating (OER) system, which was based on 800 interviews and measurements over a wide range of dwellings – it states that if the $D_{nT,w}$ is less than 44dB between two dwellings, then this would be deemed to be intolerable. However, there were several cases shown where the HHSRS would say that no improvement measure was required for $D_{nT,w}$ of less than 44dB.

Jack Harvie-Clark's (Apex Acoustics) first appearance of the day looked at the practical application of G and C50 in classrooms. He demonstrated that reverberation time is not a good way to assess whether a classroom has good acoustics or not and suggested a measurement method of G and C50 that could be used to analyse classroom acoustics.

After coffee the ever-reliable Andrew Parkin (Cundall Acoustics) gave a case study of wobbly washing machines in a lightweight timber residential building. Even though the building passed the requirements of the building regulations, the vibration and noise caused by the washing machines were completely unacceptable to the occupants. The paper explored the different techniques used to reduce vibration; which included stiffening of the structure, and installing basic inertia bases to improve the situation.

The last two papers before afternoon tea, by Nick Conlan (URS) and Jack Harvie-Clark, were about naturally ventilated dwellings. We well know how hard it is to provide sufficient ventilation in accordance with Approved Document F without letting too much noise in. More and more dwellings are now being ventilated by mechanical means, but this creates noise problems in itself. It was really useful to understand all the factors at play and what acousticians need to be addressing to get the right balance of ventilation and acoustics.

Raf Orlowski (Ramboll) kicked off after tea with a look at four interesting case studies of refurbished buildings for the performing arts. I particularly enjoyed learning about Wilton's Music Hall which is a Grade II listed building in London and is the oldest operational music hall in Europe. I think I'll be making a visit.

Elena Prokofieva (Edinburgh Napier University) then talked about new products for the building regulations – for me the interesting part was finding out how the regulations for noise and thermal requirements vary between England, Scotland and Wales.

Last up was Patrick Macey (PACSYS) who has developed a new method for fast acoustic analysis of rooms with constant height. He amusingly used his friend Kelvin's living room in Bridgend as the sample room for measurements. Whilst interesting, this method needs to be developed before it can become a useful tool for designers on the front line.

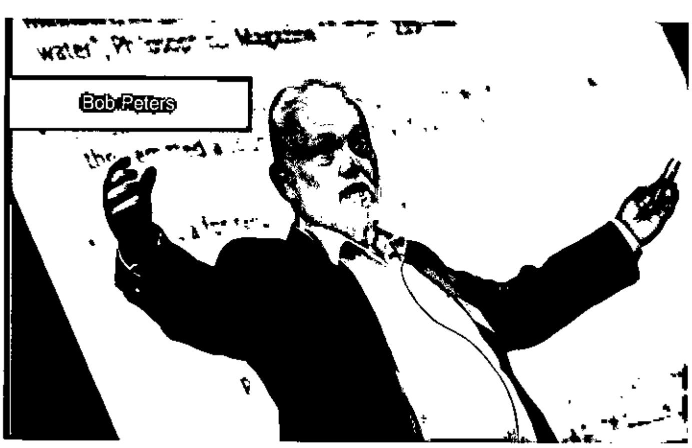
And that was that. It was a thoroughly "wonderful day" and I was encouraged and excited to see the number of people at the conference. More of these meetings please!!

### Environmental Noise

***By Steve Mitchell***

About 60 delegates joined the environmental noise session, which was chaired by Steve Mitchell, in the main conference room.

Professor Greg Watts (University of Bradford) gave the first paper on quantifying tranquillity with reference to the National Planning Policy Framework. Greg explained there is good evidence of the health benefits of tranquil and natural environments. He summarised field research that allows a tranquillity rating to be





Delegates discuss a point

given for many situations that showed good correlation to subjective scoring. This led to the possibility of assessing impacts on tranquillity from new projects, and even before and after tranquillity contours.

John Fisk and Fred Lemieux (Temple Group) explained how entire noise assessments could be managed within a project GIS, giving live examples of the tools that can be used on very large scale studies.

Jon Tofts (Environment Agency) described three cases of low frequency noise complaints that the agency had investigated, all from regulated industries. He explained how low frequency noise can be difficult to investigate and analysis of synchronised noise logging inside and outside a complainant's house can be invaluable.

Nicole Porter (Anderson Acoustics) presented some alternative noise contours for Heathrow Airport aimed at giving more information to the community than the conventional $L_{Aeq,\,16\,hr}$. Nicole has used short average levels to show temporal patterns for the varying runway operating modes throughout a typical day at Heathrow, providing clear information on "respite" which research has shown is highly valued by local residents.

Dani Fiumicelli (Temple Group) and Graham Parry (Accon) discussed how noise assessments are reported in Environmental Impact Assessments. Of 500 Environmental Statements (ESs) recorded by IEMA in 2010, 92% included noise assessments. They outlined the three options for assessing noise impact magnitude, benchmarking and relative, and concluded that effect significance can be scaled using any method so long as it is justified for the particular case. A discussion followed debating some of the issues arising, such as how the number of people affected influences significance, and the need to use terminology, such as negligible, minor, moderate and major, to describe significant effects in a way that is consistent with other environmental topics in the ES.

Jian Kang (University of Sheffield) reported the results of laboratory research into the absorption and scattering coefficients for soil and planted vegetation. He showed that planted vegetation can give varying results, and bare soil was a relatively good absorber irrespective of depths above 20mm, provided water content was not high.

Colin Cobbing (ARM Acoustics) explained that WHO guidelines are essentially values for the onset of health effects, but this does not mean there is an effect immediately they are exceeded; in fact the vast majority of people would not be affected. He reminded us that WHO guidelines do not attempt to set standards, and standards must take into account all local factors. In the UK the Noise Insulation Regulations for railways can be used as the Significant Observable Adverse Effects Level (SOAEL).

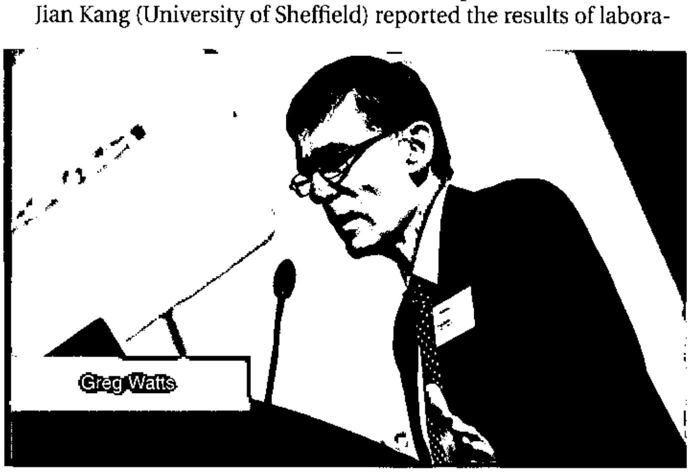
Paul Lepper (Loughborough University) stepped out from chairing the parallel underwater noise session to give an interesting insight into the current state of the art of assessing underwater noise effects on mammals, fish and other marine dwellers. He explained how modelling propagation is challenging, and how dose-response relationships for some receivers is sparse, but assessments have been required in EU waters since 2010, and the science is developing.

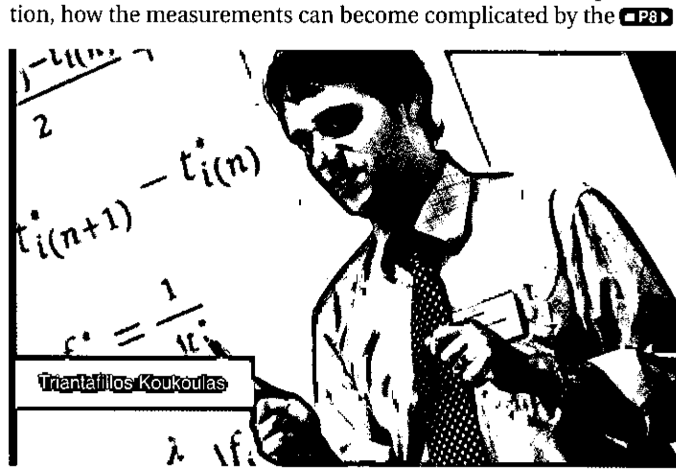
## Measurement and Instrumentation

***By Triantafillos Koukoulas***

The session was chaired by Triantafillos Koukoulas from the National Physical Laboratory (NPL).

The first paper of the session, *The influence of the acousto-optic effect on LDV measurements of underwater transducer vibration and resultant field predictions,* was presented by Professor Victor Humphrey (ISVR). He explained how use of a scanning laser Doppler vibrometer (LDV) has the potential to be a fast, non-invasive method for both source characterisation and field prediction, how the measurements can become complicated by the P8


Greg Watts


Triantafillos Koukoulas

P7 acousto-optic effect and how alternative measurement configurations can reduce its effect.

The next two papers were from NPL. Triantafillos Koukoulas presented on *Particle velocity and pressure measurements of underwater sound using laser Doppler anemometry*, explaining how optical heterodyne interferometry can be used to measure particle velocities (and hence pressure) due to propagating underwater sound over a wide frequency range. Ben Piper presented on *Advances in the free-field measurement of acoustic particle velocity using gated photon spectroscopy*, outlining how this optical technique can be used to measure particle velocities in free-field conditions and how the mean flow can be decoupled from the acoustic velocities under investigation.

After lunch, Mike Hutley (consultant, retired) gave an interesting practical presentation on *Stroboscopic contour prediction* using fringe projection for musical instruments. Mike outlined a simple optical mechanism where fringes produced by a suitable grating can be projected onto the surface of musical instruments and can provide visual information of the phase difference between wavefronts.

Ian Strath (LMS International) then presented on *Sound brush technique for 3D visualisation of complex stationary sound fields* in which he explained the principle behind the operation of the device in terms of requiring a 3D sound intensity probe with measurement microphones and a position and orientation tracking system. On-line 3D visualisation of the sound field is produced as the operator moves the device and is applicable to noise emission studies amongst others.

The following two presentations were from Silixa, with Veronique Mahue introducing *Characterisation of intelligent distributed acoustic sensor in comparison with vibroacoustic sensors*, followed by Daniel Finfer on *A demonstration 1D waveguide for the intelligent distributed acoustic sensor*. These presentations demonstrated use of a distributed acoustic sensor technology to measure acoustic fields at points along the length of an optical fibre. Examples included, amongst others, a waveguide approach via use of a PVC tube wrapped with fibre optic cable, with the waveguide excited by injecting air bubbles at the bottom of the tube, leading to measurement of bubble size distribution as well as the ability to monitor changes in the fluid properties.

The session concluded with a research paper from Antoni Torras-Rosell (Danish Fundamental Metrology / Technical University of Denmark) on *The versatility of the acousto-optic measuring principle in characterising sound fields*. Antoni presented three different acoustic applications based on the acousto-optic in airborne acoustics – visualisation of sound based on acousto-optic tomography; the localisation of noise sources employing an acousto-optic beam-former and the identification of acoustic sources using nearfield acousto-optic tomography.

## Musical Acoustics

***By David Sharp***

The musical acoustics session was chaired by David Sharp and provided an excellent overview of the musical acoustics research currently being carried out in the UK.

First, Gerry Swallowe (Loughborough University) reported on *Studies with a small gamelan gong*. He described the Indonesian gamelan orchestra and presented images of the vibrational modes of a gamelan gong measured using both Electronic Speckle Pattern Interferometry and Scanning Laser Doppler Vibrometry. The measured mode shapes agreed well with those predicted by a Finite Element Model of the gong. Further studies on other gamelan gongs are planned.

Shahab Faiz Minhas (University of Manchester) then presented *Supervised signal processing for separation and independent gain control of different percussion instruments using a limited number of microphones*. He introduced a novel methodology for separating the sounds produced by different percussion instruments using the signals recorded by just a small number of microphones. This allows individual drum sounds to be amplified, without altering the sounds produced by the other instruments. Audio examples demonstrated the effectiveness of the approach.

Next, David Sharp (Open University) presented *The Mari-Cha lion – did it once roar?* in which he described the physical make-up of a medieval bronze lion statue and reported historical evidence which suggests that it may once have made a roaring sound. David speculated on the different mechanisms by which this may have occurred and presented measurements of the resonances of the surviving lion structure.

The issue of *Pitch drift in a capella choral singing* was then discussed by Richard Seaton (Open University). He described a pilot survey of choral conductors which provided a number of suggestions as to why choirs singing without instrumental accompaniment are often prone to going flat or sharp. A national survey is now planned, along with carefully designed experimentation involving several choirs.

Ian Perry (Cardiff University) kicked off a sequence of talks concentrating on string instruments by discussing his work on the *Radiation efficiency and radiativity sound fields of classical guitars*. He compared measurements of the radiation efficiencies and radiativity fields of three guitars as functions of frequency. All three P10

Delegates absorb a point

◂P8▪ instruments were shown to have improved radiation efficiency between 200 Hz and 500 Hz and between 1 kHz and 1.3 kHz. However, the two higher quality guitars exhibited noticeably greater radiation efficiency between 200 Hz and 500 Hz than that measured for a lower quality guitar.

William Roberts (Cardiff University) continued by presenting work on *Perceptual thresholds for string-body coupling in guitars.* Using theory developed by Colin Gough for a string mode coupled to a body mode, he showed how the coupled mode frequencies and Q values are perturbed as the string-body coupling is increased. He then described a listening test designed to establish the smallest perceivable perturbations in the frequencies and Q values of the fundamental of a synthesized guitar note, and used the results to plot a coupling threshold curve.

The guitar discussions were brought to an end by Bernard Richardson (Cardiff University) who gave a presentation on *Mode placement in guitars revisited* where he used a three mass model to investigate the effect that altering the back plate tuning has on the mode frequencies, Q values and peak heights of the resonance triplet in the input admittance curve. He commented that peak heights are more important than their frequency placements, and that the global qualities of the instrument are much greater influenced by mode effective masses and mode radiativities.

Colin Gough (University of Birmingham) then presented a *Generic shell model for the violin family* where he described how, by treating the violin as a thin walled guitar-shaped box with arched plates and creating a Finite Element Model, the effect of varying the material properties and coupling strengths over a wide range of values could be investigated. Colin presented results which provide increased understanding of how the modes of the assembled instrument are related to the free plate modes, and of the way that the individual component parts couple together to give the characteristic acoustic properties of the complete violin.

The string instrument discussions were brought to an end with *From electric to acoustic violin: digital synthesis and emulation,* given by Patrick Gaydecki (University of Manchester). He described a system, based on DSP technology, which processes the raw electrical output from an electric violin to produce an output signal which closely approximates the timbre of an acoustic violin. The device holds in memory up to fifty impulse responses of real instruments which the user can select from.

The musical acoustics session concluded with three wind instrument talks. Paulina Kowal (Open University) started these by reporting on her work on *Analysing differences between the input impedances of five clarinets of different makes.* She discussed impedance measurements made on five clarinets over the whole playing range of the instrument and then presented several variations of a graphical method for analysing the differences between the magnitudes and frequencies of the peaks across the large number of impedance curves generated.

Mike Hutley (consultant) then presented *A detailed study of single reeds for early and folk instruments* in which he described a simplified reed/pipe system designed to allow precise control of all relevant parameters. He presented measurements which highlighted the transition from "quasi-free reed" to "beating reed" behaviour and he discussed folk instruments with single reeds which appear to operate in different ways depending on the pitch of note being produced.

Finally, Alan Woolley (University of Edinburgh) brought proceedings to a close with *A review of the pipe organ related research carried out at the University of Edinburgh over the past ten years.* In particular, he described an investigation into the extent to which players can influence transients by altering how they press the keys of mechanical action organs, concluding that the design of the action prevents transient control except with extreme variations of key movement.

## Noise and Vibration Engineering

***By Stephen Walsh***

Nine papers were presented during this session, which was chaired by Dr Stephen Walsh. Five papers considered different aspects of automotive noise, vibration and harshness (NVH); one paper discussed the effects of vibration in cycling equipment; two papers investigated railway vibration; and the final paper outlined an approach to vibration damping using acoustic black holes.

The morning session opened with a paper presented by Gaurav Kumar (LMS International) entitled *Examining the NVH challenges posed by hybrid and electric vehicles.* The presentation outlined the main sources of noise and vibration in vehicles with electrified powertrains and gave details of an NVH simulation applied to a switched reluctance motor. Audio playback of the synthesised sound of the motor provided a good insight into the final product sound.

This was followed by Ashley Gillibrand (Jaguar Land Rover) whose paper *Engineering the sound of the Jaguar F-Type* illustrated the importance of the engine sound in communicating the character of a Jaguar. The presentation explained how the sound required from the new V6 engine for the F-Type was designed and validated using a driving simulator and how key decisions on hardware design can influence the character of the sound. Ashley had arranged for a Jaguar F-Type to be on display at the conference. This car was launched in April 2013 and has received many outstanding reviews in the motoring press.

This theme was continued by Andrew Wolfindale (Jaguar Land Rover) who presented the next paper, entitled *Exhaust sound quality tuning – the influence of vehicle cabin acoustic transfer* P12▸


Delegates network

A visitor to the LMS SoundBrush stand

◀P10 *functions in the exhaust development process.* In this presentation it was explained how the interior sound of the vehicle is the product of both the sound from the vehicle exhaust and the exhaust transfer function to the vehicle interior, in particular, the balancing required to achieve an optimal sound for the driver whilst not introducing unpleasant sound for the rear seat passengers.

The afternoon session opened with a paper presented by Jordan Cheer (University of Southampton) entitled *Design and implementation of a directive sound field for an electric car warning sound.* Electric cars are quieter than conventional cars and for electric vehicles travelling below 20 mph, where tyre noise is low, there is a need for additional warning sounds. This presentation explained the modelling and construction of a low-cost 'end-fire' array designed to produce a directed sound field in front of the vehicle.

Stephen Walsh (Loughborough University) concluded the vehicle NVH theme with a paper entitled *Prediction and measurement of air intake system noise in a turbocharged petrol engine during surge event.* The presentation focused on modelling the sound of a downsized turbocharged petrol engine during sudden transient manoeuvres. Co-author Ajith Pai was also in attendance and contributed to the following technical discussion.

The next paper entitled *Vibration in cycling equipment and the effects on the cyclist* was presented by Eugenie Sainte Cluque (Clement Acoustics). The author presented an analysis of measured vibration signals from a bicycle on different road surfaces and outlined the complexity of interactions of varying factors, such as speed, road roughness and body position, in obtaining a comprehensive understanding of the resulting whole-body vibration.

The first of two papers on railway vibration was presented by Dimitrios Kostovasilis (University of Nottingham) and entitled *The effect of curvature on the dynamic behaviour of railway tracks.* The author presented modelling results for the dynamics of a curved track, in particular, the forces transmitted to the track bed. The second paper on railway vibration was presented by his colleague Samuel Koroma (University of Nottingham) and entitled *The effects of railpad nonlinearity on the dynamic behaviour of railway tracks.* Modelling results for both linear and nonlinear railpads were presented and compared.

Victor Krylov (Loughborough University) gave the closing paper entitled *Acoustic black holes: a new approach to vibration damping in light-weight structures.* The author presented a review of the theory of acoustic black holes and reported on recent experimental investigations on a variety of beam-like and plate-like structures containing one- and two-dimensional acoustic black holes.

## Speech and Hearing
***By Gordon Hunter***

The sessions attracted papers on a wide variety of topics, ranging from speech perception intelligibility to ear canal modelling and signal processing.

Nick Durup (Sharps Redmore Acoustics and London South Bank University) presented a paper based on his PhD project on links between vocal stress experienced by primary school teachers and poor acoustics in the school teaching rooms. He noted that teachers spend a much higher proportion of their working day actually speaking than was the case with most other workers, and that around 73,000 teaching days were lost across the UK each year due to teachers' voice problems, causing them health concerns and costing the taxpayer an annual sum estimated at £15 million. His work aims to measure acoustic parameters such a reverberation times and SPL for classrooms in schools of various different ages and designs, both during classes and when the rooms are empty, with a view to correlating these factors to the vocal problems experienced by each school's teachers.

Iain Paterson-Stephens (University of Nottingham) presented work on speech intelligibility for both native and non-native English speakers in teaching rooms at the university. He noted that a much higher proportion of UK university students now were second language English speakers than was the case, say, 20 years ago, and that what constituted "adequate" intelligibility conditions for such students might be different from that for native speakers. He described measurements of reverberation time, and speech transmission index (STI) at many different listening points in each of a variety of different types of classroom, ranging from large lecture theatres to small tutorial rooms. He also outlined subjective listening test experiments on word identification tasks under "good" to "poor" listening conditions for both first (L1) and second (L2) language English speakers. He concluded that STI was a good predictor of performance for L1 speakers, but poor for L2 speakers. The latter group showed large error rates when listening in poor conditions.

Christian Füllgrabe (MRC Institute of Hearing Research) described experiments studying speech perception in noise by "normal" hearing individuals of various ages. The experiments included both a "cross sectional" study, where each individual took part on one occasion, and a "longitudinal study", where each participant was assessed several times over a period of years. He concluded that correct recognition of speech in noise declined as people aged, which co-occurred with deterioration of both physiological auditory processing and general cognitive function.

John Braiden (Braiden Acoustics) outlined work modelling the human ear canal, with a view to improving the design of hearing aids and ear plug and other hearing protectors. This was based on measurements made from moulds taken from real bodies of people of a variety of ages. A "two port" mathematical model of sound transmission through the canal, treating it as complex impedance, was used and the results from this compared with data from pressure measurements in artificial ear canals made from the moulds taken of real ears. The canals tested were categorised on the basis of length and curvature, using a "mixture of Gaussians" approach to clustering. Future work would focus on incorporating leakage, bone conduction and shear compliance of the canal into the model, possibly using a finite element approach.

Alan Boyd (University of Strathclyde and MRC Institute of Hearing Research) described studies using information on head movements to increase the accuracy in computational auditory scene analysis. This is an issue for listeners with hearing aids and/or cochlear implants. Use of Fourier analysis combined with lagged correlation between the signals at each ear could provide information concerning the direction of the sound source. This could be combined with measurements from head-mounted accelerometers, magnetometers and a gyroscope in order to give accurate data of the orientation of the listener's head. The results showed that use of a microphone array on the user's head could resolve confusions regarding the location of a sound source, particularly in relation to whether it was in front of or behind the listener.

Noushin Karimian (University of Manchester) presented some novel signal processing approaches, based in Least Mean Square and Kalman filters, to echo cancellation in order to improve the quality and intelligibility of speech signals. A combination of these methods gave good perceptual quality whilst keeping computational time and resource requirements within acceptable levels.

The sessions concluded with a talk by Gordon Hunter (Kingston University) on using the sounds produced by honeybees to predict the absence of a queen in a hive and hence decide if intervention were needed. Anecdotal evidence from beekeepers had suggested that audible differences could be detected between the sound of ▶

Christian Füllgrabe

a "queenright" and "queenless" hive, and the presentation described how spectrographic and pattern recognition techniques had been applied to this problem, with some promising results.

Following the conclusion there was a tour of the facilities of the MRC Institute of Hearing Research, including its anechoic chamber and apparatus for monitoring brain waves (using EEG) produced when listening to speech stimuli.

## Underwater Acoustics

***By Ed Harland and Paul Lepper***

A series of strong underwater acoustics session were run throughout the day organised by Peter Dobbins, with almost all the papers related to the topic of underwater noise particularly in context of the developing offshore renewable energy industry.

The first session, chaired by Paul Lepper, had presentations from Paul Barker (Loughborough University), Patrick Macey (PACSYS) and Michael Wood (ISVR, University of Southampton. Leading off, Paul Barker talked about developments in detection and assessment of metrics for measurement of high amplitude impulses related to marine piling events and its context in the automated impact assessment systems. This was followed by Patrick Macey's presentation on finite element modelling analysis of ground roll waves or "interface travelling wave" seen in the seabed produced by high energy piling events relating the pile vibrational and generated seabed vibrational modes. This analysis allowing comparison of modelled with measured data from a real pile. Michael Wood then gave a presentation of modelling of marine piling events using a wave equation analysis techniques allowing inclusion of energy lost in pile penetration into sediment and relationship to residual energy in the water column. Using the wave equation analysis technique improved accuracy in the consideration of sediment influence in the motional to acoustic energy transfer models was achieved.

After coffee the piling theme was continued with a presentation by Karl-Heinz Elmer (Offnoise-Solutions Gmbh) in a session chaired by Ed Harland and Philippe Blondel. Karl presented work on technical innovations to offer cheap and easily deployable solutions to the problem of reducing underwater noise levels from offshore piling. The new method using Hydro Sound Dampers (HSD) is cheaper, easier to deploy and has demonstrated an overall reduction of 16 dB in radiated noise. Ed Harland (Chickerell BioAcoustics) then presented a method of portraying the variability of the sound field around renewables that would be easier to understand by non-expert users compared with mean spectra or percentile plots. The method is based on the spectral probability density and can convey information on variability and data quality in a single plot. Finally, the session was ended with a presentation by Philippe Blondel (University of Bath) on the exciting work carried out to acquire long-term measurements of marine activities, both biological and debris, around a renewable energy system using a multi-beam sonar. This presentation described an instrumentation package utilising multi-beam and imaging sonars to study the environment close to a tidal turbine. The data is combined with non-acoustic data from a variety of sensors to study how the turbine may impact the environment. The unit has been deployed once at the EMEC Fall of Warness test site with further deployments planned for this summer.


Michael Woods

# Launch of IOA Good Practice Guide on wind turbine noise assessment

*By Richard Perkins, Chairman of IOA wind turbine working group*

The long-awaited *A Good Practice Guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise* was officially launched at a one-day meeting, the eighth in a series of IOA events on the subject, in Bristol in May. The guide is published at:
**http://www.ioa.org.uk/pdf/ioa-gpg-on-wtna-issue-01-05-2013.pdf**

The full capacity meeting was opened by Richard Perkins, Chairman of the working group appointed by IOA Council to produce the guide. His opening was followed by a warm welcome from Bridget Shield, IOA President. Bridget explained how pleased Council was with its publication, its production in record time, and to a very high standard. She thanked the working group, all the peer reviewers, and the contributors to the various workshops and the consultation exercise. She also reminded delegates that the work did not consider the noise limits within the ETSU-R-97 document, and it did not confirm or otherwise the IOA's position in relation to those limits; those would be discussed further by Council at a later date.

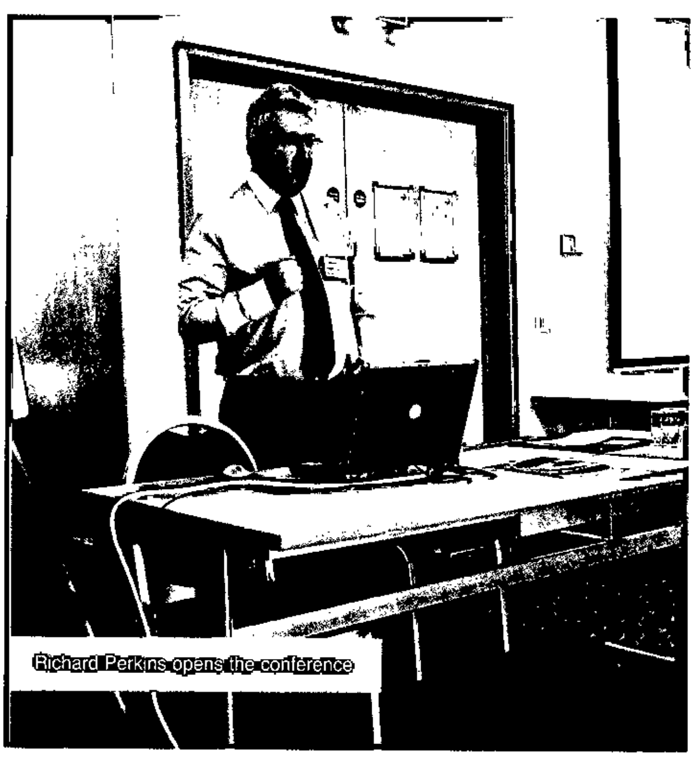
The technical papers began with an introduction to the whole process from Richard Perkins, who also edited the guide. He explained that the work began with an invitation from the Department of Energy and Climate Change (DECC) to the IOA to take forward the recommendations of the report *Analysis of How Noise Impacts are considered in the Determination of Wind Farm Planning Applications* Ref HM: 2293/R1 dated 6 April 2011. The IOA agreed terms of reference for the work with DECC, which did not include looking at the limits. He noted that there had been two peer reviews and a consultation in summer 2012, to which 56 detailed responses had been received.

Richard then introduced the guide and detailed how it was intended to be used. He explained the key topics in section 1, which include an overview of the ETSU-R-97 methodology in written and flow chart form, and the need for consultation and engagement. He noted that this was an IOA document approved by Council for use by its members and other interested parties, but that any further endorsement would be considered by Government. [At the time of writing, the guide has already been endorsed by Government in England and Wales, and a response from Scotland and Northern Ireland is expected shortly]. He then introduced his colleagues on the working group who proceeded to talk through the rest of the guide.

Robert (Bob) Davis took delegates through section 2, which covers the collection of noise, wind and rain data. All of these are not as straightforward as they may first appear, and care must be taken in choosing the equipment, placing it correctly to minimise uncertainties, and ensuring the correct settings are used in a time synchronised manner to obtain a robust dataset. Bob explained the many aspects of data collection covered in the guide that all have the potential to invalidate a survey, if not considered and carried out correctly. He also highlighted some common misconceptions, such as the need to measure wind speed at the turbine location (as it represents the turbine noise), and why an enhanced wind shield should be used to minimise effects from turbulence on the microphone.

Malcolm Hayes then explained the difficult topic of data analysis and wind shear. He explained how to remove data from the dataset that is affected by rain, and atypical events such as the dawn chorus. The remaining dataset should be sufficiently robust once the data has been removed on which to derive a best fit curve relating wind speed to background noise from which the limits are derived. Malcolm then explained why wind shear is an important issue and must be taken into account.

Matthew Cand introduced the section on noise propagation from wind turbines, a topic on which ETSU-R-97 is silent. He explained how current good practice uses ISO9613-2 as the method of choice, but also that the appropriate input parameters must be used otherwise there is a potential to underestimate the noise from the turbines. The correct input parameters will provide realistic predictions that are sufficiently robust. ▶


Richard Perkins opens the conference


Matthew Cand explains noise propagation

Matthew also explained that there was a variety of different sound power data in existence, and how to interpret the information appropriately to ensure sufficient allowance for uncertainty has been included.

The increasing common problem of dealing with cumulative impacts was dealt with by Chris Jordan. As more and more sites are developed, the chances that an adjacent site contributing to noise levels in the area are higher. ETSU-R-97 is very explicit that the background noise should not include an existing wind farm noise, which presents problems in establishing the current background. Chris explained a number of ways that the background could be derived in a variety of situations, and how the noise limits can be shared between the various wind farm sites. He stressed that in no circumstances could the cumulative noise from wind farms exceed the ETSU-R-97 limits at any time.

Richard Perkins then returned to explain why only a sample planning condition was included in the guide, which should only be used with legal assistance, and why the working group had stopped short of providing prescriptive guidance on how to write reports. He explained why there would soon be six supplementary guidance notes to accompany the guide, and that they would contain some expanded commentary on points made in the guide, and some good and bad practice examples to further understanding.

Richard then went on to explain several notable omissions from the guide, such as low frequency noise, amplitude modulation, uncertainty analysis, and the noise limits. He stated that whilst the working group were confident that the guide was a significant step forward, a number of other aspects, such as AM, were still to be resolved, and that the door was still open to consider "new" good practice in the future.

Dani Fiumicelli, a member of the peer review group, then gave his opinion on whether the terms of reference had been achieved. He explained why the guide was needed, and concluded that, on the whole, the aim of the work had been achieved. He added that the inability to deal with the issue of "excess amplitude modulation (AM)" was extremely disappointing, but applauded the IOA ownership of the guide, and therefore the ability to react quickly to any significant changes in current good practice. He suggested that a supplementary guidance note to deal with AM would be welcome once a new proposed condition to deal with it has been tried and tested, and the results of the RUK study have been published.

As has become customary at these one-day meetings, an interesting discussion then followed where delegates were able to quiz the working group and other experts on various topics relating to wind farm noise, and a brief discussion on whether the IOA should be lobbying Government on the noise limits. Young members were then able to join the meeting for free to pose their questions to a panel of experts. After closing the meeting, the working group retired to the bar to reflect on a job well done.


The working group (left to right): Bob Davis, Richard Perkins, Malcolm Hayes, Chris Jordan and Matthew Cand

# Bob Peters receives the Institute's RWB Stephens Medal

Bob Peters has been awarded the Institute's RWB Stephens Medal, which is given in alternate years for "outstanding contributions to acoustics research or education". He received the award from the President, Bridget Shield, at Acoustics 2013 in Nottingham. Below is her citation.

Dr Robert Peters, known to everyone as Bob, has been active in research, teaching and consultancy in acoustics for nearly 50 years. It is for his extensive and outstanding work in acoustics education that he has been awarded the RWB Stephens Medal. This award is particularly appropriate as Professor Stephens was Bob's PhD supervisor at Imperial College in the late 1960s; he was also Bob's proposer when he first joined the IOA in 1977, and again when he was elected as a Fellow in 1980.

Bob's early career was spent doing research, first in underwater acoustics at Imperial College (leading to his PhD) and subsequently with CAV (Lucas) Ltd studying diesel engines.

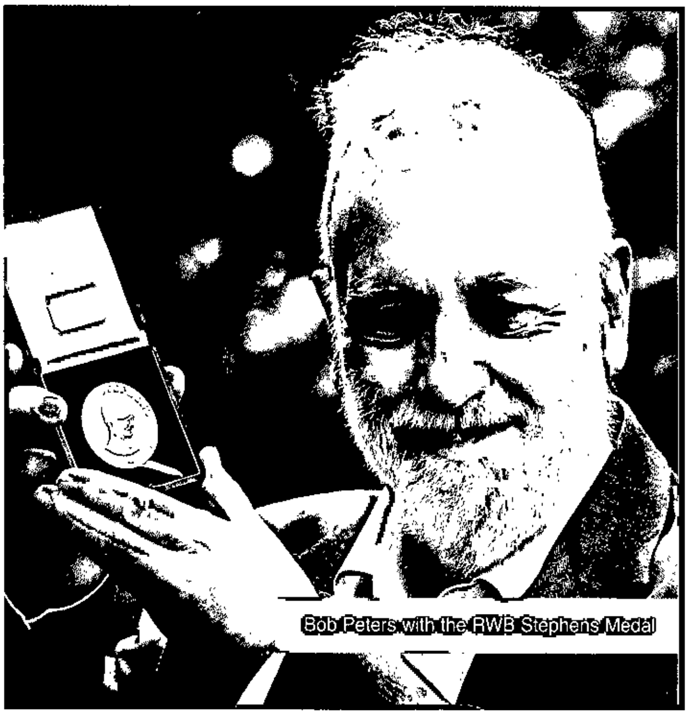
Much of Bob's teaching career was spent at North East Surrey College of Technology (NESCOT) where, among many other responsibilities, he developed short courses in acoustics and noise control and taught on the IOA Diploma and Certificate courses. Bob has also acted as guest lecturer at many other institutions, teaching acoustics to undergraduate and postgraduate students on a range of courses. After retiring from NESCOT in 1997, he embarked on a career in consultancy, while continuing to teach part time at several colleges and universities, and as a tutor on the IOA Diploma distance learning course. He was a leading member of the Diploma revision team, writing the notes for the General Principles of Acoustics and project modules, and has been the project examiner for several years.

Hundreds, if not thousands, of people working in acoustics today will have been taught by Bob at some stage of their career. He is held in high regard and with great affection by past and current students and colleagues. Not only is he recognised as an outstanding teacher, for both his teaching style and extensive knowledge, but he is also extraordinarily generous in the time and support he personally offers to students. Bob has also written influential and popular text books in acoustics. His most well-known book is *Acoustics and Noise Control* (now in its third edition), which was originally designed as a text book to accompany the IOA Diploma course but is also used extensively by students on other courses.

As well as developing and delivering IOA courses, Bob has contributed enormously to the life of the Institute in many other ways over the past 40 years. He has been chair of the Industrial Noise Group, chair of the London branch, chair of the Workplace Noise Certificate Committee and chair of the Education Committee. In these roles he has organised many IOA conferences. He has also been a member of Council and the Vice President for Groups and Branches, and continues to serve as a valued member of Education Committee.

Bob has also played a leading role in developing noise and vibration policy at a national and international level, through membership of various BSI, CIBSE and I-INCE committees.

For his distinguished and dedicated work in acoustics education, through which he has inspired many generations of students, the Institute is delighted to award the RWB Stephens Medal to Dr Robert Peters.



Bob Peters with the RWB Stephens Medal

# Institute sets up task force to encourage sustainable design

IOA Council is supporting a joint proposal by Peter Rogers (The English Cogger LLP) and Richard Cowell (Arup) to explore ways and means for the Institute to encourage sustainable design.

This might include the provision of supporting material, encouraging events to share lessons with members, engaging with the concepts, and removing obstacles to implementation. A key component is stronger connection with other disciplines to encourage holistic design. Work has begun to form a small task force.

Peter said: "No matter whether you are a sceptic or a campaigner, the world is demanding that sustainable design leads on many projects these days.

"We are convinced that acoustics has a lot to offer in helping society to restore a balance, and that the Institute can help members with clear and practical guidance.

"The simple fact is that no matter how modest the design for a project is, it can't be truly sustainable unless it works well for those using it for the duration of its lifespan. It is therefore a challenge to see how, as an industry, we can contribute not just to the debate, but also to action."

The initial objective is to involve all of the specialist groups, look at what additional tools can help acousticians, and identify a number of recommendations. These will be reported to Council for evaluation of an action plan.

The task force is not intended to supplant existing activities in specialist groups, but to look to add more support. It is not permanent and will operate only as long as members find the contribution valuable. Progress will be reported in the Bulletin.

The first meeting is expected to take place in the next two months. If you have any contribution to make, or wish to express an interest to be involved please contact **linda.canty@ioa.org.uk** and she will pass on your contribution to the team.

# Get registered with the Engineering Council

*By Peter Wheeler, IOA Engineering Manager*

The strong level of interest in gaining CEng or IEng status through the Institute seen last year has been maintained since the New Year. Nick Durup, Rick Methold and Mark Scaife have gained CEng registration and Jon Lee has gained IEng registration.

In the last month the Engineering council has held a further series of interview days at IOA HQ. Candidates have to prepare, and substantiate, at a professional review interview with two peer Institute members, an account of their professional development and responsible experience, written in the context of a set of competencies set out by the Engineering Council in UK-SPEC and interpreted by the Institute for their particular field of acoustical engineering.

Other supporting evidence of training and continuing professional development also needs to be provided. You do not need to hold an engineering degree, and our successful registrant members come from many backgrounds. You do need to demonstrate at interview that you have acquired the relevant engineering "learning outcomes" specified in UK-SPEC.

More than 300 of our corporate members hold Engineering Council registration, either through IOA or one of the other engineering institutions. The success rate is close to 100 per cent, thanks in part to the support provided to candidates by the Engineering Division Committee.

We also need help with our committee work, interviews and support to candidates. If you are already registered either through IOA or another institution and would like to play a part in our work please contact us. In either case email us at **acousticsengineering@ioa.org.uk**

Here are profiles of recent candidates:

## Nick Durup

**Sharps Redmore, CEng**


Nick Durup

Nick graduated from Anglia Polytechnic University in 2003 with a BSc in audio and music technology.

He joined Sharps Redmore five years ago and has in that time completed the Institute's Diploma, a MSc in acoustics and won the Newman Award in 2010 for his Master's dissertation. He is currently researching for a PhD at London South Bank University, studying vocal stress in teachers, along with handling an ever-increasing list of clients and consultancy projects.

"I'm very pleased with gaining CEng registration, having been working towards this for a number of years with the regular and valuable guidance of the IOA throughout," he said.

"The process itself is very robust and requires critical consideration of your competencies, skills and professional responsibilities. Holding CEng status is valuable in demonstrating professional competence to clients and colleagues and the widely recognised status of CEng across disciplines reinforces this."

## Jon Lee

**Waterman Group, IEng**


Jon Lee

Jon graduated from University of Salford with a BSc in Audio Technology in 2004. He started his acoustics career at RPS Group specialising in environmental noise and vibration before joining Waterman Energy Environment & Design as an acoustic consultant.

"I initially found the Engineering Council registration documentation quite in depth and difficult to relate specifically to my experience as an acoustic consultant," he said.

"The guidance provided by Peter Wheeler and the supporting documentation available on the IOA website proved very helpful in being able to present a quality case for the technical report route to registration.

"The interview process enabled me to expand on my documentation and explain further technical and commercial aspects of my role to the panel. The registration process as a whole allowed me to develop understanding of my role as a consultant by requiring me to demonstrate specific areas of my capability.

"Dealing more and more with clients and colleagues in the field of engineering, the status of Incorporated Engineer has become important to demonstrate my aptitude and commitment to continuing professional development. I will be on the route to Chartered Engineer very soon following advice from Peter and the Engineering Division interview panel.

"I would highly recommend the IOA registration process to anyone thinking of taking the plunge to Engineering Council registration."

## Mark Scaife

**WSP Middle East, CEng**


Mark Scaife

"As I have a non-accredited degree (audio technology, University of Salford), I followed the individual route to registration," he said "This involved gathering a range of project examples together and annotating them to demonstrate where the various competencies are met. I found it useful to provide covering notes to the technical reports to provide information on some of the commercial aspects of my role that are not necessarily picked up in a consultancy report. The input from Peter Wheeler prior to the interview was also extremely helpful.

"The process of gathering information was useful, as it made me realise that I was taking for granted the value of our role as acoustic engineers and the process we go through every day on every project.

"The interview was a thorough grilling but not in an aggressive way. It covered a wide range of topics including risk, sustainability, health and safety, commercial acumen, business development and technical issues. The questions were asked in an open manner to invite discussion.

"Becoming a Chartered Engineer is becoming increasingly important in the Middle East, with clients demanding senior members of design team not only have relevant experience but are chartered as well.

"Aside from that I am extremely proud that I have been assessed by my peers and that I 'met the grade'. I thoroughly recommend it."

# TV sound system for hard of hearing scoops young person's award

A researcher who is developing a loudspeaker system to help people with hearing problems listen to television without affecting the sound for other viewers has won the 2013 Institute of Acoustics' Young Person's Award for Innovation in Acoustical Engineering.

Marcos Simón has devised an array-based system which produces a sound 'hot spot' by boosting the audio signal in the area of a room where a hearing impaired person is sitting but maintaining the same audio levels elsewhere.

His prize is a weekend for two in Paris and £500, donated by the award sponsor, IAC Acoustics, a global leader in noise control. He will also receive a silver trophy.

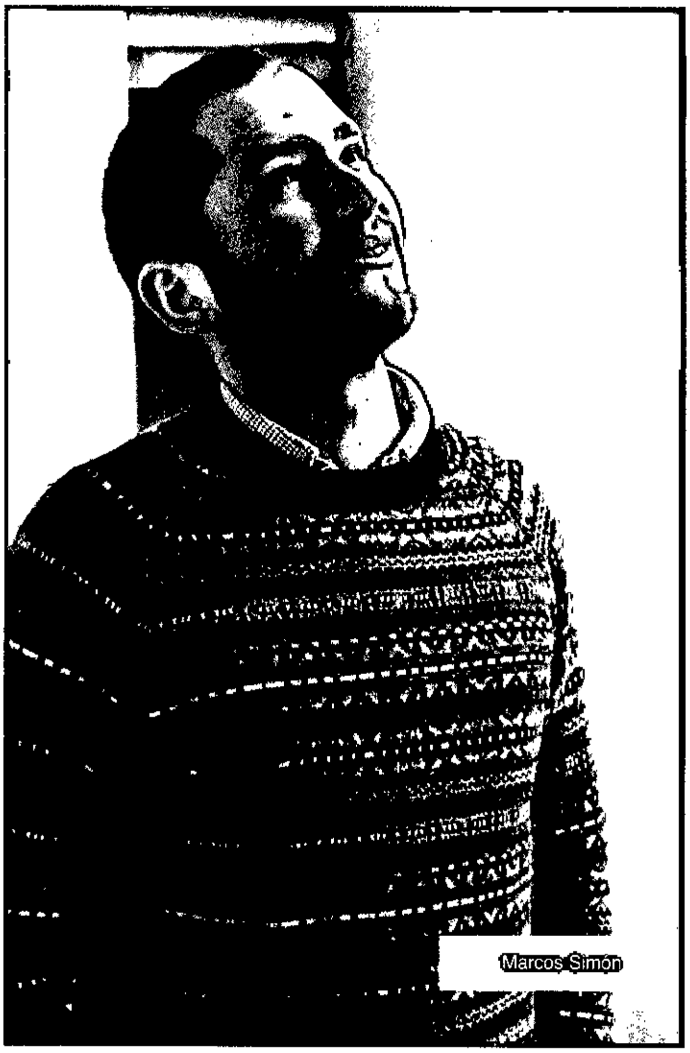
Marcos, aged 24, a PhD researcher at the Institute of Sound and Vibration Research at the University of Southampton, said: "It's estimated that disputes over TV volume affect one in 10 households, and these are often caused by some family members having age-related hearing loss.

"Because only about 20 per cent of such people wear hearing aids, the only way to resolve this problem is to improve the level of sound for them without annoying other viewers in the household with normal hearing who don't want to be subjected to a loud volume."

Marcos's array design, which comprises eight phase shift sources, is based on the degree of hearing impairment and its frequency range for a 70-year-old woman, so that a boost of about 10 dB was required between 500 HZ and 8 kHz.

He is now producing an improved version for testing this summer. "A lot of work still needs to be done, but my hope is that one day it will go into production so it becomes available for households where such problems exist."

Bridget Shield, IOA President, said: "Many congratulations to Marcos. Members of the Institute have always been at the forefront of ground-breaking innovation in acoustics, and this project is an outstanding example of a young person using his skills to devise a system that has the potential to bring widespread benefit."



Marcos Simón

Calum Forsyth, IAC Acoustics Chief Executive, added: "A worthy winner of this prestigious award. Marcos has done a fantastic job in using his theoretical knowledge and creativity to address a real issue for so many households. As an organisation, IAC Acoustics encourages young talent in the industry to bring theories to life and create the best possible solutions to unwanted noise."

For full details of Marcos's entry, see page 42.

# Vibration from transport and industry

## Eastern Branch meeting

*Report by Martin Jones*

In what was the first meeting on vibration for some considerable time, the branch welcomed Roger Kelly, Managing Director of CDM (UK), to the Quality Hotel, Colchester in May.

The talk covered the principles of building vibration and both prestigious and problematic schemes upon which CDM has been involved. Roger gave an entertaining talk and conveyed the highly interesting information in a lively way which was enjoyable to listen to. This was far from a "we sell this and we sell that" presentation; it was a real insight into the challenges, besides the obvious ones, of floating an entire building.

The talk gave us all information into the methods for isolating buildings and the history of doing so. One of the most informative parts of the session was where Roger went through examples of projects and showed great examples and in situ photos of the treatments in place and how they are installed.

A large section of the presentation was a discussion on the trouble shooting of a number of schemes which hadn't gone as planned. This was of particular interest as we were all in agreement that substantially more is learnt from a challenging situation than 100 "run of the mill" successes.

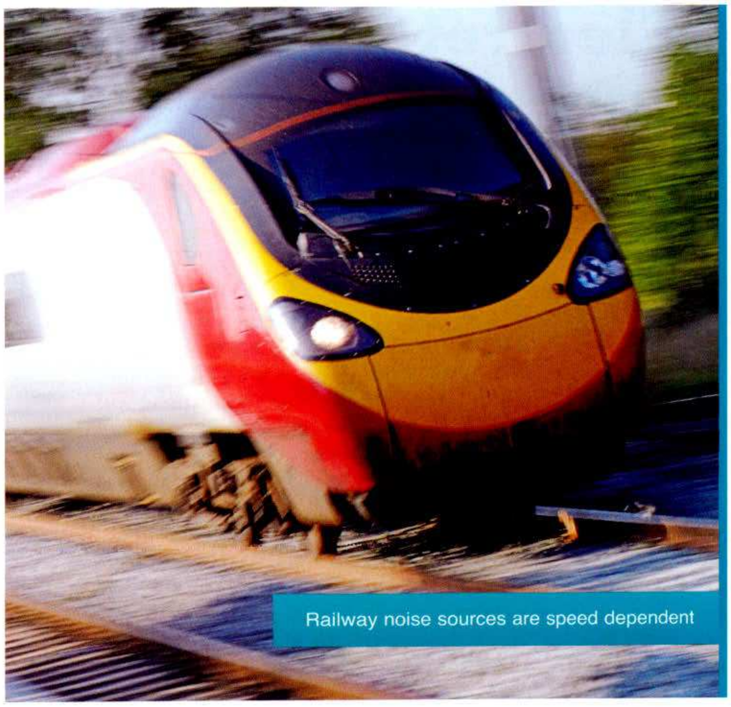
A key point raised during the presentation was how the consultant's role is often limited and the initial planning advice in terms of vibration measurements obtained and the conclusion that floating the building is necessary is often the sole extent of a consultant's involvement in a project.

Roger showed through his project examples that such a limited involvement could lead to both design problems and issues in installation and also missed opportunities for quite significant cost savings where newly constructed foundation conditions change the vibration input to the building in comparison with the initial survey data. Roger was very much an advocate, as am I, for having the acoustic consultant's input placed in higher regard and the consultant retained into the construction phase.

# Railway noise – get it right first time

## London Branch meeting

*Report by Nicky Shiers*




Brian Hemsworth, internationally renowned expert in the field of railway noise and consulting, guided a packed audience through the most fundamental principles and issues in this subject area. With over 40 years' experience, Brian discussed many different aspects, including the fundamental sources of railway noise, modelling and prediction techniques, legislation, and noise control.

Noise sources were found to be speed dependent. It was explained that at high speeds aerodynamic noise dominates, but at mid speeds rolling noise is prevalent. Other lesser sources include the power equipment at the front of the train and overhead connection noise. Brian explained that much research has been carried out into the reduction of rolling noise, which is caused by a combination of wheel, sleeper and rail vibration. A number of ways to reduce this type of noise have been identified, including the use of disc braked or composition tread braked wheels instead of the rougher cast iron tread braked wheels and also routine track grinding to reduce rail roughness.

Brian went on to examine prediction techniques and explained that accurate prediction of railway noise is extremely complex. Unlike road noise, where a combination of car and HGV movements are considered, the types of train rolling stock in existence are many and varied. In the cases of long term projects the type of train to be used may not have even been built, and assumptions have to be made. Where areas of multiple tracks exist, accurate modelling becomes even more complex.

Legislation relating to railway noise was the next topic discussed. It was explained that it was only with the prospect of the Channel Tunnel and the proposed construction of a high speed rail link to London that the Mitchell Committee was tasked with recommending Noise Insulation Regulations (NIR) for Rail, which led to the 1996 publication of NIR for Railways and also CRN. Brian explained that this applied to new, additional and altered railways. However, only moving trains are considered in relation to residential buildings within 300 metres, with station activity, shunting trains, perceptible vibration and ground borne noise outside the scope of the regulations. Brian continued by discussing the 2002 Environmental Noise Directive and Environmental Regulations (England) 2006, whose aim is to map sources of noise including the railways.

Noise control was the final presentation topic. Brian explained that it was ineffective and not commercially viable to reduce train speed, but that the key to success is in the understanding of the level of noise; how it is produced; identifying the controlling parameters; and building an accurate model based on this understanding. Options such as rail dampers, wheel tuned absorbers and the use of barriers and vehicle mounted shrouds were all considered.

The branch committee would like to thank Brian for an interesting presentation and WSP for its continued support in hosting the London Branch evening meetings.

# Midlands Branch meetings

*Reports by Kevin Howell*

### An introduction to environmental vibration

The branch took the opportunity to hold its May meeting on the evening of the IOA spring conference at the same venue at the University of Nottingham. There was a near record attendance for the meeting, resulting in a slightly delayed start as everyone moved to a larger room. The topic for the evening was *An Introduction to Environmental Vibration*, presented by Jorge de Avillez of URS.

Many acousticians deal with vibration projects infrequently and often find them less straightforward than dealing with sound. Jorge began by considering the differences between assessing sound and vibration. He then described the various tools and processes available for measuring and analysing vibration, and then went on to outline the relevant aspects of a vibration project that determine which measurement systems and analysis processes should be used. Using real field data, Jorge contrasted the different assessment methods and demonstrated the significance of choosing the right or wrong procedure. Jorge's presentation was illustrated with many clever power-point images.

After Jorge's presentation he was joined by a number of vibration experts for a Q&A session. The panel was: David Waddington (University of Salford); Chris Jones (URS); Rupert Thornley-Taylor (Rupert Taylor); Mohammed Hussein (University of Nottingham); Colin Cobbing (ARM Acoustics) and Jorge himself. There were a number of detailed questions resulting in equally detailed responses.

Many thanks go to Jorge and the distinguished expert panel, to the conference attendees who stayed on for this presentation and to the many Midlands Branch members who joined them. Thank you also to Linda Canty and IOA HQ for arranging and funding the room. The meeting was followed by a record attendance of 20 for an excellent curry.

### Railway noise – get it right first time

The branch's April meeting was held at the University of Derby where Brian Hemsworth made his presentation to a large audience. Brian described the noise prediction process for new railway lines and the mitigation measures available when predicted noise levels are too high. The presentation was similar to that given by him to London Branch in March, which is reported above. Many thanks go to Brian and to Derby University.

# Electret microphones in the field; care and the effects of the environment and damage

*By Dave Robinson of Cirrus Research*

In the last issue, effects of specific physical damage to a microphone capsule were presented where it was seen that capsules can carry on performing surprisingly well despite near complete destruction of the membrane. In this article, we consider the effect of the measurement environment itself upon the immediate performance of a pre-polarised electret condenser microphone, as typically used on the vast majority of sound level metering equipment.

## Environmental effects on capsule performance

### Barometric pressure

The small fluctuations expected by standard atmospheric pressures have minimal effect; Zuckerwar[1] reports 0.001dB/mbar changes to be typical for a 1-inch capsule. If the capsule were to be used in near-vacuum environments, the matter changes entirely; damping reduces significantly and the resonant frequency shifts, giving a very peaky response. Fortunately, such effects are only to be seen well below 100mbar; clearly, nowhere on Earth's surface presents a concern!

### Humidity

Historically, humidity presented a major concern to the measurement microphone before the advent of the electret condenser. An increase in humidity within the membrane-backplate gap increases the conductivity of the air and thus the chances of arcing between the 200V polarised backplate and the membrane. With a pre-polarised electret capsule, humidity has very little effect. Strictly, the density of air changes with humidity, thus affecting the compliance (damping) of the backplate-membrane air layer and of the back chamber. This would allow for higher maximum deflections around resonance and alter the resonant frequency, but this change is very negligible. Certainly, from a measurement perspective, the effects are so far within stipulated measurement uncertainty tolerances that humidity is relatively ignorable. The only concern for an operator of an SLM is that the dew point has not been reached; condensation on the membrane would increase the moving mass and, as the membrane mass is extremely small (less than 2mg), quite drastically affect the measurements; typically the response will drop overall and even more so at higher frequencies.

### Temperature

Capsules are supplied as being capable of measurements within standard atmospheric conditions; operation to the required tolerances within the temperature range -10°C to 50°C is stipulated by the standard for working microphones EN 61094-4:1995. Interestingly, by careful use of similar materials within manufacture, the design of the condenser microphone is reasonably resilient to drastic fluctuations in response and sensitivity due to temperature. Increasing temperature decreases the tension in the membrane by an increase in ductility, which would lead to a higher maximum displacement and consequentially a higher sensitivity. However, this is partly counteracted by the thermal expansion of the ring to which the membrane is attached. In fact, thermal expansion of all the capsule components causes the backplate/membrane air gap distance to increase, thus reducing sensitivity and part-compensating the change in tension. As with changes in humidity, the viscous damping of the backplate/membrane gap is also affected due to the change in air density with temperature.

Using newly-developed equipment, which is the focus of upcoming publication from research at Cirrus, measurements of the change in the frequency response of a MK224 microphone capsule have been made recently; here presented in figure 1.

Temperatures experienced at standard atmospheric P22

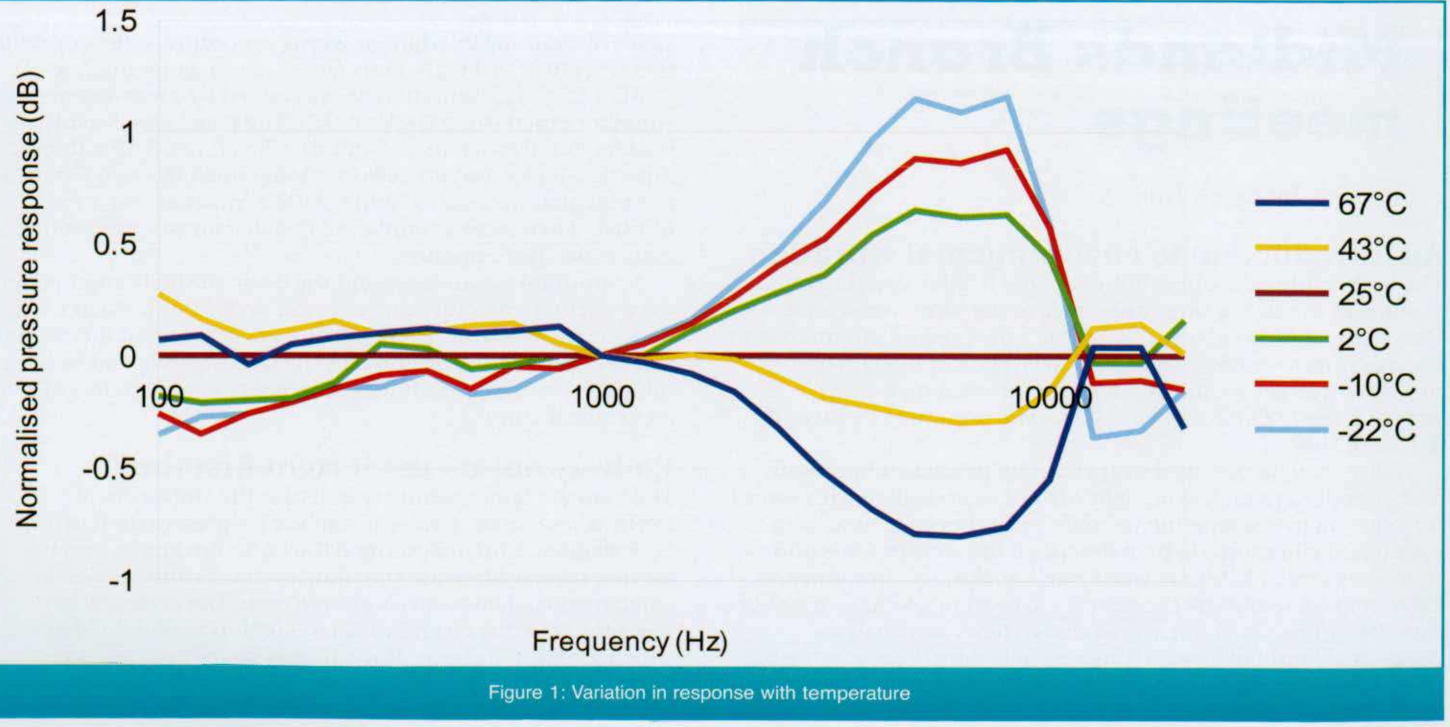



Figure 1: Variation in response with temperature

◂P20 conditions can therefore contribute to a measurement difference of over 1dB at high frequencies. While this is one of the major components of uncertainty, it is allowed for by the IEC measurement standard, and is unlikely to push the boundary of even Class 1 metering.

**Effect of temperature cycling on capsules**

Within this same document, it is stated that "*Large or rapid temperature changes (temperature shock) can lead to a permanent change of microphone sensitivity*". Despite this, recent investigations at Cirrus have indicated capsules to be considerably resilient to such conditions. Figure 2 is of a capsule that was cycled repeatedly from -20°C to 65°C as quickly as equipment would allow (approximately ten minutes) over a period of one week, removed for testing at daily intervals.

Whilst a very slight change could be suggested, the sensitivity would appear to have increased, which could be explained by a slight loss of membrane tension. This is far within the uncertainty of the measurement system used to perform the tests and a conclusion as such would be unfounded. Future testing is intended to incorporate far more rapid temperature changes to ascertain the limits at which permanent damage occurs.

In very extreme cases very high temperatures can completely destroy a polarised microphone capsule. Temperatures reaching 100°C cause the charge upon the electret to begin to dissipate at an increasing rate until 170°C where the charge will be entirely lost. Partial loss of charge (which occurs naturally at ambient levels as the capsule ages) results in a drop in sensitivity without a huge effect upon the characteristic frequency response, which can be compensated for by the standard calibration of a SLM, but near-to-complete loss of charge renders a capsule due for replacement. This worst case appears highly unlikely, but considering industrial processes that are likely to be in operation in areas requiring noise level assessment, exposure to such high temperatures is not impossible. It is also important to consider that sources of some infra-red radiation, such as that from heat lamps, are able to heat metals to very high temperatures from a fair distance. This effect was also investigated within the recent work, as shown in figure 3.

It is interesting that the frequency response flattened as the capsule underwent the tests; the response was originally poor (hence choosing this capsule for such testing!). Such effects would be typical of an upward change in diaphragm tension. Strikingly,

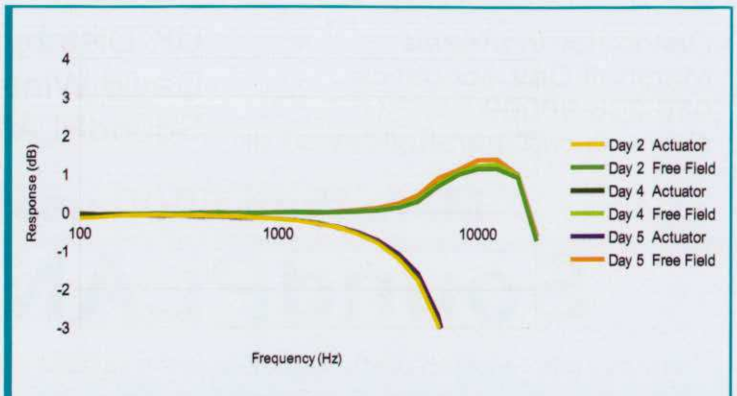



Figure 2: Temperature shock testing of an MK224 microphone capsule – measured on an electrostatic actuator microphone measurement system

the capsule stood up to higher temperatures than were expected before charge was completely lost, and would have been able to make valid measurements even after the 180°C bake.

## Conclusions

Environmental effects are a major cause for the levels of uncertainty in SLM measurements made to IEC 61072-1:2003. Fortunately, for the user of metering equipment all such effects are taken into account by equipment design. Most effects of the environment can be discounted, but temperature certainly plays a part in the care of a capsule to ensure maximum product life. By the temperature tests performed, it is fair to say that the MK224 microphone capsule is resilient against quite rapid changes in temperature. While the very high temperatures required to destroy a capsule in a matter of minutes are highly unlikely, users need to remember that a capsule's sensitivity will decay at an increasing rate with any increase in temperature, so remember; we cook expensive electret microphone capsules so you don't have to...!

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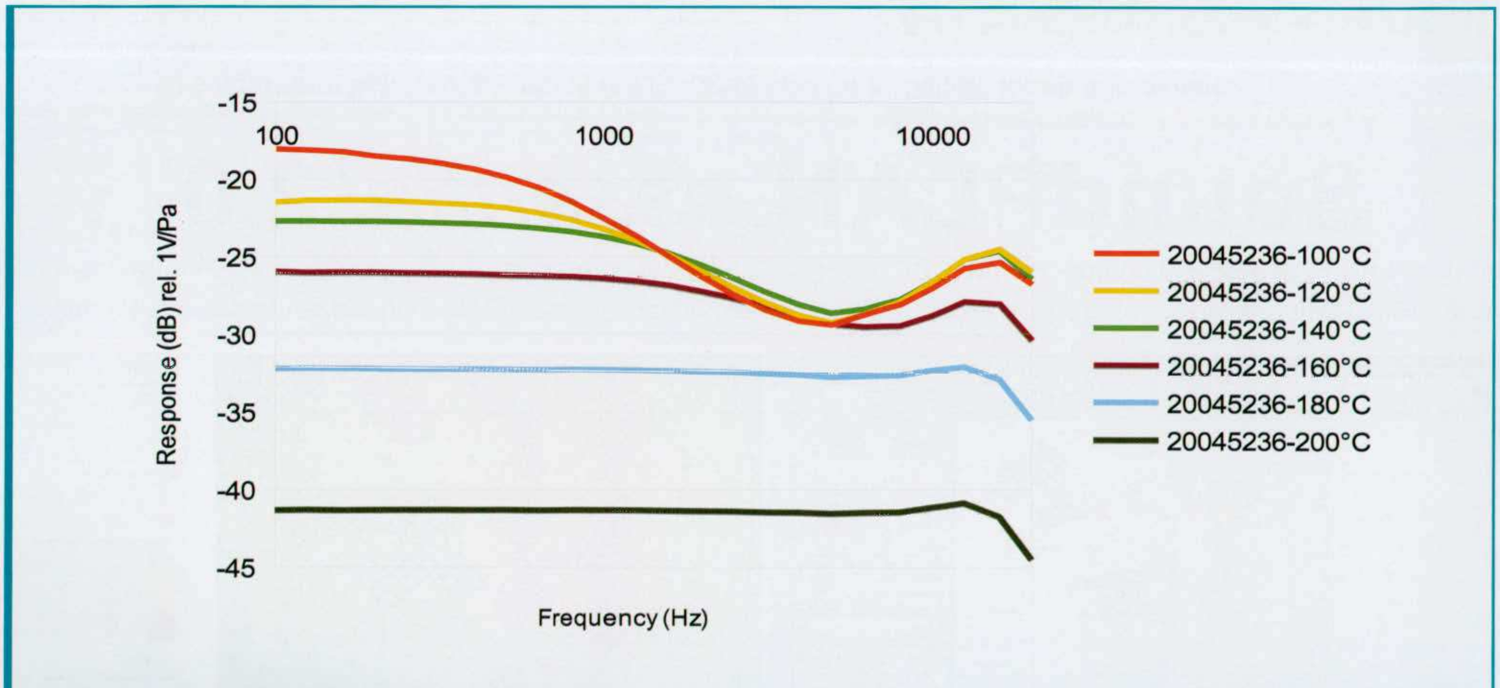


Figure 3: Effect of successive 15 minute intervals at increasing extreme temperatures upon MK224 capsule performance

# Are we listening to acousticians?

*By Julian Treasure of the Sound Agency*


Julian Treasure

Our world is getting noisier. We have all experienced it, from the hubbub of densely populated areas to the roar of busy traffic. The detrimental effect of noise pollution has been proven for decades, yet most of us – including those with the ability to effect significant change – remain unaware.

Whilst the sources of this noise are sometimes necessary or hard to manage, the reverberant indoor spaces that compound the damaging effects are entirely within our control. As a result, the role of the acoustician, and their relationship to architects, engineers and decision makers, is one of the most pressing issues within the design world today. The lack of such a relationship has resulted in dangerously noisy spaces that cause quantifiable and significant damage to our health, education and economy.

The World Health Organisation has conservatively estimated that noise pollution is costing one million years of healthy life every year in Europe alone[1] – that's one day per year for every European adult and child – with direct links to the onset and worsening of serious medical conditions. These range from high blood pressure and heart disease to insomnia and memory less.

Shockingly, hospitals are some of the worst offenders when it comes to noise: the noise level in a recovery care unit averages 67dB, with the loudest recordings peaking at 94db – that's the level of sound one would expect to hear on a busy motorway. This degree of noise not only disrupts sleep and raises blood pressure but it far surpasses the 65dB level at which the incidences of heart attack increase[2]. As a result, the poor treatment of sound in hospitals is compromising the building's core purpose: recovery.

Education tells a similarly disturbing story. With noise in German classrooms averaging 65dB[3] and speech intelligibility just 50% for some pupils[4], communication, behaviour and staff welfare are disintegrating. Modern teaching methods encourage group work, triggering a vicious spiral of disruption as students and teachers speak louder and louder to make themselves heard, often whilst struggling against long reverberation times. Consequently, we have a generation of children who are receiving little of the education that we are trying so hard to give them.

The Essex Study in 2012 proved that modest investments in improving the acoustics of a classroom can transform the working environment. By reducing reverberation through the use of wall-mounted boards and ceiling panels – at the cost of £2,500 per room – the behaviour and involvement of all pupils P24

◄P23 improved, whilst reducing the stress of the teachers[5].

At the other end of the scale is Norman Foster's 2012 £30 million flagship school. Despite being designed to give its pupils the very best education, the building was based around an open-plan design: a vast central atrium surrounded by classrooms with no back walls. Predictably, the environment was so noisy that £600,000 had to be spent on acoustic improvements to create functioning classrooms[6]. The presence of an acoustician from the outset of the project would have ruled out such additional costs and allowed the building to be designed for optimal performance.

The economic cost of noise pollution is mounting. The European Union calculates a financial cost of €40 billion every year, due to impaired learning, reduced productivity, healthcare costs and lost working days – that's 0.4% of GDP.

Given our circumstances, it is little wonder that acoustics are often an afterthought. The ubiquity of noise – be it accidental or commercial – is causing us to suppress a lot of it through our habituation circuit, a basic survival instinct that makes us cease to hear an unchanging background noise. It is crucial to reinstate an awareness of sound in order for its affect to be acknowledged and for change to happen. For as long as our relationship with sound remains unconscious, our visual culture will continue to take precedence in the design process. The acoustic properties of most buildings are an accidental by-product of the way it looks. Spaces are being designed for appearance rather than experience.

Technology now allows acousticians to demonstrate the benefits of engineering the sound environment, through allowing them to experience it first hand. Auralisation (the acoustic equivalent of visualisation) allows clients, developers and designers to experience the effect of acoustic solutions and variables as the building is being designed. It is an effective and engaging method to explain acoustic concepts to non-specialists and allow proactive decisions to be made.

It is important that acousticians do not see their trade in isolation but rather as part of a bigger sound network, with considerations towards noise reduction, sound systems and content. This differentiation will allow decision makers to understand the full potential of sound, and the role that acoustics plays in the delivery of it. It's a challenge, but progress is being made; forward thinking organisations are starting to embark on programmes to harness the benefits of sound.

Sound, noise and acoustics affect our everyday lives more than most of us realise. It's in the nature of an acoustician to focus on the physics of sound, but this approach is unlikely to trigger the realisation in those who are unaware. Relating the physics to the human experience – from the raised heartbeat of the stressed teacher, to a generation's impaired education – is the only way that this message can be heard in an increasingly noisy world. ◘

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# Acoustic imaging reveals secrets of 'Britain's Atlantis'

A University of Southampton professor has carried out the most detailed analysis ever of the archaeological remains of the lost medieval town of Dunwich, dubbed "Britain's Atlantis".

Funded and supported by English Heritage, and using advanced underwater imaging techniques, the project led by Professor David Sear has produced the most accurate map to date of the town's streets, boundaries and major buildings, and revealed new ruins on the seabed.

He said: "Visibility under the water at Dunwich is very poor due to the muddy water. This has limited the exploration of the site.

"We have now dived on the site using high resolution DIDSON acoustic imaging to examine the ruins on the seabed – a first use of this technology for non-wreck marine archaeology.

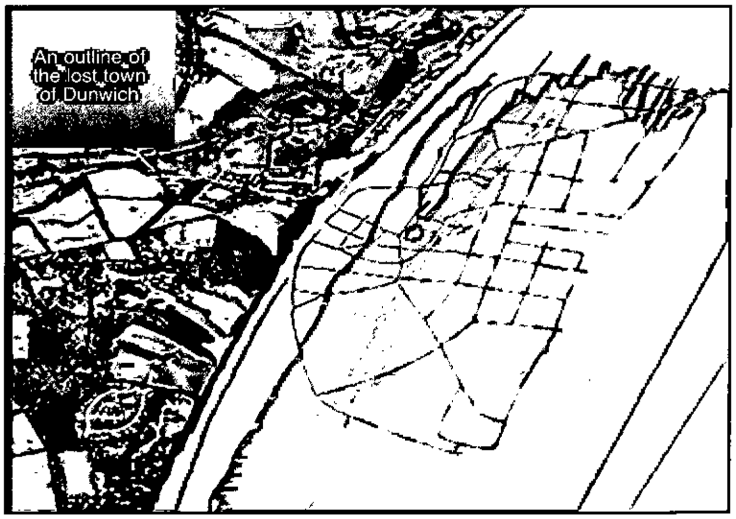
"DIDSON technology is rather like shining a torch onto the seabed, only using sound instead of light. The data produced helps us to not only see the ruins, but also understand more about how they interact with the tidal currents and sea bed."

Peter Murphy, English Heritage's coastal survey expert, said: "The loss of most of the medieval town of Dunwich over the last few hundred years – one of the most important English ports in the Middle Ages – is part of a long process that is likely to result in more losses in the future. Everyone was surprised, though, by how much of the eroded town still survives under the sea and is identifiable.

Present day Dunwich is a village 14 miles south of Lowestoft in Suffolk, but it was once a thriving port – similar in size to 14th century London. Extreme storms forced coastal erosion and flooding that have almost completely wiped out this once prosperous town over the past seven centuries. This process began in 1286 when a huge storm swept much of the settlement into the sea and silted up the Dunwich River.

The project to survey the underwater ruins of Dunwich began in 2008. Six additional ruins on the seabed and 74 potential archaeological sites on the seafloor have since been found. Combining all known archaeological data from the site, together with old charts and navigation guides to the coast, it has also led to the production of the most accurate and detailed map of the street layout and position of buildings, including the town's eight churches.

Professor Sear's full report can be found at: http://www.dunwich.org.uk/ ◘



An outline of the lost town of Dunwich

# Urban greening reduces noise pollution, say researchers

Green roofs have the potential to significantly reduce road traffic noise in the urban environment, according to a new study. The results suggest that greening of roofs and walls with materials suitable for growing plants softens the urban environment keeping sound levels low, whereas hard, manmade structures tend to amplify traffic noise.

The Environmental Noise Directive (2002/49/EC) recognises the need to protect quiet areas in cities and towns as sites of value to the local community. Plants can play a role in this by softening the urban environment and reducing noise. Green roofs and vertical gardens also offer far greater benefits than noise reduction, and thus 'greening' is also considered under the Green Infrastructure Strategy (COM(2013)249)2.

Researchers at the University of the West of England investigated what type of greening produced the greatest benefit in terms of reducing noise in places that were already of some value as 'quiet areas'. They considered green roofs, green facade walls on the fronts of buildings and low, vegetated screens at the edges of flat roofs.

Researchers simulated how sound made by cars travelling at different speeds would be transmitted to enclosed courtyards shielded from the road by buildings. In the simulations, each courtyard was positioned at the centre of a six-storey tower block building, with each block separated from the next by a crossroad. To show how sound would travel between the road and the courtyards, two numerical methods for simulating sound propagation were used. One method modelled how sound travels in three dimensions, whereas the other modelled it in only two dimensions, but was able to account for the complex characteristics of the materials involved. The study only considers the noise from the adjacent street – the authors add that distant noise may also be important depending on the wind direction.

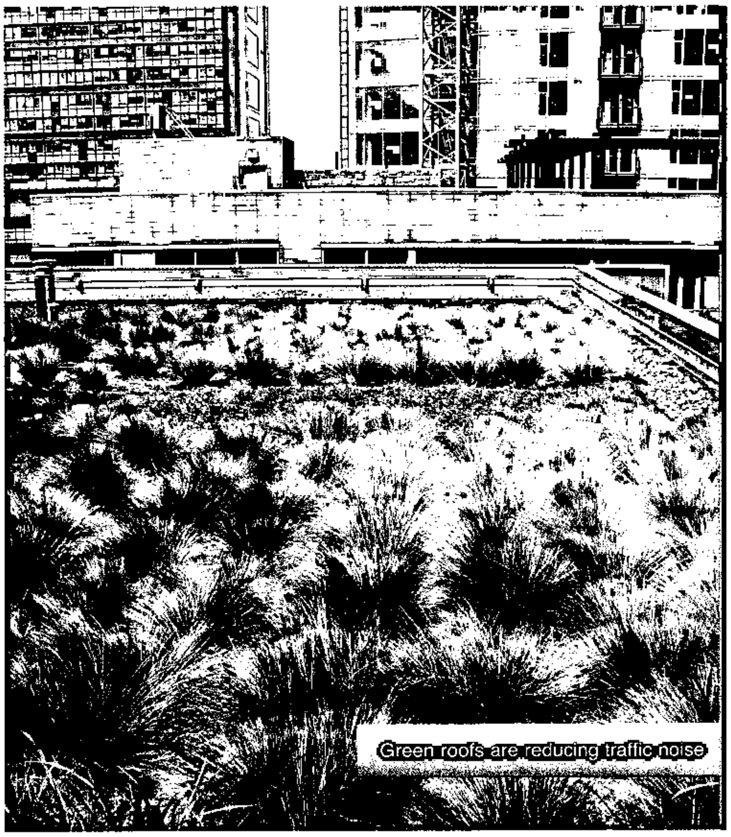
The substrate materials modelled (i.e. those used to provide a surface for plant growth) accounted for most of the noise reduction seen in the simulations. According to the results, green roofs have the greatest potential for attenuating noise, and on certain roof shapes, may be able to reduce noise by up to 7.5 decibels. The noise reduction was smaller for green facade walls, and depended on the materials used in the adjacent street – the harder the bricks in buildings on the street, the greater the reduction in noise in the roadside courtyard.

The model also predicted that green facade walls would be best positioned high up on the walls surrounding the courtyard, unless the materials used for buildings in the nearby street are softer, in which case the facades would be better positioned around the courtyard itself. Vegetated screens on roof edges were only effective when the screens themselves were made from absorbent materials as opposed to rigid materials, which even had the potential to increase noise levels.

The researchers also used their models to test combinations of different types of building greening. Soft roof edge screens in combination with either green roofs or walls were the most effective at reducing noise.

According to the researchers, greening could be used to limit noise from other sources, such as air conditioning units, although the current study focuses solely on traffic noise. Vegetation (as part of 'Green Infrastructure') also has other important environmental benefits, such as absorbing carbon dioxide, improving air quality, reducing the urban heat island effect, increasing urban biodiversity and making streets and roofs look more attractive.

This report is based on an article in *Science for Environment Policy* published by the European Commission.


Green roofs are reducing traffic noise

# Safety experts call for action on noisy machinery

A Health and Safety Executive (HSE) survey of machinery instructions has found that more than 80 per cent had inadequate noise emissions instructions.

The HSE says that as a result it is highly likely that buyers and users of the machinery will be unable to make informed choices regarding the safety of potential purchases or understand what control measures are necessary to mitigate the risks from noise during use.

The aim of the study, carried out at the Health and Safety Laboratory, Buxton, was to assess the suitability of information on noise emission required under the Supply of Machinery (Safety) Regulations and the Noise Emission in the Environment by Equipment for Use Outdoors Regulations for workplace risk assessment. The noise information provided by manufacturers and suppliers of a wide range of machine types for which noise declaration is required was assessed.

Following a review of more than 300 safety standards for machine types where noise was considered a significant hazard, Health and Safety Executive and Health and Safety Laboratory (HSL) noise specialists selected 20 machine types for further investigation based on:

- The equipment was likely to be a major contributor to significant noise exposure in the workplace
- There was potential for reducing noise emission, for example by better design
- Further investigation could make a positive contribution to reducing noise exposure in the workplace.

The noise emission information contained in the machinery instructions was analysed using the method developed for a European project, referred to as NOMAD, set up by the Administrative Cooperation Group for market surveillance under the Machinery Directive (Machinery ADCO). This method enabled both the quality of the noise emission data and its compliance with the requirements of the Machinery Safety Regulations to be assessed.

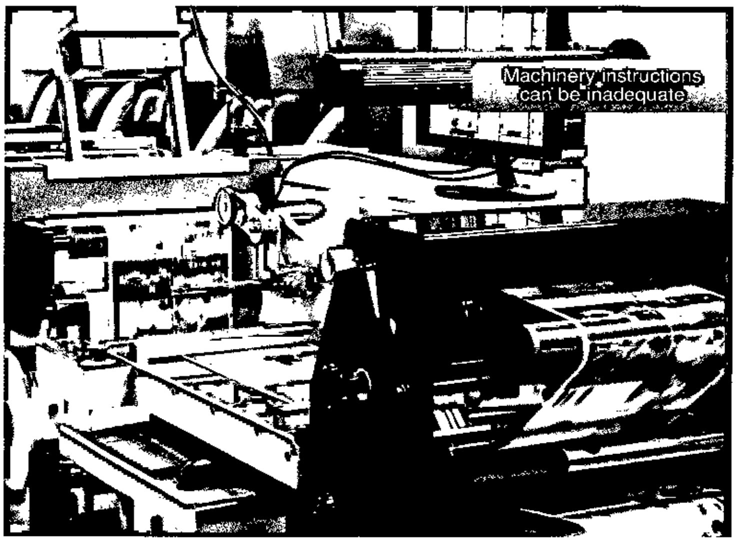
Seventy-three sets of instructions were obtained from the manufacturers and suppliers of 14 different categories of tools and machines. The noise emission information contained in 60 sets of instructions (82% of the sample) failed to satisfy the requirements of the Supply of Machinery (Safety) Regulations for the following reasons:

- Absent or incomplete declared noise emission values
- Absent or incomplete traceability to operating conditions for declared noise emission values
- Lack of adequate (or in some cases any) information on safe use, residual risks, or noise control measures.

The information contained in 13 sets of instructions satisfied the requirements of the regulations; six were judged as including comprehensive and high quality noise data and information. Most of the compliant instructions were for tools and machines in the following categories: compaction machines, powered lawnmowers and edge banding machines

The study recommends that manufacturers and suppliers should be influenced to supply users with the required noise emission information, either through guidance or enforcement activities. Guidance is also needed on the responsibilities of manufacturers of partly completed machinery and bespoke machinery.

Several machine categories were identified during the study where further investigation of the noise emission and real use noise exposure should be considered. These include granulators, shredders, masonry and stone cutting machines, floor cutting-off machines, and balers/compactors.


Machinery instructions can be inadequate

# Salford team designs earmuffs to block out low frequency noise

Researchers at the university of Salford have designed highly advanced artificial materials that can be used to shield low frequency noise in military or industrial environments.

Low frequency noise is traditionally difficult to cut out without the use of heavy walls and barriers but, by using the emerging science of metamaterials, the researchers at Salford have created a design which could be incorporated into a wearable set of earmuffs.

Metamaterials are entirely artificial materials that cannot be found in nature. At Salford, physicists have already been part of research to design materials that make objects invisible and have now turned their attentions to the uses of this revolutionary technology to affect sound.

Using a combination of measurement and modelling metamaterials comprised of several thin membranes which have been created and tested in the university's acoustics labs, the team now believe that it is possible for a working prototype to be created which can be tested in environments such as armoured vehicles or airports, where extreme levels of low frequency noise have serious health implications for people.

For electromagnetic waves, metamaterials can take many forms, such as a series of coils and wires that have the ability to bend waves around them in a predefined way. There are numerous and enormously promising applications for this technology. As well as invisibility and sound reduction, the ability to bend light will lead to significantly increased computing processing speeds in the future.

Thanks to the unique properties of the metamaterials, it is also possible to configure the earmuffs so that other frequencies can be heard – for example human voices – whilst the more damaging frequencies are cut out.

# Are architects scared off by the 'black arts' of acoustic consultancy?

The ANC AGM on 21 May saw the quickest approval of the chairman's report and the annual accounts in recent years, before getting stuck on a discussion on the detail of changes to the Rules & Bylaws.

Once those were finally agreed, the only change to the Board was to elect Miles Woolley (Environoise Consulting) to join the existing members: Phil Dunbavin (Philip Dunbavin Acoustic Consultant), Andy Parkin (Cundall), Richard Greer (Arup), Matthew Hyden (Temple) and Jack Harvie-Clark (Apex). Thanks were recorded to Richard Mackenzie (RMP) who has stepped down at the conclusion of his two year term.

The speaker at the dinner which followed was Peter Caplehorn, a member of the RIBA Council, who pondered on whether architects were scared off by the "black arts" of acoustic consultancy, but then moved on to consider opportunities for better connectivity between RIBA and ANC.

He set out some areas where common themes could be developed such as on Building Regulations, British Standards and BIM (Building Information Modelling), which he suggested – to general approval – might be the death knell of value engineering.

He noted that the RIBA Plan of Work had just been revised and aimed to shape a set of unified work stages suitable for use by all the members of the project team.

Peter's words were well received and seen as an excellent first step in securing better links with other professions and the construction industry's representative bodies, which is one of ANC's objectives.

Phil Dunbavin (left) welcomes Peter Caplehorn

# ANC launches excellence in acoustics awards

The ANC has launched a set of awards to promote and recognise excellence among UK acoustic consultants and raise the profile of the acoustics industry. The four awards are environmental acoustics, sponsored by Brüel & Kjær; architectural acoustics, sponsored by Ecophon; building services acoustics, sponsored by IAC; and sound insulation design, sponsored by Robust Details. It is expected that further awards will be added in subsequent years.

The awards are looking for examples of work that display innovation, and originality in acoustic design or approach to a particular project. There are no restrictions on size or type of project. Work must have been undertaken in the last two years (but need not be complete) and the consultancy must be in operating in the UK although the project may be elsewhere. Full details are available on the ANC website www.theanc.co.uk The closing date for entries is 31 July 2013 and the awards will be presented at a dinner following the ANC conference on 8 October 2013 at the Crowne Plaza in Birmingham.

The presentation offers an opportunity to promote acoustics consultancy to a wider audience through coverage in the construction press and involvement of representatives from RIBA, CIEH and CIBSE in the judging process. Further details will be announced over the next few weeks.

# Gym music puts users' hearing at risk

Loud music played in some gym classes can damage users' hearing, according to new research carried out in Australia.

A paper published in the *Archives of Environmental & Occupational Health* suggests sound levels in high-intensity gym classes are often too high.

As part of the study, noise levels were tested during 35 low-intensity and 65 high-intensity classes in 1997-98 and again in 2009-11. The study assessed noise levels at four different gyms. Noise levels in both time periods were similar, averaging at about 93.1 decibels. Noise levels in low-intensity classes dropped from 88.9dB to 85.6dB

Janette Thorburn, principal audiologist at Australian Hearing, said it was "astonishing" that some gyms were playing music at these levels. "We know that one gym in the United States has recorded a level of 106dB in a spin class," she said. "That is insane. If you are an instructor and you do a few classes back to back at high levels it is definitely damaging to your hearing.

"Our research arm is now looking at noise levels in gyms. The Australian standard is 85dB of continuous noise over eight hours. If you raise the levels to 91dB then you can only be exposed for two hours safely and so on. Recreational noise is a hugely ignored public health problem."

The author of the paper, research psychologist at the National Acoustic Laboratories, Elizabeth Beach, said it was time for more awareness around the issue. "Fitness class providers are trying to make their classes like nightclubs to entice people in the doors which is not necessary," she said.

"Another strategy could be to vary tempo as opposed to turning the volume up to dangerous levels." About 14 per cent of young Australians (aged 18-35) are being exposed to noise levels that are over the safe work place limit. The damage is often done during their leisure time when they listen to loud music on electronic devices or visit nightclubs or live concert venues. Often the damage is done, Beach says, and because hearing issues often don't materialise until later in life, people tend to put off worrying about it.

"Hearing loss may not become evident for another 20 years but that's why we talk about tinnitus now," she said. "People need to imagine what it is like to have that tinnitus not go away. The human system is not designed to hear sounds like the ones pumping out of gym speakers over a long period of time, we simply have not evolved to deal with those sorts of sound levels."

This article is based on one that appeared in *The Canberra Times*

# Road traffic noise increases risk of diabetes

Road traffic noise levels increases the risk of diabetes, new Danish research has revealed.

In the study, partly conducted under the EU QUIET1 project, researchers signed up more than 50,000 residents in Copenhagen and Aarhus aged 50-64.

To assess how much noise each person was exposed to, the researchers recorded the residential addresses of every individual since 1988 and combined this with spatial information on noise.

The amount of road traffic noise at each address was estimated using data on factors including the average number of vehicles, their speed, the type of road, and the height of surrounding buildings. Finally, instances of diabetes diagnoses for the participating residents during the study were obtained.

When analysing the data, the researchers were careful to rule out aspects which might also affect the risk of diabetes, such as sex, weight, diet and smoking. One factor which was particularly important to control for was air pollution, since this is higher in areas of higher traffic noise, and has also been linked to diabetes.

Overall, 3,869 individuals were diagnosed with diabetes during the study. The results demonstrated that an increase in average noise exposure of 10 decibels (at all residences in the five years before diagnosis) was associated with a significantly higher risk of diabetes. Long-term exposure (five years) was linked with higher diabetes risk than shorter periods (one year).

The study was unable to control for such factors, such as bedroom location, noise from neighbours or hearing impairment, all of which may have had an impact on the actual noise experienced. However, adjustments to account for air pollution did not alter the overall conclusions, suggesting that noise has an effect that is independent of this influence.

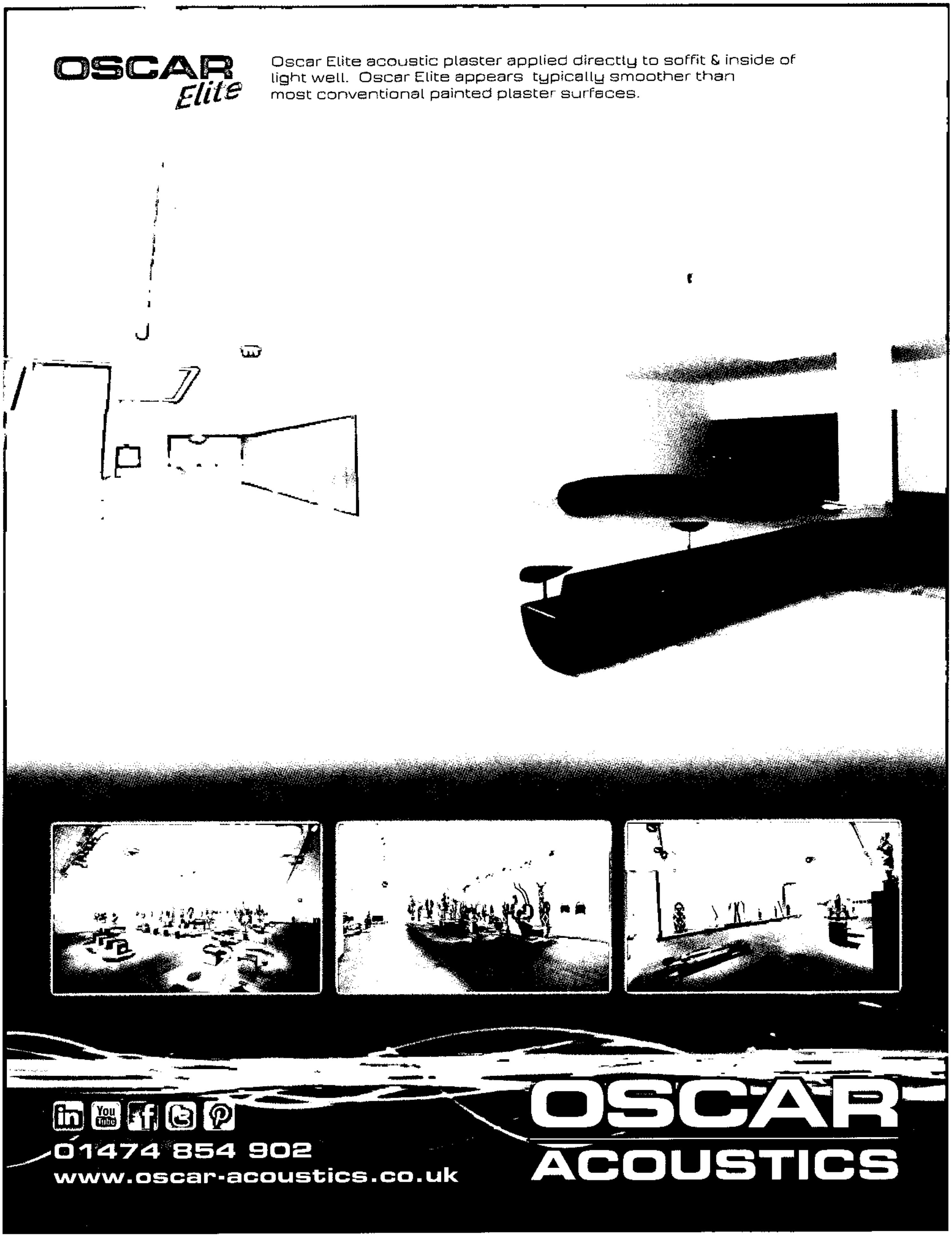
The researchers were further unable to distinguish between type 1 diabetes (which is largely genetically determined) and type 2 diabetes (which is often triggered by lifestyle factors) in this study. However, these results are very likely to reflect the effects of noise on type 2 diabetes, since this constitutes 90-95% of all cases of diabetes, and type 1 is generally diagnosed during childhood.

They also acknowledge that because many people live with undiagnosed diabetes, the date of diagnosis may not accurately represent when the disease developed.

And in another study in Strasbourg, France, researchers examined the effects of long-term exposure to railway noise. In particular, they investigated whether individuals exposed to railway noise in the long term can become used to the noise and are therefore less affected by noisy nights.

The results indicated that individuals who lived in noisy environments at home had slower reaction times, increased lapses in attention, and greater sleepiness throughout the day, compared with those who lived in quiet environments. This was probably due to the enhanced 'diurnal cerebral slow wave' activity which characterises sleep pressure.

This suggests that individuals experiencing long-term exposure do not adapt, but in fact suffer a chronic sleep debt. This adds to the evidence of other studies that have reported impaired cognitive performance in children living near airports. However, the researchers do caution that the number of people who took part in this study was rather low (40) and there is no absolute guarantee that the two groups did not differ in some important influential factor on cognition other than noise exposure.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# How spherical loudspeakers came into auralisation

*By Michael Vorländer, Institute of Technical Acoustics, ITA, RWTH Aachen University, Germany*

## Introduction

Recording and reproduction of sound aim at the transmission of a sound event from one place to another. This can be done from a live performance into a living room, for example, or from a recording studio via a digital audio device to headphones. Usually the audio signal processing and sound mixing create a certain desired quality which, too, can be considered as part of the sound event apart from the performance itself. Finally, all those situations lead to the perception of pre-designed sound events.

The technique of auralisation is a tool for specific sound design. It combines source recording, sound propagation modelling and sound reproduction in a way that the components of this chain can be changed. Very important applications are found in architecture, sound reinforcement system engineering, or in car industry. By changing this and that component of the sound transmitting system, for instance, the overall auditory impression can be studied, and the optimal constellation be found. In case of real-time auralisation, this process is interactive, so that changes in the system are audible instantaneously. Changes can be modifications of the geometry, insertion of absorption material, but also movements of listeners and sound sources. For such dynamic scenes in virtual reality environments an extremely quick update rate is required. This can only be achieved with either multi-processor or GPU computational power, or with low-cost computers, large memory spaces and pre-processing. In this article the focus is on auralisation with ordinary computers such as standard PCs.

When it comes to a consideration of the listener interaction, the most used interaction movement of listeners in virtual environments is head rotation. This is far more relevant than translational movements. These head rotations contribute significantly to source localization, even unconsciously. The order of magnitude of such significant head rotations may be around or below a degree in angular resolution. Hence, the challenge for auralisation systems is implementation of head rotations very efficiently. Source movements may be of interest, too, as far as a live performance is concerned. Thus for musical instruments rotations could be considered as well.

A very interesting task is therefore the development of a recording, coding, and reproduction system by using spatial sound technology with a free choice of the directionality of the input and output. Imagine a directional sound source radiating into the space and a human listener or a dummy head, both connected by a transfer function containing the sound transmission path. Usually this function or its equivalent in time domain, the binaural impulse response, is measured. In this measurement, however, the source as well as the receiver must be chosen, and accordingly their directional characteristics are included in the transfer function. Usually, in standard room acoustic measurements, an omnidirectional source and an omnidirectional receiver is used, or a dummy head.

Auralisations of such situations suffer from the facts that a) the source directivity is not accounted for, and b) the listener directivity (in best case a good dummy head) is already fixed.

The scope of this contribution is the presentation of a system with allows sound reproduction which a flexible and individualized directivity at both the source and receiver side. This is possible with the definition of a measured or simulated directional transfer function tensor in between the source and the receiver. With this data and sufficient memory space of the computer, rather little computational power is required, so that real-time auralisation of complex and large spaces can be provided on standard PCs.

## Approach

The key to a flexible spatial reproduction system is interfacing both the source and the receiver with the transfer function by using a spherical functional basis. The approach is the logical continuation of Michael Gerzon's invention of ambisonics [1] and B-format recording on the one hand, with another spherical harmonic decomposition dealing with the source, on the other.

In classical ambisonics recording, any specific directional sound field at the listener position in a room is captured in a four channel B-format, or with a higher number of channels in higher order ambisonics, HOA. The sound source, however, is still included with its actual directivity either in direct recording or in an impulse response measurement. In the latter case the source signal must be convolved with the impulse response. The result is a multi-channel audio recording or a multi-channel impulse response with fixed source data. For higher orders, the number of channels increases depending on the order and degrees represented in the mathematical formulation of the directional sound field at the listener position.

## Theoretical background

For combining the angular components in azimuth and elevation of sound source and receivers, a set of orthonormal base functions called spherical harmonics (SH) is defined. The spherical harmonic base functions are

$$Y_n^m(\theta,\phi) = \sqrt{\frac{(2n+1)}{4\pi}\frac{(n-m)!}{(n+m)!}} \cdot P_n^m(\cos\theta) \cdot e^{jm\phi} \qquad (1)$$

with n and m describing the order and degree of the spherical harmonics, respectively is the associated Legendre function whose definition can be found in mathematical textbooks [2].

Any kind of directional pattern is then decomposed into contributions of the base function, the SH components. They represent monopole, dipole, quadrupole etc. patterns, which must be added in an appropriate way in order to obtain a best match with the specific directional pattern of interest. Similar to the correspondence between time signals and frequency spectra in the Fourier Transform, there exists a transformation between the spatial (directional "balloon") domain and the SH coefficients. Due to orthogonality, a weighted sum of SH coefficients is a complete and unique representation of the spatial directivity pattern.

More detailed definitions of spherical harmonics for the decomposition of spherical functions can be found in *Fourier Acoustics* by Earl Williams who gives a concise overview of the methods with a focus on acoustics [3].

## Implementation

So far, ambisonics and HOA are well known as a very efficient spatial audio format. In the technique proposed here, a second spherical harmonic decomposition is used: for the sound source. Thus, the results obtained do not belong to a specific source and a spherical receiver, but to *any* source and to *any* receiver, both coupled by a tensor of transfer paths for all combinations of directions. An example for one tensor element is depicted in figure 1, where the room transfer function is represented for a dipole-to-hexapole pattern.

The challenge is to obtain such complex data by using spherical microphone arrays and spherical loudspeaker arrays at the same time. If, however, this is successful, the acoustic transfer functions are easy to change for a) varying directivities

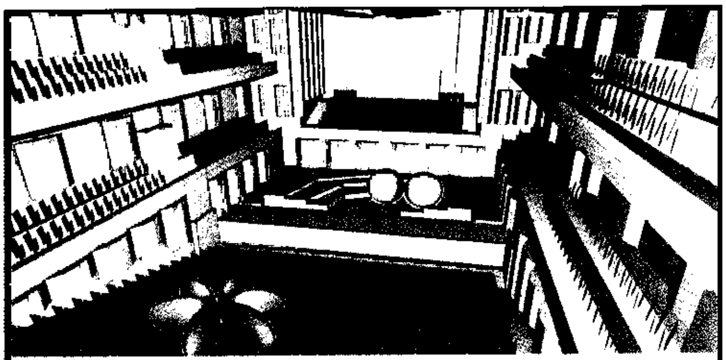

Figure 1. Transfer function representation between a dipole source and a higher-order receiver

Receiver directivity $1 \times N_R$ × Rotation $N_R \times N_R$ × SH to SH room impulse response $N_R \times N_S$ × Rotation $N_S \times N_S$ × Source directivity $N_S \times 1$

Figure 2. The Spherical Harmonic Impulse Response Tensor, SHIRT, a compact data format for the acoustic transfer path between arbitrary sources and receivers

◄ and b) rotational cues in dynamic scenes.

For the computation or measurement of the central tensor it is necessary to excite the room with a spherical loudspeaker array and the record with a spherical microphone array. The question which of the two arrays should represent the real source and which one the real listener, is subject to discussion. It should be remembered that the sound propagation path (its impulse response and transfer function) is reciprocal, so that we have a free choice here. The decision finally depends on the complexity of the directivity of the source and the receiver, and the best choice is made if the higher-order transducer is used for that part, which requires more spatial resolution. It should be also mentioned that further studies on similar questions focus on theoretical considerations such as multiple-input multiple-output (MIMO) theory applied to room control [4].

Thus, the basis for the technique is the simulation or the measurement of the SH-SH impulse response tensor (called "SHIRT"). Instead of a one-channel or two-channel (binaural) impulse response a tensor of size $N_S$ X $N_R$ is to be created, which contains impulse responses in each tensor element. For each n-to-m constellation there are various degrees to be considered, for example three dipoles to seven hexapoles in their 21 combinations. In the example in figure 1 just one of those is shown.

The total signal transmission from the source to the receiver is then represented by a SH expansion for the source with maximum order $N_S$, the transmission tensor, and the SH expansion of the receiver with maximum order $N_R$.

## Acquisition of input data

As mentioned above and as illustrated in figure 2, we need two transducers and two sets of data. The two data sets are required to introduce the directional characteristics of the source (i.e. a musical instrument), and directional data of receivers (usually called head-related transfer functions, HRTF). It should be noted that the latter part is executed after the tensor was built – in post-processing. This allows comparison of room acoustic perception between different HRTF, for instance. Or the room response can be analysed with regard to different directivities of musical instruments. P32►

## Where to get directivities of musical instruments?

◄P31 The pioneer of measurement of directivities of musical instruments is Jürgen Meyer [5] who first published data in 1965. Later, when multi-channel digital recording systems were available, Otčenášek and Štěpánek [6], Rindel [7], Pollow et al. [8], Pätynen and Lokki [9], measured various instruments. Pedrero et al. applied the same approach for recording choir singers for a virtual reconstruction of 11th century Spanish worship spaces [10]. The database created by Pollow et al. [8] is currently processed for a SH decomposition.

## Where to get individual HRTF?

There are various ways to obtain HRTF by measurement or numerical simulation [11]. While photographic or scanning methods and numerical simulations suffer from uncertainties, the main problem in direct measurements is the duration of several hours. Fortunately, fast sweeps measurement methods were developed which allow individual HRTF of be measured within minutes [12, 13, 14].

## SHIRT implementation in room acoustic computer simulation

It is straightforward to include this concept in room acoustic simulation software. At the source and receiver points, all reflection paths can be multiplied with the directional functions of the $N_S$ X $N_R$ spherical harmonics (eq. 1). Imagine a wall reflection in figure 1 being multiplied with the amplitude of the dipole and the hexapole amplitude and phase at the angle of radiation and incidence, respectively. All data representing the direct sound and reflections are pre-processed and stored in the computer memory [15].

During the spatial audio reproduction, the rotational cues of the listener can be added very easily with a computationally cheap operation. Similarly rotation of the source can be taken into account, thus adding an interactive component during the listening experience, see figure 3.

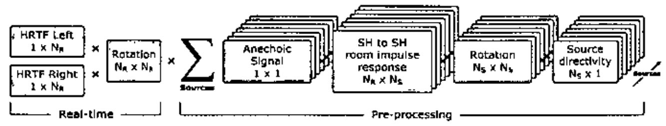


Figure 3. Applying the SHIRT approach in real-time room acoustic auralzation of computer simulations.

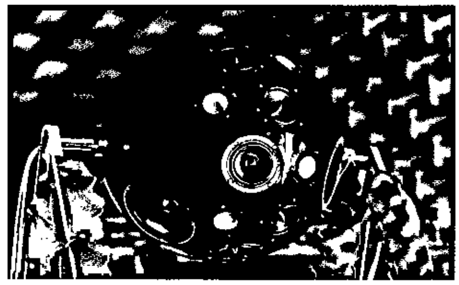

Figure 4. Prototype of the spherical loudspeaker array (Klein [19, 21]).

## SHIRT implementation in measurements – spherical loudspeaker arrays

Spherical microphone arrays can be found already as commercial products. Spherical loudspeaker arrays are commonly known as dodecahedron speakers but in that case they are only driven with all speakers in phase for getting an omnidirectional radiation. Using loudspeakers for directional radiation, sound sources with adjustable radiation patterns can be designed [16, 17, 18] as well. Hereby a set of speakers is mounted into a spherical chassis being able to create the radiation of sound sources with a specific directivity pattern. The achievable spatial resolution is limited by the number of loudspeakers used, similar to what we find with limited sampling rates and corresponding aliasing effects. Due to the physical size of the single transducers and the requirement for different membrane sizes for a full spectral coverage, the resolution is usually severely limited with these speakers, see also [18, 19, 20].

In figure 4 the recently developed measurement equipment at ITA is depicted. It is used for the measurement and auralisation of room impulse responses with arbitrary and in post-processing adjustable directivity pattern of the sound source. With its multi-band excitation this kind of controlled directivity can be obtained for a frequency range up to 8 kHz. Instead of fully covering the sphere with transducers the concept is to use a stepwise rotation in order to cover the whole sphere in an automatic sequential measurement procedure. In the process of source development a simulation model based on a set of analytical descriptions of spherical sound sources was applied. This model allows the analysis of the radiation processes of all individual drivers involved. From this it was achieved an optimum between the transducer size distribution for the various frequency ranges and their distribution on the sphere. Then a SH-based composition was made with a position optimization on the sphere depending on the transducer radius and the space necessary for mounting and separation of the magnets, etc.

This design opens the theoretical basis for a synthesis of spherical harmonic orders up to $N_{max} = 23$ at about 8 kHz. In a thesis project [19] a first prototype of the new measurement system was built to evaluate its performance in real measurements. The transducers have been chosen according to the aperture concept.

In first applications, this source served as a Dirac pointer source as presented by Pollow [20] or as an HRTF source for reciprocal binaural measurements, as presented by Klein [21]. Both studies are based on fast sequential measurements with interleaved sweeps suggested by Majdak [12] and improved by Dietrich [14].

When applied to room acoustic measurements, distinct early reflections can be evaluated and auralised. This allows innovative studies on the perception of reflections regarding their spatial and spectral contributions. Evaluation of scattering surfaces will be of interest as well and possibly new approaches to an in-situ measurement of wall absorption and scattering.

In another study it was tried to synthesize HRTF and to apply the source as a binaural receiver in reciprocal measurements. Room impulse responses are reciprocal between source and receiver. Accordingly the question of best choice for the best-obtainable spatial resolution must be discussed. Usually ISO 3382 measurements are done with omnidirectional sources and monopole, dipole or binaural receivers. In any case, the challenge to listener directivity is rather high, whereas the omni-directionality of dodecahedron loudspeakers is far from being perfect.

But with the source presented and a ½ inch microphone, a quasi-perfect constellation can be found in the reciprocal approach: A perfect omnidirectional microphone transducer on the stage (equivalent to the "source") and an adaptive SH source (equivalent to a monopole, dipole, or HRTF "receiver") in the audience.

Thus there is the task to post-process the SH response in order to obtain the desired equivalent listener directivity, as explained above. It is emphasized again that this procedure requires just one measurement session in the room, while all data are obtained in post processing, including the possibility to construct binaural room impulse responses for individual listeners.

Figures 5a and 5b show the comparison of an original HRTF directivity balloon at 1 kHz and its reproduction from the SH decomposition via the spherical loudspeaker array. Figure 6 depicts a preliminary comparison of a narrow-band part of a room transfer function of an original directional source with its simulation by a dodecahedron loudspeaker array. P34►

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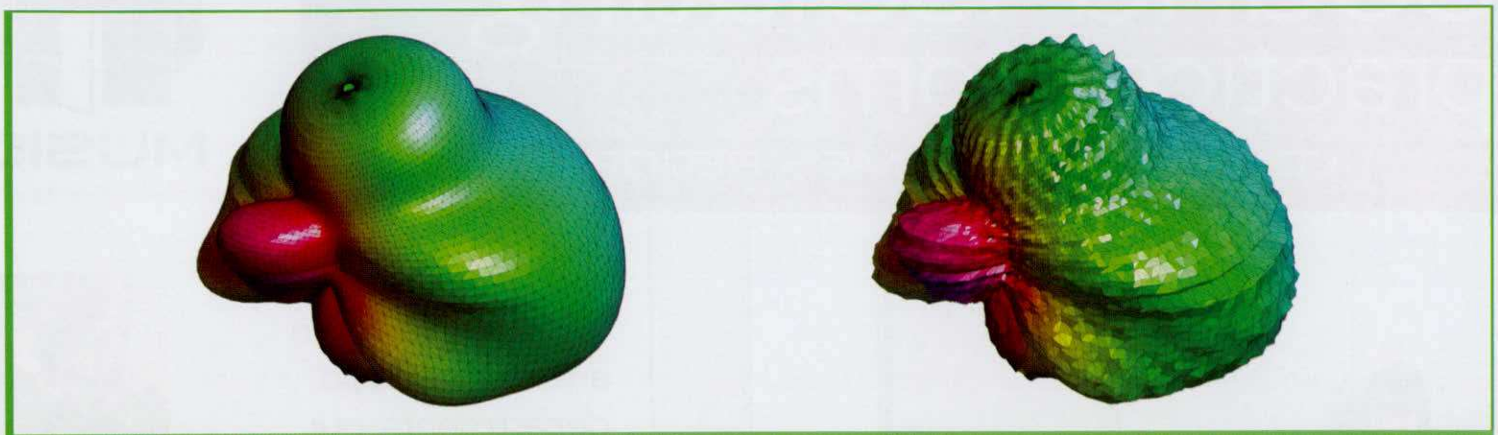

Figure 5. Balloon plot of an HRTF at 1 kHz (left) and its simulation by the spherical loudspeaker array (right).

## Conclusions and further work

◄P32 A spherical loudspeaker array was discussed, which allows a high spatial resolution. Under non ideal conditions due to time variances, measurements are still possible using just one rotational degree of freedom and an SH order of up to 11. With this approach and a microphone array as the second transducer it is possible to measure SH to SH room impulse responses (SHIRT). In playback situations a quick implementation of head rotations during real-time playback for auralisation of measured rooms is possible. Furthermore, auralisation of individual reflections including their manipulation or comparison with regard to changes in absorption or scattering is possible, and finally post-processing into individual HRTF seems to be a very promising technique.

The technique of multiple loudspeaker to microphone systems is in the focus of many researchers working on beam-forming and array signal processing. Typically the "rooms" considered in the area of beam-forming have very short reverberation times, typically 0.3 seconds. The applications in ordinary rooms and large room such as performance spaces, however, must be studied in future as well.

The biggest challenge in the application of the technique presented is the necessity of sequential measurement during which the room under test must be time invariant. Any speed-up of the multi-channel excitation is therefore important. The limits of this technique are still under investigation.

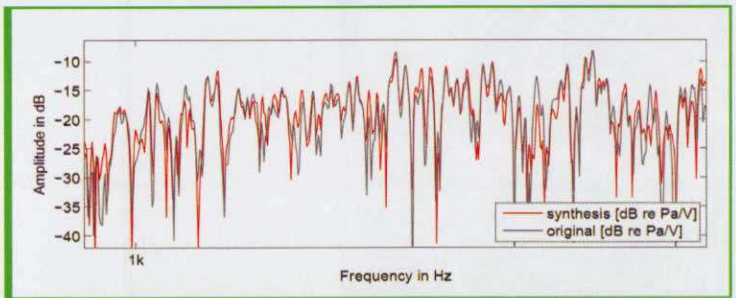


Figure 6. Narrow-band room transfer function (magnitude) obtained with an original directional source and with its simulation by a 12-channel controlled spherical loudspeaker array.

## Acknowledgements

The author is grateful for the good ideas of the doctoral assistants who joined forces in this research area. Martin Pollow started the activities on the Spherical Harmonics technique in ITA. Pascal Dietrich improved the fast sweep measurement technique. Together with him, Johannes Klein developed the multi-channels loudspeaker array. Sönke Pelzer implemented the SHIRT components into the room acoustics computer simulation framework, RAVEN, at ITA. All components of signal processing and data management are part of the ITA MATLAB toolbox (http://www.ita-toolbox.org/).

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# Advances in the measurement of road and tyre noise

*By Alan Bennetts of Bay Systems and Neil Crookes of Cooper Tire*

## Introduction/abstract

Traffic noise is annoying and disturbs the sleep of many millions of people worldwide. It is acceptable only to those who do not have to live with it and is hated with a passion by those whose lives are blighted by it. However, the economic life of a country is dependent upon the movement of goods and people which makes the eradication of traffic noise next to impossible to achieve. The imposition of strict urban speed limits on cars and freight vehicles may reduce noise but the longer journey times will also increase industry costs and, in consequence, may act to reduce economic growth and prosperity, a result that is bad for society at large.

The alternative to reducing speed is to make vehicles quieter. At speeds >50kph the dominant noise source is road noise i.e. the interaction between tyre and road.

The Tyre Cavity Microphone (TCM) was developed to capture tyre tread noise in the laboratory test chamber and on the road. The original premise was that the noise inside the tyre was likely to be closely related to the noise radiated outside the tyre. Measuring noise outside the tyre is fraught with difficulties whilst inside the tyre is a nice safe environment for a microphone. The primary customer for TCM was envisaged to be the tyre manufacturers and the development of TCM was hugely assisted by Cooper Tire at Melksham in the UK.

Subsequent to gathering the first on road data recordings and while attending exhibitions and conferences, it became clear that TCM data was attracting the attention of local authority and university environmental engineers; they believed that TCM data might characterise road surfaces and in particular the road surface noise.

## Development of the Tyre Cavity Microphone (TCM)

Development of TCM started in 2005 as an attempt to build a transducer that might help explain the structure within tyre noise. As in most endeavours, progress was slow with many broken prototypes and a good deal of frustration, caused by data overloads as soon as tyre speeds exceeded 30kph. Eventually, a microphone and radio link system was developed that produced good data. From this prototype version the current system has been developed.

The TCM fits inside the wheel, see figure 1 and is approximately the same size as the original Tyre Pressure Monitoring Systems (TPMS). TPMS has now reduced considerably in size, reflecting the almost universal fitment to vehicles in North America and worldwide. TCM is a R&D transducer and is unlikely to achieve the sales volumes that would enable true miniaturization of the scale seen in TPMS. TCM also has to withstand hundreds, if not thousands, of fittings inside a variety of tyres while TPMS is unlikely to be disturbed more than six times in its entire life. TCM's need to be much more robust as the tyre P36

◂P35 fitting environment is not benign.

As an example of and an insight into the structure of pure tyre noise (averaged over four microphones positioned 1 metre from the tyre contact patch) and measured in a hemi-anechoic chamber, see figure 2a. Close inspection will reveal that the colour contour plot contains a lot of structure which is missing from roadside pass-by noise measurements. Roadside pass-by noise is always the superposition of at least four tyres and when analysed appears as a relatively unstructured pulse of mid frequency (600-3kHz) noise; the colour contour plot of a typical car pass-by at 80kph is shown in figure 2b. Conclusions drawn from the data in figure 2b are likely to need wide error bars!

The results from a single tyre in the laboratory, figure 2a, suggest a complex relationship between the tread input forces and resonances that must be present in the tyre, rim and tyre cavity. This structure is effectively masked in an on road measurement.

To explain, these colour contour plots that will be used throughout this paper and may not be familiar to all readers. In figure 2 a & b, the abscissa ( x axis) records frequency in Hz from 0Hz to 4500Hz and the ordinate (y axis) is the road speed; decreasing from 100kph down to 30kph. The colour reflects SPL with blue being low and red high. The scale on the right hand side allows interpretation of level from the plotted colour.

Looking at the data in figure 2a the first impression is one of many hundreds of orders, closely spaced. A closer inspection reveals some distinct banding of the levels that run parallel to the ordinate, due to resonances in the system.

Three possibilities existed for the source of these resonances:

1. Room effects i.e. the hemi-anechoic room was allowing some room modes.
2. Resonances in the road wheel, a 1.7m diameter steel wheel on which the tyre is running, together with its associated drive mechanism.
3. Structural and cavity resonant modes in the tyre and rim.

Measurement of the room RT60 times and running the road wheel without a tyre and with a simple ribbed tyre eliminated options one and two, leaving structural and cavity modes of the wheel and tyre as the explanation of the banding (amplitude modulation). This explanation fits well with the published explanations for tyre noise mechanisms in that the radiated noise is influenced in the mid frequencies 200- 1500Hz by the structural and cavity modes of the tyre and rim. At frequencies above 2kHz the air pumping mechanism of the tread pattern is dominant.

The data was acquired at a sampling rate of 100kHz per channel and 16 bit resolution. A laser tachometer and axle accelerometer channel were recorded in addition to the four external microphones and the internal TCM.

To establish the frequency of the cavity modes was a straight-forward task; as the first six cavity modes are easily excited by simply tapping on the tyre with a hammer, see figure 3. In this particular tyre and rim combination the primary cavity resonance is at 213Hz. It is sometimes assumed that the cavity modes are a true harmonic series but this is not the case; they are a series of modes that fit the annulus of the tyre's cavity, see table 1, forming an approximate harmonic series.

Tapping the tyre excites structural modes as well as the cavity modes, see table 2. These modes wheel structural modes are the standard modes that would be expected i.e. the rim moving out of phase with the tyre in a breathing tyre mode shape and then many higher order versions that include rocking and twisting of the rim inside the tyre.

At higher frequencies resonance peaks are present but are not unambiguously identifiable, see table 3.

At 100kph (60mph) the tyre will be revolving at approximately 14Hz (858rpm) as each of the wheel orders crosses a cavity or structural resonance its level will increase, see figure 4, where the 220/440/660/860Hz cavity modes can be seen to be "lit up" by the orders passing through them. By translating the data to the order domain this effect can be better appreciated, see figure 5. In this colour contour plot the abscissa is the wheel rotation order number, the ordinate the speed in kph and the colour is again the SPL.

Radiated noise is not significantly boosted by the 220Hz primary cavity mode. There is however a very strong band of noise radiated between 900 and 1700Hz that does overlie the 4, 5 and 6th cavity modes. The averaged external microphone Awt SPL is shown in figure 6. where between 75 and 45kph the radiated noise will be dominated by this band, for example at 55kph, P38▸


Figure 1

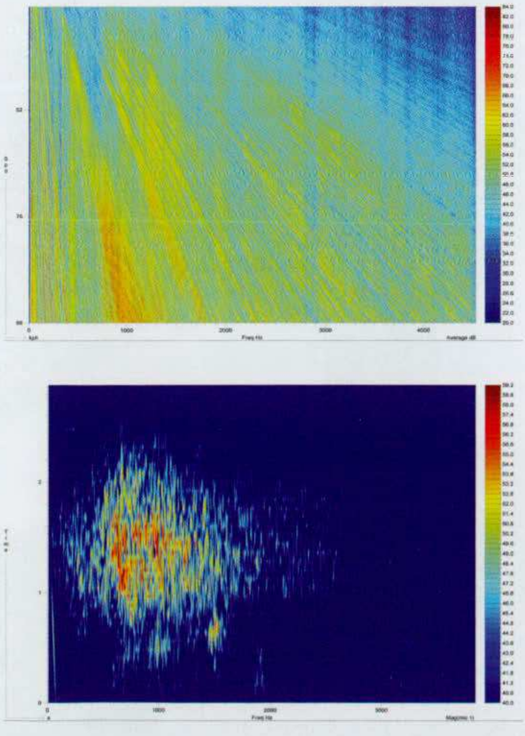


Figure 2a & Figure 2b

| Cavity mode number | Cavity mode frequency | Harmonic Frequency in Hz | Difference between measured and harmonic prediction in Hz |
|---|---|---|---|
| 1 | 213.6 | 213.6 | 0 |
| 2 | 442.5 | 427.2 | +15.3 |
| 3 | 662.2 | 640.8 | +21.4 |
| 4 | 866.7 | 854.4 | +12.3 |
| 5 | 1080.3 | 1068 | +12.3 |
| 6 | 1303.1 | 1281.6 | +21.5 |

Table 1 Comparison of actual cavity mode frequencies and a true harmonic sequence.

| Mode SM1 | SM2 | SM3 | SM4 |
|---|---|---|---|
| 64 | 91 | 109 | 340 |

Table 2. Structural modes of the wheel

| Mode HM1 | HM2 | HM3 | HM4 | HM5 | HM6 | HM7 |
|---|---|---|---|---|---|---|
| 1367Hz | 1501 | 1532 | 1635 | 1702 | 1837 | 1901 |

Table 3. Additional modes at higher frequencies

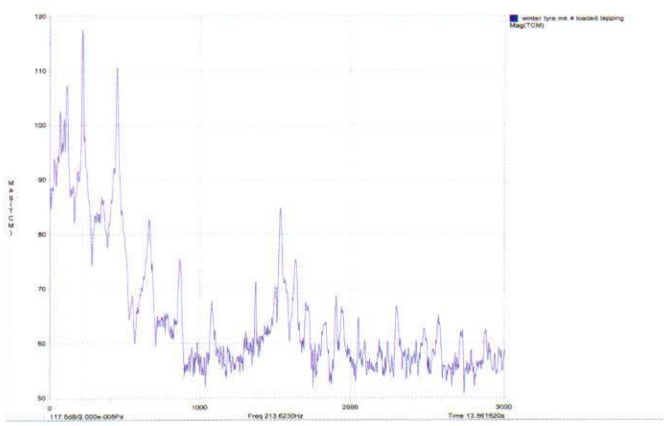


Figure 3

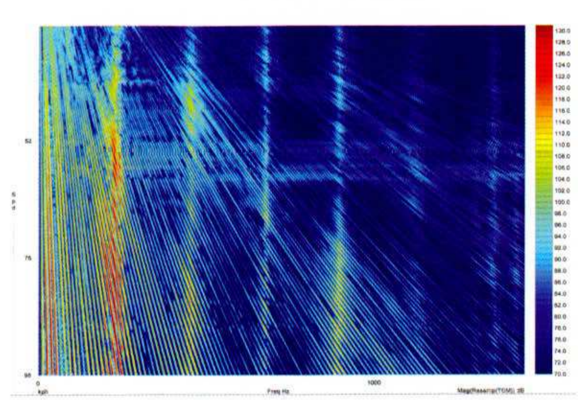


Figure 4

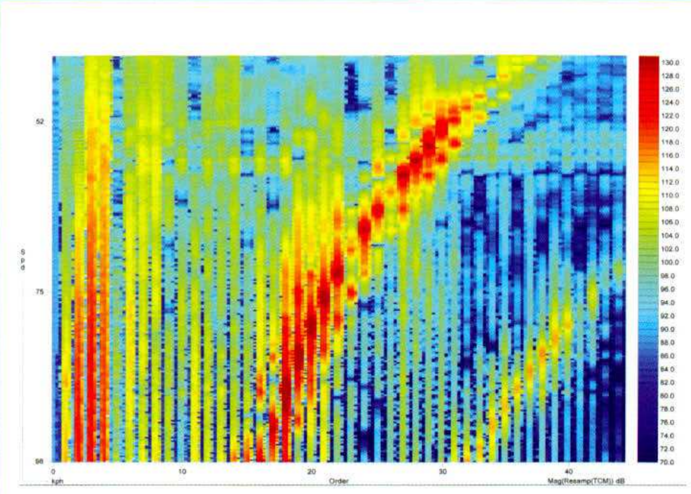


Figure 5

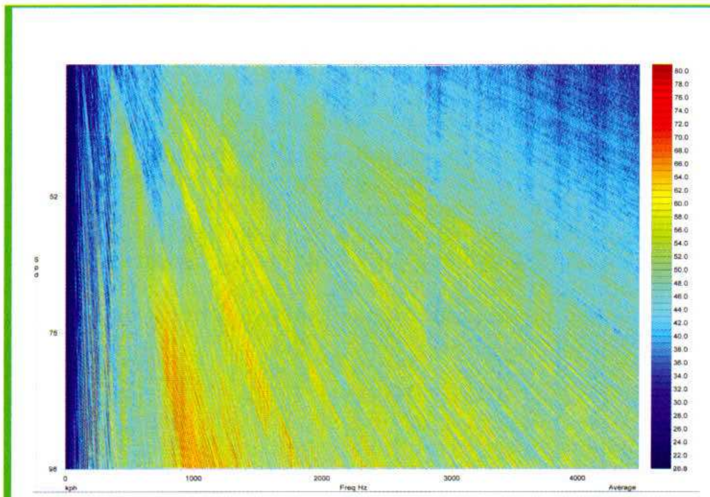


Figure 6

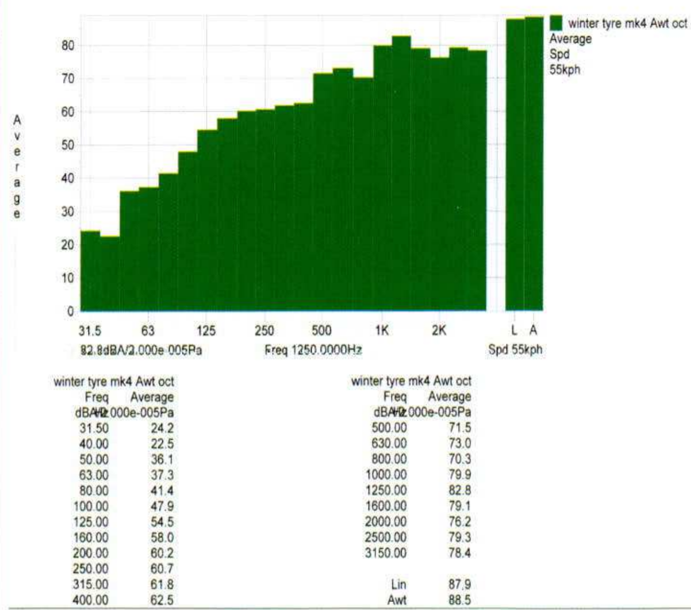



Figure 7

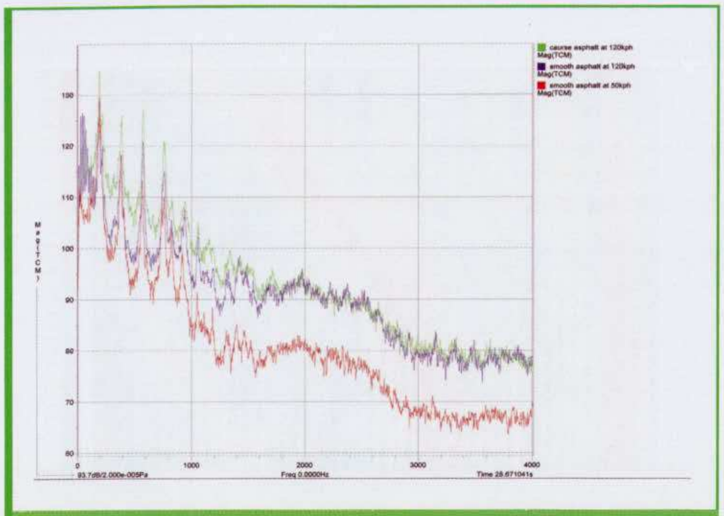


Figure 8

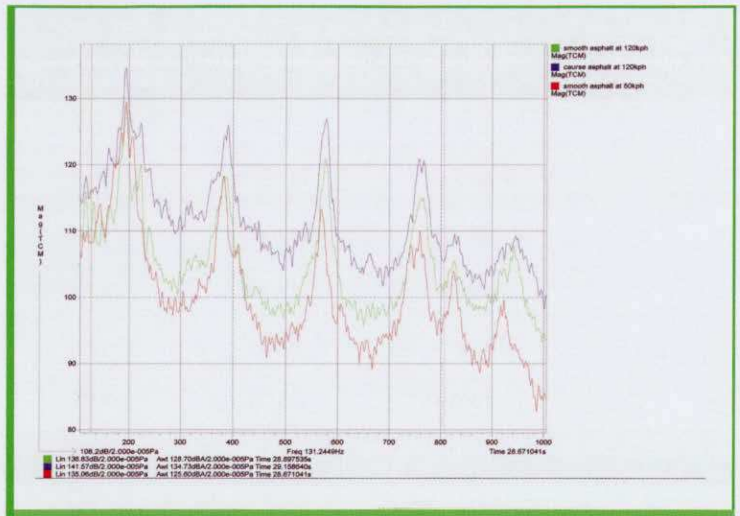


Figure 9

◄P36 see figure 7. It is, however, important to remember that when the wheel is running on the road the energy feeding the system is coming from the tyre tread pattern and the road surface irregularities, in these laboratory measurements there is no texture on the steel road wheel.

At this point in the development of TCM we were fairly confident that we could now explain some of banding (amplitude modulation) in terms of the interactions between tread inputs and the cavity and structural resonances. For the tyre manufacturer the challenge was to build tyres with all the desirable and necessary wet grip and energy efficient running characteristics and, in addition, to subtly change the carcass construction and the tread pattern to lower resonance based amplification of tread noise.

## Road surface noise measurement

Running tyres with TCM fitted on test tracks and roads required some redesign of the system. The two principal difficulties to overcome were:

1. Safety – Can TCM be guaranteed not to become detached inside the tyre and cause a catastrophic tyre failure at speed?
2. Usability – Can the battery life be extended to allow for the inevitable delays that will occur between fitting and running the vehicle on the test track or road?

In all the hundreds of tyres tested at Melksham with TCM fitted we have never had a module break free inside the tyre. We had run at speeds up to 100kph (60mph) but we recognised that test track drivers were unlikely to keep to such a low limit. Changes to the securing method resulted in the allowable speed to be extended to 160kph (100mph). Various automotive manufacturers specified that they would need TCM to be in a standby state for up to eight days and then operate for six hours. This was achieved by selecting very low power consumption components and increasing the battery capacity.

The ability to differentiate the noise rating of a road surface using any microphone-based system will require either measurements are made at a controlled speed or the measured data is corrected for speed. Clearly driving on the public highway at a set speed is likely to be considered somewhat inconsiderate by other road users and so a correction for "reasonable" variation from the target speed would be advantageous. The accuracy of the measurement is also likely to be dependent upon the tyre used but as yet this variable has not been explored. The results that are available today use the same car/wheel/tyre and are for speeds of 50 amd 120kph over coarse and smooth asphalt, see figure 8. There are two points to note:

1. At 120kph the change from smooth to coarse asphalt increases the SPL level measured by TCM by 6dBA from 128.7dBA to 134.7 dBA


Figure 10

2. Increasing the speed on smooth asphalt from 50kph to 120kph resulted in a noise increase of 3.1 dBA from 125.6dBA to 128.7dBA i.e. the large increase in speed did not greatly increase the measured dBA noise level.

The sensitivity to surface and speed is greater at the cavity modef requencies, see figure 9, by concentrating on the 100Hz - 1kHz region the ability to differentiate the surface is further enhanced.

Correlation of internal tyre SPL and pass-by radiated noise. The standard noise test, required by the EU, for tyres has been the noise generated by a four tyres coasting by at 80kph on a special ISO road surface. This noise rating at 80kph is reached by a linear regression for speeds from 70 to 90kph. The car approaches the measurement gate at speeds incrementing in 2kph steps. The rule of thumb, established over decades of testing, is that the noise goes up by approximately 0.5dBA for every 2kph increase in speed. The result obtained for the internal tyre noise mirrors this increase, see figure 10.

## Conclusions

The noise measured inside the tyre cavity tracks the level and frequency content of the far field radiated noise from the tyre. The roughness of the road surface is also transmitted into the tyre cavity. The chances are fairly high that the measurement of the internal tyre cavity noise level will describe the noisiness of a road surface. Research is required to prove this contention and then to define the most appropriate tyre for such measurements.

# The Wilson Committee Report 50 years on

*By Adam Lawrence*

It is 50 years since the Committee on the Problem of Noise published its final report (command paper 2056), and this article examines what has changed and what has remained the same over this period. The committee was chaired by Sir Alan Wilson, and the report is commonly known as the Wilson Committee Report, or just Wilson.

I first became aware of this report when writing my dissertation at Salford University in 1995 and several of my colleagues at Atkins had copies on their bookshelves when I started in 1996. This report, to me, contains a comprehensive review of noise at the time. Readers should note that I was born about 10 years after it was published, so I don't have first-hand experience of the noise climate reported. I would like to thank colleagues who gave feedback on this article.

As background to the report, in November 1959 the Minister of Health was addressing matters regarding noise abatement. Following this, the Cabinet Home Affairs Committee asked the Minister of Health (in consultation with other ministries) "*to put before them as soon as possible proposals for the constitution and terms of reference of an enquiry into the problem of noise*".

The Wilson Committee on the Problem of Noise was appointed by The Rt. Hon. Viscount Hailsham QC, Lord President of the Council and Minister for Science, "*to examine the nature, sources and effects of the problem of noise and to advise what further measures can be taken to mitigate it.*" The main committee first met in April 1960 and an interim report 'Noise from Motor Vehicles', was published in June 1962 (command paper 1780). The committee undertook several years of research and investigation, consulting with a whole appendix of contributors, and clearly there is not enough space here to consider every aspect of their work.

Here I have attempted to compare 1963 with 2013 following the order of presentation and chapter titles from the 1963 Final Report. The committee accepted the definition of noise as "*sound which is undesired by the recipient*"." This definition is still used today.

## Effects of noise

The main effect of noise described is sleep disturbance, with particular attention drawn to the early part of the night when people are trying to get to sleep. The other effects noted are annoyance and speech interference. The committee was unable to find any specific evidence that mental or nervous illness resulted from noise and they were unable to draw conclusions as to whether noise affected productivity and accidents.

The World Health Organisation (WHO) concluded in 1999 that there was a weak link between long-term high levels of noise and risk of cardiovascular effects, and that there were some negative cognitive performance effects, affecting productivity and learning. These effects are detailed further in the 2011 WHO Burden of Disease from Environmental Noise report, which also develops sleep disturbance and annoyance. The UK HPA identified in 2010 that noise gave rise to raised levels of stress hormones (Environmental Noise and Health in the UK). There is still no clear link between noise and mental illness.

## Law

At the time of the report the Noise Abatement Act had been recently enacted (in 1960). The report describes how the Act works, and gives an overview of Civil/Common Law. The committee made a number of proposals for additional laws with their objective that legislation should have the main aim of preventing noise. I shall not try to list all of the current Acts and Regulations relating to noise in the environment but will just observe that none of these prescribes a "maximum" noise level which should not be exceeded.

## Noise in towns

The report describes a number of surveys of noise undertaken in 1948, 1951 and 1961/62 and offers a comparison. In the 61/62 survey 84% of locations in central London were dominated by noise from road traffic, which was identified as the source which most disturbs people. By comparison with the 1948 study there was a significant increase in those who notice noise outdoors. The report looks at the problem of road traffic and notes that urban road schemes are short term solutions and by-passes and ring roads are recommended. The report was published just after the opening of the first section of motorway in 1959, part of the M1. A vision is given for towns "50 years or so ahead" where through roads are underground or pavements are all at first floor levels with windowless ground floors. Towns would have precincts with housing facing away from major roads.

The Defra 2000 National Noise Incidence study found that road traffic noise was heard at 88% of sites. In the corresponding Noise Attitude Survey 84% of people were found to hear traffic noise and 40% of people were bothered by it to some extent. Regular travellers will know that there has been little underground or 'surface tunnel' road construction in towns built in the last 50 years, but there has been some movement with having buildings acting as barriers to shield sites. I'll mention the 1970s Byker Wall as one example.

## Noise within buildings

This chapter in the report draws on the 1960 revision of the code of practice "Sound Insulation and Noise Reduction", first published in 1948 (and which became BS8233 in 1987).

Recommended maximum internal noise levels are set for dwellings for day and night periods in terms of dB $L_{A10}$, set at the level which would be acceptable to 70-75% of the population, P40


Steam trains were still running in 1963

◄P39 based on the results of the 1960/61 survey in London, allowing a reduction in external noise levels of 10dB for open windows and 20dB for closed.

| Situation | Day | Night |
|---|---|---|
| Country areas | 40dB $L_{A10}$ | 30dB $L_{A10}$ |
| Suburban away from main traffic routes | 45dB $L_{A10}$ | 35dB $L_{A10}$ |
| Busy urban areas | 50dB $L_{A10}$ | 35dB $L_{A10}$ |

The noise levels of 30 and 35 dB are still used for bedroom noise limits, although in $L_{Aeq}$ terms and not $L_{A10}$ terms, and are related to WHO sleep disturbance research. It should be noted that the 2009 WHO Night Noise research recommends a night time noise level of 40dB $L_{night,outside}$ to protect against health effects including sleep disturbance.

The report also considers sound insulation – a reduction of 50dB between dwellings was considered to be acceptable to most people (Grade 1 performance from BRS Digest 88, 1956). Noise in schools, hospitals and other buildings is also discussed.

## Noise from motor vehicles

The chapter discusses the various sources of noise from motor vehicles, and refers to the 1955 Motor Vehicles Regulations which did not permit excessive noise. As is currently the case, noise could be controlled by maintaining the vehicle, by altering driver behaviour, and by attention to the way the vehicle is loaded.

The highest noise levels from vehicles were identified as being when the vehicle is accelerating, and a measurement procedure (BS3425:1961) was described which measured noise under controlled hard acceleration. The basis of this was that if you controlled the maximum noise then the overall noise would be lowered. A study was undertaken to determine an acceptable level of maximum noise from a motor vehicle (motorcycles ~83dBA, other vehicles ~80dBA) and to recommend that all new motor vehicles except motorbikes should not exceed 85dBA, with motorbikes limited to 90dBA balancing desirability and cost. Earlier in 2013 MEPs voted for noise from new cars to be limited to 68dBA, reduced from the current 74dBA limit.

## Noise from other surface transport – railways

The main issue in the Wilson report is the noise effects of the gradual replacement of steam trains with electric and diesel trains and the public unfamiliarity with the "new" noise sources. At that time it was already policy to replace jointed track with continuously welded rail. The noise level inside most rolling stock was described as "uncomfortably high". The cost of installing double glazing and air conditioning in all passenger coaches was described by the British Transport Commission as "too high". There was no evidence of widespread public annoyance from railway noise.

One of the main changes with railways at that time was the Beeching report, The Reshaping of British Railways, published in March 1963, just before the publication of the Wilson Report. I'll also draw the comparison with the next unfamiliar new railway source – high speed trains.

## Aircraft noise

The Wilson report focused on noise from Heathrow, and this subject had the biggest page count and appendix count of all topics. It was a time of transition with the introduction of larger turbojet aeroplanes in 1958, resulting in a peak number of complaints in 1960 before people became acclimatised to the new noise source. It was observed that Heathrow had been established in a much too densely populated area and that "noise to which many people near London Heathrow Airport are subjected is more than they can be reasonably expected to tolerate". No good solution to the acute noise problem was considered possible. In the wider context it was concluded that there were no sparsely populated sites in the country suitable for large civil airports. However, properties were continuing to be built near Heathrow, suggesting that people were prepared to balance the impacts of noise against the benefits of the location. Doctors working near the airport concluded that noise did not have any significant effects on the health of their patients.

The report discussed the operational impacts of placing restrictions on the flights and how that might affect the viability of the airport and the economics of the country. The expectation was that Heathrow would be at capacity by 1970, and from then quieter aircraft would reduce the noise levels.

There was a discussion around the provision of costs of providing insulation to existing dwellings, and a scheme recommended, noting that it was unprecedented to pay compensation for loss of amenity. Much research was done for the report to establish acceptable levels of aircraft noise, and the Noise and Number Index was proposed as the preferred index for assessing aircraft noise. Noise maps were prepared showing the extent of the noise impacts.

In 2013 the discussion is around a new hub airport, with evidence being collected by the Davies commission, acknowledging that Heathrow in its current form is effectively at capacity and that the desire to maintain a premier international airport means a significant solution is needed. The 2006 results of the Strategic Noise Mapping exercise showed that in the UK there were over 800,000 people exposed to aircraft noise over 55dB $L_{den}$, of whom about 70% live near Heathrow.

## Noise from industry

Industrial noise causes annoyance, but there were differing social and economic attitudes to industry, and people were more tolerant of such noise in industrial areas than in other areas. A definition of light industry was given where work could be carried out in a residential area without detriment from noise or vibration. At the time of the report the noise output of a process was rarely considered in the decision making process, although it was noted that noise had been the grounds for refusal for some planning applications. The usual noise control solutions were described – reduction at source, reduction of the transmission, reduction at receptor, and various suggestions were made to control industrial noise.

An assessment procedure was given for industrial noise where a noise measurement would be taken at a property. A basic noise level would be allowed for the source, and a noise limit derived following a series of allowances which would be made for operating time, type of area and the intermittency of the noise source. If the measured value exceeded the limit then complaints might be expected.

It was noted that some processes were especially noisy, for example a drop forge, and it was suggested that these processes should be registered and best practicable means used for noise control. The presumption was that all other industrial noise sources could be mitigated to acceptable levels. It was thought that this registration would enable the defence of best practicable means to be removed for those not-especially-noisy processes.

The method for assessing industrial noise in 2013 is BS4142, which was first published in 1967 using the method outlined in the Wilson report. Larger industrial activities are covered by the EU Integrated Pollution Prevention and Control (IPPC) Directive 1996, which requires application for a permit to operate, and which includes noise.

## Noise from construction and demolition

The report came at a time when the majority of construction noise came from equipment/plant, much of which had been brought into use in the previous 20 years. It was stated that noise had not been a concern of the equipment manufacturers, and that there was a need to create conditions where contractors requested quieter plant. The biggest noise improvement described was the introduction of vibro-driving sheet piles over impact driving.

Noise limits for such activities were suggested such that conversation should be possible in nearby buildings with the windows closed, and appropriate planning was considered necessary. It was noted that buildings works at night were rare, giving noise limits of external levels of 65-75 dBA, with 70/75 being recommended between 07:00 and 19:00 depending on location. Another emphasis for this chapter was the need for publicity for works, beginning with raising the awareness of the impacts of noise in the industry. It was recommended that there should be statutory control over construction noise and that contractors should agree in advance of their works, ►

◘ what plant they were going to use and how much noise they were going to make.

In 2013 the situation is very similar, and those suggested 70/75 dBA noise limits are referenced in the 2009 version of BS5228 (Part 1, Annex E2) as a valid approach for considering construction noise. It is noted that other methods of assessment are now also given.

## Entertainment and advertising noise

This chapter referred to the noise caused by people enjoying themselves or by advertisers. Essentially the entertainment part was considered to be general disturbance in public places, music from cafes, pubs and clubs and motor sport. The advertising part was considered to be from mobile shops and from hawkers. The context was another time of transition, with the "recent" arrival of transistor radios, juke boxes and ice cream van chimes. Three types of noise were considered:-

- Occasional and unpredictable noise – it was observed that there was less noise from rowdiness and street musicians than there was 30 years ago, and the noise was expected to decrease as living standards increase.
- Occasional and predictable noise, for example fun-fairs and sporting activities, meant further noise controls were not needed, but events needed to be planned so not to cause unreasonable disturbance. There was a need for prior approval for this type of event.
- Frequent and predictable noise – for example pubs, clubs, cafes and advertising noise – should be controlled in advance by the use of planning and licensing.

In 2013 planning and licensing control many of the noise sources described above, and noise in the street can be a statutory nuisance (Noise and Statutory Nuisance Act 1993).

## Noise in the country

The introduction to this chapter observed that noise in the countryside was increasing as a result of the greater number of townspeople being able to visit, the construction of motorways and the increase in machinery used in farming. It was observed that urban noises made in the countryside might give rise to greater annoyance because of the lower background noise levels.

The chapter discussed noise from mineral workings, agriculture and forestry, but concluded that the machines which caused the most complaint were lawnmowers. The report recommended legislation to limit noise from lawnmowers, but observed that at the time there was no incentive for manufacturers to reduce noise levels since quieter models were more expensive to produce than nosier ones.

In 2013 noise from equipment used in the outdoors, including lawnmowers, is limited by legislation, with a sound power limit given for each type of equipment (The Noise Emission in the Environment by Equipment for use Outdoors Regulations 2001). I'll also mention another new noise source in the country – wind turbines.

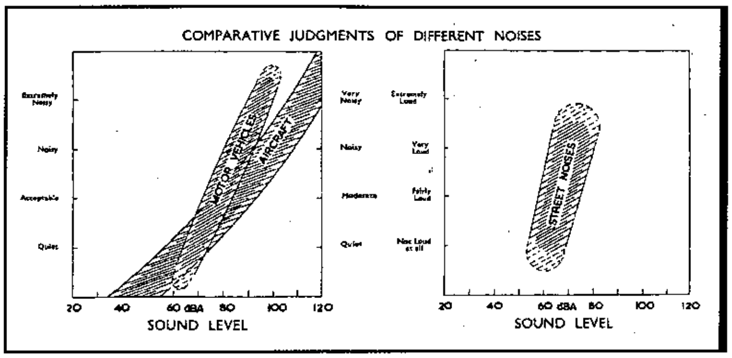
## Occupational noise

The final chapter of the report considered occupational noise. A review of various studies which recommended that hearing protection should be worn when noise levels were about 90dBA (derived from results presented in octave bands indicating protection should be applied when the level in any band was exceeded). These were based on working day exposures. The principle of using energy averaging was discussed, although it was not thought to be applicable to exposures of less than one hour. Peak noise limit recommendations were made of 135dB or the threshold of pain. In 2013 occupational noise is controlled via legislation in a similar way which includes daily exposure and peak limits (The Control of Noise at Work Regulations 2005) with eight hour equivalent noise levels above 80dBA now being considered.

## Concluding remarks

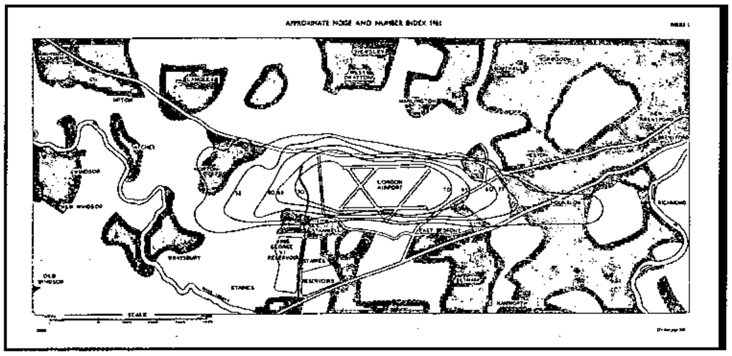
It was my observation after reading the report that the soundscape of the UK at the time was undergoing a significant change. Motorways had recently been introduced which had neither speed limits nor vehicle noise limits and there were many plans for large-scale road schemes. Steam trains were gradually being replaced by diesel and electric trains, passenger jet aircraft had been introduced, there was increased mechanisation of construction and agricultural work, and amplified music was becoming prevalent. I then considered if this was a particularly unusual time by comparison with today, with electric cars, wind turbines and high-speed trains being introduced, heavy industry and mining decreasing, the use of the internet and out-of-town retail affecting personal travel and goods deliveries, and the prevalence of earphones disconnecting much of the population from the sound environment. Perhaps Wilson was simply a good snapshot of a particular time in our ever-changing audible environment?

However, looking at this from an acoustician's point of view there are many things that the Wilson Committee did which still affect our working lives: The assessment of aircraft noise was fixed, and a scheme for insulation grants provided. Industrial noise assessment was simplified and formalised. Noise data was presented in the form of noise maps and subjective 'dose-response' figures were presented. Throughout the report the impacts of noise were considered together with the cost and practicality of noise control as well as the demand for reduced noise levels. There are many other recommendations and statements made in the Wilson Report which are relevant today, and which have influenced many decisions made in the 50 years since its publication. ◘




**Comparison of people's reaction to noise at home in the 1948 and 1961 surveys**

| Individuals' reaction to noise | External noise (per cent. of people) | | Internal noise (per cent. of people) | |
|---|---|---|---|---|
| (i) | 1948 (ii) | 1961 (iii) | 1948 (iv) | 1961 (v) |
| Those who are disturbed by noise ... ... | 23 | 50 | 19 | 14 |
| Those who notice but are not disturbed ... | 19 | 41 | 21 | 14 |
| Total of people who notice noise ... ... | 42 | 91 | 40 | 28 |
| Those who do not notice noise ... ... | 58 | 9 | 60 | 72 |
| | 100 | 100 | 100 | 100 |



The IOA is holding a meeting entitled The Wilson Report – 50 years on at the Royal Society, London on 29 October. See the website for more details.

# Hearing enhancement with an array of phase shift sources

*By Marcos Simón*

It is estimated that disputes over TV volume affect one in 10 households. This is often caused by some family members having age-related hearing loss. Although about half of people over 60 have some degree of age-related hearing loss in the UK, only about 20 per cent of these people wear hearing aids, for one reason or another, making other means of improving the perception of the TV sound desirable. The aim of the innovation is to create an array-based system to enhance hearing while viewing TV, which would improve speech intelligibility for hard of hearing viewers, without annoying other viewers with normal hearing. In the case where people with different hearing thresholds are watching TV together, there would then be no need to turn up the volume of the TV in order for the hearing impaired to listen properly. The array would boost the audio signal in a spatial zone where the hearing impaired person/s are sat, while maintaining the same audio levels at other positions. The array design was based on the degree of hearing impairment and its frequency range for a 70-year-old woman, so that a boost of about 10 dB is required between about 500 Hz and 8 kHz.

The array comprises eight phase-shift sources, which can be driven to give a highly directive response, while minimising the reverberant excitation of the room. Although line arrays have been studied for many years, the approach previously used to reduce the radiation at the rear of the array, and hence reduce reverberant levels for other listeners, has been to position a second set of loudspeakers at the back of the array to cancel the sound in that direction. The array presented here uses individual loudspeaker elements that are specially designed first-order acoustic radiators, or phase shift sources, thus saving cost and improving the robustness of the array to variations in the sensitivity of the elements. The phase shift sources create a reduction of directivity at the rear of each element, due to a delay network formed by the speaker's cabinet and a rear port acting as an acoustic resistance, in an analogous way to how a phase shift microphone works. The loudspeakers used for the array are designed to have a close-to-hypercardioid directivity from 500 Hz to 8 kHz, which is obtained by optimising the frequency dependent resistance for the rear port, as shown in figure 1. The hypercardioid directivity is chosen since it has the minimum radiated power for a given on-axis response, which will least excite the reverberant field. The rear port resistance value increases with frequency, allowing the rear port to act as a negative delayed secondary source at low frequency, when the phase shift effect is working, but making the cabinet work as a closed back cabinet at high frequency, when the loudspeaker has a naturally high directivity due to its beaming.

The front and back of an individual loudspeaker element is shown in figure 1, together with the array of eight elements. The driving signals for the eight sources line array are designed using novel beamforming techniques, which makes the array superdirective at low frequencies. As the individual sources have been optimised to work as hypercardioids, the input to the reverberant field is reduced, which is important if the array is placed inside a room. The measured directivity Index of the array is shown in figure 2, together with the results of a simulation performed with free field point hypercardioid sources, with which the agreement is reasonably good. figure 3 shows the directivities obtained at different frequencies when the array is optimised to maximise the acoustic pressure between radiated at angles of 0° and -15°, and minimise it everywhere else. ■

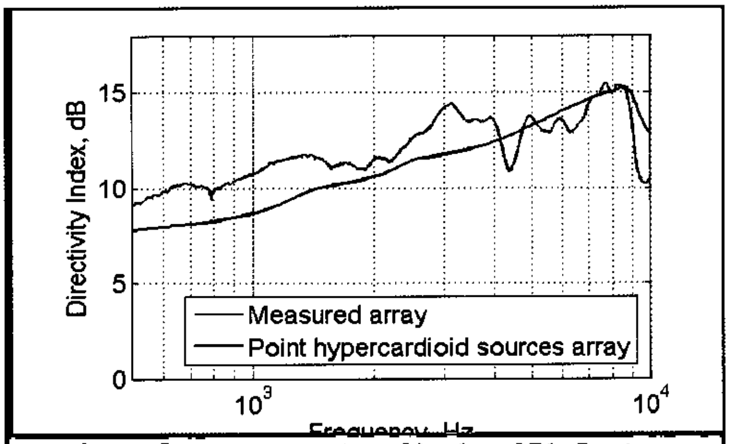



Figure 1 The front and back of one of the phase shift loudspeaker elements used in the array (left) and the eight elements arranged in a linear array (right)

Figure 3 Measured directivities of the array at different frequencies when this is optimised to maximise the acoustic pressure between 0 and -15 and minimise it everywhere else. From left to right measured in the free field at 1 kHz, 2 kHz, 4 kHz and 6 kHz.

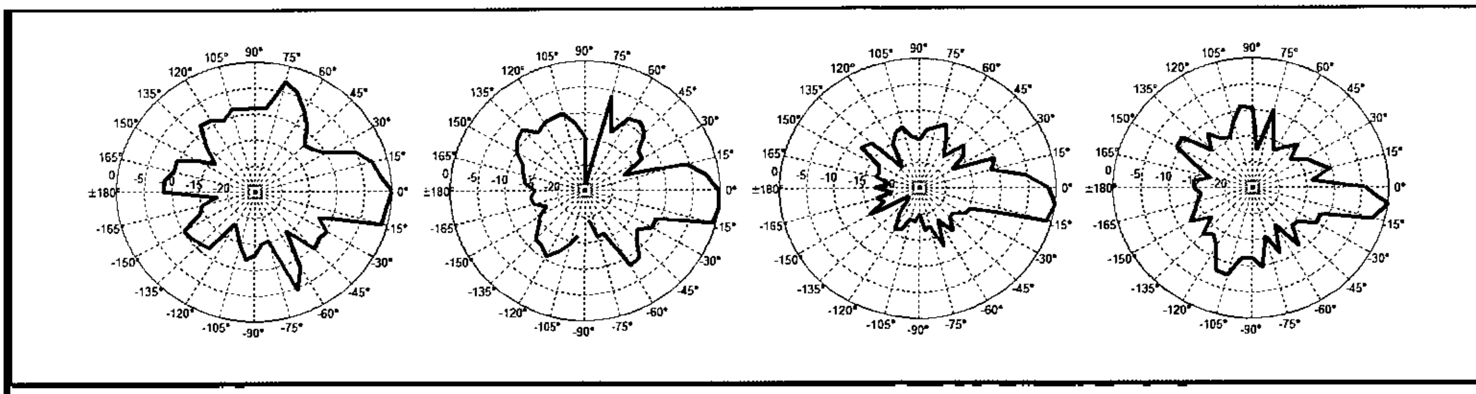


Figure 2 Directivity Index of the 8 source array using phase shift sources, measured in the free field and calculated from simulations using point hypercardioid sources

# Improving the design of dissipative silencers used in HVAC and gas turbine applications

*By James Hill, AAF, Ray Kirby and Paul Williams, School of Engineering and Design, Brunel University*

## Introduction

Dissipative silencers are very common in HVAC and gas turbine applications, where they are used to attenuate broadband noise. Knowledge of the acoustic performance of these silencers is essential before generating a suitable design for a given application and here this design process has traditionally relied on:

1. An exhaustive testing program that is carried out to gather as much data as possible, from which silencer insertion loss predictions are interpolated; or
2. A calculation method, which is normally derived from design charts or relies on the symmetry between silencer designs in order to simplify the equations to be solved.

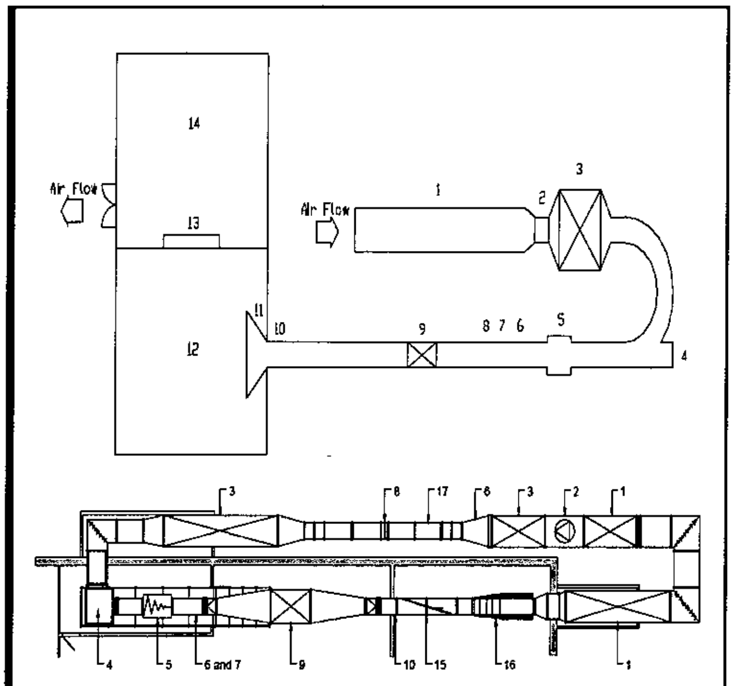
Two Knowledge Transfer Partnership (KTP) projects, one between Brunel University and Caice Acoustic Air Movement Ltd [1], and another between Brunel University and AAF Ltd [2], have set out to assess the suitability of these traditional design methods in a modern engineering environment.

In addition, the two projects resulted in a collaborative project between Caice and AAF, in which the measured insertion loss of silencers taken on two different test rigs were compared. Caice measured silencer performance at their own facility developed as part of the KTP project and AAF measured the performance of the same silencer at the test rig they commissioned at Salford University. This provided an opportunity to compare the effect of the different termination conditions allowed within the ISO 7235 standard [3].

Some of the key problems that the projects have attempted to address are:

1. How reliable are silencer measurements on an ISO 7235 test rig and how do the different end conditions affect the measurement?
2. How accurate are silencer insertion loss predictions when compared to ISO 7235 measurements?
3. How does temperature affect the silencer performance?

A summary of the results from these investigations is reported in this article, as well as a discussion on the implications of these results for both HVAC and gas turbine silencer design.




1. Fan inlet silencer
2. Fan unit
3. Fan outlet silencer
4. Loudspeaker plenum
5. Modal filter
6. Inlet temperature probe
7. Inlet pressure tapping point
8. Flow rate sensor
9. Silencer test piece
10. Discharge pressure tapping point
11. Transmission piece
12. Source reverb room
13. Acoustic louvres
14. Receiving reverb room
15. Microphone measurement test duct
16. Anechoic termination
17. Additional pressure tapping point

Figure 1. ISO 7235 test rigs commissioned by Caice and AAF.

## Commissioning an ISO7235 test rig

Both AAF and Caice have commissioned test rigs in accordance with ISO 7235. However, AAF utilised a reverberation room as the termination condition and measurement location whereas Caice used an in-duct measurement with anechoic termination. It is a significant undertaking to design and construct a test rig conforming to ISO 7235, with many tests needing to be performed and a large amount of work tweaking the design in order to meet the criteria set out in ISO 7235. Notably, there are requirements for the reflection coefficient of the source and termination, the longitudinal attenuation of the modal filter and background noise levels. In addition, there is a requirement that the sound field in front of the test object is dominated by an acoustical plane-wave mode.

The layouts of both the test rig at Salford University, commissioned by AAF and the test rig at Caice, are shown in figure 1. The majority of the qualification requirements were unaffected by the differences between the two rigs. The limiting insertion loss of the Caice rig is slightly better with no flow but this is most likely due to the part of the rig including the sound source being located outside rather than anything to do with the termination conditions. With flow, the Salford rig was capable of measuring slightly higher insertion losses which is thought to be due to the arrangement of the loudspeaker source.

In the ISO 7235 standard (and also the American E477 [4] standard) a preference is given towards the use of a reverberation room as the termination condition. Whilst the reasoning behind this is not extensively covered in either the standard or the literature, the most obvious reason would be to do with the difficulty of accurately measuring the sound field in a duct with flow. However, it became obvious when trying to commission the test rigs that it was only practical to take measurements with low flow velocities in order to overcome the effects of flow noise. This is largely because of the requirement for an incident plane-wave, which lowers the signal to noise ratio by requiring (i) a modal filter and (ii) a source arrangement that closely matches a loudspeaker P44

P43 baffle attached to the duct. It was found that the only way to meet the source requirement was with the loudspeaker pointing straight down the duct, meaning either a bend or obstruction in the flow path was required. Thus, it was observed that when commissioning an ISO 7235 test rig significant problems were caused by flow noise when measuring with mean flow, and that the resulting reduction in signal to noise ratio limited the measurements to relatively low silencer face velocities.

## The effect of the termination conditions on ISO7235 measurements

Following the successful commissioning of the two test rigs, the insertion loss of an identical silencer was measured on both test rigs [5]. It was found that the reproducibility across the two test rigs was equivalent or better when compared with the expected repeatability quoted in the standard for a single test rig for the frequency range 100Hz to 10kHz. Between 50Hz and 80Hz the reproducibility started to deteriorate, moving above the quoted repeatability. One explanation for this, given that the low frequency measurements taken on the in-duct rig more closely match theoretical predictions, is that the reverberation room used for the Salford rig was only qualified down to 100Hz. The reverberation room had a volume of 125m$^3$, therefore it may be the case that a room qualified down to 50Hz, where a volume of approximately 300m$^3$ is required, may deliver repeatability in the results below 100Hz. However, when the additional cost of a reverberation room of this size is considered, the benefits of using this approach over an in-duct method appear to be minimal. In reality, it would appear that the user would be better advised to use whichever termination method is more convenient, which will probably be dependent on whether the reverberation room is required for other uses.

## Comparison of FEM predictions with ISO7235 measurements

In the KTP projects undertaken by the authors, as well as previous work by Kirby et al [4-6], computational models suitable for predicting the insertion loss over a wide range of different silencer designs have been developed. The computational models are based on the finite element method and are designed to use the most efficient modelling techniques available. In this way, insertion loss predictions may be generated relatively quickly and so readily integrated into a commercial design process. It is, however, important to fully validate the theoretical models and here the KTP projects have delivered large amounts of experimental data obtained at room temperature, which has allowed for the validation of the theoretical model over a large number of different silencer designs.

Two examples of the validation process are shown in figures 2 and 3. In figure 2, the IL for a traditional parallel baffle design is compared against experimental measurements at room temperature; and in figure 3, prediction and measurement are compared for a bar (or brick) silencer. It is evident in both these figures that agreement between prediction and measurement is generally good, although it is noted here that for silencers of low open area (typically below about 35%) the theoretical predictions may overestimate silencer performance at higher frequencies. This effect may be mitigated by amending the impedance of the perforated screen that separates the porous material and the airway, and this correction has been applied here. This correction to the perforate impedance has been obtained following comparison between prediction and measurement for up to 40 silencers, and the factor used is the same for all silencers studied. Thus, by making small amendments to the theoretical model for silencers of low open areas we have been able to maintain good agreement between prediction and experiment across a wide range of silencer geometries. Accordingly, through the implementation of an extensive measurement programme, the KTP projects have delivered a validated and working theoretical model for computing the performance of dissipative silencers.

## The influence of high temperatures on silencer performance

It is common for dissipative silencers to be used in high temperature applications such as in the exhaust systems for gas turbines [2]. Here, temperatures can reach up to 670°C and clearly it would be impracticable to use ISO 7235 to measure the performance of these silencers. Therefore, the only alternative is to use theoretical models to estimate silencer performance and here the KTP project with AAF ▶

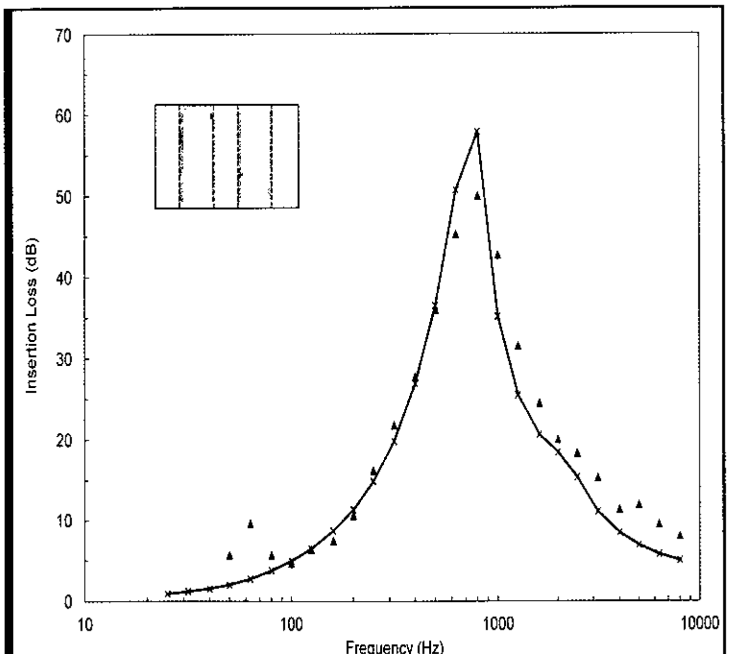



Figure 2. Insertion loss for parallel splitter silencer at room temperature: ▲ measurement; ——— prediction.

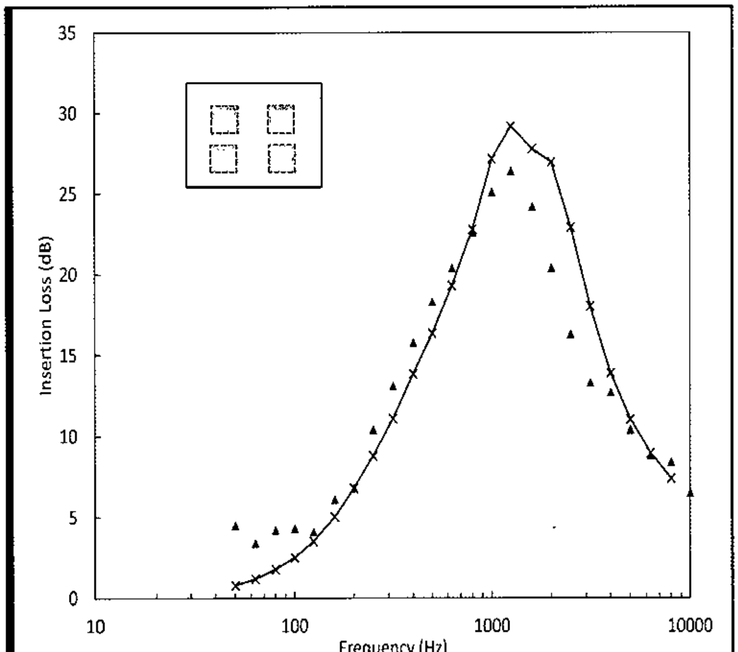



Figure 3. Insertion loss for bar/brick silencer at room temperature: ▲ measurement; ——— prediction.

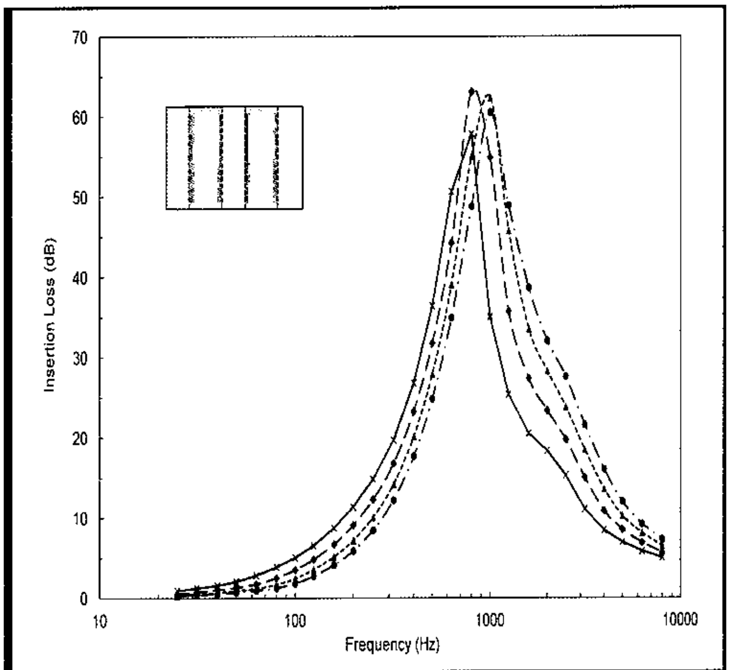
sought to measure the acoustic properties required by the theoretical model in order to deliver predictions at higher temperatures. The most important properties are those related to the performance of the attenuating material, which for gas turbines is normally a rock/basalt wool, or a glass fibre. Accordingly, the bulk acoustic properties of these materials were measured at higher temperatures before then feeding back this data into the theoretical model.

In order to measure the bulk acoustic properties, an impedance tube was designed according to ISO10534-2:2001 [9], see figure 4. The nominal frequency range of the tube is between approximately 500Hz and 1950Hz at 20°C. In practice the usable frequency range varied because of the accuracy of the signal processing equipment and the quality of the material samples. In order to accommodate higher temperatures, the standard impedance tube design was modified so that the bulk acoustic properties of a material could be investigated between 20°C and a maximum temperature of 500°C. Heating was provided by 11 band heaters, which were equally spaced along the impedance tube. The heaters were controlled automatically using K-type thermocouples placed within the tube, which allowed the temperature within the tube to be equalised. To prevent heat damage to the loudspeaker a water jacket was placed around the loudspeaker end of the tube, and to prevent damage to the microphones steel probes were used with heat-sinks to dissipate excess heat. An acoustically transparent barrier was also placed inside the impedance tube in order to reduce convection currents between the region surrounded by the cooling jacket and the high temperature section of the tube.

The most challenging aspect of these measurements lies in maintaining a constant temperature within the tube. Following many modifications to the test rig, it was found possible to achieve a maximum temperature difference within the tube of 5°C in the axial direction, and 2°C in the radial direction for all of the tests undertaken. However, for most of the tests these temperature differences were found to be even lower, and this temperature profile was judged to be acceptable. Measurements of the bulk acoustic properties of rock wool, basalt wool and fibre glass were then obtained at temperatures of 20°C, 200°C, 300°C, 400°C and 500°C using a two microphone method [9]. The bulk acoustic properties for fibre materials may then be represented using the method of Delany and Bazley [10], which requires the calculation of eight regression coefficients. These coefficients are found by plotting the bulk acoustic properties against the non dimensional parameter $\xi$, where

$$\xi = \frac{\rho f}{\sigma}.$$

Here $\rho$, is the density of air, $f$ is frequency and $\sigma$ is the material flow resistivity. It is, of course, straightforward P46




Prediction of the effect of temperature on the insertion loss of a parallel splitter silencer: 20°C, 200°C, 400°C, 600°C

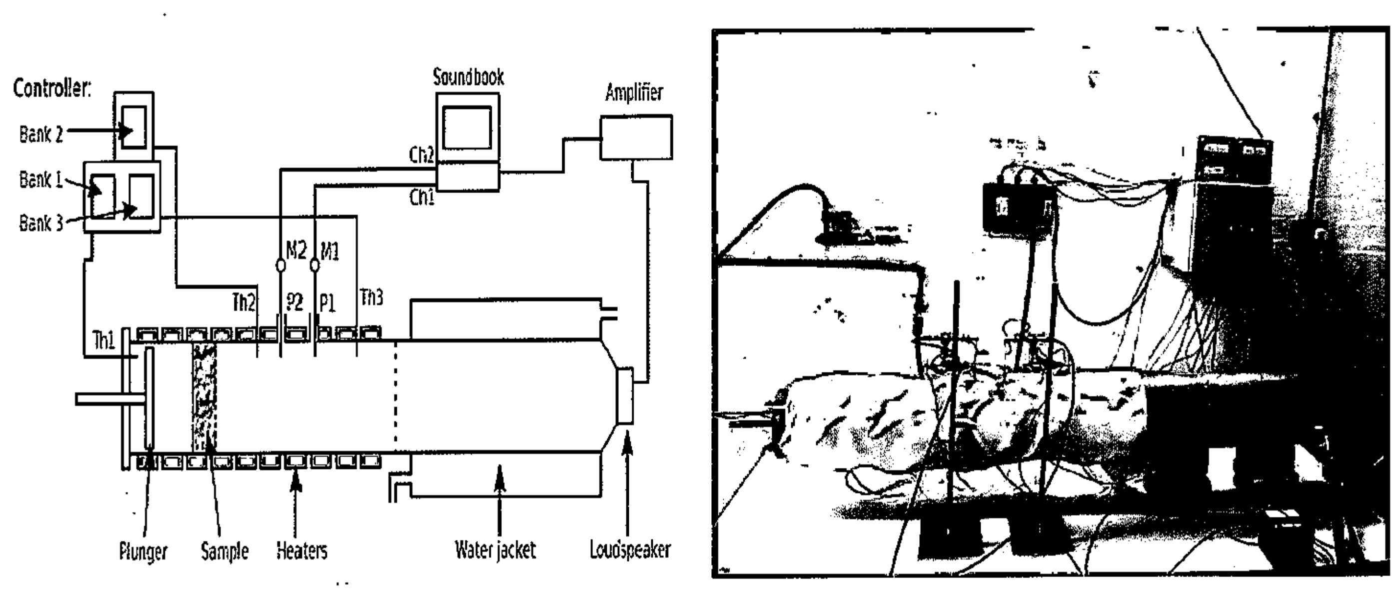



Figure 4: High temperature test rig for measuring the bulk acoustic properties

◄P45 to correct for the effects of temperature on the density of air, but for $\sigma$ a different approach is required. The following relationship between flow resistivity and temperature was suggested by Christie [11]

$$\sigma = \sigma_0 \left( \frac{T + 273}{T_0 + 273} \right)^{0.6},$$

where $T$ is temperature, and the subscript 0 denotes room temperature. Following the measurements at high temperature it was found that, provided one uses Christie's correction for the flow resistivity, it is possible to collapse the data measured at all temperatures using the method of Delany and Bazley. That is, one need only measure the Delany and Bazley coefficients at room temperature, and then correct for the effects of temperature on $\rho$ and $\sigma$ in order to obtain the bulk acoustic properties at higher temperatures.

The results obtained for the bulk acoustic properties at high temperatures make it very straightforward to account for a change in temperature in the theoretical model. In figure 5 the effect of temperature on the predicted performance of a splitter silencer is shown for a range of different temperatures. Here, it can be seen that as the temperature increases, the low frequency performance of the silencer reduces, whereas some increase in performance is observed at higher frequencies. This frequency shift is to be expected because of the rise in the speed of sound caused by the increase in temperature, although in order to properly capture this change in performance it is necessary to fully model the effect of temperature on the performance of the porous material. Figure 5 also illustrates that it is important to include the effects of temperature when designing dissipative silencers for gas turbine applications.

## Implications for silencer design

The process of measuring a large number of HVAC silencers, as well as developing theoretical models capable of capturing and explaining silencer performance, has generated new knowledge regarding the use of dissipative silencers in HVAC systems. Here, it is observed that traditional methods for estimating silencer performance and/or the extrapolation of experimental data drawn from generic experimental testing undertaken many years ago, has proved to be unsuitable for capturing the true performance of a HVAC splitter silencer [12]. Accordingly, it has been found during these KTP projects that it is necessary (i) to measure the performance of a new silencer design following ISO 7235 [3], or (ii) to use a validated theoretical model to estimate silencer performance, which for the silencers traditionally used in HVAC systems will require a sophisticated numerical model [6-8]. This is the only way in which one can have confidence in the quoted performance for a splitter silencer, at least on the basis of specifying its performance according to ISO 7235 [3]. Furthermore, this approach should then deliver more appropriate silencer specifications for a particular application and deliver the ability to avoid the practice of over sizing, which may in turn reduce the pressure losses in a typical HVAC system.

Silencers to be used in gas turbine exhaust systems are normally designed conservatively, and this is thought to be caused by the following:

1. A lack of understanding of the effect of temperature on material properties
2. The lack of suitable modelling methods
3. The physical size of the silencers and the impracticality of interpolating between a (necessarily) limited series of experimental measurements
4. The associated cost of providing a remedy to problems.

Therefore, through carrying out these collaborative projects, a thorough understanding of silencer performance has been achieved, including the effect of temperature on silencer performance. This has led to the development of a finite element model suitable for use in a day-to-day engineering environment within AAF, which has delivered a reduction in the length of their gas turbine exhaust silencers by approximately 20%, on average. This has led directly to a reduction in cost of the silencers, as well as a significant reduction in pressure drop, which increases the efficiency of the engine and therefore decreases emissions. The project has also delivered more confidence in the design of more complex silencer geometries such as bar silencers, which deliver an improvement in performance over traditional splitter silencer designs, including better airflow profiles, improved high frequency attenuation and less thermal stress. Thus, improved design techniques have allowed AAF to generate better silencer designs that deliver lower up-front costs, with the potential for silencer packages to deliver lower running costs, longer lifetimes and lower emissions in the future.

## Acknowledgements

The authors would like to thank the UK Technology Strategy Board for their funding of the work covered in this article through the KTP program (www.ktponline.org.uk) and Salford University for the use of their acoustic testing facilities.

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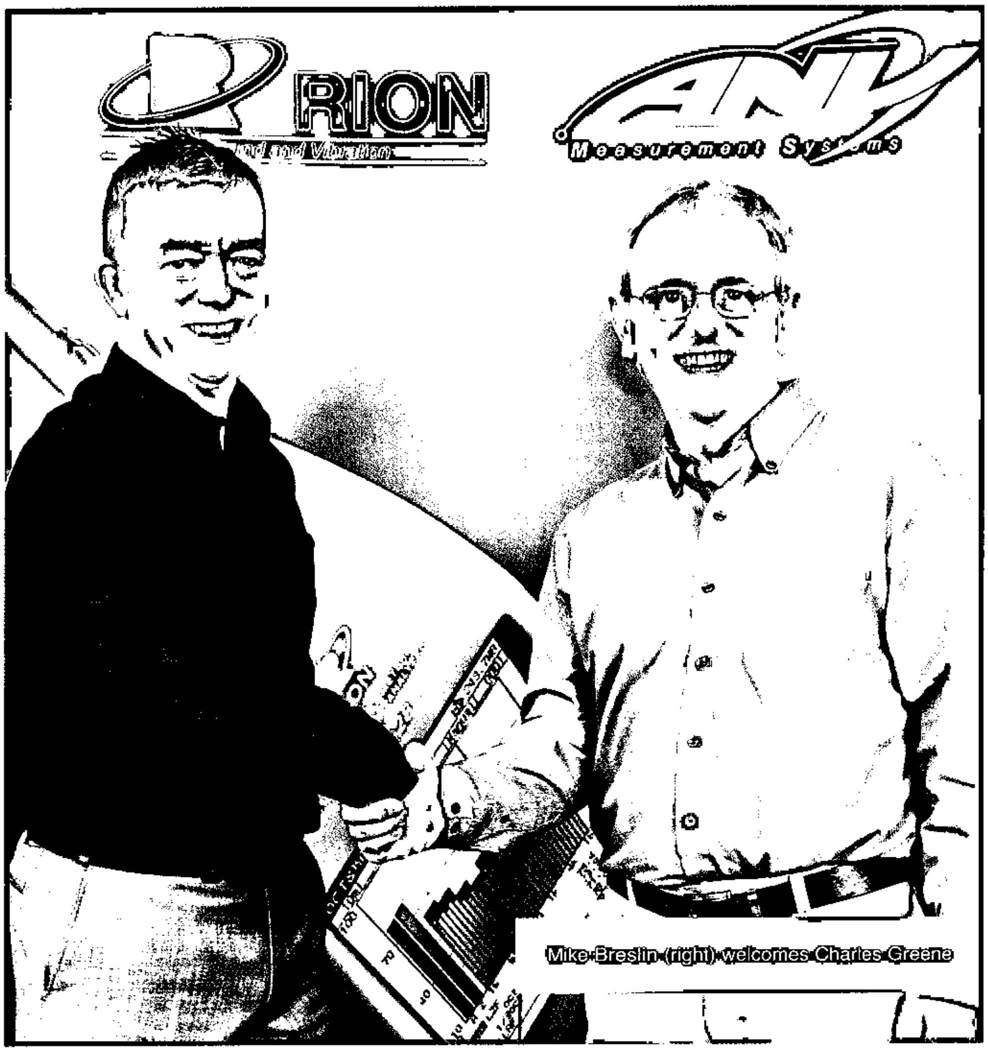
# Charles Greene comes aboard at ANV



Mike Breslin (right) welcomes Charles Greene

ANV Measurement Systems, Europe's largest distributor of Rion sound and vibration measurement systems, have appointed Charles Greene as UK Sales Manager.

Charles joins ANV from Brüel & Kjær where he spent almost 12 years working both in Denmark as Global Market Manager for the hand-held range of B&K instruments and in the UK as a Senior Sales Account Manager.

At ANV Charles will be responsible for managing the highly experienced sales team and introducing exciting new product lines and services planned for release throughout the year.

Mike Breslin, Managing Director of ANV, said: "I am delighted to welcome Charles to ANV where, along with our Service Delivery Manager, Andy Jones, and our recently appointed Calibration Manager Kiran Mistry, we will continue to improve and expand the range of calibration, hire and instrument services offered to our customers throughout the UK."

# Sasha Villa heads new Anderson Acoustics office


Sasha Villa

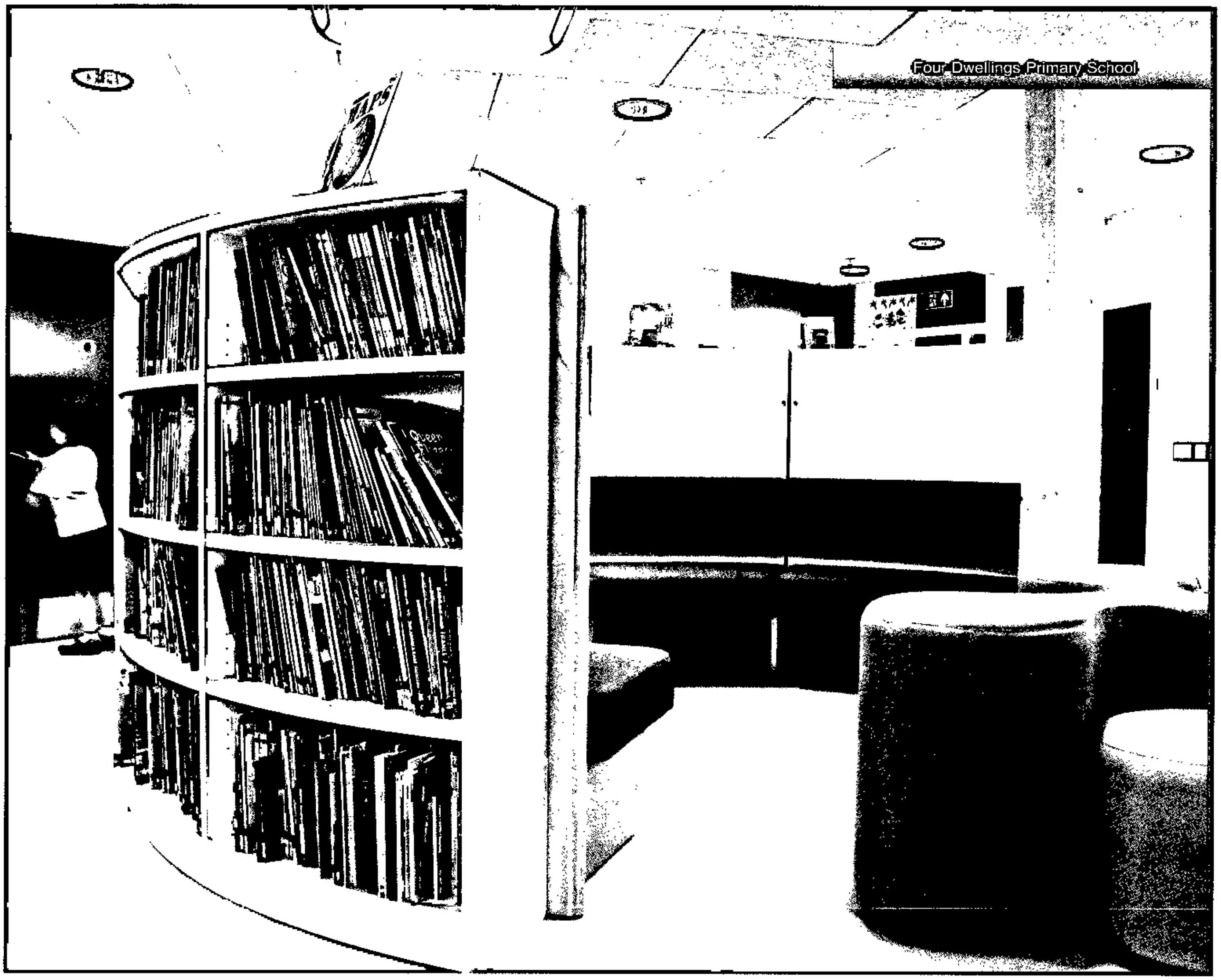
Sasha Villa has joined Anderson Acoustics to head the new London Bridge office of the Brighton-based company. He will be responsible for direction and leadership of the London team, providing technical expertise and supporting the growth of the company as a whole. He joins from Temple Group where he helped develop a large and successful acoustics team over a number of years.

Andy Knowles, Managing Director of Anderson Acoustics, said: "We are delighted to announce Sasha's appointment. Sasha brings a wealth of experience in environmental acoustics, having managed the acoustic elements of several high-profile projects, including HS2 appraisal of sustainability, Crossrail Farringdon and the Shard. As Anderson Acoustics enters its next exciting phase of development, his experience and skills will prove invaluable."

# 'Sound design' for new school

Four Dwellings Primary School in Birmingham, built as part of the Government's Building Schools for the Future programme, features extensive use of Troldtekt ceiling tiles in the study areas and library as well as in the play areas and sports hall which is traditionally very noisy. The panels were chosen as they offer several benefits, including high sound absorption, high durability, natural breathability, low cost life cycle performance and sustainability.

For more details ring **0844 8114877** or visit **www.troldtekt.co.uk**



Four Dwellings Primary School

# SATRA expands hearing protection testing service to include US standards

SATRA has expanded its hearing protection testing service to include testing to US and Australian/New Zealand standards.

In addition to offering a UKAS-accredited testing service for the EN 352 series of European standards, SATRA can now test to the US standard ANSI/ASA S12.6-2008 and the Australian and New Zealand standard AS/NZ 1270:2002.

SATRA launched the testing service last year following significant investment and the construction of a hemi-anechoic chamber at its Kettering base designed to create the stringent conditions needed to test hearing defenders.

SATRA is able to test ear muffs, ear plugs, and helmet-mounted hearing protection devices, along with level-dependent, active noise reduction and electrical input variations.

As well as acoustic testing, SATRA also tests the products' physical properties, such as weight, construction, sizing, adjustability, cup rotation, headband force and flexing and cushion pressure.

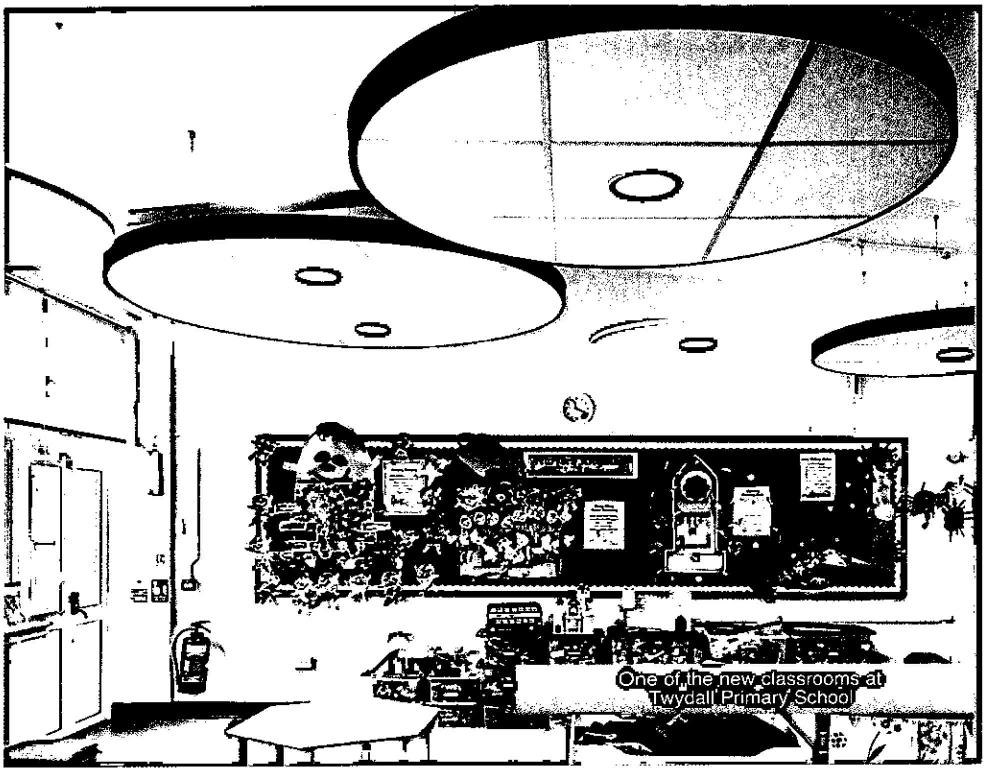
For more information, call **01536 410000**, email **hearingprotection@satra.co.uk** or go to **www.satrappeguide.com**

# New canopies help hearing-impaired pupils

Hearing-impaired pupils at Twydall Primary School, Gillingham, Kent are benefitting from the installation in six classrooms of Armstrong Ceilings' relocatable modular Axiom circular canopies with highly light reflective Ultima OP (Open Plan) mineral tiles.

In other classrooms, the nursery and the school halls, more than 160 of Armstrong's concave and convex Ultima mineral canopies were suspended from the soffit, while Ultima OP tiles and fine fissured tiles were installed in a new administration block.

For more details, go to **www.armstrong.co.uk** or email **as-info-uk@armstrong.com**



One of the new classrooms at Twydall Primary School

# SRL absorbers eradicate village hall's excessive echo and reverberation problems

Sound Reduction Systems (SRS) has eradicated excessive echo and reverberation problems in two rooms at Brigsteer Village Hall, Cumbria, by installing Sonata Vario acoustic absorbers from the ceilings and at high level on the walls. The panels can be removed and replaced easily for any future decoration or maintenance work.

SRS also solved similar problems in the new dining space at Arbuckles restaurant and bar, Downham Market, Norfolk, which had many harsh, acoustically reflective surfaces within it, through the installation of special panels.

The company's recommendation to install 115 square metres of Sonata Aurio absorbers on ceilings at Bromley Council's offices has resulted in a significant reduction in noise levels.

Acoustic performance at Tiddington Community Centre, Oxfordshire, has also been considerably improved by SRS's installation of 30 square metres of Sonata Vario absorbers and two Sonata memo boards.

For more details, ring **01204 380074**, email **info@soundreduction.co.uk** or visit **www.soundreduction.co.uk**

Sounds goods: Brigsteer Village Hall

# French aerospace group acquire PULSE system for wind tunnel testing

The French aerospace research centre, ONERA, has acquired a 200-channel Brüel & Kjær PULSE™ acoustic data acquisition system for wind tunnel testing.

The system's first use will be for scale-model, aero-acoustic measurements at the S1 large sonic wind tunnel in Modane, after which ONERA will use the system in a number of its other wind tunnels.

This system integrates with the wind-tunnel control system at the Modane facility, which can remotely control the data acquisition process. During data recording, process data is simultaneously displayed together with real-time acoustic data in the form of time/frequency plots.

Based on Brüel & Kjær's standard PULSE LAN-XI Data Acquisition Hardware and analysis platform, the system provides a dedicated, streamlined workflow to handle the system setup, data recording and post-processing analysis – and is suitably sized to handle the large data throughput.

Acoustic measurements in wind tunnel systems are categorised by the large number of channels needed, high data sampling frequencies, tight phase matching between channels and the high dynamic range of recorded levels.

For more details visit **www.bksv.com**


Coming soon...

# Noise Mapping in the EU, Models and Procedures

## Edited by Gaetano Licitra

*Review by Simon Shilton of Acustica*

Last year the EU Environmental Noise Directive 2002/49/EC (END) was 10 years old. Since the Green Paper on Future Noise Policy in 1996, through to the on-going efforts to develop Common Noise Assessment Methods for Europe (CNOSSOS-EU), there has been an extensive array of research, workshops, symposia sessions, journal publications, working groups, software tools, measurement equipment, projects and guidelines; however there has not been a comprehensive summary and overview published, until now.

Edited by Gaetano Licitra, Head of Technical Sector Promotion and Production of Activities and Services at the Environmental Protection Agency of Tuscany Region (ARPAT) and Professor at the University of Pisa, Italy, who has been working in the area since the drafting of the Directive, the book brings together a number of the leading figures involved from across Europe, to create a collection of articles providing a concise overview of the lifecycle of activities undertaken under the Directive, a critical review of the results of the first round in 2007 – 2009, an insight into the challenges ahead and possible future solutions.

The END sets out a framework of activities which each Member State in the EU is to undertake on a five yearly cycle in a harmonised manner. Monitoring the state of environmental noise exposure through strategic noise mapping, providing information to the public on the extent of noise and its harmful effects, and adopting action plans to prevent and reduce environmental noise where necessary, whilst preserving environmental noise quality where it is good.

The book presents the whole process of implementing the Directive, topped and tailed with a historical overview and future perspectives. The overall presentation helps place the technical work in a relevant context, including some of the political and policy challenges, but most importantly illustrates the multi-disciplinary nature of the work. Noise mapping and action planning requires acoustics, traffic engineering, geographical information systems, public relations, project management and a host of other areas of expertise, something which becomes clear as the various articles unfold.

The chapters within the book are authored from a number of perspectives, including researchers, consultants, software developers and environmental agencies. After a brief introduction into the fundamentals of acoustics (D Palazzuoli and G Licitra), the book is organised into five main parts:

PART 1 Noise evaluation and mapping: Legal basis on noise mapping in the European Union and the directive 2002/49/EC (P de Vos and G Licitra); Measurements (J L Cueto and R. Hernandez); Road traffic noise (G Dutilleux); Railway noise (P de Vos); Industrial and harbour noise (J R Witte); Airport noise (R Butikofer); The Good Practice Guide, Version 2 (G Licitra and E Ascari); Uncertainty and quality assurance in simulation software (W Probst).

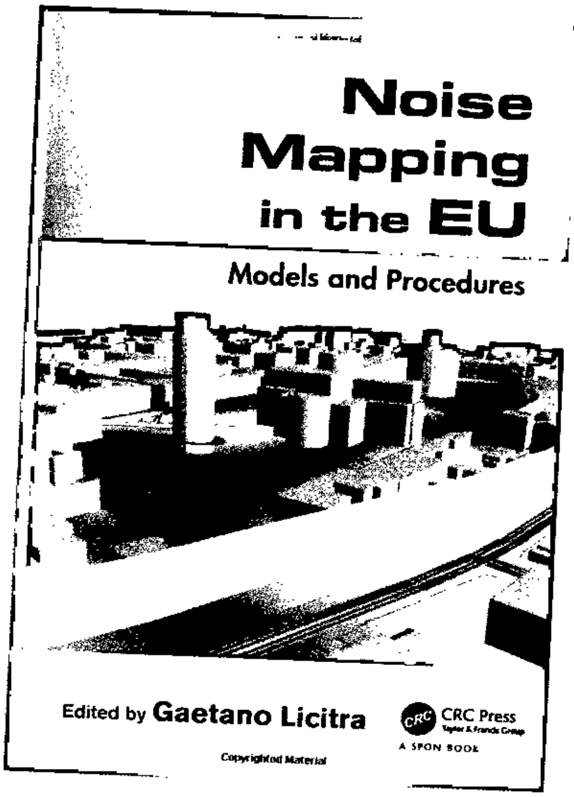
PART 2 Noise mapping and geographic information systems (GIS): Geographic information system tools for noise mapping (J L Cueto and G Licitra); Maps and geographic information systems in noise management (D Manvell); The evaluation of population exposure to noise (G Brambilla).

PART 3 Noise mapping in Europe: Noise maps in the European Union: An overview (P de Vos and G Licitra); Noise maps from different national assessment methods: differences, uncertainties, and needs for harmonisation (S Kephalopoulos and M Paviotti).

PART 4 Communication and action plans: Communication to the general public (P McDonald); Which information for the European and local policy makers? (L Maffei); From noise maps to critical hot spots: Priorities in action plans (W Probst).

PART 5 Future perspectives: From noise to annoyance mapping: A soundscape approach (G Memoli and G Licitra).

As may be expected with such a range of authors, there is variation in style and focus between the chapters, but the potential problems of overlap and contradictions have been successfully avoided. The depth and insight of the articles varies from chapter to chapter, but they do universally provide a detailed and thorough review of the area, and an extensive list of references which includes almost all the key documents, thereby ensuring that the book provides an excellent starting point for further research. There are a few typographical errors, with one unfortunately being a chapter title, and some interesting phrasing from the perspective of a native English speaker, but these issues are minor and do not interrupt the flow or the clarity of the story. There is an unavoidably vast array of abbreviations and acronyms throughout the chapters, and whilst most are introduced, it may present a challenge for those unfamiliar with the subject area, and possibly a glossary alongside the index would have been useful.




*Noise Mapping in the EU, Models and Procedures*
Edited by Gaetano Licitra Published by CRC Press
£120 hardback (ISBN 978-0-415-58509-5)

The book takes the reader through the background legal basis of the Directive, into a detailed technical review of the noise calculation methods, and onto a discussion on the challenges and uncertainties of undertaking strategic noise mapping across large areas. The use of GIS systems, and the range of tools and techniques available to complement the noise calculation software, helps to provide insight into some of the practical solutions required when undertaking such projects. The book then moves to review the results delivered by the MS during the first round and reviews the DG JRC research into differences between calculation methods. Together these strongly illustrate why the current focus is on development of a common method of assessment, and a consistent means of implementation. Amidst the technology of noise mapping, the public communication and action planning are often overlooked, and the discussion presented alongside the effects on public health and future perspectives, including soundscape concepts, is welcome if a little light in comparison to proceeding sections.

Presenting a detailed, comprehensive and thorough overview of the entire process under the END is a challenging brief, but in 442 pages it has been met admirably and provides a unique source of information for those setting out to understand it. It will also provide a useful reference for those more familiar with the area, as it presents so many of the key technical details and results in one place.

# Armstrong ceiling tile pioneers new certification

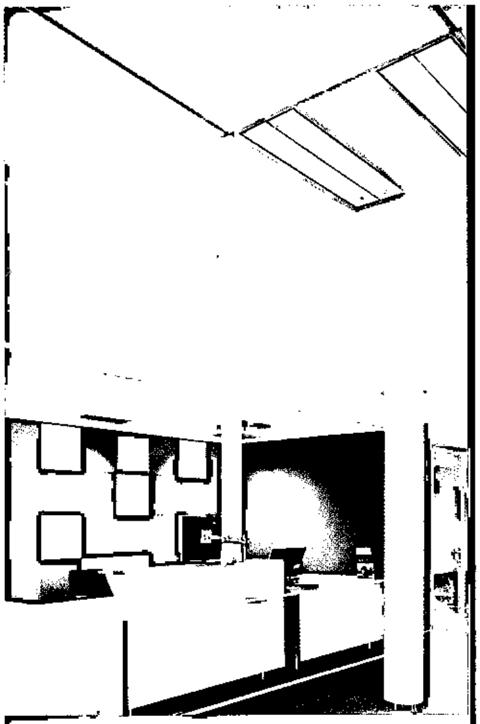
A mineral fibre tile from Armstrong Ceilings has become the first in the world to be granted Cradle to Cradle certification.

Its recyclable Perla OP.95 tile won Basic accreditation after several months of assessment. Plans are now in place to redesign the tile to achieve Silver.

The Cradle to Cradle programme has been developed to meet growing customer demand for sustainable products, with certification already becoming a requirement for building projects in America and parts of Europe.

The tile performs acoustically to Sound Absorption Class A and is highly light reflective (85%). It is available in five tile sizes and four plank sizes.

For more details go to **www.armstrong-ceilngs.co.uk**



Standard setting: the Perla OP.95 tiles

# Measuring tool visualises sound fields in 3D

LMS International has introduced a new acoustic troubleshooting solution that visualises sound fields in 3D while measuring.

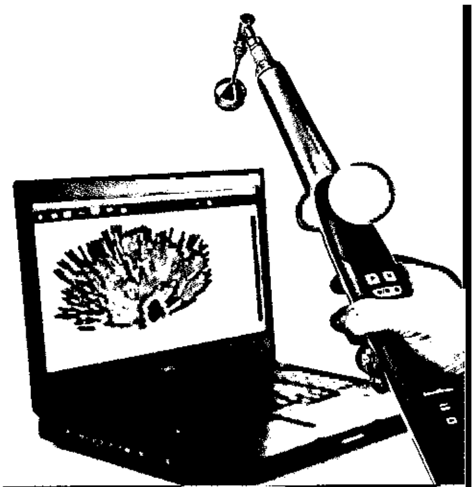
SoundBrush is described as "a revolutionary, easy-to-use and complete" tool that enables engineers to map sound propagation around an object and localise acoustic sources.

At its heart is optical tracking technology, which can be combined with either a GRAS sound and vibration sound pressure microphone or a 3D intensity sensor.

When moving the SoundBrush probe freely around the test object in any orientation or position, the sound field is immediately visualised on screen in 3D.

Bruno Massa, Vice President of the LMS Test Division, said: "What sets it apart from other applications is the automatic position detection and the real-time visualisation of the 3D sound field. This provides detailed, on-the-spot results for easy identification of noise sources."

For more details go to **http://www.lmssoundbrush.com/**



The SoundBrush measuring tool

# In 'the driving seat' – the Sonoscout NVH recorder

An intuitive new sound and vibration recorder lets engineers analyse their measurements on the go, using an iPad to manage data and listen to recordings.

Using the portable Sonoscout system, engineers can validate recordings in real-time, to remove the risk of recording bad data and then having to repeat expensive testing.

Sonoscout is unique among mobile noise, vibration and harshness (NVH) recorders in offering real-time monitoring and analysis. It is fast to set up for 'grab and go' measurements – and does not require a manual to learn how to use it.

The Sonoscout NVH recorder in action

The Sonoscout system teams a portable data acquisition front-end, with an iPad and binaural microphone headphones, to record and replay sound. Sound, vibration and auxiliary data from up to 12 channels is streamed wirelessly to the iPad from the front-end, which is powered by a seven-hour battery.

Maximum test confidence comes from viewing continuous information on the iPad's screen, which is clearly visible from the driver's seat. By connecting to the vehicle's CAN bus, Sonoscout displays all important test parameters including engine speed, vehicle speed and NVH signals. The user marks events and time periods with a single tap, which can then be displayed in Google Earth, along with GPS route information.

Setting up the system is very fast and engineers can simply wear the microphone headset to record sound at the ear positions. Cabling is minimised with battery power and Wi-Fi connectivity. Smart features, such as the automatic transducer recognition using TEDS, minimise setup time, while input ranging is unnecessary thanks to Brüel & Kjær's Dyn-X technology. This avoids over-ranges, under-ranges and signal clipping - and gives an effective dynamic range of over 160 dB.

The analysis functionality includes Fast Fourier Transformation (FFT) analysis, order extraction, synthesised 1/3 octave analysis, spectrogram displays and sound quality metrics. The user can quickly choose to display up to four analyses of up to four different tests.

A stand-alone recording option saves data to SD card. Using this option, data is first recorded directly to SD card in the front-end and then, after the recording is complete, quickly transferred to the iPad by Wi-Fi for analysis and use as normal.

Downloading data to PC for further analysis – and sharing – is done by simply entering the IP address of the iPad into a browser's URL bar and transferring by Wi-Fi. Other options include iTunes and DiskAid.

Sonoscout is said to fit perfectly with Brüel & Kjær's PULSE Reflex post-processing software.

For more information see **http://list.bksv.com/t/22840/40257240/8808/0/**

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## Committee meetings 2013

| DAY | DATE | TIME | MEETING |
|---|---|---|---|
| Thursday | 18 July | 11.30 | Meetings |
| Tuesday | 8 August | 10.30 | Diploma Moderators Meeting |
| Thursday | 15 August | 10.30 | Membership |
| Thursday | 5 September | 11.00 | Executive |
| **Thursday** | **19 September** | **11.00** | **Council** |
| Monday | 30 September | 11.00 | Research Co-ordination |
| Thursday | 3 October | 10.30 | Diploma Tutors and Examiners |
| Thursday | 3 October | 1.30 | Education |
| Thursday | 10 October | 10.30 | Engineering Division |
| Thursday | 17 October | 11.00 | Publications |
| Thursday | 31 October | 10.30 | Membership |
| Tuesday | 5 November | 10.30 | ASBA Examiners |
| Tuesday | 5 November | 1.30 | ASBA Committee |
| Thursday | 7 November | 11.30 | Meetings |
| Thursday | 14 November | 11.00 | Executive |
| Wednesday | 20 November | 10.30 | CCENM Examiners |
| Wednesday | 20 November | 1.30 | CCENM Committee |
| Tuesday | 3 December | 10.30 | CCWPNA Examiners |
| Tuesday | 3 December | 1.30 | CCWPNA Committee |
| **Thursday** | **5 December** | **11.00** | **Council** |

Refreshments will be served after or before all meetings. In order to facilitate the catering arrangements it would be appreciated if those members unable to attend meetings would send apologies at least 24 hours before the meeting.

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