SOUND AND VIBRATION NEWS

WAVES

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MUSIC IS IN THE HANDS OF THE BEHOLDER

IoT TECHNOLOGY MAKES CITIES SMARTER

EV – THE NEXT GENERATION OF SOUND

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Brüel & Kjær

BEYOND MEASURE

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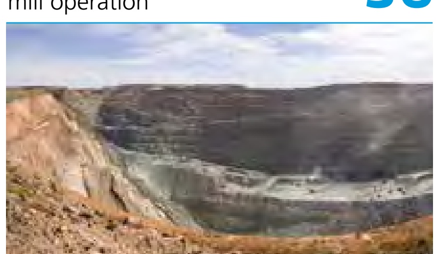

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Brüel & Kjær
BEYOND MEASURE

LETTER FROM OUR PRESIDENT

BIG CITIES, SMART SOLUTIONS

Noise pollution is often cited as one of the main problems of life in large, 24-hour cities, but new products and technologies to reduce noise are continuously being developed and becoming part of our lives, and the sound challenges that we face are being tackled head-on.

For example, electric vehicles have been welcomed for their quiet, eco-friendly motors, but they have meant that some acoustic engineers thought they might be out of a job. Read about how Applus+ IDIADA was surprised when they tested electric vehicles and how they have been tackling new sounds that were previously masked by combustion engines.

Another well-known noise challenge facing big cities is managing sound at large, open-air concerts and sports events. How can the latest technologies help keep concert attendees happy while ensuring minimal noise disturbance for the neighbours? Read about the MONICA project, which aims to develop an acoustic system using Internet of things (IoT) and machine learning to reduce noise outside a concert area while not interfering with the sound for the audience in the venue.

Our articles often touch upon topics such as IoT, machine learning and the adoption of automation technology. But how will product development ecosystems look in the future? Our vision study, Beyond Tomorrow, sparks these discussions and, if you are a Waves subscriber, you can discover some of our conclusions in the special insert in this issue.

In the News section of this issue, you can also find out about our new BK Connect™ sound and vibration analysis software that we have just released to the world and are extremely proud of. This cutting-edge platform has been designed around user workflows and tasks, and it includes many innovative features. We are looking into a future with more data-driven product development, and BK Connect™ will enable sound and vibration specialists to meet the challenges ahead – helping everyone to work smarter.

I hope you enjoy reading our latest issue of Waves.

SØREN HOLST
PRESIDENT

THE SOUND OF A SMART CITY

ABOUT MONICA

The MONICA project stands for Management of Networked IoT Wearables – Very Large Scale Demonstration of Cultural Security Applications. A three-year project co-funded by the European Commission, it involves 29 partners in nine countries. In Denmark, participants include Tivoli Gardens, which represents an amusement park with outdoor concerts; the Technical University of Denmark, which is optimizing and predicting sound transmission; and Brüel & Kjær, responsible for detecting, measuring and analyzing the sound data.

The first demonstrations of the project are expected in Spring 2018, and the six pilot sites are located in Bonn, Copenhagen, Hamburg, Leeds, Lyon and Torino.

SEE MORE

www.monica-project.eu

> "IN TIVOLI, WE CONTINUOUSLY EXPLORE WAYS TO MINIMIZE THE IMPACT ON THE ENVIRONMENT AT THE SAME TIME AS PROVIDING THE BEST POSSIBLE QUALITY OF EVENTS."
>
> MICHAEL FREJDAL,
> HEAD OF PRODUCTION, TIVOLI GARDENS

Every big city knows the challenge: pleasing concert organizers and attendees, while appeasing the neighbours of the concert venues. The MONICA project is demonstrating how IoT technologies can manage both sound and security at large, open-air cultural and sporting events – and keep everybody happy.

When Keith Richards sends the first notes of "(I Can't Get No) Satisfaction" out over the screaming crowd of Rolling Stones fans, you want those ticket holders to feel like they've indeed gotten every bit of their money's worth. But you certainly don't want it to be at the expense of dissatisfying the neighbours.

How can you tell what portion of the sound wafting through city streets and sidewalks is actually coming from the concert, and how much is just the 'normal' noise of a pulsing metropolis?

That's where the MONICA project comes in. A large-scale demonstration of how cities can use the Internet of things (IoT) to meet such challenges, MONICA deploys a cloud-based platform to wirelessly connect various IoT-enabled devices. Control systems monitor the data collected and can automatically induce required actions based on the information gathered.

One hoped-for outcome of the project is an acoustic system that can reduce low frequencies outside a concert area, while not interfering with the music in the audience area of venues that use it. It should be able to support designated quiet zones within the concert venue as well. The acoustic system will be automatically adjusted for changes in weather, audiences, music types and other variables.

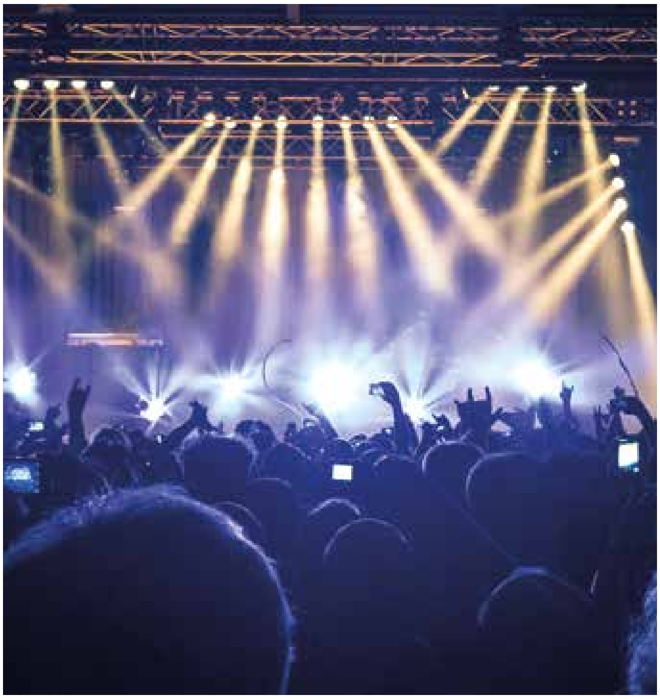
TWENTY-NINE PARTNERS FROM AROUND THE EU

Brüel & Kjær is one of the many partners involved in the MONICA project. The company's role is threefold: 1) to create and deliver IoT-enabled sound level meter prototypes for use at the EU pilot sites; 2) to develop the complex algorithms that can accurately estimate the impact of the different sound contributions; and 3) to automatically detect sounds that could indicate a 'security situation'.

"It's going to enable not just Brüel & Kjær, but also all the other partners in the project, to collect the data they need – it will be possible to deploy our solution anywhere," says Brüel & Kjær Research Engineer Karim Haddad, PhD. All data is protected to ensure privacy, and MONICA will comply with the applicable national and EU regulations on data protection, privacy, informed consent and authorization.

Karim adds: "The sound level meters will contain GPS info, so you can recognize exactly where they are and collect the data you need in the cloud."

As part of the process of data collection, microphones are placed wherever sound optimization is required and according to the landscape's unique demands. Anything from the weather, to the location of surrounding buildings, to the sounds themselves affect how sound propagates. ►



THE SOUND OF
A SMART CITY


Photo © Anders Bøggild, Tivoli

Fredagsrock (Friday's rock) at the Open Air Stage in Tivoli

CAN IT REALLY BE THAT DIFFICULT?

One of the many challenges in distinguishing between concert and city noises is distinguishing low-frequency noises from each other. Because low-frequency sounds like a bass drum, bass guitar, car, truck or thunder have a far narrower frequency (Hz) range than high-frequency sounds, they are harder to differentiate – both for the human ear and for a machine.

The Brüel & Kjær solution uses machine learning to detect, first of all, whether the sound being measured actually does come from the concert or not; then, the algorithm determines how MUCH of the total, synchronized sound picture is from the concert.

"If there's a long stretch without buildings near the concert area, then the sound waves can travel far distances. But behind a building, there's not much sound contribution, so you might not hear the concert at all. Temperature, wind and humidity can also affect how sound travels, and some noises carry farther distances than others. It's quite complex," says Wookeun Song, PhD, Brüel & Kjær Research Engineer.

IS IT CONCERT NOISE OR CITY NOISE?

Of course, measuring sound levels is only useful in the context of the MONICA project if it's possible to detect how much of the overall sound is from concert activities and how much is city noise.

That requires Brüel & Kjær to create algorithms, placed in the cloud and linked with IoT-enabled devices that can calculate the different sound contributions.

Some of the algorithms depend on time synchronization between the sound level meters – within virtually a millisecond. Otherwise, it's impossible for the algorithms to determine how sound actually propagates between different locations. And decisions about what actions need to be taken to ensure optimal sound depend on the availability of accurate data.

"Distinguishing between different sound sources is not an easy task. Furthermore, no one has created this type of algorithm distinguishing concert noise from city noise before," says Wookeun.

Brüel & Kjær uses machine learning, as well as other types of algorithms, to solve the basic problem of identifying concert noise vs city noise. During the 'training' phase of machine learning, a learning algorithm enables the system to determine how to distinguish concert noise from other types of noise.

A GUINEA PIG IN TIVOLI GARDENS

To create the vast amounts of data necessary for machine learning, Brüel & Kjær has already monitored hundreds of hours of sound at different times of year in Copenhagen, Denmark. This includes different weather conditions, as well as an entire season of Friday Rock concerts at Tivoli Gardens in downtown Copenhagen.

Tivoli, one of the world's most popular amusement parks, wants to be both a great place for concert patrons and a

Karim Haddad and Wookeun Song work in Brüel & Kjær's Innovation Team – the team responsible for researching new methods and technologies that solve and simplify our customers' existing and future sound and vibration challenges

great neighbour, which makes their interest in contributing to the project a natural fit.

Brüel & Kjær is analysing the data now and is taking even more measurements during the new season of Tivoli Friday Rock concerts, which begins this month. This will enable validation of the algorithm.

Six pilot sites, including Tivoli, are included in the MONICA project. Where the sound level meters will make their formal debut is unknown as of the Waves publication date. ▶

> "ESTIMATING THE CONTRIBUTION IN AN AUDIO RECORDING OF A SPECIFIC SOUND, SUCH AS MUSIC, WHEN OTHER TYPES OF SOUNDS OVERLAP, IS NOT EASY."
>
> KARIM HADDAD
> RESEARCH ENGINEER, BRÜEL & KJÆR

THE SOUND OF **A SMART CITY**

SAFE AND SOUND

Security is another aspect of the MONICA project in which sound plays a role. Although video cameras are used at concert venues, they are only as useful as what they can see – which sometimes is a shoulder-to-shoulder 'wall' of people.

Sound, however, has no line-of-sight issue, so we can detect acoustic abnormalities instead. Say, for example, there's a fight going on among some concertgoers, but it's not visible from a video camera. If there are sound level meters deployed throughout the area, it is possible to determine that there's trouble near a specific microphone and dispatch security personnel to the location.

By combining video and audio, the picture of what's actually happening at or near the concert area becomes even more accurate.

SMARTER CITIES, SMARTER RESIDENTS

Devices such as smart wristbands, video cameras, loudspeakers, mobile phones and smart glasses will also be part of the portfolio of applications MONICA will be able to offer to enhance city services.

The project has the potential to be used in a wide variety of ways. Based on open standards and architectures, the platform can be reused across multiple applications, with only the application layer specific to the deployment setting.

Look for results of the project in a future issue of Waves.

A NEW WHITE PAPER FROM THE STACKS

ANALYSIS OF VEHICLE VOICE RECOGNITION PERFORMANCE **IN RESPONSE TO BACKGROUND NOISE AND GENDER-BASED FREQUENCY**

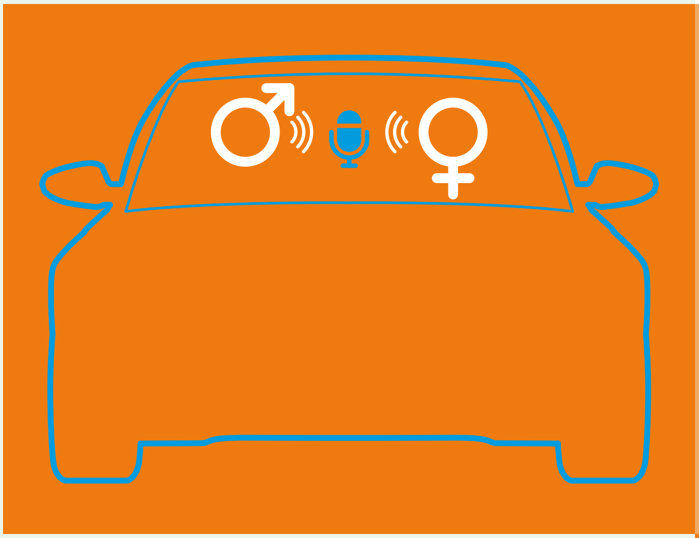
To address customer complaints on voice recognition (VR), Hyundai and Brüel & Kjær Global Engineering Services analysed the performance of the in-vehicle VR system and the sensitivity to background noise and gender-based frequency.

Connected and smart devices are all around us in our daily life and their use is anticipated to increase exponentially over the years. Most of these devices are controlled by voice-activated assistants, and the quality of the VR system can be affected by multiple parameters.

For vehicles, VR is constantly reported as a major quality issue. For the 2017 model year, market research indicates that it is again the most frequent problem reported in vehicle dependability studies. In a vehicle, the performance of VR is affected by multiple parameters, including the background noise, the placement of the microphone and the voice command itself. In addition, the gender of the speaker plays a role too, as it differentiates the speech pattern and the frequency content.

The North American team of Hyundai performed an R&D project together with Brüel & Kjær Global Engineering Services to analyse the performance of in-vehicle VR. The team defined a process based on actual vehicle tests to identify the sensitivity of the VR performance with respect to background noise and speaker gender. The results showed, as one would expect, that background noise can be detrimental to VR, but that the effect can be reduced with proper tuning of the noise cancellation algorithm. The team also found out that for specific vehicles, there is a significant reduction in the recognition rate for female speakers compared to male speakers. For these investigations, the team developed a consistent process for lab-based VR evaluations that can be used to assist with the tuning and calibration of VR systems. ■

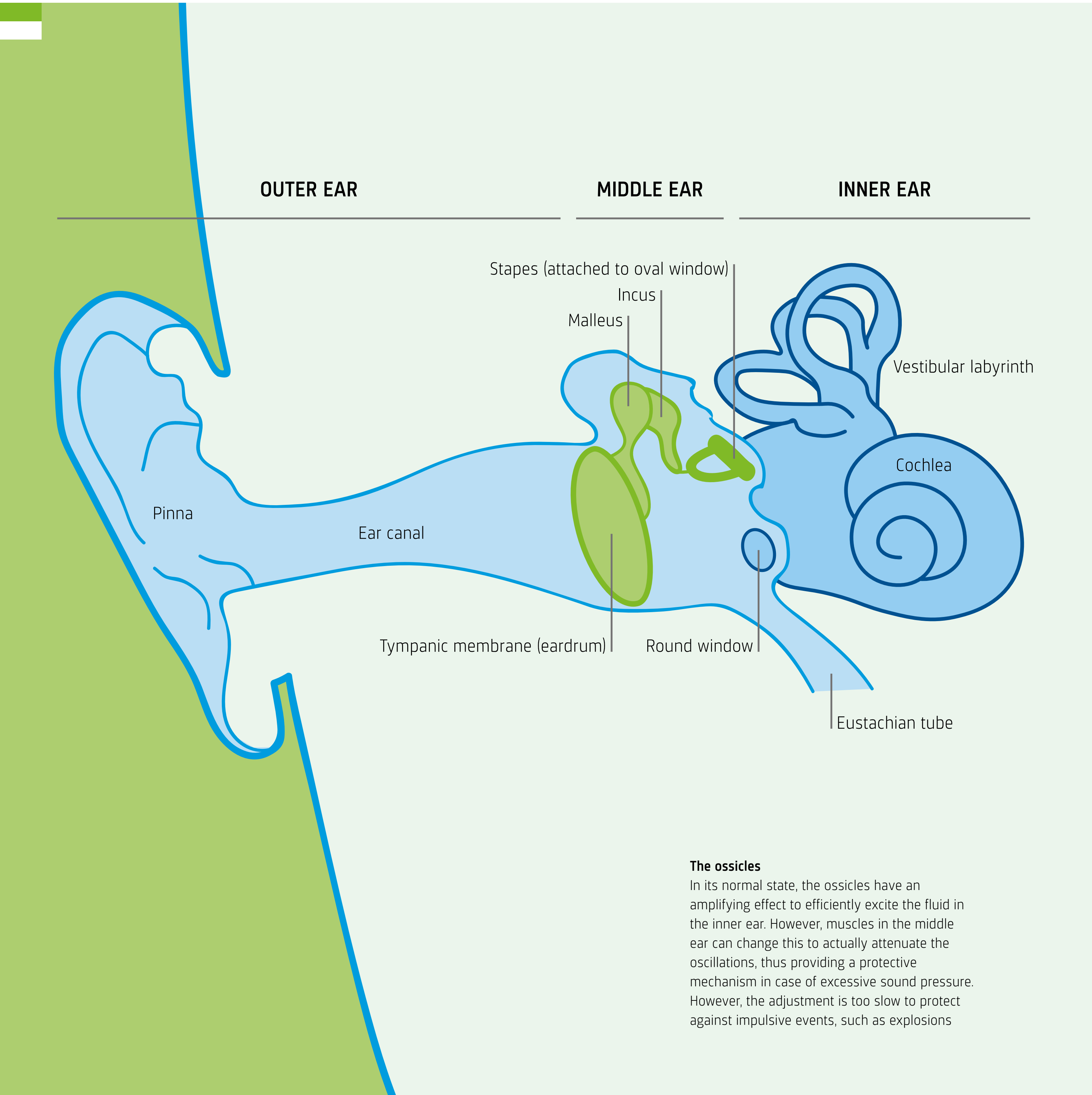
SEE MORE
Read the full white paper at
www.bksv.com/whitepapers



"WITH SPEECH RECOGNITION BECOMING THE GO-TO TECHNOLOGY FOR THE AUTOMOTIVE INDUSTRY CUSTOMERS, THE URGENCY TO IMPROVE THE RECOGNITION RATE WAS SO IMPORTANT. THIS PROJECT ADDRESSED THAT NEED, AND THE OUTCOME WAS VERY BENEFICIAL TO HYUNDAI AND ADDED NEW INSIGHT IN TERMS OF THE RECOGNITION PERFORMANCE AND HUMAN BEHAVIOUR."

RASHEED KHAN, MANAGER,
MULTIMEDIA VALIDATION & PRODUCT QUALITY,
HYUNDAI-KIA AMERICA TECHNICAL CENTER, INC.

ANATOMY OF THE HUMAN EAR



The ossicles
In its normal state, the ossicles have an amplifying effect to efficiently excite the fluid in the inner ear. However, muscles in the middle ear can change this to actually attenuate the oscillations, thus providing a protective mechanism in case of excessive sound pressure. However, the adjustment is too slow to protect against impulsive events, such as explosions

The human ear is a complex system consisting of three distinct parts, each with a specific role in the process of picking up and analysing sound.

The outer ear collects sound, the inner ear transfers these vibrations into neurological signals that can be processed by the brain, and the middle ear provides the coupling between them. In this issue, we follow sound through the ear to the tips of the hair cells, where vibrations turn into neurological signals. What happens then is the material for a future chapter.

THE OUTER EAR

The outer ear consists of the pinna and the auditory canal. As already discussed in 'Listening in 3D' (Waves, October 2017), the pinna plays an important role in the auditory source location. In addition, its horn-like shape provides a smooth transition from the 'infinite' space around the head, funneling the sound into the narrow auditory canal. The canal then guides the sound towards the eardrum, a thin membrane separating the outer from the middle ear.

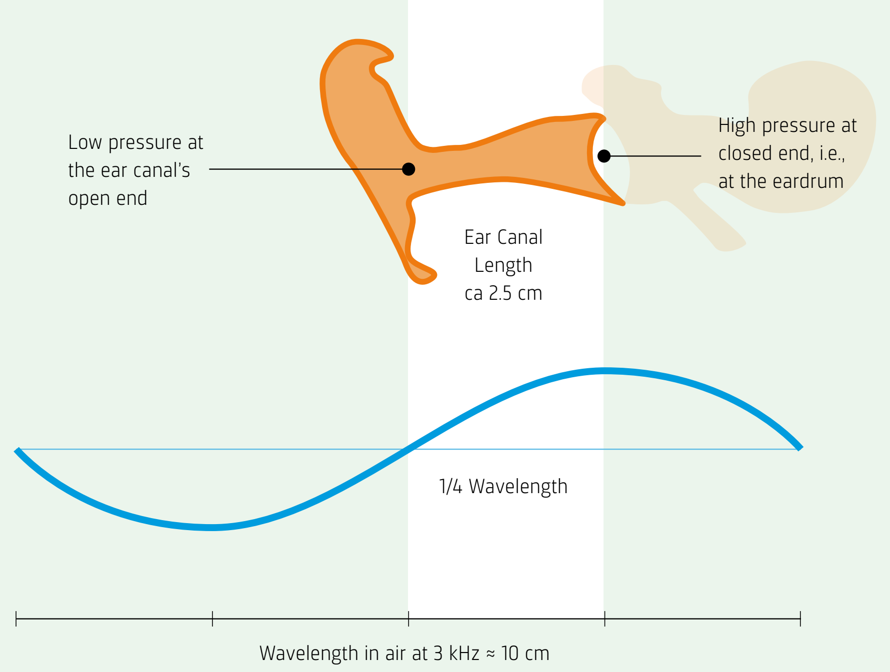
THE MIDDLE EAR

The middle ear is a small air-filled chamber between outer and inner ear. The purpose of this chamber is twofold. First, it contains a mechanism of three bones, called the auditory ossicles, connecting the eardrum and the inner ear. This gear box like mechanism is needed since the inner ear is filled with a fluid, making direct excitation by the eardrum inefficient.

Secondly, the middle ear is needed to equalize pressure across the eardrum. A healthy eardrum is completely airtight, preventing airflow from the outer ear into the middle ear. The pressure difference between the two chambers moves the membrane in and out, which is exactly what is needed to pick up the rapid pressure fluctuations of sound. ▶

OUTER EAR DIMENSIONS AND AMPLIFICATION

The outer ear is especially sensitive to frequencies between 1 and 5 kHz. Not coincidentally, this range is important for communication, with 3 kHz being the frequency around which our hearing is most sensitive. Acoustically, the outer ear works like a tube resonator, with the strongest first resonance around 3 kHz, where a quarter wavelength of sound in air (10 cm / 4 = 2.5 cm) fits the length of the auditory canal. In contrast, sensitivity drops significantly at lower frequencies where the wavelengths are large compared to the ear's size.

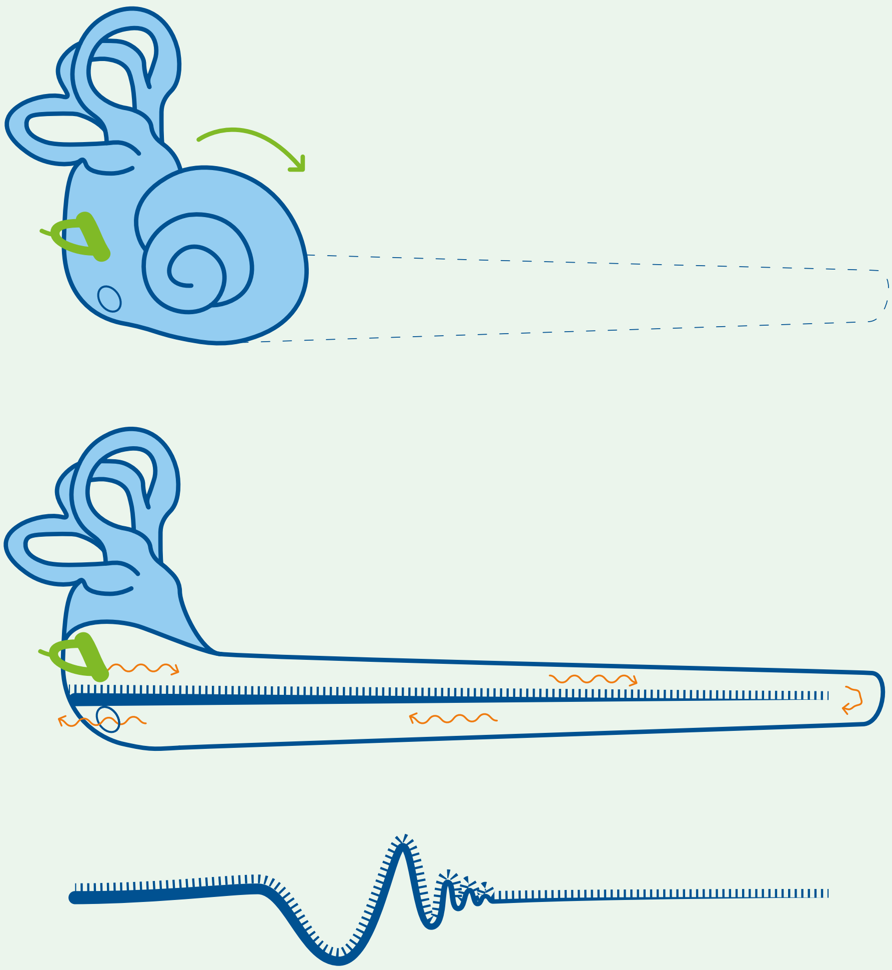


ANATOMY OF THE HUMAN EAR

BY: **MATTHIAS SCHOLZ**
User Interface Designer
PhD Applied Acoustics
Brüel & Kjær

COCHLEA WITH BASILAR MEMBRANE

Even when excited by the sound of a pure tone, the entire basilar membrane will be set into motion. However, the area associated with the frequency will react the most; that is, the lateral oscillations will peak around this section



However, a problem can arise when the atmospheric (static) pressure in the outer ear differs from the pressure inside the middle ear.

This mechanism is not that evident in everyday life but is easily experienced during lift-off and landing on an aeroplane, where the ambient pressure changes significantly due to the change in altitude. The pressure in the outer ear follows the ambient pressure in the aeroplane, whereas the pressure on the inside of the eardrum remains unchanged. The constant pressure difference applies a pre-tension to the membrane, pushing it either in or out, which gives an unpleasant sensation and leads to sound being perceived duller.

The Eustachian tube, which connects the middle ear to the throat, helps to equalize this pressure. When we swallow, the tube opens briefly causing the static pressure on the inside of the eardrum to equalize

WHEN WE SWALLOW, THE EUSTACHIAN TUBE OPENS BRIEFLY CAUSING THE STATIC PRESSURE ON THE INSIDE OF THE EARDRUM TO EQUALIZE TO THAT OF THE OUTER EAR.

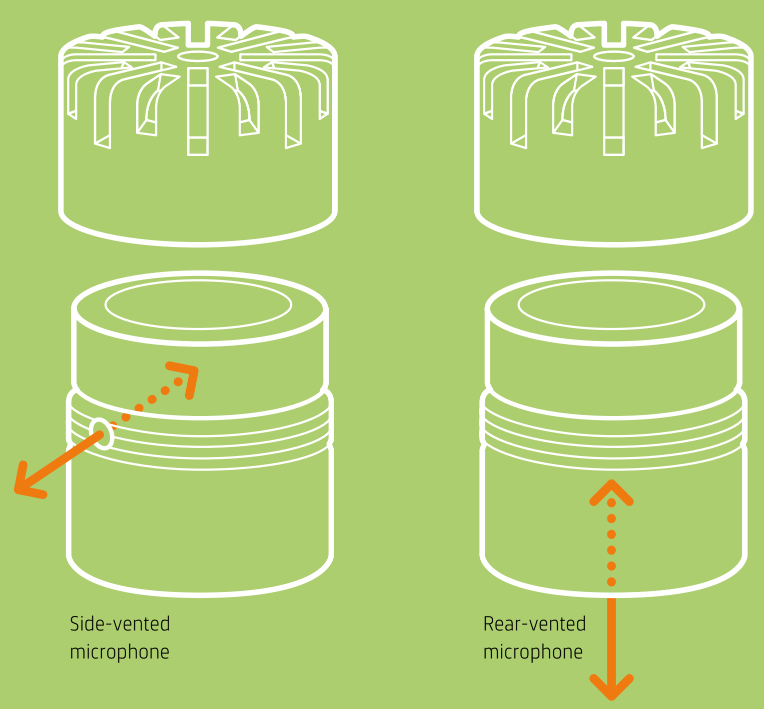
to that of the outer ear, resetting the eardrum to its neutral position. The eardrum will have its normal sensitivity and sound will again be bright.

THE INNER EAR

The inner ear is the most complex element in the chain. It is a fluid-filled chamber and consists of two parts: the vestibular labyrinth, which functions as part of the body's balance mechanism, and the cochlea, containing the basilar membrane and the organ of Corti, a sensory element that converts sound into nerve impulses so that our brain can process the information. Sound that has been funneled into the auditory canal, will set the eardrum into motion. The auditory ossicles in the middle ear pick up these oscillations and transfer them to the fluid through the oval window, one of two flexible surfaces between the cochlea and middle ear. Exciting this membrane generates waves in the fluid-filled inner ear that travel along the basilar membrane, thereby setting it and the organ of Corti in motion.

This organ contains thousands of small hair cells, which are connected to the acoustic nerve. The oscillation pattern of the basilar membrane is quite complex, with different areas being stimulated more or less by different frequencies. For each of these areas, a different group of hair cells will be activated and send impulses through the nerves to the brain. Thus, the organ of Corti splits up the sound into its spectral components, similar to rain drops splitting up sunlight into individual colours.
Well, at least this is the short version. The long version is much more complex, but also exciting, explaining many of the phenomena in our perception of sound. It deserves a separate chapter, so stay tuned...

STATIC PRESSURE EQUALIZATION IN CONDENSER MICROPHONES



To convert sound pressure into an electrical signal, Brüel & Kjær's condenser microphones use a delicate diaphragm stretched across a backplate with a very narrow gap between them, forming a capacitor. Impinging sound deflects the diaphragm, and the variation in distance to the backplate produces an electrical signal proportional to the sound pressure.

The diaphragm seals the microphone at the top so that a variation in the static, ambient pressure would change the diaphragm's neutral position relative to the backplate. The ear solves this problem with the Eustachian tube, and condenser microphones use a similar design. A narrow air channel at the side or rear of the microphone ensures that the internal cavity's static pressure equalizes with the environment.

SEE MORE
about the theory and development of microphones in our Microphone Handbook (behind login)

www.bksv.com/handbooks

THE NEXT GENERATION OF SOUND

Future challenges of electric vehicle noise control.

When electric vehicles (EVs) first appeared on the market around ten years ago, acoustic engineer Xavier Montané thought he would soon be out of a job. "It's funny to remember that many of us young acoustic engineers thought that if the car was to become silent, our whole mission and purpose was over! But the reality has proven just the opposite: a new range of noises that were previously masked by combustion engines have become more prominent. There is still plenty for us to do and I think our jobs are secure," Xavier smiles.

Xavier is NVH Testing Coordinator at Applus+ IDIADA. He and his colleagues work with all types of vehicles, from passenger cars and motorbikes to commercial vehicles. "I remember when we tested the first EV, we were surprised at how loud the road noise was. We experienced the sound differently before because it was masked by the engine. Now it was much more invasive."

Applus+ IDIADA

Testing an iTORQ Toyota Urban Cruiser 4WD with four individual inboard electric motors (one per wheel), modified by IDIADA. The iTORQ system is a motion-control module that distributes drive torque between the wheels depending on driver input and road conditions

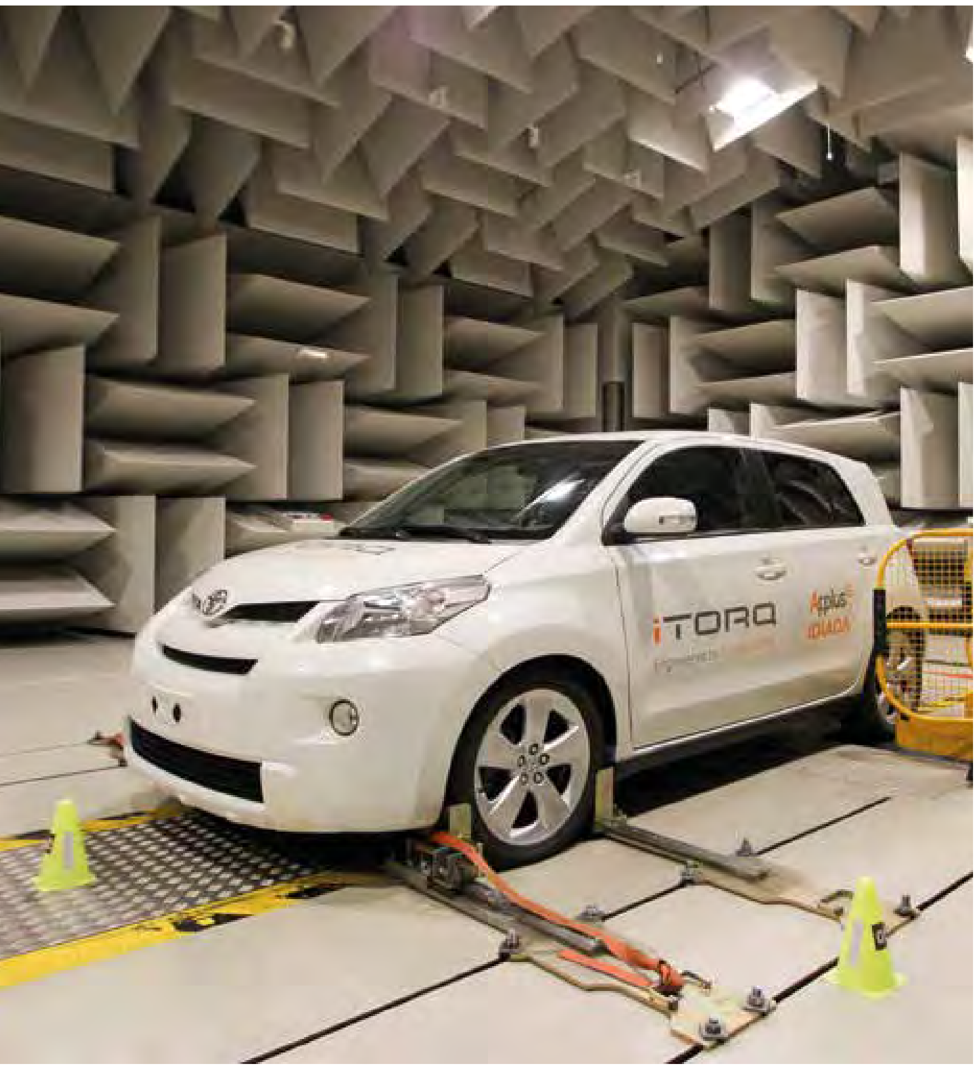
THE SCIENCE OF HUMAN PERCEPTION

In NVH, human perception is very important as people experience sounds differently. Some people prefer low-frequency sounds and some prefer high-frequency sounds. This even varies across cultures. "For example, Europeans are more bothered by high-frequency sounds and the Japanese find low-frequency noises a bit irritating," Xavier explains. ▶

"WHEN WE TESTED THE FIRST EV, WE WERE SURPRISED AT HOW LOUD THE ROAD NOISE WAS."

XAVIER MONTANÉ,
NVH TESTING COORDINATOR,
APPLUS+ IDIADA

THE NEXT GENERATION
OF SOUND



A big part of the job when doing NVH subject assessments for OEMs is understanding these cultural and market characteristics and how to apply them to the vehicle evaluation. This is a skill that only comes with experience. "We have tools that can assist this process," says Xavier, "but ultimately, the microphone can't measure human perception. Only we humans can."

PREPARING FOR THE FUTURE

Xavier began working on Applus+ IDIADA 15 years ago, fresh from university. After initially studying Telecommunication (audiovisual systems), he changed his focus to acoustics. "I had always been interested in math and physics and I discovered that acoustics were more firmly based in science than cinema or television. So, I decided to become an acoustic engineer." As EVs and hybrid electric vehicles (HEVs) continue their rise in the market, and as cities continue to grow and focus on mitigating noise pollution, the world needs acoustic engineers now more than ever.

Although EVs require no combustion engine, no fuel tank, no air intake or exhaust systems, no long drive shafts or centre bearings, there are other noise sources taking their place. Electric motor noise, road and tyre noise, wind noise and ancillary system noise to name a few. As EVs and HEVs become more ubiquitous, these are the noise sources Xavier and his team will be focusing on in the future.

ELECTRIC MOTOR NOISE

"Even though they are quieter than internal combustion (IC) engines, it would be wrong to assume that electric motors are completely quiet," says Xavier. These motors generate high-frequency tonal noises that can be quite annoying. The noises originate from the different components of the engine, such as the inverter and DC/DC converter. "Although electric motors present a lesser challenge than IC engines, it still requires a major effort to develop strategies for mechanical and acoustic isolation of the motor. We have a lot of people working on this right now."

ROAD AND TYRE NOISE

Most of an EV's life is spent operating between 25 and 50 miles per hour. At this speed, wind noise is still minimal and motor noise is mostly masked by road and tyre noise. That means that the most dominant noise experienced by drivers and passengers of EVs will mostly be road and tyre noise.

"Changes on weight distribution, mixing heavy battery packs and lighter weight vehicle structures make it difficult to mitigate road and tyre noise," says Xavier. "We try to confront this with a focus on tire technology, mechanical isolation in the suspension and innovative noise control materials in the interior and exterior of the car. And, of course, we must do this without adding weight and cost to the vehicle."

The quality of roads is an issue that cities and governments are working to solve. "Tyre companies are working to improve tyres, but if the roads aren't good enough, they will not be able to achieve any major improvements. As a part of noise pollution control, cities will need to find a better material for road surfaces that can absorb the noise caused by the impact of the tyre on the road."

PROTECTING PEDESTRIANS

"When you first cross the street, the first thing you use is your ears. As all vehicles become quieter, the lack of exterior noise poses a danger to pedestrians." Governments are becoming increasingly focused on this. Over the past few years, Applus+ IDIADA has participated, along with a few OEMs, in a project led by the European Commission. The goal was to get a better understanding of which exterior sounds EVs could generate to signal to pedestrians that vehicles are approaching.

"We tried to design a vehicle that detects pedestrians and sends a focused sound in the direction of the pedestrian to alert them." This work by the EC will likely lead to the development of regulations that will define the sound that OEMs and car manufacturers must use in their vehicles. When this regulation is imposed, Xavier and his team will be ready to help their clients produce the correct sound.

ANCILLARY SYSTEM NOISE

Without an engine to drive the air conditioning and heating, the windows and other mechanical systems, a whole range of electric ancillary devices will be needed to provide these functionalities. Each of these devices bring with them vibration and acoustic challenges that individually are relatively minor, but as a whole could become significant.

"Most of these sounds will become background noise if the vehicle is on the motorway, but when it's stationary or moving at lower speeds, these buzzing and whirring sounds could become annoying. In future, it will become an even higher priority for OEMs to reduce the noise of these ancillary components."

NEXT-GENERATION DRIVERS

Looking to the future, Xavier ponders what the preferences of the next generation of drivers will be. "When today's drivers make the transition from IC to electric engine, they tend to miss the sounds that give them the feeling of being in a car – the feeling of motion and control," he explains. OEMs are creating fake noises that compensate for this.

"I'm wondering if the new generation of drivers will continue to enjoy these sounds or if perhaps they will become redundant or even annoying to them. Maybe instead, they will want to customize their internal sounds with funny or novel noises. Or maybe they will prefer no noises at all – just as quiet a ride as possible." Only time will tell what preference future drivers will have for their car sounds, but in any case, Xavier and Applus+ IDIADA will be ready to deliver. ■

SPOT THE DIFFERENCE

Can you spot the five differences between these two pictures?

See the solution on page 35.

CONFIDENT DATA ACQUISITION WITH THE ACCELEROMETER MOUNTING CHECK

The physical mounting of accelerometers on a test structure is the first, and often most problematic link in the measurement chain. Problems here will corrupt the measurement and cannot be corrected later.

The Accelerometer Mounting Check (AMC) – based on Brüel & Kjær's patented technology – provides an easier and faster way to check that transducers are correctly mounted, replacing lengthy visual and manual inspection. Let's dive into the technical details.

THE THEORY BEHIND THE TECHNOLOGY

We model an accelerometer mounted on a structure as a mass-spring-damper system where m_s, m_b and m_t are the seismic mass of the accelerometer, the mass of its base and the mass associated with the test object, respectively (Figure 1). The two first masses are connected by a spring with stiffness k_{PZ} that represents the piezoelectric element. A spring/damper element k_M is added to model the influence of the test object. The masses can move along the vertical axis, and their coordinates are x_s, x_b and x_t,

BENEFITS OF THE ACCELEROMETER MOUNTING CHECK

- Avoid having to redo measurements due to loose transducers
- Save significant time checking transducers are correctly mounted
- Have increased confidence in your data quality

QUICKLY VERIFY ALL CHANNELS

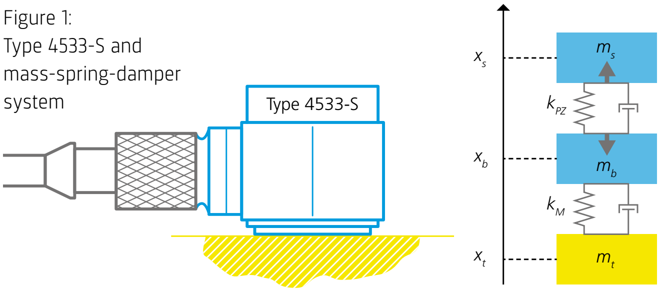
Accelerometer Mounting Check automatically verifies that accelerometers are working and whether the mounting has changed:

- It is built-in for all new S-type Brüel & Kjær CCLD accelerometers
- All charge accelerometers are supported when used with LAN-XI modules

Use it with:

- Brüel & Kjær LAN-XI data acquisition hardware
- BK Connect™ software

Figure 1:
Type 4533-S and
mass-spring-damper
system



respectively. The easiest way to derive the equations of motion is to use Lagrange's equations: first we construct the Lagrangian $L = T - V$, where T and V are kinetic and potential energy of the system:

$$T = \frac{1}{2} m_s \ddot{x}_s^2 + \frac{1}{2} m_b \ddot{x}_b^2 + \frac{1}{2} m_t \ddot{x}_t^2$$

$$V = \frac{1}{2} k_{PZ} (x_s - x_b)^2 + \frac{1}{2} k_M (x_b - x_t)^2$$

With no external forces acting on the system and omitting dissipation, the Lagrange equation is:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}_j}\right) - \frac{\partial L}{\partial x_j} = 0$$

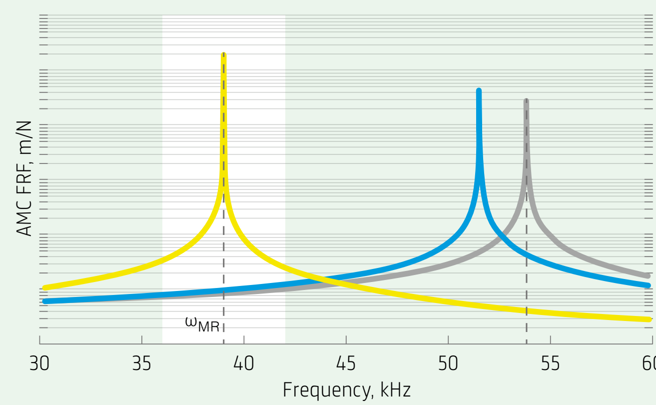
where x_j is one of the coordinates x_s, x_b and x_t. Differentiation yields three equations of motion, which in matrix notation are:

$$\begin{bmatrix} m_s & 0 & 0 \\ 0 & m_b & 0 \\ 0 & 0 & m_t \end{bmatrix} \begin{Bmatrix} \ddot{x}_s \\ \ddot{x}_b \\ \ddot{x}_t \end{Bmatrix} + \begin{bmatrix} k_{PZ} & -k_{PZ} & 0 \\ -k_{PZ} & k_M + k_{PZ} & -k_M \\ 0 & -k_M & k_M \end{bmatrix} \begin{Bmatrix} x_s \\ x_b \\ x_t \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \end{Bmatrix}$$

or more compactly, $[M]\{\ddot{x}\} + [K]\{x\} = \{0\}$.

The system has three degrees of freedom (DOF), one of them being the rigid-body motion of the assembly. Following the AMC approach, a periodic electrical charge is applied to the piezoelectric element, making it contract and expand; this applies forces (denoted by the grey arrows in Figure 1) acting on the seismic mass and base. Simultaneously, AMC measures the response of the accelerometer, which is proportional to the deformation of the piezoelectric element $(x_s - x_b)$ and calculates the AMC FRF between the response and applied charge. It is possible to obtain the AMC FRF analytically. As the elements of the matrix $[\alpha(\omega)] = ([K] - \omega^2 [M])^{-1}$ are the FRFs between the corresponding DOFs [Ref. 1], the AMC FRFs can be combined from the elements of $[\alpha(\omega)]$. Figure 2 illustrates AMC FRFs computed for three important scenarios: a properly mounted accelerometer, a free hanging accelerometer and the accelerometer properly mounted on a structure made of a light material (like wood) or on thin metal or plastic plate. Comparing the measured curves, AMC is able to detect the mounting quality. ■

FIGURE 2: AMC FREQUENCY RESPONSE FUNCTIONS



The plot sketches the AMC FRF (yellow curve) when the accelerometer is perfectly mounted on an infinitely heavy object $(k_M \to \infty, m_t \to \infty)$. The FRF has a peak at *mounted resonance frequency*, $\omega_{MR}^2 = k_{PZ}/m_s$. The grey curve represents the FRF of free hanging accelerometer $(k_M \to 0)$; it has a peak at $\omega_{FH}^2 = k_{PZ}(m_b + m_s)/(m_s m_b)$. For a typical accelerometer $m_b \approx m_s$, and $\omega_{FH} \approx \sqrt{2}\,\omega_{MR}$, [Ref. 2]. Before initiating AMC, one needs to make sure that the accelerometer is properly mounted on the structure. When initiated, AMC looks up the value of the mounted resonance frequency in the transducer database and generates a swept sine excitation in the range around ω_{MR} (the white region). The measured AMC FRF, which should be close to the yellow curve, is stored as a reference. Occasionally, the procedure is repeated, and the newly measured AMC FRF is compared with the reference curve. If during the test, an accelerometer falls off the structure, its AMC FRF will rather look like the grey curve that corresponds to the free hanging accelerometer; the algorithm detects if the two curves significantly differ in the white region and asks the user to check the accelerometer mounting.

If the accelerometer is mounted on a structure made of light material, the reference AMC FRF may look like the blue curve $(k_M \to \infty, m_t$ small). In the white region, it is almost impossible to distinguish it from the free hanging AMC FRF, and thus the AMC can fail. To prevent this, the BK Connect™ software introduces a pre-test wizard to help recognize such situations.

READ MORE
about BK Connect™ and how
to book a demo on page 42

References:
[1] Ewins, D.E. 2000. "Modal Testing: Theory, Practice and Application", Research Studies Press Ltd., Baldock, England
[2] Serridge, M., Licht, T.R. 1987. "Piezoelectric Accelerometers and Vibration Preamplifiers", Brüel & Kjær Publications, Denmark

PAINTING THE

A world on the move – the growing number of people with the means and desire to fly has created an estimated need for more than 40,000 new aircraft over the next 20 years.

THE VALUE OF COTS

The rapid availability, lower costs, and low risk of COTS (commercial off the shelf) products make them great alternatives to their custom-built equivalents. Safran Aircraft Engines test engineers agree, "Using both COTS hardware and software provided faster resolution of hardware issues, faster upgrades, reduced support costs, and opened up a wealth of standard analysis features for further investigations."

SKY GREEN

The aviation industry is facing stringent requirements to reduce its environmental footprint. But technological innovation and development – from concept to certified product – can take decades. In fact, the aircraft of 2050 are now under study within the framework of R&T programs and face a long schedule of ground and flying demonstrations before they can be approved to safely carry passengers.

Safran Aircraft Engines' Open Rotor demonstrator, developed through the European Clean Sky R&D initiative, is part of Safran Aircraft Engines' plans to develop a propulsion system that will meet the needs of aircraft manufacturers in 2030. The Open Rotor configuration aims at meeting several technological challenges such as a new propulsion mode, an innovative aerodynamic configuration and unprecedented manufacturing processes. The innovative architecture of the Open Rotor concept engine is unique. Built around a Safran Aircraft Engines' M88 Rafale engine, chosen for its compactness, the Open Rotor has two counter-rotating fans with 12 and 10 composite blades respectively. The front propeller is 4 metres in diameter, and the rear one slightly smaller to avoid interaction with vortices generated by the tips of front propeller blades. Unlike a classic engine, they are unshrouded, not only reducing the overall weight but also increasing the drawn airflow providing a bypass ratio (ratio between cold and hot airflows) exceeding 30:1. The increase of engine airflow results in a higher propulsion efficiency, improving fuel consumption and consequently cutting CO2 emissions. The Open Rotor engine, could eventually reduce fuel consumption and emissions by 30% compared to today's turbofan engines.

Clean Sky encompasses six so-called Integrated Technology Demonstrators (ITDs). Leading the SAGE (Sustainable and Green Engine) ITD of Clean Sky, Safran Aircraft Engines, together with its industry partners, aimed to deliver and ground test a full-scale Open Rotor engine. Now, following eight years of development, Safran Aircraft Engines have successfully performed its first ground test of the Open Rotor demonstrator at its brand-new, purpose-built, open-air test bench in Istres, southern France.

TESTING A DEMONSTRATOR – A COMPLEX AFFAIR

Testing is an essential part of this groundbreaking project, and with a pioneering new design like the Open Rotor, this is no small affair. With the revolutionary unshrouded engine architecture, use of cutting edge new materials and innovative manufacturing processes, the engine test must capture all manner of dynamic data to both ensure the reliability and integrity of the test, and to provide the reams of data for design analysts to ponder. For this, Safran Aircraft Engines test engineers utilized the Brüel & Kjær gas turbine test solution, that had earlier proven its worth in the even larger scale tests run during certification of CFM's LEAP* engine. Testing requires instrumenting the engine with a multitude of different sensors to measure, monitor and record engine behaviour. High-performance data acquisition equipment placed in containers right next to the motor base collects the data and transfers it to the 600 m^2 technical centre through a network of 10000 m of fiber optic cables.

When putting a prototype engine through its operating envelope, the dynamic and vibratory aspects of the open rotor prototype engine need to be followed very closely to maintain the integrity of the engine throughout the testing period. ▶

* LEAP is a trademark of CFM International, a 50/50 joint company between GE and Safran Aircraft Engines

PAINTING THE
SKY GREEN

Engineers sit at some thirteen monitoring stations to closely follow the vibration and dynamic response in real-time. All data acquired is then sent directly to Safran Aircraft Engines' design offices in Villaroche for post-test analysis. Being able to share data easily between sites accelerates the process of data assessment and decision making.

CONFIGURING IT OUT – FAST, EASY AND FOOLPROOF

Before any test can be performed, engineers must complete the complex task of pre-test planning and set-up, which consists of two potentially time-consuming phases. The first phase involves defining the many different sensor types and measurement aspects. A lot of upfront information needs collating from the test team, and then configured into the test system. This can be a laborious finicky exercise, which is a prerequisite for a successful test but ripe for introducing errors. By collating this data into one Microsoft® Excel® file during the planning phase, Safran Aircraft Engines could simply load it into the master data acquisition PC and set up the entire system. The spreadsheet contains all the defined parameters for time recording and processing of the signals, as well as all sensors with their measurement characteristics. Additionally, it contains all the set-ups for the data monitoring terminals, and the alarm monitoring system that can signal alarms to the test bed pilot and test operators.

The second phase consists of physically connecting the many hundreds of channels of diverse data such as vibration, strain, pressure and dynamic displacement to the acquisition system. This can be a complex affair of sorting out what goes where and how. However, as the system is built around Brüel & Kjær's LAN-XI hardware unit, which has no channel binding, any channel can be connected to any input. This provides flexibility when configuring the system and saves time, as there is no need to designate specific sensor types to specific data acquisition types. The same data acquisition system input plug can accept all type of transducers, again easing set-up, and providing versatility.

> “THE SPEED OF CONFIGURATION IS AN IMPORTANT CRITERION. THE INTEGRATION OF THE EXCEL FILE INTO THE SYSTEM CONFIGURATION ALLOWS US TO NOT ONLY SET UP AND CONTROL THE TEST FROM THE SPREADSHEET, BUT ALSO TO PERFORM A TEST WHILE PREPARING THE CONFIGURATION OF THE NEXT TEST ON A SEPARATE STATION, AND STILL TRACK EACH CONFIGURATION FOR EACH TEST.”
>
> TEST ENGINEER,
> SAFRAN AIRCRAFT ENGINES

KEEPING TABS ON THE TEST

Keeping a close eye on things during all stages of the test is important to ensure the validity of the test and to confirm that dynamic parameters remain within limits. Engineering teams monitor vital parameters in real-time to safeguard the integrity of the engine. Real-time alarms can warn of limit breaches, and logbooks keep a record of test process.

The individual engineering teams who track the acquired signals have very different needs in terms of visualization and data processing. Each monitoring station is, therefore, configured independently providing each department with only those signals relevant to their respective applications. Data is available in real time and a wide range of measurement displays are available to feed the right information to the right people at the right time. Data can be meticulously processed immediately or played back during or immediately after each test, so that each phase of testing can be analysed and evaluated before moving on to the next.

SHARING DATA WHEN AND WHERE NEEDED

Many parts of the test organization need access to data as and when it is recorded. The independent monitoring stations can be configured individually for the specific investigation, so partners and clients can be provided with full access to their own proprietary data. With many different people involved looking at very specific and different parts of the engine, it is of

"THE SYSTEM NEEDS TO BE ABLE TO MANAGE ALL TYPES OF SENSORS, OFFER FAST IMPLEMENTATION AND ALLOW REAL-TIME MONITORING OF SIGNALS ON DIFFERENT COMPUTER STATIONS."

TEST ENGINEER,
SAFRAN AIRCRAFT ENGINES

utmost importance that test engineers learn how to use the system quickly with a minimum of training. One of the test engineers concludes, "It was extremely easy to explain the use of the system in very short time to all different engineering departments and partners". Data needs to be shared on-the-fly with off-site departments in specific formats. Study departments at Villaroche can access test data the same day. The same engineer adds, "The real-time conversion to datx format and the speed with which data is transferred to the engineering office is unbeatable".

Following four days of testing on the open rotor, we asked an engineer returning from the site what he thought of the dynamic data acquisition system provided in Istres. His reply was encouraging, "I have nothing special to say; it did everything I wanted it to do. What else can I ask for?" A short pause and he adds, "I just wish that I could do the same real-time analysis from my office, because a lot of my time was spent on site waiting for the engine to rotate."

For Safran Aircraft Engines, the overall results of this first phase of testing were promising. The next phase will bring new challenges, but each step of the programme represents a huge stride forward towards a greener, cleaner sky. ■

Photos © Eric Drouin, Safran Group

Open Rotor at the test bench, Istres

EXPERT PROFILE

HOOKED ON THE SCIENCE OF SOUND

Audio guru Sean Olive grew up in Ontario, Canada, in a small city called Brockville, the gateway to the Thousand Islands. A musical childhood playing the piano, French horn and trumpet, and singing in a choir led to a music degree and a career dedicated to the perception and measurement of sound quality.

What initially drew you to acoustics?
Beyond a Bell & Howell tape recorder I received at Christmas when I was about five years old, my interest in audio started in my undergraduate studies at the University of Toronto. I lived in a men's residence comprised of primarily engineers. Audio and music were frequent topics of conversation, and many of my house-mates built their own amplifiers and loudspeakers. In 1979, at the end of my first year, I purchased my first audio system – paid for by playing the piano

> The biggest problem in audio today is the lack of a meaningful loudspeaker and headphone standard common to both the professional and consumer audio industries. Consumers cannot experience what the artist intended unless their loudspeakers or head-phones are similar in performance. It's a personal ambition to help solve this problem through education and better standards.

at night at a local hotel. It cost $1000, which was a lot of money back then.

Meeting Dr Floyd Toole at the National Research Council in 1985 was really the transformative event that was the beginning of a 30+ year research career in audio and acoustics. I applied for a summer job in his acoustics lab at the National Research Council to complete my master's research and thesis and ended up spending seven years there. He was doing pioneering work into the perception and measurement of loudspeakers that fascinated me. It was the first time I saw someone taking a scientific approach towards measuring listeners' impressions of loudspeaker sound quality and correlating them with acoustic measurements. Finally, there was a way to bring scientific understanding to the field of audio that was in dire need of it. I was completely hooked.

Your first degree was in piano, your post-graduate in sound recording. What took you from one to the other?

As an audiophile and music student, I had two traumatic experiences where recordings of my final year piano recital and a jazz orchestration that I wrote were so abysmal that I decided to take matters into my own hands. Upon graduation, I enrolled in McGill's Graduate Sound Recording programme to learn how to make better recordings.

What is the most challenging thing about what you do?

The biggest challenge is designing listening tests that can provide accurate and reliable ratings of sound quality. At the root of the problem is controlling the numerous physiological, psychological and acoustic nuisance variables at play. When done properly, we can begin to see correlations between listeners' perceptions and the acoustic performance of sound being evaluated. From these listening tests, we have learned that humans, regardless of age, culture and listening experience, generally agree on which products sound good and which don't. There is a universal definition of what is good sound.

What's your latest project?

We are currently developing scientific methods for measuring the subjective and objective sound quality of smart loudspeakers like Google Home, Amazon Echo and the smart speakers that Harman has developed. The goal is to figure out how to optimize and predict their sound quality through machine learning, much like we've done for traditional loudspeakers and headphones. ▶

DR SEAN OLIVE

Company and Job Title:
Acoustic Research Fellow, Harman International, responsible for sound quality research for consumer, professional and automotive products

Location: Greater Los Angeles area

EDUCATION

2001 – 2007: McGill University, PhD, Sound Recording
1983 – 1986: McGill University, MMus, Sound Recording
1978 – 1982: University of Toronto, BMus, Piano

PREVIOUS JOBS

2013: President: Audio Engineering Society
1993 – 2015: Director of Acoustic Research, Harman International
1986 – 1993: Research Scientist, Acoustics and Signal Processing, National Research Council of Canada

> "I'VE ALWAYS HAD A PASSION FOR MUSIC, SCIENCE AND HUMAN BEHAVIOUR. SO, CONDUCTING RESEARCH IN THE PERCEPTION AND MEASUREMENT OF SOUND AND MUSIC REPRODUCTION IS THE PERFECT MARRIAGE OF TWO PASSIONS."
>
> DR SEAN OLIVE

HOOKED ON THE SCIENCE OF SOUND

Sixteen-year-old Sean Olive, star of the Lions Club Music Festival, at the piano

An influential Christmas gift for five-year old Sean – a Bell & Howell tape recorder

Photo courtesy of Norm Bernicky

In your most recent paper, you proposed a statistical model that predicts listeners' preference ratings of headphones. How did you first come upon the concept of the model?

The headphone research has been an ongoing five-year project. Our focus on in-ear headphones began in 2016. The statistical model for predicting listeners' preference ratings of headphones based on deviations in its frequency response was really an extension of a similar model I developed in 2004 for predicting listeners' loudspeaker ratings. The only difference is the headphone ratings are based on a single curve whereas the loudspeaker's radiation uses several curves to characterize its sound over a sphere. One of the big challenges was figuring out how to do a controlled scientific listening test with different headphones, which led to our virtual headphone test method. The current model only considers the headphone's frequency response, which is the dominant factor related to its sound. Future models should incorporate any audible non-linear distortions.

How close do you think the industry has gotten to perfection in headphone design?

We now understand what the target response should be for achieving good sound. The industry now needs to figure out how to design headphones that consistently hit the target. This is a more difficult challenge for passive designs but easier for active headphones with digital signal processing (DSP). The new AKG N5005 in-ear headphone uses multiple drivers making it easier to hit the target. Beyond that, there is still progress to be made in controlling leakage effects, which can significantly affect bass and active noise control (ANC) performance, and finding mechanical and electroacoustic

> "THE CURRENT ITU AND EBU STANDARDS FOR HEADPHONE PERFORMANCE ARE OUTDATED AND NEED TO REFLECT WHAT MAKES A HEADPHONE SOUND GOOD."
>
> DR SEAN OLIVE

Sean Olive and one of his favourite pastimes – skating; seen here with his children and sister on a frozen lake in a snowstorm

solutions to provide better fit and sound for individual listeners. Listening to stereo over headphones is a spatially unrewarding experience, as most sounds appear inside or near your head, so there is work to be done there. The current ITU and EBU standards for headphone performance are outdated and need to reflect what makes a headphone sound good.

In the future, what will be the most exciting changes in the audio industry?

I think technologies like augmented reality (AR), virtual reality (VR) and autonomous driving cars are going to be very disruptive to audio. Consumers will want and expect high-quality audio with 3D spatial rendering that matches the quality of the visual and tactile cues. Autonomous cars will allow more time and opportunity to enjoy these rich experiences. Imagine sitting back enjoying a performance in a virtual Boston Symphony Hall while being driven home in your car.

What do you consider to be the all-time-best music recording?

There are so many good recordings, but most recently, I heard a DVD concert of 'Paul Simon and Friends' recorded live at the Library of Congress. To me, it sounded pretty good, probably much better than if I was sitting in the audience at the event. It's not unusual today that the reproduced sound you hear at home is significantly better than the sound at the live event. Plus, there is no freeway traffic, $25 parking, or long line-ups at the bathroom.

WHO SAID WHAT?

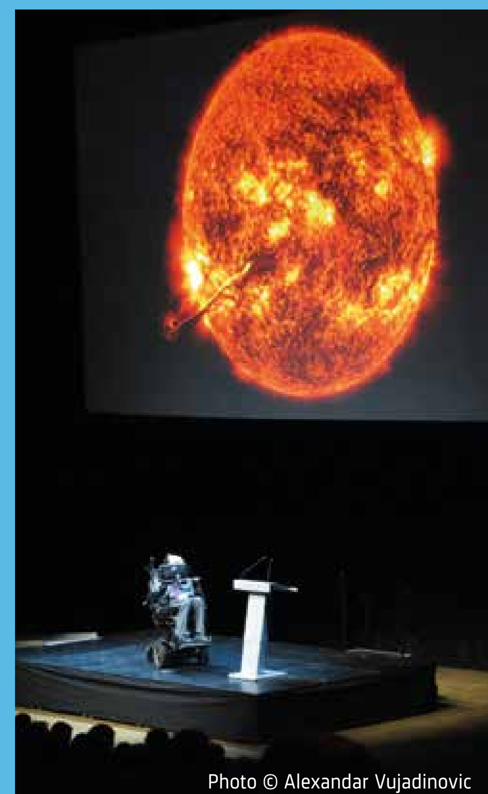


Photo © Alexandar Vujadinovic

> "SO REMEMBER TO LOOK AT THE STARS AND NOT DOWN AT YOUR FEET."
>
> STEPHEN HAWKING (1942 – 2018)

"This boy will never amount to anything" – that is what one teacher wrote on Stephen William Hawking's school report. However, his more perceptive classmates called him 'Einstein', a much better description of the boy who became a visionary physicist and a brilliant mind.

And despite immense adversity, Hawking always stayed curious and never gave up.

BAT VS MOTH: SEARCH AND DESTROY VS ESCAPE AND EVADE

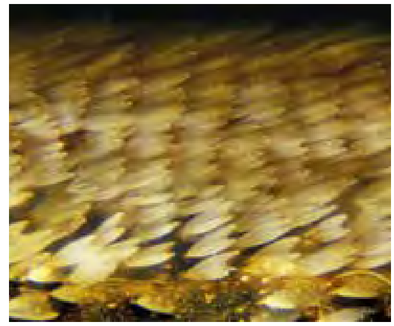
BY: **PAMELA RIVERA-PARRA**
MSc
Departamento de Biología
Escuela Politecnica Nacional
Quito-Ecuador

There is a whole world happening outside of what we can hear. Up in the night sky while we sleep, bats and moths face each other in a deadly battle every night. They encounter in an acoustic arena where the signals bats produce to hunt are the same signals moths use for evasion.

Insectivorous bats use ultrasonic tones to find their prey: they emit tones that range from 18 to more than 150 kHz (humans can register up to 20 kHz), and they listen to the returning echoes to locate and characterize their prey. Bats analyze the changes in the amplitude modulation of the echo in order to locate the insects. The movement of the wings of insects during flight causes a change in the echo, so every time an insect flaps its wings it is giving away its location to the predators.

In the terms of evolutionary biology, moths and bats are entangled in an evolutionary arms race. To defend against the bats' targeting tactic, moths have evolved a tympanic organ that enables them to hear the ultrasonic calls of bats and elicit an escape behaviour or an acoustic response. Our team is interested in analyzing the effects of the behavioural responses that moths display in reaction to the bats' targeting signals. ▶

BAT VS MOTH: SEARCH AND DESTROY VS ESCAPE AND EVADE



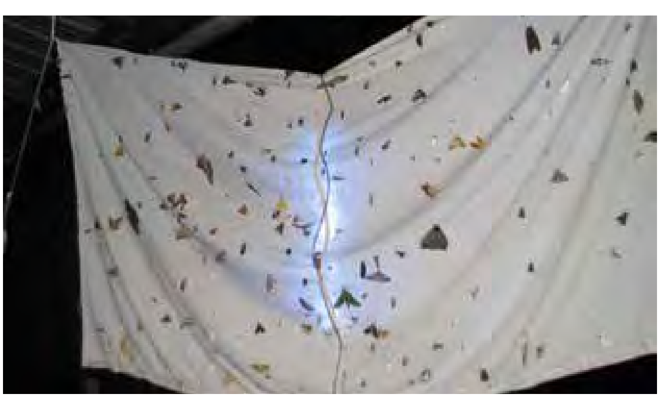
Close-up of moth wing scales. Photo courtesy of Vladimir Carvajal

TAKING THE BAT/MOTH RELATIONSHIP TO THE LAB

Our research is conducted in the tropical forest of Ecuador, where there can be 110 species of bats and hundreds of species of moths at the same location. In order to explore the bat/moth relationship, we have had to purchase and build a number of different microphones and ultrasound speakers. And because our experiments involve playbacks and record the returning echo, we must work in a non-reverberant environment for some analyses and in a highly reverberant environment for others.

Every year we go to the field, assemble our flight tunnel and start our work night. Once we have caught our moths, the real work starts. The moths are placed inside the tunnel to restrain flight, so we can make high-speed videos while they respond to a playback of ultrasonic tones and bat calls. The flight tunnel is wired with ultrasound microphones to record the returning echo of the moth, or in other words, the signal a bat would perceive.

For accurate data, we have had to design and build a small-scale reverberation chamber to conduct experiments with moth wings. Our design was based on a previous design (Zeng et al., 2011; Ntelezos et al., 2017) where they used Cox and D'Anto-nio-modified primitive-root diffusers that are based on the frequency we are going to work with, consisting of wells of the same width and different depths.



To attract and catch the moths, we utilize the latest in moth-attracting entomological equipment: a white sheet and a blacklight

Creating a functional 15 × 15 × 10 cm reverberation chamber that would work with ultrasound was a substantial challenge

PRIMITIVE-ROOT DIFFUSERS

Diffusers can be used to neutralize echoes. They can be particularly useful because they reflect the sound waves in many directions to create a diffuse field, preventing echoes without reducing sound energy.

The primitive-root diffusers used in this chamber consist of a series of wells of the same width and different depths and were designed using a number-theory sequence based on primitive roots derived from the target frequency.

THE MEASUREMENT CHAMBER

The reverberation chamber uses two types of diffusers: empiric diffusers that are no more than semi spheres of glass, and modified primitive-root diffusers. The chamber also houses an ultrasound microphone and two ultrasound speakers. Carlos Ramos, from Universidad de las Americas in Quito, is the acoustic engineer in charge of running the code to produce our signal and make sure our technical acoustic components run smoothly.

SOUNDS ABOUT RIGHT...

WORKING WITH SOUND ALWAYS HIGHLIGHTS NOISE ISSUES

Ultrasound is tricky to work with; we don't even realize that even keys jingling in our pockets, motion detectors to turn on lights and even some lights themselves, produce ultrasound. So, in order to work in a noise-free environment, we had to build an anechoic chamber in which to put our reverberation chamber. The chamber-in-chamber design also provides electric insulation since the local electric connections are not always properly isolated.

SURVIVAL OF THE STEALTHIEST

We found that the moths present an acoustic startle response when presented with bat calls: they change the position of their body and wings and pause in-flight for a moment. This reaction causes a reduction of the amplitude modulation in the returning echo. For a moment, the moth is able to hide, acoustically, from hungry insectivorous bats.

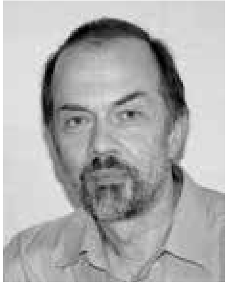
Interestingly, after further examination of the videos, we notice that when the moths exhibit this response they will also turn their wings. This behaviour raises two questions: why do moths turn their wings, and do the wings play a role in the reduction of the acoustic modulation?

We are in the process of experimenting with and analyzing the wings of a number of different moth species. So far, we see that, in fact, moth wings are absorbing ultrasound and that the main frequency at which amplitude is decreased seems to be different between species. We have also started to look into the anatomy of the wings; it is amazing to see the structure of the scales under a microscope – they resemble acoustic foam used in anechoic rooms. This may be part of an anti-bat strategy that moths have evolved to avoid being detected and, more importantly to the moths, eaten by bats. ■

The results have also opened an exciting second line of research based on analyzing the ultrasound-absorbance qualities of moth wings. We continue to work with our hypothesis that the scales of the wings are the structures playing an active role in the absorbance in ultrasound. ■

TECHNICAL REVIEW

The articles published in Brüel & Kjær's 'Technical Review' offer a deeper understanding of the many specialized disciplines within sound and vibration. It is where you will find the latest in-depth theory, measurement techniques and details about specific instrumentation and technology.



BY: **JØRGEN HALD**
PhD,
Research Engineer
Brüel & Kjær

The paper below deals with a method to minimize the effects of flow noise in microphones, primarily for array measurements in wind tunnels. Similarities between flow noise and the target wind noise produced in a vehicle make it difficult to use other existing methods.

REMOVAL OF INCOHERENT NOISE FROM AN AVERAGED CROSS-SPECTRAL MATRIX

The noise created by a wind burst in a microphone is a phenomenon that probably everyone is familiar with – for example, from TV interviews recorded outdoors. When performing microphone array measurements outdoors or in a wind tunnel, such flow noise in the individual microphones cannot be avoided. The level of the noise can be reduced using windscreens, but the noise cannot be completely avoided, and if the screens are not much smaller than the spacing between the microphones, the noise generated in one microphone will also be picked up by the nearby microphones. However, in the case of a voice recording taken outdoors, the flow noise and the voice have quite different statistical and spectral properties that can be exploited to develop algorithms for (partial) removal of the flow noise. This is more complicated with microphone array measurements in a wind tunnel, where the target aerodynamic noise from a vehicle and the flow noise in the individual microphones have similar properties.

Array measurements in a wind tunnel are typically taken in an open, semi-anechoic facility, where the walls and the ceiling are sound absorbing and where the vehicle under test is in a flow region in the lower middle part of the facility. Arrays can then be placed outside of the core flow but as close as possible to the vehicle (and the flow) to get the highest possible resolution of sources on the vehicle. At the array position, the average flow speed will, therefore, be low (usually less than 5 m/s), but there will be turbulence. Arrays can be placed on the sides and/or above the vehicle. ►

Close-up picture of a single microphone with the wind screen pushed aside

TECHNICAL
REVIEW

Source map produced using Clean-SC

Noise source localization is typically performed for each array using delay and sum (DAS) beamforming with the cross-spectral matrix (CSM) between all microphones in an array as input. The CSM has one row and one column for each microphone in the array. A selected element in the matrix contains the cross-power spectrum between the two microphones specified by the row and column indices of the selected element. The elements on the diagonal of the matrix, therefore, represent the autospectra for each one of the microphones.

We now assume the following:

- The flow noise induced in one microphone is not picked up by any other microphone
- The flow-noise signals generated in different microphones are incoherent/independent

This implies that, after a sufficiently long averaging time, the flow-noise contributions will be insignificant outside the matrix diagonal while they will remain on the diagonal, that is, in the autospectra. Theory and practical experience show that the two assumptions hold true to a large extent.

When an averaged CSM is used in DAS beamforming, use of the CSM diagonal can be avoided – a technique referred to as Diagonal Removal. Unfortunately, the use of Diagonal Removal also has some side effects, such as under-estimation of source strengths, and in addition DAS has some severe limitations in the form of limited dynamic range (sidelobes) and poor resolution at low frequencies. Other beamforming methods typically require use of the full CSM, including the diagonal. The referenced Technical Review article describes a method to remove precisely the (flow) noise added on the diagonal of the CSM, assuming there are no (flow) noise contributions outside the diagonal. The method, called Diagonal Denoising (DD), is shown to work very well, provided the number of significant independent/incoherent target sources (on the vehicle) is effectively smaller than the number of microphones – an assumption that is shared with all array methods based on use of an averaged CSM.

With real measurements, however, there will be off-diagonal residual contributions from the incoherent flow-noise signals because of the finite averaging time used to obtain the CSM. These off-diagonal contributions will limit the flow-noise reduction in the autospectra achievable by DD. Based on simulated measurements with equal noise levels added in all channels, an approximate empirical model of the impact was developed. According to the model, the number of averages required to reduce the noise autospectra by a factor α is approximately $\alpha^{-2}(M-1)^{1.25}$, M being the number of microphones. Thus, the required number of averages increases with an increasing number of microphones. According to the paper, this seems to be because the number of off-diagonal elements in the CSM increases faster than the number of diagonal elements, when the number of microphones is increased. Requiring, for example, a reduction by a factor $\alpha=0.1$ (10 dB) for an array with 100 microphones, the required number of averages will be approximately 31,000. Measurements have been performed on a small loudspeaker with a section of the array exposed to airflow. The measurement results agree well with the predictions from the empirical model.

The article contains a detailed description of the DD method. It investigates the conditions under which it works, and it examines the requirements it sets for the measurement to achieve a specific noise reduction.

READ THE COMPLETE WHITE PAPER

Visit our Knowledge Centre and read the latest issue of the Technical Review that has the full details of this white paper.

The issue also features a second white paper detailing a three-year-long research project that proved it possible to detect a 15-centimetre crack in a wind turbine blade without stopping the wind turbine: 'Active vibration-based SHM system for wind turbine blades: demonstration on an operating Vestas V27 wind turbine'. ■

KNOWLEDGE CENTRE

The Brüel & Kjær Knowledge Centre is our online library containing a wide range of detailed technical information.

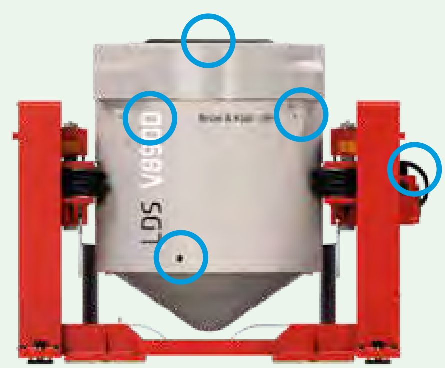
Here you will find:

- Case studies
- Application notes
- Conference papers
- Primers and handbooks
- Technical reviews ■

SPOT THE DIFFERENCE

The V8900 shaker on page 17 had been modified in five places.

Did you get it right?

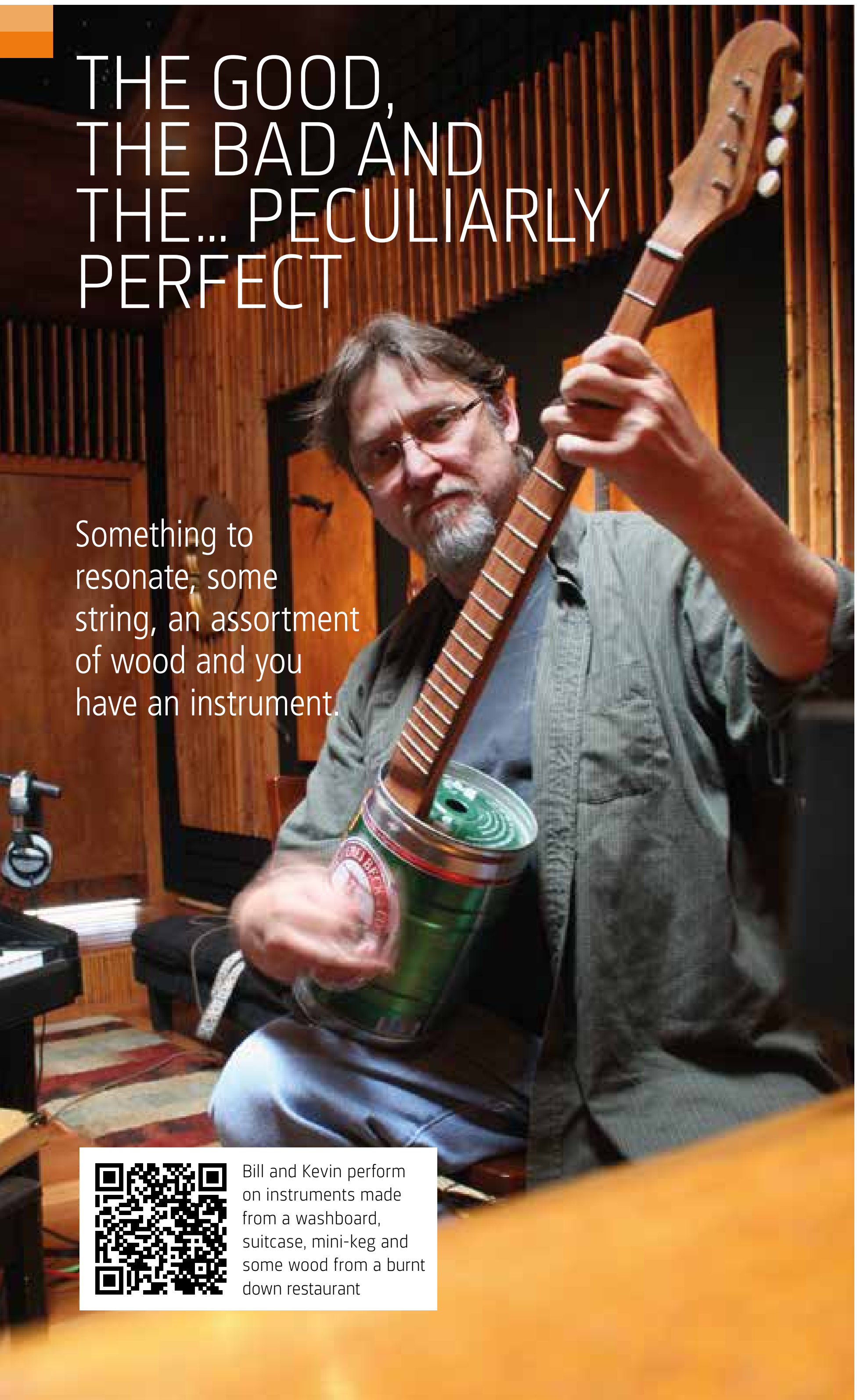


Our LDS V8900 shaker is an air-cooled electrodynamic shaker with a high overturning moment and a force rating of 80 kN (17,894 lbf), for high-performance vibration and shock testing of large devices. Ideal for the aerospace and defence and automotive industries. ■

SEE MORE

www.bksv.com/V8900

MUSIC IS IN THE HANDS OF THE BEHOLDER



THE GOOD, THE BAD AND THE... PECULIARLY PERFECT

Something to resonate, some string, an assortment of wood and you have an instrument.

Bill and Kevin perform on instruments made from a washboard, suitcase, mini-keg and some wood from a burnt down restaurant

Most who come across these odd-to-the-uninitiated cigar box instruments assume that they are cobbled together by someone who wants to play but can't afford a guitar. And because the rise of the cigar box style can be attributed to post-American Civil War soldiers, that assumption has some truth to it – but it's not a universal condition. Paul McCartney, Tom Waits, Ed King of Lynyrd Skynyrd and Billy Gibbons of ZZ Top have all played and recorded with cigar box instruments. So, it seems that there must be more to it than lack of funds.

William (Bill) Jehle and fellow enthusiast and bandmate, Kevin Craig, were kind enough to provide some insight, not just about construction, but also why.

WHY A CIGAR BOX?

Looking back, the cigar box instrument tradition originated in the 1840s – coinciding with a shift in cigar packaging to the cigar box sizes that are still common today – but really began to take off in the 1860s. The Civil War soldiers were very much products of environment, where 'one made due' with what was on hand, and with the convenience of the new cigar box dimensions, the right conditions for the advent of the cigar box guitar were brought together. So, the idea that these instruments sprang up from a lack of ability to acquire 'standard' instruments is not wrong.

THE ANECDOTAL GATEWAY

Similar to the origins of cigar box bands in general, Bill's interest began with wanting particular sounds without the means to purchase the custom instruments he needed.

As a child, a neighbour gave him the pieces of a guitar, and he and his father rebuilt it. Later researching a custom

“BILL INVITED ME TO SEE HOW LOUD WE COULD PLAY THESE THINGS FOR A CIGAR BOX GUITAR EXHIBIT, AND EVEN AFTER THE BAND RAN ITS COURSE, I WAS HOOKED.”

KEVIN CRAIG

Bill Jehle is the author of two books on the history of cigar box guitars and an accomplished homemade-instrument craftsman and musician

Kevin (left) with a shovel-handle cigar box bass and Bill (right) with a cigar box guitar from their days in 'Nadaband'

guitar that would be all that he wanted, he realized he could buy the tools he needed and build the guitar for the same final price – tools included. But during construction, a friend sent him a copy of Make magazine with a cigar box guitar on the cover. Here was this functional guitar made from a cigar box, some twine, a 1 × 2-inch board and what appeared to be some chopsticks. He gave it a try, and his dream of the perfect guitar was shot. Why spend a fortune on the ‘perfect’ guitar when you can have dozens of individual instruments, each with its own unique characteristics for a fraction of that price?

WHY ARE CIGAR BOX GUITARS STILL HERE?

Bill and Kevin are not alone. People love music, and if the materials to make music aren’t readily available, people will find them. While a lack of funds may have been the initial impetus behind the instruments, the current trend stems from the unique natures of a cigar box guitar’s individual components, enabling unique acoustic traits, appearances, or even emotions. In the end, Bill and Kevin both agreed that the cigar box guitars’ idiosyncrasies are the keys to their rise in popularity and are what make them more enjoyable to play than the perks of the high-end guitars.

“THERE’S ALWAYS ANOTHER WAY TO MAKE A SOUND: STRETCH OUT SOME STRING AND YOU CAN HIT IT WITH A STICK, BOW IT, PLUCK IT – HECK, I’VE USED DENTAL FLOSS BEFORE. NOT ALL OF IT SOUNDS GOOD, BUT SOMETIMES IT’S MAGIC. IT’S THE EXPERIMENTATION, THAT’S WHAT KEEPS ME GOING.”

BILL JEHLE

NOISE MONITORING FOR OPTIMAL MILL OPERATION

Mining companies around the world continue to face the challenge of increasing productivity and reducing downtime. As part of its SAG mill control system, Manta Controls developed the Manta Mic: a robust and reliable acoustic analyser that prevents mill damage.

MANTA® CONTROLS

With its headquarters in Southern Australia, Manta Controls develops unique advanced control systems to help optimize semi-autogenous grinding (SAG) mills. SAG mills are primarily used at gold, copper and platinum mines where steel balls are used for the grinding. The Manta Controls Advanced Control System, called the SAG Cube, automatically monitors and controls a SAG Mill, keeping track of critical process variables impacting mill throughput. For most sites, one hour of operation provides a revenue between AUD$ 20,000 per hour up to or greater than AUD$ 100,000 per hour. Therefore, any downtime is very costly.

John Karageorgos, Managing Director of Manta Controls, explains the latest challenge: "In essence, we are trying to listen to a grinding mill and measure when the mill can be damaged from the steel balls hitting the steel liners of the mill. If we have a reliable measure of 'damage' then we can control the mill and not operate in the damaging mode."

"WE TRIED A NEW IDEA, AND WE FINALLY GOT THE CONTROL SYSTEM TO COMMUNICATE WITH TYPE 2250, DIRECTLY. I'LL NEVER FORGET THAT DAY!"

JOHN KARAGEORGOS,
MANAGING DIRECTOR, MANTA CONTROLS

PROBLEM SOLVING

The answer to this challenge turned out to be a new generation of SAG mill acoustic analyser, the Manta Mic, which takes advantage of Brüel & Kjær's products for analysing acoustic emissions. However, it wasn't a straightforward development process.

Manta Controls had previously been using a Type 2238 sound level meter. "We have been working directly with Brüel & Kjær for two years, but working with Brüel & Kjær equipment for the past 20 years," explains John Karageorgos. "Brüel & Kjær provides the 'Rolls Royce' of equipment with regard to anything acoustic, and we rely on it to be reliable and robust."

When Type 2238 became obsolete, Manta Controls looked at Type 2250 for their replacement solution. "The only catch was that we lost our capability of having a 4–20 mA signal, because Type 2250 had an Ethernet connection," explains John Karageorgos.

One key objective of the new solution was to eliminate the need for a computer from the architecture; Manta Controls invested approximately AUD$ 200 k in R&D to find a robust solution to communicate with Type 2250 directly from a control system, without a computer connected to Type 2250.

RESEARCH PAYS OFF

"When we started this project, no one knew if it was achievable, so in the beginning it was pure research work. We were prepared to try and then walk away if it didn't work. That's the risk with developing anything new," explains John Karageorgos.

After almost 12 months of development, things were not going so well and the research team had not managed to communicate directly with a Type 2250 from a control system without having a computer as a gateway. ▶

NOISE MONITORING FOR
OPTIMAL MILL OPERATION

John Karageorgos explains: "We were nearly ready to pull the pin on the project, but we gave it one last chance. We tried a new idea, and we finally got the control system to communicate with Type 2250, directly. I will never forget that day! Once we did that, we knew we had a product!"

UNEXPECTED DISCOVERY

By solving a particular problem with the communication to Type 2250, Manta Controls discovered something new: "We then managed to pull through the entire frequency spectrum from Type 2250 directly into a control system with no computer being used as a gateway or interface. This has never been done before with Type 2250.

So now we are able to listen to any SAG or AG mill and measure the entire frequency spectrum live from a Type 2250, or a Type 2270, and pass the entire frequency spectrum directly into a control system with no computer. This makes the entire solution simple and elegant and very robust," explains John Karageorgos.

This discovery has started a new R&D project where Manta Controls are trying to use the live data to monitor operating conditions, such as the optimum volumetric percentage filling and the condition of the lifters. This could also be deployed on other mining equipment as well, not just on SAG or AG mills.

PROTECTING AND OPTIMIZING MILLS

The main benefits of this type of reliable SAG mill monitoring are accurate and repeatable decibel signals at the various frequencies – information that is used to protect the mills.

The next phase of the project is to provide measurements that can help customers operate a SAG or AG mill optimally. John Karageorgos explains: "Optimization is our bread and butter, so once we have the measurements we are looking for, incorporating them into our SAG Cube solution is easy. The hard part is developing these new operating parameters that tell us whether a mill is operating optimally or not."

FUTURE POSSIBILITIES

Manta Control customers seem pretty excited about the new solution because it offers capabilities that were simply not possible before.

"Now we can offer a simple and elegant yet robust solution with the added benefit of the quality that Brüel & Kjær equipment provides. This has also opened the door to some new ideas. We have plans to further develop the solution to offer additional capabilities. For example, we are looking at capturing even more data with two microphones to monitor two locations, and then we'll try an array of microphones. Plus, we are looking at using sound and Brüel & Kjær accelerometers on some other applications – but we are keeping them to ourselves for the time being!" concludes John Karageorgos.

The new rugged Manta Mic holder showing the Brüel & Kjær preamplifier and microphone

Manta Mic just before packing into the crate for shipment

CUSTOMER NEWS

BIOMASS WASTE
HELPS REDUCE IN-CABIN NOISE

Assoc. Prof. Iwan Yahya, The Iwany Acoustics Research Group (iARG), Indonesia

For the past many years, the focus of The Iwany Acoustics Research Group (iARG) at Sebelas Maret University's physics department has been the research and development of green acoustic material for room acoustics and vehicle noise applications. Together with partners PT. RMA Jakarta, supplier of material for cabin noise reduction to leading Indonesian automotive manufacturers, iARG has developed a high quality felt using the waste from the textile industry as raw material.

iARG's green approach is part of its long-term strategy to help the environment and create better value for biomass waste, and its commitment to the development of green material for noise control applications has led to a new type of felt exploiting Indonesia's huge amount of coconut husk waste. By mixing coconut husk fibre with other raw materials, PT. RMA and iARG have not only developed the aptly named coco-felt but also a foam for motorcycle seats. The acoustic characteristics of these materials are determined in terms of absorption and transmission loss according to automotive standards, using a Brüel & Kjær impedance tube and dedicated material testing software. ■

BRÜEL & KJÆR NEWS

BK CONNECT™ IS RELEASED

BK Connect, our new flagship sound and vibration (S&V) analysis software, has been released to the world, and the S&V community has taken note. Just after release, the innovative and user-centric platform has already garnered sales, worldwide.

This platform is designed to work like its users work, not just a mass of tools that a project can be forced into. BK Connect is a fully integrated solution for multi-channel data acquisition using our industry-leading LAN-XI hardware. The user interface is easily tailored to any workflow, adaptable to the needs of different users and processes throughout the organization, enabling sound and vibration specialists and operators to work together with high efficiency and productivity.

This first release includes the core BK Connect applications: Data Viewer, Hardware Setup, Time Data Recorder and Data Processing. These applications are designed for general-purpose sound and vibration engineering. Together, they provide a comprehensive set of tools for real-time measurements and data processing with the flexibility to deal with a wide range of engineering scenarios – from complex troubleshooting investigations to repetitive, standardized testing.

And to ensure that testing capabilities are maintained during the transition to the BK Connect platform, a core PULSE™ LabShop licence has been embedded in BK Connect Data Processing licences. Additionally, individual PULSE LabShop applications and calculation licences required for tasks that are not currently available natively in BK Connect have been included within the relevant BK Connect licences. This ensures that there is no loss in testing capabilities.

BOOK A DEMO

To learn more about BK Connect in general, get the latest news about future releases and arrange for a demo licence, you can visit the dedicated campaign site: **www.bksv.com/bkconnect**

SEE MORE

For the full picture, please download the Final Report and Project Findings at:

www.beyondtomorrow.dk

Beyond Tomorrow, tomorrow and tomorrow

The Beyond Tomorrow project is complete, a symposium has been held and the findings are all published, but the future still awaits. This vision study has been a joint effort led by Brüel & Kjær and the Copenhagen Institute for Futures Studies with added expertise and insights provided by selected experts and organizations.

At the conclusion of this vision study, a panel of experts and industry leaders in the field of sound and vibration testing discussed at length their visions of where product development is heading, and why. Their commentary was informed by the megatrends identified over the course of the project, and they tended towards a common vision.

For more information about this project and some food for thought concerning your product development as 2030 approaches, this issue contains an insert with a selection of insights.

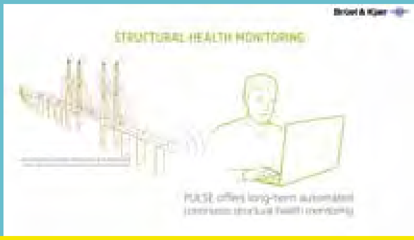
New videos for Operational Modal Analysis and Structural Health Monitoring

Due to the demonstrable benefits of Operational Modal Analysis (OMA) and Structural Health Monitoring (SHM), their usage is on the rise. Two videos are now available that introduce the applications and describe some typical use scenarios.

Take a few minutes to learn more about these Brüel & Kjær solutions and how they can help you.

OPERATIONAL MODAL ANALYSIS

STRUCTURAL HEALTH MONITORING



Accelerometer Mounting Check

Accelerometer Mounting Check (AMC) is a new Brüel & Kjær tool included as part of BK Connect's system verification for ensuring reliable and confident data acquisition.

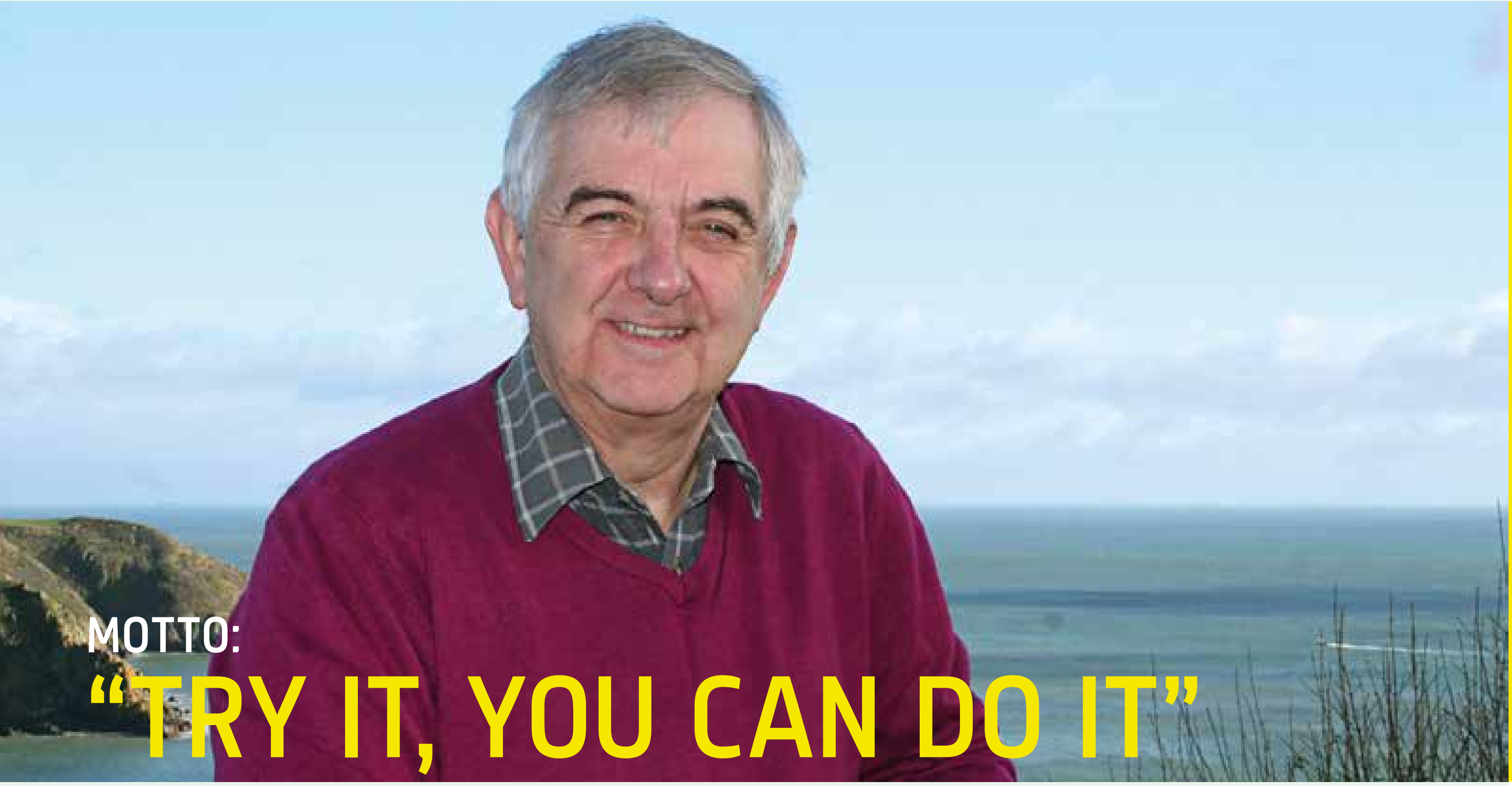
SEE MORE
Read more about AMC and the technology behind it on pp 18 – 19

Ensuring that accelerometers are mounted and stay correctly mounted on the test structure is often the most problematic link in the measurement chain. Any problem here will irrevocably corrupt the measurement. Sometimes accelerometers are mounted in locations difficult to visually inspect, and even when visual inspection is possible, mounting errors can just be missed.

AMC is easy to use and reliable. Because it detects potential mounting problems before, during and after measurement, this tool saves time and money and provides confidence in your acquired data.

FIVE QUESTIONS FOR RICHARD JOHNSON

71-year-old Business Development Manager Richard Johnson was born in Southend-on-Sea, England (home to the longest pleasure pier in the world). When not working, he enjoys sailing, gliding or spending time with his family, including four grandchildren, at his hideaway in Devon. He is passionate about solving problems.



MOTTO: "TRY IT, YOU CAN DO IT"

What attracted you to Brüel & Kjær?

For my final year project at university in the 1960s, I used Brüel & Kjær equipment for the first time, sparking my interest in NVH. Working for Brüel & Kjær seems the obvious place to be after almost 50 years in sound and vibration measurement. Here, I enjoy my role integrating our team (which joined Brüel & Kjær 18 months ago) into Brüel & Kjær's Global Engineering Services organization and continuing to develop the consulting business. I also enjoy the challenge of keeping ahead in an increasingly competitive world, both technically and globally.

What is the most challenging project you have been involved in?

I am part of a team that has helped to get the NVH Simulator technology to be adopted as a standard part of our clients' vehicle development process.

What irritates you most about your own personality?

I would rather listen than talk.

If you could have one super power, what would it be and why?

Time travel – so that I could experience great historical events and prevent future disasters.

Favourite things

Food: Beef Stroganoff.

Book: 'Sigh for a Merlin – Testing the Spitfire' by Alex Henshaw.

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