SOUND AND VIBRATION NEWS

WAVES

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BOXING CROWD BREAKS NOISE RECORD

REIGNITING GUITAR EVOLUTION

IN SEARCH OF THE WORLD'S QUIETEST CAR

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Brüel & Kjær

BEYOND MEASURE

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FRONT COVER IMAGE
Denmark's Patrick Nielsen defends his title on home territory, making short work of Mexican opponent, José Pinzón.

Brüel & Kjær
BEYOND MEASURE

LETTER FROM THE MANAGING DIRECTOR

EXCITING STORIES IN SOUND & VIBRATION

Welcome to the first edition of our newly redesigned Waves magazine. We want to better encompass the abundance of fascinating stories from our company and the industry. To support this we have introduced a new graphic look that provides us with a flexible framework to showcase our passion for sound and vibration. Subject diversity is definitely on display in this issue, which contains articles on topics ranging from unravelling the mystery of a guitar's sound (p. 22) and analysing crowd noise at a boxing match (p. 4) to a peek inside Shure® headphones (p. 8).

The business of providing sound and vibration solutions is increasingly relevant to everyday concerns that affect us all. Rapid globalisation and population growth mean that we are living in a world that becomes noisier by the minute. A world in which monitoring and controlling sound will be increasingly important, as evidenced by articles in this issue about the 'Windsor Hum' (p. 38) and the quietest car (p. 12). Similarly, as product life cycles become radically shortened, demand will grow for methods to predict sound and vibration in the product development process. To see how we are helping all of our customers keep up with this demand, take a look at the article about how our Application Research Center (ARC) facility in the Detroit area provides a one-of-a-kind noise and vibration solution centre (p. 34).

I hope you will find the new Waves interesting and inspiring. The magazine will be published twice a year; to subscribe, please sign up at www.bksv.com/subscribe. We would very much like to hear from you at waves@bksv.com with any comments or suggestions you may have about articles or new subjects.

I wish you good reading and hopefully some inspiration as to how Brüel & Kjær can assist you with your sound and vibration challenges.

LARS RØNN
MANAGING DIRECTOR

LET'S MAKE

PATRICK REINHARD NIELSEN

Age:	22
Division:	Middleweight
Stance:	Southpaw
Reach:	185 cm
Height:	183 cm
Weight:	72.5 kg
Won:	21 (10 by K.O)
Drawn:	0
Total:	21

Fifteen kilometres west of Copenhagen lies the suburb of Albertslund, aka A-town. Its concrete mix of houses, shops and apartment blocks reveals its '60s origins, but the industrial exterior is deceptive as the grey buildings intermingle with small canals and lakes – making the town appear both tough and vulnerable. Nestled within this setting is Albertslund's Musikteater, the home of theatre, concerts and films.

SOME NOISE...

"WE'LL HAVE EVERYTHING WE NEED TO GET OUR NAMES IN THE RECORD BOOKS – A GREAT VENUE, A CRAZY CROWD AND FANTASTIC FIGHTS."

NISSE SAUERLAND
PROMOTER

But on this particular Saturday night, A-town's theatre would be transformed into a true arena. Team Sauerland's Nordic Fight Night was in town and at centre stage, one of Albertlund's own. The 22-year-old local boy and undefeated WBA & WBO Intercontinental Middleweight Champion Patrick Nielsen would be defending his title against Mexican José Pinzón and fighting in his own backyard for the first time in his career. The scene was well and truly set for The Homecoming.

THE WARRIOR RETURNS

Team Sauerland is Europe's leading boxing stable and, together with Viasat, came up with the Nordic Fight Night concept in 2012. The idea is not only to boost Scandinavian boxing but also to provide fans with an opportunity to experience world-class boxing at different venues around the country and live on TV.

Tonight it was Albertslund's turn to be in the spotlight, and Patrick Nielsen, having returned home from Berlin to fight in front of friends, family and fiercely loyal and boisterous fans, was not going to disappoint. And with Patrick's younger brother, Mikki Nielsen, also in action in the ring, a lively evening was in store. And if that wasn't enough drama, Team Sauerland decided to up the ante even further and pit the 1200 rowdy Patrick Nielsen fans against 17,000 followers of the Sacramento Kings basketball team in an attempt to break the Guinness World Record for loudest crowd roar at a stadium (indoors). The current record of 106.6 dB(A) had remained unbeaten for almost five years and was claimed during a second time-out in the third quarter of the LA Clippers v Milwaukee Bucks game at Bradley Centre, Milwaukee, Wisconsin, USA, on 20 December 2008. ▶

Brüel & Kjær Product Manager Brian MacMillan checks the sound level meter is properly calibrated before the live TV record attempt

WHEN TWO TRIBES GO TO WAR

The two challenges for the record, both officially accepted by Guinness World Records, would take place within 24 hours of each other. Promoter Nisse Sauerland was confident, "We'll have everything we need to get our names in the record books – a great venue, a crazy crowd and fantastic fights. The atmosphere will be sensational on Saturday." Patrick Nielsen added, "I am so grateful for the support I get from my fans, it would be great to break the record together. When I hear their screams and shouts, I know that I am not alone in the ring and that gives me a big energy boost. I will do my part and give the crowd an exciting fight. Let's make some noise." The gauntlet was well and truly thrown down. Denmark and America were going head-to-head.

STICKING TO THE RULES

Having looked at the official Guinness World Record guidelines, Johannes Berendt, Head of PR, Sauerland Promotion, contacted Brüel & Kjær for some technical help with the noise measurement. The rules were clear:

- The sound level must be measured using a certified and calibrated Class I precision measuring sound level meter
- The microphone should be positioned between 1.5 and 1.6 metres above the ground

> "WHEN I HEAR THEIR SCREAMS AND SHOUTS, I KNOW THAT I AM NOT ALONE IN THE RING AND THAT GIVES ME A BIG ENERGY BOOST."
>
> PATRICK NIELSEN,
> INTERCONTINENTAL MIDDLEWEIGHT CHAMPION

- The microphone must be at least 2.5 metres away from the closest participant
- External instruments such as horns, drums, plastic noisemakers, vuvuzelas, etc., can be used
- Measurements should be made in dB(A), with the highest peak reading to be recorded
- A statement must be provided by a sound engineer or similarly qualified individual who can verify, based on testing, that the measuring device is properly calibrated and functioning correctly
- A print or photograph of the peak recording should be provided

After perusing the guidelines carefully, Brüel & Kjær Product Manager Instrumentation Brian MacMillan, was not worried. "Besides a little confusion about peak and maximum, the guidelines were similar to what our consultants in local governments and consultancies work to," he said. In Brian's opinion, the biggest challenge was needing to be 2.5 metres away from the closest participant. But that didn't faze him for long, "It just meant that effectively the microphone needed to be inside the ring." Simple as that.

TAKING IT ON THE CHIN

However, the first blow on Saturday was not delivered by one of the fighters. It came from the other side of the world – the world record for loudest crowd roar at an indoor sports event had been broken and confirmed on Friday night, just one day before the Danish attempt. The fans of the Sacramento Kings (USA) had roared their way into the record books achieving a mighty 126 dB(A) at Sleep Train Arena, Sacramento, California. It was going to be tougher than originally thought.

"May the loudest fans win," said promoter Nisse Sauerland, "and even if we can't break the record, we will still scare the hell out of our boxers' opponents." Patrick Nielsen added, "The atmosphere will be amazing. My fans will take the roof off."

The setup was quite simple – a microphone placed on a tripod in the middle of the ring was connected to Sound Level Meter Type 2270. The planned three attempts at breaking the brand-new record were all transmitted live on TV to an audience of 132,000 Danes. The old record of 106.6 dB(A) was easily broken on the first attempt – the Albertslund crowd achieving 114.5 dB(A). The two final attempts managed a respectable 115.5 dB(A) – not a world record maybe, but a European one nonetheless.

More importantly, the hometown boys were triumphant. Micki Nielsen made short work of his German opponent Björn Blaschke with a knockout in the first round, and a lightning left hook by Patrick resulted in a technical knockout in the fifth round and a convincing victory. Patrick Nielsen remains unbeaten – it was a good homecoming.

PUMP UP THE VOLUME

The Sound of the Crowd – The Human League
Pump Up the Volume – M.A.R.S.
Cum on Feel the Noize – Slade
Shout – The Isley Brothers
Let's Get Loud – Jennifer Lopez
Scream – Usher
Boom Bang a Bang – Lulu
Bang, Bang – Sonny & Cher
Make Some Noise – Beastie Boys
Boom Boom – John Lee Hooker

KEEP IT DOWN

There's a Kind of Hush – Herman's Hermits
The Sound of Silence – Simon & Garfunkel
Don't Speak – No Doubt
Silence is Golden – The Tremeloes
Shut Up – Black Eyed Peas
Careless Whisper – George Michael
Hush – Deep Purple
Enjoy the Silence – Depeche Mode
Our Lips are Sealed – The Go Go's
Shush Shush Charlotte – Serge Gainsbourg

Photos courtesy of Photo Wende

INSIDE **HEADPHONES**

With a wide variety of headphones to choose from, many users are looking for guidance to help them select the right headphones for their application.

What practical information could be offered in helping them make the best choice? We like to explode myths – were there any here?

We decided to get the scoop from Principal Engineer Yuri Shulman, a 32-year veteran of Shure® who leads the development of Shure's growing product line. We chatted about sound signatures, frequency response and even touched (very lightly) on the science of psychoacoustics.

What can you tell us about frequency response? Isn't there a sense that a flat frequency response is preferable to a more shaped sound? Frequency response has a strong effect on perceived timbral quality and is, therefore, an essential component in high-quality headphone design. The issue goes back to the loudspeaker industry where a flat response (when a speaker's acoustic output stays the same for every frequency) is usually preferred. However, there is a major difference between acoustic measurements made on loudspeakers and headphones.

While a loudspeaker frequency response can be evaluated in free-field conditions, headphones have to be coupled to the ear if a frequency response measurement representative of what listeners perceive is intended. This requirement implies that the ear must be included in the measurement system.

Several methods have been used to take the ear into account. These include the perceptual loudness comparison as well as instrumental measurements made with artificial ears and couplers. In the headphone measurement techniques, the resulting frequency response includes the filtering effect of the listener's ear, and therefore the reference of a flat frequency response no longer applies in this context. Instead, the target headphone response is designed to provide a 'natural' listening experience, similar to one received while listening with flat loudspeakers in the 'sweet spot' in the room.

Many of our headphones are designed to be perceived as flat. They deliver naturally balanced, non-equalised sound. Of course, there are special user situations when deviation from a perceived flat frequency response is desired.

So, the actual differences in the structure of a listener's ear have an impact on user preferences? It's difficult to design something that will sound perfect to everyone – in fact, it's impossible, and yes, that's based, in part, on the actual physical characteristics of the listener's ear. When designing Shure headphones, we use industry standard ear simulators that represent an average human ear. Its physical characteristics are based on carefully measured ears. There can, however, be significant deviations from this standard ear in some individuals. In addition, personal taste is also a factor in user preferences.

When is a flat response preferred? Someone who is recording or mixing needs to hear every component in the sound spectrum with full resolution and high timbral accuracy, so it's important to have a tool that's neutral in character.

When would a shaped response headphone be used? For example, accurate sound reproduction is not of concern for DJ headphones. These are designed to provide enhanced, strong, low frequencies and crisp highs. It's the kick drums, snares, and hi-hats you're paying attention to when mixing, not intricate sonic details.

Here's something we hear pretty often: headphones require a 'burn in period'. Is this true? This is more myth than fact. Some people make the argument that the driver suspension could be a little unsettled when the headphones are brand new.

At Shure we don't subscribe to that thinking – again, what could be true for some loudspeakers (where there can be a 100-hour or so burn-in period) doesn't directly apply here. It's a matter of perception. Shure headphones sound the same after using them for a year as they did brand new.

WHILE A LOUDSPEAKER FREQUENCY RESPONSE CAN BE EVALUATED IN FREE-FIELD CONDITIONS, HEADPHONES HAVE TO BE COUPLED TO THE EAR IF A FREQUENCY RESPONSE MEASUREMENT REPRESENTATIVE OF WHAT LISTENERS PERCEIVE IS INTENDED.

SHURE'S SRH1840

PROFESSIONAL OPEN-BACK HEADPHONES

SENSITIVITY: 96 dB SPL/mW
IMPEDANCE: 65 Ω
MAXIMUM INPUT POWER: 1000 mW
FREQUENCY RANGE: 10 Hz – 30 kHz

SHURE'S SRH1540

PROFESSIONAL CLOSED-BACK HEADPHONES

SENSITIVITY: 99 dB/mW
IMPEDANCE: 46 Ω
MAXIMUM INPUT POWER: 1000 mW
FREQUENCY RANGE: 5 Hz – 25 kHz

ENHANCED LOW FREQUENCIES COULD COMPENSATE FOR LOST SOUND PRESSURE EFFECTS ON THE BODY SUCH AS BONE/CHEST TRANSMISSION AND NASAL CAVITY COMPRESSION.

If everyone hears differently depending on the physical shape of their ears, their hearing abilities (and even right ear/left ear hearing differences), how is it possible to develop standards when you beta-test headphones? Here, for example, is one of our techniques: we utilise the Head and Torso Simulator (HATS) when developing headphones. We use outer silicone ears of different sizes and densities with artificial inner ears that match the impedance of the average human ear. We measure the headphone's actual performance affected by resonance in the ear canal and shape of the ear. Data is collected and used to engineer the response of each model to produce a flat or other desired frequency response profile as perceived by the 'average' listener.

According to Yuri, Shure's simulator is simply called 'HATS', and he carries a Shure associate ID, at all times

Of course, we also beta-test with trained human listeners – both audiophiles and professional sound engineers. While professional users look for a perfectly flat, smooth spectral balance and highest possible detail resolution, the audiophiles are more concerned with musicality or ability of the headphones to communicate the musical message as it was intended by the performers. Harmonic and intermodulation distortions, fatigue factor and wearing comfort are also graded by both groups of beta testers.

Enhanced bass seems to be a trend with consumer headphones, correct? Yes, some popular consumer headphones have dramatically enhanced bass response. However, this excessive correction leads to increased distortions and added listening fatigue. Actually there may be good reasons to enhance low-frequency response on certain headphones assuming this is done correctly, and responsibly. Let me give a few examples where such enhancement could be of benefit:

- Listening at very low levels would benefit from boosted bass according to the equal-loudness curves (Fletcher-Munson). Our ears are less sensitive to low frequencies as listening volume decreases
- Listening on the subway train or city bus – increased output of low-frequencies will help to mask outside noise for a better overall experience
- Browsing the Web, playing electronic games, listening at work – boosting low frequencies can create more excitement
- Certain recordings with poorly recorded bass may sound fuller if the headphones provide some additional bass
- Enhanced low frequencies could compensate for lost sound pressure effects on the body such as bone/chest transmission and nasal cavity compression. These are present when listening to a live performance or loudspeakers with a strong low end in the room

Some headphone models are open back. Why would users want that type? It's more like listening to a pair of loudspeakers. Your ears don't get as hot because ventilation is built in and that makes you more comfortable, especially if you're listening for hours. They usually offer a better stereo image – a psychoacoustic effect due to removed occlusion. Outside noises are somewhat reduced, but you still hear them. They sound more open and airy, but the price paid is a loss of isolation. We believe each type of headphones have applications where they are best suited.

Last, but not least, are there any safety issues associated with headphone use? I don't recommend blasting the volume! Headphone users should use safe and comfortable volume levels to preserve good hearing health.

YURI SHULMAN

Position: Principal Engineer
Experience: 32 years at Shure
Member of: Audio Engineering Society (AES)
Previously: Research Engineer-Physicist at the Institute of Low Temperature Physics, Academy of Sciences of the USSR
Education: Kharkov State University, Ukraine: MSc Physics, 1972
Shows attended: National Association of Music Merchants (NAMM), National Association of Broadcasters (NAB), and AES Conventions
Music choice: Classical, jazz, rock, world music. "At the moment I am listening to Misa Criolla by Ariel Ramirez with José Carreras (Philips CD), an absolutely beautiful work and an amazing quality recording as well!"
Age: 68

IN SEARCH OF THE WORLD'S QUIETEST CAR

SEE MORE
details about all test models at

www.bksv.com/waves

Photo courtesy of Audi

14 MODELS IN NOISE TEST

Audi A3 SB1.8 TFSI	Audi R8 V10	Bentley Mulsanne	BMW 428i	BMW X1 18d	Fiat 500L	Ford C-Max 1.0
180 HP	525 HP	512 HP	245 HP	143 HP	105 HP	125 HP

Stationary noise

Acceleration 0–100 km/h

Driving at constant speeds

Maximum velocity

Cobblestone road

Auditory perception

Speech intelligibility

Engine, car body, tyres, chassis – every part of a car produces noise of some sort. German magazine AUTO BILD decided to thoroughly test and evaluate the resulting impact of the total noise of 14 different cars.

The rear of the engine compartment knocks, squeaks and rattles. The wind noise rushes and hisses over the side windows, intensifying as the car accelerates. Metal panels tremble, tyres rumble, gears grind and parts of the trim squeak and rattle – all resulting in an unearthly cacophony of noise. Without a doubt, a drive in the good old VW Beetle provides a lot of aural input. Yes, it really is noisy in this classic bug from Wolfsburg.

Luckily, things have changed since then. Engines are quieter and car bodies are better insulated. Most cars are only noisy at high speeds or during acceleration when the engine roars into life. And that's when a grumpy diesel engine will become even more annoying. Just as the speed increases, the noise mix produced by the tyres, chassis and wind intensifies.

AUTO BILD tested 14 current car models to see how noisy a car can get in unfavourable conditions. The 14 cars ranged from the quiet, represented by the ultimate example – the Rolls-Royce Ghost, and the almost soundless electric car, to their complete antithesis – the Audi R8 V10 supercar.

The noise the 14 cars produced was not only measured in the usual decibels, more precisely dB(A), but also captured in sones. In contrast to the decibel, which only measures the physically detected sound, the sone provides a more realistic evaluation of how humans experience noise.

The system used for the test measures sound with amazing accuracy. For example, it is capable of differentiating between noise produced by tyres, wind and the engine. Even the difference between sitting close to the window or in the centre of the car is filtered out by the software used. It is even possible to measure speech intelligibility. During the test, the system could identify which specific sounds could affect the degree to which speech could be understood.

The results collected from the seven measured parameters were summarised and evaluated using a points system. And with every car given an overall mark, the quietest car was found. Here's a clue – it wasn't the VW Beetle! ▶

SONE IS THE UNIT OF PERCEIVED LOUDNESS

Mazda MX-5
160 HP

Mercedes S 500 LWB
455 HP

Opel Ampera
150 HP

Renault Zoe
88 HP

Rolls-Royce Ghost
570 HP

VW Golf Blue TDI
150 HP

VW Beetle 2003 Model 46 HP

1ST PLACE

MERCEDES S 500 LWB

V8 twin turbo, front engine, rear drive
CAPACITY: 335 kW (455 hp) at 5250 rpm
TYRES: Pirelli W 240 Sottozero III
245/45 R 19 V
ACCELERATION: 0-100 km/h in 4.8 s
TOP SPEED: 250 km/h

CONCLUSION: A whispering engine and a meticulously insulated chassis – the S-Class purrs its way into first place.

2ND PLACE

ROLLS-ROYCE GHOST

V12 twin turbo, front engine, rear drive
CAPACITY: 420 kW (570 hp) at 5250 rpm
TYRES: Goodyear Efficient Grip
V./h. 255/45 – 285/40 ZR 20 Y
ACCELERATION: 0-100 km/h in 4.9 s
TOP SPEED: 250 km/h

CONCLUSION: A travelling, peaceful oasis – as long as you don't ask the engine to pull out all the stops. Who would do that, anyway? It's a Rolls ...

3RD PLACE

BENTLEY MULSANNE

V8 twin turbo, front engine, rear drive
CAPACITY: 377 kW (512 hp) at 4200 rpm
TYRES: Dunlop SP Sport Maxx GT
265/40 ZR 21
ACCELERATION: 0-100 km/h in 5.1 s
TOP SPEED: 296 km/h

CONCLUSION: The engine shows what it can do – also acoustically. Nevertheless: the noise level in the Bentley is extremely low.

Only those who drive the new S-Class at maximum acceleration will hear anything from the supercharged, V8 petrol engine tucked under a bonnet lined with abundant, non-woven insulation. Sprinting up to 100 km/h, the noise produced by 455 hp penetrates the interior as a subtle growl. However, cruising at a maximum speed of 130 km/h, you will hear almost nothing from the twin turbo. The impressive calm at constant speed – also on cobblestones – and the faint wind noise at 250 km/h, underline the low noise level of this limousine. And when stationary, you'll hear nothing from this purring machine. You might just hear a whisper from the air-conditioning fan on the first notch.

Driving at a constant speed (at 50, 100, 130 km/h)
8.47 / 14.55 / 20.51 sone*
Acceleration (0–100 km/h)
20.44 sone
Top speed
45.72 sone
Cobblestones (at 40 km/h)
25.27 sone
Interior noise (stationary and idling)
3.81 sone
Auditory perception (subjective score for noise type)
Score 1
Speech intelligibility (determined at 130 km/h)
Score 1-

** Sone is the unit of perceived loudness*

Quiet area: Thanks to the double-glazed side windows, the wind noise won't disturb you

Peace in the cabin: The V8 is luxuriously packed in insulation and hums very quietly

According to historical Rolls-Royce advertising, the loudest noise in the interior of the car was the ticking of the clock. Today the Rolls leaves us with a very different acoustic impression. While sprinting, the giant 570 hp engine really comes into its own and makes itself heard. However, this seems to be intentional, ensuring that customers are in no doubt that 570 hp prevail here. However, when the Ghost drives away at constant speed, there is almost complete silence. On cobblestones, the colossus effortlessly rolls along as expected. However, the measurement microphones do detect a faint creaking from an area at the rear backrest adjustment, which does make the car feel noisy.

Driving at a constant speed (at 50, 100, 130 km/h)
9.21 / 15.34 / 21.07 sone
Acceleration (0–100 km/h)
21.82 sone
Top speed
56.52 sone
Cobblestones (at 40 km/h)
27.08 sone
Interior noise (stationary and idling)
4.61 sone
Auditory perception (subjective score for noise type)
Score 1
Speech intelligibility (determined at 130 km/h)
Score 1-

Feel-good area: Inside the car, road noise and engine sounds are rare

Shielded area: the V12 under thick cover in the Ghost

The engine whispers quietly despite the brutal performance and sporting pedigree. And even on cobblestone roads this luxuriously insulated limousine glides gracefully. However, a slight hum from the wheel wells is clearly audible. One glance into the engine compartment reveals that the engine is completely encapsulated – not much chance of a lot of noise escaping through there. Only at full acceleration does the V8 engine finally raise its voice – a little too robustly. With such an impressive maximum speed – the car achieves nearly 300 km/h – one could wish that more of the wind noise stayed outside this luxury limo; instead it roars, despite the double-glazing.

Driving at a constant speed (at 50, 100, 130 km/h)
8.49 / 14.21 / 19.7 sone
Acceleration (0-100 km/h)
21.87 sone
Top speed
64.73 sone
Cobblestones (at 40 km/h)
29.43 sone
Interior noise (stationary and idling)
4.53 sone
Auditory perception (subjective score for noise type)
Score 1+
Speech intelligibility (determined at 130 km/h)
Score 1-

Isolation cell: The engine is enclosed in plenty of covers

Passenger cell: At a speed of 130 km/h passengers will not hear the engine

IN SEARCH OF THE
WORLD'S QUIETEST CAR

HOW THE TEST WAS PERFORMED

Product Manager Krestian Møller Pedersen (left) and Application Engineer Nick Prgomelja (right) from Bruel & Kjær

The tests were carried out by German magazine AUTO BILD in cooperation with Brüel & Kjær. As part of their luggage, the two engineers had brought with them the latest measuring equipment, specially designed for use in passenger cars. The Head And Torso Simulator (HATS) is placed in the front (or rear) of the vehicle, and picks up noises via microphones inside its head. In addition, a binaural headset was used, allowing one of the engineers to listen to the recordings. Both systems were connected via WLAN to a tablet PC, making it easy to monitor the measurements during the test drive. A prerequisite for an accurate measurement is the avoidance of unnecessary noise, so loose objects such as pens or key chains were not allowed in the test car. Each test run was carried out on the AUTO BILD test track in Bremerhaven by a test driver and an engineer.

THIS IS HOW THE POINTS WERE AWARDED

The conclusion was the combined results of seven test events of different weighting. The inner sound (front of car) was measured for all candidates. In the case of constant speed driving, the average value of the results at speeds of 50, 100 and 130 km/h were evaluated. In the case of the zero to 100 km/h acceleration, the

The car's measurement results were tracked during the test drives using the Sonoscout™ iPad® app

MEASUREMENTS WERE ACCURATELY TAKEN OF WHERE NOISE WAS GENERATED AND WHETHER IT DISTURBED THE QUIET ATMOSPHERE IN THE CAR.

highest measurable value (peak) was evaluated. AUTO BILD determined the top speed results on the autobahn (German motorway). Speech intelligibility was judged on how well passengers managed to understand each other on the autobahn at a speed of 130 km/h. For many participants, this was not a problem. In fact, the only time a conversation was virtually impossible at high speeds was during the extremely noisy VW Beetle test drives. While measuring the auditory perception parameters, the subjective noise perceived for the 14 candidates throughout the entire test was assessed. Here, sound quality was the most important parameter. In the end, AUTO BILD preferred the V8 sound range of the Bentley to the V12 whisper of the Rolls Royce.

THE RESULT

Precision microphones, sophisticated measuring software and attentive tester ears hear everything. Or too little, as in the case of the winner – the Mercedes S 500. The limousine marks the lower end of the current noise threshold when driving – it was even quieter than the Rolls Royce. The electric cars showed that a silent motor alone is no guarantee for in-car comfort – noise is also generated by wind and tyres.

Test photos courtesy of R. Rätzke, S. Krieger - Auto Bild

HOW SOUND IS MEASURED

Sound is pressure fluctuations that are perceived by our ears. A microphone converts pressure fluctuations into an electrical signal. Unwanted sound is called noise.

DECIBELS, dB

The strength of a sound or noise is measured in decibels (dB). The threshold of hearing is 0 dB, whispering 20 dB and a normal conversation around 50 dB.

A-WEIGHTING, dB(A)

In addition to the strength of a sound, a human ear also perceives different tones, or pitches, differently. That is why the evaluation of sound is done using a weighting filter. The most common is the A-weighting filter, which mimics the response of the human ear and the sound is then expressed in dB(A).

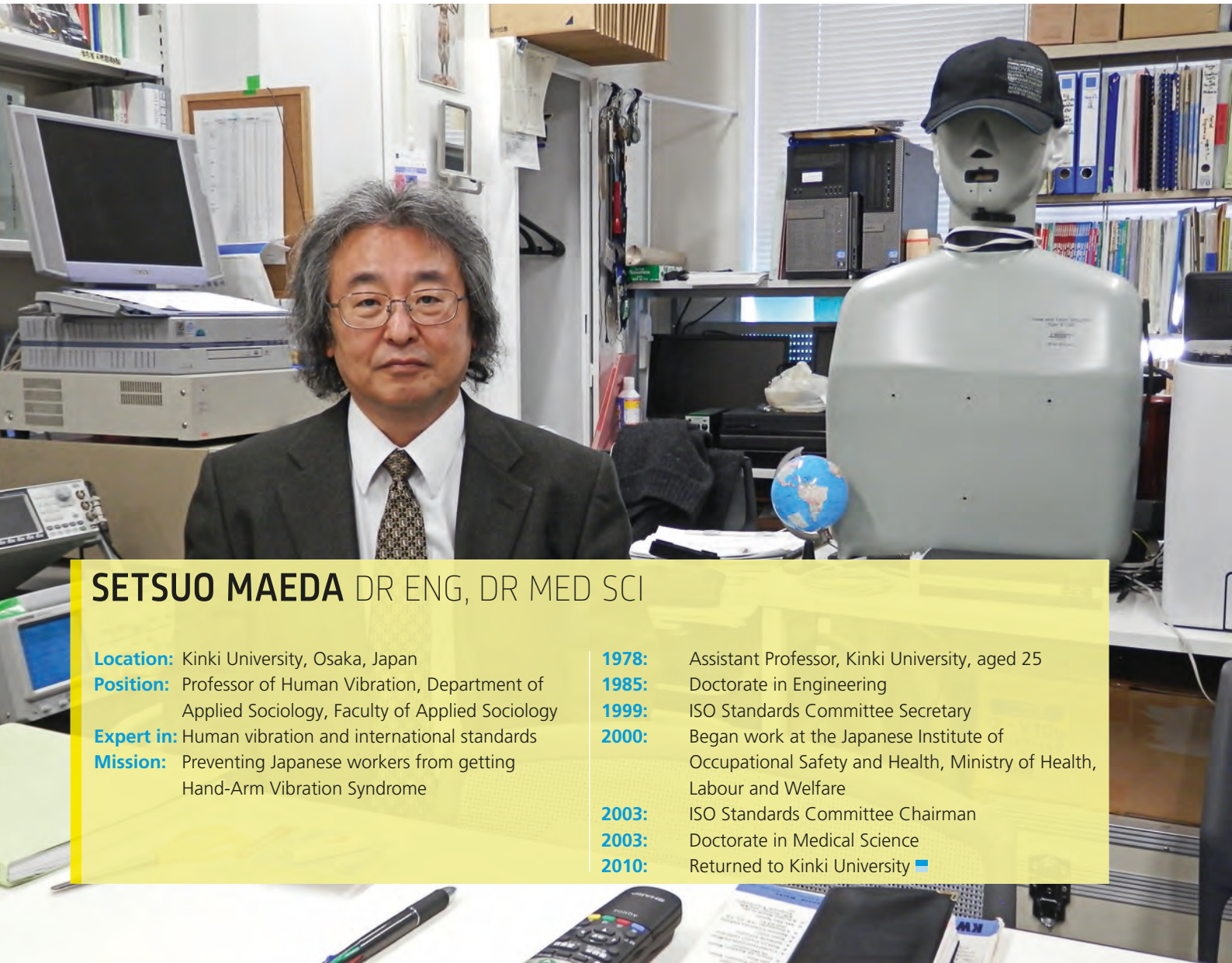
SONE

There are certain sound pitches that we perceive as more disturbing than others. In addition, we react in a more sensitive way when the sound strength is lower. The evaluation in sones connects the subjective human perception of sound with the sound pressure, which can be measured by our instruments. In acoustics, the sone is the unit of perceived loudness.One sone corresponds to 40 phon, which is the same as 40 dB(A) at 1000 Hz. Two sones are 50 phon and correspond to a doubling of the strength of the sound.

EXPERT PROFILE

JAPANESE PROFESSOR OF HUMAN VIBRATION

When a typhoon wreaked havoc during his formative years, Dr Setsuo Maeda altered the course of his career, resolving to help Japanese workers in the clean-up effort by reducing their vibration injuries. He went on to spearhead Japan's adoption of ISO standardisation in the area, and now teaches a sought-after course that prepares Japanese students for the globalised world.



SETSUO MAEDA DR ENG, DR MED SCI

Location: Kinki University, Osaka, Japan
Position: Professor of Human Vibration, Department of Applied Sociology, Faculty of Applied Sociology
Expert in: Human vibration and international standards
Mission: Preventing Japanese workers from getting Hand-Arm Vibration Syndrome

1978: Assistant Professor, Kinki University, aged 25
1985: Doctorate in Engineering
1999: ISO Standards Committee Secretary
2000: Began work at the Japanese Institute of Occupational Safety and Health, Ministry of Health, Labour and Welfare
2003: ISO Standards Committee Chairman
2003: Doctorate in Medical Science
2010: Returned to Kinki University

A typhoon in the 1970s left 2500 Japanese workers with Hand-Arm Vibration Syndrome, as they intensively used chainsaws to clear up the damage

We caught up with Dr Setsuo Maeda in his office at Kinki University, 560 km west of Tokyo in Osaka Prefecture. Surrounded by shelves of ISO standards and with the green HATS manikin standing nearby, he answered our questions.

Why did you become an expert in human vibration? I began in noise research, but there were many noise researchers in the 1970s, and not so many researchers into the human response to vibration. And at that time, there were a lot of sufferers from Hand-Arm Vibration Syndrome (HAVS), so I changed the focus of my research after my PhD.

Why were there so many sufferers? We had a big typhoon in the Hokkaido area in the 1970s, and many trees had fallen down. So there were many people using chainsaws, and afterwards many had HAVS. There were 2500 patients, so the government had to give a large amount of money to each worker. I felt that I could contribute something to prevent workers from getting this syndrome.

At that time there was less focus on human vibration, and no attention to international standards. Nowadays those 2500 people receiving compensation for HAVS is down to 300, thanks to several government actions.

Do you teach your students about HAVS now? Yes, especially relating to ISO standards. But it's a big change – we never used to learn about standards at all.

So how did you learn about ISO Standards? I learned on my own. In 1992, I was at an ISO meeting in London as an observer from Japan. I saw many people from different countries getting involved, and I was very surprised that teachers and researchers were writing so many of the papers. They were making standards to protect workers from human vibration effects. So I thought I must do something from the Japanese side, for the Japanese workers.

> "I THOUGHT I MUST DO SOMETHING FOR THE JAPANESE WORKERS. SO I BOUGHT MANY ISO STANDARDS TO READ, USING MY OWN MONEY."
>
> SETSUO MAEDA

So I bought many ISO standards to read, using my own money; I was determined to read them. So I always fought with my wife, saying I need this standard! And now of course the university pays, and nowadays all students must learn about ISO/EU directives. Almost all of my students will go to a company, and Japanese companies must follow EU directives if they want to export to Europe. ▶

HOW DO YOU DEFINE HUMAN VIBRATION?

"It consists of two things: whole-body vibration, which concerns general health effects and comfort, and hand-arm vibration, which can lead to Hand-Arm Vibration Syndrome (HAVS), where the target is to reduce vibration in the fingers."

A thermal image demonstrating the loss of heat in a Reynaud's sufferer – a disease that can result from vibration exposure

JAPANESE PROFESSOR
OF HUMAN VIBRATION

Do you work with any companies? Within the automotive industry I work with Toyota, Mazda Motor Corporation, and with Delta Industries on making vehicle seats. In the construction industry, there is the Takinaka Corporation, and with Panasonic I've been working on bone-conducting headsets. I think all university teachers should have some connections with industry.

Do you work with any other organisations? I work with universities, for example, Loughborough in the UK, Connecticut University in the USA as well as The National Institute for Occupational Safety and Health (NIOSH) there, and other universities in Canada and the USA. I also work with Malaysia University, and with the ISO Standards organisation.

What standards work do you do? Now we are working on a standard that includes the perception of the human finger, checking the difference between the ISO standard and the Japanese people. It seems Japanese people are more sensitive! Most standards come from colder countries like Norway, Finland, the USA, etc., but we don't have enough data from tropical countries like Malaysia and Japan.

> "I THINK ALL UNIVERSITY TEACHERS SHOULD HAVE SOME CONNECTIONS WITH INDUSTRY."

His cherished MG Rover sportscar is right-hand drive - traffic drives on the left in Japan

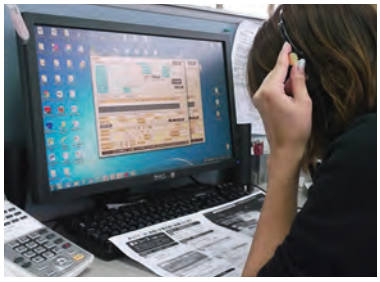
What is the Japanese community of human vibration experts like? About 20 years ago I made a group focusing on human response to vibration, and now we have about 300 researchers from universities, government or companies all doing some human response to vibration work. Every year we have a conference.

What are the hot topics in human vibration today? Many people have done research into the effect on the whole body, but in the real world you have simultaneous vibration, noise and visual stimuli. We are now trying to find out the combined effect using a six-axis driving simulator at the Hiroshima Campus of Kinki University. The other stimuli reduce the perceived comfort level, as does moving the position of vehicle seats, so automotive manufacturers must think of this.

What else will be important for human vibration in future? As well as the multi-sensory research, we are looking at vibration everywhere, such as tall buildings in motion. In the big earthquake two years ago, tall buildings moved up to 4 metres at the very top, making a lot of vibration. Japanese building companies are very good at making buildings that won't get damaged, but inside the building the people feel very scared and get motion sickness. We don't have those kinds of design target criteria for these tall buildings, and there are not so many researchers in the world looking into earthquakes, so I feel I must do something about that.

Finally, do you have a name for your Head And Torso Simulator? I always say HATS-Kun! It means Mr HATS. ■

SEE MORE
about 'Hearing loss in call centres' at
www.bksv.com/casestudies



Dr Maeda has investigated the causes of hearing loss in Japan's call centres

One of the earliest known units to measure length is the Egyptian cubit, which dates from the 3rd millennium BC.

THE BIRTH OF CALIBRATION

The common cubit was the length of the forearm from the elbow to the tip of the middle finger – usually around 45.7 cm. The 'royal' cubit was slightly longer: a common cubit plus the width of the palm of the Pharaoh ruling at the time.

The single royal cubit master (primary standard) was a rod carved from a block of black granite. Surviving cubit rods are between 52.2 and 52.9 cm in length. Workers were then supplied with copies – cubit sticks made of wood or granite. The royal architect or foreman of each construction site was responsible for maintaining the accuracy of these.

At every full moon, the cubit sticks had to be brought to the royal cubit master and compared to it. Failure to do so was punishable by death.

With this standardisation and uniformity of length they achieved amazing accuracy. The Great Pyramid of Giza is constructed with sides of 440 cubits (230.364 metres). Using cubit sticks, the builders were within 11.4 cm – an accuracy better than 0.05%.

Thus the basic ideas of modern calibration were born over 4000 years ago: common units of measurement, traceability, a hierarchy of standards and regular re-calibration intervals.

RMN-Grand Palais (musée du Louvre) / Hervé Lewandowski

WHO SAYS WHAT?

"TRUTH IS SO OBSCURE IN THESE TIMES, AND FALSEHOOD SO ESTABLISHED, THAT, UNLESS WE LOVE THE TRUTH, WE CANNOT KNOW IT."

BLAISE PASCAL (1623-1662)

Blaise Pascal was a French mathematician, physicist and religious philosopher, after whom the unit pascal (Pa) is named. Pascals are fundamental to the measurement of sound since they measure pressure, and therefore sound pressure.

One pascal is defined as one newton per square metre. Pascals are thus derived from fundamental SI base units – kilograms, seconds and metres. These are three of the seven interdependent SI base units that govern the internationally agreed standards to which all instruments are calibrated. Read all about the whys and hows of calibration on page 28.

REIGNITING

Raquel Benito playing a Manjon guitar produced according to the centuries-old handmade tradition. Even today we don't fully understand the link between construction and sound quality

Photo courtesy of Martín Gallego

In Spain, an aura of mysticism surrounds the construction of guitars, with the best concert-level instruments commanding enormous respect.

GUITAR EVOLUTION

To reach a sound quality of sufficient richness and roundness, the dedicated artisan takes over two months, using skills so steeped in tradition they have changed little in the last two centuries. Even in today's information age, modern technology is largely absent from the workshops of guitar makers, who can make two identical guitars that end up sounding different. No one knows why – it's just the magic of 'El duende'.

The top guitar makers (luthiers) of today are masters of selecting materials and design features in order to create precise sound performance. They interpret the subjective desires of customers and use their accumulated knowledge to construct beautiful instruments that deliver the sound balance they want. But the very fact that luthiers follow painstaking, traditional construction techniques moves many to believe that the evolution of acoustic instruments has essentially reached its limit.

STRANGE BEDFELLOWS

But technology might just hold the answer according to a group at Universitat Politècnica de Catalunya – BarcelonaTech. Here, a diverse collection of engineers, acousticians, material scientists, and museum curators have come together with one of Spain's top luthiers in an attempt to deepen the understanding of what makes guitars sound like they do. They are analysing the vibrational and acoustic performance of concert-grade classical guitar components throughout the construction process, beginning with just the soundboards, and steadily working up through different stages of completion to the final, finished guitar. Then, in a second phase, they are analysing antique guitars from long-dead masters like Antonio de Torres, with the kind help of the Museu de la Música de Barcelona. Since obviously the group cannot unglue these components of Spain's heritage, the group instead characterises the complete instrument, and then draws revealing comparisons with the results gleaned from modern instruments. ▶

Photo courtesy of Toni Valls

MARCO A. PÉREZ

Marco A. Pérez, PhD, is researcher at the Laboratory for the Technological Innovation of Structures and Materials (LITEM), an interdisciplinary research centre of the Universitat Politècnica de Catalunya – BarcelonaTech, supported by a team of PhD Engineers in the fields of Strength of Materials and Continuum Mechanics.

> "FOR ME, THE MOST INTERESTING PART HAS BEEN TO SEE HOW IMPORTANT THE INTUITION IS. TO CREATE A SUPERIOR INSTRUMENT IT DOESN'T MATTER WHAT LEVEL OF SCIENTIFIC KNOWLEDGE YOU HAVE."
>
> MARCO A. PÉREZ

Ultimately, they hope to find relationships between the structural properties and the acoustic performance of the very best guitars, to help understand how to select materials and construction methods better than ever before.

"It's an ambitious project," admits Marco, the acoustic expert and keen guitar player leading the effort. "Working with historical instruments in my country is pioneering, and research into guitars has not been done with an interdisciplinary group like this before." It took considerable effort to bring together: engineers were not used to working with musical instruments, while luthiers were initially sceptical, fearing the engineers' mathematical ways entering their artistic domain.

THE ARTISTIC DOMAIN

Antonio Manjón makes some of the top guitars in the world today. He met Marco at a conference and became intrigued by this opportunity to develop his understanding of guitars. For Antonio, it was a new way to gain some deeper insights into different woods, constructions, and how they interact while, for Marco, it was a perfect catch: now he could test throughout the development process of a master.

"I think knowledge based on experience and tradition is also a type of scientific knowledge, just done by instinct. The luthier intuitively analyses and creates solutions based on that analysis, and even though the process is in many cases unconscious, it is still an analytical process," says Antonio. "Among us guitar makers there is some mistrust of science; it has rarely been seen as another tool that we can use, and we need to break this wall. I want to feed this intuition with new knowledge that will make this intuition take more accurate decisions each time, and I think science can contribute to it."

CONVINCING THE MUSEUM

For Marco meanwhile, having won top prize in the luthier search, he still had a lot of convincing to do at the museum, where it turned out that asking to 'hammer test' irreplaceable antiques doesn't go down very well. "It sounded a bit brutal," says Antonio. "So we decided it would be better to call it 'impulse' testing." Finally, Marco's demonstration on his own concert-grade guitar – with a polyamide protector between the hammer and guitar – convinced the museum to allow modal testing on the cherished classics.

BUILDING ON A WOODEN TRADITION

What makes a guitar sound good is about 50% down to the quality of the wood, and 50% the skill of the luthier, according to Antonio. But the wood selection itself is part of the luthier's skill. As Marco explains, "The traditional process of material selection is dictated by a set of requirements which include not only the type of wood, the orientation of the cut and the general width of the annular rings, but also a certain raw acoustic characteristic which is empirically determined by tapping the plank and listening to its response."

Small details make all the difference. "It is relatively easy to get a good guitar, if you work with quality material," says Antionio. "Making an outstanding guitar is much more difficult." To do this, it is vitally important to anticipate cumulative and synergistic consequences in as much detail as possible. "There are many choices to make, and it would be very helpful to know more and be able to quantify the sound I will obtain if I do certain things like changing rib positions," says Antonio.

THE NEW NORM

Nowadays, customers want a precise balance of sound characteristics, but communication about guitar sound uses concepts


Photo courtesy of Toni Valls

Marco A. Pérez (left) and Antonio Manjon perform a modal test on a guitar soundboard using a Brüel & Kjær impact hammer to excite the structure, and an accelerometer together with LAN-XI data acquisition hardware to capture the response

and words that are difficult to quantify and explain, like 'sweet', 'clear', 'rich', 'deep', and 'round'. "If you only support this with your intuition, then the message might not be that concrete," explains Antonio. Players' needs and tastes for guitar sound have also changed. Guitars are now conceived of as instruments for chamber music or individual playing, so luthiers look to increase sound power – requiring new construction methods.

Their traditional selection process is complicated by the fact that compared to the days of masters like Antonio de Torres, access to quality woods is democratised and people can easily access more exotic wood like Canadian Cedar, Mexican Rosewood, Ziricote, etc. There is now more information available about it too, but, Antonio says, that does not equate to knowledge. "I think we have lost knowledge because in many cases it is not necessary," he says. "Society is much more specialised today and this makes the knowledge more parcelled. However, ancient knowledge was much more global; the luthier needed to know the whole process of wood in terms of growth, cutting, drying, and transportation."

SCIENCE SERVES INTUITION

Given all these challenges, the project aims to overcome the 'stalled' design evolution by adding more knowledge, in order to understand guitar construction more intricately than ever before. By rapidly building a knowledge base, they plan to help anticipate the interactions of different woods and construction methods. Importantly, they use scientific means to foster – but not replace – the intuitive tradition of the luthier. ▶


Photo courtesy of Martín Gallego

> "KNOWLEDGE BASED ON EXPERIENCE AND TRADITION IS ALSO A TYPE OF SCIENTIFIC KNOWLEDGE, JUST DONE BY INSTINCT."
>
> ANTONIO MANJÓN

ANALYSING THE RESONANCES OF GUITARS

The loudness and richness of the instrument depend considerably on the behaviour of the soundboard's resonant frequencies. Consequently, the project follows five soundboards made from German Spruce through their production, throughout their incorporation, and finally in the finished guitars. It takes about a year to make five guitars, but so far the structural properties in terms of the modal parameters have been obtained for each stage, from the initial flat shape up to the finished soundboard.

THE EFFECT OF TUNING

They have also investigated the effect of tuning. "I like guitars that differentiate the different voices of the strings, so that you can hear each string clearly," says Antonio. "Varying string tension can make the peak amplitudes of the string coincide with the peaks of the frequency spectrum of the soundboard," says Marco. "The result is an unbalanced instrument." Complicating matters, some older guitars are no longer able to reach the normal tuning pitch.

LESSONS FOR THE MASTER?

So what is it like for a master craftsman to see his inherent talents displayed on a graph? "On one side, it's a bit cold because you cannot see the love and passion that has gone into it on a graph," says Antonio. "But on the other hand, it's surprising that you can get so much information from just one hammer strike. And we have made 12,000 strikes during the study. The biggest learning from this is discovering all the possibilities there are, and seeing how deeply you can understand sound."

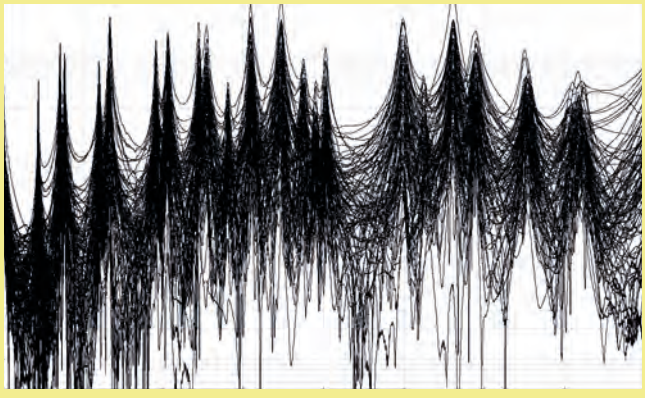
Surprises for Antonio included the symmetry of the soundboard. "I thought that the structure being symmetrical would impart the sound equally between the high and the low tones, but an asymmetric design made the high notes more stable," says Antonio.

For Marco meanwhile, the most significant parameter obtained so far is the equivalent stiffness of the soundboard. "When luthiers manufacture a soundboard, they apply a bending load with their thumbs to evaluate the stiffness of the plate. In fact, what they are doing is determining the transverse equivalent stiffness of the soundboard. According to their knowledge, they reduce the thickness of the plate or the distribution of the supporting ribs in order to achieve a desired stiffness. We have quantified this inherently qualitative parameter. During the initial process, the different soundboards presented different transverse stiffness. At the end of the process, the stiffness values converged. It proves that the luthier is able to estimate this property and work to achieve a desired behaviour."

They have also confirmed some things that Antonio already knew, finding that a thicker 'fan' of supporting ribs increased the stability of the instrument. "The response from the instrument is much clearer when the fan work is more advanced, with more resonance and longer sound duration, so the frequencies are more

SOUNDBOARD FREQUENCY RESPONSE

Each curve represents a hammer strike, giving a Frequency Response Function (FRF) for the soundboard. Usually a large number of peaks is desirable since each represents a natural resonant frequency that amplifies the input – creating a richer sound. The width of each peak is also critical, since it is related to the structural damping and therefore to the sound energy dissipation. In general, the lower the damping the better it is for a guitar's sound. Luthiers are naturally adept at ensuring this without the aid of frequency spectra. ■



stable throughout," he says. In addition, they have quantified the effects of the wood's moisture content upon the structural properties and the vibration response.

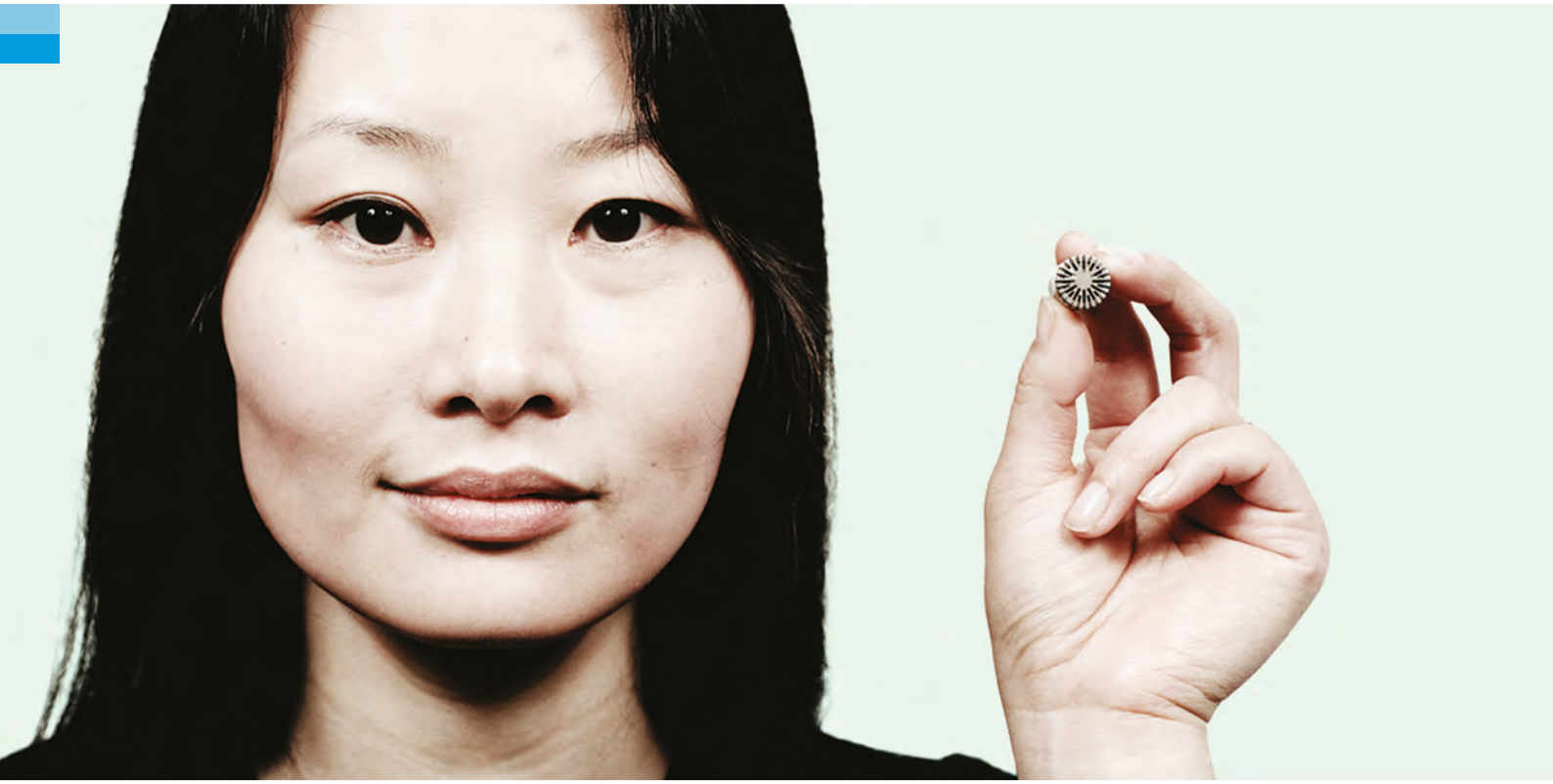
PROGRESS SO FAR

"It's a fascinating subject and a promising research area with so much still to do, like studying the effect of different couplings between the backboard and the soundboard," says Marco. But to advance, more funding is needed. One of the biggest challenges, and an important goal in itself, has already been achieved: the creation of an interdisciplinary group around music and acoustic research, and the application of technology and equipment in fields that traditionally have been far removed from engineering.

"When one is working far from his own field, it is always an enriching experience," says Marco. "But for me, the most interesting part has been to see how important the intuition is. To create a superior instrument it doesn't matter what level of scientific knowledge you have. Intuition, scientific and critical thinking, however, are essential."

So what of the mystery of El Duende? "In my opinion," says Antonio, "El Duende appears as you work according to your knowledge together with commitment, love and passion. That's the mystery."

AIMING FOR ABSOLUTE PRECISION



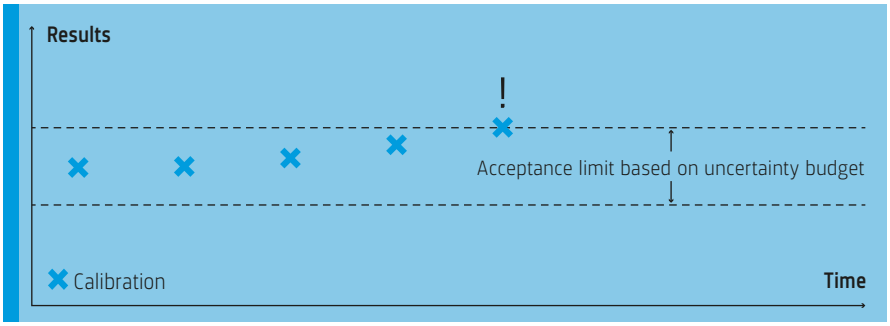
It is a philosophical realisation that no perfect measurement can be made. While we might trust instruments completely, they rely on mechanical and electrical mechanisms that are affected by the stresses of the world.

SO WHY CAN'T AN INSTRUMENT MEASURE PERFECTLY?

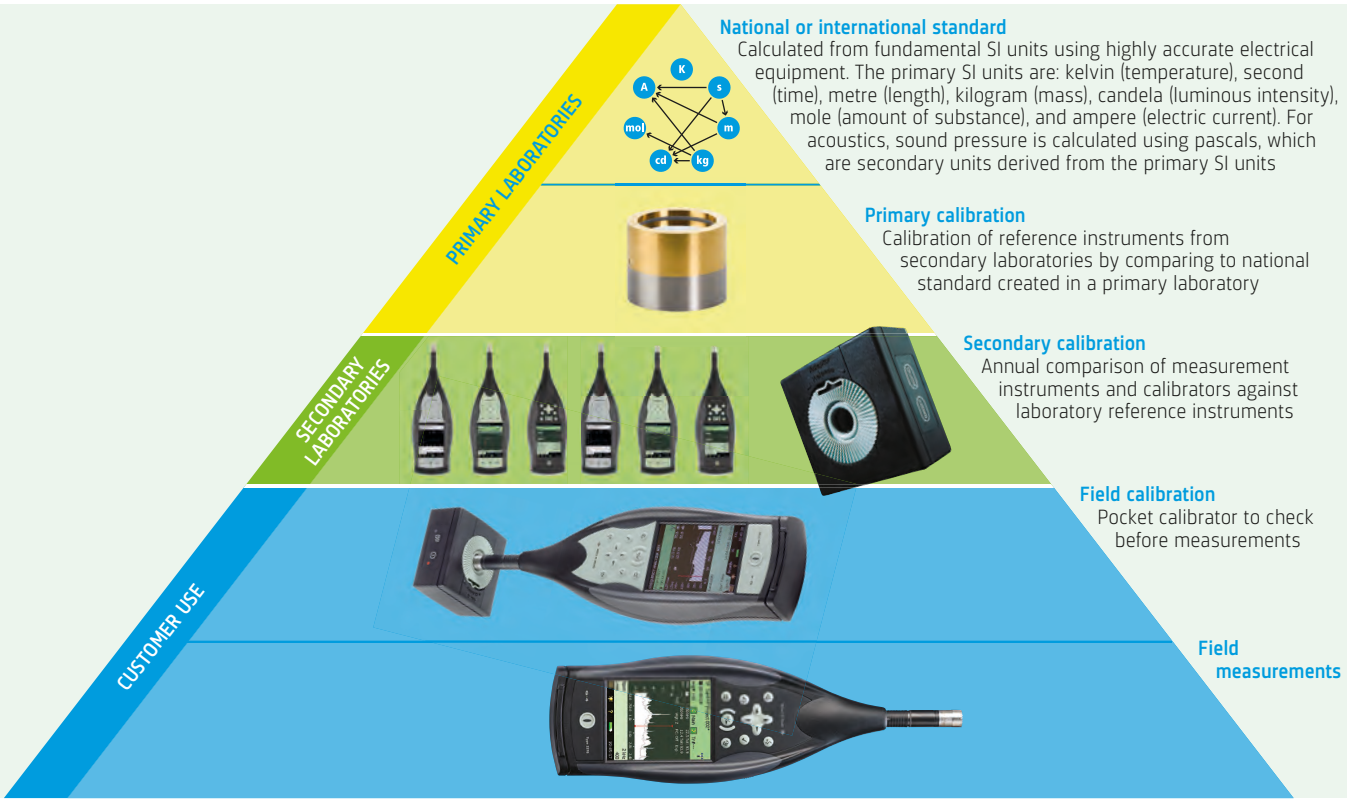
Because instruments do not define what they measure, although we might think they do. Instead they react to phenomena and compare them to their imperfect 'memory' of an absolute, primary standard. The phenomena themselves exist absolutely and faultlessly. The instrument merely describes them and cannot do so perfectly because it is made of solid materials, and physical forces affect its structure and therefore its readings.

So we rely on all instruments to be good enough. Even on space vehicles, the most accurate, critical measurement instruments give readings within an acceptable margin of error – the 'uncertainty budget'. It is one thing to build an instrument with the precision to do this consistently. It is another to relate the values the instrument shows to an 'absolutely' correct authority – the goal of calibration. But maintaining these abilities through the rough and tumble of atmospheric changes, daily knocks and material fatigue requires regular checks, in the form of recalibration.

"For certain businesses like helicopter manufacturers, calibration is critical," says Greta Koch, Brüel & Kjær's Calibration Production Manager. "Accelerometers



Calibration is always performed before and after adjustments, allowing users to verify their results to date, to analyse trends and see how accuracy drifts, and predict when results might occur outside of the designated uncertainty budget



monitor their gearboxes' health, but if the system doesn't detect an error because it is not calibrated to measure correctly, the consequences could be catastrophic."

QUALITY, SPEED AND EFFICIENCY

For manufacturing industries, which depend on how well products are made, calibration is the key to consistently outperforming competitors on quality. Without re-calibration, end-of-line test equipment – such as at a mobile phone factory – can appear to function correctly while concealing decaying accuracy.

And inaccurate tests lead to customer warranty complaints, damage to the manufacturer's reputation and expensive recalls – along with unplanned production downtime. Within a large organisation, the design, engineering, production and validation time of any product – from a truck to a satellite – depend on reliably relevant, timely and accurate measurement data, and on complete confidence in it. Any discrepancies cause friction and delays, so the unquestionable, uniform baseline that calibration provides assists hugely with data confidence. With less questioning, troubleshooting, and reworking, time-to-market is inevitably reduced. Meanwhile, efficiency is enhanced by fewer design changes, and less wastage from false rejections of passable products.

PROTECTING CONSULTANTS

Neglecting calibration can have consequences that resound through different businesses. Acoustic consultants make measurements that their customers depend on, both legally and economically. They can affect large decisions, like choosing the most economical windows necessary for a tower block. An acoustic measurement on a building project can contribute to the overall noise tolerances of the building. But if the noise level inside the finished building proves too high, it can be hugely costly to rectify. And if this is due to an erroneous instrument that hasn't been calibrated in the time specified by the relevant ISO or IEC standard, the acoustic consultant could be liable. The only defence is a legal basis for measurement integrity – accredited, traceable calibration. ▶

AIMING FOR
ABSOLUTE PRECISION

If a plane is certified to carry less cargo, it can mean millions in lost earnings. Inaccurately calibrated equipment could result in the take-off noise level being measured at the limit, when in fact it is 0.1 dB below. This leaves unused noise potential, which would allow more power – permitting more weight

TRACEABILITY IS EVERYTHING

Since no instrument can measure perfectly, no measurement can be trusted unless the instrument has been recently calibrated to read within a specified uncertainty budget at a calibration lab. Then the calibration lab's own reference instruments have to be recently calibrated to a tighter uncertainty budget, and so on up an unbroken chain to the top laboratory in any jurisdiction: the primary laboratory.

This traceability hierarchy is fundamental. The only defence against an endless spiral of relativity is the ability to trace – through a secondary lab – every measurement anyone makes anywhere to one of these primary labs. As Henning Ploug, Calibration Manager at Brüel & Kjær says, "The validity of this entire chain depends on the integrity of the instrument above it. Any error can mean questionable results, and can extend damage exponentially out through different businesses."

SECONDARY LABORATORIES

These workhorses of the calibration ecosystem perform normal calibration on a huge amount of instruments – over 10,000 calibrations per year in Brüel & Kjær's Denmark lab alone, on 1500 different types of instruments. Here experts rigorously check important parameters in controlled atmospheres, relating all measurements to their own reference instruments (highly accurate microphones and accelerometers). Most measurement procedures are dictated by IEC and ISO standards, for which secondary labs must keep over five years of records.

Most instruments should be recalibrated every year, or even more often. It depends on the level of use and temperature fluctuations they receive, since more wear, tear and dust will affect accuracy sooner. Calibrations take about a week because of the rigorous procedures needed. Nothing can be rushed, and instruments must first acclimatise to the precise humidity and temperature, and stabilise for between four hours for basic instruments, up to 24 hours for primary reference microphones.

Partly to save shipping and customs delays, Brüel & Kjær has 12 secondary labs around the world, making over 30,000 calibrations per year. These are all legally verified in the countries that require it and certified by national accreditation bodies – the highest authorities in their respective countries. These bodies check procedures, record keeping and competence. Above all, they ensure the measurement chain remains unbroken up to the highest authorities of all: primary laboratories.

WHY DO PEOPLE SKIP CALIBRATIONS?

Technological overconfidence – Some people think that digital instruments don't need it, but they all do.
Legal ignorance – Some don't realise that to measure to ISO standards or national standards, their instruments must be calibrated regularly.
Cost – Calibration requires downtime, but to skip it can create a false economy. According to a survey commissioned by Advanced Technology Services in 2008, the average cost of poor quality calibration for US manufacturers is $1,734,000 each year. Looking only at large companies that generate revenues of over $1 billion per year, the annual average is $4,000,000.

PRIMARY LABORATORIES

Primary laboratories create, maintain and disseminate standards to the rest of the measurement world; to secondary labs and organisations that need a very high degree of accuracy. Aircraft manufacturers are one example. "For them, a 0.1 dB error can mean serious costs," says calibration expert Erling Sandermann Olsen. "If an aircraft's noise level exceeds the stated specifications, they can get heavy fines from airports. And if an engine received an incorrect noise certification, it could prevent aircraft from operating at some airports entirely."

Denmark has one of the most active primary calibration laboratories for acoustics and vibration in the world, the Danish Primary Laboratory of Acoustics (DPLA) which is partly run by Brüel & Kjær, although it's a completely separate entity. At DPLA, only reference transducers are calibrated, such as reference instruments from secondary labs, and Brüel & Kjær's own production line testing equipment – which are compared to primary reference instruments.

Some organisations, especially aircraft manufacturers, have so many instruments that they can't afford the time to send them away, and invest in their own secondary calibration lab. These, as well as other secondary labs worldwide are served by Brüel & Kjær's commercially available reference instruments and calibration equipment. Through such Brüel & Kjær reference instruments, a very large share of the world's sound and vibration measurements are traceable to DPLA.

AWARD-WINNING CONSTRUCTION NOISE MANAGEMENT

Cited as Europe's largest civil engineering project and jointly sponsored by the Department for Transport and Transport for London, Crossrail will provide a new railway linking Heathrow Airport, the West End, the City of London and Canary Wharf.

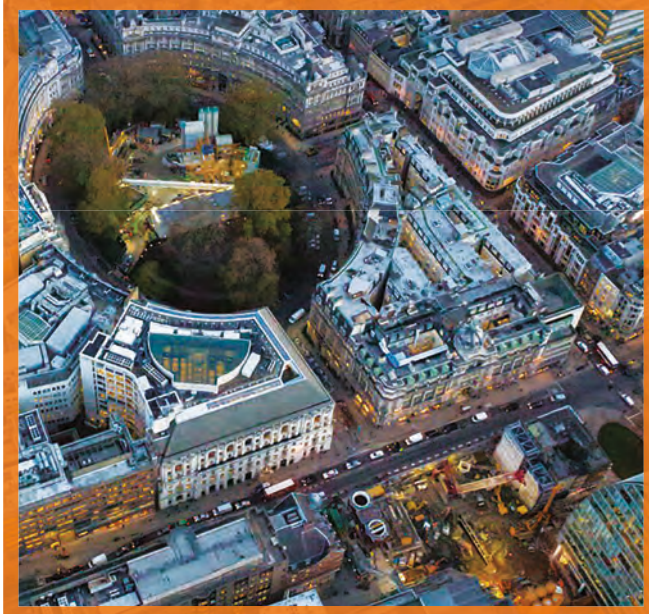
Costing £14.8bn, the route will run more than 100 km via 38 stations and include 21 kilometres of new, twin-bore tunnels under central London. Eight custom-made, tunnel-boring, giant machines weighing 1000 tonnes each will work 24 hours a day excavating the ground and building the tunnel walls as they dig. The Crossrail trains will bring an additional 1.5 million people within 45 minutes commuting distance of London's business district and carry 72,000 passengers per hour in peak times along the central section, which should be completed in 2018 and be fully operational in 2019.

GOING UNDERGROUND

A massive construction project such as Crossrail brings with it an abundance of noise and vibration challenges. The C501 Moorgate shaft is a 35 × 35 metre, 55-metre-deep hole excavated right next to the existing Moorgate Station. Reinforced concrete panels sixty metres deep are being installed to form a box below ground, which will house a new ticket hall.

The site is one of the most constrained on the Crossrail scheme and offers little opportunity for multi-tasking; each job has to be done one step at a time. In fact, space is so constricted that the main contractor, BAM Nuttall Kier JV (BNK JV), opted for modular accommodation erected on a steel grid on columns above the access points to the underground. The operating conditions, established with the City of London, are also complex in order to both limit noise impact and provide periods of respite to the different stakeholders day and night. Permitted noise levels vary up to 12 times throughout the day. BNK JV needed to be sure that the priorities and expectations of stakeholders were met while enabling the project team to make progress with construction and fulfil obligations to the local authority and project owners, Crossrail.

In addition, the site is surrounded by buildings – some listed (protected due to their heritage value). ▶



The oval-shaped worksite between the buildings in the centre provides a temporary access shaft for the main construction site at bottom right

AWARD-WINNING CONSTRUCTION NOISE MANAGEMENT

Moor House, one of London's largest office buildings, various hotels, a school and an exclusive apartment building are all close to the construction site and have to be taken into account regarding noise nuisance. In such a built-up area there are also many sources of noise other than the construction at Moorgate – air, road and rail transport create significant noise disturbance as well as other nearby construction sites. This makes it a challenge not just to keep construction noise levels below limits but also, should a breach occur, to determine the cause.

DRILLING DOWN INTO THE DETAILS OF DATA

In order to deal with these challenges, BNK JV turned to acoustic consultants Anderson Acoustics for a real-time noise-management solution that would fulfil the Crossrail project's noise pollution restrictions, and prevent operations being delayed. With advice from Anderson Acoustics, BNK JV chose Noise Sentinel, a subscription-based service that combines established monitoring practices with new innovations, such as continuous assessment and easy data sharing with stakeholders, to help industry manage noise impact in the community. Noise Sentinel records the audio when levels are high, allowing users to investigate noise breaches by replaying the noise and thereby determining if it was construction-related, and if so, take action to address it.

Construction shift teams are equipped with a duty phone that receives warnings or alerts from Noise Sentinel via e-mail and SMS so that they can react quickly to noise events above set limits. Cloud-based computing allows any member of the team to have

DID YOU KNOW

Two thirds of the excavated material will be donated to the RSPB (Royal Society for the Protection of Birds) to create a new, 1500 acre reserve at Wallasea Island in Essex.

> "BRÜEL & KJÆR'S NOISE SENTINEL DEMONSTRATED THE SUCCESSFUL CREATION AND IMPLEMENTATION OF PRACTICAL SOLUTIONS TO DIFFICULT NOISE PROBLEMS."
>
> GLORIA ELLIOTT,
> CHIEF EXECUTIVE OF THE NOISE ABATEMENT SOCIETY

access to web pages that detail real-time noise levels, historical noise data and alerts.This robust and effective system is designed to take away the headache of monitoring from the construction team. Noise Sentinel is constantly monitored by Brüel & Kjær and any equipment failure is identified and quickly rectified without the involvement of the project team. So while Brüel & Kjær focuses on its expertise – noise management technology, the contractor team is left to focus on its core business – construction.

The system has continuously monitored noise around the site since November 2011 and has exceeded both the expectations of the City of London and the contractual requirements of Crossrail. The history of noise data from Noise Sentinel is provided to the City on a monthly basis to show the site's noise performance. Regular meetings with environmental health officers then look at more detailed data. As a result, the construction team is seen to be a 'good neighbour', which will work well for future construction bids, and can get more done because they know what their real noise impact is and don't have to worry about breaching noise regulations.

A WINNING TEAM

BNK JV been awarded Crossrail's Green Line Scheme award for the project and Noise Sentinel has not only won the UK Noise Abatement Society's John Connell Technology Award, sponsored by the Institute of Acoustics, but also been shortlisted for the Environmental Initiative of the year at the 2013 International Tunnelling Awards.

Moor House, one of London's biggest office buildings is adjacent to the construction site

NEWS FROM THE ARC

In the bowhunting world, vibration is a big deal. It causes noise that can spook the target animal, and it creates unpleasant hand shock. This is why G5 Outdoors needed assistance to gain technical insight into their bows.

TARGETING VIBRATION

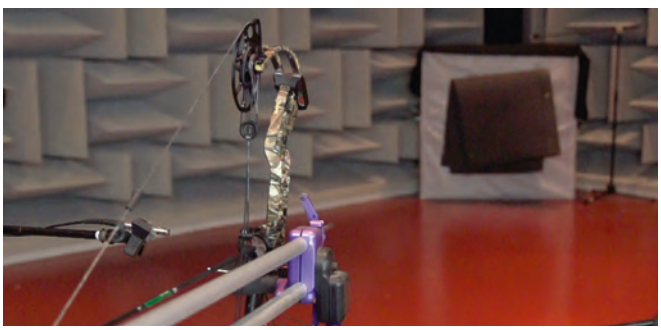
A division of Grace Engineering, G5 Outdoors is a small family-owned company in the US state of Michigan's 'thumb' area. They have been making hunting products for years, beginning with all-steel broadheads (arrowheads), but they're new to making bows. With the aim of building on their reputation as the technical expert supplier for bowhunters, G5 needed help to fine-tune a quiet, shock-free bow. "We definitely needed the setup offered by Brüel & Kjær at the Application Research Center (ARC) testing lab," says Dave Hawkey, Marketing Manager for G5 Outdoors. "Naturally, we don't have noise and vibration experience, and testing outdoors wouldn't have given us the results we needed. The ARC gave us a world-class lab and the technical expertise we needed, both in terms of general acoustic knowledge and operation of data acquisition equipment."

A ONE-OF-A-KIND FACILITY

Fortunately for G5, the ARC lab was located nearby, just outside Detroit, Michigan, and houses a one-of-a-kind noise and vibration solution facility with a wide array of state-of-the-art NVH testing capabilities, as well as advanced computer simulation and materials development and testing capabilities. It was founded by three companies – Brüel & Kjær, Material Sciences Corporation (MSC), and Link Engineering. MSC launched their Quiet Steel® damping material in 2001 and needed a facility to test it and demonstrate its value to customers. In 2003, MSC approached several suppliers of noise and vibration test equipment and decided to enter into a partnership with Brüel & Kjær and Link Engineering to help build, staff, and equip the ARC. The facility was completed and commissioned in June 2006. All of the test equipment at the ARC – including transducers, shakers, front-ends, PULSE measurement systems, and NVH test/analysis software – is supplied by Brüel & Kjær.

A DAY'S WORTH OF VALUABLE DATA

"We accomplished the testing for G5 Outdoors in one day," says Andrea Frey, Project Engineer for Brüel & Kjær North America, "but it was a long day, about 13 hours. It could have been split into two days, but G5 is located 90 minutes from the ARC, and we didn't want G5 driving two days in a row. The work itself was not complicated. We did the testing in one of the ARC's hemi-anechoic chambers, with the target at one end and the shooter at the other. G5 brought several bows to the ARC, with the goal of capturing the vibration of their bows and a few competitors' bows, so we instrumented each bow with triaxes [triaxial accelerometers] at several locations. ▶



TARGETING VIBRATION

"There is also apparently a phenomenon during deer hunting where the deer could possibly 'jump the string' after you release the arrow, and there's some speculation that it might be because they can hear the bow. So we set up microphones on either side of the shooter and also right by the target. We used our Reflex post-processing software to separate the sound of the bow's vibration when the arrow is released from the sound of it hitting the target. The goal was to see if the release sound was in a deer's range of hearing – it was."

G5 was hoping to get straightforward data that would simply point to which bow vibrates the most. Although the results were not that clear-cut, G5 did end up with a lot of valuable data. They can use this to fine-tune their products by answering a range of specific questions, such as:

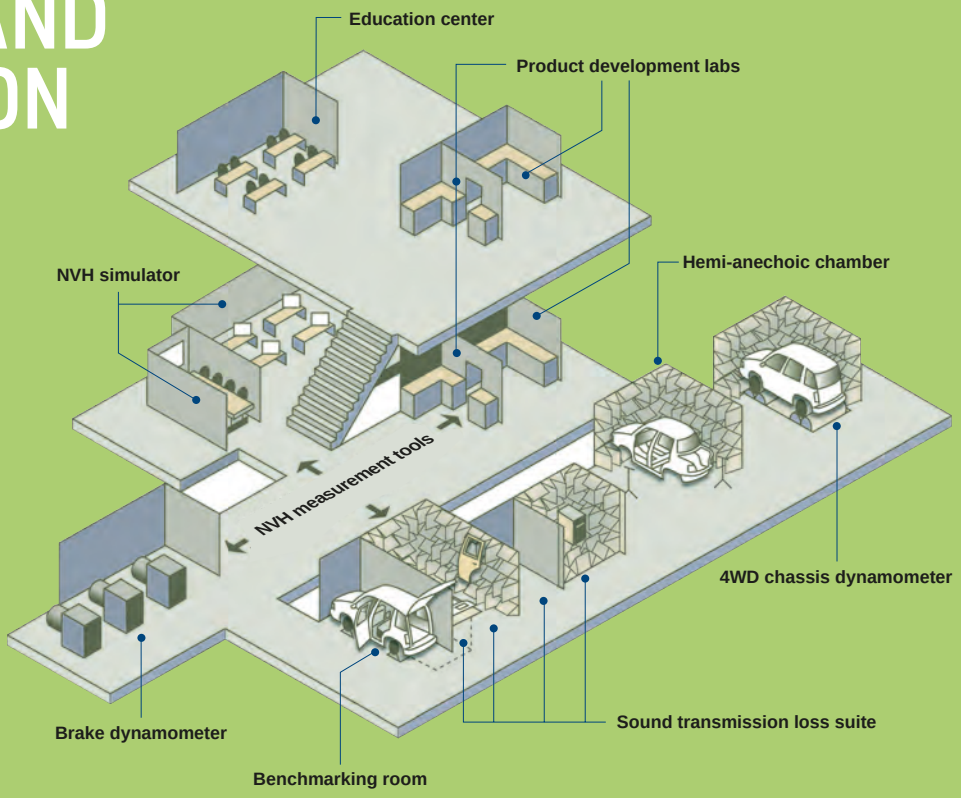
- Why does one bow vibrate more front to back than side to side?
- A damper on one of their bows reduces vibration, but does it do so at a frequency that matters to the shooter in terms of comfort?
- How can they change their bow design to decrease vibration?
- Could they run a vibration quality jury study to determine what their customers want?

A bonus to the long day's testing was that it provided an ideal high-tech environment for video and still photos that G5 plans to use in their marketing materials.

THE APPLICATION RESEARCH CENTER – 'THE ARC'

SOUND AND VIBRATION SERVICES

- Customisation
- Equipment rental
- Material testing
- Noise source identification
- NVH simulation
- Production line testing
- Sound quality
- Source path contribution
- Structural vibration
- Training
- Troubleshooting
- Vehicle pass-by testing
- Vibration testing



"WHEN IT BECOMES TIME TO DO SOME MORE INVESTIGATIVE DESIGN WORK, WE'LL HAVE EVERYTHING G5 NEEDS FOR THAT TOO. THE ARC IS 'ONE-STOP SHOPPING' FOR THEM."

ANDREA FREY

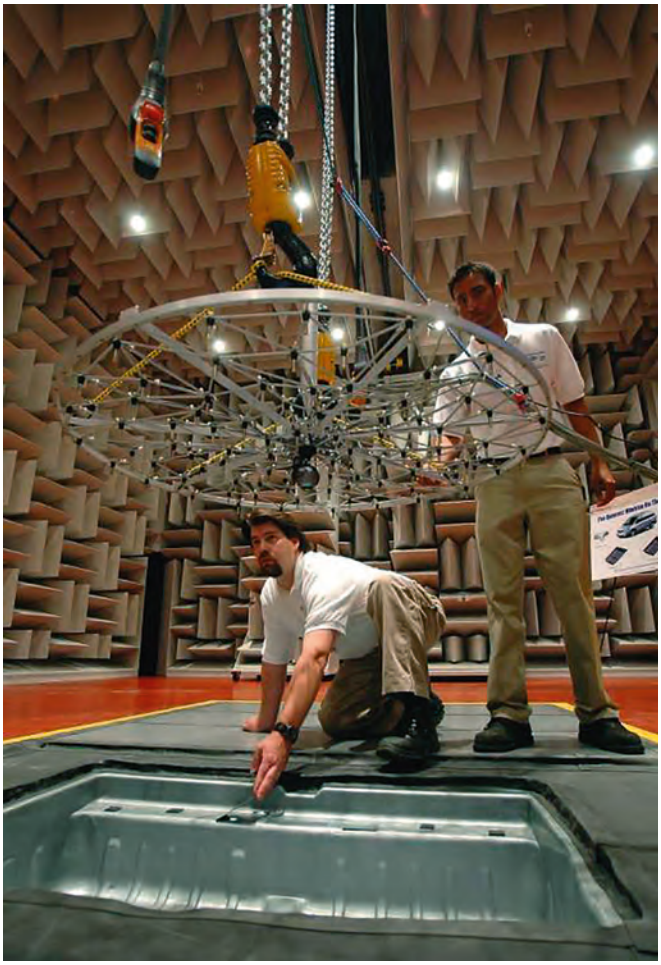
A PERFECT MATCH

"I think the ARC was a perfect match for G5," says Andrea Frey. "Other companies in our area have hemi-anechoic rooms but we are one of the few independent companies. We use it strictly for third-party work as opposed to development of some product of our own. Unlike our competitors, who offer limited facilities and expertise, we have access to Brüel & Kjær's full suite of equipment. We didn't have to move accels [accelerometers] around on each bow to get vibration in each location. We weren't limited by channel count. And when it becomes time to do some more investigative design work, we'll have everything G5 needs for that, too. The ARC is 'one-stop shopping' for them."

G5 Outdoors joins a growing list of companies worldwide that have taken advantage of the ARC laboratories to perform a wide range of sound and vibration testing. Many do not have their own test facilities, or are using their own facilities for other work. One example is a Japanese Tier 1 automotive supplier, an industry leader for precision motors that develops more custom assemblies than any competitor in North America. To test production parts they shipped hundreds of parts to the ARC and set up camp in the fully anechoic chamber for several weeks. The ARC also helped one of the world's largest manufacturers of professional hand and power tools to ensure that their products do not produce unacceptable amounts of vibration that could harm the user. Noise and vibration testing is a crucial but only occasional need for that company, so buying equipment and training their personnel doesn't make sense. Taking advantage of Brüel & Kjær's engineering services at the ARC is a perfect solution.

As these examples suggest, the ARC's ability to provide 'one-stop shopping' for a very broad range of testing needs is fundamental to Brüel & Kjær's commitment to providing full noise and vibration solutions – and the result of a service philosophy that acknowledges that customers are sometimes better served by consulting services than by equipment purchase.

Brüel & Kjær's Application Engineer Scott Sumerton (left) and MSC's Strategic Account Manager Dhaval Jain prepare for noise source identification measurements on a vehicle's rear 'trunk' section



BY: **COLIN NOVAK**
Professor, PhD, PEng
University of Windsor
Canada

IN PURSUIT OF THE WINDSOR HUM

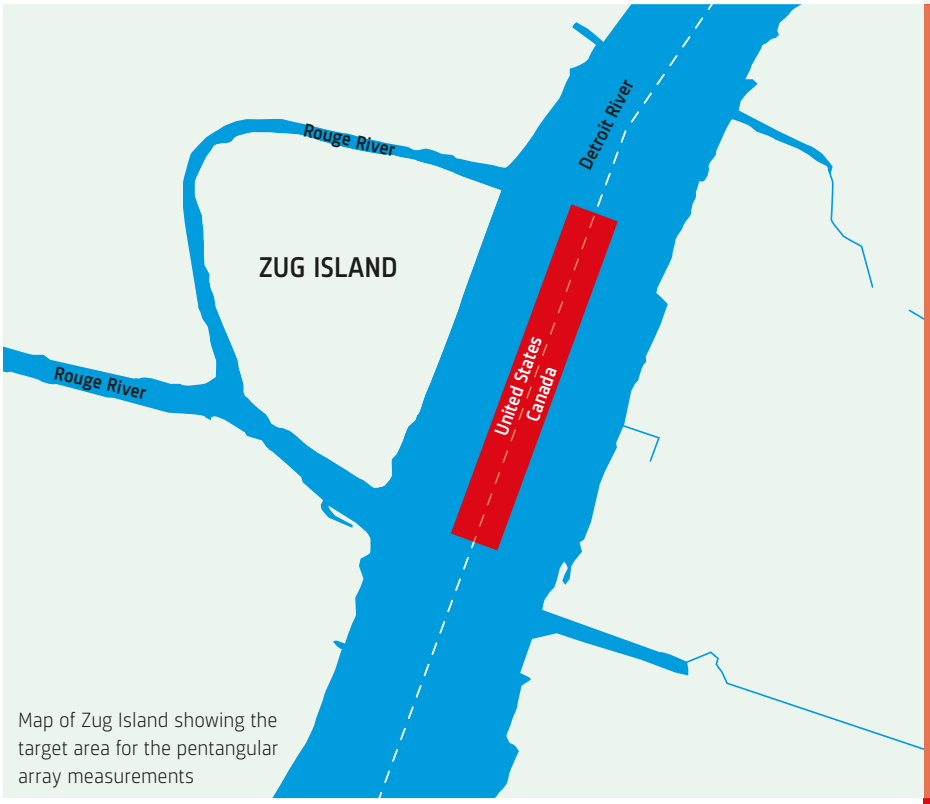
There is a rumble in the air in Windsor, Ontario, Canada, or more accurately, a hum. A low-frequency, rumbling sound rattles the windows in this border community, which lies just across the river from motor city – Detroit.

Locals have described it as a steady droning sound, much like a large diesel truck idling, or a loud boom box. Whatever it is, some residents say it is driving them crazy, and that the source must be found.

Since the early '70s, similar phenomena have been perceived on a worldwide scale. Reports of humming, howling, and rumbling have littered the news in communities including Sydney, Australia; Taos, New Mexico; Leeds, England; and Vancouver, Canada. In each of these cases, the media have told stories of residents being kept awake at all hours of the night, subject to intermittent humming noise in their own homes and consequently disrupting their lives. With each report comes a wide range of potential sources. Predictions vary from mechanical sources (submarine activity, generators, worn industrial machines), sonar systems and radio towers, environmental features (rock faults and coastal shifts), to human traits, such as psychological problems and tinnitus. Whatever the theory is, all those affected demand a resolution be found to alleviate their discomfort.

CONCERNED CITIZENS

The hum in Windsor generated concern among the citizens of this industrial city to the point where the Canadian government agency for natural resources, National Resources Canada, performed a study to find the source. While they were able to confirm its existence, the study fell short of identifying the cause. However, through triangulation of ground vibration measurements, they were able to estimate the origin of the source to Zug Island, a highly industrialised piece of land on the US side of the Detroit River. This is where researchers from the University of Windsor came in, since the research arm of the Canadian Federal government did not have the technical resources to investigate further. The department of Foreign Affairs and International Trade approached the university's Noise, Vibration and Harshness and Sound Quality Research Group to further investigate the source of the elusive rumble.



Map of Zug Island showing the target area for the pentangular array measurements

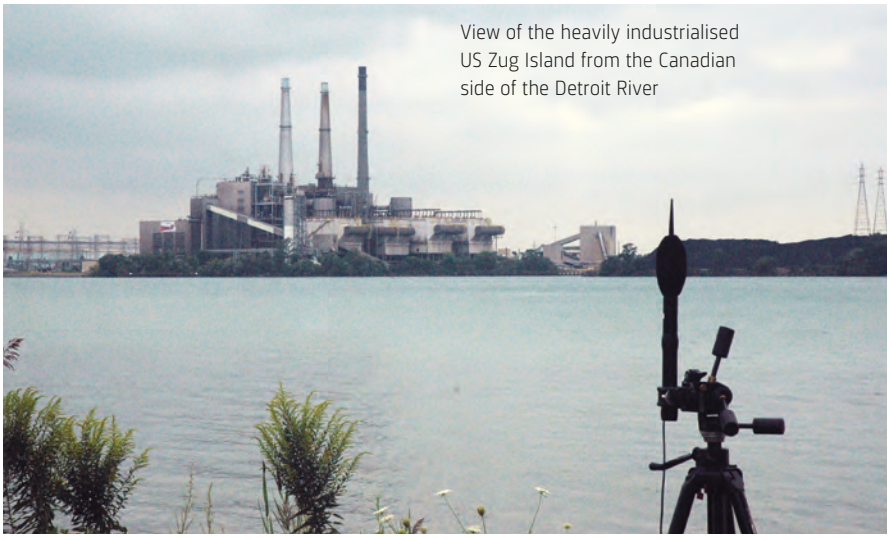
In January 2013, a press conference was held at the University of Windsor to announce federal government funding to locate the source of the 'Windsor Hum', in an attempt to protect the quality of life of Windsor's citizens. The proposed research was separated into two phases; the first, to validate the existence and characterise the nature of the phenomenon, and the second, upon confirming these characteristics, to use advanced source identification techniques to zoom into specific areas of interest – the only methodology available to the research team without having direct access to Zug Island.

CLOUD-BASED NOISE MONITORING

For the first phase, two Brüel & Kjær Noise Monitoring Terminals (NMTs) were deployed. These units are designed for permanent, mobile, or portable monitoring, where long-term, real-time, unattended outdoor noise measurement is required. The measurement data is recorded and communicated to Noise Sentinel servers, a cloud-based service where continuous noise data is remotely logged and noise level exceedances are flagged. ▶

IN PURSUIT OF THE **WINDSOR HUM**

Pentangular microphone array on the university research vessel



View of the heavily industrialised US Zug Island from the Canadian side of the Detroit River

In this case, the communications were transmitted using 3G cellular technology, where the data is then available to the researchers through any Web interface. This way, the researchers were able to see, hear, and analyse the measured noise data from the comfort of their laboratory.

The first NMT was a permanent unit installed near the Detroit River shoreline, directly across from Zug Island. The second NMT was a portable unit that was installed and relocated to different residential areas of the city where reports of the Windsor Hum were made on a regular basis. Due to the remoteness of the deployment sites, the NMTs were powered using batteries and solar panels, remaining independent of mains power supplies.

FIRST BREAK IN THE CASE

While the first few months of data collection were relatively uneventful, the first real break occurred in early July with a definite recording of the characteristic hum that lasted through most of the night until approximately four in the morning. The excitement within the research team was as if they had captured a detailed photograph of the elusive Big Foot creature. Better yet, the hum continued to manifest itself every night for several weeks, usually beginning in the late evening and stopping at about the same time.

To better characterise the acoustic signature of the hum, the Windsor researchers deployed a portable LAN-XI data acquisition system with the LAN-XI Notar™ stand-alone recorder. This setup allowed the researchers to record extremely high-resolution data in the field and then perform post-processing analysis using PULSE Reflex™ back in their laboratory. From this, a very high amplitude, low-frequency tone was finally identified, which looked and sounded like the varied reports from the community.

Having found and characterised the hum signal, the next step was to locate the actual source. Because the team did not have access to the US land on the island, they again looked to their arsenal of Brüel & Kjær equipment and decided to use a pentangular array to 'see' the hum source. The large, 3.5-metre-diameter array, equipped with 30 microphones, uses acoustic beamforming to visualise acoustic emissions – a result which looks very much like a thermal image, where bright powerful colours represent loud sources of noise and darker colours represent quieter areas of emissions. While the pentangular array is best for sounds above 100 Hz, it still proved to be a useful tool.

UNDER COVER OF DARKNESS

The next challenge was to get the pentangular array in close proximity to the island. For this, the array was mounted in a small boat usually used to research marine life in the North American Great Lakes. Because the hum was most prominent at night, the researchers also had to take the array near to the US shore in the dark and collect their data at about 100 metres from the shoreline. This of course raised the suspicions of both the US Coast Guard and Homeland Security, who appeared out of nowhere in the darkness to investigate the researcher's activities. Nonetheless, the team was able to collect sufficient data and make it back to the Canadian shore without spending any time in a US jail cell.

The pursuit of the Windsor Hum has gained international notoriety from prominent news reports, resulting in enquiries from people affected by similar hums around the world. Both the Canadian government and the University of Windsor researchers, armed with their Brüel & Kjær 'noise solution toolboxes', are dedicated to solving this mystery. A final report is expected to be reviewed by the Canadian government in early 2014 with the hope of alleviating the concerns and discomfort of the community, who only wish for a good night's rest once again.

BRÜEL & KJÆR NEWS

64-bit software for your vibration controller

Our new vibration control software for LASER USB and COMET USB controllers – version 9.0 – now supports the following 64-bit operating systems:

WINDOWS XP
WINDOWS 7
WINDOWS 8

2nd channel unleashed on sound level meters

Now Type 2270 sound level meters can receive two channels of simultaneous input from vibration or acoustic sources, giving new abilities like comparing interior vs. exterior noise, and assessing how vibration from machinery relates to noise.

It will also help environmental officers and consultants reduce the time they spend conducting multi-point acoustic measurements.

The 2-channel option is compatible with a signal recording option that attaches the recorded signal to a measurement project for later analysis.

Global education catalogue

Get your hands on the catalogue for all courses, webinars, and seminars that will be delivered by Brüel & Kjær throughout the world in 2014. There are over 400 courses and webinars to choose from, covering a huge range of sound and vibration applications.

ASK YOUR LOCAL BRÜEL & KJÆR CONTACT FOR A COPY.

Titanium microphones developed fast for aerospace leader

When a leading aerospace customer needed a very specific microphone, Brüel & Kjær's R&D team rose to the challenge. Delivering three prototypes within three weeks, and delivering 30 fully tested production units just seven weeks after the original quote. The new ½-inch pressure-field microphones are now available for purchase. Being prepolarized, the units support CCLD and thus use cheaper cabling and conditioning. Uniquely for this type of microphone they are titanium, which was specified for its corrosion resistance and low sensitivity to magnetic interference – making it ideal for electric vehicle applications.

CUSTOMER NEWS

Snecma boosts engine testing abilities

French aircraft and rocket engine specialist Snecma has enhanced its engine testing capabilities with new sub-miniature charge accelerometers that operate in continuous 260°C temperatures.

The accelerometers' low weight minimises the loading on engine components, while their high sensitivity-to-mass ratio ensures a low noise floor for accurate low-frequency measurements – normally a shortcoming of lightweight units.

Engines like Snecma's LEAP and Silvercrest are very challenging test environments, so Snecma's new accelerometers feature a high resonance frequency, low sensitivity to environmental influences, and an integral cable to avoid connector malfunctions. ■

Gaia probe clear to map Milky Way

Carrying the most powerful camera ever produced in this world, the Gaia satellite began a five year journey to map the stars in our galaxy, on 19 December 2013.

Each of the camera's sensors was vigorously tested on an LDS vibration test system to ensure they could withstand the vibration during the rocket's launch.

Gaia's ambitious mission is to chart a three-dimensional map of our galaxy, and help reveal its composition, formation and evolution.

Gaia will provide unprecedented positional measurements for about one billion stars in our galaxy – about 1% of its stellar population. ■

German test house relies on V9 shaker

SEE MORE
about the 'V9x Shaker System' at

www.bksv.com/casestudies

TÜV SÜD provides environmental testing services for world-leading German car makers and sub-suppliers. At their Mannheim facility there is no such thing as a typical test, demanding high-performance, flexible vibration test capabilities. "This is where the V9 shaker comes into its own," says Wolfgang Jakobi, Environmental Solutions Head.

"The V9 can quickly switch from vertical to horizontal testing. It's also useful for combining temperature cycling, as our environmental chamber fits over it."

With several head expanders up to 1500 mm and a slip table the same size, they can test a whole pallet packed with equipment and products in one go, making it excellent for transport testing.

The V9's 3"-long stroke, and high performance with respect to force and velocity makes it "really good for shock and low-frequency testing," according to Lab Manager Haridmos Mountogianakis. "The V9 now runs the toughest test we do." ■

FORD RACERS GET A FEEL FOR NASCAR WITH SONOSCOUT

Racing drivers at top NASCAR tracks need every edge they can get, and Brüel & Kjær's iPad®-based data recorder is helping to sharpen Ford's. On the 1.5 mile Atlanta Motor Speedway in the USA, Sonoscout™ captured data at speeds of over 160 mph (257 km/h), to help drivers get a feel for the car. Since a more 'tuned in' driver can mean the difference between winning, losing, or even crashing, improving the ability of engineers to tune vehicles to their driver's preferences is essential.

Understanding vibration and noise phenomena, and feeding data into a simulator, helps the driver give feedback to engineers about how the car should feel and sound – before they build it. According to the testers, "The recording quality is excellent."

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Airbus grows lab at Spain's aviation birthplace


Getafe, Copyright © Airbus Group

Airbus Group (formerly EADS) has expanded its vibration test capabilities with a new LDS-V875 shaker and controller at their Structural Test Laboratory in Getafe, Madrid. This facility is where aviation in Spain began in the very early 20th century, and is a main site for Airbus Military.

The system adds to PULSE LAN-XI and Type 2250 sound level meters used for flight testing at Getafe, and enables Airbus Group to test on flight elements of aircraft including the A400M, CN295, MRTT, according to procedures and standards in RTCA-DO-160 and MIL-STD-810.

FIVE QUESTIONS FOR DMITRI

45-year-old Russian Dmitri Tcherniak is a Research Engineer specialising in structural dynamics and vibration, and is part of Brüel & Kjær's Innovation group. He has an MSc in Naval Architecture and a PhD in Applied Mechanics from the Marine Technical University of St Petersburg.

What are you passionate about?
Technical progress and Belgian beer.

What was the best day of your life?
So far ... the day I arrived in Denmark to start postdoctoral research at Denmark's Technical University (DTU). I arrived from a Russia devastated by 'perestroika', and I felt I'd landed on another planet. But life goes on, I'm sure the best day is still to come.

Who do you admire most and why?
Project managers who were able to implement outstanding breakthrough projects, for example, Russian and American space programmes. Why? Well, that requires a combination of perfect technical skills and the ability to motivate and organise thousands of people in order to realise their dreams.

What irritates you most about your own personality?
Spending too much time finding an optimal way of solving tiny problems. Sometimes, a quick decision followed by a straight-forward, brute-force approach is more effective.

If you had all the money and time in the world, what would you be doing right now?
Probably the same as I'm doing now. Maybe with a bit more vacation time to see the world.