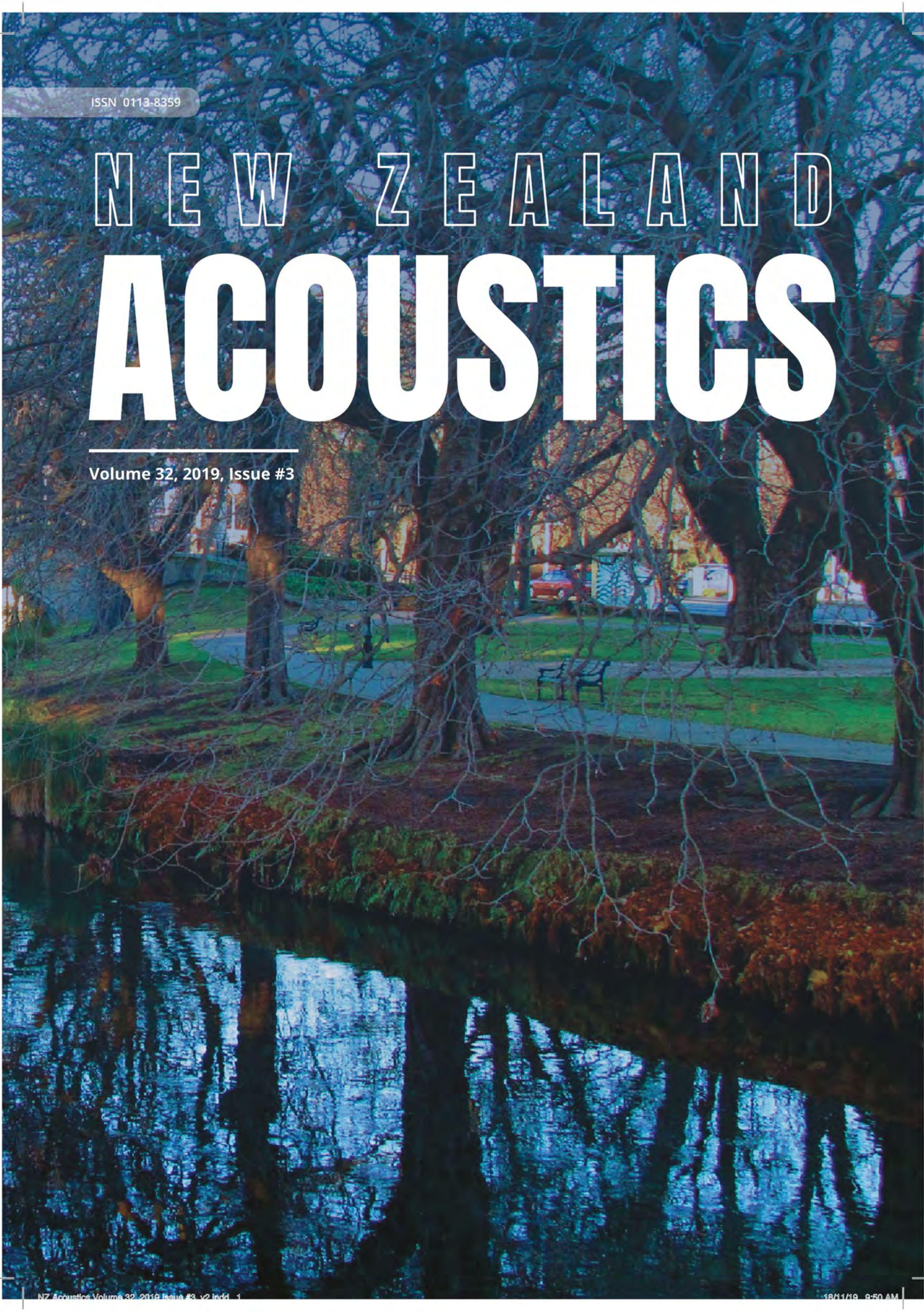
ISSN 0113-8359

NEW ZEALAND ACOUSTICS

Volume 32, 2019, Issue #3



CONTENTS

Dear Members,

You will now have seen the impressive new format and layout of our Journal! The journal team have done a fantastic job of bringing it together under a whole new format and with the assistance of our new Design team at Cardno. It's brilliant, and I am looking forward to reading this issue cover to cover.

As we head into the summer season there is plenty of work being done by the Council, with the organisation of our 2020 joint conference with the Australian Acoustical Society well underway and in the capable hands of the hard-working conference committee. Stay tuned for more details. The quality and quantity of papers at next years' conference is going to be impressive, so make sure that you register as soon as registrations are open, and encourage your colleagues, employer, interested friends and partners (to the dinner at least!) to do the same.

This is a short column from me in this edition, so there is more room for excellent technical papers and advertising from our fantastic supporters. I hope you can all have a relaxing few months in the lead up to Christmas!

Cheers,

Jon Styles

President of the Acoustical Society of New Zealand

Officers of the Society

President
Jon Styles
president@acoustics.org.nz
www.acoustics.org.nz

Vice Presidents
Tim Beresford (North Island)
George van Hout (South Island)

Secretary
James Whitlock
secretary@acoustics.org.nz

Treasurer
Siiri Wilkening
treasurer@acoustics.org.nz

Council Members
Lindsay Hannah
Grant Emms
Neil Jepsen
Robbie Blakelock
Tracy Hilliker
Michael Kingan
Mathew Legg

Editorial Board

Editor-in-Chief
Lindsay Hannah
Wyatt Page
journal@acoustics.org.nz

Editors
Online: Grant Emms
Copy: Tessa Phillips
Associate: Mike Kingan

Advertising Manager
George van Hout
advertising@acoustics.org.nz

Design & Production Manager
Noor El-Matary
production@acoustics.org.nz

Submission All Articles
News, Products, Enquiries
journal@acoustics.org.nz
+64 4 566 0022

New Zealand Acoustics is published by the Acoustical Society of New Zealand Inc
PO Box 1181, Shortland St,
Auckland 1140
ISSN 0113-8359

Production by

Cardno

Follow ASNZ on LinkedIn

Welcome to the final edition of NZ Acoustics for 2019. Wyatt and I both took on new roles this year and along with this major change and the day to day life it's been a busy year. Our members will have by now received the new look journal. If you have any feedback on the new journal please get in contact as Wyatt and I would like to hear from you. Based on the positive feedback to date, the journal team will continue towards making small tweaks over the next few editions so please bear with us as there are a few more minor changes to come.

As it's the end of the year we would like to take the time to make some special mentions. The first is you our members who without we would not have a journal. We would also like to thank our advertisers who make production of the journal possible with their support. We ask all our members to please consider supporting our advertisers and their products. In the same vein I would like to make a special mention to George our new advertising Manager. George has recently come on board and taken over the job like a duck to water, so thanks George!

I also can't forget the rest of the journal team, Noor who produces the journal has done a fantastic job with the new design and Tessa, Grant, Mike and Lynn who all have their own expert roles. I also extend my thanks to all the authors who have submitted work, we acknowledge the time and effort it takes to produce a paper and thank you for sharing that with our members.

In this edition we have our regular items as well as some very interesting papers on rain noise that I would recommend you take the time to read.

Lindsay Hannah

Wyatt Page

We have a special edition for the first journal of 2020 on the World Health Organization Noise Guidelines, so keep an eye out for that next year. I can't wait for summer to role in, it's been a longer Wellington winter. The journal team hope you all have a great break and Happy New Year.

Lindsay Hannah & Wyatt Page

Principal Editors

NEWS

Cafe & Restaurant Acoustic Index – CRAI app

The CRAI is a rating system for eating and hospitality venues in New Zealand according to their acoustic environment. The CRAI is a 5-star rating system where a 5-star is quieter and more subdued than a 1-star venue. Philip Jepsen, a professional software engineer has developed the CRAI into an app for use on smartphones via the Android platform. Philip is currently working on the development of the same app for the Apple iOS. More to come on this soon.

Google Assistant is going to stop listening so intently to your conversations

Google Assistant will soon store fewer of your queries and instructions, and give you more control over how your audio snippets are used. Several tech companies, including Google, Amazon and Apple, have come under fire in recent weeks for using human workers to transcribe snippets of audio recordings from smart speakers and virtual assistants. They wanted to make sure their software was correctly transcribing spoken commands – but users weren't aware that other people were listening in. There were also concerns that the smart assistant could occasionally record incidental background audio, including potentially sensitive information. Such data was deleted without being transcribed, but it was still a worry for users. Google Assistant will now store less audio in general, and is making its policy on human listeners much more transparent. The service has always included an option called Video and Voice Activity, where users can choose whether or not their voices can be used to improve quality of the transcriptions. Google is also adding an extra snippet of text explaining that audio samples may be reviewed by humans, and users will need to explicitly opt in to allow this – if they don't re-confirm their settings, their voices will go unheard by Google's transcribers. If you're worried about Google Assistant recording conversations happening in the background you can now adjust its hotword sensitivity, making it easier or harder for Google Home speakers to pick up the words 'Hey Google'.

***More information** – https://www.techradar.com/news/google-assistant-is-going-to-stop-listening-so-intently-to-your-conversations*

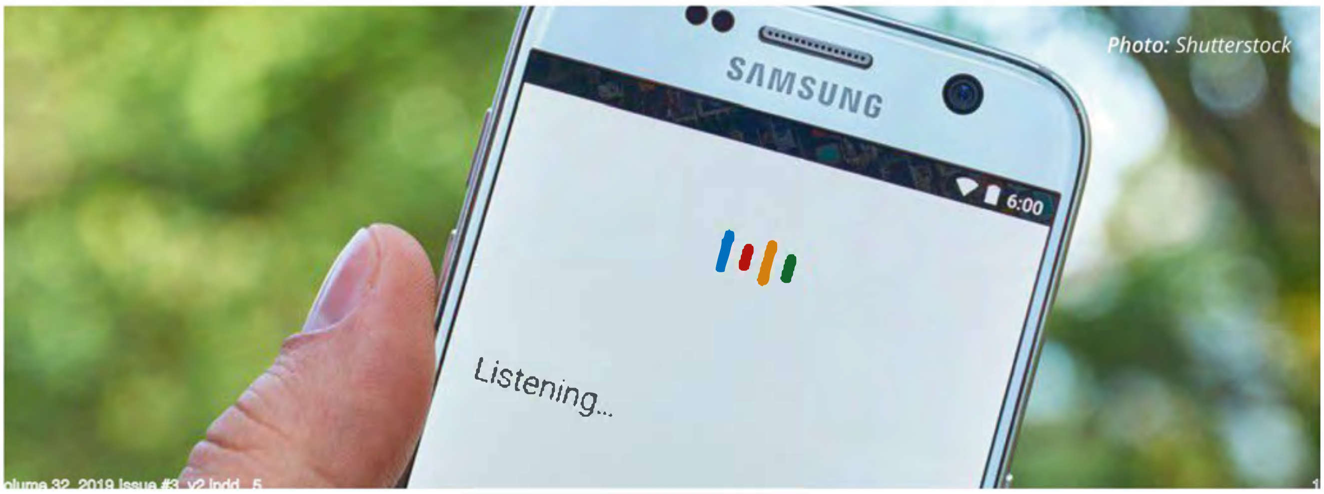
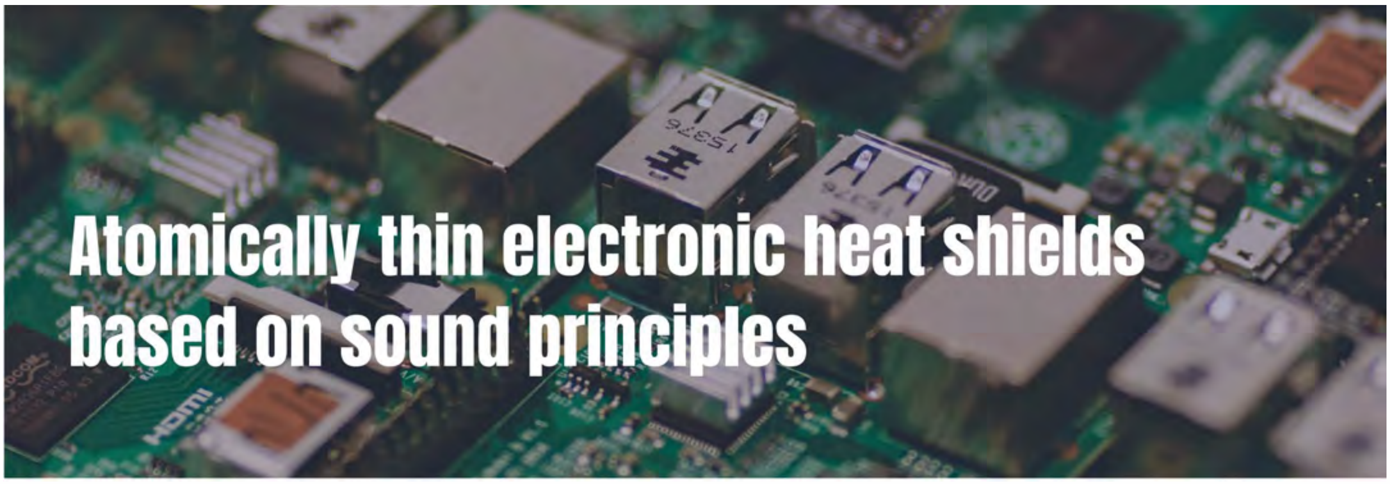


Photo: Shutterstock



Atomically thin electronic heat shields based on sound principles

> **“Engineers... know quite a lot about how to control electricity, and we're getting better with light. But we're just starting to understand how to manipulate the high-frequency sound that manifests itself as heat at the atomic scale.”**
>
> **– Eric Pop**

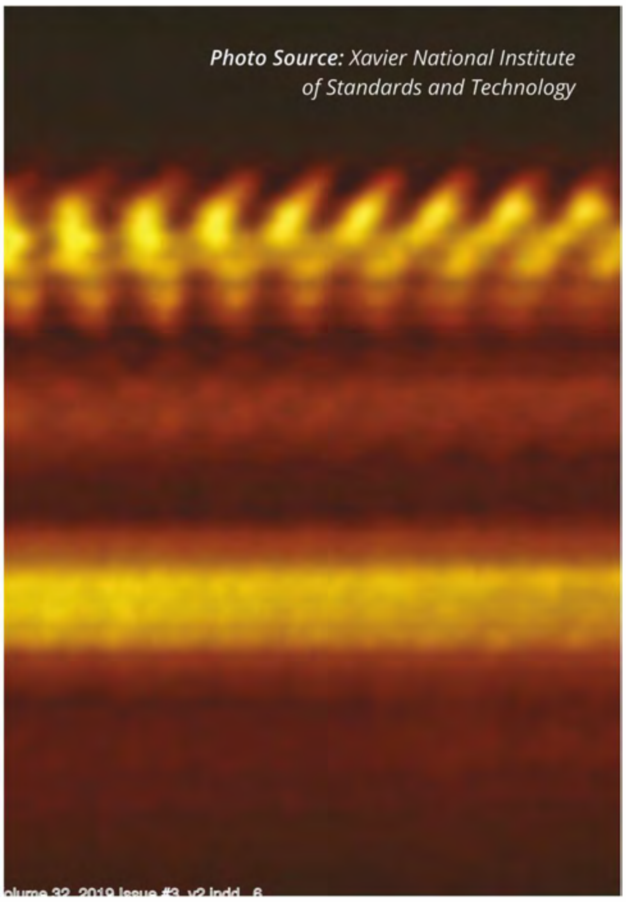


Photo Source: *Xavier National Institute of Standards and Technology*

Below is an image of greatly magnified four layers of atomically thin materials that form a heat-shield just two to three nanometers thick. The heat-generating components in smartphones, laptops and other electronics can cause a host of problems, from user discomfort to device malfunctions to lithium battery explosions. The issue is typically pre-empted by inserting glass, plastic or layers of air as insulation. But new research at Stanford University has shown that the same protection can be offered by a few layers of atomically thin materials, which paves the way for electronic devices to be even more compact than they are today. Perhaps what is most interesting about the research, however, is that it was based on thinking of heat as a form of sound.

That's right: The heat one feels from a smartphone or laptop comes from electricity in the form of electrons flowing through wires. These electrons collide with the atoms of the materials they pass through, causing them to vibrate; as more current is added, more collisions occur. Ultimately, all those electrons beating on all those atoms creates a cacophony of vibrations moving through solid materials at high frequencies, outside the range of audibility. It's that energy that is perceived as heat. "We're looking at the heat in electronic devices in an entirely new way," said Eric Pop, a professor of electrical engineering and senior author of a paper published in *Science Advances.*

It was Pop's background in college radio that prompted him to think about how sound is blocked in a recording studio — with thick panes of glass. The same principle could be applied to a heat shield, although simply making it thicker would defeat the purpose of reducing the size of devices. Borrowing a principle used in residential windows — installing multi-paned windows, which are typically comprised of layers of air between sheets of glass with varying thickness — proved the key to the new approach. The Stanford team used a layer of graphene and three other sheet-like materials, each three atoms thick, to create a four-layered insulator just 10 atoms deep. Atomic vibrations are dampened as pass through each layer of the insulator, resulting in less heat getting through.

For nanoscale heat shields to be practical, however, the researchers will need to find a mass production technique to deposit atom-thin layers of materials onto electronic components during manufacturing. Beyond that goal is a larger ambition: to one day control the vibrational energy inside materials the way that electricity and light can be controlled today. As the understanding of heat in solid objects as a form of sound increases, a new field known as phononics is emerging. The term is named for the Greek root words behind telephone, phonograph and phonetics.

More information *– https://electronics360.globalspec.com/article/14080/atomically-thin-electronic-heat-shields-based-on-sound-principles*

Email: *tony.pallone@ieeeglobalspec.com*

It's a one-way street for sound waves in this new technology

Imagine being able to hear people whispering in the next room, while the raucous party in your own room is inaudible to the whisperers. Yale researchers have found a way to do just that – make sound flow in one direction – within a fundamental technology found in everything from cell phones to gravitational wave detectors. What's more, the researchers have used the same idea to control the flow of heat in one direction. The discovery offers new possibilities for enhancing electronic devices that use acoustic resonators.

The findings, from the lab of Yale's Jack Harris, are published in the April 4 online edition of the journal *Nature.*

"This is an experiment in which we make a one-way route for sound waves," said Harris, a Yale physics professor and the study's principal investigator.

> **"Specifically, we have two acoustic resonators. Sound stored in the first resonator can leak into the second, but not vice versa."**

Harris said his team was able to achieve the result with a "tuning knob" – a laser setting, actually – that can weaken or strengthen a sound wave, depending on the sound wave's direction.

Then the researchers took their experiment to a different level. Because heat consists mostly of vibrations, they applied the same ideas to the flow of heat from one object to another.

"By using our one-way sound trick, we can make heat flow from point A to point B, or from B to A, regardless of which one is colder or hotter," Harris said. "This would be like dropping an ice cube into a glass of hot water and having the ice cubes get colder and colder while the water around them gets warmer and warmer. Then, by changing a single setting on our laser, heat is made to flow the usual way, and the ice cubes gradually warm and melt while the liquid water cools a bit. Though in our experiments it's not ice cubes and water that are exchanging heat, but rather two acoustic resonators."

Although some of the most basic examples of acoustic resonators are found in musical instruments or even automobile exhaust pipes, they're also found in a variety of electronics. They are used as sensors, filters, and transducers because of their compatibility with a wide range of materials, frequencies, and fabrication processes.

Source: Yale University

More information – https://www.sciencedaily.com/releases/2019/04/190403135011.htm

Why is the brain disturbed by harsh sounds?

Neuroscientists from the University of Geneva and Geneva University Hospitals, Switzerland, have been analysing how people react when they listen to a range of different sounds – to establish the extent to which repetitive sound frequencies are considered unpleasant. Surprisingly, their results showed not only that the conventional sound-processing circuit is activated but also that the cortical and sub-cortical areas involved in the processing of salience and aversion are also solicited. This is a first, and it explains why the brain goes into a state of alert on hearing this type of sound.

Alarm sounds, whether artificial (such as a car horn) or natural (human screams), are characterised by repetitive sound fluctuations, which are usually situated in frequencies of between 40 and 80 Hz.

But why were these frequencies selected to signal danger? And what happens in the brain to hold our attention to such an extent? Researchers played repetitive sounds of between 0 and 250 Hz to 16 participants closer and closer together in order to define the frequencies that the brain finds unbearable. "

Participants had to classify on a scale of 1 to 5, 1 being bearable and 5 unbearable. "The sounds considered intolerable were mainly between 40 and 80 Hz, i.e. in the range of frequencies used by alarms and human screams, including those of a baby," says Arnal.

Since these sounds are perceptible from a distance, unlike a visual stimulus, it is crucial that attention can be captured from a survival perspective. "That's why alarms use these rapid repetitive frequencies to maximise the chances that they are detected and gain our attention," says the researcher. In fact, when the repetitions are spaced less than about 25 milliseconds apart, the brain cannot anticipate them and therefore suppress them. It is constantly on alert and attentive to the stimulus.

Harsh sounds fall outside the conventional auditory system. The researchers then attempted to find out what actually happens in the brain: why are these harsh sounds so unbearable? "We used an intracranial EEG, which records brain activity inside the brain itself in response to sounds," explains Pierre Mégevand, a neurologist and researcher in the Department of Basic Neurosciences in the UNIGE Faculty of Medicine and at HUG.

When the sound is perceived as continuous (above 130 Hz), the auditory cortex in the upper temporal lobe is activated. "This is the conventional circuit for hearing," says Mégevand. But when sounds are perceived as harsh (especially between 40 and 80 Hz), they induce a persistent response that additionally recruits a large number of cortical and sub-cortical regions that are not part of the conventional auditory system. "These sounds solicit the amygdala, hippocampus and insula in particular, all areas related to salience, aversion and pain. This explains why participants experienced them as being unbearable," says Arnal, who was surprised to learn that these regions were involved in processing sounds.

This is the first time that sounds between 40 and 80 Hz have been shown to mobilise these neural networks, although the frequencies have been used for a long time in alarm systems. "We now understand at last why the brain can't ignore these sounds," says Arnal. "Something particular happens at these frequencies, and there are also many illnesses that show atypical brain responses to sounds at 40 Hz. These include Alzheimer's, autism and schizophrenia." The neuroscientists will now investigate the networks stimulated by these frequencies to see whether it could be possible to detect these illnesses early by soliciting the circuit activated by the sounds.

More information – *https://www.sciencedaily.com/releases/2019/09/190920111349.htm*

Photo: *–todayifoundout.com*

Introducing BeltBox – Soundproof your singing and conversations

Many people at work either use a headset or headphones to manage a call hands-free. Beltbox not only allows you to be hands-free but you can now muffle the sound of your voice up to 30 dB. Having a device that lowers the sound of your voice can prove very useful when discussing sensitive matters. If that isn't enough to convince you, it could work wonders as a Christmas present for that noisy relative that likes to sing in the shower.

More information – *http://www.beltyafaceoff.com*

NATIONAL FOUNDATION FOR
Deaf & Hard of Hearing

A conversation with Natasha Gallardo -

CE National Foundation for Deaf and Hard of Hearing

Chief Executive diagnosed with hearing loss as a teenager, Natasha has first-hand experience of the challenges people with hearing loss face. In 2018, after 15 years working in senior executive positions in Melbourne, as well as building a successful business, Natasha returned home to Auckland to take up the Chief Executive Role at NFDHH.

Can you explain what the National Foundation for Deaf & Hard of Hearing do and their day to day role in New Zealand?

NFDHH has been supporting New Zealanders who are deaf or have hearing loss for over 40 years.

We advocate for vital services and support for people living with a hearing loss.

We listen to New Zealanders and undertake research. This vital information forms the basis of our new programmes, initiatives and advocacy work.

We educate people on the risks of hearing loss and how to protect their precious hearing.

We work together with organisations who share our purpose – to improve the lives of people who have a hearing loss or a hearing disorder.

We guide. We offer guidance to workplaces and schools to ensure people with hearing loss are recognised and supported and have access to the tools and services they require.

What are some of the challenges the NDFHH face when trying to achieve their day to day goals?

Funding is always a pressure point for NFDHH as we do not receive government funding, we rely on the generosity of everyday New Zealander's Trusts, Grants and Corporate funding. This always puts pressure on what we can achieve with the funds available.

In terms of the deaf and hard of hearing community – our goal is to raise the awareness of what it means to be deaf or hard of hearing to break down the barriers and stigma that still exists. If we can educate people on how common hearing loss actually is (1 in 6 New Zealanders currently have hearing loss, and globally 1 in 5 teenagers have hearing loss) then this could help to normalise the conversation.

What are some of the signals that someone might be experiencing hearing loss or not hearing properly and what should they do to seek help?

Asking people to repeat themselves, having the TV up too loud, ringing in their ears, in noisy situations having difficulty hearing. Any of those initial triggers would warrant further investigation and best to seek out the help of your nearest Audiology clinic.

What is the best way to get the attention of a person who is deaf or hard of hearing?

If someone is profoundly deaf then a gentle tap on their shoulder, or a wave in front of them. With someone who is hard of hearing the same thing, and most importantly making eye contact.

What initially drew you to this role and what drives you in your day to day work?

As I was on the NFDHH Board initially, the opportunity arose to take on the CE role after the resignation of the prior one. I was attracted to this role because I have had hearing loss since I was diagnosed as a teenager. My mother has two cochlear implants, my brother two hearings and other family members have hearing loss too. It is essentially a big part of who I am. I am driven to do what I can to bring a greater awareness of what it means to be hard of hearing and deaf for people to understand what living with this disability is like and how they can better support their family members, co-workers, staff, customers etc. I am particularly focused on youth hearing loss right now as globally we are seeing an alarming increase (up 30% since the 1990's) due to personal device use e.g. headphones and this will create many implications for youth in the future and for New Zealand as well. This is preventable hearing loss so one of our main focus areas is on educating teenagers on how to better protect their hearing to reduce this increase.

What are the most satisfying things about your work and why?

Just being able to bring my corporate expertise to this role and to really try and make a difference for the deaf and hard of hearing community. It can be a hard road having a disability and I want to do as much as I can to support our community, particularly the young ones coming through, so they can be better supported in the future and for their journey to be much smoother.

Can you tell us about some of the most common causes and types of hearing loss and do these causes greatly differ in New Zealand say, compared to other developed countries?

Right now, in youth it is personal devices – headphones. Noise Induced Hearing Loss is common also, however preventable. Hearing loss can also come from infection, accidents, genetics.

What can an individual do on a day to day basis to ensure we have good healthy hearing long term?

Reduce the amount of noise you are exposed to. Only wear headphones for short periods and at low volumes. If you work in noisy environments ensure your workplace has robust hearing protection policies in place as well as being committed to reducing the noise in the workplace. If you go to a concert or sporting event or nightclub wear ear plugs and be conscious of how much noise you are being exposed too.

What are some misconceptions about the deaf and hard of hearing community you can share with us?

There is a lot of stigma attached to being deaf or having hearing loss. That it can be difficult to communicate however with technology now there is no barrier anymore. Having a hearing loss isn't a disability when in fact it impacts most of your life.

What is deaf awareness training?

How to better communicate with people who are deaf or hard of hearing. The aim is to provide training on Deaf community and culture, effective communication strategies including the Do's and Don'ts around communication, lip reading and writing, working with New Zealand Sign Language Interpreters and an introduction to New Zealand Sign Language, overcoming attitudes and barriers and looking at ways to improve access to services for Deaf, customers, staff etc

If there was just one single thing you wanted people to know on the topic of hearing what would it be?

To be considerate and inclusive of people who are deaf or hard of hearing.

FEATURES

How acoustics can influence the construction of a new city: A Christchurch case study

Jeremy Trevathan[1], and William Reeve[1]

[1]Acoustic Engineering Services Ltd, PO Box 549, Christchurch 8140, jt@aeservices.co.nz

Original peer-reviewed paper

Abstract

The devastation to built infrastructure in the centre of Christchurch resulting from the 2010 / 2011 earthquake sequence has been widely publicised. In a paper entitled Entertainment Noise Rules in a Vibrant City presented at the 22nd Biennial Conference of the Acoustic Society of New Zealand in 2014, Camp [1] discussed the challenges and opportunities that this presented with respect to noise and the hospitality industry. Another four years on, the construction and establishment of new hospitality, commercial, civic and accommodation facilities within the central city is now well progressed.

This paper discusses how acoustics have influenced reconstruction activity, and examines whether a better outcome has been achieved compared to the situation which existed before the earthquakes. Founded in the 1850's, the central city had been shaped by ad hoc development, the state of scientific knowledge, availability of materials, practical limitations in construction and various financial and societal factors. Starting again with close to a 'blank slate', the rebuild was well placed to benefit from modern approaches to land use planning, noise management, acoustic design and building design. However, the process has revealed a number of issues, including the tension between land use planning ideals and commercial reality, and new challenges presented by modern building techniques. The situation has also provided a unique insight into the role of user expectations and the importance society actually places on good acoustic outcomes when faced with other constraints.

This paper also considers how these experiences may allow the acoustics community to better communicate the benefits of high-quality acoustic outcomes, when competing with other more readily relatable considerations such as cost, safety, aesthetics and buildability.

Introduction

The earthquake sequence which devasted the centre of Christchurch in 2010 / 2011 left a landscape unrecognisable even to those who lived and worked in the city everyday. While the earthquakes set the city back many decades in a number of ways, they did present a unique opportunity to those in the planning and building industries.

The perception may have been that the city was starting from a blank slate (and hence 'big picture' thinkers suggested it may be a good time to relocate the entire city centre or replace it with a lake). However, to anyone with a closer understanding of how a city is formed it was obvious that the remnants that remained below, on and above the ground represented far from a blank slate. It costs billions less to repair damaged infrastructure than to design and build from scratch. Water supply, sewer, stormwater, electricity networks were all in place, along with roading and the built structures which survived. From a planning perspective, the overarching framework of the Resource Management Act [2] remained in place – albeit modified somewhat in an effort to facilitate a speedy and structured rebuild. There were always therefore going to be some constraints on what followed.

From an acoustics perspective, the question is – did this partial 'reset' present the chance to create something which took some 21st century steps forward in the way sound was considered, managed and used to enhance people's interaction with the built environment? Or would the remnants that remained, and plain old 'reality' mean little progress was actually made?

The opportunity

By October 2014, 1544 property demolitions had been completed in the central city [3]. This included the majority of high rises and a large number of heritage buildings.

The opportunity to apply modern thinking, knowledge and techniques to the design and construction of the new city centre would be expected to provide obvious advantages in the following areas.

Land use planning – State of the art principles

From an acoustics perspective, it would seem that 'starting from scratch', the rebuild of the central city would have allowed best-practice planning solutions to be developed to respond to the following issues, which are endemic in many existing city centres.

Incompatible land uses

There was potentially an opportunity for any land uses which were poorly compatible from an acoustic perspective (for example hospitality and residential) to be kept separate, with buffer areas. This would have ensured that noise emitters were not restricted, and noise sensitive activities would not need to spend money protecting themselves from others.

However, while this may be a desirable outcome from an acoustic perspective, it is difficult to envisage a situation where that arrangement would ever really be desirable from any other perspective – particularly with regard to the efficient use of land. Fundamentally, the upgrade of built structures or management are much more cost-effective ways of reducing noise than distance. In addition, 'mixed use areas' are generally perceived as desirable in a city centre.

Mixed use areas

The encouragement of 'mixed use areas' often appears to be key to creating the perception of a 'vibrant' desirable city centre. This means that acoustically mismatched uses are located in close proximity to each other.

If a 'mixed use' area is deemed to be desirable for non-acoustic reasons, in a situation where an entire city centre is being rebuilt this can at least be clearly articulated from the outset in the relevant planning documents, and noise rules can be developed which are practical and effective but still allow noise producers to operate in a financially viable manner. Appropriate reverse sensitivity controls can also be included, to ensure new noise sensitive activities are not unduly affected.

Camp [1] summarised some of these same concepts in the Christchurch context as follows:

"Well thought-out noise rules should be able to assist the planning process by guiding the type of businesses that are compatible with each area."

"The recovery plan encourages large-scale developments that incorporate features such as internal laneways and courtyards. This creates opportunities for hospitality businesses to internalise their noise effects."

"There are very few existing residential/traveller accommodation buildings. This means that façade sound insulation rules can be applied to almost all of the noise-sensitive buildings in the central city as they are rebuilt."

Building materials and design – Modern thinking and technologies

With regard to the buildings which would then be constructed, again it would also appear that an opportunity existed to provide a significantly improved environment.

Generally, appreciation of the value of higher quality buildings, and therefore building design standards have improved over time. Areas where quality has improved include seismic design, design for thermal comfort and fresh air, and the use of sustainable materials and methods. Due to all of these improvements, the solutions provided and resulting quality of experience for occupants has undoubtably improved since the 1800's.

With regard to acoustic design specifically, the fundamental aspects controlling the acoustic quality of a building are now well understood – the way that sound is transmitted through structures, the role that surface finishes and volume of internal spaces play in controlling reverberation and the control of noise from building services are all well understood.

In addition, it is now typically recognised in the building industry in New Zealand that engaging with an acoustics expert will add value to a project, and a variety of companies are able to provide these services. Acoustic engineering consultants have become adept at communicating with the industry during building projects to ensure that appropriate measures are integrated into building designs, and then constructed correctly on site.

There therefore appears to be no reason in theory that any new construction would not offer a significantly enhanced acoustic experience, compared to that provided by older buildings.

Completed reconstruction work

A variety of developments now been completed in the central city, as follows:

- Among the first developments to be completed were a number of new commercial and office buildings. Examples include the Duncan Cotterill Plaza, King Edwards Barracks Buildings and the Awly Building. Some dedicated office buildings such as the Environment Canterbury Offices have also been completed. A number of these developments are in or near the Retail Precinct, and accommodate retail space on the ground floor including the ANZ Centre, BNZ Centre, Grand Central and The Crossing.
- A number of the crown led anchor projects have been completed. The central Christchurch Bus Exchange was the first anchor project to be completed and opened in 2015. The Justice and Emergency Services Precinct and the central library Tūranga have opened more recently.
- Hospitality development has established in pockets throughout the central city. Clusters of bars and restaurants have established on Victoria Street, St Asaph Street and Lichfield Street. Multiple tenancies in the riverside Terrace hospitality strip and the Hoyts Ent X cinema complex opened in 2018.
- Although some residential development has taken place in the CBD, this has been relatively slow to establish and the number of people living in the central city is still below pre-quake levels. A significant amount of residential development is planned for the East Frame, with up to 900 homes. However, the majority of this is still in the construction or planning stages.
- Some visitor accommodation facilities have also been re-established. The larger facilities include the 204 room Crowne Plaza which is housed in the old Forsythe Barr office building and opened in 2017, and the Distinction Hotel in the former Millennium Hotel building which opened in 2018. Smaller hotels and serviced apartments are also establishing in various areas of the central city.
- A large number of heritage buildings were destroyed during the earthquakes, demolished soon after, or are still awaiting restoration. However, some remaining heritage buildings have been restored, such as the buildings at the Arts Centre dating from 1877. This complex has undergone extensive restoration, with over half of the site reopened to the public. Other examples of restorations include the Isaac Theatre Royal, a 1908 theatre building, reopened in 2014, and New Regent Street buildings in 2013.
- Dedicated performance venues are scarce in the central city, although The Piano, with a concert hall, and smaller performance and function spaces opened in 2016. The Christchurch Town Hall, Christchurch's largest performing arts facility is still undergoing restoration, and is due to reopen in March 2019.
- In 2017, the University of Canterbury moved parts of the College of Arts into the central city, at the Arts Centre of Christchurch. In the same year, the new Kahukura Engineering and Architectural Studies Building was completed at Ara Institute of Canterbury. Construction of the Ao Tawhiti "metro school" is well progressed and is due to open in 2019.

Overall, the amount of reconstruction work completed is adequate to allow an examination of the success of the planning and building design concepts discussed above.

Observations

The overarching observation from the reconstruction experience is that it is too simplistic to think of the modern way of doing things as superior. This is explored further in the following examples:

Land use planning – who is really in control?

With reconstruction now well underway and the Christchurch Central City Plan having been in place for a number of years, it has been possible to reflect on how successful even 'well thought out' noise rules have been in guiding development.

A general observation is that when looking to establish, businesses have very little regard for the noise rules. With regard to hospitality for example, decisions appear to be made based on commercial and other more ethereal reasons. The noise rules are only consulted when a decision to move forward has already been made. The noise rules (along with the majority of other planning controls) are then part of the 'red tape' through which a way must then be found.

While a thorough review of the planning context may seem to be a logical early due diligence step to some, a hospitality operator is more concerned with trying to sense current and future trends in an area and considering existing or possible new premises which may be suitable.

It appears that based solely on the above, a commitment may be made to a concept and site on the basis that it is expected to be a profitable business venture. Any consultation of the District Plan is very general (for example, to check the zoning of the site). This rarely extends to locating the relevant noise rules and trying to understand what they mean. The establishment of a new hospitality venture is seen as a fraught exercise which will involve many regulatory challenges for any site. Contending with any issues with noise rules is amongst the more minor of those issues.

From the perspective of an acoustics expert, it may seem obvious that unrealistic or impracticable management measures, stringent and unrealistic noise limits or limitations on types and levels of music, people outdoors and operating hours will potentially have a very real impact on the business case for a venue. The noise rules should therefore be considered right at the start, before any commitment to a site is made. However, it does not typically seem obvious to people – even when they are in a high-risk situation from an acoustic perspective. This appears to be due to lack of experience or previous inconsistent experiences which painted a confusing picture as to the role of noise rules. This could be due to factors such as variations between Plans in Districts, or variation between rules in different zones, or variations in consenting processes or enforcement. There is also a very common misconception that because someone else in the area is already operating in a certain way, it will be straight-forward to obtain consent for a new, similar operation.

The following examples consider how hospitality development has occurred in two parts of the city centre, contrary to the outcome the planning controls sought to achieve.

Example 1: The Welles Street area

The area around Welles St between Colombo and Manchester Streets is in a Category 3 *Entertainment and Hospitality* precinct, as described in part 6.1.5.2.2 of the Christchurch District Plan. In this area the noise rules were not structured to be helpful for the development of hospitality (the noise rules in the Category 1 and 2 precincts are deliberately more lenient, as discussed below). In particular the daytime noise limit is 55 dB L_{Aeq} and the night time limit is 45 dB L_{Aeq}. These limits are typical of what is required to protect residential amenity and allow for sleep during night time with windows open based on NZS6802:2008 [4]. The only leniencies are a delay of the onset of night time until 2300 hours (2200 hours is typical in a residential area), and an exemption for noise from people in outdoor areas of premises licensed for the sale of alcohol under 50m^2 (which in itself has created some unintended consequences, acting as an incentive for café type operations to be licensed).

In this area a number of older low-rise buildings have remained intact and in use, which include commercial on the lower floor, and residential on the upper. A large new Fletcher Residential multi-level apartment development is nearing construction in the area. There is a link through to Manchester Street where a number of restaurants operate out of surviving buildings, and transform after 2200 hours to provide late night 'night club' style entertainment. A number of other developments are underway on Welles Street, transforming several surviving single level buildings into boutique or artisan outlets – which will provide a genuine industrial and eclectic ambience and aesthetic. This contrasts with the more sterile or artificial environments which fitouts of completely new buildings inevitably provide.

In this context, the area appears to have become attractive to new hospitality enterprises – the likes of which would have been technically more suited to the Category 1 or 2 *Entertainment and Hospitality* precincts, where the night time noise limits are 15 dB higher up until 1 am or all night. These new enterprises appear to have been attracted by the potential for synergies with the current operators in the area, and the general ambience and aesthetic provided by the surviving commercial and residential activity. There is also the promise of a major influx of new inner-city dwellers when the Fletcher Residential development is fully occupied. Interestingly, to these hospitality operators, the presence of residential activity in the area and the prospect of a genuine 'mixed use' environment is seen as a positive, rather than as a challenging proposition which is best avoided.

Some of these new hospitality operators have faced a challenging Resource Consent process. This is not surprising in a situation that involves repurposing existing 1950's buildings to host music at 'night club levels', with residential neighbours and a noise limit of 45 dB L_{Aeq}. This has led directly to significant additional costs for the hospitality operators – for example upgrading or replacing existing roof / ceiling structures with high mass layers, and agreeing to restrictions on the use of outdoor areas, and restrictions on the type and level of music – along with a protracted and expensive consenting process.

However new hospitality continues to be successfully established and the area continues to gather momentum – in apparent defiance of the framework set out in the noise rules.

Example 2: The Category 1 Entertainment and Hospitality Precinct

By contrast the development of new hospitality operations in the Category 1 Entertainment and Hospitality precinct some 200 metres to the north and largely bounded by Tuam, Colombo, Cashel and Manchester Streets has been muted. In this area there is a 24-hour noise limit of 60 dB L_{Aeq} which excludes noise from people in outdoor areas of premises licensed for the sale of alcohol. Within this area there are also no sound insulation requirements for new noise sensitive uses, as such uses are not envisaged to the point of being Discretionary.

Prior to the earthquakes this area included the popular 'Poplar Lane' precinct which was made up of a series of late-night bar premises in historic buildings. The Category 1 *Entertainment and Hospitality* precinct also includes a portion of Manchester Street which was the centre of the 'night club' scene before the earthquakes.

However even with this apparent encouragement in the noise rules, very little hospitality activity has re-established within the Category 1 *Entertainment and Hospitality* precinct. This appears to have been due to the following factors:

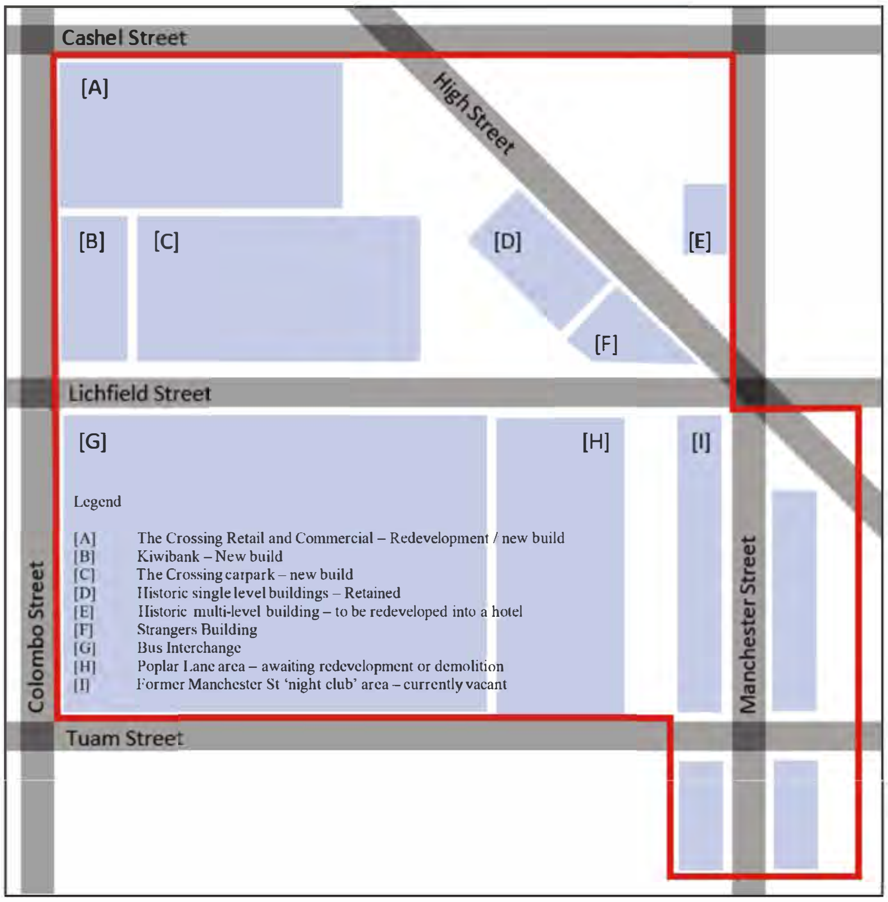


Figure 1 – *The Category 1 Entertainment and Hospitality Precinct*

- Of the two city blocks set aside for this Category 1 Entertainment and Hospitality precinct (the only such area in the central city), almost half a block has been taken up with the crown-lead central Christchurch Bus Exchange project.

- Another half of a block has been taken up with 'The Crossing' retail and commercial development and car park building. 'The Crossing' is a hybrid redevelopment / rebuild project of a facility of a similar footprint which existed before the earthquakes. While this area includes some hospitality tenancies, the vision for the project does not include becoming a late night 'night club' area.

- The buildings which housed the 'night club' area adjoining Manchester Street were of a low quality, and have all been demolished with the exception of one - which sits derelict. No plans have been announced publicly to rebuild in this area.

- Historic single level buildings fronting High Street have been retained, and continue to house various minor commercial tenants.

- The 'Strangers Building' on the corner of High Street and Manchester Street was one of the first rebuild projects. It has office space on the upper levels, and a number of small, internalised hospitality tenancies off 'Strangers Lane'. However, this group of operators are significantly isolated geographically in terms of late-night foot traffic from areas such as Welles Street and 'The Terrace' development which has just opening on Oxford Terrace.

- The Poplar Lane area remains cordoned off pending demolition or redevelopment.

- One of the few surviving multi-level buildings in the precinct is to be repurposed as a hotel.

These areas are shown in figure 1 above.

This analysis suggests that the planning structure may not have accurately foreseen how this area would actually develop. While issues such as the continued lack of progress with the redevelopment of Poplar Lane may not have been reasonably anticipated, other aspects of what subsequently transpired should perhaps not have been unexpected including:

- The likely lack of commercial incentive to replace the poor building stock on Manchester Street for 'night club' type tenancies (given that area is now on the fringe of the central city, and adjoins the eastern frame residential developments).

- That the Christchurch Bus Exchange would take up a significant portion of the precinct.

- That 'The Crossing' was likely to be redeveloped and continue to operate as a retail precinct, not a late-night hospitality venue.

This experience appears to suggest that where it does not make commercial sense to establish hospitality due to lack of synergy or complementary activity in the area, lack of suitable buildings, lack of scale and general isolation, permissive planning requirements including noise rules make no difference. With reference to the Welles Street example above, it may still make more sense to force something to happen in a location with an unfavourable planning context.

Building materials and design – is newer actually better?

The second area where the rebuild has provided some insight is in allowing a relatively immediate contrast between the acoustic quality of buildings which had emerged via the ad hoc developed of the city since the 1800's, and those which have been recently constructed. As described above, the later have presumably benefited from modern knowledge, materials and building processes.

Much like the situation described above for land use planning, in this area economic reality has been found to play a significant role in dictating the final outcomes. In particular:

- Modern buildings and spaces within them are typically designed to be able to be utilised to the greatest extent possible (to avoid providing multiple specialist spaces) or to be an as efficient use of space as possible, and

- The most common modern building techniques are optimised around cost of materials and cost and ease of construction.

In combination, this means that while a great deal more may now be understood by the acoustics community as to what may be ideal in terms of building design, layout and materials, this is rarely reflected in a pure form in the final built structure. This is illustrated in the following three examples.

Example 1: Long Reverberation Time music performance spaces

The majority of the large spaces used for performance music around the city prior to the earthquakes had a long Reverberation Time. Many of these spaces were built as worship spaces within churches – but other secular spaces were also frequently used for unamplified performance music such as the Great Hall within the Arts Centre.

The long Reverberation Time of these spaces was typically primarily due to:

- The large volume of the spaces. While it may seem obvious, this was a function of a large floor area designed to house large congregations, and high ceilings. In some cases, the large volume of the space was deliberately created by an architect who understood that a large volume added to the acoustic quality. It is likely however that the overall aesthetic and sense of grandeur were more frequently key drivers.

- Hard surface finishes. For spaces constructed 100 years ago, this simply reflected construction methods and materials of the day. The use of brick and stone were common (including as the finished internal surface). Where timber was used it was thick and solid, rigid and well supported. This means that the vibrational modes of internal wall surfaces occurred at high frequencies compared to modern plasterboard walls. Few products existed which could be applied to internal surfaces to provide mid and high frequency absorption.

These spaces were often furnished with pipe organs -which signals a type of use entirely suited to a long Reverberation Time (slow melodic pieces, choral arrangements and the like). As electric sound reinforcement and practical sound absorption products were not available, there was no particular decision to be made as to the balance between what is ideal for music or for speech.

Many of these spaces were partially or completely destroyed in the earthquakes. During the design process associated with rebuild work, many decisions were required reflecting the reality of the modern situation, including:

- The volume of the space. It proved very common that the rebuilt space was reduced in volume compared to the original. This was typically due to smaller footprints to reflect either smaller congregation sizes or to reflect different compromises in terms of balancing typical versus peak use of the space. A decision was often made to design a space which was ideal for week to week use (with regard to the costs associated with initial construction and then ongoing heating, cooling, lighting and maintenance), and then modern methods would be used to accommodate larger events (for example operable walls to link to adjoining spaces, or audio-visual systems to link to other spaces). High ceilings just for aesthetics, grandeur or acoustics rarely make it past the Quantity Surveyor.

- Surface finishes. It is more likely that the 'default' surface finishes provide some level of acoustic absorption. Ceiling tiles in a grid are frequently put forward as a light weight and cost-effective ceiling solution. Where plasterboard or decorative timber is proposed, this is typically thin and supported on framing or battens and so provides a degree of low frequency absorption.

In addition to these likely 'practical' constraints, the user group representatives involved with the projects were commonly mindful of being able to accommodate a wide range of uses. In some cases, this was just with regard to their congregation (for example, more modern music with faster tempo and rhythm and well as more traditional music). In other cases, a fundamental aspect of the economic model for the rebuild was that the space be able to be hired out for as wide a variety of uses as possible.

Overall, the ultimate decision for many of the spaces was to design for a lower Reverberation Time because it simply made more practical and economic sense. On some occasions this created significant tensions. This was particularly evident for projects where a pipe organ had been retrieved from the original space, and was to be installed in the new space. Those who work closely with pipe organs would on occasion express in the strongest of terms their desire for a long Reverberation Time. They would emphasise the indelible link between this, the performance of the organ and the worship experience of those within the space. In a number of these cases, the issue with installing the pipe organ in the new space was not just the lack of support from the room due to the lower Reverberation Time, but the potential 'over-volume' of the sound, due to the low ceiling and small space.

Table 1 – *Examples of design Reverberation Times.*

Project	Reverberation Time (Seconds)
Charles Luney Auditorium	1.1
St Albans Baptist Church	1.1
Opawa Methodist Church	1.1
St Paul's Trinity Pacific Church	1.1
The Village Presbyterian	1.2
Christchurch North Methodist	1.2
TSA Gracefield Avenue	1.2
St Peter's Church	1.3
St Matthew's Catholic Church	1.5
Christ's College Chapel	2.0

Table 1 outlines the design Reverberation Time for a number of these spaces, where the 'multi-use' compromise is clearly evident.

Notably, the three projects with the highest design Reverberation Times were not complete rebuilds – but involved the strengthening, modification or refurbishment of existing (and in some cases, historic) structures.

Therefore, while the number of worship and performance spaces available in the Christchurch may eventually reach pre-earthquake levels, it appears inevitable that the spaces will have a lower median Reverberation Time – and there will be significantly reduced opportunities to hear a Pipe Organ in a space which it was best suited.

Example 2: Lathe and plaster

Lathe and plaster was extensively used in the construction of internal walls and ceilings within low-rise multi-unit residential and hotels. These buildings, constructed up until around the 1950's, were very common in the central city prior to the earthquakes. The lathe and plaster layer itself typically consisted of the following:

- Wall linings – 9 mm thick timber laths approximately 40 mm wide at 5 mm spacing. 15 to 20 mm plaster layer over laths.
- Ceiling linings – 9 mm thick timber laths approximately 40 mm wide at 5 mm spacing. 10 to 15 mm plaster layer over laths.

The plaster layer generally consisted of base layers of a sand and cement mix, with a topping coat of gypsum plaster. The wet plaster base layer was forced between the laths and the resulting 'nibs' held the set and dry system in place. The outer gypsum layer was overlaid with heavy paper, which then painted or wall papered.

These low-rise timber framed buildings did not fare well in the earthquakes, and a large number were demolished and rebuilt by insurers under a 'like for like' policy scheme.

However, as illustrated in ***Figure 2,*** while a modern light weight timber framed wall (10mm plasterboard each side of 90 x 45 timber framing) may be 'like for like' from an aesthetic point of view, it does not provide a 'like for like' replacement from an acoustic perspective. Even with insulation added to the cavity (which the insurance company may struggle to accept is not 'betterment' if the original building did not have sound absorption), will not match the performance of the lathe and plaster, which has no acoustic absorption in the cavity.

Reflecting on the transmission loss curve it is noted that:

- The mass of the overall structure is higher for the lathe and plaster system – however the mass law alone does not appear to explain the level of performance through the portion of the curve typically expected to be controlled by mass.
- It appears possible that the nature of the cavity within the wall created by the back side of the lathes and plaster nibs provides some benefit in terms of the sound field in the cavity, compared to the regular flat parallel surfaces within the wall cavity of a modern construction.
- The structure of the lathe and plaster is very anisotropic and complex. It appears to be more highly damped and so therefore does not lend itself to strong low frequency modes in the same way that a modern light weight wall does. For this reason, there is potentially improved performance at low frequencies (where individual modes may begin to otherwise dominate).
- For the same reason (high damping) the coincidence dip is not as pronounced.

There therefore seems to be a genuine argument that the default 'modern' solution in this case is inferior. However, the situation is also confused somewhat as any direct comparisons are limited to subjective recollections from former occupiers. It is rarely possible to conduct a thorough investigation of the 'before' situation, as the buildings in question were likely to have been demolished (or extensively damaged to the extent that in-situ testing is potentially compromised to an unknown degree). Testing other 'similar' undamaged structures does not necessarily provide further clarity, as because lathe and plaster was virtually an artisan process, there is the possibility that the variation between building elements was much more significant than that with modern mass-produced building materials.

Example 3: New materials and building techniques

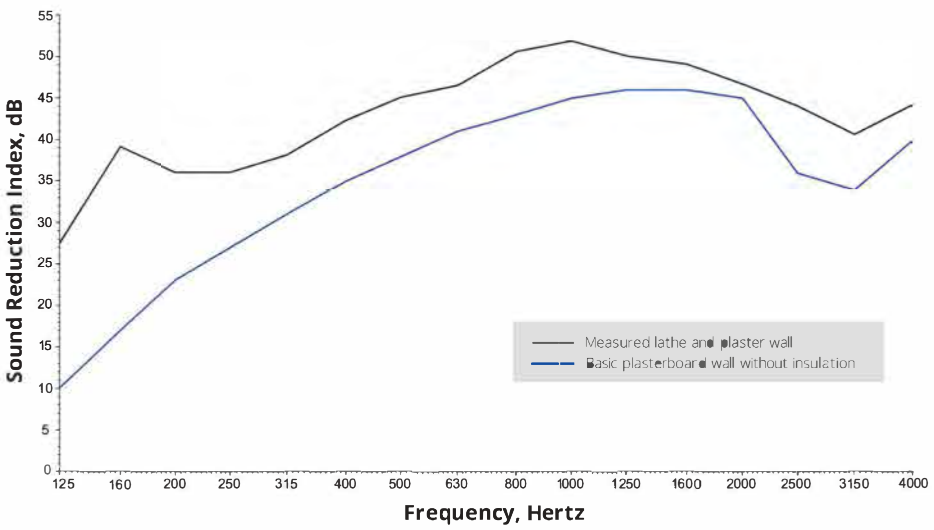
Like lathe and plaster, from a noise transmission perspective, on reflection it appears that many of the historic building materials were actually inherently rather effective. Materials such as stone, concrete and double brick provided high levels of mass. New light-weight, high seismic displacement, building techniques have provided significant advancement in terms of safety, but have created new challenges in terms of noise transmission.

In many cases, for modern multi-level buildings in areas with high levels of possible seismic activity and poor ground strength, the overall objective is to minimise the mass of buildings. This has economic benefits in terms of foundation and structural design. Many buildings are also designed to allow significant relative displacements between floor plates up the height of the building during a seismic event, settling back into place with no or only cosmetic damage. This is the opposite to a massive, stiff building which stands or falls together in a seismic event. Sustainability is also increasing the popularity of timber structures which present similar noise transmission challenges due to their light-weight structure.

Overall some of the acoustic challenges which these modern buildings present which did not need to be contemplated during the construction of the majority of the demolished buildings (including those constructed within the last 30 years where the structural systems still typically revolved around concrete beams and columns, and thick concrete floor slabs), include:

- Multi-level buildings with a steel structural frame, and thin concrete floors. The topping slab in some locations may be as little as 65 mm thick. This means that ceilings become essential in achieving even a moderate noise transmission rating between floors. In some situations, acoustic absorption may be required in the ceiling cavity of an office building or a high CAC ceiling tile may be required. Inevitably costings up to that point will have been completed based on a minimal mineral ceiling tile alone. Penetrations and weaknesses in these ceilings then also become more critical. This is in stark contrast to a situation where the floor slab includes 150 mm of concrete – in which case the ceiling is really just required to provide absorption in the space below. With such thin concrete slabs, potential issues with horizonal flanking under walls via the slab may also begin to emerge, as discussed by Quartaruolo and Beresford [5].
- Large seismic movement allowances. In some cases, vertically successive floor plates must be able to move 50 – 100 mm relative to each other, and then settle back into place. This means that internal walls cannot be full height and specific acoustic detailing which allows relative motion but still provides an adequate acoustic seal is required. When these details started to be required in the Christchurch context, bespoke solutions were devised – resulting in innovation and widely ranging solutions between projects. They are now common place enough however that a range of 'standard solutions' have settled in. This detailing does however add cost during both the design and

Figure 2 *– Sound transmission loss comparison*



construction stages of a project, and introduces numerous new risks and possible failure mechanisms with regard to site performance – both upon completion and over the life of the building.

- Preference for very light weight cladding materials. Products which are thin and stiff, and offer very poor levels of sound insulation are popular based on cost, weight and ease of installation. This includes aluminium composite, polycarbonate products or aluminium / polystyrene composite panels. Whereas with older buildings the glazing (and poorly sealed window frames) were almost guaranteed to be the weakest point in the façade, with these materials even portions of 'solid' façade may require specific review and upgrading.

- Alternative 'light weight' flooring solutions. Flooring systems based around aerated concrete, CLT and timber joist floors all present challenges which are largely avoided with high mass floors – particularly with regard to impact isolation. For these systems there is often a dearth of accurate data, and the only modelling techniques available are not practical for one-off commercial projects. This means that solutions are inevitably overdesigned, as the consequences of failures on site are significant – and difficult to correct.

As a result of these types of issues, while perhaps more time and effort are invested in the acoustic design of these new buildings, the majority of this effort is dedicated to simply achieving a result which is similar to that which would have already been associated with some aspects of more historic buildings (where the structural systems would have inherently provided better acoustic outcomes), rather than providing built environments which are clearly superior.

Conclusions

Conclusions regarding Land Use Planning

Based on the above, it appears that noise rules may have a limited ability to influence land use outcomes – for the example of hospitality at least. While a structure can be put in place which makes use of best practice controls from a planning and acoustic point of view, this then intersects with both the reality on the ground and the other criteria people use to make business decisions. In many cases noise controls are ultimately powerless to force any particular outcome. People always have the option to apply for Resource Consent to legitimise a non-compliance with a rule. People always have the option to pursue a development in one location, and not in another.

One question arising for local councils and the planning and acoustics communities is whether there is a better way to communicate the intention of any noise related land use planning controls. Even if this information is contained in a District Plan which is available online, this is still a significant barrier for most people. With regard to the Christchurch situation, currently if you navigate to the correct rule in the e-plan, there is simply reference to "the Central City Entertainment and Hospitality Precinct Overlay planning map" which is very difficult to then locate. Thought could perhaps be given to distilling the fundamentals of the noise rules from the Plan into some simple, common-English guidance aimed at anyone contemplating a new endeavour in the District, to be made available on a web platform.

Conclusions regarding Building Materials and Design

As described above, despite in the Christchurch situation having the advantage of working to design a building stock with the aid of modern knowledge and materials, inevitable universal issues such as economics, the availability of materials and competing constraints from other disciplines work to limit any significant advancement. Therefore, despite acoustic engineers now being armed with a greater range of knowledge and analysis tools, the default designs favoured by other disciplines would provide inherently poor acoustic outcomes and so much effort is dedicated to simply maintaining a reasonable level of acoustic quality.

It is therefore not a time to sit back and assume that modern thinking will provide superior outcomes. Conversations about acoustics are more important than ever to have at the earliest possible stages of a project – so the case for the provision of quality acoustic environments is clearly heard alongside more head-line grabbing messages such as seismic safety and sustainability. The need for acoustic engineers with a strong practical bent, and the ability to clearly communicate the importance of good acoustic design and outcomes is therefore as important as ever.

References

[1] S. Camp, "Entertainment Noise Rules in a Vibrant City," 22nd Biennial Conference of the Acoustical Society of New Zealand, 24 – 25 November 2014, Christchurch, New Zealand.

[2] New Zealand Government 1991, Resource Management Act, Wellington, N.Z.

[3] Canterbury Earthquake Recovery Authority (2014), Canterbury Earthquake Recovery Authority Annual Report 2014

[4] Standards New Zealand, "NZS6802:2008 Acoustics – Environmental Noise"

[5] G. Quartaruolo and T. Beresford, "Method to predict airborne flanking through concrete floors with nibs at the base of lightweight walls using ISO 12354-1" New Zealand Acoustics Journal, vol 31, 2018#1, pp. 26-34

Overview of Developments in the Description and Assessment of High Intensity Impulse Noise Exposure

Peter Teague, James Conomos and Vasos Alexandrou

Vipac Engineers and Scientists Ltd, Brisbane, Australia

Original peer-reviewed paper

Abstract

The precise description and assessment of high intensity impulse noise can be difficult due to the rapid onset-rates, short durations, very high peak noise levels (and overpressures) and the non-linear acoustic behaviour in the near-field of the source. Furthermore, determining the likely impact on hearing is limited by the current tools available for assessing the actual noise exposure/dose, auditory hazard risk and potential (irreversible) hearing damage. This paper provides insight to the recent developments in the measurement, prediction and assessment of impulsive noise exposure. Guidance is given on the relevant standards and guidelines, the range of measurement and prediction methods, impulse waveform pressure-time characteristics, relevant noise metrics/ descriptors, models of impulsive noise exposure and hearing damage mechanisms. Recently developed electroacoustic hearing models are explored, including the Auditory Hazard Assessment Algorithm for Humans (AHAAH) and exposure metrics such as Auditory Risk Units (ARU). Other emerging influences and synergistic effects due to ototoxic substances, human vibration and extended work-shifts are investigated. Real-world examples and the mitigation of high intensity impulse noise are explored along with the need for further research and innovation.

Introduction

Exposure to high intensity impulse noise represents a significant occupational noise hazard, especially in certain industries such as defence, mining, trades and industrial plants. Noise Induced Hearing Loss (NIHL) is one of the most prevalent and serious occupational health conditions and is a consequence of being subjected to long term exposure to high noise levels, and exposure to very high peak noise. Compensation claims paid to employees who suffer from some form of hearing loss is estimated to be well into the hundreds of millions globally, and assessing and understanding the health risks to a workers' health have become a key responsibility for employers.

In relation to the description and assessment of high intensity impulse noise, problematic issues are associated with the accurate measurement and prediction of impulsive noise events due to the very short durations, rapid onset-rates, large amplitudes (high peak noise levels/overpressures) and the non-linear acoustic behaviour close to the source. In addition, the previous tools available for assessing the actual noise exposure, auditory hazard risk and potential hearing loss are limited. For impulse noise, there is a need for determining the number of peak events above a certain threshold that is allowable before the risk of permanent NIHL becomes too high.

Recent developments in the description and assessment of impulsive noise exposure provide improved guidance in the areas of impulse measurement and prediction methods, applicable noise exposure descriptors and criteria, models of hearing damage mechanisms and new methods for determining impulsive noise exposure.

Relevant standards and guidelines

A brief overview is provided of the relevant standards, legislation and guidelines within Australia and internationally. There have been recent developments in the methods of measurement, prediction and assessment of impulsive noise exposure. The primary standards that relate to impulse noise, with a brief summary, include:

- AS/NZS 1269, *Occupational Noise Management* (comprising 5 parts, 0 to 4; latest version: 2005)

AS/NZS 1269.1 *(Part 1: Measurement and assessment of noise immission and exposure)* stipulates the preferred measurement quantities and metrics for occupational exposure of $L_{Aeq,T}$ (or $E_{A,T}$) and $L_{peak.}$ The L_{peak} level is used to determine impulse noise exposure. AS/NZS 1269.3 (*Part 3: Hearing protector program*) Appendix B provides a normative method for selecting a hearing protector for when L_{peak} exceeds $L(crit)_{peak}$: for impulse noise from small-calibre weapons and tools, use Class 5 hearing protection (HP); and for impulse noise from large-calibre weapons and blasting, use double HP with at least Class 3 earplugs and earmuffs of any classification.

- ISO 1999, *Acoustics – Estimation of noise induced hearing loss*

ISO 1999 :2013 specifies a method for calculating the expected noise-induced permanent threshold shift in the hearing threshold levels of adult populations due to various levels and durations of noise exposure. It provides the basis for calculating hearing disability when hearing threshold levels at measured audiometric frequencies exceed a certain value.

Tested on all aspects- get that due diligence box ticked

Peace of mind – that's what you get when you choose Echo Barrier. The world leader in temporary noise control ensures their full range of noise control barriers are independently lab tested to a number of international standards. The new H10 is tested to both BS 7837 – 1996 and ASTM E84 fire resistance standards. That's the complete product, not just one component of the barrier that is tested. This gives you peace of mind when recommending Echo Barrier products to clients, as they have been fully tested to a number of aspects and perform as advertised. Contact us today to discuss how we can solve noise issues on site without cutting corners.

SFI SUPPLY FORCE INTERNATIONAL

0800 66 66 473 | supplyforce.co.nz | info@supplyforce.co.nz

- Estimates of NIHL are based on time-varying exposures to steady-state noise and may not be reliable for impulse noise (sound levels greater than 140 dB); the standard therefore may not provide valid estimates of hearing loss for impulse noise. Note: AS ISO 1999:2003 (based on old ISO 1999 :1990 version, including noise exposure estimation) has been superseded and the new version, ISO 1999:2013, now applies.

- ISO 9612, Acoustics – *Determination of occupational noise exposure – Engineering method*

ISO 9612 :2009 provides an engineering method and equations to calculate time-averaged sound exposure levels. Like ISO 1999, the standard does not adequately address impulse noise, apart from noting highest L_{Cpeak} levels, and the standard is therefore less likely to provide valid estimates of noise exposure for impulse noise.

- AS/NZS 3817, *Acoustics – Methods for the description and physical measurement of single impulses or series of impulses*

AS/NZS 3817 :1998 is a direct text adoption (DTA) of the international ISO 10843 :1997 standard, described below. This standard is likely to be reconfirmed as a DTA of the latest version of ISO 10843; if this is the case then AS/NZS 3817 will be withdrawn and the new standard will be AS ISO 10843.

- ISO 10843, *Acoustics – Methods for the description and physical measurement of single impulses or series of impulses*

ISO 10843 :1997 (with Technical Corrigendum 1 :2009) describes preferred methods for the description and the physical measurement of single impulsive sounds or short series of impulsive sounds and for the presentation of the data. It does not provide methods for interpreting the potential effects of series of impulses of noise on hearing and receiver points. ISO 10843 provides the range of parameters and metrics that define impulse noise characteristics, and methods for measurement of phase-sensitive parameters and time-integrated quantities.

- ISO 13474, *Acoustics – Framework for calculating a distribution of sound exposure levels for impulsive sound events for the purposes of environmental noise assessment*

ISO 13474 :2009 provides an engineering method for calculating a statistical distribution of event sound exposure levels at locations which are some distance from high-energy impulsive sound sources. Hence, it is specifically intended for environmental noise assessment at distance and not for the assessment of the risk of occupational noise exposure. However, the standard does provide guidance on the determination of impulse source characteristics such as the measurement and estimation of sound emission properties of muzzle blast and projectile sound. It generally uses the methods defined in ISO 17201 with some modifications.

- ISO 17201, Acoustics – *Noise from shooting ranges* (comprising 5 parts, 1 to 5)

ISO 17201 provides guidance for calculating the sound propagation of shooting sound from shooting ranges, primarily for environmental noise assessment purposes. The standard applies to firearm calibres of less than 20mm

or explosive charges of less than 50g TNT equivalent. The five parts of the standard include: ISO 17201-1 (*Part 1: Determination of muzzle blast by measurement*), ISO 17201-2 (*Part 2: Estimation of muzzle blast and projectile sound by calculation*), ISO 17201-3 (*Part 3: Guidelines for sound propagation calculations*), ISO 17201-4 (*Part 4: Prediction of projectile sound*), ISO 17201-5 (*Part 5: Noise management*). These parts are described further in section 4 of this paper. A new Part 6 has been proposed for guidance on occupational noise exposure from impulsive shooting or blast noise at close range to the source, and is currently under preparation.

- MIL-STD-1474, *US Military Standard*

The United States' Department of Defence has developed a Design Criteria Standard, MIL-STD-1474 (latest version: MIL-STD-1474E, issued 15th April 2015), for *Impulsive and Continuous Noise of Platforms and Weapons Systems (Design Criteria – Noise Limits).* It provides noise criteria for designing defence materiel having noise levels that minimise the risk of permanent noise induced hearing loss. While this standard is not enforceable in Australia, it is a useful guideline for the impact of high intensity impulsive noise, in lieu of a suitable AS. The MIL-STD-1474E (Appendix B – Impulsive Noise) uses two methods to determine the noise risk associated with impulsive noise that exceeds an LC_{peak} of 140 dB, including a new exposure metric, the Auditory Risk Unit (ARU). The MIL-STD-1474E recommends noise criteria, based on the ARU metric, to minimise the likelihood of permanent hearing loss; which is described further in section 5 of this paper.

- Other relevant standards and guidelines include: European Union (EU) Directive 2003/10/EC, NORDTEST Method NT ACOU 112 (2002-05), American standard ANSI S3.44, US OSHA standard 1910, US NIOSH

Standard *(Criteria for a Recommended Standard – Occupational Noise Exposure)*, UK Control of Noise at Work Regulations L108 and the World Health Organization (WHO) *Occupational Noise Exposure Criteria.*

National legislation in Australia (WHS Act 2011, WHS Regulations 2011, WHS Code of Practice) states that employers must ensure employees are not exposed to noise levels within the workplace that exceed the national exposure standard (NES) for noise; i.e. $L_{Aeq,8h}$ of 85 dB(A) or L_{Cpeak} of 140 dB(C).

Impulse characteristics and descriptors

The sudden onset of a sound is defined as an impulse. High-level, short-duration noise can arbitrarily be categorised as impulse noise, which is the product of explosive devices (e.g. gunfire), or impact noise, which is generated by the forceful meeting of two hard surfaces (e.g. hammering, impact wrenches).

Impulse noise is typically characterised as having the following main properties:

- rapid onset-rates – the onset rate is the slope in dB/second of the straight line approximation between the starting point and end point of the impulse waveform time history (typically greater than 10 dB/s).
- very short durations – the first positive pulse duration can be of the order 1 to 5 ms for weapon firing and a pulse width of up to 10 ms for some sources.
- large amplitudes for high intensity sources, i.e. very high peak noise levels (greater than 130 dB and up to 180-190 dB).
- extreme overpressures for high energy sources (greater than 1 kPa and up to 100 kPa).
- high-energy impulsive sound sources comprise prominent low-frequency components.

The typical descriptive measures of impulse noise are the initial peak level and the duration of the first overpressure. This is the A-duration and is typically less than 1 millisecond (ms) for small-medium calibre firearms (e.g. rifles, machine guns) and several milliseconds for large calibre weapons (e.g. cannons). For impact noise, the two principal descriptors are the highest peak in a series of successive peaks (i.e. reverberations) and the so-called B-duration, the duration from the highest peak level to a point in time when the reverberations have decayed by either 10 or 20 dB. B-durations typically range from 50 to 300+ ms.

The character and prominence of the impulse at an immission or receiver point depends on the character of the emitted sound, the distance and propagation path from the sound source and the background noise.

In the near-field of impulse sources (within about 20m to 30m for large calibre weapons, depending on source) the acoustic field exhibits non-linear behaviour, and presents difficulties for accurately measuring or predicting noise levels in this region. Many studies have found that non-linear effects can occur in high pressure wave propagation, and as a result, application of non-linear mathematical methods (e.g. Hilbert transform, causality indices) are employed to describe high intensity sound waves and are justified by the fact that linear approaches do not provide accurate solutions for high pressure acoustics (Lenchine & Teague, 2008).

The region within which non-linear acoustics applies is above 154 dB (1 kPa) – this is where strongly non-linear waves and shock waves are generated (where dynamic pressure is close to static pressure of 100 kPa or 194 dB), leading to different sound speeds in different parts of the wave and causing additional/non-linear attenuation. Distances should be 2 – 3 times longer than the longest wavelength in order for lowest frequencies to fully develop.

The two primary sound generating sources from firearm/weapon firing are the muzzle blast (sound from explosion inside gun barrel, rapid directional volume expansion of gases and resulting pressure waves) and the projectile sound (non-linear sonic boom of supersonic projectiles plus any turbulence, scattering, reflection).

Measurement and prediction methods of impulse propagation

Measurement methods

ISO 10843 describes preferred methods for the physical measurement of single impulsive sounds or series of impulsive sounds. It provides the range of parameters and metrics that define impulse noise characteristics, and specifies methods for: 1) measurements of phase-sensitive parameters (such as peak sound pressure level and duration, which characterises the variation of sound pressure with time) and 2) measurements of time-integrated quantities (such as frequency-weighted sound exposure level or sound energy level). However, it does not provide methods for interpreting the potential effects of series of impulses of noise on hearing and receiver points.

ISO 17201 provides guidance for calculating the sound propagation of shooting sound from shooting ranges. The standard applies to firearm calibres of less than 20 mm or explosive charges of less than 50g TNT equivalent, and applies at distances where peak pressures are below 1 kPa (154 dB), outside the non-linear acoustic region. Energy-based levels (L_{AE}, L_{CE}) are used to describe or assess annoyance due to impulse noise (for environmental noise assessment purposes) and maximum or peak levels (e.g. L_{IAmax}) may not be considered valid.

ISO 17201-1 (*Part 1: Determination of muzzle blast by measurement*) provides an engineering method for determining the angular source energy distribution of a firearm muzzle blast from measurements. The source energy, its directivity and spectral structure can be used as input for sound propagation models for environmental noise assessment. The angular source energy distribution levels, $L_q(\alpha_n)$, are estimated on the basis of the sound exposure level measurements, $L_E(r_m, \alpha_n)$, at N discrete angles α_n at the distance r_m (assuming rotational symmetry). Due to ground reflections when measuring above ground, the sound exposure level $L_E(r_m, \alpha_n)$ will also depend on rotational angle β; however, corrections are provided to remove ground reflections. In order to calculate the total source energy and to provide a continuous directivity function, a curve fitting for the angular source energy distribution level is needed, and curve-fitting methods describe the periodic behaviour of the directivity function.

Detailed measurement procedures and sound data requirements are provided in ISO 17201-1. At least five measurements of the sound exposure, $E(\alpha, r_m)$, are required to be made at each microphone position (and angular increment step should not exceed 45°). Simultaneous measurements should be made at all microphone positions; however, measurements may be made sequentially but two microphones should be used with one microphone remaining at the same position. If the peak sound pressure level exceeds 154 dB at any of the microphone positions, the measurement distance shall be increased. The peak sound pressures should preferably be read from the time/pressure signal, where the error due to limited equipment high-frequency response can be corrected.

Aside from detailed sound level meter measurements of impulse noise, one common method used to assess occupational noise exposure is that of personal noise dosimetry sampling. However, there are serious limitations to obtaining accurate and reliable measurements of impulsive noise levels using dosimeters. This is due primarily to the limitations of most standard dosimeters to maximum peak levels of 140 dB (high impulse levels often exceed this measurement range threshold) and the occurrence of extraneous peak events due to accidental or intentional tapping/knocking the dosimeter while being worn.

Prediction methods

ISO 17201-2 (*Part 2: Estimation of muzzle blast and projectile sound by calculation*) provides methods for estimating the acoustic source data (i.e. spectral angular source energy distribution) of muzzle blast and explosions and the source data of projectile sound on the basis of non-acoustic data for firearms. This part effectively provides an interpolation method between measurements of muzzle blast. Firearm muzzle blast is highly directive, and both the angular source energy distribution and spectrum vary with angle from the line of fire.

The method is separated in two parts: firstly, the acoustic energy of the shot is estimated; secondly, the directional pattern of the source is applied and the spectrum calculated. The procedure allows the use of very general data or, if available, specific data to provide a more accurate result. Therefore, the procedure allows the use of alternatives such as default values or specific values for certain parameters. The estimate of the muzzle source energy (from estimating chemical energy, energy conversion efficiency, acoustic energy and Weber propellant energy density parameters) is used to determine the acoustical source data, including blast source directivity, spectrum and projectile sound source energy. This allows the sound exposure to be determined at a reception point, depending on the path length from the source position.

ISO 17201-3 (*Part 3: Guidelines for sound propagation calculations*) provides an engineering method for predicting sound exposure levels of shooting sounds for single shots at a certain receiver point, for open field and non-open field situations. This part uses a modification of the ISO 9613-2 method and also provides guidance on how to calculate other acoustic measures from the sound exposure level. Modelling of projectile sound is specified in ISO 17201-2 and ISO 17201-4. ISO 17201-4 (*Part 4: Prediction of projectile sound*) also gives guidelines for the calculation of the propagation of projectile sound (as far as it deviates from the propagation of other sound) such that for the attenuation for projectile noise, A_{excess}, ISO 9613-2 can also be used. The other attenuation parameters such as divergence, air absorption and non-linear attenuation are specified in ISO 17201-4.

In open field situations, especially in front of the firearm when the distance to the trajectory is short, projectile sound can be a relevant source for the sound exposure level of shooting sound. If a shot is fired in a shooting range, projectile sound is in general of minor importance in the estimation of the sound exposure level at a reception point. However, if measures are taken to reduce the sound emission of the muzzle blast, projectile sound can then become a dominant factor.

The propagation calculation may be performed using ray-tracing or more sophisticated models, which take specific weather conditions into account. To calculate a long-term L_{eq}, the results are weighted with respect to the frequency of occurrence of weather conditions pertinent to the time periods of interest. ISO 17201-3 also provides estimate relations for the conversion of sound exposure level to various L_{max} metrics.

Models of hearing damage and noise exposure

Effects of noise and hearing damage

The effects of impulse noise on the auditory system and likely hearing damage mechanisms are briefly described. Impulse noise creates several special hazards to the human auditory system.

First, the high peak levels associated with gunfire (140–190 dB) may damage the cochlea by causing rapid mechanical failure and injury (Humes et al, 2006, Henderson & Hamernik, 1986). A series of rapidly occurring impulses can be partially attenuated by the acoustic reflex, a reflexive contraction of the middle-ear muscles, while isolated impulses reach the cochlea before the activation of the acoustic reflex. Thus, intense explosions may result in large cochlear lesions and significant hearing losses. This damage is termed "acoustic trauma", and hearing at most frequencies may be affected. Additional symptoms include a sense of fullness in the ears, speech sounding muffled and a ringing in the ears (i.e. tinnitus). Although some recovery of hearing takes place after an acoustic trauma episode, the individual is often left with a severe, permanent hearing loss (Humes et al, 2006).

The relationship between noise-induced hearing loss and the peak amplitude of an impulse or impact noise is complex. Systematic research has shown that at the lower range of exposure to impulse noise (< 140 dB) or impact noise (< 115 dB), the hearing loss is likely to be proportional to the total energy of the exposure (peak level × number of impulses). However, above these peak sound pressure levels, the auditory system is damaged primarily by the large displacements caused by high peak levels. The dividing line between the "energy" and "peak-level" behaviour is referred to as the "critical level", taken to be 140 dB but is dependent on the impulse waveform.

Humans experiencing blasts at very high sound levels (> 170-180 dB) may suffer damage to the middle ear, including haemorrhage in or perforation of the eardrum and fracture of the malleus. If the eardrum does not rupture during such an intense exposure, the organ of Corti is likely to rupture off the basilar membrane. When a portion of the organ of Corti ruptures, it does not reattach to the basilar membrane and it eventually degenerates. Individuals with mild or moderate permanent NIHL typically have some structural damage in their cochleas. The damage may initially involve scattered loss of sensory cells, primarily outer hair cells, in the organ of Corti. Permanent NIHL may also result in damage to or destruction of other important structures in the cochlea, including fibrocytes in the spiral ligament and limbus and cells of the stria vascularis (Humes et al, 2006).

For high-intensity low frequency sounds, good consistency has been observed in human and animal studies between the frequency content of the exposure stimulus and the location in the cochlea experiencing the greatest damage or injury. For narrow-band stimuli, the maximum cochlear insult is often one-half to one octave higher in frequency than the exposure stimulus. For broad-band noises and impulses, more commonly at military and industrial sites, the damage is greatest in the high-frequency (i.e. basal) portion of the cochlea. Also, the differences in location of the greatest cochlear damage are accurately reflected in the pattern of hearing loss.

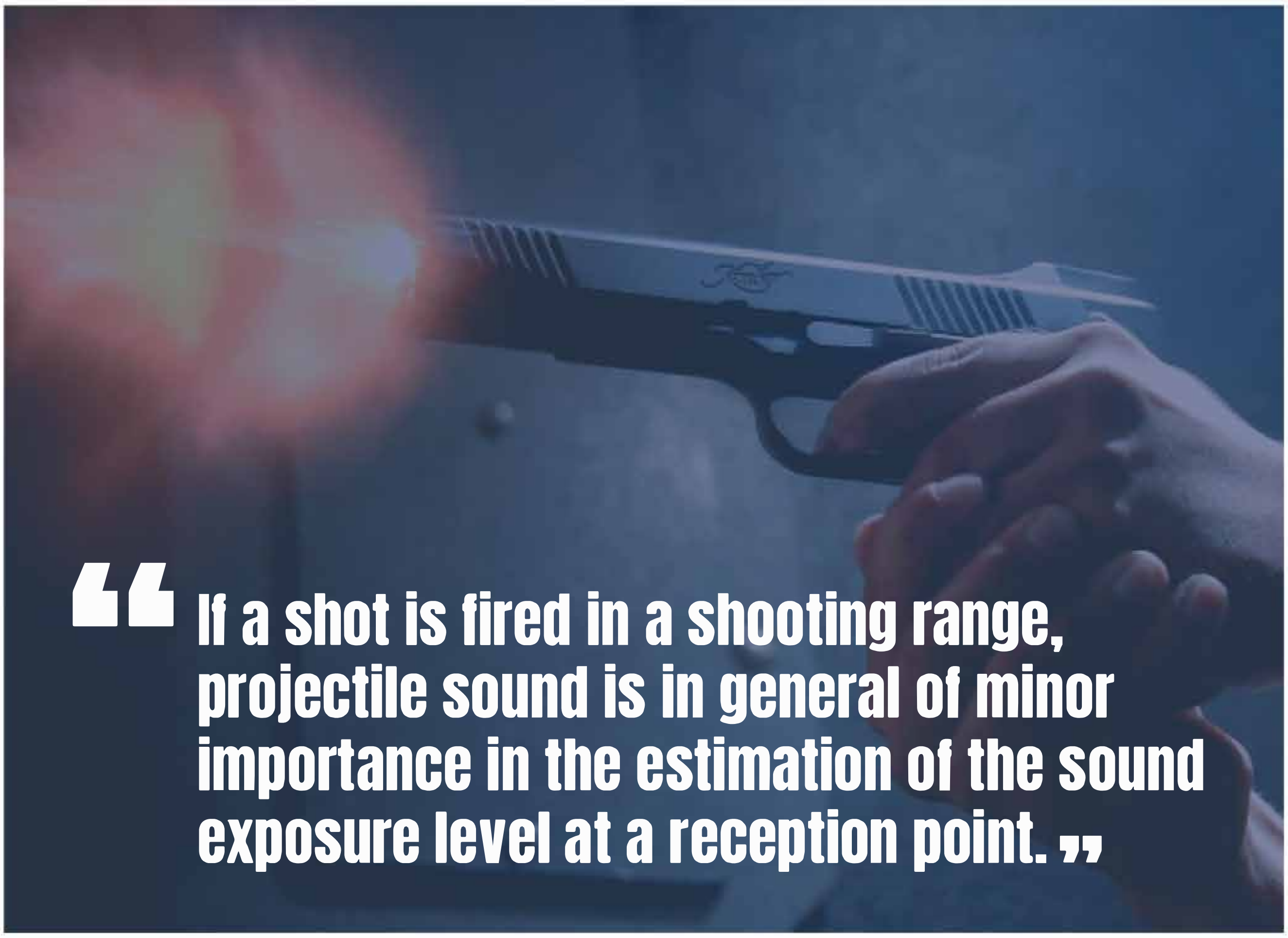
Hearing damage mechanisms relating to impulse noise are difficult to establish with certainty and further research is required. There is a well-defined need for better tools and models for simulating and estimating the hearing damage resulting from impulse noise exposure.

Noise exposure and hearing models

The accurate determination of the likely impact of impulse noise on hearing and the auditory system is limited by the previous tools available for estimating and assessing the actual noise exposure, auditory hazard risk and potential hearing loss. Theoretical and semi-empirical hearing models provide predictive methods for the estimation of hearing damage mechanisms, damage risk criteria (DRC) and resultant noise exposure. In general, for noise exposure, one can add 10logN to the one shot exposure to determine the noise exposure from N shots.

Advanced electroacoustic, biomechanical and dynamic hearing models have been recently developed and tested. One such model is the Auditory Hazard Assessment Algorithm for Humans (AHAAH) mathematical software model *(http://www.arl.army.mil/ahaah),* which represents an advance in the evaluation of hearing damage risk associated with impulsive noise (Fedele et al, 2013). The AHAAH algorithms apply pressure response dynamics measured for the external, middle, and inner ear, to bio-mechanically model the ear's non-linear physical response to impulsive sound and accurately determine the strain-induced fatigue occurring in the cochlea's organ of Corti. It models the 95th percentile (most susceptible) human ear. It also applies a user-selected direction from which sound is incident on the ear; sound traveling toward the head along the inter-aural axis is a worst-case condition.

The AHAAH Model calculates the auditory hazard of impulsive sounds by dynamically modelling their transmission from the free field, through hearing protection (if used), through the middle ear, into the inner ear, where noise-induced hearing damage typically occurs. The model includes an active auditory reflex, involving middle ear muscle contractions,



which can occur in response to the arrival of an intense sound or in anticipation of the arrival of such a sound. The output of the model is given in Auditory Risk Units (ARUs), which are physically related to damage resulting from displacements of the basilar membrane in the inner ear. The AHAAH model was developed based on the mechanical and fluid dynamic properties of the ear, and includes wave motion analysis of the basilar membrane in the cochlea based on the Wentzel–Kramers–Brillouin wave dynamics method.

The US standard MIL-STD-1474E (Appendix B – Impulsive Noise) uses two methods to determine the noise risk associated with impulsive noise that exceeds an L_{Cpeak} of 140 dB. Note that these new methods supersede the previous MIL-STD-1474D method and the Free-field Exception (FFE) and Proportional Dose (PD) methods. The two methods in MIL-STD-1474E employ the following two metrics for assessing noise exposure:

- $L_{IAeq,100ms}$ metric (equal energy model), and
- Auditory Risk Unit (ARU) metric, calculated from the AHAAH model.

A comparison between the two methodologies is presented in Table B-11 of the standard. The MIL-STD-1474E recommends the following noise damage risk criteria (DRC) to minimise the likelihood of permanent hearing loss:

- a total of 500 ARUs is the maximum allowable 'dose' (within a 24 hour period) for *occasional* exposures (e.g. less than once per week on average), noting that doses greater than 500 ARUs are predicted to produce permanent hearing loss; and
- For occupational exposures occurring *more regularly* (i.e. on average, daily or near daily), the limit should be reduced to 200 ARUs (within a 24 hour period) to reduce the likelihood of permanent hearing loss.

This prescription is based on the direct relation between ARUs, temporary changes in hearing sensitivity and the probability of permanent hearing loss. A dose of 500 ARUs is barely safe, a dose of 200 ARUs is more reasonable as an occupational dose limit where daily exposures could occur. The allowable number of rounds (ANOR) of weapon fire is determined based on noise exposure limits of 200 and 500 ARU.

Inputs to the AHAAH model include the high resolution pressure-time history of the impulse waveform, and the model predicts the resultant transfer functions and in-ear displacements. The AHAAH model and MIL-STD-1474E allow the calculation of the attenuation of different default hearing protection configurations (for both "warned" and "unwarned" scenarios). The Hearing Protector Module (HPM) of the AHAAH software models all hearing protectors as passive level independent linear (LIL) devices. The model includes several level dependent non-linear (LDNL) hearing protector devices (HPDs). These LDNL HPDs are modelled linearly, based on Real Ear Attenuation at Threshold (REAT) measurements performed with the HPDs worn in the closed and the open modes.

Other models have been investigated and include: 1) MIL-STD-1474D, 2) NATO Models, 3) LAeq8 Model. The previously used MIL-STD-1474D standard model has shown to be inaccurate for determining impulse noise injury. The other models have their merits but have generally been shown to be deficient in the prediction of impulse noise impacts compared to the AHAAH Model in a recent review (Wightman et al, 2010). The AHAAH Model has been extensively evaluated, peer-reviewed and fully vetted and is the new standard (as is the case with the current MIL-STD-1474E). Even though the AHAAH Model is the best model currently available, it still requires further refinement in the areas of stapes non-linearity, basilar membrane displacements, reflexes and metabolic exhaustion.

Notwithstanding the advances in hearing models for impulse noise, the correlation between model predictions and actual hearing damage can be deficient or inconsistent. There is a need for extensive comparisons with real-world measurements of impulse noise levels (in field and laboratory) and measurements of actual hearing damage extent, which will inform future improvements to noise injury models and hearing protection requirements.

Other influencing effects

Other emerging influences and synergistic effects due to ototoxic substances, human vibration and extended work-shift periods can increase the risk of hearing loss in combination with noise and impulse noise.

Exposure to ototoxic substances and chemicals such as Volatile Organic Compounds (VOCs) can lead to hearing loss. The extent of hearing loss can be exacerbated through combined exposure to both noise and ototoxic agents. There are three major classes of ototoxic substances: solvents, heavy metals and asphyxiates. Activities where these substances may become an issue include painting, construction, fuelling, degreasing, weapons firing and fire-fighting. Ototoxic substances are often present in marine, mining, vehicle and defence industries, specifically fuels and carbon monoxide in engine spaces and maintenance personnel who are exposed to fuels, metals and solvents. Recent review papers provide an overview of ototoxic agents and effects (Mahbub et al, 2016, Teague et al, 2016).

Live weapon firing (large and small-medium calibre) is known to generate ototoxic chemicals, including lead, manganese, arsenic, hydrogen cyanide and carbon monoxide (and

toluene compounds), via airborne inhalation and dermal contact (Quemerais, 2013). The airborne concentration and total exposure levels (and the combined effects of different ototoxic agents) will vary depending on a range of factors such as weapon type, propellant charge types, firing scenarios, number/frequency of firing rounds, local weather conditions etc.

The WHS Code of Practice (COP) recommends that monitoring hearing with regular audiometric testing should be conducted where workers are exposed to:

- any of the ototoxic substances (listed in the COP Appendix A) where the airborne exposure (without regard to respiratory protection worn) is greater than 50 per cent of the national exposure standard for the substance, regardless of the noise level; or
- ototoxic substances at any level and noise with $L_{Aeq,8h}$ greater than 80 dB or L_{Cpeak} greater than 135 dB.

The COP also recommends reduced noise criteria of 80 dB (and L_{Cpeak} no greater than 135 dB) in situations where personnel may be exposed to ototoxic substances in addition to noise.

It is also widely recognised throughout industry that there is a link between exposure to hand-arm vibration (HAV) and hearing loss (Pyykko et al, 1987, Pettersson et al, 2012). Note that significant levels of HAV in conjunction with noise may occur with the use of a range of hand tools, pneumatic tools, machinery/vehicles and small to medium calibre automatic firearms. It is suggested that vibration exposure from hand-held tools reduces the blood flow in the cochlea by activating the sympathetic nervous system, leading to increased risk of hearing loss (Pyykko et al, 1987). Longitudinal and case-control studies on subjects who have contracted vibration-related disorders found that subjects with vibration white fingers (VWF) have an increased risk of developing hearing loss. The risk of hearing loss is confounded by several factors such as age, medical, chemical and genetic factors. It is also suggested that whole body vibration (WBV) from operating machinery and vehicles may also increase the risk further.

Work shift durations greater than 8 hours impose a higher health risk to exposed workers. The increased health risk occurs from the additional damaging effect that continued exposure to noise has, once the maximum temporary threshold shift is reached. Risk may be further increased if there is a reduced recovery time between successive working shifts. To compare the effect of noise exposure during a workday other than 8 hours, one needs to normalise this exposure to an equivalent 8 hour exposure $L_{Aeq,8h}$ using equation 9(4) in AS/NZS 1269. In addition, AS/NZS 1269 suggests an additional penalty adjustment to the 8-hour normalised level according to shift length.

A combination of the described effects above can occur in some workplaces which increases the risk of excessive exposure. For example, trades such as aircraft refuellers and vehicle/workshop mechanics can be exposed to high peak levels, extended work-shift noise exposure, ototoxic substances (e.g. fuels, solvents) and HAV, often during the same work-shift. Such situations require careful exposure assessment (including a lower noise exposure standard or additional adjustments) and application of a range of specific control practices.

Real-world examples and mitigation

Examples of Real-world situations

A subset of real-world examples of the measurement and estimation of noise exposure from a sample of high energy impulse sources is summarised for a range of exposure metrics and criteria.

Noise exposure data was determined for small calibre firearms (SCF, calibre < 10mm) and large calibre weapons (LCW, calibre > 100mm) from high-resolution measurements (sample rate of 200 kHz; time resolution of 0.005 ms; at a range of distances/angles with high-pressure microphones) and calculations conducted in accordance with MIL-STD-1474E (and the AHAAH Model). Exposure calculations were performed for actual near-field operator scenarios (e.g. at or near gun firing position; for cases with and without hearing protection) to determine:

- Calculated in-ear peak pressure level;
- Auditory Risk Unit (ARU) exposure;
- $L_{IAeq,100ms}$ per impulse;
- Calculated $L_{Aeq,8h}$ for a number of impulses;
- Allowable number of rounds (ANOR), based on an ARU of 500 limit;
- Allowable number of rounds (ANOR), based on an ARU of 200 limit.

In terms of hearing protection (see also section 6.2), MIL-STD-1474E and the AHAAH model allow the calculation of the attenuation of different hearing protection device (HPD) configurations (for various scenarios). A range of default HPD options includes earplugs only, ear muffs only and double hearing protection (earplugs plus ear muffs), based on actual Real Ear Attenuation at Threshold (REAT) measurements for a range of available HPDs.

Based on the measured noise levels and the AHAAH model outputs, the ANOR for unprotected exposure and various HPD (at or near gun firing position) is presented in Table 1. An assessment was conducted against the:

1. WHS Legislation with consideration of ototoxic substances ($L_{Aeq,8h}$ NES of 80 dB);
2. WHS Legislation without presence of ototoxic substances ($L_{Aeq,8h}$ NES of 85 dB); and
3. MIL-STD-1474E ANOR using 200 ARU criterion.

Table 1 indicates that *unprotected* exposure will result in hearing loss, due to the allowable number of rounds being significantly less than 1. The allowable number of rounds provided is based on an in-ear noise level calculation. When considering all assessment methods, the standard WHS Assessment (using $L_{Aeq,8h}$ criteria) is more conservative than the MIL-STD1474E/AHAAH method and thus allows the least number of rounds per 24 hour period (13 to 20 shots with ear plugs, and 70 shots with ear muffs). When fitting double hearing protection (as is the requirement in the near-field of the LCW), between about 140 and 180 rounds can be fired per 24 hour period.

In the presence of ototoxic substances and with double hearing protection (within 20m to rear and 40m to side of the LCW, using a particular propellant charge), up to approximately 40 rounds can be fired per 24 hour period. If further research shows that no significant ototoxic chemicals are produced from LCW firing, then up to approximately 140 rounds could be fired per 24 hour period. Note that, at the gun operator positions, peak levels of up to 170 dB L_{Cpeak} were measured and $L_{IAeq,100ms}$ levels of up to 140 dB were measured per impulse.

Table 2 provides the current requirements and the recommended updated requirements (for up to 40 rounds in a day) in the near-field of a Large-Calibre Weapon (LCW), noting the high directivity of noise emission.

Note that this assessment is only for LCW firing with a certain propellant charge, and that stricter requirements will probably apply for LCW use with other (larger/noisier) charge types, after confirmation from further noise testing. For small calibre firearms (SCF), it was found that Class 4 ear plugs do not provide satisfactory attenuation for more than 6 rounds in a day, assuming that ototoxic substances are present – hence, a new requirement of at least Class 5 ear muffs (or ideally double HP for up to 200 rounds/day) would be required for SCF.

Noise Exposure Controls

Where noise exposure controls are required from the measurement data and subsequent exposure risk assessment, the hierarchy of noise control should be applied. Engineering noise control is the preferred method of initial

Table 1 – *Allowable number of rounds for a large-calibre weapon based on different noise criteria*

	Allowed number of Rounds (ANOR), AHAAH Model			
	No HPD	Ear Plugs	Ear Muffs	Pluggs & Muffs
		(Default 04)*	(Default 04)*	(Default 06)*
$L_{Aeq,8h}$ WHS adjusted NES, 80 dB	0.1 – 0.2	4 – 6	21	43 – 53
$L_{Aeq,8h}$ WHS standard NES, 85 dB	0.3 – 0.7	13 – 20	70	142 – 178
MIL-STD-1474E Assessment (200 ARU)	0.3 – 0.5	19 – 28	272 – 355	283 – 389

**The Default 02 Ear Plug (within AHAAH model) closely matches the attenuation levels provided by the Class 4 EAR Classic plug, the Default 04 Ear Muff closely matches a Comtec Noise Cancelling Headset, and Default 06 represents double hearing protection.*

Table 2 – Current and proposed hearing protection requirements in the near-field of a large-calibre weapon

Current Requirements	Proposed Requirements
• Double Hearing Protection (ear plugs + muffs) required within 5 metres of LCW; and • Single Hearing Protection (ear plugs or muffs) required between 5 and 100 metres of LCW.	*At side of LCW (e.g. 90 or 270 degrees):* • Double Hearing Protection (ear plugs + muffs) required within 40 metres of LCW; and • Single Hearing Protection (ear plugs or muffs) required between 40 and 200 metres of LCW.
	At rear of LCW (e.g. 180 degrees): • Double Hearing Protection (ear plugs + muffs) required within 20 metres of LCW; and • Single Hearing Protection (ear plugs or muffs) required between 20 and 100 metres of LCW.

noise reduction, however this is not always practicable. As such, the implementation of mandatory personal protective equipment (PPE) usage and administrative controls are normally applied and used widely within industry.

Administrative control measures recommended and applied throughout industry include job rotation, work scheduling, changing work processes, limiting exposure times for high noise tasks, minimum rest periods, limiting distances from noise hazards, limiting exposure to ototoxic substances and hand-arm vibration, and ensuring equipment is maintained. In particular, for impulse noise from weapon firing, minimum safe distances and the allowable number of rounds (ANOR) should be specified (as described in the last section). For high intensity impulse noise (e.g. from large calibre weapons), double hearing protection is required, i.e. ear plugs and ear muffs. As an example, the combination of a Peltor COMTEC Noise Cancelling Headset (Class 3, 21 SLC_{80}) with either EAR Classic Platinum or HL Bilsom 303L ear plugs (Class 4, 23 SLC80) would meet the primary requirement (selection rule) in AS/NZS 1269.3 (Appendix B) for impulse noise.

Observations made throughout most site surveys showed improper fitting of HPDs. Improper fitting can mean that the HPD will not achieve the attenuation it is designed to provide, and that wearers could be under-attenuating noise levels by up to 10 to 15 dB. Therefore incorrect fitting of HPDs has the potential for workers to be exposed unknowingly to unacceptably high noise levels and subsequent health risks. As such, a recommended action is for training on the use and proper fitting of HPDs for all workers. Personal hearing protectors should be selected and maintained in accordance with WHS Regulation 44, the Code of Practice and AS/NZS 1269.3. Employers should involve workers in the HPD selection process and ensure that workers are comfortable with the HPD of choice.

It is important to note that workers exposed to ototoxic substances may require additional PPE in the form of respiratory protection in addition to suitable hearing protection. This would depend on the number of ototoxic agents exposed to, the exposure levels to specific ototoxic agents (relative to standard exposure criteria for each chemical agent) and the combination with the level of noise exposure.

Noise controls applied within industry for work processes include: buying quiet equipment, acoustic screens in high noise areas (e.g. workshops), silencers and low noise fittings to specific tools, HPDs etc. These solutions have proven effective in reducing occupational noise exposure for high noise areas within Defence (Teague et al, 2014).

WHS legislation requires that workers exposed to high noise levels must have regular audiometric testing. In the area of the measurement of hearing damage, advances in audiometric testing are being made. For example, the measurement of evoked otoacoustic emissions (OAE), such as DP (Distortion Product) and TE (Transient Evoked) testing, could provide a more objective, sensitive and accurate clinical determination of hearing damage (to auditory stimuli in real-time) than standard pure-tone threshold-shift audiometry (Carter, Williams & Seeto, 2015). However, there are limitations in this area given that there are currently no accepted normative values available that can be used in relation to hearing health; and, as such, further research in this area is required.

Conclusions

Recent developments have been made in the description and assessment of impulsive noise exposure. This paper has summarised the relevant standards and guidelines, and has provided an overview of the previous work and applicable methods for impulse measurement and prediction, noise exposure metrics, models of hearing damage mechanisms and approaches to determining the resultant impulsive noise exposure. A discussion on the control of noise exposure highlights the hearing protection and other measures required to mitigate impulse noise.

Recently advanced electroacoustic/biomechanical hearing and noise injury models (such as the AHAAH Model) provide a more robust estimation of likely hearing impact from impulse noise and applicable damage risk criteria. However, there remain limitations to the accuracy and coverage of such models, which require further work including comparisons with real-world measurement data and subsequent verification/validation. Looking forward, in order to minimise severe health risk and injury to workers' hearing from impulse noise, this demonstrates the need to apply a conservative approach and the need for further research and innovation.

References

[1] Carter, L, Williams, W & Seeto, M 2015, 'TE and DP optoacoustic emission data from an Australian cross-sectional hearing study', *International Journal of Audiology*, 54, pp.806-817.

[2] Fedele, PD, Binseel, MS, Kalb, JT & Price, GR 2013, 'Using the Auditory Hazard Assessment Algorithm for Humans (AHAAH) With Hearing Protection Software - Release MIL-STD-1474E', ARL-TR-6748, Army Research Laboratory.

[3] Henderson, D & Hamernik, RP 1986. 'Impulse noise: Critical review'. *Journal of the Acoustical Society of America*, 80(2), pp. 569–584.

[4] Humes, LE, Joellenbeck, LM & Durch, JS 2006, *Noise and Military Service: Implications for Hearing Loss and Tinnitus*, Institute of Medicine, The National Academies Press, Washington DC.

[5] Lenchine, V & Teague, P 2008, 'Atmospheric Propagation of High Pressure Sound Waves and Causality', *Proceedings of INTER-NOISE 2008*, 26-29 Oct 2008, Shanghai.

[6] Mahbub, S A, Warwick Williams, W & Connolly, R 2016, 'Exposure to Ototoxic Agents and Noise in Workplace – A Literature Review'. *Proceedings of ACOUSTICS 2016*, 9-11 Nov 2016, Brisbane.

[7] Pettersson, H, Burström, L, Hagberg, M, Lundström, R & Nilsson, T 2012, 'Noise and hand-arm vibration exposure in relation to the risk of hearing loss', *Noise Health*, 14, pp. 159-65.

[8] Pyykko, I, Pekkarinen, J & Starck, J 1987, 'Sensory-neural hearing loss during combined noise and vibration exposure. An analysis of risk factors', *Int Arch Occup Environ Health*, 59, pp. 439-54.

[8] Quemerais, B 2013, 'Occupational Exposure to Atmospheric Emissions Produced During Live Gun Firing (105mm/155mm)', Journal of Environment & Pollution, Vol 2, No 4.

[9] Teague, P, Conomos, J, Alexandrou, V & Jennings, M 2014, 'Development of an Occupational Noise Exposure Reduction Project for Defence in Australia', *Proceedings of INTER-NOISE 2014*, 16-19 Nov 2014, Melbourne.

[10] Teague, P, Alexandrou, V, Burgess, M & Williams, W 2016, 'Consideration of Non-Auditory Synergistic Impacts on Occupational Hearing Loss'. *Proceedings of AIOH 2016*, Australian Institute of Occupational Hygienists, Dec 2016.

[11] Wightman, FL, Flamme, G, Campanella, AJ & Luz, GA 2010, 2010, *Peer Review of Injury Prevention and Reduction Research Task Area – Impulse Noise Injury Models*, American Institute of Biological Sciences, US Army MRMC.

Acoustic Testing Facility in Christchurch

Aaron Healy[1], Mike Latimer[2] and Hedda Oosterhoff[3]

[1]The University of Canterbury, [2]JSK Consulting Engineers, [3]T&R Interior Systems

Original peer-reviewed paper

The loss of the acoustic testing facilities at Canterbury University was keenly felt by many in the industry. It became apparent that there was a need and market for another facility in New Zealand. T&R Interior Systems and Angus Ceilings worked together to secure a Callaghan Innovation funded Masters' Thesis through the University of Canterbury Acoustics Group. The thesis was to include the design and commissioning of a new reverberation room. In October 2018, planning and research started on the reverberation room. Construction started in late March and was completed at the end of July. Acoustic commissioning concluded in August this year.

The operation of the testing is now conducted independently by JSK Consulting. The facility is located at 180 Hazeldean Road. The new facility consists of a reverberation room, control room, and transmission loss openings, along with the CFN facility previously run by the University of Canterbury. These spaces will facilitate the measurement to the following standards:

Sound absorption

- AS ISO 354-2006: *Acoustics – Measurement of sound absorption in a reverberation room*

Sound transmission loss

- BS EN ISO 10140-2:2010: *Acoustics – Laboratory measurement of sound insulation of building elements* – Part 2: Measurement of airborne sound insulation
- ISO 15186-1-2000: *Acoustics – Measurement of sound insulation in buildings and of building elements using sound intensity* – Part 1: Laboratory measurements

Transmission loss through small samples

- In accordance with ISO 10140-2:2010: *Acoustics – Laboratory measurement of sound insulation of building elements* – Part 2: Measurement of airborne sound insulation

Ceiling flanking noise (CFN)

- ASTM E1414-11a: Standard Test Method for Airborne Sound Attenuation between Rooms Sharing a Common Ceiling Plenum

Rain noise

- ISO 10140-5:2010/Amd.1:2014(E): *Acoustics – Laboratory measurement of sound insulation of building elements* – Part 5: Requirements for test facilities and equipment Amendment 1: Rainfall sound

In early January this year, a meeting was arranged to finalise the design of the Reverberation Room. At this meeting, Associate Professor John Davy from Australia visited Canterbury University to pass on his expertise. (John Davy has been involved with the design of facilities in Australia and is on the committee of ISO 354). At the meeting, a cuboid shaped chamber was decided on, as this form is becoming more popular in Europe and has benefits for construction and controlling room modes.

The room construction is of a unique design, consisting of double steel stud framing covered with multiple layers of plasterboard, plywood and a layer of aluminium. Although classed as a lightweight structure, it contains a total of 11 metric tons of plasterboard, 10,000 screws and 200 litres of adhesive.

JSK Consulting Engineers have taken on the running of the Testing Facility with the aim to provide an easily assessable, reliable facility to the New Zealand acoustics community. The facility is an ideal resource for ongoing improvement, product verification and for research and development. JSK are looking to get the testing facility IANZ accredited, which means the labs will be compliant with NZS ISO/IEC 17025:2005: *General Requirements for the Competence of Testing and Calibration Laboratories.* Watch this space.

Reverberation room design: Technical

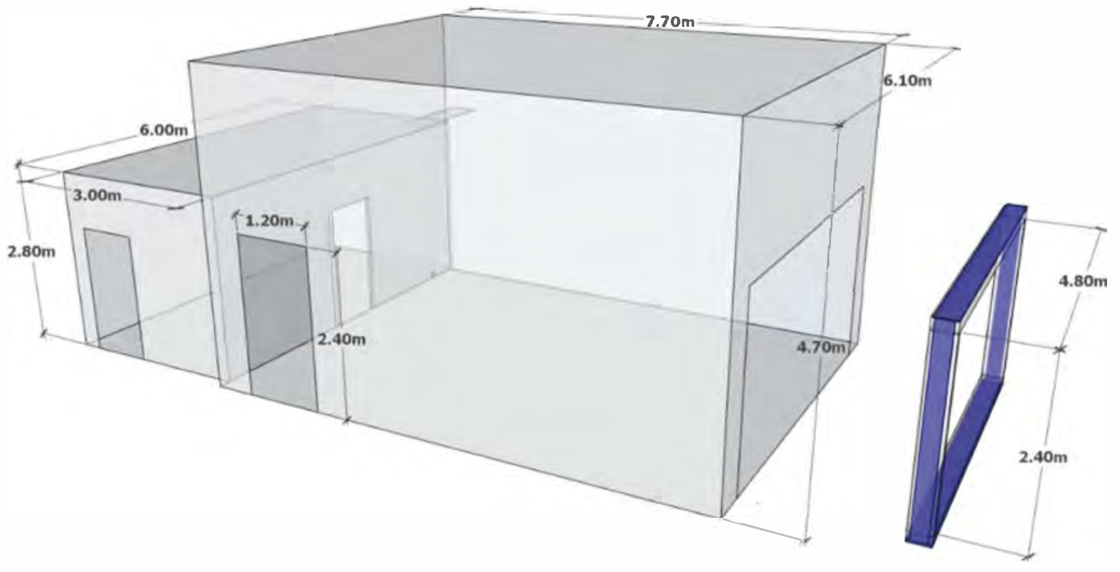
Overview

The reverberation room was designed with the ability to be multipurpose. While still meeting the requirements in AS ISO 354:2006 for absorption measurement, additions were made to facilitate transmission loss and rain noise. A double wall construction increased the transmission loss of the room, while a drop in collar allows test walls to be easily built and measured. Not included in ***Figure 1*** are the opening for rain noise measurement in the control room ceiling, and the door on the factory side of the reverberation room, which is only shown as regular size, but was built 2.4 m x 2.4 m.

Volume

The room volume is 221 m^3, chosen to exceed the minimum requirement of 200 m^3 for AS ISO 354:2006. While large rooms achieve better low frequency diffusion, high frequency performance suffers from high sound absorption through the air in large rooms. Exceeding the minimum volume by 20 m^3 allowed for some leeway in the future if additions were required.

Figure 1 – Facility Design



Shape

To meet AS ISO 354:2006 no two dimensions may be a ratio of small whole numbers, and satisfy the equation

$$l_{max} < 1.9V^{\frac{1}{3}}$$

Where l_{max} is the length of the longest straight line, in meters, which could fit inside the room, and V is the volume of the room in cubic meters.

The effect of this is to restrict the room from being too short in any one dimension.

To maximise the uniformity of the modal distribution, especially in low frequencies, attention must be paid to the specific dimensions chosen. Following a recommendation from ISO 354:1985 the ratio of room dimensions of $1:2^{1/3}:4^{1/3}$ was chosen.

Applying this ratio of dimensions to the desired volume resulted in the wall dimensions of 7.7m long, 6.1 wide, and 4.7m high.

Diffusion of the sound field

AS ISO 354:2006 requires a diffuse sound field so a uniform sound field will be incident on the test specimen. This is achieved using stationery and volume diffusers. Many reverberation rooms also incorporate non-parallel walls to vary the angle of reflected sound waves.

Wall angles

The requirement for walls at varied angles to each other was investigated using acoustic modelling. Two rooms were modelled, one rectangular room, and one with two walls offset by 5° from parallel, and the roof on a 3° slant. A small benefit was observed from in the uniformity of sound pressure level when angling the walls, however the simulations showed that without diffusers a cuboid room still performed well if the walls are highly reflective and the speakers radiate sound towards the corners of the room. The prevalence of diffusers throughout reverberation rooms of all designs globally show that diffusers will be necessary regardless of the shape of the room. A study performed by Hasan and Hodgson[1] found an improvement in low frequency sound pressure level (SPL) deviation with non-parallel walls, however not a significant enough difference to justify the added complexity. The relevance of the difference for sound absorption tests is limited, given that the minimum one-third octave band reported in ISO 354:2003 is 100 Hz, and the single number ratings NRC and α_w are calculated from a minimum frequency of 250 Hz. The sound pressure level deviations found in the study are displayed in ***Figure 2***.

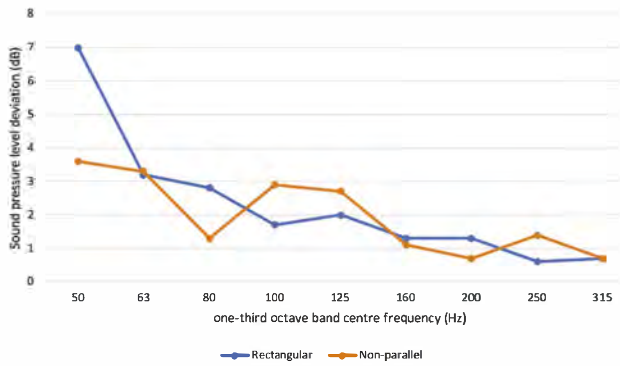


Figure 2 *– Spatial variation in sound pressure level between two 150 m³ reverberation rooms*

Consequently, the reverberation room was designed and constructed as a cuboid shape with parallel walls.

Diffusers

AS IS0 354:2003 recommends that diffusers should have low absorption, a mass per unit area of greater than 5kg/m², a surface area between 0.8 m² and 3 m² for a single side, and an area (both sides) 15-25% of the total surface area of the room for rectangular rooms.

The chamber has six stationary hanging diffusers made from galvanized sheet metal 1.2 m x 2.4 m x 0.95 mm thick, weighing 7.72 kg/m².

The diffusers are suspended in varied orientations to promote a diffuse sound field in accordance with AS ISO 354:2006.

[1]*Hasan, M. M., and Hodgson, M. (2016). Effectiveness of reverberation room design: Room size and shape and effect on measurement accuracy. Buenos Aires: International Congress on Acoustics.*

To check the diffuser area is sufficient in line with AS ISO 354:2006 a highly absorbant sample was set up in the room, and the sound absorption measured while adding diffusers. ***Figure 3*** shows the average absorption in high frequency one-third octave bands (500 Hz to 4000 Hz).

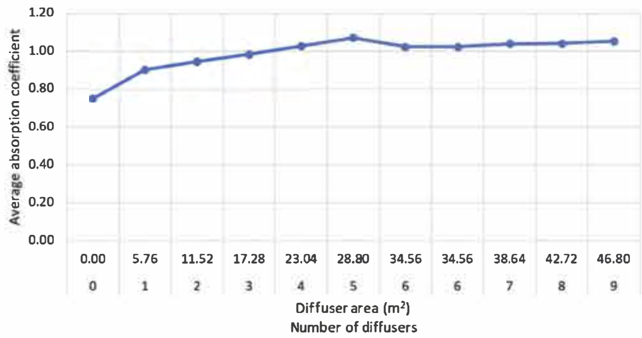


Figure 3 *– Diffuser area check*

From ***Figure 3*** it appears the diffuser area reaches a sufficient maximum with five hanging diffusers. However the absorption curves were still notably jagged. To address this problem the six metal diffusers were left hanging and other variations of diffusers were added.

- There is one floor mounted stationary diffuser 1.2 m x 1.8 m constructed from 0.55 steel stud and covered with 10 mm plaster board coated both sides with a reflective film.
- A polyhedron volume diffuser constructed from 2 mm dampened aluminium sheet, fixed centrally and offset to the ceiling of the chamber. The diffuser is 2.08 m at the base and 0.6 m high.
- Two adjacent corners of the chamber are blocked with melamine covered MDF volume diffuses in the form of an acute Isosceles triangle 0.75 m at the base and 1.1 m high.

With the addition of these changes the performance shows strong agreement with performance in the old University of Canterbury, and current University of Auckland reverberation rooms. A comparsion of measured performance is in ***Figure 4***. It is worth noting that the NRC valeus calculated from all three of these measurement are the same, and that globally a 20 % variation in performance has been noted between reverberation rooms. While the performance is suitable for measurements, JSK is committed to a plan of continued improvement to get the best possible performance from the lab.

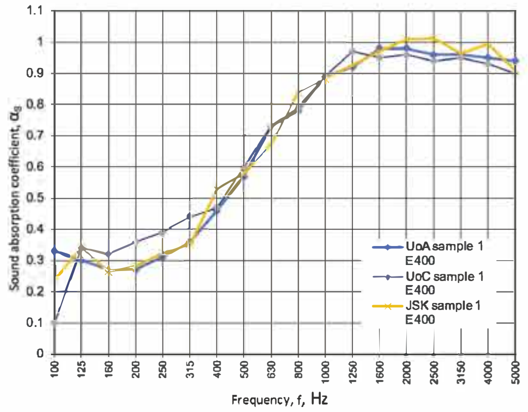


Figure 4 *– Measured absorption performance between labs*

Construction Details

In essence, the reverberation chamber is a room within a room, created using a double stud wall construction. High quality building work and careful detailing around the doors and the transmission loss testing collar was essential.

Floor

The existing concrete slab in the warehouse was cleaned and a new 75mm concrete slab poured on top of it. A full depth perimeter cut was made through the original floor slab to reduce structure borne vibration from environmental sources.

Walls

Solid concrete walls of up to 300 mm thick are commonly used for reverberation room construction. Due to several constraints and design considerations, a light weight framed wall construction was decided upon instead.

To facilitate transmission loss measurement of wall constructions with an STC up to 55, the reverberation room walls required a minimum STC of 65, while also being highly acoustically reflective to obtain the required surface absorption to meet AS ISO 354:2003.

As a preliminary design concept, a wall construction was chosen from the NRC testing programme March 19983, the wall (TI-93-320) [2] had an STC of 65. This basic construction showed a double wall with two layers of 13 mm plasterboard outside each stud and insulation inside. Additional layers were added to meet the needs for the test room. A 2mm aluminium sheet layer is glued to the inside of the wall to increase the surface density for increased reverberation. Plywood was also added both next to the inside stud, to stiffen the wall, and on the exterior to protect the plasterboard from hazards in the factory. The full wall and slab construction is displayed in ***Figure 5***.

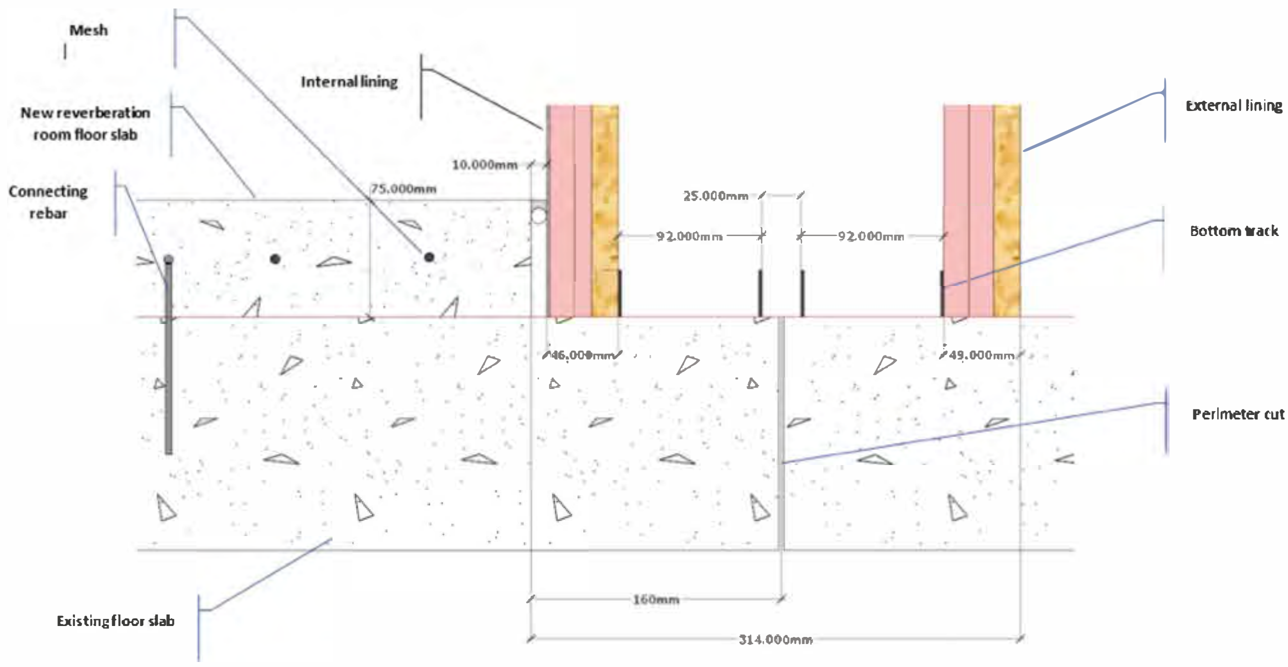


Figure 5 – *Wall cross-section*

Roof/Ceiling

The roof/ceiling construction matches the wall construction, with some minor design changes as required for horizontal loadings. The only obvious difference is the 2mm aluminium which was left off in place of railings for attaching t-nuts and eye-bolts into to suspend diffusers.

Transmission Loss Testing Collar

Transmission loss testing provided a challenge. How to build a room with a STC over 65, while being able to remove and replace a significantly large section of wall with ease? The solution found for this was the testing collar and transmission loss plug. The collar is a 250 x 75 x 8 mm parallel flange channel filled with concrete. Into this collar, transmission loss test-walls can be built and measured.

A way to plug the gap -that does not harm the absorption performance of the room- is required when the opening is not in use. For this, a double layer of aerated concrete panels backed with plywood is inserted. To further increase reverberation in the room 3 mm steel plate was glued and screwed to the interior side of the plug.

Control room

The purpose of the control room developed greatly during the design process. From a storage room for equipment and place to stand, it developed into an integral part of the facility. The space is now suitable for facilitating rainfall measurement and small opening transmission loss. The room is 6.1 m long, 3 m wide, and 2.8 m high, for a volume of 51 m3. It is constructed with the same interlocking metal panels filled with aerated concrete as the plug for the transmission loss opening. The inside of the room is lined with polyester sound absorption panels to decreases reverberant sound when it is being used for sound intensity measurements. A pleasant side-effect of the lower reverberation time is the increase in speech clarity and decrease in background noise level, making the room more pleasant to work and converse in.

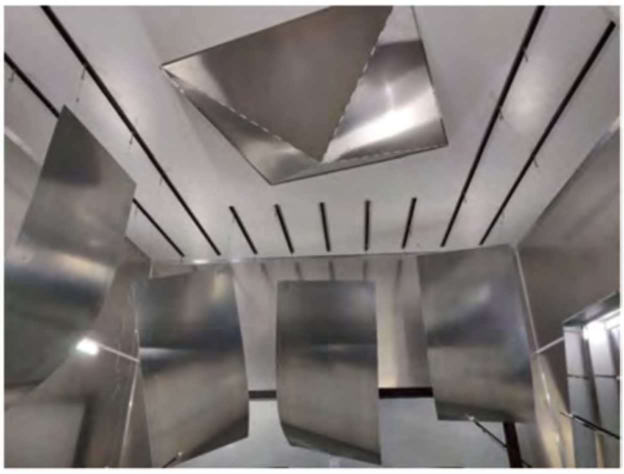


Figure 6 – *Reverberation room interior*

Figure 7 – *Transmission loss opening with collar and plug*

[2] *National Research Council Canada. Gypsum Board Walls: Transmission Loss Data Halliwell, R.E.; Nightingale, T.R.T.; Warnock, A.C.C.; J.A; Internal Report IRC-IR-761 March 1998*

Figure 8 – *Control room with access through doorways to the reverberation room (left) and factory (right)*

Figure 9 – *Control room drop in ceiling being installed*

For measuring rain noise the control room ceiling has a drop in ceiling to fit a rain noise test roof in line with ISO 10140-5:2010/Amd.1:2014(E). The installation of the drop in ceiling is in ***Figure 9***. Being able to remove the ceiling will make the testing process much easier.

Ready for Testing

After months of commissioning, the facility is now able to accept commercial and research projects. A range of products have already been tested for a number of clients. Members of the Acoustical Society are encouraged to come and check it out and to see the facility first hand. Please contact JSK to organise a visit.

How sound is your acoustics knowledge?

1. In a sentence or two describe the difference between the accuracy and precision of a sound measurement?

2. What is an audiometer?

3. Define ‘Agglomeration’

4. **True or False?**
‘ISO’ is the International Organization of Standards

5. What is coulomb damping?

6. What is meant by the term ‘colouration’?

7. **True or False?**
The Sound Exposure Level (SEL) may also be written as L_{AE} ?

8. Define the term 'Jerk

9. 'Mel' is a unit of what?

10. What is the definition of the ‘round window’ in regards to hearing?

(answers on pg.40)

2019/20 Upcoming Events

30 November - 06 December 2019

San Diego, California

178th Meeting of the Acoustical Society of America

(date TBC) November 2020

Wellington, New Zealand

ASNZ bi-annual conference

17 - 19 February 2020

Napoli, Italy

Structural Dynamics and Vibroacoustics

3 - 6 May 2020

Oslo, Norway

Baltic-Nordic Acoustics Meeting

Quiz Answers

1. The accuracy of a reading is the degree to which it might be different from some notional 'true' value while the precisions of a measurement is an indication of the smallest change in the measured quality.

2. An audiometer is an instrument that measures human hearing sensitivity.

3. Agglomeration is an area having a population in excess of 100,000 persons and a population density equal to or greater than 500 people per square km.

4. False. ISO is the International Organization of Standardization not Standards?

5. Coulomb damping is a form of damping in which the damping force is constant and independent of a particular frequency.

6. Colouration is some change to a sound from the original version detectable to a listener.

7. True the Sound Exposure Level may be written as L_{AE}.

8. Jerk is the rate of change of acceleration.

9. Mel is a unit of pitch.

10. The round window is a diaphragm or membrane at the end of the cochlea which connects with the middle ear.