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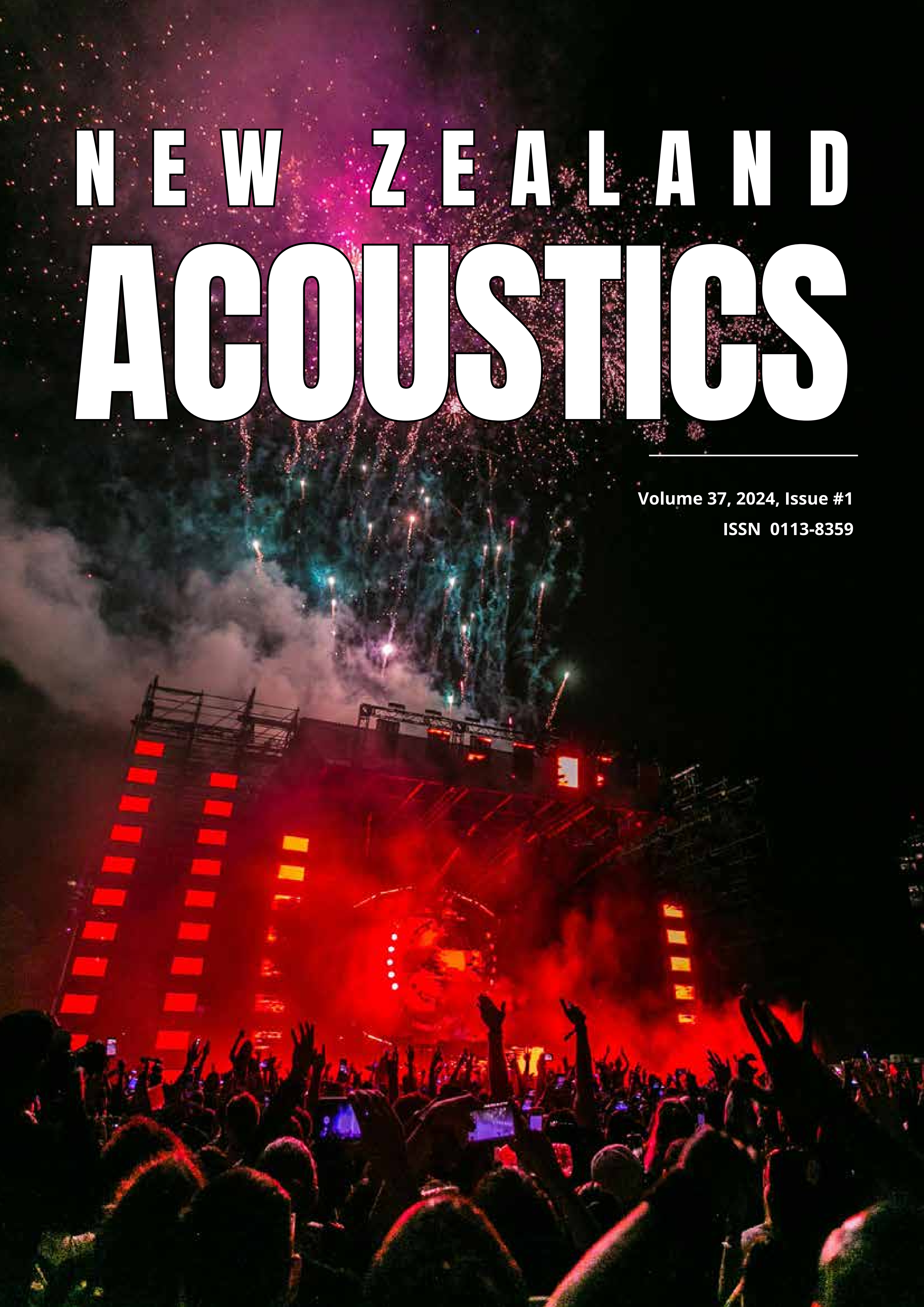

The Acoustical Society of New Zealand

ACOUSTICS 2024

THE ACOUSTICAL SOCIETY OF NEW ZEALAND CONFERENCE

Acoustics: Reflecting on the past, innovating for the future

Ōtautahi Christchurch | 2-4 September

www.acousticsnz2024.co.nz

The Acoustical Society of New Zealand (ASNZ) will hold the Acoustics 2024 Conference within the heritage-listed Christchurch Town Hall of Ōtautahi Christchurch New Zealand, from the 2–4 September 2024. We invite you to come and reflect on the past in this beautifully restored and refurbished venue, nestled on the banks of the Avon River in the Central City.

Acoustics 2024 will provide engineers, scientists and professionals in all fields of acoustics the chance to exchange views, the latest research and share experiences with colleagues. This location holds significance to our Society, as we continue to enjoy the acoustic design and associated research advances of lateral reflected sound in concert halls, as completed by ASNZ Fellow Sir Harold Marshall in the late 1960's. Be inspired by venue acoustics, integrated technology, iconic architectural features and riverside views. We look forward to guest keynote speakers, sharing a full and interesting programme covering a wide range of topics, along with excellent social functions, and networking opportunities. There will also be a unique opportunity for manufacturers and suppliers to showcase the latest developments in acoustic instrumentation, software, and noise and vibration control products. All of these opportunities are aptly reflected in our conference theme for 2024, *Acoustics: Reflecting on the past, innovating for the future.*

Christchurch is the gateway to the stunning South Island and is easily accessible by international and domestic flights into Christchurch airport, which is only a short 15 min drive to the CBD and venue. Known as the Garden City of New Zealand, Christchurch boasts over 700 parks and gardens, along with 80 kilometres of city walking tracks. As you explore the central city you will discover amazing street art, innovative projects, and state-of-the-art architecture nestled between restored historic buildings. Enjoy the farmers market, go punting down the Avon River, take a tour on the City Tram loop, or have a picnic in Hagley Park. From Christchurch you can explore mountains and the ocean all in one day – and there is something for everyone. Go walking in the Port Hills and take in the breathtaking scenery of the Canterbury Plains and Southern Alps, take a ride up the Gondola, go zip-lining or bike-riding at the Adventure Park, head to the exquisite wine country of North Canterbury, or have a dip in the hot pools at New Brighton pier.

The Acoustical Society of New Zealand Council, and Acoustics 2024 Organising Committee looks forward to welcoming you to Ōtautahi Christchurch next year. We hope that the conference gives you an opportunity to strengthen your existing networks and that you leave with great memories, fresh ideas, and new friendships.

Keep up to date with the latest conference information by visiting: www.acousticsnz2024.co.nz, with Registration and Abstract Submissions opening in early 2024.

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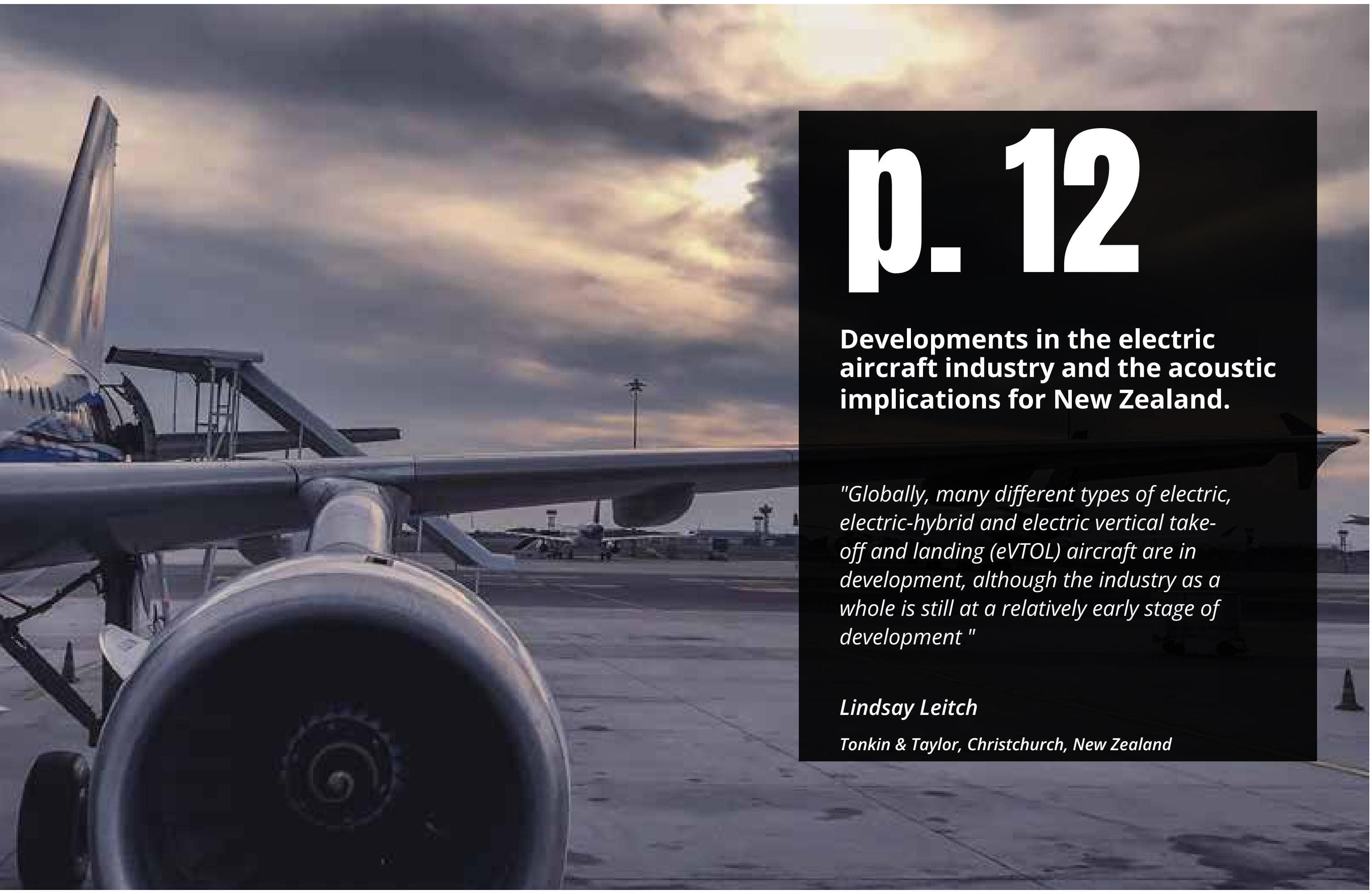
How carpet can reduce the apparent sound transmission class of walls

"Analysis of recent on-site ASTC measurements showed a reduction of 9 points when carpet and underlay were added to both the source and receiving room."

Brendon Shanks

Marshall Day Acoustics, Auckland, New Zealand.



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Developments in the electric aircraft industry and the acoustic implications for New Zealand.

"Globally, many different types of electric, electric-hybrid and electric vertical take-off and landing (eVTOL) aircraft are in development, although the industry as a whole is still at a relatively early stage of development "

Lindsay Leitch

Tonkin & Taylor, Christchurch, New Zealand

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Development of a dual-beam shotgun microphone for use on unmanned aerial vehicles

"A lightweight microphone array has been developed for use on unmanned aerial vehicles (UAVs). The microphone array uses 80 MEMs microphones configured in a line array."

Mark Poletti [1], Shaun Pentecost [2], Sudhir Singh [1], Eberhard Deuss [1] and Hin Loh [2]

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Kia ora koutou,

I hope 2024 is finding you well so far, and you're managing to avoid those gloomy thoughts of the recession which has officially been announced. At least the ASNZ is continuing on, stronger than ever, with our highest ever membership base, social media engagement, number of lunch bunch events and social activities, etc. We have a great Council of people who are happy to get stuck in and really keep the momentum going!

Organisation of the upcoming ASNZ conference in Christchurch is well underway and abstracts should all be submitted by now. This is going to be a truly exceptional event, hosted at the Christchurch Town hall – a venue of global significance to acoustic designers, putting into practice Sir Harold Marshall's concepts for spaciousness by providing early lateral reflections from the stage to the audience. We hope to see you all in Christchurch in September.

A new guideline for interpreting the NZBC acoustic clause G6 has been released by the Association of Australasian Acoustical Consultants' (AAAC). This document, prepared by several ASNZ members from different firms (including yours truly), is for anyone considering the acoustics of multi-residential projects and clarifies those ambiguous parts of G6 for consistent application. It also offers recommendations for sound insulation criteria where G6 is silent (or rather, noisy, as the case may be).

The ASNZ Council will be meeting in person in May to discuss important directions for the ASNZ over the next year. Items on the agenda will include an updated website, student prizes, social media outreach, preparations for the upcoming AGM, changes to the Incorporated Societies Act, and many other thrilling topics.

Immediately following this in-person meeting, a Fellowship award event will be held in Wellington to recognise and celebrate the outstanding contributions of two of our ASNZ Members, and we look forward to a great turnout from the local acoustical fraternity. More details on this event to follow, so please check your emails.

Ngā mihi,

Tim Beresford

President of the Acoustical Society of New Zealand

Kia ora koutou,

Welcome to 2024. We hope you all have had a well-deserved break and holiday; we certainly have. The warm weather finally arrived so those of us living in cooler climates could finally defrost after a cold and wet Winter and Spring. Summer is always a fantastic time of year to get out and enjoy what our great country has to offer, especially the great outdoors. This is the first issue of New Zealand Acoustics for 2024 and we have all the regulars, including news items, quiz and a host of fantastic papers for you to read.

This year we have upcoming New Zealand Acoustic Conference in Ōtautahi Christchurch, which if you can attend, we would encourage you to come along. The more support and networking among our wide range of members and acoustic community the better. All are welcome! You may even want to consider presenting a paper.

Lindsay Hannah & Wyatt Page

Principal Editors

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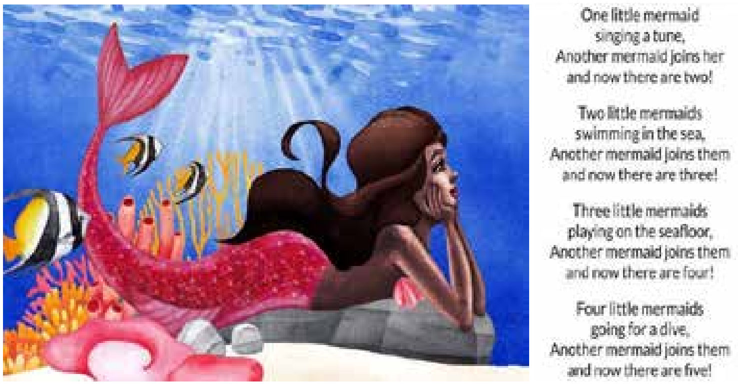
NEWS



How would a mermaid sound underwater?

Article: https://www.snexplores.org/article/mermaid-underwater-sound

Lyrics: https://theflannellibrarian.wordpress.com/

Auckland Zoo alligators curious about their new neighbours - a bunch of noisy parrots

At low speeds (below 30 km/h) they are so much quieter that to reduce the risk of accidents for pedestrians the EU has introduced a regula on for electric vehicles, imposing a minimum of 56 decibels at low speeds

https://ourauckland.aucklandcouncil.govt.nz/news/2023/02/auckland-zoo-alligators-curious-about-their-new-neighbours/htps://www.youtube.com/watch?v=tRc1A-Zf_DE

Heat pumps 'too noisy' for millions of British homes, Government told

https://www.dailymail.co.uk/news/article-12742513/Noise-experts-tell-Government-cool-heat-pumps-new-study-suggests-loud-millions-homes-throwing-net-zero-target-plans-disarray.html

How the Brain Decodes Speech in Noisy Rooms

Vinay Raghavan, the lead author of the study, says, "When listening to someone in a noisy place, your brain recovers what you missed when the background noise is too loud. Your brain can also catch bits of speech you aren't focused on, but only when the person you're listening to is quiet

https://neurosciencenews.com/speech-decoding-noise-23407/

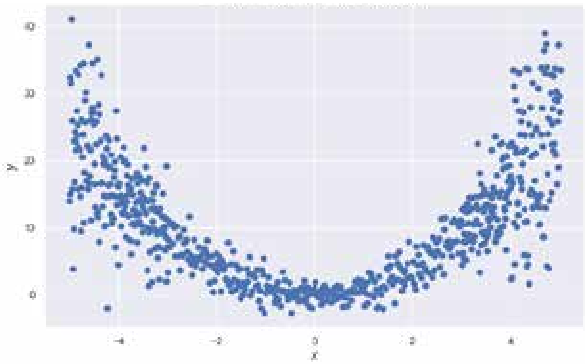
Noisy Bella claims loudest purr record (for living cat)

The feline controversy for loudest purring cat saga continues! The Guineness World Records has now formally registered a purr that measured 54.59 (!) decibels from Bella the Cat who is now recorded as the loudest purr by a living cat. Keep up to date with the saga and find out more by visiting

https://www.guinnessworldrecords.com/news/2023/10/my-cat-purrs-louder-than-the-tv-noisy-bellaclaims-loudest-purr-record-759482

What Are Those Noises After Take-Off?

https://www.youtube.com/watch?v=rSwrIzpCkTw&list=WL&index=25



Noisy Data May Help Us Unlock The Secrets of High-Energy Particles

Researchers have recently discovered that usually-annoying "air showers" may actually contain a wealth of information on the particles that cause them.

Window goes up window goes down

Tesla laminated glass substantially reduces exterior noise at the most sensitive frequency range

https://www.youtube.com/shorts/uytr9u2PI_M

Are Kids to Blame for China's Noisy Trains?

https://www.sixthtone.com/news/1013750

Oceans will be 5 times louder by 2100!

A study reveals the underwater world is becoming increasingly noisy due to the effects of climate change, which is impacting marine life. "In some places, by the end of this century, the sound of ships, for example, will be five times as loud," says study first author Luca Possenti, oceanographer at the Royal Netherlands Institute for Sea Research

https://studyfinds.org/ocean-noise-climate-change/

Resident calls for more action over 'noisy, intimidating, scary' street racers

Stuff have reported A Palmerston North resident wants more action to be taken to prevent illegal street racing after a large meeting blocked off a suburban part of the city.

https://www.stuff.co.nz/national/300985477/resident-calls-for-more-action-over-noisy-intimidatingscary-street-racers


LISTEN UP!
See the Jepsen Permanent Noise Logger at www.noiseandweather.co.nz
Contact us:
0274 428 094
njepsen@gmail.com

Developments in the electric aircraft industry and the acoustic implications for New Zealand

Lindsay Leitch

[1] Tonkin & Taylor Ltd, Christchurch, New Zealand

Abstract

Benefits of electric aircraft include the potential to reduce noise emissions as well as fuel emissions. Globally, many different types of electric, electric-hybrid and electric vertical take-off and landing (eVTOL) aircraft are in development, although the industry as a whole is still at a relatively early stage of development. In New Zealand, recent developments include the importation in 2020 of the first recently certified 2-seater Pipistrel Alpha Electro all-electric aircraft by ElectricAir; the announcement by Sounds Air of the proposed introduction of 19-seater all-electric Heart Aerospace aircraft to its commercial fleet in 2026; and the development by Wisk of its eVTOL with trial passenger flights planned in Canterbury.

This paper will look at the current developments in the electric aircraft industry as well as the potential uptake of electric aircraft in New Zealand. It will investigate what information there is currently available around noise levels from electric aircraft, how these compare to conventional aircraft and what implications this may have.

Introduction

Global drivers for aviation to reduce fossil fuel emissions have resulted in many developments in the electric aircraft industry; however, the industry is still very much in its infancy. Small all-electric aircraft are currently viable and are starting to be certified by aviation regulators such as the Civil Aviation Authority in New Zealand, but the current state of battery technology limits the ability of larger aircraft to become all-electric. Innovative designs are in the pipeline, from hybrid aircraft to electric vertical take-off and landing (eVTOL) aircraft.

Following the importation of the first electric plane into New Zealand last year, this paper looks at the current state of development of the electric aviation industry globally, as well as developments in New Zealand. Available in-formation on noise levels from electric aircraft is discussed, together with the potential benefits of lower noise levels from electric aircraft in specific circumstances.

Drivers for Electric Aircraft

The electric aircraft industry is currently in a fledgling stage, but as technologies develop and battery costs come down, the market share of the global aviation industry is anticipated to expand rapidly over the next 10-20 years as viable aircraft enter the market (Hanano 2021).

It is becoming increasingly urgent that globally we must reduce fossil fuel emissions. The aviation industry as a whole is responsible for 2-3 % of global emissions, and has a huge investment in significantly reducing emissions, fuel consumption and noise for its petroleum (kerosene) powered world fleet. As other industries such as trans-portation electrify, and the demand for airliner passenger capacity increases, emissions from aviation in its current form are likely to contribute a larger share – estimates range from 10 % of global emissions by 2050, up to 24 % if other sectors significantly reduce their emissions (Hanano 2021). The International Civil Aviation Organisation (ICAO) is calling for a cap on the emissions of the aviation industry, therefore if the industry is to expand, it will need to dramatically reduce its emissions. Electrification of at least part of the industry is one way in which emis-sions can be cut.

A similar driver exists for noise levels. Noise is currently a significant constraint on flight numbers around large airports such as London Heathrow, particularly for night flights. If numbers of air passengers are to double, as is predicted by 2035 from 2016 numbers (IATA 2016), and noise levels around airports are to decrease by 50 % or more (a stated aim of the EU Flight Path 2050 is for perceived noise emissions to reduce by 65 % (European Commission 2011)), then the noise produced by individual aircraft will need to decrease at least four-fold on average. It may well be that reduced noise levels from electric aircraft will be seen as a considerable advantage of the developing technology.

There is very little legislation at this stage to encourage electrification of aircraft due to the relative newness of the industry, with Norway leading the field: the country's airport operator announced in 2018 that all short haul flights are required to be electric by 2040 (The Guardian 2018).

Barriers to Development

The process of development and certification of an aircraft is long, expensive and onerous. It can take up to a decade for an aircraft design to progress from the drawing board and through the certification process, with the costs of eventual certification for a small commercial aircraft in the order of $100 million (Siemens 2021). Zunum, which was developing a prototype 6-12 seater hybrid electric airliner, was forced to shut down in 2018 before bringing a viable product to market due to lack of funds (Wikipedia 2020). In addition, there will need to be new rules and regulations developed for new technologies, which take time to develop, often lagging behind the pace of technology development, but essential from a safety perspective prior to commercial flights. Developments in air traffic controls will also be required for some types of flights. Aviation noise certification limits decrease as technology allows and this decrease tends to occurs over many years due to the slow implementation of the certification process.

The main limitation of current battery technology is the battery power to weight ratio. Compared to aviation fuel, which has an energy density of 12,500 Wh/kg, a lithium-ion battery has a mere 160 Wh/kg. Electric motors are typically around 90 % efficient compared with around 25 % efficiency for a petrol engine which offsets some of this difference. However, it remains the case (at least with current technology) that larger aircraft requiring more power simply do not have the space to accommodate the batteries that would be required for a reasonable range and consequently are unable to convert to fully electric. Overheating of batteries has also been problematic with the use of higher voltages, prompting an increased requirement for heat dissipation. Developments in battery technology will be needed for all-electric medium to large-scale aircraft to become viable.

All-Electric Light Aircraft

All-electric light aircraft appear to be the most viable type of electric aircraft at the current time. In Vancouver, an existing float plane was converted to electric with a trial flight in 2019 (Cogley, 2021), to become the first commercial electric aircraft. The purpose-built two-seater Velis Electro, manufactured by Pipistrel in Slovenia, was the first to be type certified in 2020. Its sister plane, the Alpha Electro, has airworthiness certification (specific to the individual aircraft). Both these aircraft have a flight time of around one hour (90 minutes total, with 30 minutes in reserve), cost only a few dollars to charge the batteries for a flight, and anecdotally are significantly quieter than their conventional counterparts.

Larger all-electric aircraft are following as battery technology develops. Heart Aerospace are developing a 19-seater electric aircraft due to come into service in 2026 (Heart Aerospace, 2021). A still larger all-electric plane is under development by Wright Electric in partnership with EasyJet. The 186-seater aircraft is planned to enter into service in 2030, with flight testing planned by 2023. It is envisaged that batteries for the aircraft will be swappable to enable a faster turnaround time at airports (Wright Electric 2021).

Hybrid Aircraft

Hybrid aircraft, where an existing aircraft with a conventional combustion engine is supplemented with an electric motor, are currently the most viable option for medium-sized aircraft. They are also likely to be easier to certify, as dual systems can provide reassurance over the safety of the aircraft. Partial electrification results in a more efficient running of the engine with lower emissions, in much the same way a Prius hybrid car works. This can be as simple as electrifying more of the non-flight systems such as cabin pressurisation and replacing hydraulic flight controls systems. There are examples of current and emerging aircraft designs where virtually all systems (including hydraulic and pneumatic) are electric driven from enlarged engine generators, such as the Boeing 787 Dreamliner (Wikipedia, 2021).

Ampaire has modified a Cessna 337 Skymaster by replacing the forward engine with an electric motor to produce the Electric EEL hybrid aircraft. This aircraft currently holds the record for the longest flight by an electric aircraft at 341 miles (549 km).

eVTOL

eVTOL aircraft are small electric aircraft which can take-off and land vertically, with some designs able to transition to forward flight which increases the range available. There are a lot of innovative eVTOL prototypes, typically with several small rotors somewhat resembling large drones. They can be unmanned, or capable of carrying up to four people. This type of aircraft is likely to provide intra-city transport, replacing taxis and public or private vehicles over relatively short distances.

There are many different designs currently under development by companies such Joby, Beta and Lilium. The Japanese company SkyDrive is developing a single seater drone-style flying car with the aim of bringing it to market in 2023. The company staged a test flight of the prototype aircraft in August 2020.

Developments will also be needed in the air traffic control systems to manage eVTOLs, but regardless of this Morgan Stanley Research predicts that the electric vertical takeoff and landing market, which includes flying cars, cargo and delivery drones, will be worth US$1.5 trillion by 2040 (Morgan Stanley Research, 2019).

Noise Levels from Electric Aircraft

In an electric aircraft, there is no noise from the exhaust, and the motor is significantly quieter than for a conventional aircraft, although there will still be noise from the propeller.

The certification data for the Alpha Electro includes a single value noise level of EPNL 60.0 dB, from measure-ments under the flight path during take-off. The equivalent value for the same aircraft with a conventional engine is EPNL 70.0 dB, giving an indication of the reduction in noise level during take-off (European Union Aviation Safety Agency, 2021).

Siemens has performed some detailed measurements of small electric aircraft in direct comparison with the equiv-alent conventional aircraft (Siemens 2017). Measurements were taken of an Extra 330LT (with conventional en-gine) during take-off, a flyover at 50 ft and a flyover at 1,000 ft, then these measurements repeated for an Extra 330LE (electric propulsion). The results are notable: not only is the electric aircraft significantly quieter but the noise is also subjectively far less distinctive.

Anecdotally, the sound in the cockpit of a small electric aircraft is low enough that conversation is possible without headsets, and is far smoother with fewer vibrations. At times, a flyover at 1000 ft is not noticeable from the ground.

As long as conventional engines remain the main propulsion for hybrid aircraft, there is unlikely to be any reduction in noise emissions. Even when hybrid aircraft incorporate electric propulsion, the power required for take-off is likely to require an internal combustion engine, meaning noise levels during take-off at least are unlikely to reduce. Once the aircraft is cruising and using less power, electric power should give lower noise levels.

EVTOLs typically have several small rotors, and noise is primarily related to the tip-speed of the rotors. If tilt rotors transition to provide forward thrust, the plane of the noise source will also change.

An article on the SkyDrive eVTOL test flight (Sturmer, 2020) commented that the noise was like the "noisy whirr of 100 beehives". The CEO freely admitted that they need to work on the aerodynamics of the propellors in order to reduce noise levels, as this type of aircraft is likely to need to be virtually silent to be acceptable for residents of cities where this mode of transport is implemented.

There appears to be recognition in the eVTOL industry that in order for a fleet of eVTOLs to be acceptable, noise levels must be low enough to be unobtrusive in the urban environment. Uber has a goal of achieving a noise level of 67 dB at ground level from an eVTOL aircraft at 250 ft (76 m) (Uber Elevate, 2016), which is comparable to a land vehicle passing by at low speed.

Electric Aircraft in New Zealand

The New Zealand company ElectricAir was set up in 2020 in order to promote electric aircraft in New Zealand. It imported a Pipistrel Alpha Electro last year, and is currently running trial flights out of Christchurch and Rangiora airports. The company promotes the Alpha Electro as ideally positioned to provide aircraft training flights which are typically less than an hour, with the potential to replace around 90 % of these flights (ElectricAir 2021).

Small, all-electric aircraft have potential in New Zealand for training flights and private ownership. This has benefits for the flight school or aircraft owner of reduced running costs (although potentially a higher purchase cost per aircraft, at least in the short term), but while there is no incentive to reduce emissions or noise levels these benefits are likely to be secondary considerations for many.

It is possible that small airfields near residential areas may see the benefits of reduced noise levels due to elec-trification of the fleet. There may also be benefits due to reduced noise levels in specific circumstances such as aircraft in conservation areas where noise can be a particular concern.

Domestic New Zealand flights are all short-haul (less than three hours), and many are classed as regional (less than 500 km) which is likely to be the 'sweet spot' of electric aircraft, with potential for electrification in the medium term once technology has advanced such that sufficient passengers can be carried efficiently. Sounds Air, in the Cook Strait region, looks likely to become the first regional airline to electrify part of its fleet. As most of the flights operated by Sounds Air are less than 100 km, this is the ideal 'entry level' for electrification of commercial flights. The company announced in 2020 (Sounds Air, 2021) that it intends to purchase electric aircraft from the Swedish company Heart Aerospace, which is developing a new 19-seater all-electric aircraft anticipated to be in service in 2026.

Air New Zealand was contacted about their position on converting to electric aircraft and in response sent their Sustainability Report for 2020 (Air New Zealand, 2020) which contains the following quote from CEO Greg Foran:

New Zealand's high mix of renewable energy, reliance on aviation for domestic connectivity, and high pro-portion of relatively short distance regional flights also mean it is uniquely placed to be an early adopter of next generation aircraft (electric, hybrid and/or hydrogen). Air New Zealand is working with several aviation equipment manufacturers to accelerate development and deployment of future aircraft and engine technol-ogy. Establishing New Zealand as a hub for aircraft innovation and an attractive location for the trialling of future aircraft technologies will accelerate the commercialisation of next generation aircraft while also providing employment and regional development benefits.

This seems to be a positive indicator of the potential uptake of electric aircraft in New Zealand, albeit with no clear timescales at the current time.

The Californian company Wisk is developing an eVTOL which transitions to forward flight, backed by The Boeing Company and Kitty Hawk Corporation. It expanded into New Zealand in 2017, and in 2020 announced that it had signed a Memorandum of Understanding with the New Zealand government that it will run a trial passenger ser-vice in Canterbury as part of the Airspace Integration Trials programme run by the Ministry of Transport (MBIE, 2021).

Also involved in the Airspace Integration Trials are Kea Aerospace (Kea Aerospace, 2021), developing a solar-powered aerial imaging aircraft that will fly in the stratosphere, and Envico Technologies (Envico Technologies, 2021) pioneering specialist drones for conservation and biosecurity.

MBIE envisages that unmanned aircraft applications in New Zealand are likely to include hazard management and monitoring, agriculture, passenger transportation and cargo delivery.

Conclusions

The electric aircraft industry is still relatively young, with only the first few aircraft beginning to reach certification stage. Many different types of aircraft under development, with larger all-electric aircraft becoming more viable as battery technology improves.

In New Zealand there have been several developments in the past couple of years. Electric Air has imported the first small electric aircraft and is promoting it to flight schools and private pilots; Sounds Air has signalled its intent to purchase 19-seater electric aircraft from Heart Aerospace for commercial flights in 2026; and Wisk will be operating a trial passenger service on its eVTOL in Canterbury in conjunction with MBIE's Airspace Integration Trials programme.

Future potential in New Zealand for electric aircraft is likely to be for flight training schools and private ownership for small aircraft in the short term, and regional airlines with routes from 100 to 500 km in the short to medium term. EVTOLs may be used for regular passenger flights, starting with Wisk operating a trial service in Canterbury. MBIE envisages other uses for unmanned aircraft including eVTOLs will include hazard management and monitoring, agriculture, passenger transportation and cargo delivery.

Evidence is emerging of lower noise levels for electric aircraft compared to conventional aircraft, with the difference in the order of 10 dB between the electric Pipistrel Alpha Electro and the equivalent conventional aircraft.

The potential benefit of lower noise levels from electric aircraft may be seen in areas around flight schools which have electrified their fleet, as well as in reduced noise levels from flights over conservation area. EVTOL manufacturers appear to be well aware that in order for the technology to be widely accepted by the public, noise levels will need to be subjectively unobtrusive.

Acknowledgements

Thanks to Gary Freedman of ElectricAir for his insights into the Alpha Electro and the electric aircraft industry in general.

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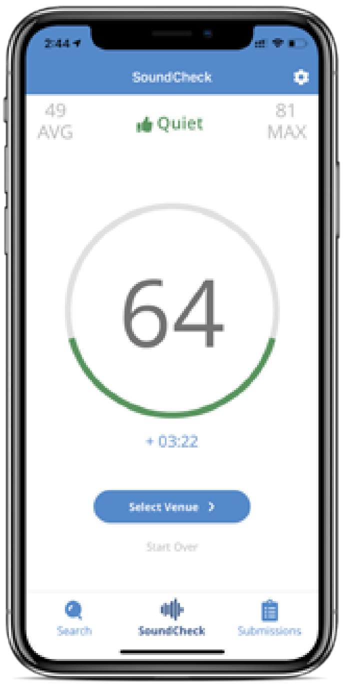

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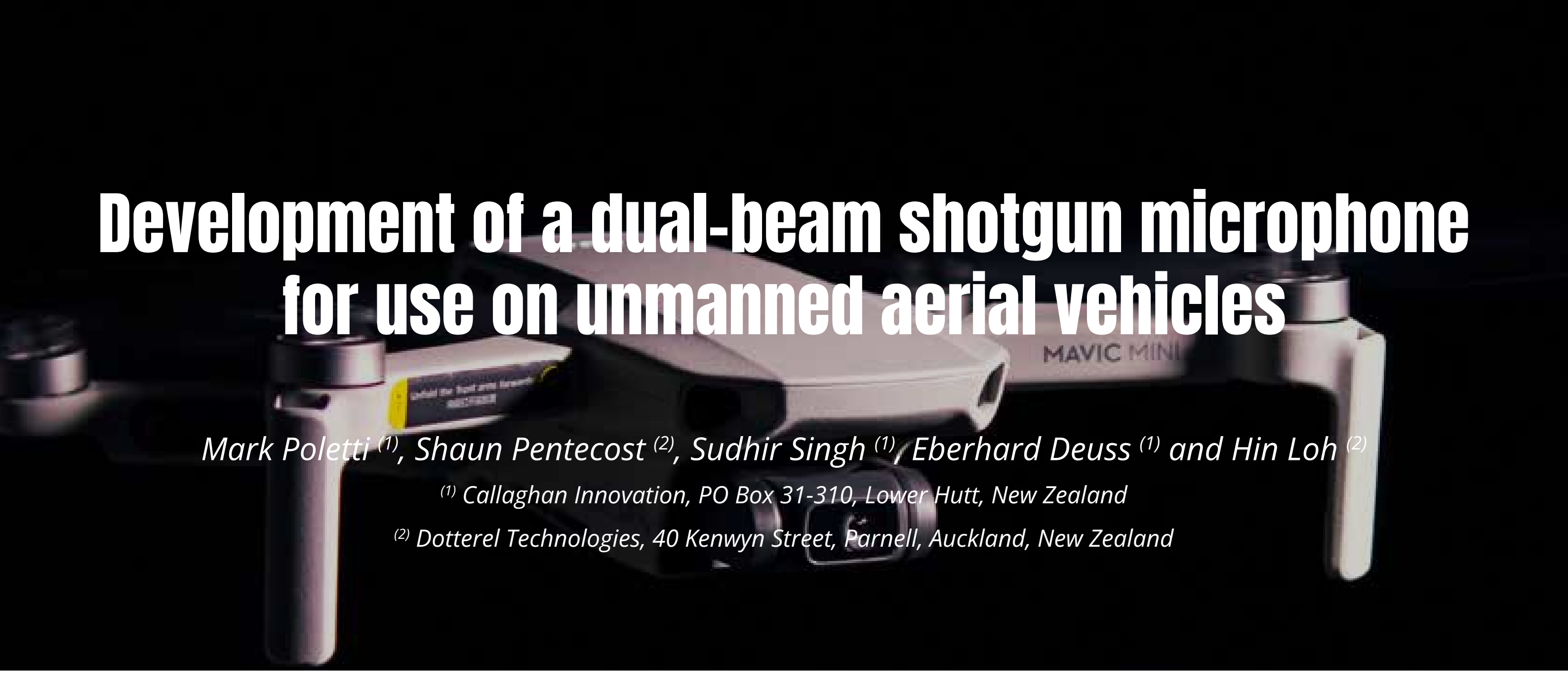

Development of a dual-beam shotgun microphone for use on unmanned aerial vehicles

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Abstract

A lightweight microphone array has been developed for use on unmanned aerial vehicles (UAVs). The microphone array uses 80 MEMs microphones configured in a line array. The microphones have digital outputs which are routed to a processor and combined to provide a highly directional "end-fire" response that detects sound from a desired target while reducing the noise from the UAV rotors. The processor also produces a second beam which points a null at the desired target. This beam detects all noise other than the intended target and is used in a post-processor to further reduce the noise in the primary beam, providing an audio output that is essentially noise-free. The array can be combined with a loudspeaker for two-way communication with a desired target. The array has a number of UAV applications and can also be used in standalone applications. The number of microphones can be increased to provide higher directivity and constant directivity beams can be produced over a wide frequency range. The principle of the microphone array and the design process is discussed, and the measured directional performance is presented.

1. Introduction

Unmanned aerial vehicles are finding increasing application in a variety of defence and civilian markets (Kislick, Dronova, and Kelly 2018; Torresan et al. 2017; Nonami 2007; Li et al. 2010; Montambault et al. 2010) . However, they also have a number of associated risks and their use is subject to civil aviation rules ("Remotely Piloted Aircraft Systems (RPAS) under 25 Kilograms – Operating in Compliance with Part 101 Rules" 2015). One of the most obvious issues with UAVs is the noise levels they produce. This causes annoyance to the public, and methods for reducing generated noise are therefore relevant (McKay and Kingan 2018),(Hioka et al. 2019).

Rotor noise also makes it difficult for UAVs to be used in any application where sound must be detected. Microphone arrays are capable of rejecting unwanted noise (Benesty, Chen, and Huang 2008). However, such arrays can be complex and must be adaptive if they are to reject sound from a moving source. An alternative approach is to mount a microphone on a UAV, where the geometry is fixed. The noise levels are high, but if the microphone is mounted in the plane of the rotors and is highly directional, it can reduce the effects of rotor noise significantly (Hioka et al. 2019).

Noise cancellation techniques can be used to further reduce rotor noise, producing useable sound recording. Many of these approaches use two microphones; one of which detects primarily the desired sound source and the other of which detects primarily the unwanted interference. Various forms of processing may then be applied to the two microphone signals to reduce the amount of unwanted sound in the desired source microphone output. Methods for achieving this include the Wiener filter (Therrien 1992), adaptive filters (Widrow and Stearns 1985) and blind source separation (Hyvärinen, Karhunen, and Oja 2001). Commercial shotgun microphones typically have only one output and so these techniques cannot be implemented unless a second microphone is also employed.

This paper discusses the design of a lightweight shotgun microphone array for use on a UAV. The array consists of 80 MEMs microphones configured as a line array to produce an "end-fire" response. The array produces a main output which is a highly directional beam that detects a desired sound source and a second output which produces a complementary beam that points a null at the desired sound source and so detects only background (rotor) noise. The secondary beam can be used to further process the main beam output to reduce any residual rotor noise. The array is one of several designs being developed by Dotterel Technologies, a New Zealand company that develops technologies for both reducing and mitigating UAV noise. Two advantages of the design are, firstly, that the beamwidth can approach frequency-invariance at high frequencies and secondly, a number of beams with different beamwidths can be selected under software control.

The general properties of end-fire arrays are first presented, and their limitations highlighted. The microphone is then described, and the method used to design the beamformers described. The measured performance is then presented.

2. Description of Shotgun Microphones

A "shotgun" microphone consists of a single microphone capsule at the end of a tube, with slots in the tube to allow an incident sound field to enter the interior of the tube (Wittek et al. 2010; Mason and Marshall 1939; Shulman 1986) (Figure 1). Sound arriving from the axis of the tube produces pressures inside the tube which are in phase, and which arrive at the microphone capsule in phase, producing a large output. Sound arriving from an angle θ_i from the axis tends to produce out-of-phase signals at the microphone and a reduced response. The shotgun microphone is based on the interference of sound in the tube and is sometimes termed an interference-tube microphone. The microphone is typically a first-order design which provides directionality at low frequencies, where the tube is too short relative to the wavelength to provide significant directivity.

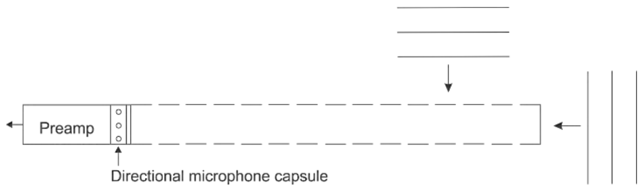


Figure 1: Interference tube “Shotgun” microphone

A simple model of a shotgun microphone treats the incident waves as plane waves and the sound field inside the tube as a sum of travelling plane waves that have entered the tube via the slots (Bai and Lo 2013),(Bigoni, Agerkvist, and Brixen 2018). Hence, an ideal shotgun microphone may be equivalently implemented using a discrete array of microphones configured in a line with the microphone signals delayed and added to produce a maximum response for sound arriving along the axis of the line array (Figure 2). For *M* microphones spaced equal distances *d* apart, the time for a sound wave arriving along the array to travel from one microphone to the next is $\tau = d/c$. If the mth microphone is delayed by $(m-1)d/c$ its delayed signals will be in phase with the first microphone signal for a sound wave arriving from along the axis. Hence the array produces a large in-phase signal for sound arriving from on-axis, in an equivalent manner to the interference tube microphone. This configuration is known as an “end-fire” array.

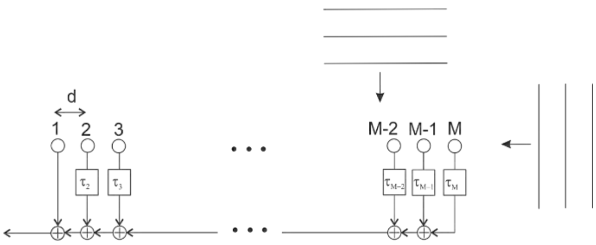


Figure 2: End-fire line array

2.1 Ideal end-fire response

An ideal end-fire array which has no spatial aliasing limitations is obtained by letting the number of microphones, *M*, tend to infinity and the inter-microphone spacing *d* tend to zero, such that the total length is a finite aperture length *D*. We assume the line array is positioned on the z axis and centered at the origin. The sound field will be described in terms of spherical coordinates, where $\theta \in [0,\pi]$ is the polar angle and $\phi \in [0,2\pi]$ is the azimuthal angle (Figure 3).

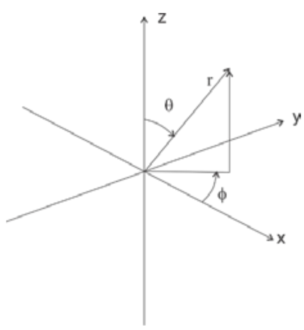


Figure 3: Spherical coordinates

An incident plane wave arriving from angle of arrival (θ,ϕ) produces a sound pressure on the z axis which is independent of ϕ and which has the form

$$p_i(r,\theta,\phi) = e^{ikz\cos\theta} \tag{1}$$

The response of the continuous array has the form

$$b(k,\theta) = \int_{-D/2}^{D/2} w(z) e^{ikz\cos\theta} dz \tag{2}$$

where $w(z)$ is an array weighting function. For the end-fire case the weighting is a delay such that all array positions produce signals that are in phase for an on-axis plane wave

$$w(z) = e^{-ikz} \tag{3}$$

The resulting polar response is

$$b(k,\theta) = \frac{1}{D}\int_{-D/2}^{D/2} e^{ikz[\cos\theta-1]} dz = \frac{\sin\left[\frac{kD}{2}(1-\cos\theta)\right]}{\frac{kD}{2}(1-\cos\theta)} \tag{4}$$

This is a sinc function response with a peak at $\theta = 0$ $(\cos\theta = 1)$ .The beamwidth of the response can be found as the angle where $b(k,\theta) = 1/2$. This occurs where

$$\frac{kD}{2}(1-\cos\theta) = 1.895 \tag{5}$$

This produces the angle (which is a function of wavenumber *k* and dimension *D*)

$$\theta_B = \cos^{-1}\left[1 - \frac{3.79}{kD}\right] \tag{6}$$

At small *kD* the argument is less than –1, the response never falls below one half and θ_B may be set equal to 180 degrees, signifying that the array response is omnidirectional.

The beamwidth is shown in Figure 4 for a 300 mm aperture. The array is approximately omnidirectional up to 300 Hz (which is approximately where D is a quarter wavelength) and the beam width reduces with frequency to around 20 degrees at 10 kHz.

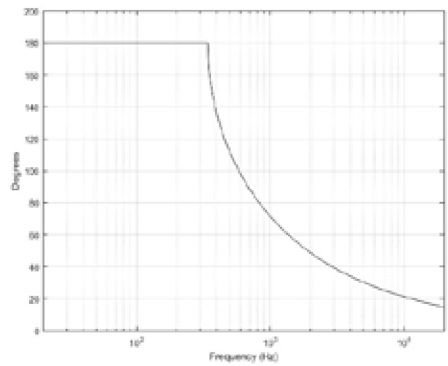


Figure 4: Beamwidth of an ideal 300 mm end-fire array versus frequency

This highlights the limitations of the end-fire array: it has poor directionality at low frequencies and the beamwidth varies with frequency. Commercial shotgun microphones use a directional capsule as discussed above to provide directivity at low frequencies, and acoustic elements are often incorporated into the interference tube to improve the directivity versus frequency.

An approximately equivalent procedure for the line array considered here is to make each microphone element directional with a first-order response

$$q(\theta) = \alpha + (1-\alpha)\cos\theta \quad (7)$$

which is independent of z. The polar response is multiplied by the element directivity (Josefsson and Persson 2006) and the combined response is

$$b(k,\theta) = \frac{\sin\left[\frac{kD}{2}(\cos\theta - 1)\right]}{\frac{kD}{2}(\cos\theta - 1)}\left[\alpha + (1-\alpha)\cos\theta\right] \quad (8)$$

The polar responses are shown in Figure 5 for frequencies from 250 Hz to 8 kHz, and for an array of length 300 mm, with omnidirectional elements ($\alpha = 1$). At low frequencies and with omnidirectional elements the array has very little directivity.

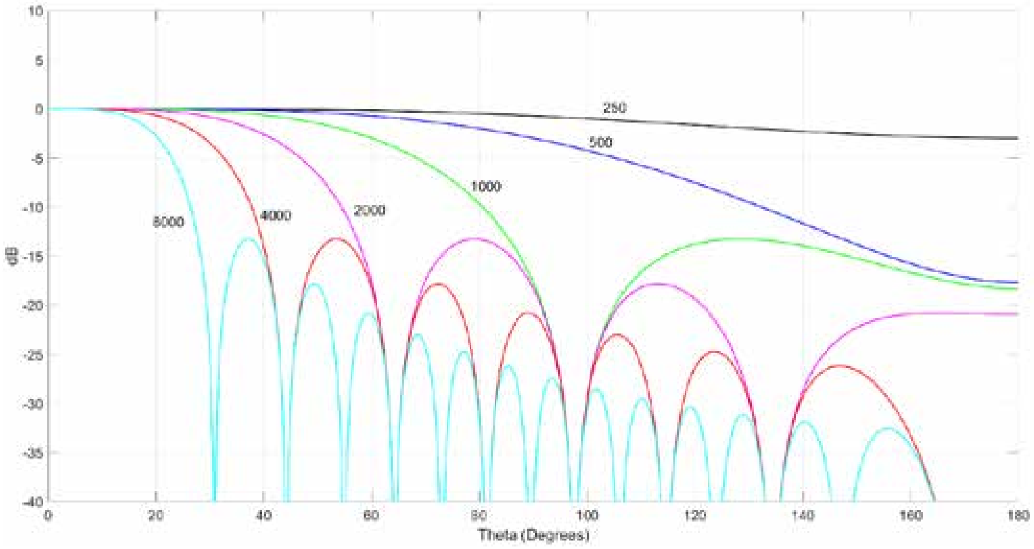


Figure 5: Ideal end-fire array response for D = 300mm, with omnidirectional elements, at frequencies from 250 Hz to 8 kHz.

Figure 6 shows the responses with a supercardioid element response ($\alpha = 0.366$), which is similar to commercially available shotgun microphones (Wittek et al. 2010). The end-fire array now has a response close to a supercardioid polar response at low frequencies which reduces the off-axis response, but still produces a significant rear lobe output for angles near 180 degrees. This rear lobe would be eliminated by using a cardioid element pattern, with correspondingly less attenuation for angles near 125 degrees.

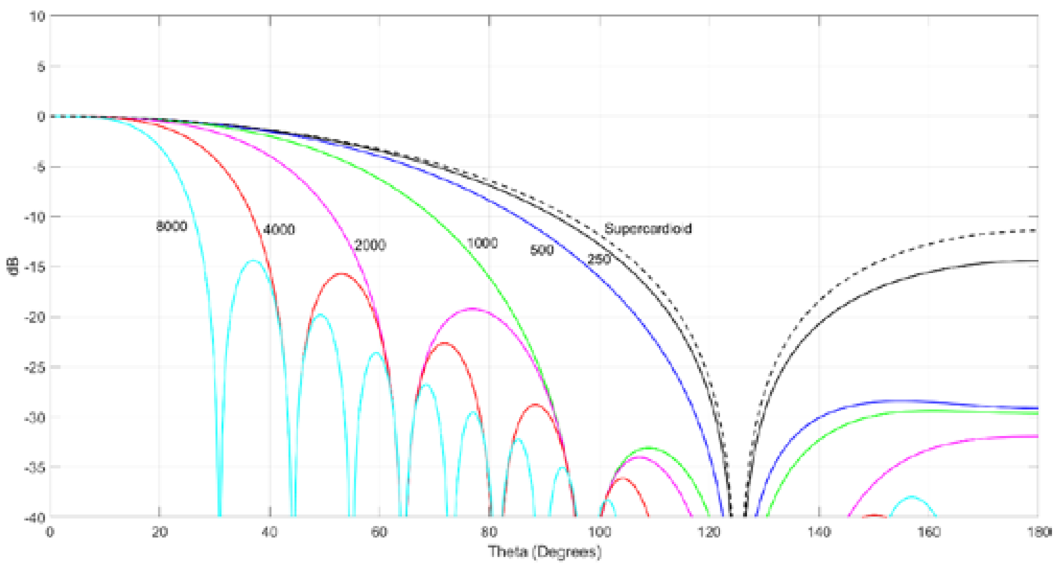


Figure 6: Ideal end-fire array response for D = 300mm, with supercardioid elements at frequencies from 250 Hz to 8 kHz. The supercardioid response alone is shown dashed

3. Array Design

The shotgun microphone is shown in Figure 7. It consists of a 400 mm by 20 mm by 20 mm enclosure constructed of printed circuit boards (to minimise weight). Each side of the array has 20 MEMs microphones spaced at 15 mm and mounted on the inside of the printed circuit board (PCB), producing a total aperture length of 300 mm. Each microphone has an entry port for sound on its underside and sound enters each microphone through a hole in the PCB. The MEMs microphones have onboard analogue to digital converters and produce serial digital outputs in the I2S format. The sample rate is 48 kHz. The outputs from 16 microphones are multiplexed onto a single high-speed data line using time-division multiplexing. Five data lines are required to route the 80 microphone signals to a rear processor which uses a gate array to de-multiplex the microphone signals and then combine them in two beamformers to produce a primary directional beam and a secondary null beam (Figure 8). Since the array has four microphones at each position along the array, each set of four microphones is added to produce a single signal that is largely omnidirectional for sound arriving around the axis of the array. The final beamformers then digitally filter 20 sets of signals and add them to produce each of the beamformer outputs (Figure 9).

Figure 7: 80-element microphone array

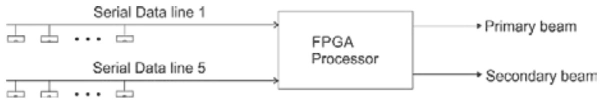


Figure 8: Digital routing and processing

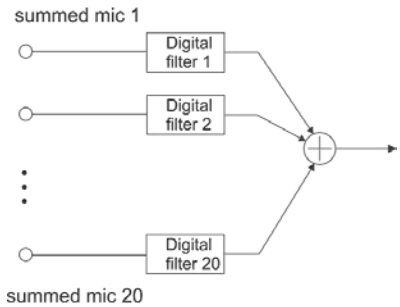


Figure 9: Beamformer processing

3.1 Least sqaures design of line array beamformer

We now describe a more general method for designing an end-fire response than the delay and sum approach used above. The *M* microphones are uniformly spaced at a distance *d* apart and positioned on the vertical z-axis and the array is centred at $z=0$. The microphone positions are

$$z_m = \left[m - \frac{(M-1)}{2} \right] d,\ m \in [0, M-1] \tag{9}$$

The incident field is given by (1). If each microphone output is multiplied by a weight w_m and the weighted outputs added, the result is

$$\tilde{b}(k,\theta) = \sum_{m=0}^{M-1} w_m e^{ik z_m \cos\theta} \tag{10}$$

where $\tilde{b}(k,\theta)$ is the polar response at wavenumber k. This can be seen to be a discrete approximation to (2). If the weights are simple delays of the form (3)

$$w_m = e^{-ikz_m} \tag{11}$$

then the resulting polar response will approximate the end-fire response in (4). The polar response will deviate from the ideal expression (4) for frequencies above the spatial aliasing frequency, where the spacing between the microphones is a half wavelength (Dmochowski, Benesty, and Affes 2009). The spatial aliasing frequency is thus

$$f_{alias} = \frac{c}{2d} \tag{12}$$

which for the design considered here with a microphone spacing of *d*=15 mm is 11.3 kHz.

To produce a more general solution than the delay-only solution, we require the resulting polar response (10) to equal a desired response $b(k,\theta)$. Equation (10) can be written, at any given frequency, set of *N* angles θ_n in matrix notation as

$$\mathbf{P}w = b \tag{13}$$

where the matrix **P** is *N* by *M* with entries

$$P(n,m) = e^{ikz_m \cos\theta_n} \tag{14}$$

The desired polar response is the *N* by 1 vector *b* with entries $b(k,\theta_n)$. The optimum weights, in the least squares sense, can be obtained by minimising the squared error

$$\begin{aligned}\varepsilon^H \varepsilon &= [b - \mathbf{P}w]^H [b - \mathbf{P}w] \\ &= b^H b - b^H \mathbf{P}w - w^H \mathbf{P}^H b + w^H \mathbf{P}^H \mathbf{P}w\end{aligned} \tag{15}$$

where superscript H denotes the conjugate transpose. Taking the gradient with respect to w^* yields the solution (Therrien 1992)

$$w = \left[\mathbf{P}^H \mathbf{P} \right]^{-1} \mathbf{P}^H b \tag{16}$$

The risk of using (16) is that the solution weights may have large magnitudes. This means that any small variations between the microphone responses, or in their positioning, would lead to large variations in the resulting polar response. In other words, the solution is not robust. Large weights also increase amplification of the microphone self-noise.

To improve the robustness of the solution, (16) can be modified by requiring that the total weight energy $w^H w$ be controlled. In addition, it is useful to be able to control how much error occurs at each angle. These two goals are achieved by first defining the weighted error

$$\varepsilon_w = \mathbf{G}\varepsilon = \mathbf{G}[b - \mathbf{P}w] \tag{17}$$

where **G** is a diagonal matrix obtained from an *N* by 1 error-weighting vector *g*, with elements

$$\mathbf{G} = \begin{bmatrix} g_1 & & & \\ & g_2 & & \\ & & \ddots & \\ & & & g_N \end{bmatrix} \tag{18}$$

and then missing

$$\varepsilon_w^H \varepsilon_w + \lambda w^H w = [b - \mathbf{P}w]^H G^H G [b - \mathbf{P}w] + \lambda w^H w \tag{19}$$

where λ is a Lagrange multiplier (Therrien 1992). Defining $\mathbf{R} = \mathbf{G}^H \mathbf{G}$ the weighted error is

$$\begin{aligned}\varepsilon_w^H \varepsilon_w &= b^H \mathbf{R}b - b^H \mathbf{R}\mathbf{P}w - w^H \mathbf{P}^H \mathbf{R}b \\ &+ w^H \mathbf{P}^H \mathbf{R}\mathbf{P}w + \lambda w^H w\end{aligned} \tag{20}$$

The optimum weights are obtained as before, yielding

$$w = \left[\mathbf{P}^H \mathbf{R}\mathbf{P} + \lambda \mathbf{I} \right]^{-1} \mathbf{P}^H \mathbf{R}b \tag{21}$$

This solution is calculated at a set of equi-spaced frequencies for a given set of design beamwidths and an inverse discrete Fourier transform used to produce a set of filter impulse responses that allow the beamformer to be implemented in a digital processor. Furthermore, a complementary beam pattern can be designed by specifying a second desired beam shape which is the complement of the main beam shape, which will detect the rotor noise required to implement noise reduction algorithms.

4. Directional Performance

The polar responses of the array were measured in an anechoic chamber by mounting the microphone on a computer-controlled turntable and measuring the impulse response at one-degree intervals using a swept frequency excitation. The measured main beam response for a 25-degree beamwidth target is shown in Figure 10. At low frequencies, the array cannot produce the required beam width and the response tends to a first-order response. At frequencies above 2 kHz the wavelength becomes less than half the aperture width and the target beam width is achieved. At high frequencies the beam becomes more frequency-invariant than the ideal end-fire response in Figure 6. At frequencies above the spatial aliasing frequency of 11.3 kHz, the response shows an aliasing lobe, whose position varies with frequency. At 16 kHz the aliasing lobe is at 115 degrees.

The complementary null response is shown in Figure 11. This shows similar behaviour to the main beam, producing a broad null at low frequencies that tends to become frequency invariant at high frequencies. The null depth is over 20 dB at all frequencies below the spatial aliasing frequency.

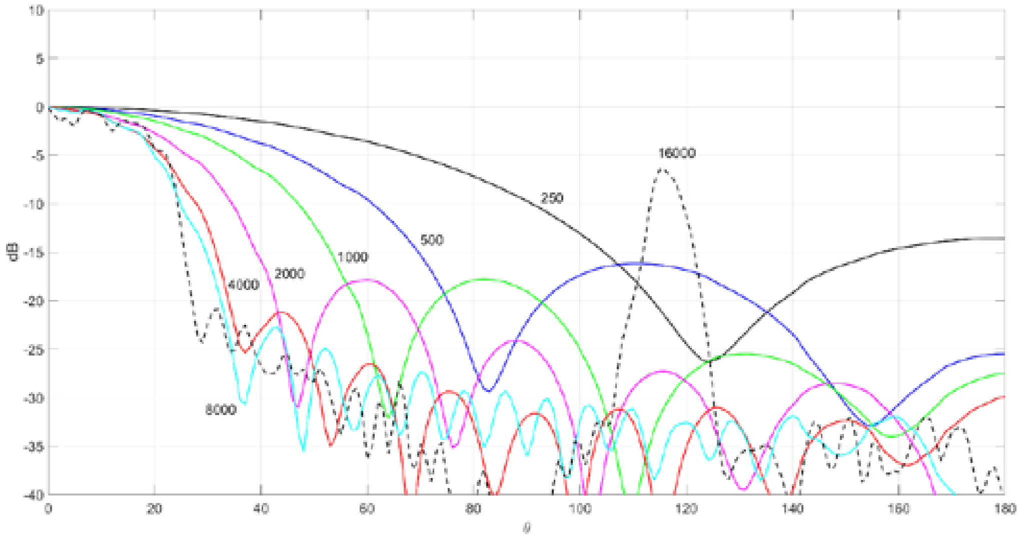


Figure 10: Main beam, 25 degrees, for frequencies 250 to 16,000 Hz.

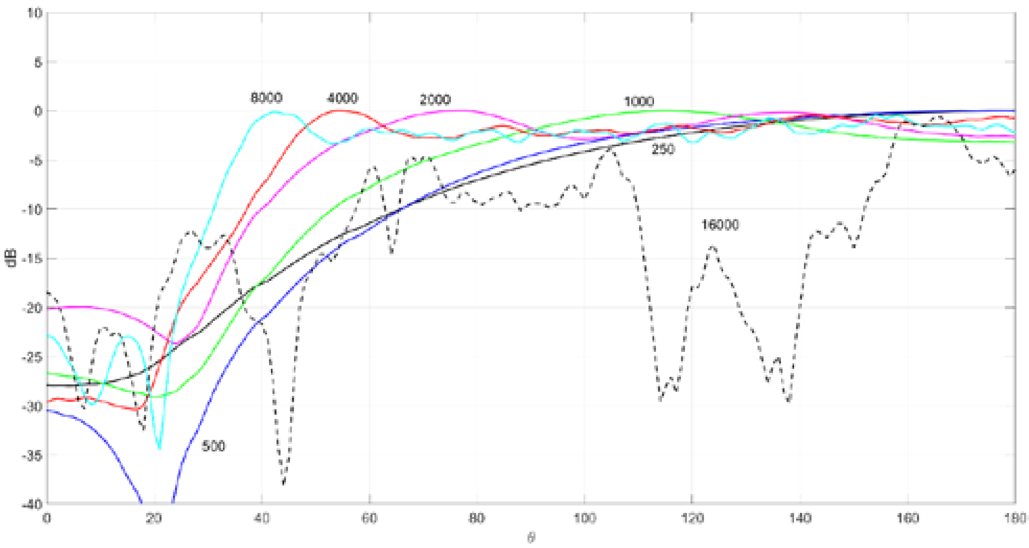
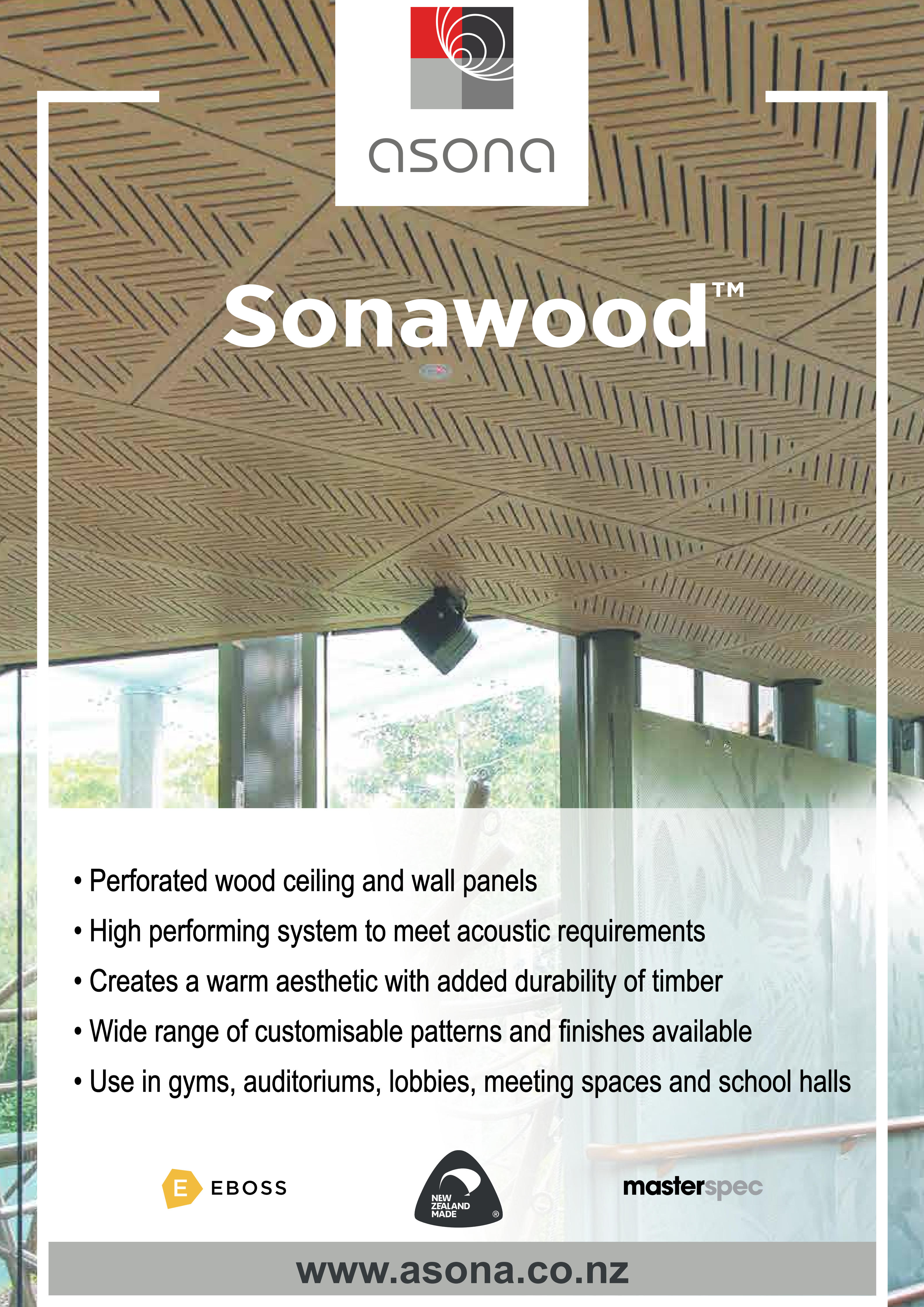


Figure 11: Null beam, 25 degrees, for frequencies 250 to 16,000 Hz.

The main and null beams are shown in Figures 12 and 13 for a 40-degree design. At wider beamwidths, the design constraints are relaxed, and the array can provide a more constant beamwidth at higher frequencies. Wider beams have advantages for detecting a source when the exact angle is unknown, or for recording multiple sources which are more widely-spaced in angle.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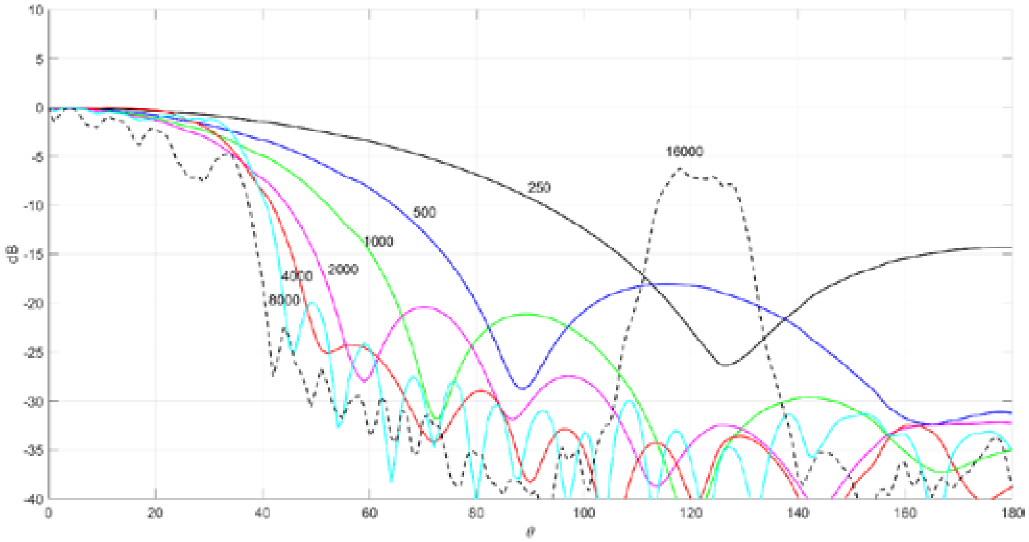

Figure 12: Main beam 40 degrees, for frequencies 250 to 16,000 Hz.

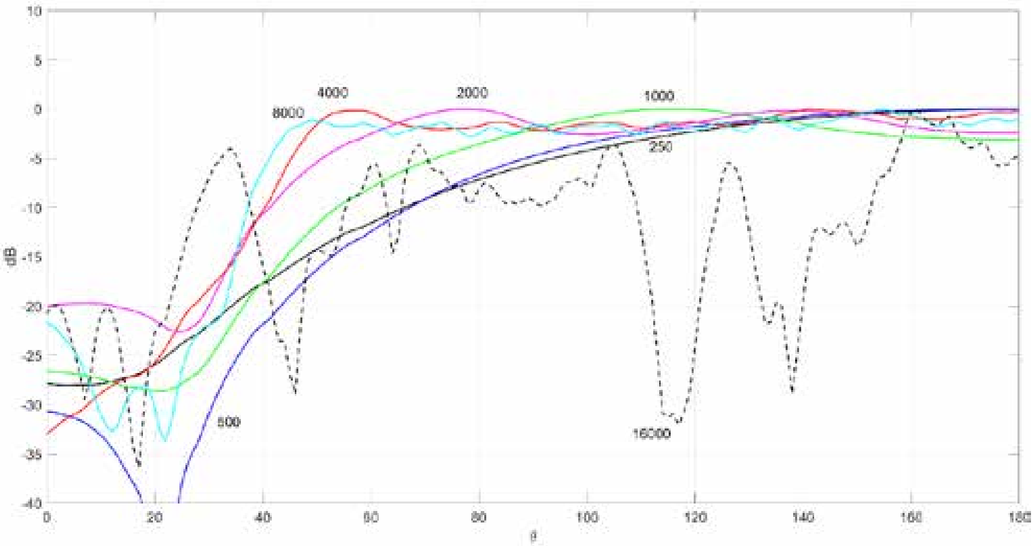

Figure 13: Null beam 40 degrees, for frequencies 250 to 16,000 Hz.

5. Conclusions

The design of a dual-output, microphone for detecting a desired acoustic source from an unmanned aerial vehicle has been described. The array produces a primary beam for recording the source and a complementary beam for detecting unwanted background noise which is used to process the signal from the main beam to reduce the unwanted noise that occurs in the main beam. The array can provide multiple beamwidths for various appli-cations which can be switched during flight. The design of the array and the beamformer filters has been described and examples of the measured performance presented.

The current design can be used as a platform for the development and testing of new beamformer designs, and other implementations can be developed with alternative microphone geometries such as those with closer microphone spacings and aliasing frequencies above the audible range.

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How carpet can reduce the apparent sound transmission class of walls

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Abstract

Analysis of recent on-site ASTC measurements showed a reduction of 9 points when carpet and underlay were added to both the source and receiving room. Our investigation of this concluded that air trapped between a concrete slab and carpet can produce a mass-air-mass resonance, which amplifies flanking under the wall. This effect has the potential to cause adjacent apartments to fail the airborne sound insulation component of the Building Code. We tested several common residential carpets and underlays at the Auckland University Acoustic Testing Service (ATS). This confirmed the resonant effect from the carpet and underlay system in laboratory conditions. Testing showed that carpet that is 'porous' and does not trap air did not produce the resonance effect.

1. Introduction

Recent on-site and laboratory testing has identified a resonant effect produced by carpet and underlay systems that has the potential to reduce the airborne sound transmission loss of a concrete slab. This effect has the potential to cause adjacent apartments to fail the airborne sound insulation component of the Building Code via direct sound transmission or flanking through a common floor slab.

Our theory is that air trapped between a concrete slab and carpet produces a mass-air-mass resonance. The frequency of this resonance is dependent on the surface mass of the carpet and the thickness of the carpet underlay.

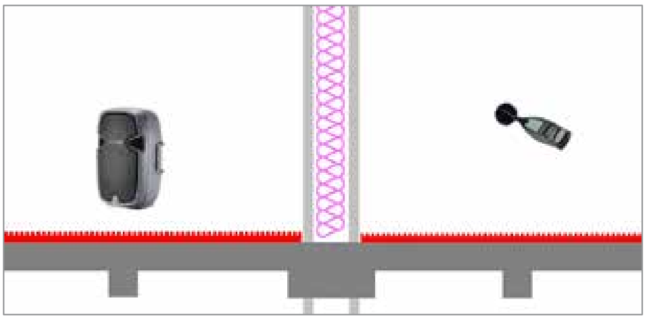
This paper:

- presents analysis of on-site and laboratory airborne transmission loss measurements for carpet/under-lay systems
- explores the resonant effect in the context of the New Zealand Building Code
- details a potential way to identify problematic carpet types without laboratory testing.

2. On-site Measurements

During sound insulation measurements of adjacent living rooms in an apartment building, we observed that the transmission loss of the IT wall reduced significantly when the carpet and underlay was installed. Analysis with an accelerometer on various surfaces in the receiving room showed that there was no change in sound energy reradiated by the wall itself. We determined that sound flanking through the concrete slab beneath the IT wall was reducing the apparent transmission loss of the wall.

Figure 1 below shows an indicative layout of the onsite tests with a source room and receiver room separated by a double stud timber IT wall which was rated STC 62. The construction of the building included a rib and infill slab with a topping of approximately 110mm.

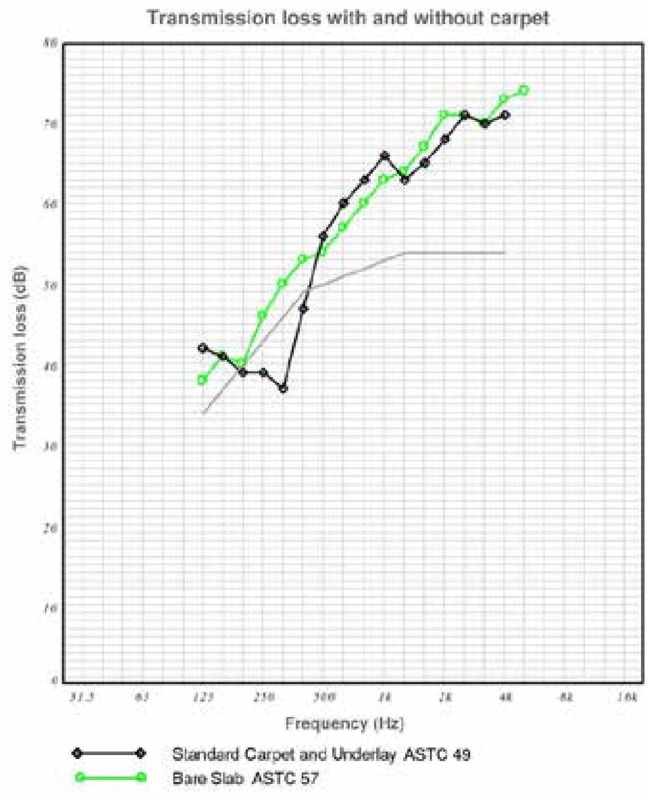


Source (B Shanks, 2021)

Figure 1: Indicative layout of on-site testing

2.1 Carpet and underlay reduced the sound insulation results

Sound insulation tests were conducted with and without the carpet and underlay installed. Figure 2 shows a plot of the transmission loss (TL) between the same rooms with a bare slab on both sides and with carpet and underlay on both sides.

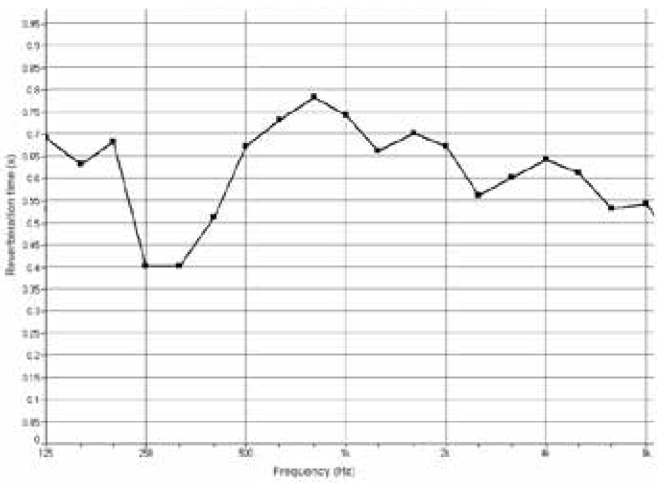


Source (B Shanks, 2018)

Figure 2: Wall apparent transmission loss with carpet and underlay and bare slab

2.2 Increased absorption was noted

We noticed during the on-site measurements that there was a dip in the reverberation time in the receiving room at the frequencies where there was a reduced transmission loss. Figure 3 shows the measured reverberation time in the apartment living room with carpet and underlay. This indicates that the resonant effect increases absorption at the resonant frequency.



Source (B Shanks, 2018)

Figure 3: Reverberation time in living room with carpet and underlay

2.3 Mass-air-mass resonance theory matches the frequency of reduced TL measured on-site

The theory we established from these on-site measurements is that there is a mass-air-mass resonance created by the carpet and underlay on the slab that enhances sound flanking through the floor slab. For this to occur, air would need to be trapped in the cavity between the carpet and the slab. The carpet appeared to be 'non-porous' i.e. it was not possible to blow air through it. The equation to calculate the resonant frequency of a mass-air-mass system can be expressed as:

$$f_{\mathrm{MAM}} \approx 60\sqrt{\frac{(M_1+M_2)}{dM_1M_2}} \qquad (1)^1$$

where:

f_{MAM} = resonant frequency of a mass-air-mass system

Air is at 20°C

M^1 = the surface mass of the carpet (4.6 kg/m²)

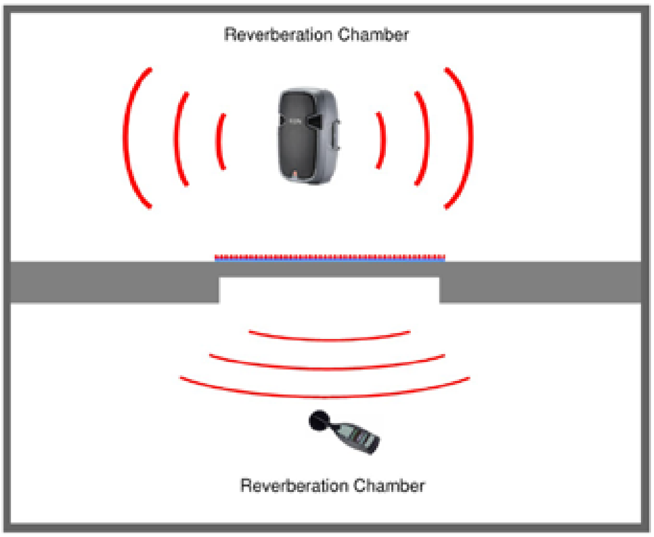
M^2 = the surface mass of the concrete slab (253 kg/m²)

d = the depth of the air cavity (0.01m)

The calculated resonant frequency based on the surface mass of the carpet and the air gap is f_{MAM} = 282Hz. This is consistent with the frequency of the reduction in transmission loss which was measured in the 250-315 Hz frequency bands.

3. Laboratory Test Methodology

To enable more detailed analysis of the resonant effect, we conducted a series of laboratory tests at the Acoustic Testing Service (ATS) at Auckland University. The tests involved laying carpet and underlay on the floor plug of the upper reverberation chamber and measuring the transmission loss through to the lower chamber. Figure 4 shows an indicative layout for the laboratory testing.



Source (B Shanks, 2020)

Figure 4: Indicative laboratory testing layout

The theory that resonance is caused by air trapped beneath the carpet relies on an impervious layer to trap the air. Based on the carpet and underlay in the on-site tests it was unclear if the air was trapped by the glue layer in the carpet or the plastic coating on the underlay.

We predicted that, if both the carpet and underlay are porous (they allow air to pass through) they would not trap air and would not elicit the resonant effect. We selected a range of carpet types that were porous and non-porous, including the carpet type that was used in apartments where the issue was identified. These were tested on a standard 10mm foam underlay with plastic coating, as shown in Figure 5. A porous underlay option was also tested to assess the effect of the plastic coating on the standard foam underlay, as shown in Figure 6.

Source (B Shanks, 2018)
Figure 5: 10mm foam underlay with plastic coating

Source (B Shanks, 2018)
Figure 5: 7mm porous underlay

The tests measured the transmission loss of the carpet/underlay systems on a concrete slab and compare these against the transmission loss (TL) of the bare slab. The result of this is a change in TL caused by the carpet/underlay system (ΔR). A negative delta R indicates that the carpet has reduced the TL.

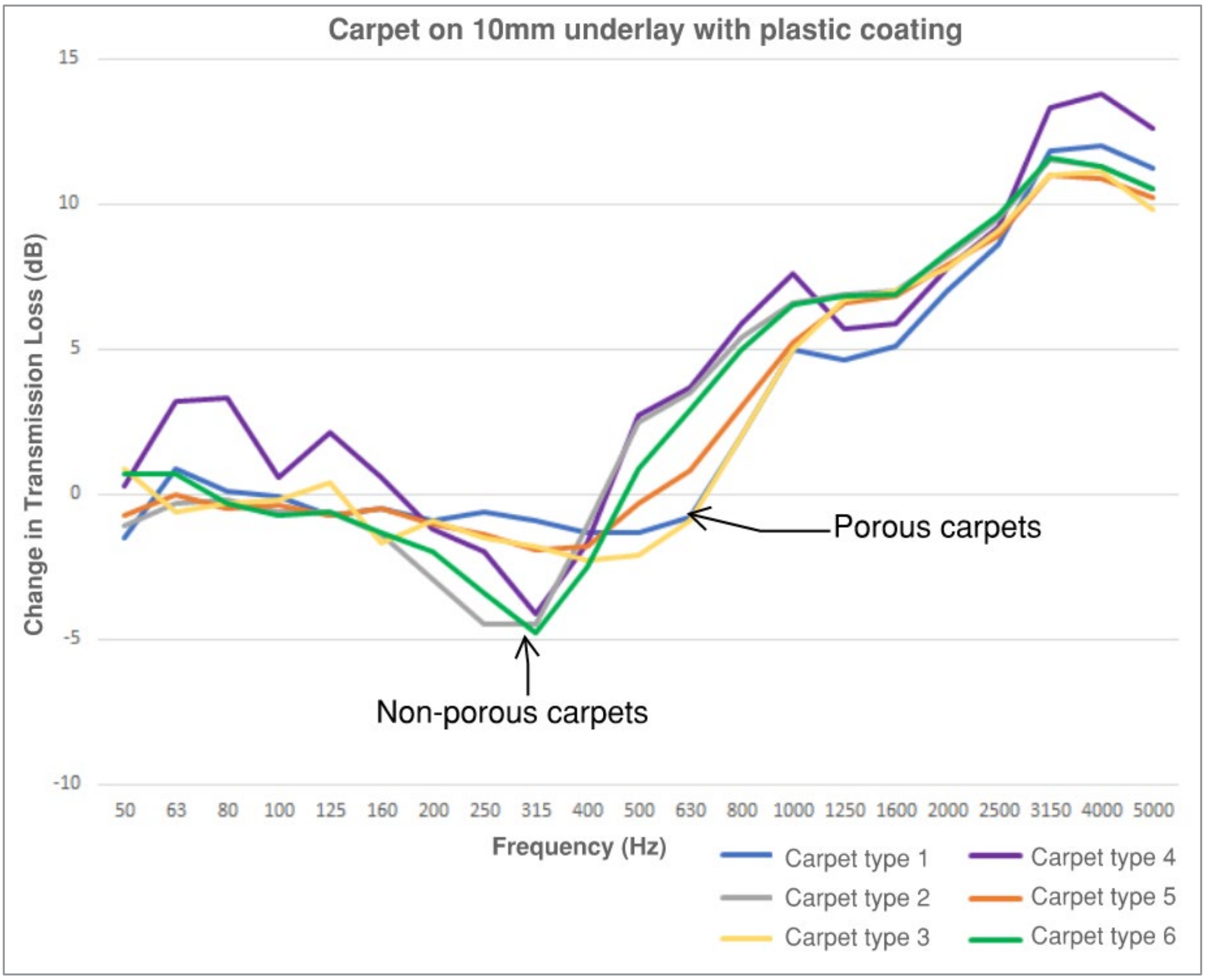
The absorption of the carpet/underlay samples was measured in the reverberation chamber during the tests at ATS.

4. Laboratory Test Results

The results of the tests are presented by plotting the change in transmission loss (ΔR) caused by adding the carpet and underlay to the concrete floor.

2.2 Carpet on plastic coated underlay

Figure 7 shows the ΔR for the various carpet types on standard foam underlay with plastic coating. Due to the plastic coating of the underlay, air may be trapped even when a porous carpet is used.

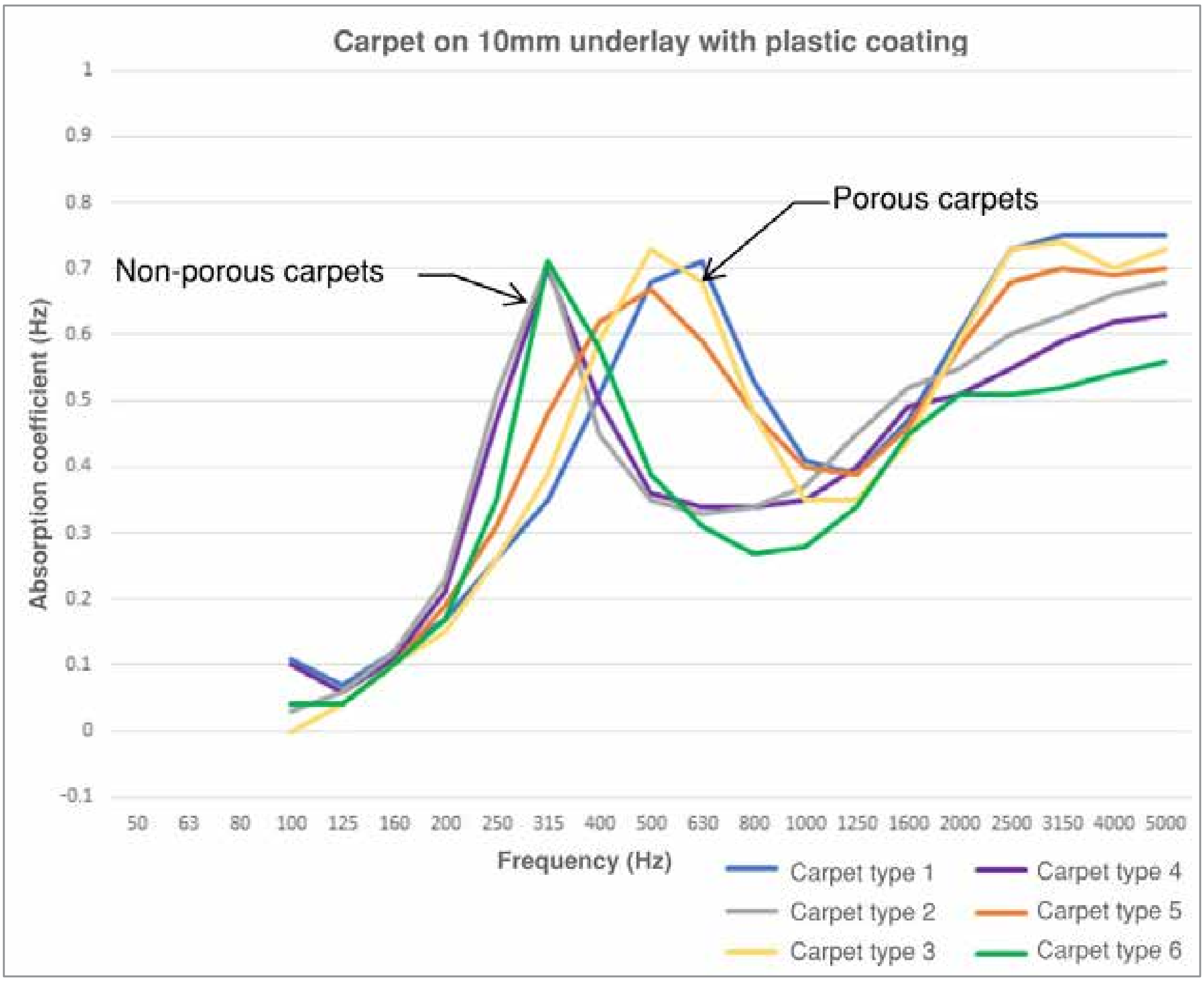


Source (B Shanks, 2021)
Figure 7: ΔR for carpet on 10mm foam (non-porous) underlay

The results show that the non-porous carpets cause a 4-5 dB reduction in TL at 315Hz. The tests in the laboratory include one resonant system in the source room only. The on-site tests in the apartments have a resonant system on the floor slab in both the source and receiver room. This doubles the effect of the flanking sound transmission. Therefore, the reduction of 4-5 dB in the laboratory is consistent with the reduction of 8 dB measured in the apartment tests.

The porous carpets do not show such a pronounced reduction at this frequency. However, they do cause a 1-2 dB reduction in TL centred around 400Hz-630Hz. This reduction is a less distinct dip and affects a wider frequency range.

Figure 8 shows the corresponding absorption of the carpets on standard 10mm underlay.



Source (B Shanks, 2021)

Figure 8: Absorption for carpet on 10mm foam (non-porous) underlay

The absorption measurements for the non-porous carpets show a spike in absorption that corresponds with the 4-5 dB reduction in TL. The absorption coefficient at 315Hz is 0.7 for the non-porous carpets. Carpet and underlay would typically have an absorption coefficient of 0.1-0.2 at this frequency.

Similarly, the absorption of the porous carpets is increased at frequencies that correspond with the small reduction in TL (400Hz-630Hz). Again, the absorption coefficient of 0.6-0.7 at these frequencies is higher than expected.

4.2 Carpet on plastic porous underlay

The results in Figure 9 show the carpet types on a porous underlay which is 7mm thick. In these tests, where a porous carpet is used, there would be no air trapped by the carpet or underlay.

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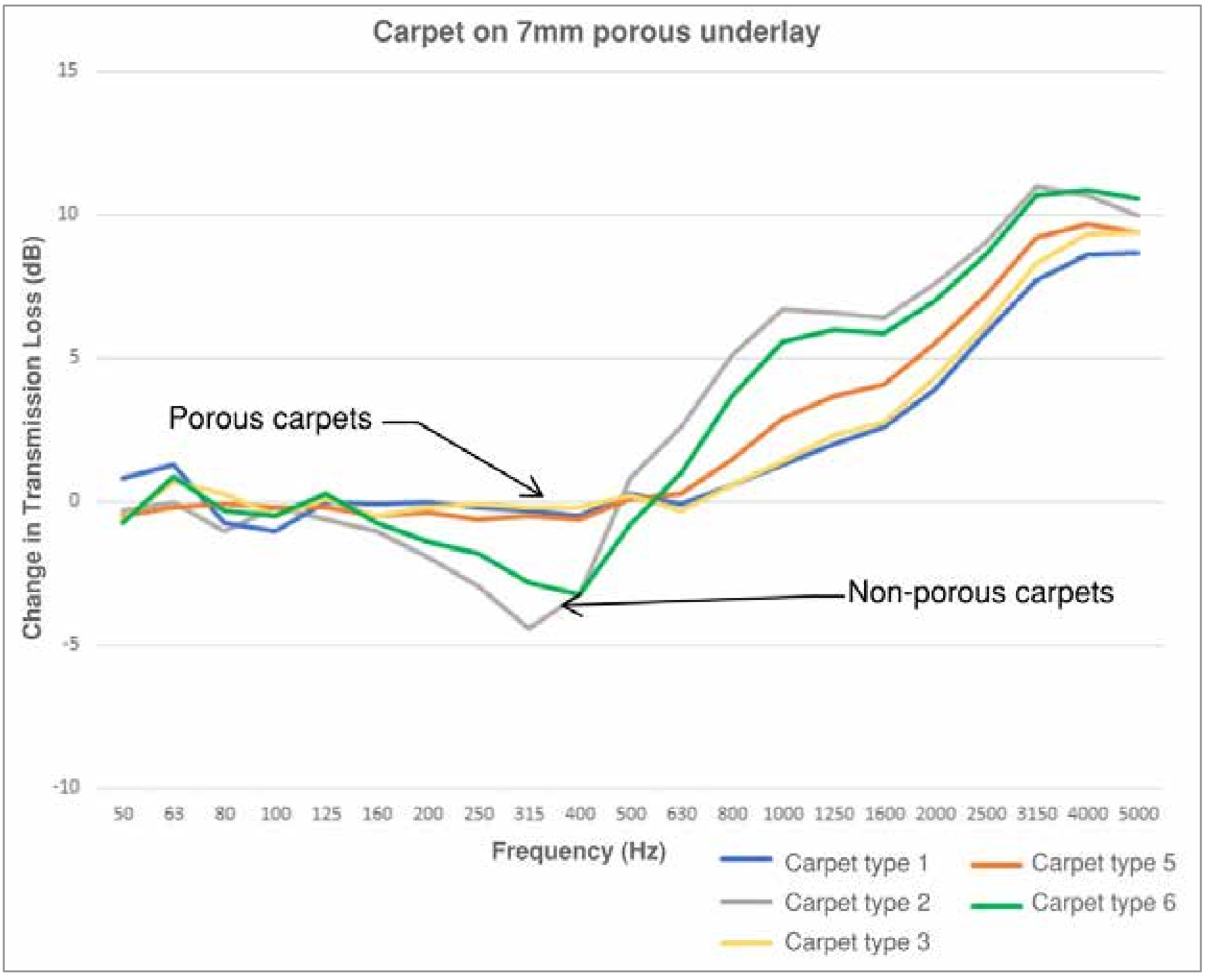
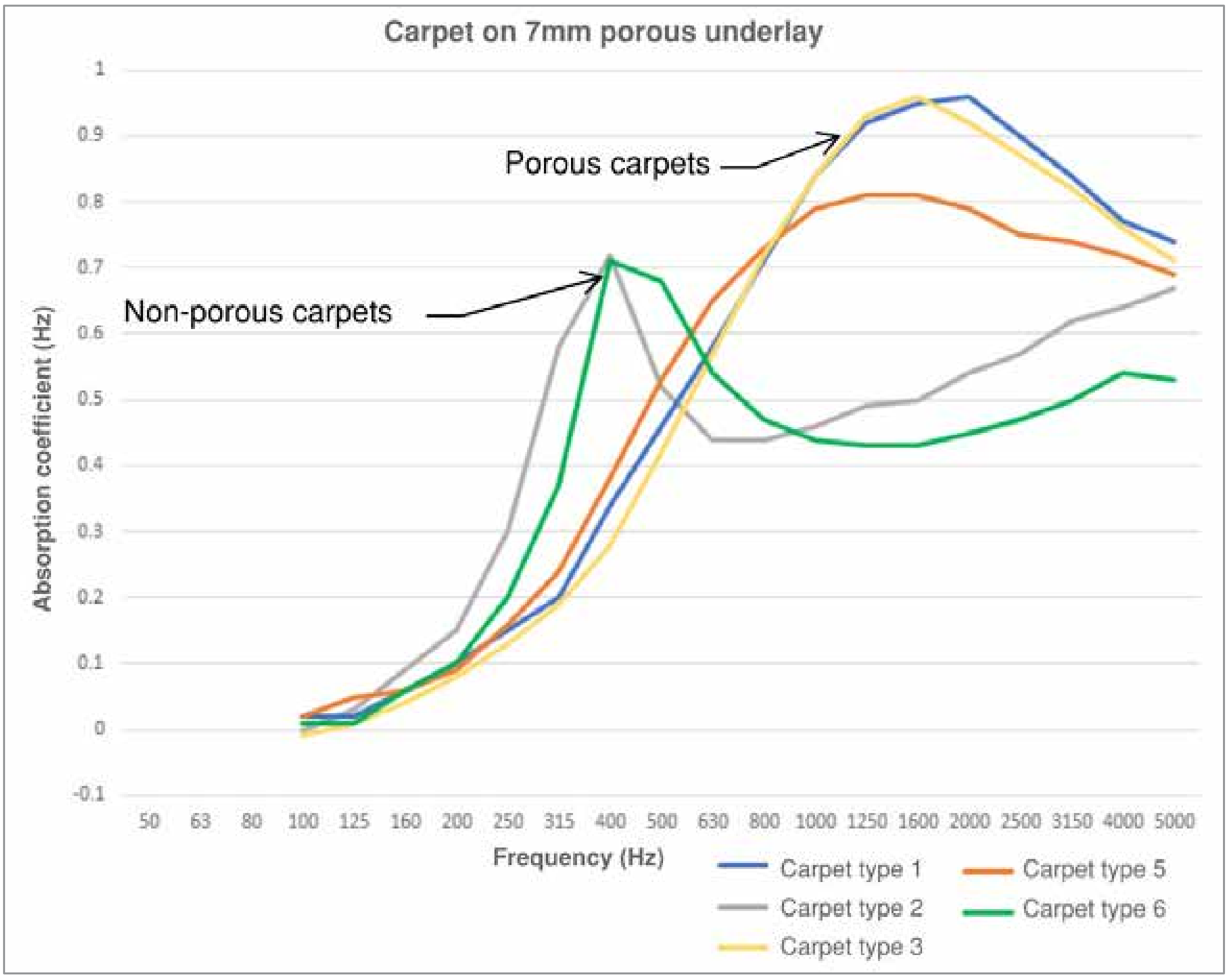


Source (B Shanks, 2021)
Figure 9: ΔR for carpet on 7mm porous underlay

The test results show that the non-porous carpets still exhibit a significant reduction in TL. Due to the thinner underlay (7mm), the reduction in TL is higher (315Hz-400Hz) than the 10mm underlay (250Hz-315Hz). The po-rous carpets on porous underlay show no significant negative delta R values.

The absorption coefficients for the non-porous carpets on a porous underlay show the same spike at the resonant frequency. The absorption coefficients for porous carpets are consistent with what is typically expected from car-pet on underlay, with low levels of absorption below 500Hz.



Source (B Shanks, 2021)

Figure 10: Absorption for carpet on 7mm porous underlay

5. Implications for Apartment Buildings

Sound flanking as a result of carpet resonance is most likely to be problematic in residential apartments for several reasons. Carpet with underlay is most commonly used in residential buildings and is not often used in other build-ing types. It is even more uncommon to have two adjacent spaces using carpet and underlay separated by a lightweight wall.

In building types where the design is focussed on speech frequencies, such as meeting rooms and offices, a reduction in ASTC at these relatively low frequencies is less likely to cause an issue than in a residential situation where low frequency noise from TV's and stereo's may be more prevalent.

Finally, residential buildings are the only building type where the New Zealand Building Code requires strict com-pliance with sound insulation criteria. While a reduction in performance may be unfavourable in other building types, a failure to achieve the design criteria is more likely to be tolerated.

5.1 NZ Building Code

Clause G6 of the New Zealand Building Code requires that a common building element (wall or floor) between habitable spaces in separate dwellings have a design performance of STC 55 and an on-site performance of ASTC 50. The on-site (ASTC) performance includes sound transmission from flanking paths, such as the floor slab under an IT wall.

The single figure ASTC value is determined by moving a reference curve between 125Hz and 4kHz such that the sum of 1/3 octave band points below the reference curve is no more than 32, and no 1/3 octave band is more than 8 dB below the reference curve.

The 8 dB rule is particularly important when considering a resonant system that reduces the apparent transmission loss at one particular 1/3 octave band. That 1/3 octave band can become the controlling point that pulls the curve down. The equivalent ISO measurement metric (Rw) does not include the 8 dB rule and is less susceptible to influence from a resonant effect.

This comparison is not intended to comment on the suitability of either of these metrics. Just to point out that where a resonant effect causes a reduction in a particular 1/3 octave band, the STC and Rw results may be noticeably different.

5.2 Building construction

The significance of carpet resonance in a building will vary depending on the type of construction. The resonance will not cause a significant reduction in the ASTC in buildings were there is adequate flanking sound insulation at the resonant frequency.

Due to matched resonance for adjacent apartments that share a common slab, the reduction in transmission loss will be greatest for flanking beneath a lightweight IT wall. If masonry IT walls are used, these will typically provide suitable blocking mass to reduce flanking between adjacent apartments. This effect was observed during on-site measurements, where adjacent apartments separated by a masonry IT wall passed the Building Code requirement comfortably.

The overall thickness of the floor slab should also be considered. For example, a 110mm flat concrete slab has a critical frequency around 270 Hz. Therefore, the bare slab already has a dip in transmission loss around 250-315 Hz and further reduction in this frequency range from carpet resonance will have a greater effect on the ASTC.

6. Identifying Problem Carpets

It is clear from the laboratory testing that not all carpets will elicit the problematic resonance. Carpets that are porous do not trap air effectively enough to produce a mass-air-mass resonance. To date, confirming that a carpet can elicit a resonant response has been demonstrated either on-site or in the laboratory test chambers.

In the context of an apartment project, neither of these options are practical from a development perspective. On-site testing requires apartments to be near completion, which is too late in the project timeline to allow for a change to the carpet type. Our experience is that the lead time for laboratory testing can be several months and this is a relatively costly exercise.

We have developed a flow resistance rig to quantify how porous the carpet is. The intention is to use the flow resistance (expressed in mks rayls) as a more practical method for determining which carpet is likely to trap air and cause resonance.

We measured the flow resistance through samples of the carpet types that had been tested in the laboratory. The carpets that produce a strong resonance have a flow resistance greater than 20,000 rayls. Those that did not cause resonance have a flow resistance of 1,000-1,600 rayls. Based on this testing, we currently have ΔR values for two distinct data points; very high flow resistance and relatively low flow resistance.

Since conducting the laboratory tests, we have conducted flow resistance tests of other carpet samples that have a resistance between these data points e.g. 6000 rayls. It is expected that the resonant dip in ΔR values will be flatter at lower flow resistances but will become increasingly prominent as the resistance increases. However, further laboratory testing is required confirm when the flow resistance becomes great enough to produce a noticeable resonant effect.

7. Conclusion

We have conducted on-site and laboratory tests that confirm that resonance in carpet and underlay systems can reduce the transmission loss when installed on a concrete slab. The effect in the laboratory reduced the trans-mission loss by 4-5 dB at 315 Hz, while the reduction due to flanking between adjacent apartments was up to 13 dB at 315 Hz.

The effect occurs when air is trapped beneath a non-porous carpet layer. We have developed a flow rig to measure the flow resistance of carpet samples. Further laboratory tests are required to determine the level of resistance at which a noticeable resonant effect is generated.

Acknowledgements

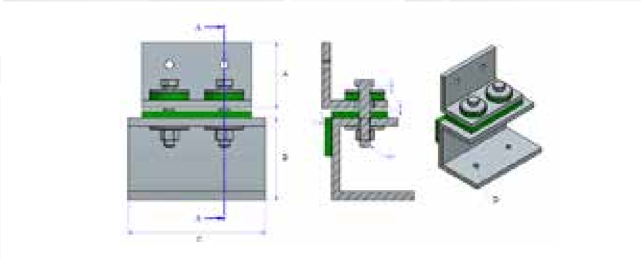
I would like to acknowledge Marshall Day Acoustics for the funding to conduct laboratory testing, and in particular Malcolm Dunn and Keith Ballagh for their technical input.

References

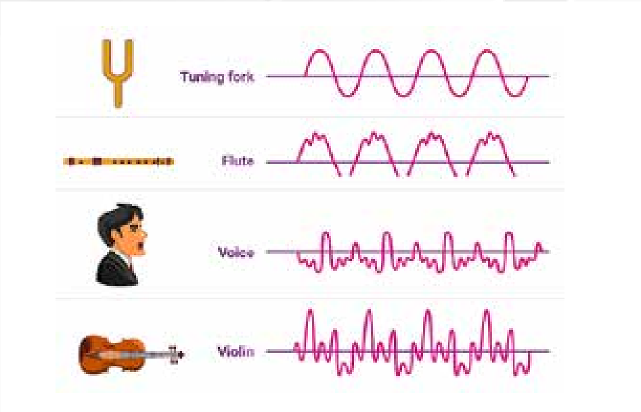
1. Hopkins, Carl. 2007. *Sound Insulation.* Oxford : Elsevier Ltd.

QUIZ

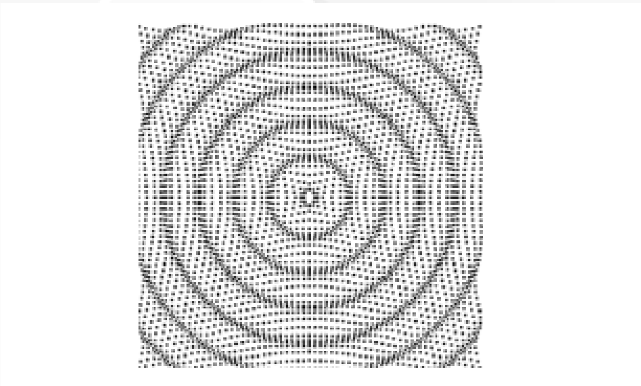
1. What is a 'snubber'?



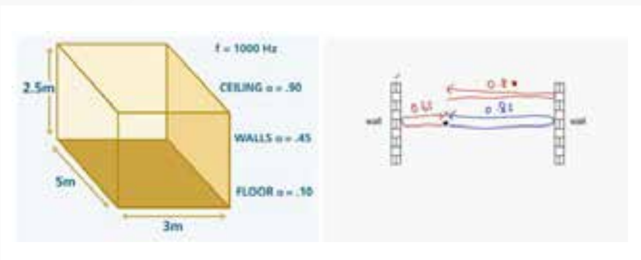
2. What is 'timbre' (pronounced tam-ber or tam-ba).



3. Define in a sentence what is a simple sound source?



4. What is the 'mean free path' and what area of acoustics is it used in?



5. True or False? Pink noise is a random broadband signal?

6. True or False? Erring's formula is a modified version of Sabines formula for reverberation time.

Sabine ?

$$T_{60} = \frac{0.161V}{S\alpha} \qquad T_{60} = \frac{0.161V}{-S\ln(1-\alpha)}$$

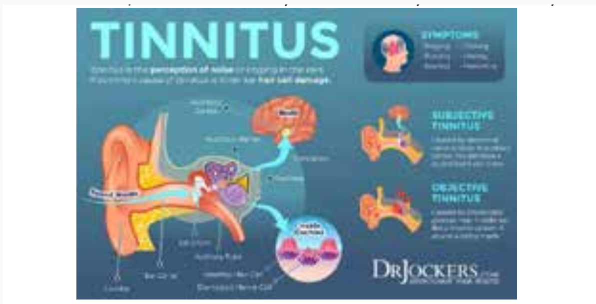
V is room volume in m³
S is the surface area
α is the average absorption coefficient per band

7. The ratio of two frequencies that are one octave apart is: A) 2:1 B) 1:2 C) 2:4 or D) 10:1

8. What is repeatability in acoustic measurement?

9. Approximately how many people worldwide are affected by Tinnitus

A) 750 million B) 50 million C) 1.2 Billion D) 2 Billion



10. What is sociocusis?

UPCOMING EVENTS

53th International Congress and Exposition on Noise Control Engineering (INTER-NOISE 2024)

25 August - 29 August 2024

Cité des Congrès de Nantes 5 rue de Valmy, Nantes, France

25th International Congress on Acoustics (ICA 2025)

18 May - 23 May 2025

New Orleans Marriott 555 Canal Street, New Orleans, LA, United States

Forum Acusticum Euronoise 2025

23 June - 26 June 2025

FYCMA Ortega y Gasset, 201, Málaga, Spain

26th International Congress on Acoustics (ICA 2028)

11 September - 14 September 2028

Pestana Casino Park Hotel Rua Imperatriz D. Amélia, Funchal, Portugal

54th International Congress and Exposition on Noise Control Engineering (INTER-NOISE 2025)

4 September - 27 September 2025

WTC Events Center Av. das Nações Unidas, 12551 - Brooklin Novo, São Paulo, SP, Brazil

Note: Dates and information is subject to change. We encourage you to go directly to the source web site of each event to ensure you have the latest and most up to date information.

QUIZ ANSWERS

1. A 'snubber' is device used to restrict or limit the lateral displacement of vibration-isolated equipment. Seismic snubbers are heavy duty versions that ensure vibration-isolated equipment does not disconnect from the mounting during earthquakes.
2. In music, timbre is the perceived quality of a sound (commonly called the 'tone colour') which is related to its harmonic structure and distinguishes different types of sounds and sound combinations. It is what makes a musical note sound different from one source to another. For example, the middle C note played on the guitar sounds very different from the same note played on the piano.
3. A simple sound source is an idealized model of an acoustic source. It is dimensionally small and radiates sound energy spherically, under free-field conditions – commonly called a mono source or point source.
4. The 'mean free path' (L) is used in room acoustics. It is the mean path length in an enclosure before a sound ray encounters a surface and is reflected/absorbed. For diffuse sound fields it has a simple formula (L = 4V/S; where V = volume and S = surface area) that holds for all room shapes.
5. True. Pink noise is a random broadband signal that is flat on a 1/1 and 1/3 octave band spectrum (constant energy per octave) but drops 3 dB/octave (1/f) on a narrow-band spectrum. Pink noise is commonly used for general noise modelling of sound sources.
6. False. It is Eyring's formula (1930) *not* Erring's (spelt differently) that is a modified version of Sabines formula (1922) for room reverberation time.
7. A) 2:1, but could also be B) since for music, an octave is a series of eight notes occupying the interval between (and including) two notes, one having twice *or* half the frequency of vibration of the other.
8. Repeatability in acoustic measurement is the variability of measurements when repeated under the same conditions.
9. A) 750 million worldwide. Researchers estimate about 14% of adults experience tinnitus while 2% experience a severe form of it. Tinnitus, commonly described as a ringing in the ears, is estimated to affect about 750 million people around the world, according to new research based on about 50 years of data.
10. Sociocusis is hearing loss arising from everyday activities that are non-occupational related.

SOUNDPRINT

The ASNZ has teamed up with **SoundPrint** to provide this curated list of acoustic ratings for food and beverage venues across Aotearoa (replacing the previous **CRAI** ratings). This data is collated from submissions made by users of the SoundPrint app, which rates venues based on the ambient noise levels present at the time of review and a subjective impression of how easy it was to hold a conversation. SoundPrint ratings follow a decibel scale, and these correspond with our awarded star ratings as follows:

Quiet		moderate	loud	very loud
70 dBA or below + subjectively "great" for conversations	70 dBA or below	70 - 75 dBA	75 - 80 dBA	80 dBA or above
★★★★★	★★★★	★★★	★★	★

The list below contains submissions from the past 3 years only. The numbers in parentheses are the total reviews over this period.

AUCKLAND		
Bellota, Auckland	★★	(1)
Birkenhead Brewing Company, Birkenhead	★	(1)
Brickhouse Espresso Bar, Auckland	★★★	(1)
Brothers Beer, Auckland	★★★	(1)
Chamate, Auckland	★★★	(2)
Copia, Remuera	★★★★★	(1)
Corner Bar, Auckland	★★★★	(1)
Dear Jervois, Herne Bay	★★★	(1)
Dizengoff, Ponsonby	★	(1)
Fabric Cafe Bistro, Hobsonville	★★★★★	(1)
Ginger, Remuera	★★★★	(1)
Kind Cafe & Eatery, Auckland	★★★★	(1)
Lieutenant, Auckland	★★	(1)
Little Bird Unbakery, Ponsonby	★★★★★	(1)
Little Creatures Hobsonville, Hobsonville	★★★	(1)
Little Culprit, Auckland	★★★★	(1)
Masala Indian Restaurant, Pukekohe	★★★	(1)
Pasta & Cuore, Auckland	★★★★★	(1)
Poni Room, Auckland	★★★	(1)
Seoul Night, Auckland	★★★	(1)
Siso Bar And Eatery, Auckland	★	(1)
St Pierre's Sushi & Seafood, Auckland	★★★★★	(1)

Sumthin Dumplin, Auckland	★★★★	(1)
The Brewers Co-operative, Auckland	★★★★★	(1)
The Chamberlain, Auckland	★★	(1)
The Dark Horse, Auckland	★	(1)
Tok Tok, Hobsonville	★★	(1)
Toto Cucina, Auckland	★★	(1)
BAY OF PLENTY		
Ohope Charter Club, Ohope Beach	★★	(1)
CANTERBURY		
Black And White Coffee cartel, Christchurch	★★★★	(1)
Coffee Culture, Papanui	★★★★	(1)
Coffee Culture, Christchurch	★★★★★	(1)
Columbus Coffee, Papanui	★★★	(1)
Doubles, Christchurch	★★★	(1)
Kohan Japanese Cuisine, Lake Tekapo	★★★★★	(1)
Kum Pun Thai Restaurant, Christchurch	★★★★	(1)
Little Poms, Christchurch	★★★	(1)
Mac's South Bar & Café, Christchurch	★★★★★	(1)
Meshino, Saint Albans	★★	(2)
Misceo Cafe & Bar, Ilam	★	(1)
Poppies Cafe, Twizel	★★★	(1)
Strange Bandit, Burnside	★★★★	(2)
Strawberry Fare, Christchurch	★★★★	(1)

SoundPrint can be downloaded from the Apple App Store and Google Play Store. More information and reviews are available at the website: https://www.soundprint.co/locations/nz

Terrace Tavern, Christchurch	★★★	(1)
Two Thumb Brewing Co Ltd, Christchurch	★★	(1)
Volstead Trading Company, Christchurch	★★★★★	(1)
HAWKE'S BAY		
Hunger Monger, Napier	★★★	(1)
Mister D, Napier	★★	(1)
NELSON		
Columbus Coffee, Nelson	★★★★★	(1)
Sprig & Fern Hardy St, Nelson	★★★	(1)
Sprig & Fern Tavern, Nelson	★★★	(1)
The Free House, Nelson	★★★★	(1)
OTAGO		
1876 Bar & Restaurant, Queenstown	★★	(1)
Farelli's Trattoria, Queenstown	★	(1)
Margo's queenstown, Queenstown	★★★★	(1)
My Thai Lounge, Queenstown	★★★★	(1)
The World Bar, Queenstown	★★	(1)
Wolf Coffee Roasters, Arrowtown	★★★★★	(1)
WAIKATO		
The Vine Eatery, Taupo	★★	(1)
WELLINGTON		
Boulcott Street Bistro, Wellington Central	★★	(1)
Caffe L'affare, Te Aro	★★	(2)
Charley Noble, Wellington	★	(2)
Crab Shack, Wellington Waterfront	★★	(1)
Crumpet, Wellington	★★	(1)
D4, Wellington	★	(1)
Dillinger's, Wellington	★★★★	(1)
Dirty Burger, Wellington	★★	(1)
Dragon Fly, Te Aro	★★	(1)
Flamingo Joe's, Pipitea	★★	(1)
Foxglove, Wellington Central	★★★	(1)

Hashigo Zake, Wellington	★★★★★	(2)
Ivy: Underground, Wellington	★	(1)
Liberty restaurant, Wellington	★★	(1)
Logan Brown Restaurant & Bar, Wellington	★★★	(1)
Mexico, Lower Hutt	★★★★★	(1)
Neo Cafe & Eatery, Wellington	★★	(2)
Panhead Tory, Te Aro	★★★★★	(1)
Preservatorium, Wellington	★	(1)
Rosie's Red-Hot Cantina & Taco Joint, Wellington	★	(1)
Scopa Caffé Cucina, Wellington	★★	(1)
Seashore Cabaret, Petone	★★	(1)
St Johns Bar, Te Aro	★★	(1)
Te Papa Cafe, Wellington	★★★	(1)
Viva Mexico, Wellington	★★	(1)

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