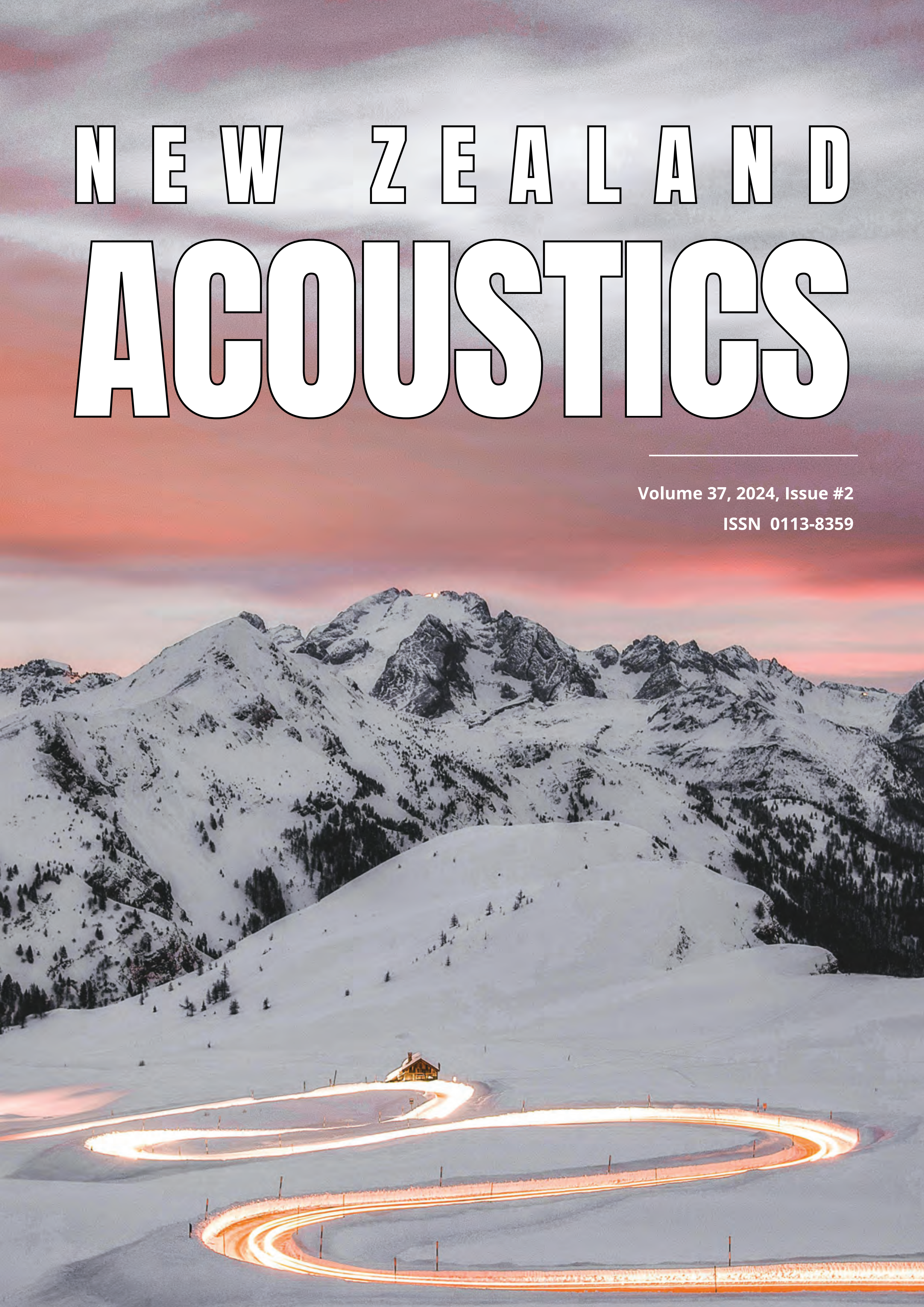
# NEW ZEALAND ACOUSTICS

Volume 37, 2024, Issue #2
ISSN 0113-8359

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# KEYNOTE SPEAKERS

**Sir Harold Marshall**
Co-Founder of Marshall Day Acoustics

**Jeffrey Mahn**
National Research Council of Canada

**Steve Dawson**
Emeritus Professor, Department of
Marine Science, University of Otago

**Felicity Hayman**
Environment and Planning Manager
Christchurch International Airport

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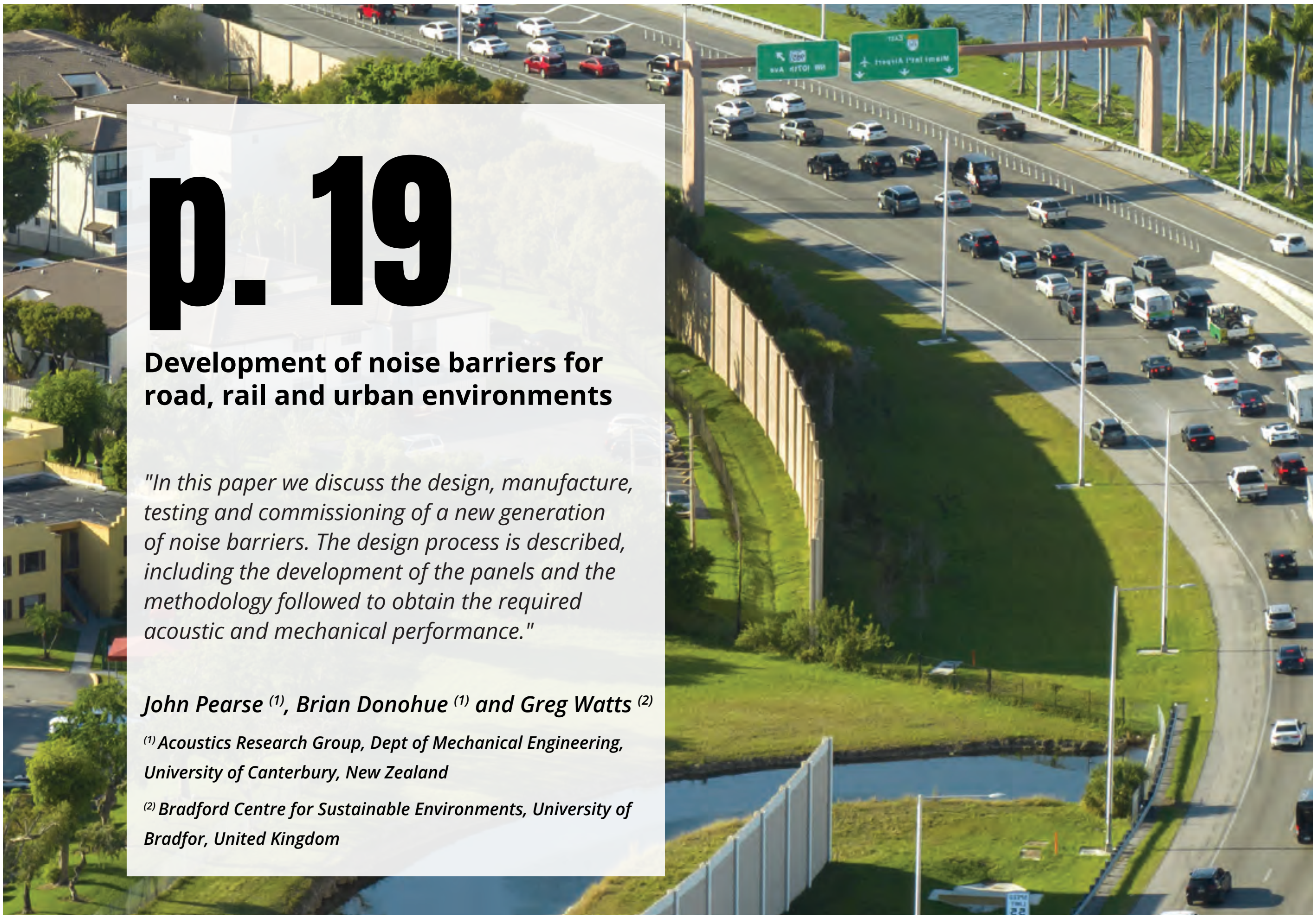

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## Development of noise barriers for road, rail and urban environments

*"In this paper we discuss the design, manufacture, testing and commissioning of a new generation of noise barriers. The design process is described, including the development of the panels and the methodology followed to obtain the required acoustic and mechanical performance."*

***John Pearse* (1)*, Brian Donohue* (1) *and Greg Watts* (2)**

(1) *Acoustics Research Group, Dept of Mechanical Engineering, University of Canterbury, New Zealand*

(2) *Bradford Centre for Sustainable Environments, University of Bradfor, United Kingdom*

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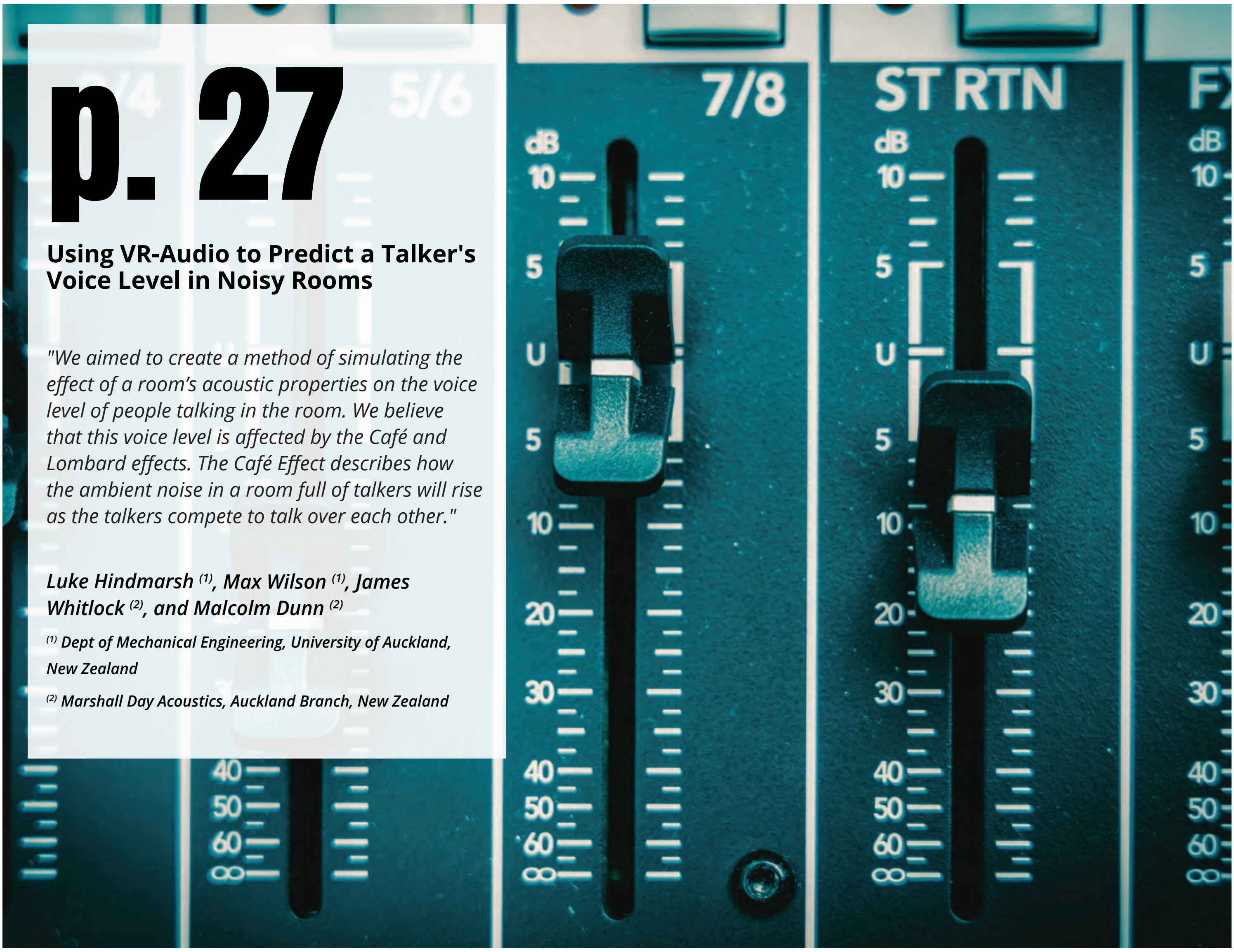
## Modelling the acoustic behaviour of porous sound-absorbing materials using the Biot theory

*"Transmission loss through a layer of porous media can be predicted by modelling the layer as an equivalent fluid."*

*George Edgar*

*Marshall Day Acoustics, 84 Symonds St, Auckland, New Zealand*



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## Using VR-Audio to Predict a Talker's Voice Level in Noisy Rooms

*"We aimed to create a method of simulating the effect of a room's acoustic properties on the voice level of people talking in the room. We believe that this voice level is affected by the Café and Lombard effects. The Café Effect describes how the ambient noise in a room full of talkers will rise as the talkers compete to talk over each other."*

*Luke Hindmarsh (1), Max Wilson (1), James Whitlock (2), and Malcolm Dunn (2)*

*(1) Dept of Mechanical Engineering, University of Auckland, New Zealand*

*(2) Marshall Day Acoustics, Auckland Branch, New Zealand*

Kia ora koutou,

I'm writing this in anticipation of the upcoming ASNZ conference in Christchurch, although you may well be reading this after the fact!

This year's conference is shaping up to be a triumphant affair, and I'd like to say a big thanks to the organising committee for their tireless efforts in bringing this event to our membership: Tracy Hilliker (chair), Mike Kingan, Mike Latimer, George van Hout, peer reviewers and all others involved. Also, thanks to Tracy Young and the team at OnCue for their assistance as conference organisers.

The conference title, *Reflecting on the past, innovating for the future*, accurately captures the key themes of the event. Set within the prestigious Christchurch Town Hall, the venue drips acoustic heritage, and is an apt setting for an acoustic conference. The Town Hall is, of course, home of the Douglas Lilburn auditorium – a concert hall of global significance that put into practice Sir Harold Marshall's concepts for spaciousness through providing early lateral reflections from the stage to the audience. For those who have not seen it yet, check out the film *Maurice and I* for a glimpse into the history and creation of the venue. Or better yet, read the 1979 paper in JSV entitled *Aspects of the Acoustical Design and Properties of Christchurch Town Hall, New Zealand or Michael Barron's book Auditorium Acoustics and Architectural Design* for a technical explanation of the hall's spatial acoustic design.

The ASNZ Council has been working away on a new, contemporary, and more user-friendly website, which is due to go public in the next couple of weeks. We have also made changes to the *ASNZ Rules* (now called *Constitution*) and the *Rules of Conduct and Disciplinary Measures*. There have been plenty of acoustics-related events happening around the country, advertised through email to our membership base as well as via the active ASNZ LinkedIn page. Get out there and join in (it will also help with your CPD points)!

It is with some trepidation that I write what will be my last journal write-up as ASNZ President, with the baton being passed onto the next worthy individual. However, I'm looking forward to many more years' involvement in the Society and plenty more paper contributions to the journal (ha, just when you thought you'd got rid of me!).

Ngā mihi,

**Tim Beresford**

Outgoing President of the Acoustical Society of
New Zealand.

Kia ora koutou,

Greetings, bienvenu, talofa and nau mai haere mai,

Welcome to the second issue of New Zealand Acoustics for 2024 (Volume 37, 2024, Issue #2).

It is that time of year where Winter is upon us and Spring is just peaking around the corner . As I write this on a cold and grey Friday afternoon I look out and see the blossoming of trees and snow on the Tararua Range. It's a good time of year to hunker down and get stuff done inside or maybe read this edition of New Zealand Acoustics.

We have our regular pieces as well as three diverse papers we recommend you all view. The first paper is on transmission loss of porous media with a second paper on noise barriers and final paper on VR- audio to predict voice levels.

As mentioned in the Presidents review this year's conference 'Reflecting on the past, innovating for the future' is soon to occur in our largest city in the South Island, the stunning garden city of Christchurch. We thoroughly recommend if able you attend. Conferences are always a great time to meet new people, make new friendships, catch up with those you know and learn a thing or two from the great range of papers that will be presented. We also wish to mimic the President's comments and take the time to acknowledge all those people that make the conference happen and all the hard work they put in.

It is Tim's last journal write up as the outgoing ASNZ President, we wish to thank Tim for his service in the role as President and all he has done for the Society during his term. The society is in a good place and a lot is going on. Tim is now the fourth President we have worked with while Editors. Wyatt and I look forward to working with the next elected President later in the year.

Ngā mihi, take care and keep warm.

**Lindsay Hannah & Wyatt Page**

Principal Editors

*Tim Beresford*

*Lindsay Hannah*

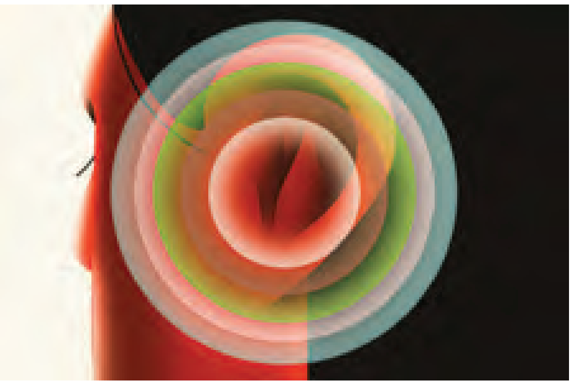
*Wyatt Page*

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

# NEWS

## Another Mystery Hum: Council could call in noise specialists

https://www.bbc.com/news/uk-northern-ireland-67410171



## Beyond white noise: How different 'color' sounds help or hurt

https://www.washingtonpost.com/home/2023/10/09/white-noise-color-sounds-brown-pink/

## Businessman and his wife are awarded £16k after judge ruled City banker's family upstairs left them suffering 'unbearable' noise

https://www.dailymail.co.uk/news/article-12747283/Victory-millionaire-couple-sued-neighbour-noisy-wooden-floor-Businessman-wife-awarded-16k-judge-ruled-City-bankers-family-upstairs-left-suffering-unbearable-noise-1m-Kensington-flat.html

## Hera asteroid mission hears the noise

https://www.esa.int/Space_Safety/Hera/Hera_asteroid_mission_hears_the_noise

The European Space Agency has reported that the Hera asteroid mission has completed acoustic testing, confirming the spacecraft can withstand the sound of its own lift-off into orbit. Testing took place within the Agency's Large European Acoustic Facility at the ESTEC Test Centre in the Netherlands. This is Europe's largest and most powerful sound system, fitted with a quartet of noise horns that can generate more than 154 decibels of extreme noise.

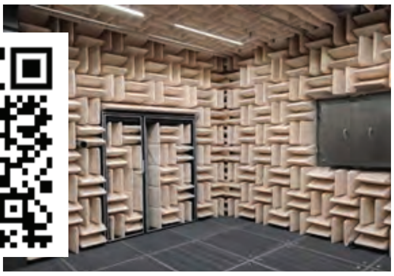
## How restorers are making the Notre Dame Cathedral sound the same after restoration

NPR have reported on the reconstruction of Paris' Notre Dame Cathedral, which was heavily damaged by a fire in 2019, includes an effort to restore its unique acoustics.

https://www.npr.org/2023/11/06/1211025654/how-restorers-are-making-the-notre-dame-cathedral-sound-the-same-after-restorati

## The Loudest Sound In The Quietest Room

https://www.youtube.com/watch?v=EBClzOM_Lbw&list=WL&index=14

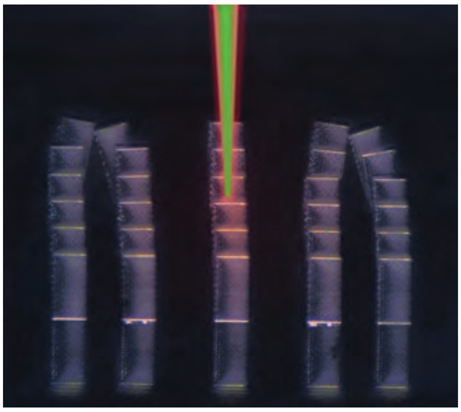


## New acoustic device to deter orcas to be tested in Portuguese waters

https://www.sailworldcruising.com/news/268703/New-acoustic-device-to-deter-orcas-to-be-tested

## New study highlights key benefits of reducing underwater radiated noise

https://safety4sea.com/new-study-highlights-key-benefits-of-reducing-underwater-radiated-noise/



## New technique could speed up the development of acoustic lenses, impact-resistant films and other futuristic materials

https://phys.org/news/2023-11-technique-acoustic-lenses-impact-resistant-futuristic.html

# Noise row silences 200-year ringing of Beith church bell

The BBC have reported a church bell that sounded every hour for more than 200 years has been silenced after a noise complaint. The 24-hour ringing at Beith Parish Church in Ayrshire was stopped after a resident told council environmental health their sleep had been disturbed. The Church of Scotland has now stopped the bell between 23:00 and 07:00. A petition to restore the 24-hour chime has gathered more than 900 signatures. Organisers say the tradition is part of the Beith's "history and heritage". What do you think?

https://www.bbc.com/news/uk-scotland-glasgow-west-67427442

# Study shows Ancient Theatre of Epidaurus is world's most perfect in terms of aesthetics and acoustics

https://greekcitytimes.com/2023/11/15/theatre-of-epidaurus-acoustics-world/

# Taupō DB Drag racing: Loud car stereos take noise to the next level

https://www.nzherald.co.nz/waikato-news/news/taupo-db-drag-racing-loud-car-stereos-take-noise-to-the-next-level/MMK2DUDRTVH53LK76STKCGLG34/

# The Las Vegas Sphere flexed its size and LED images. Now it's teasing its audio system

https://www.usatoday.com/story/tech/news/2023/07/24/msg-sphere-las-vegas-teases-most-advanced-audio-system/70460205007/

# ASNZ Fellowships

*The ASNZ bestowed fellowships upon Mark Poletti and Nigel Lloyd on 9th May at a well-attended evening event at Foxglove in Wellington. Read on for a summary of the encomia presented at the event.*

---

## Mark Poletti

Mark Poletti is an exceptional mind and a great contributor to the field of acoustics, globally.

He received his BSc in Physics in 1982, master's degree in physics in 1984, and PhD in Acoustics in 2001, which won him the prize from the University of Auckland for the best PhD thesis.

He worked for several years as the technician for the University of Auckland's Acoustics Testing Service in the late 1980's where he wrote - from scratch - the computer programs for all of the commercial testing to ISO standards. These programs were used until they were replaced by Brüel & Kjær large analysers, however, Mark compared his program for RT measurement to the B&K results and found they did not match. He eventually challenged B&K and proved that it was their software that was in error prompting a withdrawal and reissue by B&K.

During this period of work at the University, Mark began research leading to his PhD, looking at the possibility of using electro-acoustical techniques for enhancing and varying the acoustics of passive concert halls. This led to the development of the Variable Room Acoustics system which saw its early experimental adoption in the Adam Concert Room in Victoria University of Wellington. Since then, Mark's VRA system has been licenced to Meyer Sound and renamed Constellation.

Mark has spent a long career in research at Industrial Research Limited, then Callaghan Innovation, before recently branching out as an independent consultant. He has accrued a succession of national awards international recognition for his academic publications.

Mark pursues a range of hobbies, many of which focus on signal processing and maths applied to audio products (e.g. guitar amplifiers with sophisticated distortion, synthesizers, etc.). But in addition, he has found time to write a couple of fantasy books and issue several CDs featuring him as singer and guitar player.

For the Acoustical Society, Mark he served both as council member and vice-president from 2000-2012.

Mark Poletti's technical achievements in the field of acoustics are an inspiration. His understanding of physical acoustic and signal processing mathematics are extraordinary and his ability to apply these principals to solve real-world problems is what sets him apart from so many other acoustical academics and scholars. His contributions, not only to the Society, but also to the promotion of field of acoustics, as a whole, are significant. He is a worthy recipient of his ASNZ fellowship.

*Credit to George Dodd for preparing this information about Mark Poletti.*

## Nigel Lloyd

Nigel Lloyd is a progenitor of New Zealand Acoustics, and one of the early acoustic consultants in this country. He graduated from the University of Wales College, Cardiff. After two years as an acoustic consultant at the Industrial Acoustics Company, he moved to New Zealand in 1977 and spent 5 years as the Department of Labour as a noise control engineer. In 1984 he went on to found Acousafe - the consulting firm he has led ever since.

Nigel is an easy going, thoughtful guy, and always good for a chat. He's knowledgeable and willing to challenge his peers, but always with a twinkle in his eye. Peers will go hammer and tongs with Nigel all day in a hearing, over some acoustic matter or another, then enjoy a beer with him afterwards.

Nigel is said to be family man and has a family band. He is also a very keen yachtie and commodore of the local yacht club.

Nigel's involvement with the Acoustical Society is as follows:

He joined the Society Council in 1988 and was elected Vice President - North Island the next year. The year after that (1990) he was elected President. He kept that role for 3 years before returning as Vice President again in 1993, and then staying on as a Council member again from 1994 - 95. He was also back on the Council in 1999.

The Society has agreed to elevate him to Fellowship status on account of his long-standing service on the Council, as President and Vice President, and for his contribution to the acoustic consulting profession in New Zealand.

Credit to James Whitlock for preparing this information about Nigel Lloyd.

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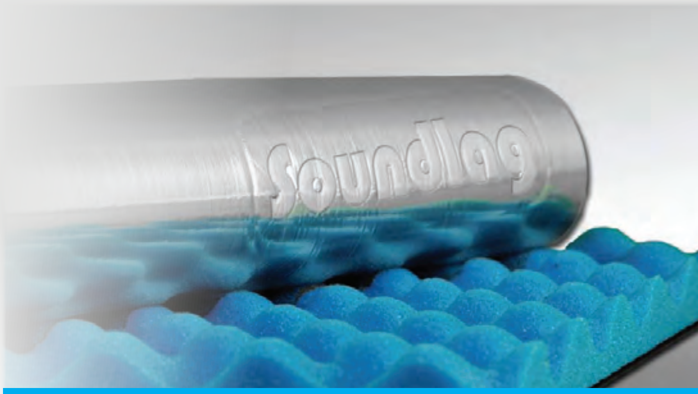

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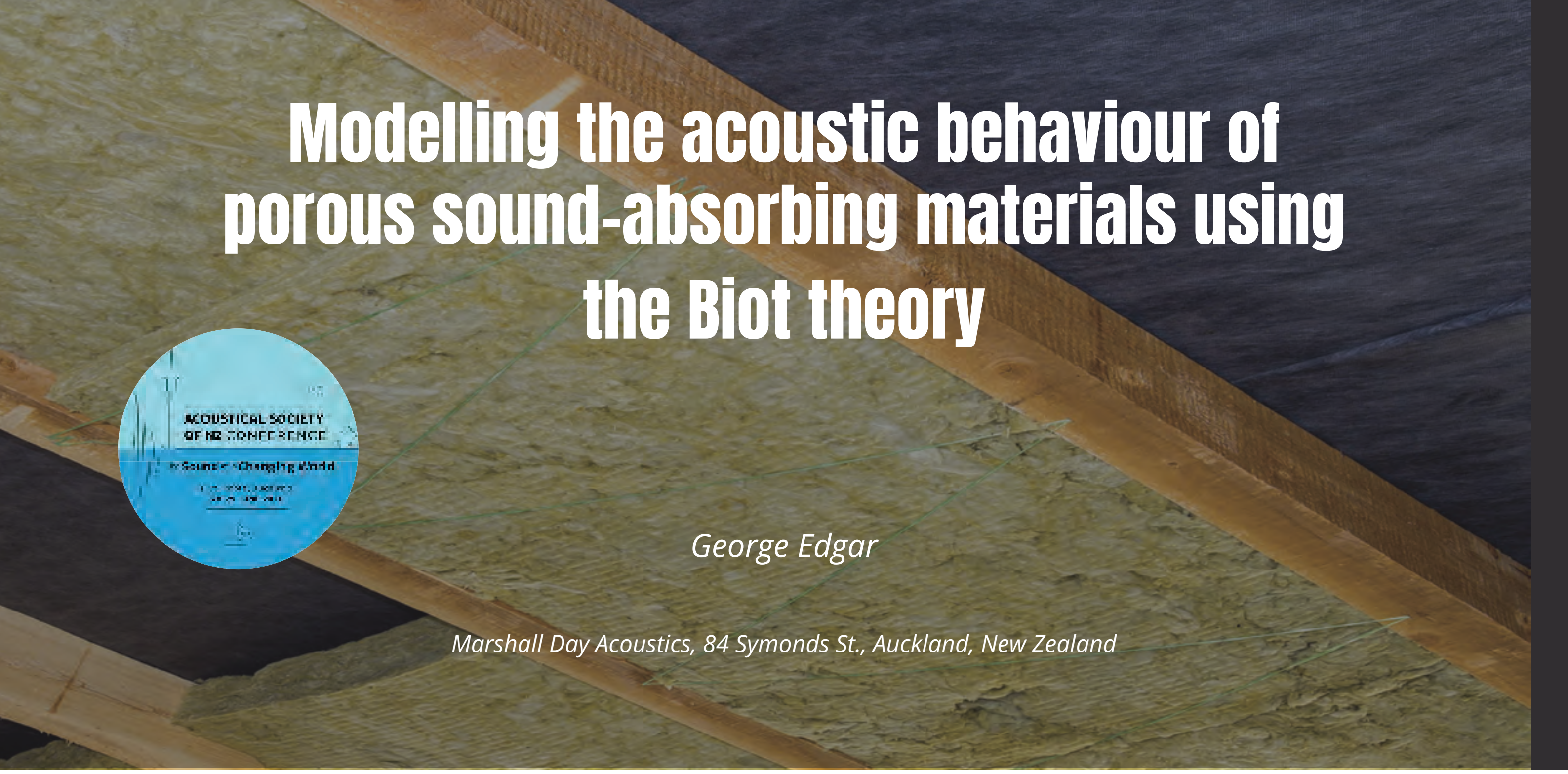

# Modelling the acoustic behaviour of porous sound-absorbing materials using the Biot theory

*George Edgar*

*Marshall Day Acoustics, 84 Symonds St., Auckland, New Zealand*

## Abstract

Transmission loss through a layer of porous media can be predicted by modelling the layer as an equivalent fluid. The porous frame is considered limp or rigid so that only one wave propagates through the medium. Though equivalent fluid models are mathematically simple, they do not consider the important interaction between fluid and frame, and hence their ability to predict transmission loss is limited. The Biot theory of poroelasticity considers the coupling between frame and fluid, resulting in 3 waves propagating through the medium: a frame-borne and an airborne compressional wave and a frame-borne shear wave. An analytical model based on Biot theory is presented for the modelling of a porous layer, of infinite lateral dimensions, bonded to a concrete slab. Results from researchers utilizing this model to predict the sound transmission loss of a dense rockwool on a concrete backing are presented. The results are compared to predictions based off the equivalent fluid model, and to experimental results demonstrating the increased accuracy of using the Biot theory. The model is then used to predict the normal incidence surface impedance of a dense porous material. Further research goals to utilise the Biot theory for more complicated acoustical systems are discussed.

## 1. Introduction

Porous sound absorbing materials, such as rockwool, glass wool and fibrous polyester are commonly used in building acoustics (Horoshenkov et al. 2007). Because of this, the accurate prediction of their acoustical properties is an important aspect of sound insulation theory. Various models have been developed that attempt to predict the behaviour of porous media (Allard and Atalla, 2009), to varying levels of success. There are three key models used commonly in acoustics research (Dazel, 2011). One approach is to model the medium as an equivalent fluid and assume the solid frame is motionless. This results in only one compressional wave in the system. The conditions where this model is appropriate are demonstrated in section 3.1. Another approach is to model the system as having a limp frame, so that the frame is moving but it's elastic effects are negligible (Panneton, 2007). For this model too, only one compressional wave exists. These models are effective when the acoustic wavelengths are much larger than the dimensions of the pores that allow fluid flow through the solid frame (Allard and Atalla, 2009). The limp model is accurate when the porous frame is of a low density, and similarly, for a frame of very high stiffness, the rigid frame model applies. The high density media, such as rockwool, that are of interest to this project, require the vibrations of the solid frame to be taken into account. The Biot theory states that there are three waves propagating in a porous medium, two compressional and one shear wave (Allard and Atalla, 2009). This model has been developed since it's inception in 1956 and it's effectiveness for predicting the behaviour of high density sound absorbing materials is presented in this report.

## 2. The Model

The model used here assumes the porous media to be homogenous and isotropic. However, Biot theory has also been used to model transverse isotropy in porous materials (Allard and Atalla, 2009., Dazel, 2011). The Biot theory has been presented in various ways (Biot, 1962., Dazel, 2011., Atalla *et al.* 1998), and in this report, the formulation using the solid displacement and total displacement – that of the solid and fluid together – pair is utilized to predicit the normal incidence sound absorption coefficient of a dense mineral wool. This formulation was first presented by Dazel, Brouard, Depollier and Griffiths (2007). It is equivalent to the original formulation by Biot, but is mathematically more simple and allows the continuity relations between layers of different materials to be written more succinctly. The Transfer Matrix Method (TMM) has been widely used to solve transmission loss problems using Biot theory (Allard and Atalla, 2009., Dazel, 2011., Chene and Guigou-Carter, 2008) and can account for diffuse field simulation. For normal incidence modelling situations, the shear wave is not present and so a simplified, one dimensional model can be utilised to achieve good results, as presented in the surface impedance section. The model takes as inputs density, elastic modulus, flow resistivity, porosity, viscous and thermal characteristic length, loss factor, Poisson's ratio, high frequency limit of tortuosity (Allard and Atalla, 2009). Measurements of these parameters are not standardised and can be hard to come by. However various methods have been proposed for their measurement (Allard and Atalla, 2009, Doutres *et al.* 2010). Most of these parameters can be estimated quite easily based on the type of material being considered or calculated from other known parameters (Kováčik, 2001).

# 3. Transmission Loss

## 3.1 Application of the equivalent fluid model

As stated earlier, the equivalent fluid model can be used as an approximation when the porous material is of a low density and sufficiently limp. To demonstrate a case where this model is sufficiently accurate, third octave band transmission loss measurements of a simple acoustical system were compared with predicitions that utilise the equivalent fluid model. The system is consists of two 13mm layers of Knauf Soundshield plasterboard screw fixed at 300mm centres to studs of a timber frame. The frame has dimensions 90mmx45mm with studs at 600mm. One 83mm layer of rockwool with a density of *32kg/m*$^2$ (Bradford R2.2 Soundscreen) is infilled within the frame. The predicition considers only the two layers of plasterboard attached to the rockwool without a frame. Figure 1 shows the results.

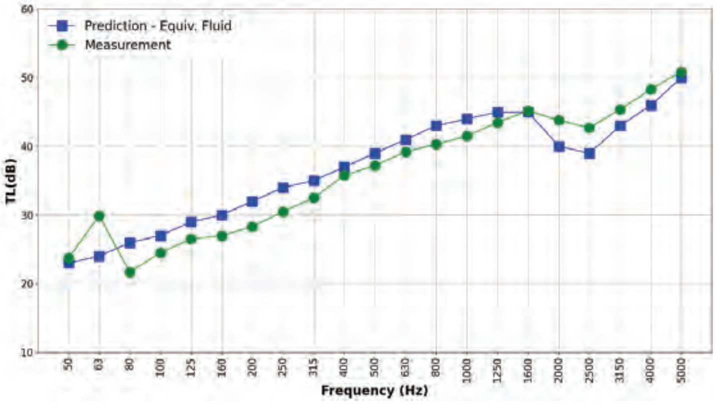

Figure 1: Transmission loss predicitions and measurements of a rockwool layer on a plasterboard backing

The predictions fit the trend of the measurements for frequencies above 100Hz, including predicting the dip in tansmission loss around 2500Hz. Below 100Hz we observe a larger difference between measurements and predicitions, but this region can be discounted because of the uncertainties regarding the sizes of the sample and measurement chambers. Up to 1600Hz the predictions are higher than the measurements, which may be due to sound radiation from the timber frame. Above 1600Hz we see the predictions drop below the measurement values. At these high frequencies, the system becomes sensitive to damping effects and this could be the reason for the difference (the measured system may have more damping than the model). For porous materials with densities around, the equivalent fluid model is shown to be appropriate for analyzing acoustic performance.

## 3.2 Application of the Biot model

This section compares the third octave band transmission loss predictions using the Biot theory, and an equivalent fluid model to measurements taken by Chene and Guigou-Carter (2008). The system consists of a 160mm concrete floor slab poured onto a 100mm rockwool layer of approximate density 110kg/m$^3$. The prediciton made using Biot theory were done by Chene and Guigou-Carter (2008), who used a TMM approach with spatial windowing to account for the finite width of the layer. The equivalent fluid model predictions were calculated using in-house software. Figure 2 shows the results.

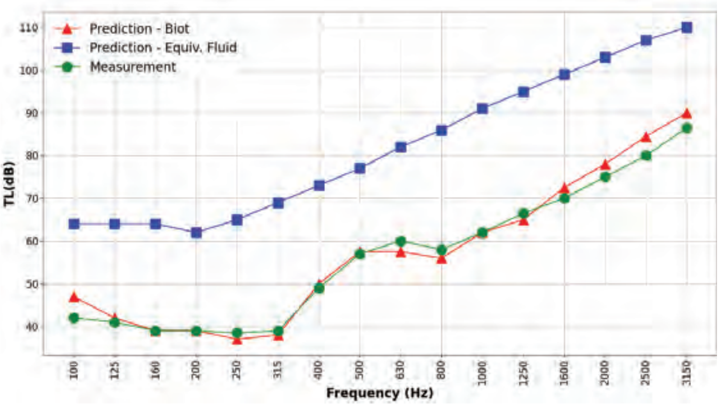

Figure 2: Transmission loss predicitions and measurements of a rockwool layer on a concrete backing

We see that the predicitions based off Biot theory are a much better fit to the experimental results than the equivalent fluid predicitions. The Biot model, accounting for the movement of the frame, is able to predict the effect of the quarter wavelength resonance of the frame-borne compressional wave that the equivalent fluid model cannot. The quarter wavelength resonance, taken from Allard and Atalla (2009) is given by equations 1 and 2. For the rockwool considered, it is approximately 500Hz, which is confirmed by the peak in the transmission loss for the Biot prediction and the measurememnts around this frequency. The equivalent fluid model, considering the material as a dense fluid, predicts a much greater transmission loss than is measured, again because it doesn't account for sound transmission through the fibrous solid skeleton of the porous material.

$$f_r = \frac{1}{4l}\sqrt{\frac{Re(K_c)}{\rho_1}} \qquad (1)$$

$$K_c = \frac{2(1-\nu)N}{(1-2\nu)} \qquad (2)$$

Here, $l$ is the thickness of the frame, $\rho_1$ is the density, $K_c$ is the elasticity of the frame in a vacuum, $\nu$ is the Poisson coefficient and $N$ is the shear modulus of the porous material.

# 4. Normal Incidence Surface Impendance

The author has has implemented a Biot model formulation for normal incident plane waves. To test this model with a simple case, it was used to predict the surface impedance of a dense porous material with a rigid backing. The rigid backing assumption means that the velocities of the backing and porous layer at their interface are both zero. This leads to a formula for calculating the surface impedance, defined as the ratio of the velocity of air particles over pressure of the air at the air-porous interface. The mathematics behind the method is described in Allard and Atalla (2009) and Dazel (2011). The model has been used to predict the normalized surface impedance of a dense glass wool described in Allard and Atalla (2009). The predicitions using both the Biot model and the equivalent fluid model are compared to measurements taken by Allard *et al.* (1991). Table 1 gives the parameters used for the predictions.

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| $l(mm)$ | $\rho_1(kg/m^3)$ | $\sigma(rayl/m)$ | $\phi$ | $\Lambda(\mu m)$ | $\Lambda'(\mu m)$ | $\alpha_\infty$ | $N(MPa)$ | $\nu$ | $\eta_s$ |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 130 | 40000 | 0.94 | 56 | 110 | 1.06 | 2.2+0.22i | 0 | 0.1 |

Table 1: Paramaters used to describe the glass wool

$l$ is the thickness, $\rho_1$ the density and $\sigma$ the airflow resistivity. The parameters $\phi$, $\Lambda$, $\Lambda$^', $\alpha_\infty$, N, $\nu$ and $\eta_s$ are the porosity, viscous and thermal characteristic lengths, high frequency limit of tortuosity, shear modulus, Poisson's coefficient and structural loss factor respectively. By setting the Young's modulus to $1\times10^{20}$ $Pa$ the rigid frame limit was obtained and the surface impedance using the equivalent fluid model was predicted. Figure 3 shows a comparison between the two predicitons and the measured results.

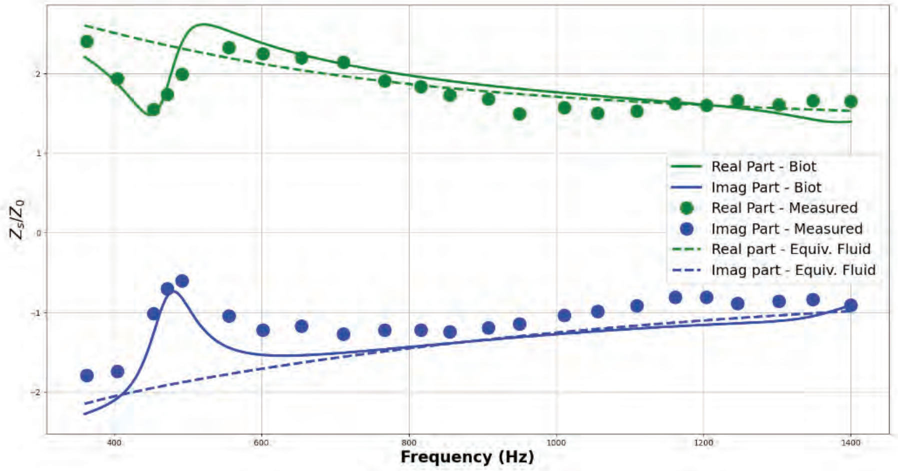

Figure 3: Normalized surface impedance predicitions and measurements of a glass wool in a free-field

Again, we see that the quarter wavelength resonance of the frame-borne wave is predicted by the Biot model and does not show up in the equivalent fluid model predictions. This illustrates the necessity of the Biot model for predicting the acoustic performance of dense porous materials.

## 5. Research Aims

The current method for predicting surface impedance for normal incidence plane waves shows a good level of agreement with experimental measurements but is limited in it's use for building acoustics. The aim of this research project is to develop a Biot model method for predicting the sound transmission loss of high density porous media in various real world applications. The Biot model has proved to be an effective way of modelling rockwool in full contact with a concrete slab but when the rockwool is attached by a set of metallic anchors, the predictions are less satisfactory (Chene and Guigou-Carter, 2008). Once the model for predicting transmission loss of a porous material in full or no contact with it's backing has been developed, the metallic anchor case will be investigated. We have experiments planned in February to measure the transmission loss and absorption coefficients of a variety of porous media setups. The experiments will be done in sound insulation test chambers using a diffuse sound field incident on 10m$^2$ samples of rockwool, and dense fiberglass. Tests with and without metallic anchors will be conducted and once the model has been developed, the measurements will be compared with model predicitions to determine the effectiveness in real world situations.

## 6. Conclusions

The Biot model for the acoustic field of a porous material has been shown to be more effective than the older equivalent fluid models for prediciting the acoustic performance of high density porous sound absorbers. The model describes three waves propagating in the medium, a frame-borne and airborne compressional wave and a shear wave. The older equivalent fluid models only describe one compressional wave. As a result the behaviour of the porous medium is better described by the Biot theory across the audible frequency range, especially where the frame-borne resonances come into effect. The future aims of this project are to use the biot theory to accurately predict the acoustic performance of high density porous media in cases common to the building acoustics industry. These include, dense rock or glass wools in full contact with a solid or attached by a series of metallic anchors.

## Acknowledgements

I would like to thank Grant Emms, Dan Griffin and Keith Ballagh for their ongoing support and encouragement. Also thank you to Catherine Guigo-Carter for her willingness to answer my questions from halfway across the world. Thank you to Marshall Day Acoustics for employing me to do this research and to Callaghan Innovation for funding the project.

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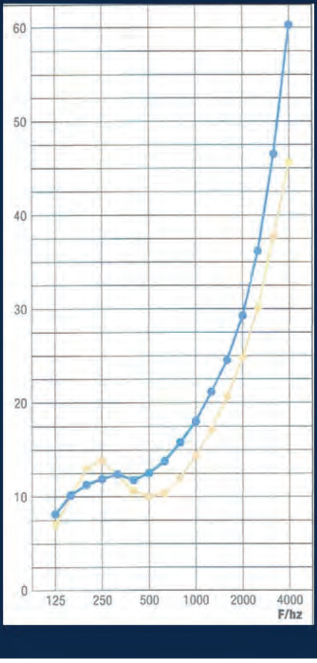
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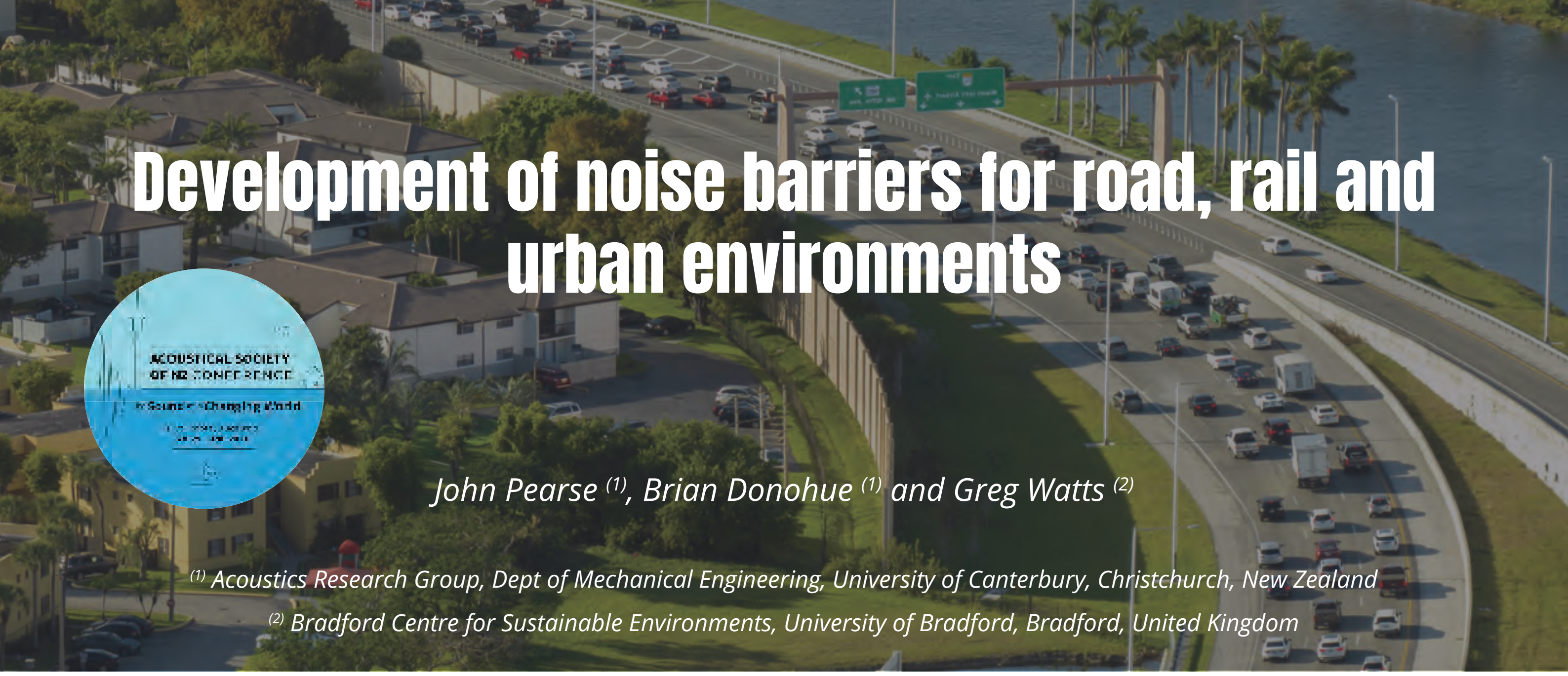

# Development of noise barriers for road, rail and urban environments

*John Pearse* (1)*, Brian Donohue* (1) *and Greg Watts* (2)

(1) *Acoustics Research Group, Dept of Mechanical Engineering, University of Canterbury, Christchurch, New Zealand*

(2) *Bradford Centre for Sustainable Environments, University of Bradford, Bradford, United Kingdom*

## Abstract

In this paper we discuss the design and development of a new generation of innovative and environmentally friendly noise barriers. The various methods for achieving the design requirements were identified and evaluated. The selected method of fabrication was rotational moulding of polyethylene, producing interlocking panels that fit into steel columns. The advantages of the resulting system include a low installed cost, a completely recyclable product, possibility of producing a variety of surface textures (including embossing), and the ability of meet a 50 year life. Installation costs are significantly reduced by the relatively long panels and ease of installation. The panel surface is very hard and not amenable to etching. The product development process is described with particular attention to obtaining the required acoustic performance and wind-load ratings. Future developments in terms of enhanced acoustic performance are identified and discussed.

## 1. Introductions

In this paper we discuss the design, manufacture, testing and commissioning of a new generation of noise barriers. The design process is described, including the development of the panels and the methodology followed to obtain the required acoustic and mechanical performance.

## 2. Design Considerations

The noise barrier requirements were to obtain a minimum sound tranmission loss rating of Rw 25 with a system with a minimum of components, that could be easily and quickly installed. Other requirements included a 50 year design life and a surface that is easy to clean and graffiti resistant. An interlocking panel concept was selected that enabled the design requirements to be met in an effective way.

### 2.1 Sound absorption

Whilst recognising that sound absorption would be a necessary characteristic to include, it was not part of the original design brief. Several options were considered at the design stage however, with a mind to make inclusion an easy option at a later stage.

### 2.2 Sound transmission loss

The sound transmission loss was set at a minimum desired rating of D3 according to EN 1793-6 (2012) and would be determined in accordance with the in-situ methodologies described in this standard.

### 2.3 The panels

A panel concept was selected that facilitates a modular construction with installation advantages and enables individual components to be readily replaced in case of damage. The panels are light weight so a crane is not required for installation with consequent cost savings. Although each panel is only 50 kg using two people makes installation easier as the panel length can be up to four metres. The ends of the panels are shaped so that they slide over the flange of a standard I-beam or column providing an acoustic seal. The top and bottom of each panel are also shaped so that they interlock when stacked. Having carried out in-situ evaluations of several different types of road traffic-noise barrier we recognised that leakage at the joints with the supporting posts degraded the performance of the system.

### 2.4 The posts

Steel columns with a standard I-section were selected for reasons of cost and availability. This also enabled the system wind loading requirements to be met. The columns are set in concrete in the ground and galvanised to resist weathering effects.

### 2.5 Materials

Polyethylene was selected as the material of choice as it has many advantges over the more traditional materials used such as timber, concrete and acrylic. This choice was founded on our experience in developing hermetically sealed panel absorbers for use as hygenic ceiling tiles.

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Photo credit: T Williams and G Moon

### 2.6 Fire rating

The base polyethylene resin meets the flammability requirement of UL 94HB. In laymen's terms, it cannot be ignited by a cigarette lighter. A higher flammability rating can be obtained by employing additional flame retardants.

## 3. Manufacturing Considerations

The lowest cost method for processing polyethylene is rotational moulding. This process is traditionally used for products of symmetrical form such as cyclinders and is widely used for manufacture of water storage tanks. By controlling the way heat flows around the mould various shapes can be moulded. Popular non cylindrical shapes include kayaks, surfboards, pump housings, road traffic safety and crash barriers. Tooling is a lot less costly than injection moulding and incorporation of surface features in the product are easily catered for.

## 4. Barrier Evaluation

### 4.1 Simulation

The sound absorption and transmission loss were predicted together with the wind loading.

### 4.2 Test facility

A dedicated test facility with a length of four panels and a height of four metres was constructed.

The method used for evaluating the transmission loss of the barriers was an in-situ method described in BS EN1793-6 (2012). The measurement equipment consisted of:

- An array of nine Bruel & Kjaer type 4189 ½" microphones, mounting frame and tripod
- A loudspeaker (12 inch, 600W) and tripod
- An amplifier and power supply for the loudspeaker
- A Bruel & Kjaer PULSE C-frame for data acquisition and signal processing
- Test signal (MLS or swept sine)
- A laptop computer

A diagram of the measurement set-up is shown in Figure 1 and a photograph of the microphone array in-situ is shown in Figure 2. A similar test without the barrier present was also carried out in order to calculate the transmission loss.

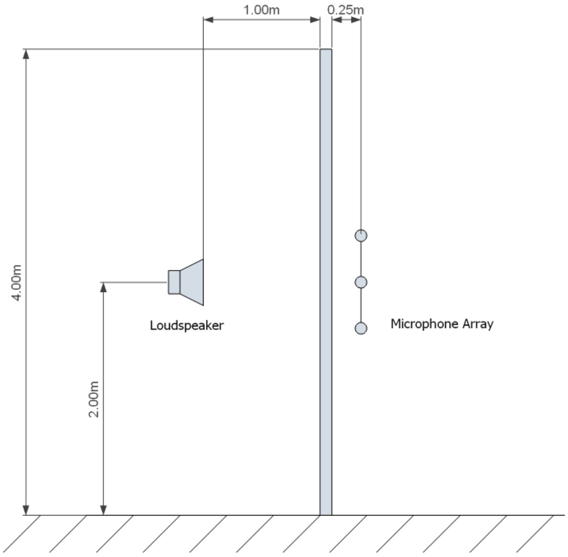

Figure 1: Schematic of in-situ test arrangment

Figure 2: Microphone array in position for in-situ testing

### 4.3 Wind loading

In Australasia, designs for noise barriers must include for wind loading as a structure using the joint standard AS/NZS1170.2:2021 Structural design actions, Part 2: Wind actions. The design procedure begins by defining a wind action W, which has two components: Wu and Ws, the regional wind actions for annual probability of exceedance (*P*) for ultimate and serviceability states. In this procedure, the regional wind speeds (VR) have to be selected based on where the barrier is to be installed. The site wind speed (Vsit,β) is then determined from the regional wind speed modified to account for terrain factors. The design wind speed (Vdes, θ) is taken as the maximum cardinal site wind speed interpolated within a ±45° range to the orthogonal direction being considered. The design wind pressures and distributed forces are then found from the design wind speed and then the wind actions are calculated. Thus each installation is site specific and referring to Table.1 it can be seen that the regional wind speeds vary between 30 to 69 m/s for non-cyclonic regions, corresponding to 108 km/h to 240 km/h.

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| Regional wind speed (m/s) | Region |  |  |  |  |
|---|---|---|---|---|---|
|  | Non-cyclonic |  |  | Cyclonic |  |
|  | A (1-7) | W | B | C | D |
| $V_{1}$ | 30 | 34 | 26 | 23 x Fc | 23 x Fc |
| $V_{5}$ | 32 | 39 | 28 | 33 x Fc | 35 x Fc |
| $V_{10}$ | 34 | 41 | 33 | 39 x Fc | 43 x Fc |
| $V_{20}$ | 37 | 43 | 38 | 45 x Fc | 51 x Fc |
| $V_{25}$ | 39 | 43 | 39 | 47 x Fc | 53 x Fc |
| $V_{50}$ | 41 | 45 | 44 | 52 x Fc | 60 x Fc |
| $V_{100}$ | 43 | 47 | 48 | 56 x Fc | 66 x Fc |
| $V_{200}$ | 43 | 49 | 52 | 61 x Fc | 72 x Fc |
| $V_{250}$ | 43 | 49 | 53 | 62 x Fc | 74 x Fc |
| $V_{500}$ | 45 | 51 | 57 | 66 x Fc | 80 x Fc |
| $V_{1000}$ | 46 | 53 | 60 | 70 x Fc | 85 x Fc |
| $V_{2000}$ | 48 | 54 | 63 | 73 x Fc | 90 x Fc |
| $V_{2500}$ | 48 | 55 | 64 | 74 x Fc | 91 x Fc |
| $V_{5000}$ | 50 | 56 | 67 | 78 x Fc | 95 x Fc |
| $V_{10000}$ | 51 | 58 | 69 | 81 x Fc | 99 x Fc |

Table 1: Regional Wind Speeds

The design wind speed is modified by factors related to the structure and its dynamic response to fluctuations in the wind. The design wind pressure is then calculated and applied normal to the barrier surface for calculation of stresses and deformations. Barriers to be installed in regions where cyclonic conditions can be expected are also subject to an assessment for fatigue loading.

# 5. Validation

## 5.1 Acoustic performance

The transmission loss of the barrier is shown in Figure 3 below.

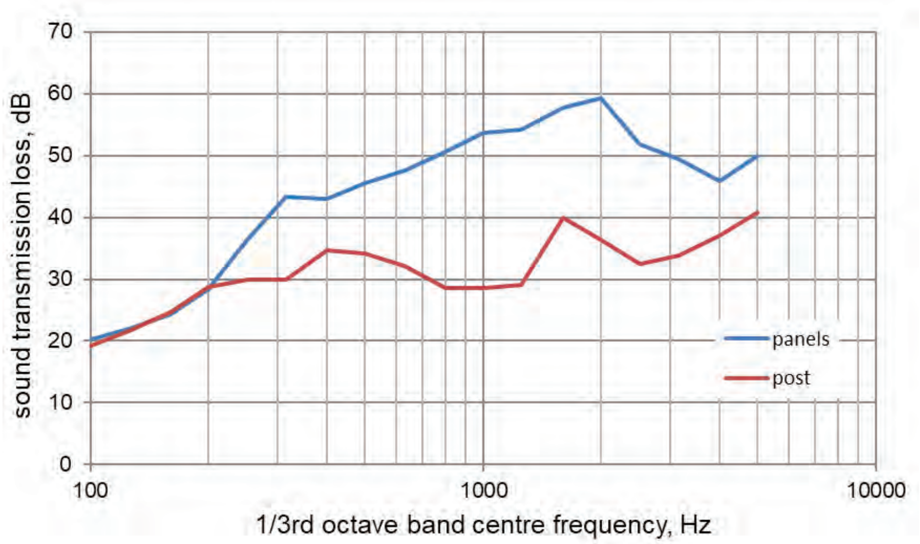

Figure 3: In-situ sound transmission loss

The results indicate that the barrier system complies with category D3 according to Appendix A of BS EN1793-6 (2012). Whle the transmission loss provided by the panels falls in the D3 category and a small increase in their thickness would increase their transmission loss and tip them into the D4 category.

Following BS EN 1793-1 (2017) method the sound absorption obtained from reverberation room measurments for an early version of the moulded panels is shown in Figure 4 below.

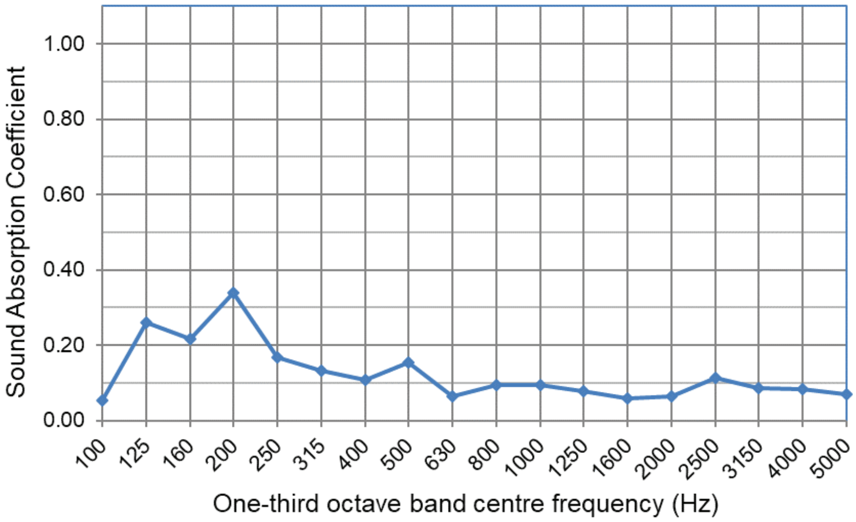

Figure 4: Sound absorption coefficients of sample road traffic barrier

### 5.1 Wind loading

An analysis of stress and deflection of the noise barrier was conducted for application in regions where the wind speed does not exceed 150 km/h, corresponding to $V_{100,}$ which applies to all areas of New Zealand except Wellington. The elements of the barrier were modelled using Solid Works and assembled into a model for analysis using ANSYS.

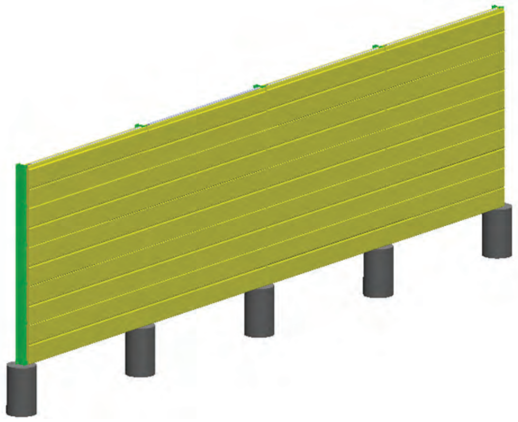

Figure 5: Solid Works model of a 4-bay noise barrier, 4 m high

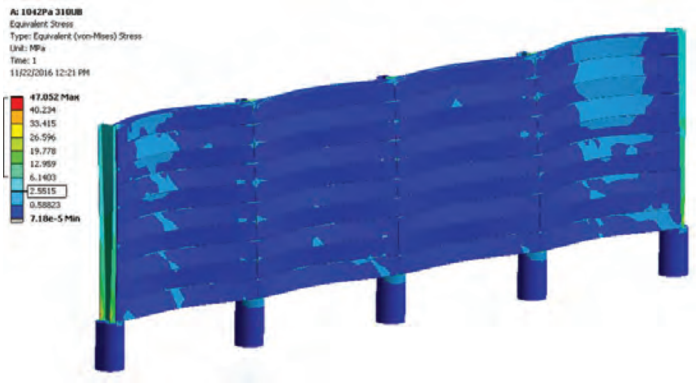

Figure 6: Stress distribution for model exposed to 150 km/h steady wind load

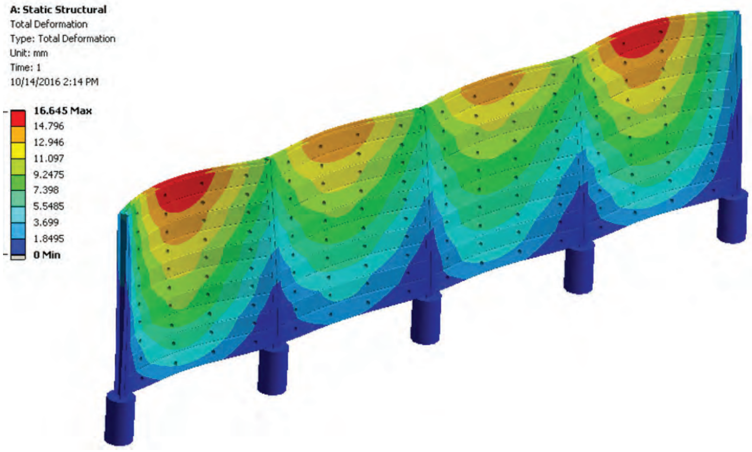

Figure 7: Deflections in model exposed to 150 km/h steady wind load

Studies were also carried out for different size columns (for lower wind loading regions) and for cases including stiffeners layed horizontally between each 'plank'.

Mechanical tests incuded static loading (Figure 8), impact testing (Figure 9), and for knife and graffiti damage.

Figure 8: Load testing of a panel

Figure 9: Impact testing of a panel from 3 m

## 6. Conclusions

The barrier system that has been developed has a number of attractive features that include ease of manufacture and installation. The panels are easily tailored in terms of surface features and have an attractive life cycle cost.

A capping to increase the transmission loss for a given barrier height, increasing the sound absorption provided by the barrier and enabling vegetation to grow within the barrier (living wall) to improve the visual aspects of the barrier are being developed..

## Acknowledgements

The support of Advanced Rotational Moulding Ltd is gratefully acknowledged.

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BS EN 1793-6 (2012): Road traffic road traffic noise reducing devices – Test method for determining the acoustic performance – Part 6: Intrinsic characteristics – in situ values of airborne sound insulation under direct sound field conditions

BS EN 1793-1 (2017): Road traffic road traffic noise reducing devices – Test method for determining the acoustic performance – Part 1: Intrinsic characteristics of sound absorption under diffuse sound field conditions

AS/NZS 1170.2 (2011): Structural design actions Part 2: Wind actions

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# Using VR-Audio to Predict a Talker's Voice Level in Noisy Rooms

*Luke Hindmarsh*[(1)]*, Max Wilson* [(1)]*, James Whitlock* [(2)]
*and Malcolm Dunn* [(2)]

[(1)] *Department of Mechanical Engineering, University of Auckland, New Zealand*

[(2)] *Marshall Day Acoustics, Auckland Branch, New Zealand*

## Abstract

We aimed to create a method of simulating the effect of a room's acoustic properties on the voice level of people talking in the room. We believe that this voice level is affected by the Café and Lombard effects. The Café Effect describes how the ambient noise in a room full of talkers will rise as the talkers compete to talk over each other. This phenomenon is driven by the Lombard Effect, which describes how a person will raise their voice if they cannot hear themselves or feel like they cannot be heard. Current models of both phenomena are limited by test conditions that are either impossible to replicate consistently or poorly represent real-life situations. To avoid using models of either phenomenon, this paper proposes the use of a human-in-the-loop system for simulating their effects. The system is comprised of any number of virtual talkers positioned throughout a simulated room, creating a realistic soundscape. A test subject hears this soundscape through a surround sound loudspeaker array. As the subject talks, the ambient noise of the soundscape will elicit a Lombard response from the subject. This Lombard response is measured using a microphone and the virtual talkers mimic this response, creating a simulation of the Café Effect. Our simulation shows proof of concept, with all test results being within a decibel of experimental models of room sound level. This suggests that the assumptions of our simulation are valid, however more comprehensive investigation is needed.

## 1. Introduction

When a large number of people occupy a room, the noise sound pressure level (SPL) of the room will rise as people raise their voices to be heard over each other. This phenomenon is called the Café Effect. The high level of noise produced by the Café Effect necessitates a large vocal effort from the talkers to be heard and reduces speech intelligibility for listeners. The main driver of the Café Effect is the Lombard Effect (Whitlock and Dodd 2008, Rindel 2012). Current understanding and models of these two phenomena limit how well spaces can be optimised to minimise them.

This project aims to create a method of simulating the effect of a room's acoustic properties on the voice level of people talking in the room. This will allow rooms and spaces to be designed to mitigate the Café Effect, making speech more intelligible and requiring less vocal effort from the room's inhabitants. This is particularly important in classrooms, where improving the acoustical properties of the room has been shown to improve the teaching and learning environment (Dodd, et al. 2001).

## 2. Literature Review

### 2.1 Lombard Effect

The Lombard Effect is a complex psychoacoustic phenomenon influenced by many different variables. It has been suggested that the purpose of the effect is both to improve communication in noisy environments and to adjust vocal intensity to suit the acoustic environment (Garnier, Henrich and Dubois 2010). In its simplest terms, this means a person will raise their voice if they cannot hear themselves or they feel like they cannot be heard (Lau 2008). This is mostly an automatic reflex which most people cannot suppress, even with training (Pick Jr, et al. 1989).

#### 2.1.1 Masking Noise

Masking noise is the sound that obscures a talker's voice and hence elicits the Lombard Effect. The primary attribute of the masking noise that affects the Lombard Effect is the SPL of the noise (Lombard 1911, J. Whitlock 2012). At higher noise SPLs, talkers will struggle to hear themselves, and so will raise their voices to be heard over the noise.

Stowe et al. (2013) and Garnier et al. (2010) demonstrated that the frequency of the masking noise relative to the subject's natural speaking voice (F0) can alter the Lombard coefficient (rate of change of vocal amplitude per unit noise amplitude). They suggest that if the Lombard Effect is related to our ability to hear ourselves, then similarity between F0 and the masking noise frequency will obscure the subject's voice more and thus increase the Lombard Effect.

Common sources of masking noise include traffic, air conditioning units and other talkers. However, many studies to date have simply used varying SPLs of a fixed masking noise, typically white noise (Pick Jr, et al. 1989, Welby 2006, Summers, et al. 1988), to study the Lombard effect. Since the type of masking noise influences the Lombard response (J. Whitlock 2012, Davis, et al. 2006, Garnier, Henrich and Dubois 2010), the findings of these studies may not be representative of the real world.

### 2.1.2 Communicative Aspect

There is evidence to suggest that the Lombard Effect is not solely a reflex to masking noise. Rather, it is a combination of this and an attempt to better communicate with listeners (Garnier, Henrich and Dubois 2010, Lau 2008, Junqua, Fincke and Field 1999). A study by Lau (2008) showed that when only the listener was in noise, the Lombard effect was still present. While the effect was not as great as when both talker and listener were in noise, it does support the idea that the Lombard Effect has a communicative component. It should be noted that this study does not prove that the SPL change when just the listener was in noise was statistically significant.

## 2.2 Café Effect

The proposed mechanism of the Café Effect is a feedback loop driven by the Lombard Effect (Whitlock and Dodd 2008, Rindel 2012). The talkers in a space will raise their vocal effort in response to the masking noise as described by the Lombard Effect. This in turn increases the SPL of the masking noise, demanding yet more vocal effort from the talkers to be heard over the masking noise. Some of the additional sound energy of the masking noise is absorbed by the space's surfaces, stopping the feedback loop from increasing infinitely.

The amount of sound energy fed back is thus correlated to the number of speakers and negatively correlated to the absorptive area of the space. These relationships can be used to estimate the steady-state ambient SPL, as is done by Whitlock (2012). This study came up with an experimentally validated model that could be used to approximate the expected behaviour of our system were it to occur in the real-world.

### 2.2.1 Effect of Room Acoustics

A room's acoustic properties will affect the timing and intensity of echoes or reverberations. Reverberations that arrive at the subject's ears within a period called the "integration time of speech" will assist the subject in identifying speech sound sources. Reverberations that arrive later will hinder this (Whitlock and Dodd 2008). As such, reverberation from surfaces in the room will affect the perceived clarity of voices, both the subject's own and those of others in the room, and thus potentially affect the subject's Lombard response.

### 2.2.2 Limitations of Current Models

Both Hodgson et al. (2007) and Whitlock (2012) suggest models for predicting the Café Effect. However, both of these models are limited in scope. Whitlock's model was derived using data from classrooms while the model proposed by Hodgson et al. was derived from a study on eating establishments. Since both models were derived using data from limited environments and tested against those same environments, the applicability of these models to different conditions is not known.

Additionally, both models depend on a model of the Lombard effect to describe the response of individual voices. In the derivation of their model, Hodgson et al. assume that the Lombard coefficients do not change between different eating establishments. However, the model they derived predicts Lombard slope coefficients varying from 0.4 to 2.61 dB/dB for the establishments they studied, placing doubt over this assumption.

## 2.3 Improving Immersion with Virtual Reality

There is evidence to suggest that providing visual context and immersion for a subject can affect how they perceive sound. A study by Maffei et al. (2016) showed that combining sound field reproduction and VR could replicate the feeling of being in a particular environment. Furthermore, a study by Iachini et al. (2012) also showed that a VR system can change how a subject perceives sound relative to a control without such a system. It should be noted that this study is limited as it did not have a control group in an ecological setting to compare the VR system group with. However, it does show that the VR system group perceived the simulated acoustic environment differently to the group without a VR system.

## 2.4 Sound Field Reproduction

The encoding chosen for the loudspeaker array is a first-order Ambisonics system, a widely recognised soundscape reconstruction methodology. Multiple studies have investigated the limitations of this technology, unearthing the following issues:

- Spatial aliasing (front and back hard to distinguish) (Moreau, Daniel and Bertel 2006)
- Room reverberation (Moreau, Daniel and Bertel 2006)
- Increasing reproduction error with increasing signal frequency (Gerzon 1975, Oreinos, Buchholz and Mejia 2013)

Spatial aliasing is potentially an issue, however, the addition of visual cues will allow the subject to bridge this error, as it has been shown that audio and visual information is combined when locating sources (Burr and Alais 2006). The issue with room reverberation affecting the model's accuracy is mitigated by the loudspeaker array being situated in an anechoic chamber. The larger reproduction errors in high frequency sounds, highlighted by Oreinos et al. (2013), are not relevant to this system as it has been shown that higher frequency noise (> 4KHz) does not affect the Lombard Effect (Stowe and Golob 2013). Therefore, any amplitude errors in the higher pitched noise will not substantially affect the experiment.

## 2.5 Literature Review Conclusions

The Lombard Effect is highly dependent on the specific environment in which it is exhibited. The vocal effort and frequency of Lombard affected speech are dependent on the frequency and SPL of the masking noise as well as the communicative intent. Thus the Lombard coefficients for modelling the effect are dependent on the specific environment being modelled. This is apparent in the varying results of previous studies of the Lombard Effect. Consequently, creating a general-purpose model of the Lombard Effect based on current understanding may not be feasible.

Current models of the Café Effect were developed using data from limited environments. This makes these models unsuitable as general-purpose models of the effect. This is due, in part, to the reliance of these models on modelling the Lombard Effect, which is highly dependent on the specific environment.

With the current understanding of the Café and Lombard Effects, models of either effect are unsuitable for use in a general-purpose simulation of talkers interacting in noisy rooms. Consequently, creating a human-in-the-loop simulation will provide a more accurate and versatile method of predicting talker voice SPL.

Using a human-in-the-loop simulation requires immersing the human subject in the simulated environment. This requires simulating both the auditory and visual context of the environment. Synthesising the sound field the subject will hear requires modelling the interaction between the sound sources and the space being mimicked. Likewise, visual context can be provided by viewing a 3D model through a VR headset.

## 3. Simulation System Design

The Café Effect simulator system is comprised of a test subject, a PC running audio processing software and a loudspeaker array. The subject will wear a headset microphone to record their voice level and a VR headset to make the experience more immersive. Figure 1 shows a person seated in the loudspeaker array wearing the VR headset.

The subject sits in the centre of the loudspeaker array, as shown in Figure 4. This loudspeaker array reproduces the sound field produced by the audio processing software. As the subject talks, they will increase the sound level of their voice to talk over the masking noise produced by the loudspeakers. The microphone is used to measure this Lombard response of the subject.

To simulate the Café Effect in real time, the audio processing software simulates multiple virtual talkers in a room, as shown in Figure 2. These virtual talkers mimic the Lombard response of the subject by matching the speech sound level of the subject. The virtual sound field produced as the sound from these virtual talkers propagates throughout the room is recreated by the loudspeaker array for the subject to hear. As shown in Figure 2, this produces a feedback loop as the subject tries to talk over the virtual talkers due to the Lombard Effect and the virtual talkers increase their voice level to match. This feedback loop simulates the Café Effect.

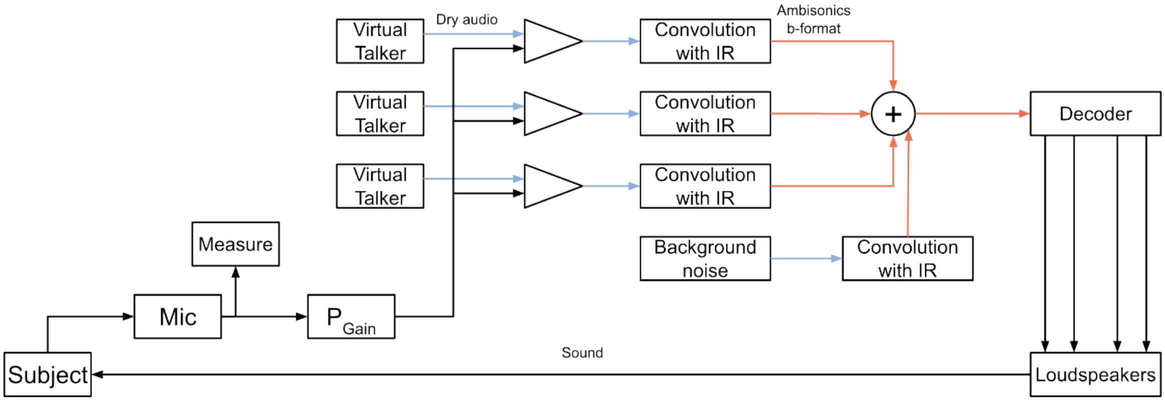

Figure 1: Block Diagram of the system's audio component

Figure 2: A person wearing the Vive VR headset in the loudspeaker array. The purple box under the loud-speaker in the top middle is a base station used for tracking the position of the headset

Figure 3: Part of the VR classroom model used for the testing system

## 3.1 Virtual Reality

The virtual reality component of the system is comprised of a 3D virtual environment and a VR headset used by the subject to view the virtual environment. The virtual environment is related to the simulated acoustic environment as it provides visual context for what the subject is hearing. Visual context includes 3D avatars in the same positions as the virtual talkers and making the virtual environment resemble the acoustic environment being simulated. This visual context can be seen in Figure 3, which shows part of the classroom virtual environment used for testing the system. The virtual environment models are created in the 3D game engine Unity.

The VR headset used by the subject to view the virtual environment is an HTC Vive. The HTC Vive uses "base stations" positioned around the room to track the position of the headset. This allows the subject to move their head to look around the virtual environment. Two of these base stations are mounted on loudspeaker mounting posts on opposite sides of the array, as shown in Figure 1.

## 3.2 Audio Processing

The audio processing system is coded in Max 8 MSP and implements the feedback loop shown in Figure 2. It measures the 1m SPL of the subject's voice and scales the SPL of the virtual talkers to match. The scaled dry audio of the virtual talkers is convolved with their respective impulse responses to model the propagation of their voices throughout the room. The resulting sound field is rendered and output to the loudspeaker array by an Ambisonics decoder.

### 3.2.1 Room Acoustics Simulation

An impulse response (IR) represents the pattern of sound radiated between two points inside a given space. It accounts not only for the sound that travels directly from the source to receiver but also for all of the sound energy that reaches the receiver after one or more reflections.

For this simulator proof of concept, the point-to-point impulse responses were calculated along all 3 axes by raytracing performed inside the 3D model of the room. This was done using the software ODEON. However, any reliable method of obtaining impulse responses will work.

These IRs are convolved with the scaled virtual talker recordings to make the sound appear to come from the correct location in the virtual room. Then, all of the convolved sound sources are summed to form the cumulative sound field at the subject's location.

### 3.2.2 Virtual Talkers

The virtual talkers emulate having multiple people talking in the room with the subject. Any number of virtual talkers can be placed around the simulated room, allowing for scalable simulations. These virtual talkers mimic the Lombard response of the subject by matching the subject's speech SPL.

The virtual talkers' dry audio files are initially scaled to a base speech SPL (typically 60dB) set in the software when the subject is not speaking. However, if the subject's voice SPL exceeds this base SPL, the SPL of the virtual talkers will increase to match the voice SPL of the subject. A feedback loop is created as the subject competes to be heard over the virtual talkers, simulating the Café Effect.

The scaling of the virtual talkers is performed by multiplying the dry audio of the virtual talker by the ratio of the subject's RMS level to the dry audio RMS level (up-scaling to match the RMS of the output to that of the subject).

### 3.2.3 Subject Voice Level Averaging Time

For the virtual talkers to match the SPL of the subject, the average SPL of the subject's voice must be measured. Determining the time window over which to average the subject's voice level was critical so that the virtual talkers would not react abruptly to the subject starting or stopping talking.

This averaging time was initially trialled at 1 million samples, or roughly 23 seconds at the system sample rate of 44100Hz. However, this window felt sluggish to respond to small changes in SPL, as well as too abrupt at the start of speech. To make the system more sensitive to small changes, the averaging window needed to be shortened. An offset was added to facilitate this without exacerbating the SPL spike at the start of measurement. The offset took the form of a pink noise signal, fixed to 10dB below the virtual talker's base SPL, added into the averaging buffer. The pink noise created an artificial noise floor that the averaging window could not fall below, lowering the effect of spikes and dips on the average SPL. This allowed the averaging window to be shortened, increasing sensitivity and reducing settling time. A final averaging window of 441,000 samples or ≈10 seconds was settled on as this felt natural during subjective tests.

### 3.2.4 Background Noise

Like the virtual talkers, the background noise generation consists of a single channel dry audio recording that is convolved with an IR. However, the background noise is reproduced at a fixed SPL and does not scale with the subject's voice SPL.

The dry audio used for the background noise is representative of the background noise in the environment being simulated by the system. For instance, if a Café environment is being simulated, the sound of the traffic outside might be included as background noise in the simulation.

### 3.2.5 Masking Noise and Speech SPL Measurement

Noise and speech levels are measured in the software as unweighted SPL equivalents. The speech levels are adjusted to be representative of the 1m SPL. To measure the SPL, the RMS of the signals over 200,000 samples (≈4.5s) is calculated and converted to dB. This averaging time was used to filter out the fluctuations in speech while still being short enough to react quickly to major SPL changes.

A dB gain is then applied to this value to ensure the SPL measured in the software is equivalent to the measurement made by a sound level meter. This gain is found during calibration and accounts for variables like the gain of the hardware, reference pressure of the sound level meter and adjusting the measurement distance to 1m.

## 3.3 Audio Hardware

### 3.3.1 Loudspeaker Array

The system is configured to use a 12 loudspeaker array in an anechoic chamber at the Marshall Day Acoustics Auckland

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branch. As can be seen in Figure 4, this loudspeaker array surrounds the subject in a sphere and reproduces the 3D sound field created by the virtual talkers and background noise in the centre of the array. To render the Ambisonics sound field for the multichannel loudspeaker array, the system uses the Harpex Ambisonics decoder VST plug-in.

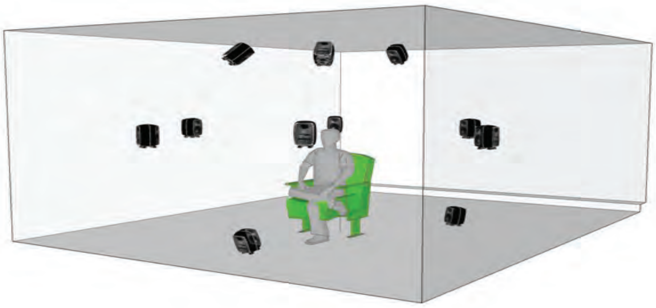

Figure 4: Marshall Day acoustics Listening Room loudspeaker array configuration

#### 3.3.2 Microphone

The subject's voice is recorded using a single channel E2 Earset headset microphone from Countryman Associates. The high off-axis rejection of this microphone makes this microphone ideal for isolating the subject's voice from the surrounding sound field (Countryman Associates 2015). Due to this off-axis rejection and the proximity of the microphone to the mouth, it is capable of accurately measuring the subject's voice SPL in ambient noise levels of up to 75dB SPL (J. Whitlock 2012).

The signal from the microphone is passed through a soundboard for hardware gain adjustment before being input into the PC running the audio processing software.

### 3.4 Asset Configuration used for Testing

For a previous project, Marshall Day Acoustics created a simulated classroom environment. This included recording IRs (as described above in 5.2.1) for talkers in the classroom, recording dry audio for these talkers and developing a 3D VR model of the classroom. The dry audio recordings were made inside the anechoic chamber at Marshall Day Acoustics Auckland branch, and included multiple adult and child voices for filling out a simulation of a classroom. These assets were repurposed for use in the Café Effect simulator.

## 4. System Calibration

System calibration involves two steps. First, the gain in the audio processing software is adjusted so that the SPLs measured and set in the software match the SPL measured from the loudspeakers. Secondly, the microphone hardware gain is adjusted so that the SPL of the microphone input into the software plus the software gain equals the 1m speech SPL. 1m Z-weighted SPL was measured using a Brüel and Kjær 2250 sound level meter for calibration.

### 4.1 Audio Processing Software Gain Adjustment

For the software gain adjustment, the loudspeaker array SPL was measured by placing the 2250 sound level meter in the centre of the array. The sound level meter was positioned facing vertically, in line with the middle ring of loudspeakers.

In the software, a virtual talker function block was configured to play pink noise at the base speech level through a 1m IR. For calibration, the base speech level was set to 60dB and the microphone was disabled to prevent Café Effect scaling. This provided a simulated 1m SPL for the virtual talkers. The software gain was then adjusted so that the 1m SPL (as measured by the sound level meter) equalled the base speech level of 60dB.

### 4.2 Microphone Pre-Amplifier Gain Adjustment

Calibrating the microphone involves comparing the microphone SPL measured in the software to the 1m SPL of the subject's speech. To measure the 1m SPL of the subject's speech, the sound level meter was placed vertically, 1m from the subject's mouth. The sound level meter was rotated so the subject could see the measurement. This was done to help the subject maintain a constant SPL. The subject was then asked to sing an 'ah' sound at a constant SPL. The microphone gain on the sound board was then adjusted so that the microphone SPL measured in the software plus the processing software gain was equal to the 1m SPL measured by the sound level meter. This ensured the SPL of the subject's voice in the software was directly comparable to the SPLs of the virtual talkers. The microphone gain is re-calibrated every time the microphone is removed or adjusted to ensure accurate measurements.

For measuring the speech, long integration times could not be used as the value had to be comparable to the real-time value in the software. Therefore LAF measurement was preferable to $L_{Aeq}$ for its faster integration time and thus faster updates on the SLM readout.

## 5. Verification Testing

Three different tests were run to verify the system. The first test was to ensure the system accurately predicted the ambient SPL of a room with a certain number of talkers. The second test checked that the virtual talkers correctly scaled to match the SPL of the subject. The final test was to verify that the system was triggering the Lombard Effect and accurately simulating the Café Effect.

### 5.1 Testing Room SPL Prediction Accuracy

For the first test, the microphone and background noise were disabled and the base speech level was set to 65dB. The virtual reality headset was not used for this test. The sound level meter was positioned vertically in the centre of the loudspeaker array, in line with the middle row of loudspeakers. For this test, 7 virtual talkers were set to talk at 75dB. Each of the virtual talkers was positioned in the virtual room so that the sound level meter measured the ambient SPL of the room without any disproportionate SPL contribution from specific virtual talkers.

ODEON calculated that the room under such circumstances should settle at 68.9dB(SPL). The simulation, with 7 talkers operating at once, recorded an $L_{Aeq}$ of 69dB over 20 seconds.

### 5.2 Testing Virtual Talker SPL Scaling

The setup for the second test was similar to the first, however, one of the virtual talkers was replaced by the subject and the microphone was enabled. The base speech level for the remaining virtual talkers was set to 50dB. The subject was positioned away from the loudspeaker array and in a position where they would see the subject voice SPL measurement in the audio processing software. Being able to see a real-time measurement of their voice SPL helped the subject maintain the 65dB SPL required for the test. Positioning the subject away from the loudspeaker array prevented them from disproportionately affecting the ambient SPL measured by the sound level meter. While this test did not consider the reverberation of the subject's voice in the room, it would have little effect on the room ambient SPL.

The measured room ambient SPL of the simulation with six virtual talkers and a subject singing an 'ah' sound at 65dB was 68dB. Compared to the theoretical room SPL from the previous test, this was again an SPL difference of less than 1dB, proving that the virtual talkers were correctly scaling to match the speech SPL of the subject.

### 5.3 Testing Café Effect Simulation Accuracy

For the final test, the subject sat in the centre of the loudspeaker array. They were positioned so that their ears were in line with the centre of the direct left and right loudspeakers. The background noise was disabled, the microphone was enabled and six virtual talkers were enabled. The virtual talker base speech level was set to 65dB.

The room ambient SPL was measured in software by measuring the Ambisonics sound pressure channel. This measurement is equivalent to the SPL measured by a sound level meter positioned in the centre of the loudspeaker array. To include the effect of the subject's voice on the ambient SPL, the subject's voice was convolved with an IR to virtually position the subject away from the virtual measurement. This prevented the subject's voice from disproportionately affecting the measured ambient SPL. The SPL of this convolved audio was added to the ambient SPL to measure the room ambient SPL, including the subject. The subject's voice 1m SPL was measured in software.

To start the third test, the system was turned on, the microphone was enabled and the test recording was started. This test was first run using the VR headset. For the first part of the test, if the subject was wearing a virtual reality headset, they were then asked to talk continuously about a topic of interest. Otherwise, the subject read a passage from a book. This continued for approximately 60s to establish the subject's base speech SPL which is required to calculate the theoretical room ambient SPL inclusive of the Café Effect. The microphone is disabled between test parts one and two.

For the second part of the test, the microphone and six virtual talkers were enabled. The subject was then asked to repeat part one. This established a room ambient SPL to compare to the theoretical room ambient SPL inclusive of the Café Effect.

#### 5.3.1 Data Processing

The test recording records the subject's speech as well as the 4.5s running mean for the subject's speech SPL and room ambient SPL. Each variable is recorded to a WAV file for the entire test. The data processing for test three was performed using MATLAB. The mean of the subject's speech SPL across all of part one was calculated to measure the subject's base speech SPL. Similarly, the mean of the room ambient SPL for part two was calculated to measure the room ambient SPL inclusive of the effects of the Café Effect. This value was compared with the theoretical room SPL, calculated using the model derived by Whitlock (2012), with S = 4dB, L = 0.13, N = 7, V = 568m$^3$, T=1s and B = subject's base speech SPL recorded in part one of the test. While this model is limited in scope, it was derived using data from environments similar to the classroom being simulated, so these limitations were deemed acceptable.

#### 5.3.2 Results

Table 1 shows the averages of the base speech levels, the Lombard Speech levels, and the Subject and Virtual Talkers Room SPL, alongside the model's predicted value for room level. As can be seen, the simulation successfully elicits the Lombard reflex, with both subjects raising their vocal effort by at least 10dB when the virtual talkers were enabled. Additionally, the average SPL of the room over the simulation period lines up with predicted value based on the subject's base speech level.

Table 1: Average SPLs in simulation accuracy test (dB)

| Subject | Base Speech SPL | Lombard Speech SPL | Subject and Virtual Talkers Room SPL | Predicted Room SPL |
|---|---|---|---|---|
| 1 | 55.4 | 68.0 | 70.3 | 69.8 |
| 2 | 53.6 | 63.6 | 68.3 | 67.8 |

Interestingly, despite the substantial variation in room SPL observed during subject 1's Lombard response, the average room SPL is within 0.5dB of the model's predicted value. Subject 2 achieved much more steady vocal effort and thus room SPL, and was also within 0.5dB. This 0.5dB error either side is a smaller deviation than a human can expect to perceive, so the system is deemed to have succeeded on the metric of Whitlock's model in terms of replicating realistic behaviour.

Additional experiments were conducted to see whether the communicative factors of the Lombard Effect would affect the accuracy of the model. The system was run two more times with subject 1, this time without the VR headset and with differing virtual talker noise floors. Additionally, instead of talking about something that interested them into the classroom model, the subject was asked to read a book to one of the testers. The measured values for the additional runs in the alternative configuration are recorded in Table 2.

Table 2: Average SPLs for different virtual talker base SPLs (dB)

| Virtual Talker SPL | Base Speech SPL | Lombard Speech SPL | Subject and Virtual Talkers Room SPL | Predicted Room SPL |
|---|---|---|---|---|
| 65 | 56.4 | 67.3 | 70.8 | 71.1 |
| 60 | 54.7 | 65.1 | 69.1 | 69.0 |

The main pattern identified in these two additional tests was the lack of variance of system behaviour with communicative activity or with the base SPL of the virtual talkers. This is the intended case for moving the noise floor of the virtual talkers, as their SPL should be regulated by the subject, not their noise floor. It was, however, surprising to observe that reading aloud to another person that could be seen did not noticeably change the base or Lombard SPLs. The most significant variance was seen in run-to-run variation in Lombard Speech SPL, however, the variation was not significant enough to make any assertions on the importance (or lack thereof) of integrating communication and interaction into the selected speech activity.

## 6. Discussion

This project simulated the effect of a room's acoustic properties on the voice level of people talking in the room by simulating the Café Effect in real time. By using a human-in-the-loop design, the simulation works without a mathematical model of either the Lombard or Café Effect. The system designed to achieve this uses virtual talkers that mimic the Lombard response of a subject in real time. The audio from these virtual talkers is convolved with their respective room IRs to simulate a specific room full of talkers. The resulting noise produced by these virtual talkers elicits a further Lombard response in the subject which the virtual talkers mimic in turn. This creates a feedback loop that simulates the Café Effect, providing a realistic masking noise, and hence, a realistic Lombard response in the subject. The subject's voice SPL in this environment provides a prediction of the talker voice level for a given room with a certain number of talkers.

To further improve the accuracy of the elicited Lombard response, the subject viewed a model of the simulated room through a VR headset. This provides visual context and immersion for the subject.

Comparing the simulation room ambient SPL with a formula for predicting the theoretical ambient SPL showed that the system reliably predicted the SPL within 1dB of the theoretical SPL. This suggests that the system accurately predicts the change in ambient SPL as a result of adding talkers to the room. While this preliminary testing is promising, it has some limitations.

The formula used for comparison only calculates a ambient SPL relative to a base speech SPL. While it can be used to check the relative change in SPL due to the Café Effect, it does not prove that the subject's base speech SPL measured in the simulation is an accurate representation of the subject's real-world base speech SPL.

Due to this limitation in the testing methodology, the testing found no evidence to suggest that the VR system improved the accuracy of the simulation. The simulation predicted ambient SPLs within 1dB of the theoretical SPLs regardless of whether or not the subject was wearing the VR headset. The testing methodology also failed to ascertain the effect of communicative intent on the Lombard Effect.

## 7. Conclusions

This project aimed to create a method of simulating the effect of a room's acoustic properties on the voice level of people talking in the room. By creating a real time human-in-the-loop simulation of the Café Effect, the Lombard response of the subject can be used to predict the talker voice level in a given room with a given number of virtual talkers. Since the system does not require models of either the Café or Lombard Effect, the system simulation applies to a variety of different environments and scenarios.

In testing, the system predicted room ambient noise levels within 1dB of the theoretical levels predicted by a model of the Café Effect. This suggests that the system predictions are accurate, however more comprehensive testing is required to verify the accuracy of the predictions.

## 8. Suggestions for future work

A more comprehensive study is necessary to comprehensively assess the accuracy of the voice and ambient noise level predictions made by this system. This would likely involve comparing the system predictions to real world environments, such as Cafés and classrooms. Such a study could also assess the effect of visual immersion using the VR system on the accuracy of the predicted results. Furthermore, this testing was not able to distinguish between the effect of reading and talking on the Lombard Effect. There is evidence to suggest that reading and talking result in different Lombard responses, so a study to assess which produces a more situationally accurate Lombard response could be used to improve the accuracy of the system.

## Acknowledgements

We would like to dedicate this section of the document to acknowledging all those people who have helped us in getting to this point.

Firstly Marshall Day Acoustics, the company that sponsored our system and its development, and provided us with a Part Four Project to do.

Dr Yusuke Hioka, for his advice and direction in turning this system into a successful Part Four Project.

James Whitlock, member of staff at Marshall Day Acoustics, for his prior work into classroom acoustics modelling and also for his availability and assistance throughout the year.

Malcolm Dunn, also at Marshall Day Acoustics, for always being happy to help us run simulations on the classroom model and for helping us through some of the trickier decision points on the system's architecture.

The rest of the staff at Marshall Day Acoustics for being welcoming, friendly, and willing to lend a hand if we had any issues or wanted another opinion.

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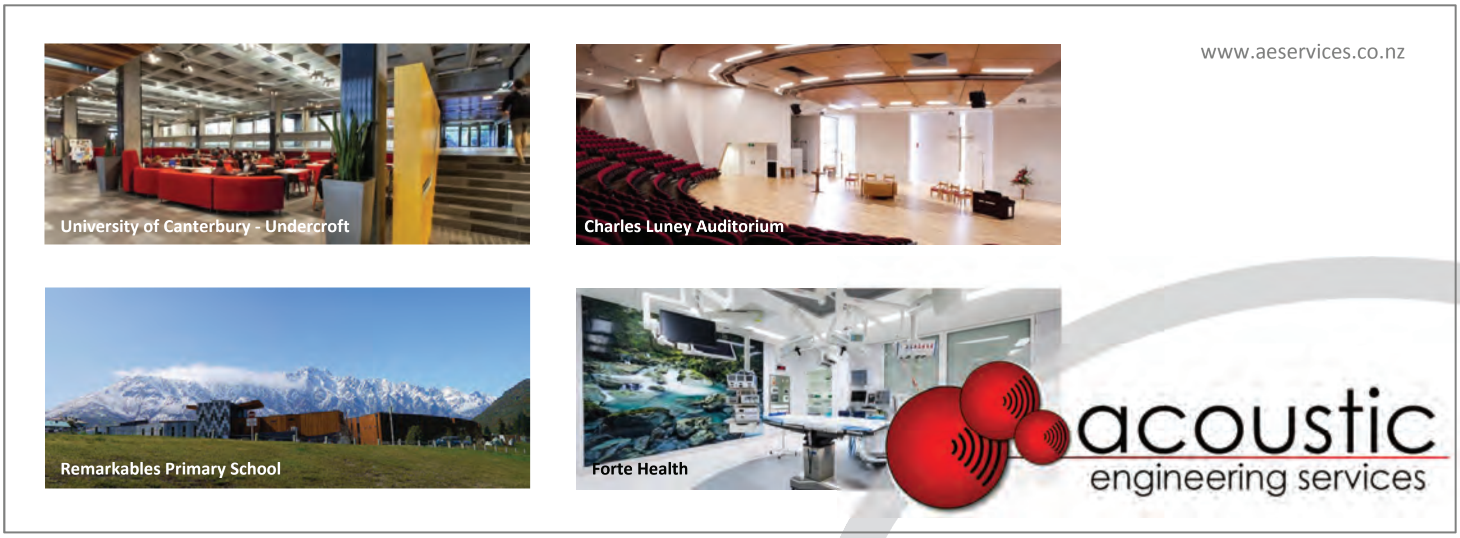

# UPCOMING EVENTS

### 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

### Online Conferences:

**Internoise 2024**

**https://internoise2024.org/**

**25 - 29 August 2024**

Detailed program now available: https://internoise2024.org/detailed-program/

**Quiet Drones 2024**

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**8 - 11 September 2024**

Detailed program now available: https://virtual.oxfordabstracts.com/#/event/public/16881/program?session=123145&program&date=%222024-9-8%22

### 26th International Congress on Acoustics (ICA 2028)

**11 September - 14 September 2028**

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

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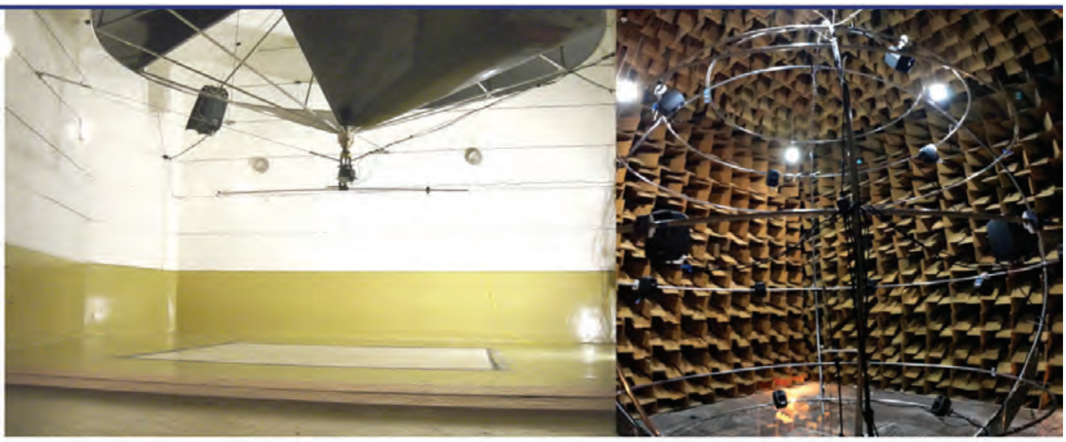

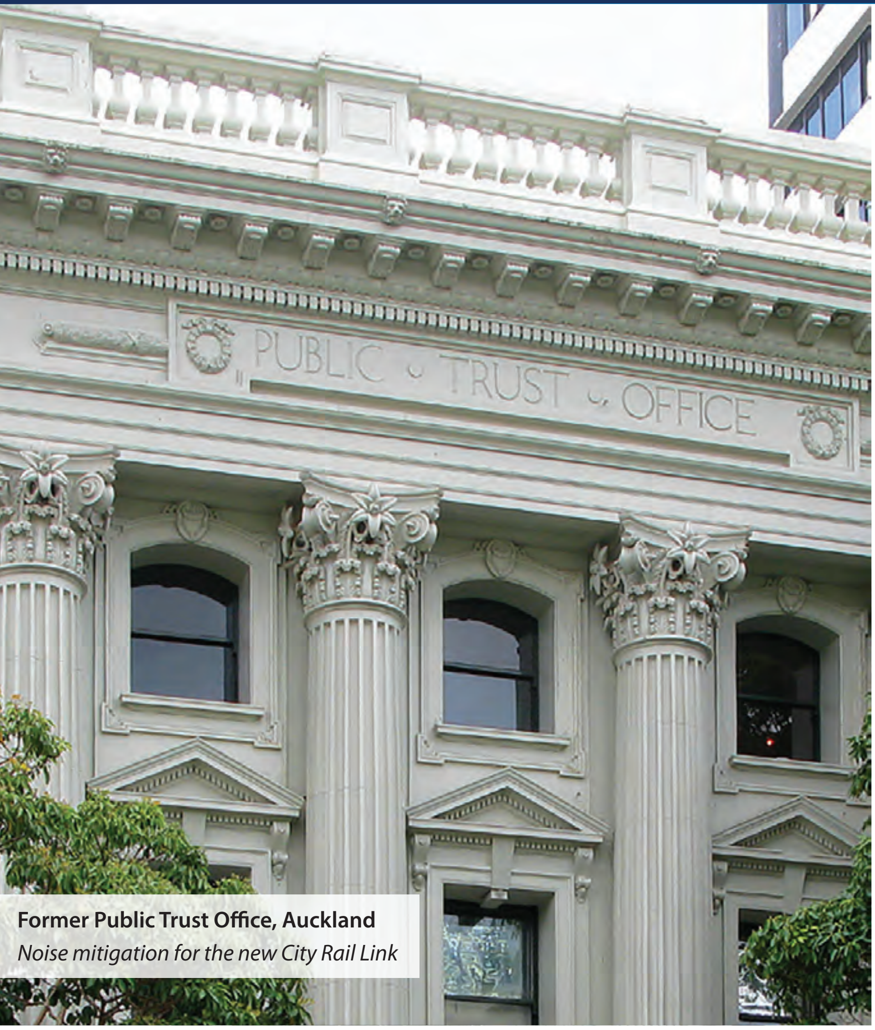

**SOUNDPRINT**

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

| | | |
|---|---|---|
| Ah Ssak, Auckland | ★★ | (1) |
| Bellota, Auckland | ★★ | (1) |
| Birkenhead Brewing Company, Birkenhead | ★ | (1) |
| Brickhouse Espresso Bar, Auckland | ★★★ | (1) |
| Brothers Beer, Auckland | ★★★ | (1) |
| Charlie Farley's, Onetangi | ★★ | (1) |
| Corner Bar, Auckland | ★★★★ | (1) |
| Dear Jervois, Herne Bay | ★★★ | (1) |
| Deco Eatery, Auckland | ★★★ | (2) |
| Dizengoff, Ponsonby | ★★ | (1) |
| Ebisu, Auckland | ★★ | (2) |
| Kind Cafe & Eatery, Auckland | ★★★★ | (1) |
| Kol, Auckland | ★★★ | (1) |
| Little Bird Unbakery, Ponsonby | ★★★★★ | (1) |
| Little Creatures Hobsonville, Hobsonville | ★★★ | (1) |
| Little Culprit, Auckland | ★★★★ | (1) |
| Manuka, Auckland | ★★★★ | (1) |
| Masala Indian Restaurant, Pukekohe | ★★★ | (1) |
| McDonald's, Albany | ★★★ | (1) |
| Nanny's Eatery, Kingsland | ★★ | (1) |
| Pocha, Auckland | ★★ | (2) |
| Poni Room, Auckland | ★★★ | (1) |
| Ssam Jang, Auckland | ★ | (1) |
| St Pierre's Sushi & Seafood, Auckland | ★★★★★ | (1) |
| Sumthin Dumplin, Auckland | ★★★★ | (1) |
| The Brewers Co-operative, Auckland | ★★★★★ | (1) |
| The Chamberlain, Auckland | ★★ | (1) |
| Tok Tok, Hobsonville | ★★ | (1) |
| Vondel, Devonport | ★★ | (1) |

## BAY OF PLENTY

| | | |
|---|---|---|
| Ohope Charter Club, Ohope Beach | ★★ | (1) |

## CANTERBURY

| | | |
|---|---|---|
| Black And White Coffee cartel, Christchurch | ★★★★ | (1) |
| Coffe 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) |
| Strange Bandit, Burnside | ★★★★ | (2) |
| Strawberry Fare, Christchurch | ★★★★ | (1) |
| Super, Lyttelton | ★★★★★ | (1) |
| The Rockpool Bar, 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) |

## MANAWATU-WANGANUI

| | | |
|---|---|---|
| Café Cuba, Palmerston North | ★★ | (1) |
| Spice Guru, Whanganui | ★★★★ | (1) |
| Viv's Kitchen, Sanson | ★★ | (1) |

## NELSON

| | | |
|---|---|---|
| Columbus Coffee, Nelson | ★★★★★ | (1) |
| Sprig & Fern Hardy St, Nelson | ★★★ | (1) |
| Sprig & Fern Tavern, Nelson | ★★★ | (1) |
| The Free House, Nelson | ★★★★ | (1) |

## NORTHLAND

| | | |
|---|---|---|
| The Gables, Russell | ★★ | (1) |

## OTAGO

| | | |
|---|---|---|
| 1876 Bar & Restaurant, Queenstown | ★★ | (1) |
| Bacchus, Dunedin | ★★★ | (1) |
| Farelli's Trattoria, Queenstown | ★ | (1) |
| Margo’s queenstown, Queenstown | ★★★★ | (1) |
| My Thai Lounge, Queenstown | ★★★★ | (1) |
| The World Bar, Queenstown | ★★ | (1) |
| Winnies Gourmet Pizza Bar, Queenstown | ★★★ | (1) |
| Wolf Coffee Roasters, Arrowtown | ★★★★★ | (1) |

## SOUTHLAND

| | | |
|---|---|---|
| Bailiez Cafe, Te Anau | ★★★★★ | (1) |
| Speights Ale House, Invercargill | ★★★ | (1) |

## WAIKATO

| | | |
|---|---|---|
| The Vine Eatery, Taupo | ★★ | (1) |

## WELLINGTON

| | | |
|---|---|---|
| 1154, Te Aro | ★ | (1) |
| Baylands Brewery, Lower Hutt | ★★★★ | (1) |
| Bethel Woods, Wellington | ★★ | (1) |
| Boulcott Street Bistro, Wellington Central | ★★ | (1) |

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| | | |
|---|---|---|
| BurgerFuel, Wellington | ★★★★ | (1) |
| Caffe L'affare, Te Aro | ★★ | (2) |
| Crumpet, Wellington | ★★ | (1) |
| Dillinger's, Wellington | ★★★★ | (1) |
| Dockside, Wellington Waterfront | ★ | (1) |
| Dragon Fly, Te Aro | ★★ | (1) |
| Elements Cafe, Lyall Bay | ★★★ | (1) |
| Flamingo Joe’s, Pipitea | ★★ | (1) |
| Foxglove, Wellington Central | ★★★ | (1) |
| Fratelli, Te Aro | ★★★ | (1) |
| Hashigo Zake, Wellington | ★★★★★ | (2) |
| Heaven, Wellington | ★★ | (1) |
| Hola Mexican Cantina, Paraparaumu | ★★ | (1) |
| Ivy: Underground, Wellington | ★ | (1) |
| Logan Brown Restaurant & Bar, Wellington | ★★★ | (1) |
| Maranui Cafe, Wellington | ★★ | (1) |
| Miyabi, Wellington | ★ | (2) |
| Neo Cafe & Eatery, Wellington | ★★ | (1) |
| Panhead Tory, Te Aro | ★★★★★ | (1) |
| Rasa, Wellington | ★ | (1) |
| Rose's Red-Hot Cantina & Taco Joint, Wellington | ★ | (1) |
| Rosie’s Cantina, Wellington | ★★ | (1) |
| Seashore Cabaret, Petone | ★★ | (1) |
| Siam Spoon, Petone | ★★ | (1) |
| St Johns Bar, Te Aro | ★★ | (1) |
| Te Papa Cafe, Wellington | ★★★ | (1) |
| Union Square Bistro, Martinborough | ★★ | (1) |
| Viva Mexico, Wellington | ★★ | (1) |
| Waitoa Social Club, Wellington | ★★★ | (1) |

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