New Zealand Acoustics

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Wind Turbine Sound Level Descriptors in New Zealand

Acoustic Optimisation at the Operator Station of Construction Machines

Trailing Edge Noise Production, Prediction and Control

1st Quarter 2nd Quarter 3rd Quarter 4th Quarter

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New Zealand Acoustics

Volume 25, 2012 3rd Quarter

Features

Regulars

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From the President and Editor

From the President

Dear Members,

First let me say that I'm humbled to have become president of this fine Society! It is no word of a lie that the acoustics community in NZ is going from strength to strength.

We have a very capable Council full of enthusiastic individuals. I'd like to welcome Jamie Exeter, and welcome back Siiri Wilkening and Lindsay Hannah who took a term off to recharge their batteries and are returning with renewed vigour. I'd also like to acknowledge our past-president and outgoing treasurer Larry Elliott for his service to the Council. He thinks he is moving on, but won't be able to escape fully because we work in the same office. Thanks also to our outgoing president Rachel, whose time at the helm has Fostered (yes… pun intended) some of the largest steps forward the Society has seen.

It's an honour to be writing my first presidential column for the NZ Acoustics journal. I have lots of things to talk about but for now I'll focus on a couple of recent successes, and hint at the main areas I plan to push for the next two years.

Our most recent success was the ASNZ Conference in Wellington on 6-7 September which was a truly excellent event, and one we can all be proud of. Mark Poletti, Miklin Halstead, Terence Bethlehem and their team dealt with the tight timeframes very well, and made excellent choices with the conference and dinner venues. The quality of the technical programme and standard of presentations was a match for any

international conference I've attended. Thanks in particular to our keynote speakers Bernard Ginn from Bruel & Kjaer and Paul Botha from Meridian Energy. Both gentlemen delivered relevant and astute presentations which

Publication Dates and Deadlines

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Associate Membership of the Acoustical Society of New Zealand is open to anybody interested in acoustics.
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led to enthusiastic discussion come question time. My enduring memory of the conference was the collegial atmosphere with suppliers, academics, researchers, students, public servants and consultants coming together in the name of acoustics... talking, laughing, forming friendships and all in all, getting on famously. It was rather uplifting.

I'd also like to acknowledge the strong response to our new membership regime. We now have 44 Members, 30 Affiliates and 5 Fellows of the Acoustical Society of New Zealand, with more signing up every week. This has been a mammoth task for our secretary Jon Styles (and his secretary Cathy Clow), which they have undertaken with alacrity. My thanks to them both.

One of my initiatives will be to start targeting and inviting key members of the NZ acoustics community who, for one reason or another, have drifted away from... or have not heard of the Society. The great strength of a society like ours is in the collaboration and collective knowledge we can foster, and this will be enhanced the more members we have. So, next time you come along to an ASNZ function (in the words of Hugh Hefner) "bring a friend".

Increasing our membership will feed directly into enhancing the quality of this journal – which I consider to the Society's billboard - bringing a greater variety of papers, topics and discussion to these pages. All members are encouraged to contribute, even if it's just filling in the odd CRAI rating form (which can be done via our website now), or forwarding an interesting article you may read to editor@acoustics.org.nz. Our editor John Cater is an astute academic with an eye for quality, and some cunning schemes for lifting the profile of the NZ Acoustics journal.

Another important area of development is our website. We have a new domain (www.acoustics.org.nz) and our new webmaster Grant Emms has fresh ideas for expanding the site in new and dynamic ways, which the Council is behind 100 percent. Make sure it's saved in your bookmarks (a bit higher up than twitter I hope) and stay tuned for further developments.

Finally, for those who don't know me, I thought I'd take up a (hopefully succinct!) paragraph or two introducing myself. For those who do, please continue into the body of the journal and enjoy!

I am a musician (originally piano and violin, but now percussionist - if that still qualifies!) who decided early on that mixing his love of music with science would make for a much more balanced (and financially stable) existence than concentrating on music alone. A BSc in Physics at Auckland Uni eventually led me to a meeting with the wonderful Dr. George Dodd, under whose guidance I completed a Master of Architectural Studies in Acoustics. My thesis was on classroom acoustics and I am still active in that field, writing the odd paper and attending the odd conference in interesting parts of the world.

In 2001 I began working for Marshall Day Acoustics, who has expanded my acoustic horizons immeasurably. I try to keep my hand in all areas of acoustics but have in recent years found myself focussing more and more on environmental vibration, helping to assess and manage the vibration effects of construction and transportation on people and structures. In truth though, it's all a cover for the real reason I work at MDA - I'm the drummer in the MDA band! At home I'm a film-loving motorsport fan with a black-belt music-teaching wife, Bek, and two gorgeous but very noisy kids, Gabriel and Sasha.

I aim to serve the Society diligently with the help of our vibrant Council members, and look forward to seeing the ASNZ go from strength to strength.

Yours faithfully,

James Whitlock

Editor's Ramble

Dear Readers,

I have to start (as seems traditional during my tenure as editor) with an apology for the lateness of this issue. This is my fault; I have just spent two months in Scandinavia, including working at Risoe DTU in Denmark on wind turbines. Unfortunately, this means that to my regret, I missed the conference in Wellington. However, it seems that I have retained editorship of this journal despite my absence!

My personal research at the moment is in the area of wind turbines... which conveniently brings me to the subject of the first article in this issue:

Lindsay Hannah, a new member on the ASNZ Council has written a paper on the variation in sound pressure level measurements using the two methods described in the recent standard. Two sites are used to gather experimental data over the course of a year, both in the acoustic near-field and in the far-field at distances representative of typical dwellings. This is an interesting read on a very topical subject. Lindsay concludes by stating that more research is needed, a proposal that I personally fully endorse!

The second article in this issue comes from Italy and describes the operation of software that can be used to improve sound quality, with the particular example of those operating construction equipment. The work uses a new multi-objective genetic algorithm to probe the link between sound quality condition and frequency content of the noise signals

The final paper is another original contribution to the journal, which comes from the University of Adelaide in Australia. This work is a review of the research being done on trailing edge noise using both experiments and computational methods and gives an overview of the mechanisms of sound production. This work has applications to both aircraft wings and wind turbine blades, with one suggestion being to create porous trailing edges for aerofoils. (There is some interesting related work on owl flight if you are in the mood to find out more.)

Also included in this edition is an announcement about Inter-Noise 2014, which is in Melbourne Australia (see page 21 for more information), a few acoustic snippets and, of course, a new crossword.

All the best and happy reading, until the next issue (which is not far away),

John Cater ¶

The Relationship between L_{A90} & L_{Aeq} Wind Turbine Sound Level Descriptors in NZ

Lindsay Hannah[1], Wyatt Page[2] and Stuart McLaren[2]

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(2) Acoustics and Human Health Division, Institute of Food, Nutrition and Human Health Massey University. Wellington, New Zealand

A review paper presented in part fulfilment of the requirements for a Masters Degree Majoring in Environmental Health and Acoustics at Massey University, Wellington, New Zealand. This work has been refereed.

Abstract

The New Zealand Wind Turbine Standard NZS6808 provides guidance on the methods for the prediction, measurement and assessment of sound emissions from wind turbine generators. This study attempted to quantify the potential variability between measured wind turbine generator sound emissions using the descriptors L_{Aeq} and L_{A90} [specified in the standard], both on the wind farm site [near-field] and at a remote receiver dwelling location [far-field] where people reside. Results of the field study showed that the mean sound level difference between the descriptors, measured at a residential location remote from the wind farm was 2.4 dB compared to 1.4 dB on the wind farm site. Of the 11,150, 10 minute sound pressure level sample pairs recorded over a 12 month period at the remote location, only 39 remained for the analysis after post-filtering to remove samples contaminated by extraneous noise. The study illustrates the difficulty in making robust measurements of wind turbine sound in the far-field.

INTRODUCTION

The current New Zealand wind turbine acoustic standard, 'NZS6808:2010 Acoustics – Wind Farm Noise', took effect in 2010. It places priority on received sound pressure levels measured at dwellings remote from the wind turbine rather than sound emission received on the wind farm site. As part of the NZS6808:2010 assessment process, L_{A90} background sound levels are required to be measured at the relevant off-site receiving locations[ ] before a wind farm site is developed. Allowable wind farm design noise limits are then derived from a comparison of the predicted wind turbine sound pressure levels and the measured background sound at the nominated off-site receiving location.

Two sound level descriptors are specified in NZS6808:2010. The first is the A-frequency weighted time-average equivalent level, L_{Aeq}, and the second is background sound level referred as the L_{A90} centile level, the A-frequency weighted level that is exceeded for 90% of the measurement period. A possible disparity arises with the use of these two different descriptors and in order to account for the potential variation between the descriptors, the standard recommends that predicted L_{Aeq} sound pressure levels at any receiver location are to be treated as equivalent to the L_{A90} value when setting wind turbine design noise limits. This means that once the wind farm is operational, compliance measurements [if required] are made using the L_{A90} descriptor and directly compared to a wind farm noise limit criterion also defined in terms of a L_{A90}.

The 2010 New Zealand Standard for wind turbine generators states that "the predicted wind farm L_{Aeq} at any receiver location is deemed to be equivalent to the L_{A90} value", that is, we are told to assume that $L_{Aeq} = L_{A90}$. It is understood that such a statement was included in the standard to deal with the potential uncertainty or possible perceived discrepancy of the actual imprecise and variable differences between these two descriptors. At the time of commencing this study, the then-current standard [NZS6808:1998] did not specifically account for the difference in the two descriptors then used, L_{A95} [the 95% centile level] and L_{Aeq}, other than to state an expected range difference between the two sound level descriptors which was described within the 1998 Standard as being that L_{A95} is 1.5 dB – 2.5 dB lower than the L_{Aeq} level. This was based on the work done in the United Kingdom by the Working Group on Noise from Wind Turbines, documented in ETSU-R-97[ ].

Clauses 4.2.1 and 4.4.2 of NZS6808:1998 for assessing sound from wind turbine generators depicts the following relationship between the L_{Aeq} and L_{A95} descriptors:

$$L_{Aeq} = L_{A95} + 2.5 \text{ dB or } L_{A95} = L_{Aeq} - 2.5 \text{ dB}$$

It was not entirely clear in NZS6808:1998 whether the difference in sound descriptors was on the wind turbine site itself or off-site however the implication of this 2.5 dB difference is quite clear - the equivalent L_{Aeq} wind farm design limit could be up to 2.5 dB above the background L_{A95} for the same measured level of wind farm noise. Thus, under the 1998 Standard there may be a perceived discrepancy as a wind farm designed to achieve a predicted level of L_{Aeq} of 40 dB at a given receiver location could only measure L_{A95} of 37.5 dB at this location, thus implying a 2.5 dB 'safety margin' when assessing compliance. A key implication of this is that wind turbine sound could potentially exceed the allowable 40 dB design noise limit [or average background sound level +5 dB] by up to a further 2.5 dB and still remain in compliance with the limits recommended under NZS6808:1998.

STUDY SITES

Two studies were conducted into the relationship between L_{A90} and L_{Aeq} sound level descriptors for commercial three-bladed horizontal contemporary wind turbine generators in a New Zealand environment. The principal study made measurements in the 'far-field', adjacent to a dwelling in the 'Project West Wind' wind farm area [Wellington, New Zealand [also referred to as Makara Wind Farm or just Project West Wind]]. The secondary study made measurements in the 'near-field' at the nominated IEC 61400-11 R_o measurement location [3] on the second site, the 'Te Apiti Wind Farm', located in the Manawatu area, New Zealand.

In addition to these two data sets, significant additional measurements were made using handheld instruments to assess the frequency spectrum characteristics and time varying nature of the sound environments. These data sets were supported with lengthy on-site observations covering both day and night time periods.

Principal Study Site - Project West Wind

Sound pressure level measurements were made approximately 15 to 20 metres south of the selected dwelling [4] with direct line-of-sight of wind turbine generator 'D12'. This turbine is a 'Siemens 2.3 MW' [SWT-2.3-82VS] generator, with a hub height of approximately 67 metres and has three blades each of 40 metres in length. The Project West Wind, turbines are pitch-controlled variable-speed turbines. This allows the blade pitch angle to be set dependant on the electrical power output, wind speed and rotational speed. As the wind turbines are variable speed, this allows the rotor to change rotational speed between 6 revolutions per minute [rpm] and 18 rpm, depending upon the wind speed. The wind turbine generators at Project West Wind have individual programming allowing them to be 'de-rated' if required. The variable speed programming also maps to an alternative power curve relationship, such that the turbines can run at lower rotational speed to reduce the aerodynamic sound output. Sound produced by the wind turbine generators, as received at locations in the far-field, subjectively ranged from low levels of audible sound to levels of sound that were at the majority of times inseparable in the context of unwanted background sound via the use of a sound level meter as the measurement tool.

Secondary Study Site - Te Apiti Wind Farm

Sound level measurements were made at the IEC 61400-11 Ro location, with direct line-of-sight with wind turbine generator, 'Tap 44', which is a 'Vestas V72' model. This generator has a hub height of approximately 60 metres and three blades, each 35 metres in length. It is noted that the NM72 [Neg Micon NM72] was renamed the Vestas V72 with the V72 being the first commercial 'mega-watt' class wind turbine generator used in New Zealand. The maximum power output of the Te Apiti wind turbine generators is controlled through active stall and as they are fixed rotational machines the ability to control their acoustic emission output is limited.

Wind Conditions and Terrain Factors at the Study Sites

The two study sites are located at the bottom of the North Island of New Zealand, at latitudes between 40 and 50 degrees south of the equator. The Project West Wind, wind farm has two predominant wind directions [relative to true north] described as 'North North West [NNW]' and 'South South East [SSE]'. The Te Apiti wind farm has two predominant wind directions described as 'North West [NW]' and 'North North West [NNW]'.

The terrain at the measurements locations on both study sites was fairly level with the wider surrounding area being undulating terrain. At the primary study site, consideration had to be given to access, proximity of local dwellings, line-of-site to the source, wind exposure and ground vegetation when siting the measurement instrumentation. Also, the terrain between the wind turbine source and measurement location at Project West Wind, was a 'complex heterogeneous terrain', meaning that there was varying altitude between source and receiver, varying ground conditions and surface gradients. This is in contrast with secondary study site at Te Apiti, with a relatively flat undulating, grass covered terrain.

MEASUREMENT APPROACH

The underlying philosophy of this study was to assess the relationship between the L_{Aeq} and L_{A90} sound level descriptors at the two wind turbine sites and capture measured sound pressure levels from the wind turbine generators, as free as possible from any additional extraneous noise.

Conceptually this approach is in line with the total-sound approach described in the base New Zealand environmental acoustics standards [NZS6801:2008 and NZS6802:2008] for finding the residual sound, the sound that remains when the target sound source[s] are removed. In principle for wind farms, this could be achieved during commissioning by taking sound measurements with the turbine rotors locked [parked] and then repeating the measurements with the turbines operational [also known as on/off testing]. However, this much more problematic to undertake if the wind farm is to remain fully operational and generating power.

A number of measurement approaches were initially trialled, including short- and long-term sample periods, in conjunction with concurrent audio recording of the sound. Lengthy periods were also spent studying the measurement locations when the turbines were operational and when parked. The final measurement method employed was to use the sound level meters directly and then to post-filter the data to remove measurements contaminated with extraneous sources. Figure 1 graphically illustrates this measurement approach and shows at the bottom, the five post-filtering steps used to remove contaminated data. The key to the potential robustness of this approach is the ability to capture a large sample set of data over a relatively limited study period of one year. The sound level meters were set up so they were synchronised with the 10 minute wind speed sampling periods [at hub height, $V_{Hub\ Height}$] of the target wind turbine generator[s] and the local 10 metre high test site meteorological mast [V_{10m}]. Wind speed measurements at the microphone were also captured.

Principal Study - Project West Wind

In total, 11,150 raw [10 minute] sound level pressure sample pairs were made, representing a continuous duration of just under 75 days. Data was collected over a period of approximately 12 months, covering all four seasons; however the majority of

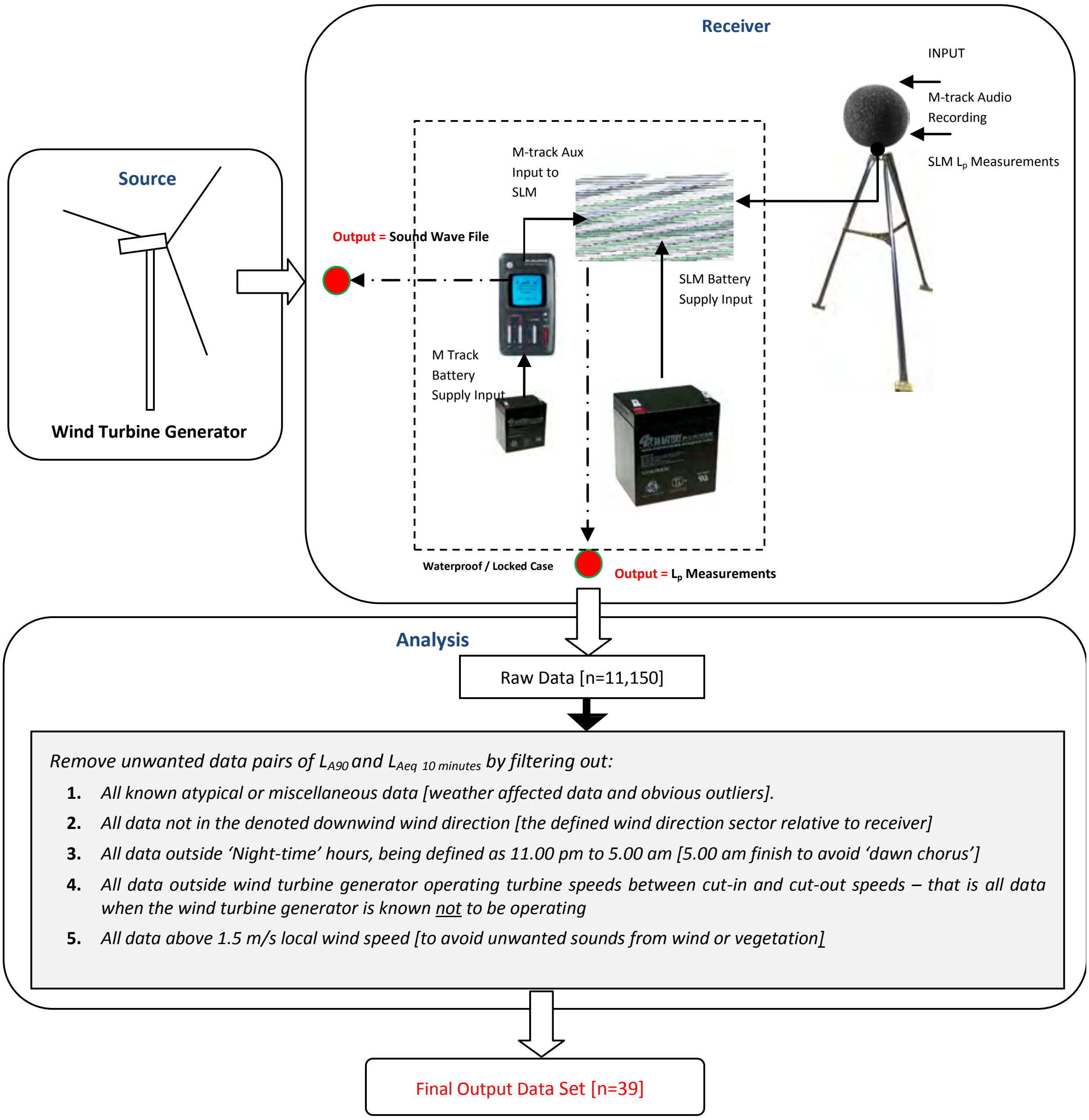

Figure 1. Graphic of field measurement approach and showing the filtering steps of the data.

survey sampling time was during the cooler winter months to avoid the more profuse effects from such influences as foliage, increasing local wind speeds and unwanted background sound from cicadas in the surrounding bush.

Equipment was synchronised so that the 10 minute averaging periods correspond meaningfully in terms of sound pressure levels, wind data and any audio recordings. It should be noted that for modern GPS equipment and sound level meters, any 'clock drift' would be expected to be significantly less than 1 minute over a period of several weeks.

Table 1 shows a summary of the data collected, starting from the entire 11,150 raw samples, than then sequentially applying each subsequent post filter step, to finally arrive a set of only 39 samples, free from extraneous noise contamination. Table 1 also shows how the levels for the two sound descriptors change as the contaminated date is removed and the mean difference between these two descriptors estimated.

Secondary Study - Te Apiti Wind Farm

The measurement approach at the Te Apiti site involved making measurements at the IEC 61400-11 Ro measurement position. Data collection was to align with 10 minute measurement periods of wind speed and wind direction measured at the hub height, over a 10 day period. The post-filtering stages adopted in the secondary study included removal of known atypical data and data affected by weather. There were no filtering restrictions on 'local wind speeds' at the microphone however filtering was applied to ensure all data pairs were directly downwind of the measurement location and included the known periods when the wind turbine was operating.

RESULTS

The results of the principal study [see Table 1] at Project West Wind, show that based on the 39 uncontaminated samples, the overall mean sound level difference between the two sound level descriptors L_{Aeq} and L_{A90}, was 2.4 dB at a remote residential location some 1200 metres from the wind farm site. The mean sound pressure level for the L_{Aeq} descriptor was 25.4 dB and 23.0 dB for the L_{A90} descriptor.

Continued on Page 10...

Product News:
Noise Control Services Ltd. Name Change

NCS Acoustics
DESIGN • MANUFACTURE • INSTALL

Noise Control Services Ltd is pleased to announce that the company has become 'NCS Acoustics Ltd'. The name change took effect from 1st July 2012. Although email addresses will change, existing ones will still get through and all phone numbers and other contact details remain the same. See the advertisement below for full address and email contact details, and feel free to call and discuss with us the humorous calls we hope will be a thing of the past!!

As part of this re-branding, the website is being rebuilt, and all the technical brochures are in the process of being updated, and these items will be progressively rolled out over the next six months.

There has been a changing of the guard in our ranks with the departure of Paul Rayner to greener pastures (presently cruising the Mediterranean). This has opened a position within our organisation for a technically minded individual to complement our design and marketing team. If you are interested please contact our HR people on 09 299 2525 and ask for Lara.

After over 30 years of operation, we look forward to assisting existing clients, and meeting new client's requirements with our unique brand of technical, application, manufacturing and installation expertise.

And remember – "If it's noisy - we can fix it"

...Continued from Page 7

Table 1. Summary results showing each post-filtering stage and the resulting number of data samples, measured sound pressure levels [with the standard deviation - SD] for the two descriptors and the mean difference [with the standard deviation - SD]

Filter	Description of Filter	Number of samples [N]	% Of raw data	L_{Aeq} [SD] dB	L_{A90} [SD] dB	Mean diff [SD] dB
0 All raw data	No filtering.	11,500	100%	-	-	-
1 Atypical data	Removal of all erroneous data, weather affected data and so forth.	8,682	75%	39.2 dB [8.2]	34.5 dB [7.5]	4.7 dB [4.5]
1+2 Downwind	Downwind data: [0 to 90 degrees and 270 to 360 degrees quadrants] and [315 degrees with 90 degree quadrant ± 45 degrees] - Observations indicate highest levels occur downwind from turbines.	3,321	29%	39.7 dB [8.0]	35.2 dB [7.2]	4.5 dB [4.3]
1+2+3 Night-time	Night-time: Winter 10.00 pm to 7.00 am - Observations indicate unwanted background sound is lowest at night; Summer 11.00 pm to 5.00 am - Observations indicate dawn chorus present and unwanted sound present up to 10.00pm.	1,981	17%	35.6 dB [7.6]	32.5 dB [7.1]	3.1 dB [2.6]
1+2+3+4 Operating speeds	Wind turbine operations between cut-in and cut-out wind speeds at Hub Height - Must be operational to produce measurable aerodynamic noise emission.	1,174	10%	38.0 dB [6.8]	34.9 [6.3]	3.1 dB [2.0]
1+2+3+4+5 Local wind speeds	Wind turbine operations with local wind speeds between 0 to 1.5 m/s - Observations indicate local wind speeds must be less than 1.5 m/s to exclude background sound masking occurring.	39	0.34%	25.4 dB [2.3]	23.0 dB [2.0]	2.4 dB [1.4]

The standard deviation of the two descriptors reduces as the filtering stages are applied and background sound contamination removed. If the normal two-standard-deviations rule for a 95% confidence interval is applied to the mean difference between the two descriptors, this mean value could be as high as 5.2 dB or as low as 0 dB. This range simply reflects the natural variability of the data.

The overall mean sound level difference between the two descriptors at the secondary study site [on the wind farm and at the nominated R_o location] was 1.4 dB. The mean difference between the two descriptors in a far-field and near-field situation, are shown graphically in Figure 2.

Relationship between L_{Aeq} and L_{A90}

Statistical techniques were applied to the final data set from the principal study site to assess if there was a direct relationship between the two noise descriptors. Two rank [order-based] correlation tests, the Kendall tau Rank Correlation Coefficient and Spearman Rank Correlation Coefficient were chosen for this purpose because they provide robust results when measuring the relationship between two variables that are non-linear.

The Kendall's tau test provides an output range of $-1 \leq \tau \leq +1$, where a value of $\tau = +1$ means a perfect positive correlation between the data sets, that is, the two sets are exactly the same. A value of $\tau = 0$ means the data is completely independent and unrelated, and a value of $\tau = -1$ means one variable has a perfect 'inverse' relationship with the other variable.

A value of $\tau = 0.64$ was calculated for the relationship between L_{Aeq} and L_{A90}, showing that there is a strong positive correlation between these two sound descriptors.

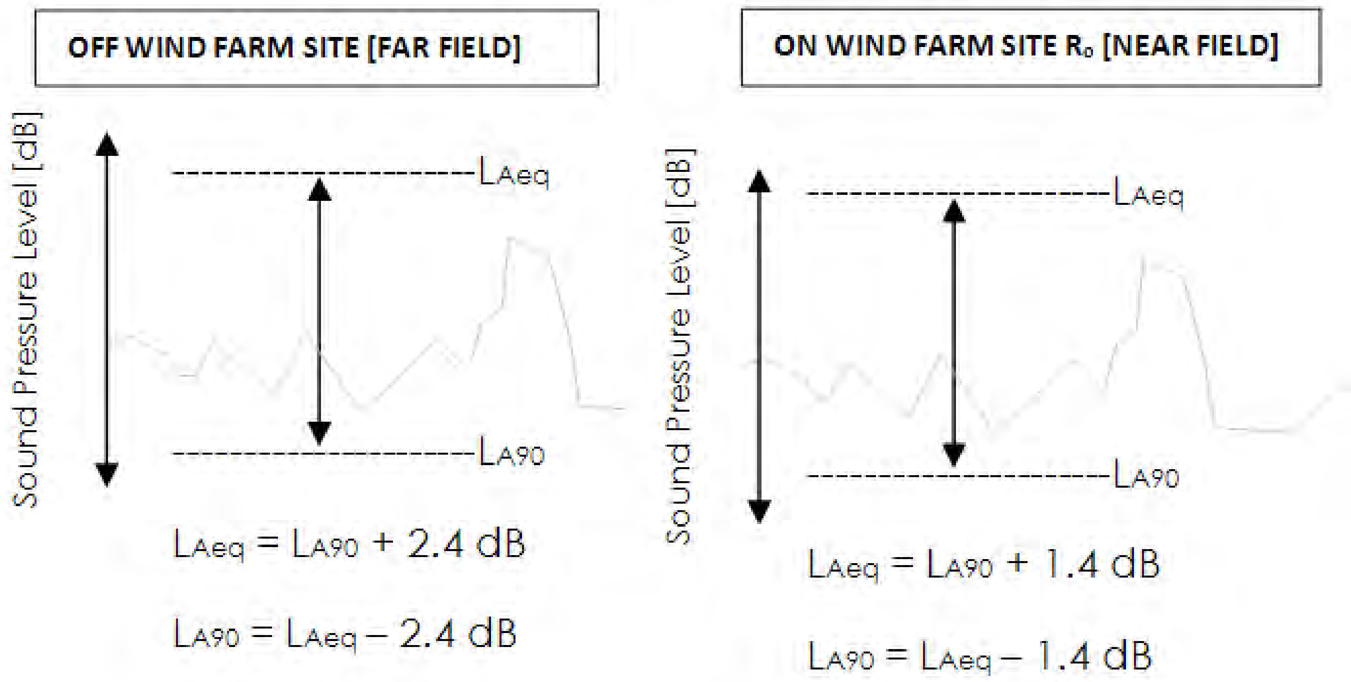

Figure 2. Mean sound level differences for Project West Wind and Te Apiti Wind Farm.

A value of 1 for the Spearman Rank Correlation Coefficient implies that two variables are monotonically related, that is if, one goes up the other goes up, and if the one goes down, the other goes down. A value of 0.8 was calculated for the final data set [n=39], illustrating a very strong correlation between the two sound level descriptors.

DISCUSSION

The key objective of the principal study was to attempt to quantify the difference between the sound level descriptors, L_{Aeq} and L_{A90}, in a typical far-field location, where people are located, from an existing commercial wind farm in the New Zealand environment. A raw data set of 11,150 [10 minute L_{Aeq} and L_{A90}] samples was collected over a 12 month period at Project West Wind, Makara. It is worth noting that the minimum sample set recommended by NZS6808:2010 is 10 days' continuous monitoring, resulting in about 1,440 [10 minute] samples [See NZS6808:2010 Section 7.2]. The standard also gives guidance on when extended periods of monitoring are required to ensure that the measurements are representative of the range of wind conditions and account for significant variation due to seasonal factors. As monitoring at the principal study site was the equivalent of 75 days distributed across the entire year, it might be concluded that this data set should adequately represent the situation. However, after post-filtering the raw data set for noise contamination, only 39 samples remained for analysis, which is equal to 0.34 % of the 11,150 samples collected.

The analysis of these samples showed that L_{A90} averaged 2.4 dB lower than L_{Aeq}, equivalent in power terms to a difference of 42%. But when the natural variability of the data was accounted for, the mean difference could be as high as 5.2 dB which is slightly more than the background +5 dB rule, used in both the 1998 and the current 2010 standard. The statistical tests for a direct relationship between these two noise descriptors showed that they were strongly correlated. While the final sample size for the analysis appears small [n=39], compared to the raw number of samples collected, it is nevertheless still statistically significant when tested.

Looking at the results from the raw data set after the first post-filtering stage [the removal of all atypical or miscellaneous samples [See Table A] the difference between the two descriptors is significantly higher at 4.7 dB and also the mean levels of both these noise descriptors of this larger [contaminated] data set were typically 11 to 15 dB higher than for the final analysis set. This is what would be expected given that the data set contains many extraneous sources of noise.

Ideally data should be collected covering a sufficient range of wind speeds, and across the operating modes of the wind turbine under investigation. The raw data set covers a wide range of wind speeds but the final analysis set [free from extraneous noise] covers a wind speed [at hub height, $V_{Hub\ Height}$] range between 4 m/s and 15 m/s [34 samples were in the 4 to 7 m/s range and 5 samples for wind speeds > 7m/s]. It should be noted that possible issues occur in the derivation of the wind turbine sound levels if wind speeds are only collected up to, say, around 8 m/s and such issues become important for variable speed machines such as those at the principal site, where noise levels would likely to continue to rise for wind speeds above 8 m/s.

Background Sound Levels and Noise Contamination

It is common in environmental acoustics to use L_{A90} as a proxy for the background sound level or residual sound level, especially where it is not practical to make measurements with and without, the target sound present. For wind farm noise monitoring, this sound level descriptor is said to provide a 'fair' representation and reduce contamination by other non wind turbine sound sources.

As wind farm sound level measurements must normally be conducted in the presence of wind, the use of L_{A90} over L_{Aeq} for sound level measurements is preferred so as to avoid influence from high level transitory events and minimise the influence of unwanted background sounds. This is because transitory high energy events such as wind gusts across the microphone or aircraft overfly may artificially increase the measured L_{Aeq} hence possibly allowing for a higher design limit, thus allowing wind turbine sound to be greater at receiver locations. Statistically such extraneous influences are less likely to affect sound levels measured using the L_{A90}. Results from the principal study show that the mean difference between L_{A90} and L_{Aeq} can be as much as 3 dB higher than the 2.4 dB difference derived for the final [uncontaminated] data set.

The acoustic output from a modern wind turbine generator is complex and depends on various factors such as the turbine design itself and surrounding environment. The difference between the L_{Aeq} and L_{A90} descriptor levels is a product of the variability in received sound levels as a function of variations in wind turbine operating mode, wind turbine design, wind turbine operating environment and the variability induced by sound propagation effects between source and receiver location. To what degree such differences actually occur in practice also depends on other complex factors including the relative temporal variations of the wind turbine, propagation conditions and the background sound environment at the receiving position.

As the sound output from a wind turbine generator will increase as a function of wind speed, so to generally will background sound level increase in a windy environment. In regards to the two study sites, increasing wind speeds generally caused increased background sound levels and hence the wind generated significantly higher local background sound levels, in part because of the movement of low lying vegetation, such as long grass. This background sound tended to mask the sound from the wind turbine generator at the receiver location and hence data samples under these conditions were removed from the data set before analysis.

A study into the difference between the operational wind farm noise and the background sound levels [5] at the Project West Wind site, revealed that the greatest level difference between historic measured background sound levels [pre-construction of the wind farm] and actual measured wind farm sound levels [with all background sound removed] occurs between 4 m/s and 15 m/s, with the background sound levels being higher than wind turbine sound at wind speeds below 3 m/s or above 15 m/s. This again illustrates how difficult it is to capture robust wind turbine sound pressure levels in isolation even when a great deal of care is taken including applying correct filtering.

Data collection and analysis of uncontaminated wind turbine sound was not an issue on secondary study site at the Te Apiti Wind Farm, because measurements were made in the near-field in close proximity to the turbines, where the turbine noise is significantly higher than the local background sound level. For commercial reasons wind speeds at Te Apiti Wind are not able to be discussed.

Comparing the difference in measured L_{Aeq} and L_{A90} wind turbine sound pressure levels between the near-field, close proximity results and the off-wind farm [far field] results, the findings indicate that L_{Aeq} sound pressure levels are on average 1.4 dB greater than L_{A90} levels at the near field location, with the L_{Aeq} sound pressure levels being on average 2.4 dB greater than L_{A90} levels at the far field location. This finding indicates the process of propagation of wind turbine sound over distance has the effect of increasing the difference between L_{Aeq} and L_{A90} in received wind turbine sound levels. This is not unsurprising when considering the effects of wind causing fluctuations in received sound levels, with these fluctuations increasing with increasing sound propagation distance.

Accuracy and Uncertainty

Every experiment has a level of uncertainty and limits which need to, at the very least, be understood and noted in terms of the scientific results. New Zealand Standard NZS6808:2010 makes reference to the University of Salford Guidelines on uncertainty of environmental noise [6] and promotes this as good practice for practitioners. No corrections or adjustments have been made to the data gathered in this study other than post-filtering to remove samples contaminated by extraneous noise. There were numerous factors which should be noted if the study were to be repeated or results used by external parties. Because the final data is likely to be specific to the study sites, caution should be taken when applying any results from the study to all wind farms or sites without first understanding the full background and possible restrictions.

CONCLUSIONS

- A limited one year semi-empirical field study was completed to review the variability between wind turbine generator sound descriptors in the typical far-field locations where people are located and on the wind farm site itself in a typical New Zealand environment.
- There is a quantifiable difference between the L_{Aeq} and L_{A90} sound level descriptors for wind turbine sounds in the far-field. At a distant receiver location some 1200 m away, the L_{Aeq} averaged 2.4 dB higher than the L_{A90}, with an upper limit of 5.2 dB difference.
- On the wind farm at the nominated Ro location in near-field, the L_{Aeq} averaged 1.4 dB higher than L_{A90}.
- The findings indicate the propagation of wind turbine sound over distance increases the difference between L_{Aeq} and L_{A90} of wind turbine sound.
- Due to the high number of intervening variables, based on the study methods adopted, it is difficult to collect a large robust sample set in a wind turbine sound investigation that does not include any superfluous background sound. For the principal study, only 0.34 % of the 11,150 [10 minute L_{Aeq} and L_{A90}] samples were free from contamination.
- If time and resources had allowed, further work such as investigating and analysing sound pressure levels as a function of frequency would have been beneficial, as would have a review of the intervening variables, conditions and full details of all uncertainties around the measurement chain.
- Further review work and measurements of possible special audible characteristics, ultra or infrasound is also recommended in distant receiver environments where people reside.

Although the study results indicate a quantifiable difference between the two sound level descriptors, the current wind turbine noise standard [NZS6808:2010] adopts a conservative approach by assuming the predicted L_{Aeq} is the same as the likely operational measured L_{A90} – noting that any differences in predicted sound pressure levels found to exist during any required compliance measurement phase would have to be rectified to achieve full compliance with any stated relevant noise conditions.

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1. NZS6808:2010 standard recommends wind farm noise only be assessed where noise sensitive locations are predicted to receive wind farm sound at levels greater than 35 dB LA90[10 min with wind turbines operating at 95% of rated power output.

2. See ETSU-R-97 "The Assessment and Rating of Noise from Wind Farms Report published in 1996. The ETSU working group was made up of independent experts being established by the Department of Trade and Industry of the United Kingdom Government [now the Department of Business Industry and Skills, UK Government].

3. The R_o location is defined in detail in Wind Turbine Generator Systems Part 11: Acoustic noise measurement techniques, International Standard IEC 61400-11. Ed 2.1. 2006. The location is a standardized measurement location where acoustic measurements are made close to the turbine in order to minimise the influence of terrain effects, atmospheric conditions or wind-induced noise.

4. The receiver location was an address in Makara Road, Wellington.

5. The Use of 10 m Wind Speed Measurements in the Assessment of Wind Farm Developments" Paul Botha, presented at the First International Meeting On Wind Turbine Noise: Perspectives for Control Berlin 17th and 18th October 2005

6. See N.J. Craven and G. Kerry. A Good Practice Guide on the Sources and Magnitude of Uncertainty Arising in the Practical Measurement of Environmental Noise. Edition 1a, May 2007, University of Salford. ISBN 0-9541649-0-3.

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Sound Quality–Based Acoustic Optimisation for Construction Machine Operators

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An original refereed contribution to New Zealand Acoustics

Abstract

Numerical simulation is widely used in product design for different purposes ranging from structural modelling, FEM analysis, vibroacoustics to multi-objective design optimisation. Unfortunately, its application to Sound Quality is still extremely limited. This paper describes the use of a multi-objective optimisation code aimed at identifying noise control solutions which can improve the sound quality at the operator station of earth moving machinery during real working conditions. In a previous study the case of stationary noise signals was analysed and a multi-objective genetic algorithm was used to find the modifications in the input spectrum which led to the minimization of the time-averaged values of loudness and sharpness. In this paper the optimisation algorithm was modified to be applied to time-variant noise signals, characteristic of real working conditions. New input variables were identified to describe the time variant characteristics of the input signals and a numerical code was developed according to the DIN-45631/A1 procedure in order to properly calculate the loudness parameter of time-variant sounds. The new multi-objective genetic algorithm was finally applied to different noise signals recorded at the operator position of loaders in working conditions, with the purpose to find the modifications in the input system which minimised the percentile values of loudness and sharpness parameters. The results confirm the significant link between sound quality condition and frequency content of the noise signals, making it possible to evaluate the spectral variations needed to obtain psychoacoustic improvements.

INTRODUCTION

As in many other fields of application, besides the mandatory provisions, the construction machine industry is now oriented towards the sound quality approach [1]. Hence, at least in the last decade, research has been dealing with the identification of a set of acoustic and psychoacoustic metrics able to describe people's auditory perception of noise signals with respect to the annoyance sensation. Results from previous studies on these noise sources showed that Zwicker's loudness and sharpness are the parameters most related to the subjective perception of annoyance [2,3].

In the meantime, numerical optimisation has extensively been used in many fields of structural design to analytically foresee which modifications of a system best satisfy a desired target [4]. When applied to stationary noise signals recorded at the operator station of a compact loader in idle condition, the acoustical optimisation permitted to analytically identify which variation in the frequency content led to the simultaneous reduction of loudness and sharpness values. As a consequence, noise spectrum modifications able to simultaneously reduce these parameters seemed to be a promising approach for improving the acoustic comfort at the operator position [5].

The validation of this numerical approach was mainly based on subjective listening tests, specifically designed to verify whether the optimisation process led to noise signals subjectively considered less annoying than the original one. The subjective validation provided clear evidence regarding the relevance of the simultaneous reduction of sharpness and loudness in improving the Sound Quality with respect to the annoyance attribute.

This paper presents the adaptation of this optimisation code to the case of time-varying noise signals, which are typical of real working conditions. New input variables, appropriate to describe the time variant characteristics of the system, were identified and a numerical module for the correct calculation of loudness for time-varying sounds was developed according to the DIN-45631/A1 procedure. This new procedure was applied to some noise signals recorded at the operator position of two different compact loaders while these machines were performing the same work cycle with the use of material.

The optimisation process led to noise signals less annoying than the original ones by means of changes in the frequency content of the input signals. Then all these solutions were further analysed in order to choose, if possible, only those satisfying two main features.

First, the optimised signals had to comply with the expectations of the operators who should use the noise emitted by the machine as a feedback of its good state of operation. Second, the spectral changes resulting from the optimisation process had to affect frequency intervals characteristics of specific machine components (engine, cooling system, hydraulic system, ...). The purpose of these investigations was to identify potential noise control solutions to improve the Sound Quality at the operator position at the design stage, with great saving of time and costs.

THE NOISE SIGNALS

The optimisation process was applied to noise signals binaurally recorded at the operator position of two compact loaders (A and B), with different dimensions and mechanical power. Recordings were performed by means of a very lightweight device consisting of two miniature pre-polarised condenser microphones

Table 1. Acoustic/Psychoacoustic parameters of the signals used in the optimisation process

	Machines			*Machines*	
Parameter	***A***	***B***	***Parameter***	***A***	***B***
Leq (dB)	77.9	75.9	N_5 (sone)	28.1	31.0
LAeq (dBA)	68.0	70.4	N_{10} (sone)	27.3	29.9
Mean Loudness (sone)	23.0	25.1	N_{50} (sone)	22.1	25.9
Mean Sharpness (acum)	1.20	1.37	N_{90} (sone)	20.4	23.1
			N_{95} (sone)	20.0	20.9
Lp_5 (dB)	81.1	78.7	S_5 (acum)	1.35	1.56
Lp_{10} (dB)	80.1	77.8	S_{10} (acum)	1.30	1.52
Lp_{50} (dB)	77.2	75.3	S_{50} (acum)	1.19	1.42
Lp_{90} (dB)	74.4	72.9	S_{90} (acum)	1.10	1.31
Lp_{95} (dB)	73.6	72.1	S_{95} (acum)	1.08	1.28

positioned at the entrance of the operator's ear canals (binaural microphones B&K 4101). The noise acquisitions were carried out while the machines were performing the same work cycle which included two main operations: the loading of the material from a stockpile and the unloading of it in a specific position. Besides the noise signals, also the tachometer signal was recorded in order to relate at each time the frequencies of the noise spectrum to the rotational frequencies of the different components of the machine. In normal working conditions, the main periodic noise contributions by the machine components are all strictly related to the engine rotational speed. These noise contributions are primarily due to the engine injection cycles, to the engine cooling system and to the hydraulic system.

Previous investigations showed that the use of materials like gravel generates noise contributions which greatly affect the annoyance sensation but they are completely unrelated to the machine components [3]. For this reason, only the noise signals recorded when the machine was working with loam were considered for numerical optimisation. Figure 1 shows the measurement setup for binaural recordings.

The recordings had a duration of 7-8 seconds and included both the loading phase and the movement of the machine. Two different recordings were made, one for each type of compact loader (A and B). As left and right tracks were fairly similar for both the recorded signals, only the right ones were used as input signals in the optimisation process.

Figure 2 shows the sonograms of the sound pressure level of the two noise signals chosen for the acoustic optimisation. Table 1 summarises the results of the objective analyses performed on these signals in terms of acoustic and psycho-acoustic parameters.

Taking into account that during the execution of the work cycle the engine rotational speed of these machines ranged from 2000 to 2500 rpm, the above sonograms highlight a significant difference between the two machines:

- At the engine characteristic frequencies (40-400 Hz frequency range) the noise levels are higher for signal A than for signal B;
- At the characteristic frequencies of the cooling and hydraulic systems (500-3150 Hz frequency range) the noise levels are higher for signal B than for signal A.

ACOUSTIC OPTIMISATION PROCEDURE

Numerical optimisation is widely used to analytically foresee which modifications of a defined system would lead to configurations that best meet the desired target. It is a powerful analytical tool but it requires an accurate definition of the best set of variables describing the system, as well as the identification of the objectives to be achieved.

As in the case of stationary signals, the target of this optimisation process was the simultaneous minimisation of the objective parameters best related to the annoyance sensation. The time dependency of these signals, however, made it necessary to choose new variables describing the system and new objective functions so that they could both reflect the same variability

Figure 1. Binaural recordings at the operator position in working conditions.

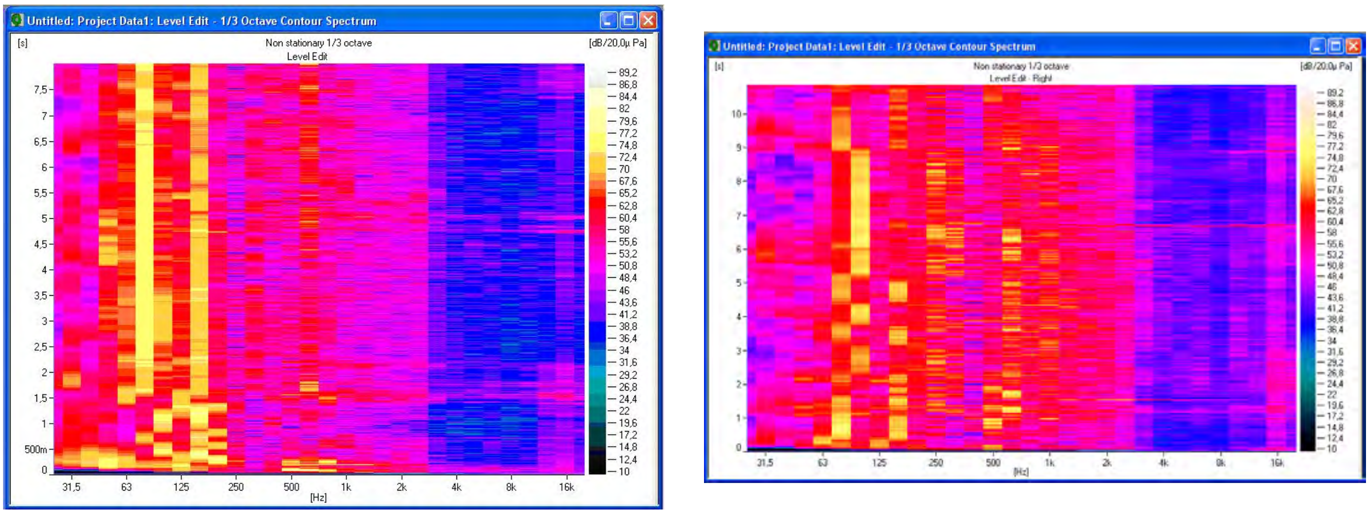

Figure 2. Sonograms of the sound pressure levels: machine A (left) and machine B (right).


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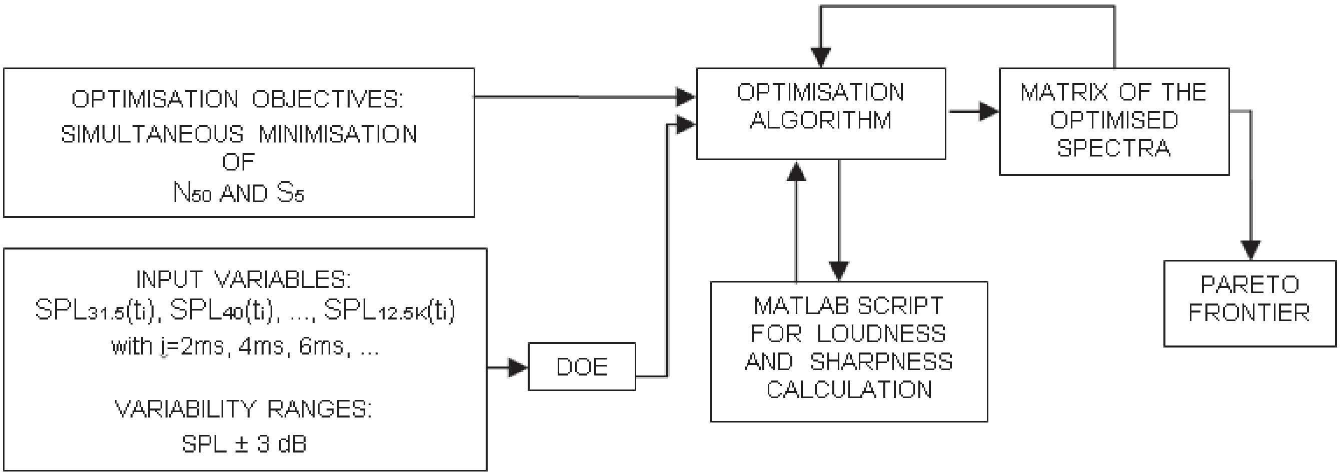

Figure 3. Flowchart of the optimisation procedure.

over time.

For an accurate description of the input system, two aspects of the noise signal had to be simultaneously considered: its time dependency and its frequency dependency. Starting from the 1/3 octave band spectrum of the input signal (from 31.5 Hz to 12.5 kHz), a complete description of this signal was obtained by a matrix of twenty seven variables; each of them being a vector containing the time history of the sound pressure level of a specific frequency band: $SPL_{31.5}(t)$, $SPL_{40}(t)$, ..., $SPL_{12.5k}(t)$. In such a way, the twenty seven sound pressure levels in the frequency range 31.5-12500 Hz, calculated every 2 ms, were identified as the most suitable set of variables to describe the input system. This specific temporal resolution was chosen as it was consistent with the characteristics of the human hearing system.

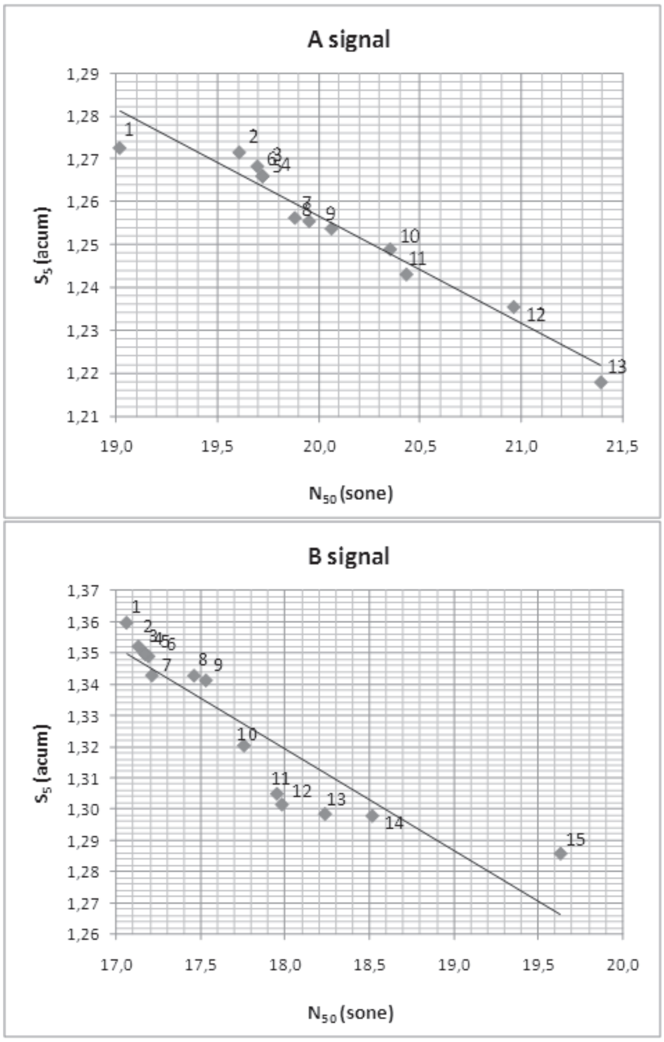

Figure 4. Pareto Frontier solutions: A (top), B (bottom).

Referring to the identification of the objective functions, the results of a previous investigation performed on time-varying noise signals were very valuable for this choice [6]. In that study we found a very high correlation between the subjective sensation of annoyance and the loudness and sharpness percentile values N_{50} and S_5. For this reason, the simultaneous reduction of the above percentile parameters was chosen as target of this optimisation process.

A second set of objective functions (N_5 and S_5) was also tested, following the suggestions made by Fastl and Zwicker [7] that the use of the fifth percentile of loudness for physical measurement of noise emission would be recommended. However, the simultaneous reduction of the percentile values N_5 and S_5 did not lead to any significant difference in the results and so it was no longer taken into consideration.

The numerical analyses were performed using the multi-objective genetic algorithm (MOGA) governed by the ModeFrontier optimisation procedure [8,9]. This procedure has the great advantage of allowing the input in the process of results from other external codes. The calculation of loudness and sharpness values was therefore performed by a MATLAB script developed for this purpose. This script read the values of the time-frequency matrix as input and gave the array of the values of loudness and sharpness as output.

The loudness values were calculated according to the procedure described in the DIN 45631/A1 standard in order to take into account the time variability of these noise signals. In fact, the simple rule to distinguish time varying from stationary sounds, based on the ratio N_5/N_{95} [10], gave values that were well above 1.1 (1.4 and 1.48, respectively), confirming the variability over time of these signals.

As with every genetic algorithm, also MOGA requires the definition of a set of reference configurations (Design of experiment, DOE) in order to be trained on the characteristics

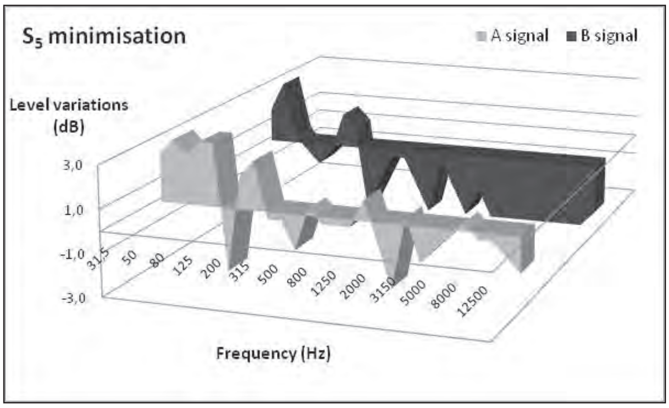

Figure 5. Spectral changes suggested for minimising S_5.

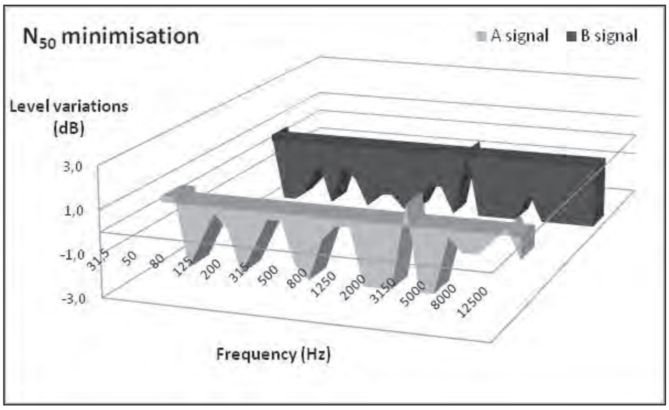

Figure 6. Spectral changes suggested for minimising N_{50}.

of the system under investigation [11]. In the ModeFrontier application, the required DOE is created according to a random approach (Sobol methodology), while the user has to specify only the range of the variations admitted for each of the 27 variables describing the system. Figure 3 shows the flowchart of the optimisation procedure applied to the two noise signals.

RESULTS

The optimisation procedure was applied to both noise signals A and B, separately. In each run the range of admitted variations for each of the 27 variables describing the system was set at ±3 dB.

The output of the optimisation process included a set of several solutions (Pareto Frontier). Each solution consisted of twenty seven dB-values representing the level variations, frequency by frequency, suggested by the optimisation algorithm in order to minimise N_{50} and S_5 parameters. All the Pareto Frontier solutions had loudness and sharpness percentile values N_{50} and S_5 significantly lower than those of the original signal. In this group, however, there were some solutions that were better than others with respect to the minimisation of the loudness percentile N_{50} but worse in relation to the minimisation of the sharpness percentile S_5 and vice versa. The identification of further constraints to the specific problem would be necessary in order to select the best solution among the many mathematically possible.

Fig. 4 shows the Pareto Frontier solutions of both signals A (top) and B (bottom) as a function of N_{50} and S_5 (objective functions). The solutions are numbered sequentially starting from the one with minimum value of N_{50}. For signal A, N_{50} ranges from 19.0 sone to 21.4 sone and S_5 from 1.22 acum to 1.27 acum. Regarding signal B, N_{50} ranges from 17.1 sone to 19.6 sone and S_5 from 1.29 acum to 1.36 acum.

Despite the fact that the two noise signals had a different distribution in frequency of the noise levels, some general conclusions about the effects of the optimisation process on the shape of the noise spectrum can be drawn. When looking at the two extreme Pareto Frontier solutions, for example, the following information can be obtained.

The best solutions with respect to the minimisation of sharpness (no.13 for signal A and no.15 for signal B) suggest significant noise reductions at medium-high frequencies, but, unfortunately, an increase of noise levels was found at low frequencies (40-630 Hz) for both signals, as shown in Figure 5.

Despite the high correlation of the S_5 parameter with the annoyance sensation caused by these kinds of signals, this solution clearly shows that noise modifications aimed at S_5 minimisation are worthless in practice due to the increase of levels at low frequency.

In addition, when applied to noise signals which have significant contributions at low frequency (for example signal A, see Fig. 2), the modifications do not lead to any significant reduction either in the overall level or in the N_{50} value. Referring to signal A, the optimisation process led to the same sound pressure overall level and to a N_{50} value about 0.7 sone below the original value. This difference, however, is lower than the value of "just noticeable difference" in loudness [12] and therefore meaningless.

The best solutions with respect to the minimisation of loudness (no.1 for both signals) suggest significant noise reductions all through the frequency range, as shown in Figure 6. This mainly derives from the fact that loudness strongly depends on sound level.

Noise modifications aimed at N_{50} minimisation are extremely effective. The overall sound pressure levels of the optimised signals are significantly lower than the original ones, with differences of about 2.5 dB for signal A and 4.8 dB for signal B. Even if these solutions are better with respect to minimisation of loudness than of sharpness, they still lead to modified signals with values of S_5 significantly lower than the original values. The differences (0.08 acum for signal A and 0.14 acum for signal B) are significant since they are higher than the "just noticeable difference" in sharpness [12].

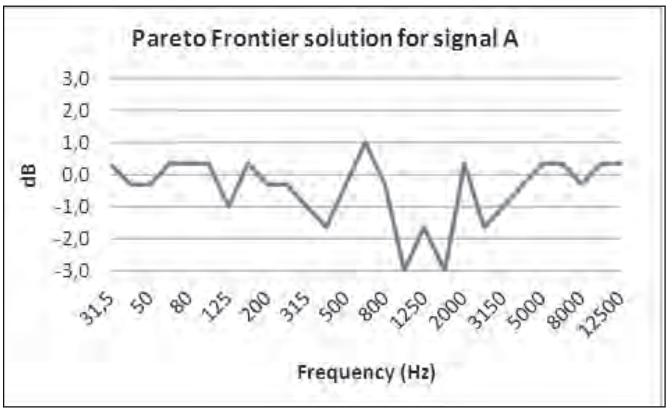

Figure 7. Pareto Frontier solution no.3 for signal A: N_{50} = 19.7 sone and S_5=1.27 acum.

Although noise modifications aimed at the N_{50} minimisation could potentially have high relevance for improving the comfort conditions, their implementation, however, turns out to be almost unfeasible in practice. Based on the above considerations, the sharpness minimisation leads to solutions with meaningless reductions both of the overall sound pressure level and of the loudness N_{50} value. On the other hand, the loudness minimisation leads to solutions with significant reductions both in the overall sound pressure level and in the sharpness S_5 value, but unfeasible in practice. Consequently, the solution to be implemented in the machine should not be chosen from these extreme solutions.

Looking for a compromise between sound quality improvement and practical constraints, the right approach could be to start from the solution with the minimum value of loudness and proceeding to solutions with progressively higher loudness values until a feasible solution is found, if it exists. As an example, Figure 7 shows the case of signal A. Solution no.3 leads to optimised values of loudness and sharpness equal to N_{50}= 19.7 sone and S_5 = 1.27 acum.

These modifications lead to a significant reduction of the overall sound pressure levels (L_{eq} is reduced by 3.3 dB and L_{Aeq} by 4.8 dBA) and they ensure a reduction of both psycho-acoustic parameters well above their corresponding just noticeable differences. In addition, the most relevant modifications mainly refer to the noise in the frequency range 800-2000 Hz which is closely related to a specific part of this machine (hydraulic system). Then the practical implementation of these suggestions seems to be feasible.

Regarding signal B, all the Pareto Frontier solutions were similar and concerned a wide frequency range. Therefore, it was impossible to find a solution which suggested modifications closely related to a specific part of this machine. In such a case all the solutions highlighted the need for more drastic modifications, not excluding a complete acoustical redesign of the machine.

CONCLUSIONS

The optimisation process applied to time-varying noise signals was aimed at minimising the loudness and sharpness percentile values N_{50} and S_5 in order to improve the Sound Quality at the operator station of earth moving machinery during real working conditions. The numerical optimisations were performed using the multi-objective genetic algorithm (MOGA) governed by the ModeFrontier optimisation procedure while the calculation of loudness and sharpness percentile values was performed by MATLAB scripts specifically developed in order to take into account the time variability of the noise signals.

The output of the optimisation process included several solutions (Pareto Frontier), all with loudness and sharpness percentile values N_{50} and S_5 significantly lower than those of the original signals. When looking at the two extreme Pareto Frontier solutions, the following information was obtained. The best solutions with respect to the minimisation of sharpness percentile value S_5 suggested significant noise reductions at medium-high frequencies, but unfortunately, an increase in noise levels at low frequencies (40-630 Hz). Despite the high correlation of the S_5 parameter with the annoyance sensation caused by these kinds of signals, this solution clearly shows that noise modifications aimed at S_5 minimisation are worthless in practice because of the increase of levels at low frequency.

The best solutions with respect to the minimisation of loudness percentile value N_{50} suggested significant noise reductions all through the frequency range. This mainly derives from the fact that loudness strongly depends on sound level. Although noise modifications aimed at the N_{50} minimisation could potentially have high relevance for improving the comfort conditions, their implementation turns out to be almost unfeasible in practice. Looking for a compromise between sound quality improvement and practical constraints, the right approach could be to start from the solution with the minimum value of loudness and proceeding to solutions with progressively higher loudness values until a feasible solution is found, if it exists.

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The Australian Acoustical Society will be hosting Inter-noise 2014 in Melbourne, from 16-19 November 2014. The congress venue is the Melbourne Convention and Exhibition Centre which is superbly located on the banks of the Yarra River, just a short stroll from the central business district. Papers will cover all aspects of noise control, with additional workshops and an extensive equipment exhibition to support the technical program. The congress theme is Improving the world through noise control.

Key Dates

The proposed dates for Inter-noise 2014 are

- Abstract submission: 10 May, 2014
- Paper submission: 25 July, 2014
- Early Bird Registration: 25 July, 2014

Further details are available at: www.internoise2014.org

Registration Fees

The registration fees have tentatively been set as*:

Delegate	$840	$720	(early bird)
Student	$320	$255	(early bird)

Accompanying person $140

*An additional GST applies to Australian based delegates

The registration fee will cover entrance to the opening and closing ceremonies, distinguished lectures, all technical sessions and the exhibition, as well as a book of abstracts and a CD containing the full papers.

The Congress organisers have included a light lunch as well as morning and afternoon tea or coffee as part of the registration fee. These refreshments will be provided in the vicinity of both the technical exhibition and poster display.

The Congress Banquet is not included in the registration fee.

Technical Programme

After the welcome and opening ceremony on Sunday 16 November, the following three days will involve 10 parallel sessions covering all fields of noise control. Major areas will include Community and Environmental Noise, Architectural Acoustics, Transport Noise and Vibration, Human Response and Effects of Low Frequencies and Underwater Noise. A series of distinguished lectures and workshops are planned to cover topics such as:

- Noise impact on high density living
- Impact on dense living
- Wind turbine noise
- Active noise control
- Aircraft noise
- Power station noise

Organising and Technical Committee

- Congress President: Dr Norm Broner
- Technical Program Chair: Adjunct Professor Charles Don
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- Technical Program Advisor: Mrs Marion Burgess
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Trailing Edge Noise Production, Prediction and Control

Con Doolan, Danielle Moreau, Elias Arcondoulis and Cristobal Albarracin

School of Mechanical Engineering, University of Adelaide,

South Australia, 5005, Australia

An original refereed contribution to New Zealand Acoustics.

Abstract

This paper describes the airfoil trailing edge noise generation mechanism and how flow over an airfoil can create tonal or broadband noise. Examples of vortex shedding as well as tonal and broadband noise spectra are presented. A brief review of how trailing edge noise can be be predicted computationally is given and some results shown using a new industrially friendly computational methodology that couples with conventional steady flow simulation software. The paper concludes with a discussion of passive trailing edge noise control devices and their effectiveness.

INTRODUCTION

Unsteady fluid flow and sharp edges are common partners in industry and nature that often create loud and unwanted sound, which is known as airfoil trailing edge noise. The most common form of unsteady flow is turbulent, and as turbulent flow passes the trailing edge of an airfoil, strong broadband noise is generated, which can be annoying to people. Less common, but equally annoying, is tonal noise generated by vortex shedding (laminar or turbulent) or a self-supported aeroacoustic feedback loop at low flow speeds. Airfoil trailing edge noise can be created by wind turbines, helicopter rotors, aircraft wings, gas-turbine blades, cooling fans, propellers and submarine control surfaces. As unwanted noise reduces quality of life and can be a public health issue, it is necessary for engineers to be able to understand, predict and control airfoil trailing edge.

In this paper, some current research results concerning trailing edge noise from the University of Adelaide are reviewed and presented. The aim of the paper is to inform the acoustics community of the physics controlling the generation of trailing edge noise, how it can be predicted and controlled along with some avenues for further research.

NOISE PRODUCTION

Unsteady fluid motion, or turbulence, is a weak source of sound, associated with the so-called "stresses" that are generated by the fluctuating fluid transporting momentum in time and space. Lighthill (1952) showed that these stresses radiate acoustic energy in a similar manner to a quadrupole source. The weak nature of turbulent quadrupole sources at low Mach number ($M = U/c_0 < 0.2$, where M is the Mach number, U is the mean fluid velocity and c_0 is the speed of sound in the ambient, surrounding fluid) means that normally, turbulence is not considered a significant noise source. However, the addition of a sharp trailing edge in close proximity to the turbulent flow introduces a scattering surface that improves the acoustic radiation efficiency of turbulent flow (Howe 1999). In effect, the edge supports a source that creates noise that has a higher intensity than would be expected for isolated turbulence.

The speed of the flow (U) approaching the airfoil, its size (chord, c) and fluid viscosity (υ) will determine if the noise generated is predominately tonal or broadband in nature. Tonal noise usually occurs when there is some kind of vortex shedding from, or concentrated fluid energy (as an eddy) passes, the trailing edge. Vortex shedding can either be laminar or turbulent (depending on the flow Reynolds number, $Re = Uc/\upsilon$ (Blake 1986)); however, different flow mechanisms are present in each case.

Tonal Noise

We will first consider vortex shedding which is illustrated in Figs. 1 and 2. These figures are results obtained from computer simulations of laminar flow over a flat-plate airfoil with an elliptical leading edge and bevelled trailing edge. Full details of the simulation and work can be found in Doolan et al. (2012). Experimental data for the same case can be found in Moreau et al. (2012a). Figure 1 shows the flow over the entire plate, which is from left to right, and shows that laminar boundary layers (indicated by the blue and red vorticity regions on the upper and lower surfaces respectively) form and approach the trailing edge. Further, unsteady eddies form in the upper surface boundary layer and these are due to a mild separation near the leading edge. Ignoring this secondary effect, the laminar boundary layer on the upper surface separates when it reaches the bevel and forms coherent vortex structures, thus starting the vortex shedding process.

Figure 2 shows a series of snapshots of the flow at the trailing edge at sequential instants of time over one vortex shedding cycle. Further, Fig. 3 shows how the lift coefficient varies during the same vortex shedding cycle. The cycle starts near the minimum point in the cycle, which corresponds to Fig. 2(a) and point (a) on Fig. 3. At this point of the lift cycle, the main shed vortex from the upper surface has just passed into the wake and a small intense vortex is being created over the trailing edge via a process where the lower boundary layer is entrained upwards by the low pressure field of the upper surface shed vortex. As time progresses to point (b), lift is generated rapidly on the plate and this is due to the formation of the intense lower surface shed vortex as well as another shed vortex on the upper surface. When time reaches point (c), the rate of lift production has slowed because the lower surface vortex has moved away from the trailing edge, leaving lift production to the low pressure core of the upper surface vortex. Lift increases further to point (d), as another upper surface vortex forms while the previous vortex exists over the trailing edge. After this point, lift is quickly destroyed (point (e)) as the upper surface shed vortex moves over the trailing edge. By point (f), the lift is at a minimum again and subsequently, a new cycle begins. Thus, the repeated shedding of vortices causes a periodic variation of force on the airfoil. This variation of force is responsible for tonal noise generation by vortex shedding.

The vortex shedding process described above was based on the laminar case. Similar vortex shedding can occur when turbulent boundary layers are present and the trailing edge is sufficiently blunt to achieve significant flow separation and hence vortex roll-up (Blake 1986).

A different form of tonal noise can occur at low Reynolds numbers (Re < 200, 000) for airfoils with sharp trailing edges. This type of noise is characterised by a primary tone and a number of sidebands, as can seen in Fig. 4, which is the noise spectrum measured from a NACA 0012 airfoil at zero angle of attack and a Reynolds number of Re = 75, 000 (Arcondoulis et al. 2012). It is widely believed that this type of tonal noise is due to an aeroacoustic feedback loop between the trailing edge (source of sound) and a point on the airfoil where convective disturbances (eddies) are created (Arcondoulis et al. 2010).

At present, the exact source of the convective disturbances is unknown and probably depends on the precise aerodynamic environment about the airfoil. One model for the feedback loop has been suggested by Arcondoulis et al. (2012) and is summarised in Fig. 5. In this model, acoustic waves generated at or near the trailing edge travel upstream and interact with the separation process near the leading edge where the shear layer is most receptive to acoustic disturbances. There is some empirical evidence to suggest that this model may hold (Arcondoulis et al. 2012), but numerical work (Jones et al. 2010) suggests that convective disturbances are generated at the leading edge. Further research is needed to resolve the exact mechanics of the feedback loop.

Broadband Noise

When the Reynolds number is sufficiently high (Re > 300, 000), the boundary layers on the surfaces of the airfoil become turbulent. Turbulent flow consists of a random number of eddies of various sizes and speed (or scales) and thus creates a broadband fluctuating surface pressure near the trailing edge of the airfoil. This broadband surface pressure is scattered by the trailing edge (Amiet 1976) and creates broadband acoustic waves that can in some cases be intense and annoying to the human ear. This form of trailing edge noise is responsible for most of the aerodynamic noise from wind turbines above 300 Hz (Oerlemans et al. 2007, Doolan 2012) as well as significant amounts of noise from aircraft wings (Lockard & Lilley 2004), propellers and rotors (Paterson & Amiet 1982) and hydrofoils (Blake 1986).

To illustrate the nature of broadband trailing edge noise, results from an experimental study by Moreau et al. (2011) are reviewed. The airfoil used in this study is a flat plate model, similar to a hydrofoil, that has a circular leading edge with a radius of 2.5 mm and the trailing edge is symmetric with an apex angle of 12^{o}, as shown in Fig. 6.

Figure 7 shows experimental noise spectra generated by the flat plate model when placed in an anechoic wind tunnel at various Reynolds numbers (see caption of Fig. 7 for actual test Reynolds numbers). The tests were conducted at a range of Reynolds numbers that extend below the natural transition point and hence turbulent boundary layers would not normally be present for cases (e) and (f). However, this model has a circular leading edge, which acts a type of boundary layer trip, that ensures turbulent flow by creating a region of separated flow just downstream of the leading edge. The free shear layer associated with this separation is very unstable and reattaches to the airfoil surface as a turbulent boundary layer.

In contrast to the tonal noise , turbulent trailing edge noise is broadband in nature and has peak acoustic energy at typically lower frequencies than tonal noise, despite the flow velocity being usually higher. This is because in turbulent boundary layer flow, turbulent energy resides in the larger scales (or lower frequencies) and in the tonal noise case, flow energy is concentrated into higher frequency (small scale) eddies. It should be noted that a practical way to control tonal noise is to disrupt the formation of these concentrated high energy vortices by placing roughness element or trips on the surface of the airfoil.

PREDICTION

Predicting airfoil trailing edge noise has many challenges, the most difficult of which is modelling the turbulence in the boundary layer. Exact analytical solutions are available to predict trailing edge noise (Ffowcs-Williams & Hall 1970, Amiet 1976, Howe 1999); however, each solution requires an estimate of the turbulent velocity or surface pressure spectrum.

Turbulence is a random, complex and highly non-linear process with no closed form solution. In an attempt to resolve this problem, turbulence models have been developed (Wilcox 2006) to avoid the computational cost of directly resolving all the scales of turbulent flow, which for typical high Reynolds number flows over airfoils, is impossible using today's computers.

Large eddy simulation (LES) is becoming increasingly popular for modelling airfoil trailing edge turbulent flow and noise (Wang et al. 2009). LES resolves only the largest, energy containing scales of turbulence, while using an analytical model to describe the smaller, dissipative scales. While this technique is able to provide accurate descriptions of the turbulent field, computational costs are still high and for many engineering design situations where multiple iterations and calculations are needed, it is prohibitive.

The normal engineering approach to turbulent flow modelling remains the steady solution of the Reynolds averaged Navier Stokes (RANS) equations with an analytical turbulence model to describe all scales of turbulence. Such a modelling methodology does not include the time-varying properties of the turbulence, instead replacing them with mean quantities of velocity, turbulent kinetic energy and dissipation. Thus, by itself, RANS simulations are not able to model the turbulent noise sources near the trailing edge of an airfoil. However, there is a need to be able to use RANS simulations for noise prediction to increase productivity during engineering design.

Continued on Page 25...


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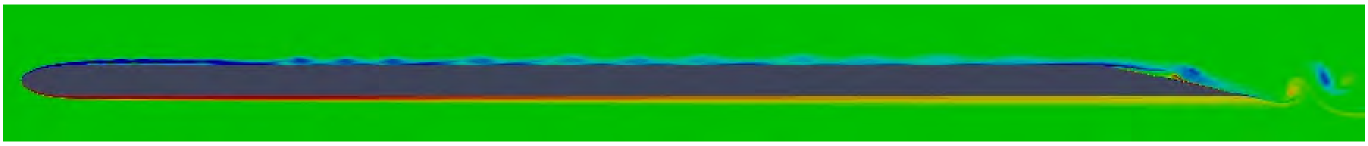
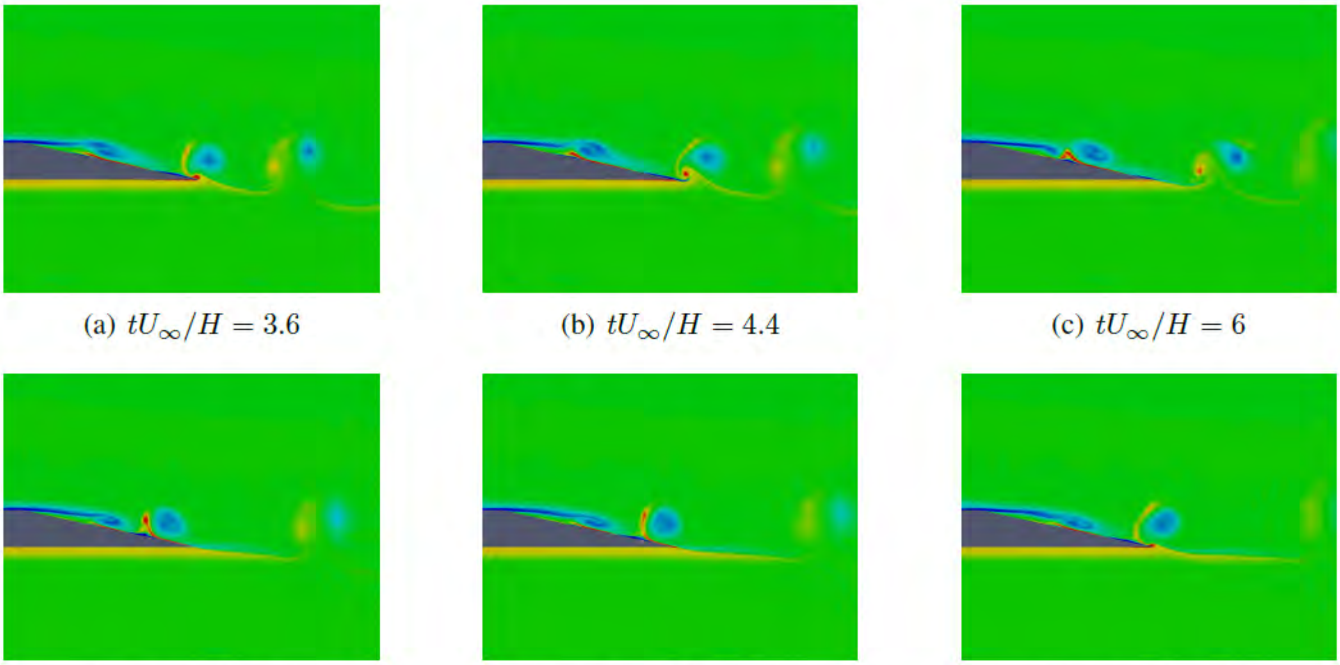


Figure 1. Contours of instantaneous spanwise vorticity about a flat plate (32 equispaced contours -7 ≤ $\omega_z H/U_{oo}$ ≤ 7, where ω_z is flow vorticity and H is the thickness of the plate).



(a) $tU_\infty/H = 3.6$ (b) $tU_\infty/H = 4.4$ (c) $tU_\infty/H = 6$

(d) $tU_\infty/H = 8$ (e) $tU_\infty/H = 8.8$ (f) $tU_\infty/H = 9.6$

Figure 2. Contours of instantaneous non-dimensional spanwise vorticity: mode II (32 equispaced contours over -7 ≤ $\omega_z H/U_{oo}$ ≤ 7, where ω_z is flow vorticity and H is the thickness of the plate).

Recently, there has been some new ideas on how to use RANS modelling for noise prediction. One such approach is the RANS based Statistical Noise Model or RSNM (Doolan et al. 2010). In this approach, data provided by the RANS solution (specifically, mean velocity, turbulent kinetic energy and dissipation) are used with a statistical model of the two-point

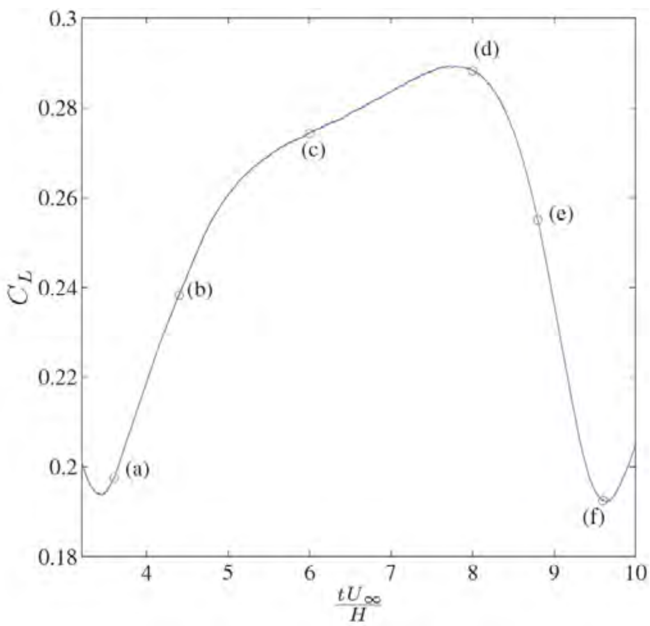


Figure 3.Unsteady lift cycle corresponding to Figure 2 (mode II), where C_L is the lift coefficient, t is time and H is the thickness of the plate.

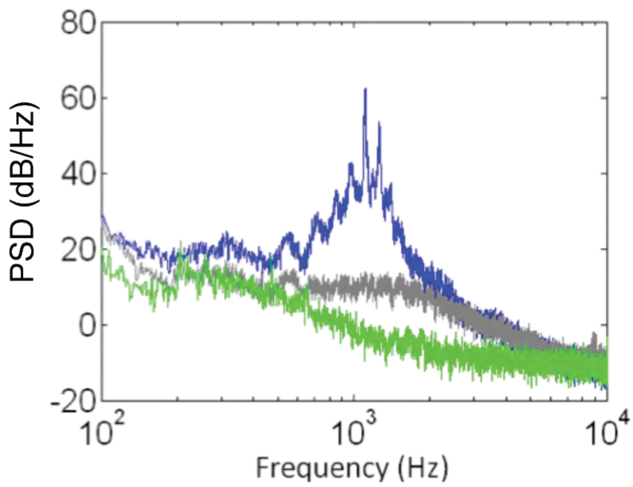


Figure 4: Acoustic spectra of a NACA 0012 airfoil at a Reynolds number of (a) 50,000 and (b) 75,000. The green, grey and blue lines represent the background noise with flow, the tripped (both surfaces) NACA 0012 airfoil and the untripped NACA 0012 airfoil, respectively. (Arcondoulis et al. 2012).

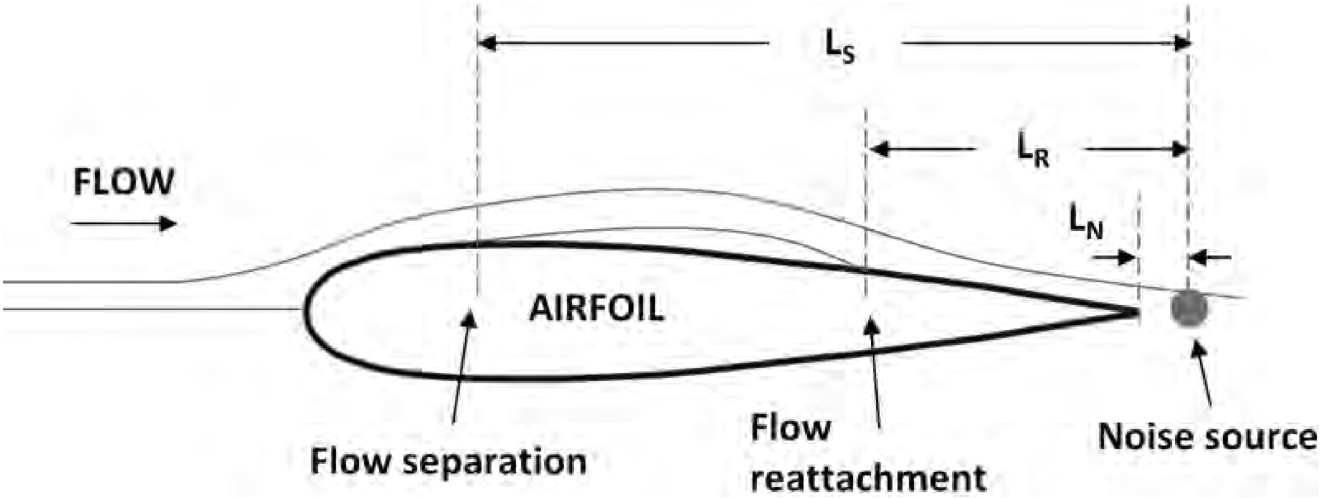


Figure 5. Suggested feedback loop of Arcondoulis et al. (2012). L_S is the distance from the noise source to the point of boundary layer separation, L_R is the distance from the noise source to the point of boundary layer reattachment and L_N is the distance from the noise source to the trailing edge.

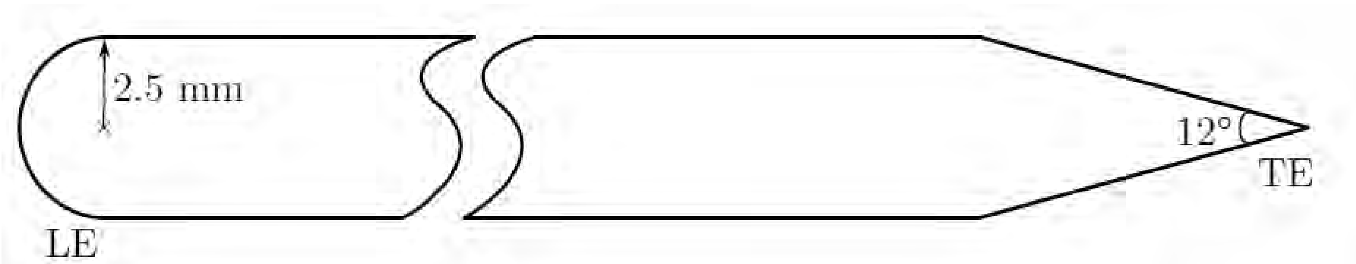


Figure 6. Schematic diagram of the flat plate airfoil model (Moreau et al. 2011). LE = leading edge, TE = trailing edge.

velocity correlation to construct noise sources in the boundary layer. Such a methodology is an accurate way to predict trailing edge noise using a fraction of the computational requirements of a LES solution. To illustrate the performance of RSNM, a comparison against some experimental data is shown in Fig. 8 (Albarracin et al. 2012).

Here, experimental one-third band noise data (Brooks et al. 1989) are compared with RSNM and a semi-empirical model (the so-called BPM model described in Brooks et al. (1989)). RSNM is able to accurately predict trailing edge noise over most frequencies.

TRAILING EDGE NOISE CONTROL

While turbulent flow is the physical source of trailing edge

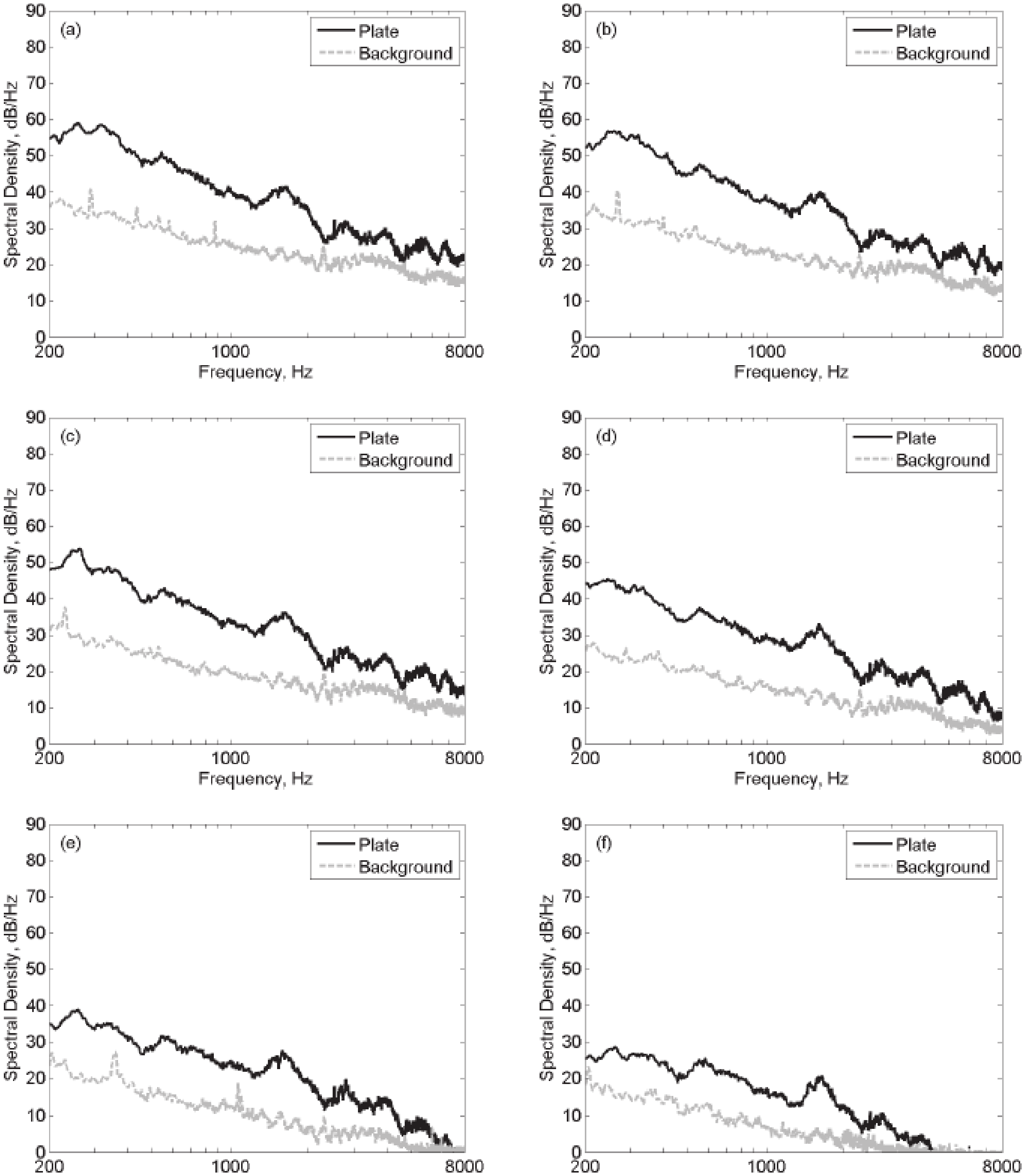


Figure 7: Far-field acoustic spectra for the flat plate model for Re = (a) 5.0×10^5, (b) 4.6×10^5, (c) 4.0×10^5, (d) 3.3×10^5, (e) 2.6×10^5 and (f) 2.0×10^5 (Moreau et al. 2011).

noise, the edge diffraction process is often the focus of noise control methodologies. Specifically, by reducing the severity of the sharp impedance change across the trailing edge, it is hoped that the mechanism whereby acoustic sources near the edge are reinforced can be diminished. Such techniques include porous trailing edges (Geyer et al. 2010) and brush attachments (Herr & Dobrzynski 2005).

Porous trailing edges can produce up to 10 dB reduction in sound pressure level at low to mid frequencies; however, an increase in noise at higher frequencies was observed and this was attributed to surface roughness effects. Similarly, brushes were found to produce up to 14 dB noise reduction (Herr & Dobrzynski 2005) but with no high frequency increase in noise level.

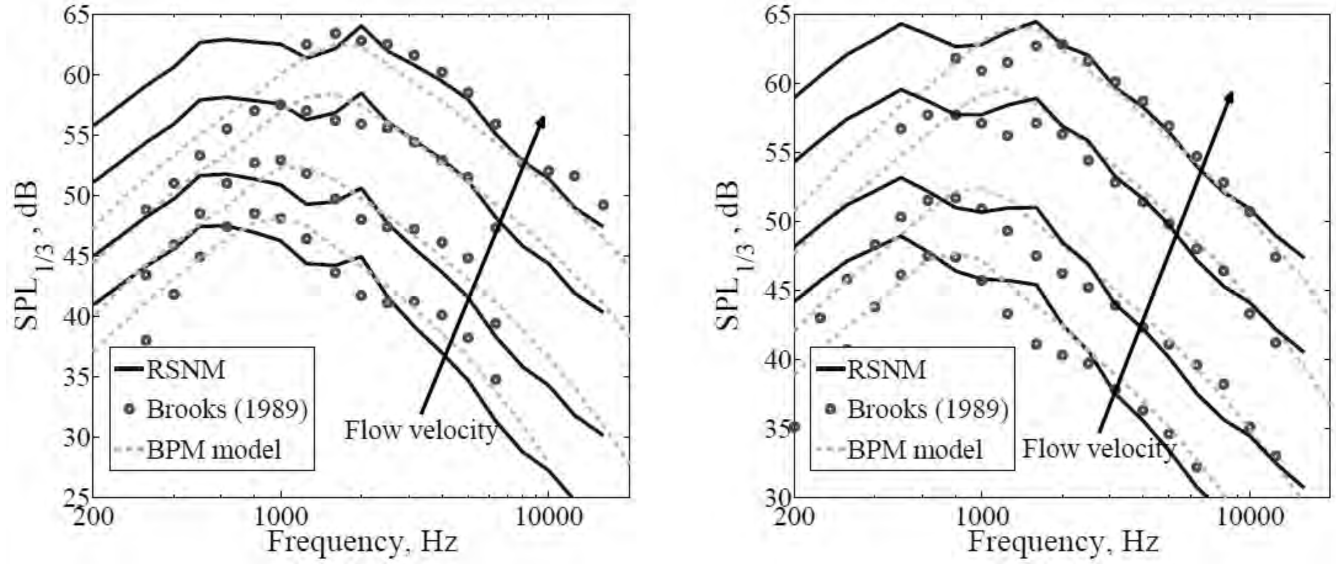


Figure 8: Noise spectra in one-third octave bands for two different chord NACA 0012 airfoils, calculated with RSNM (solid line) compared with experimental data of Brooks et al. (1989) (circles) and the BPM empirical model (Brooks et al. 1989) (dashed line) for flow velocities of 31.7, 39.6, 55.5 and 71.3 m/s; (Albarracin et al. 2012).

While effective, porous edges and brush attachments may have practical limitations, namely the fine pores or spaces between brushes are prone to collect dirt and insects making them ineffective. Thus significant effort will be required for cleaning which may not be attractive to airline operators or even possible for large wind turbines.

Another method for controlling trailing edge noise is the serrated edge (see Fig. 9), that may be easier to implement in industrial situations. Here the impedance change across the trailing edge is distributed over the serrations, which according to theory (Howe 1999), will reduce radiated trailing edge noise.

Recent measurements (Moreau et al. 2012b) of flow and noise from serrated trailing edges attached to a flat plate show that experimental noise reduction is much less than that predicted by theory and, in some frequency bands, noise may increase. In fact, it was concluded that the noise reducing effects of the serrations are mainly due to a rearrangement of the flow field by the serrations, rather than an effect on the acoustic edge diffraction mechanism.

The latest hypothesis is that the serrated edge affects the turbulent flow sources to such an extent that it overwhelms any noise reducing effects. Experiments are needed to examine in much closer detail how serrations affect turbulent flow and how these changes interact with acoustic theory in order to better explain acoustic measurements.

CONCLUSIONS & OUTLOOK

This paper has given a brief introduction to the physical mechanisms of tonal and broadband trailing edge noise generation. Tonal noise can be generated by either vortex shedding, a feedback mechanism, or both. More research is needed to identify the exact path a feedback loop takes around an airfoil. Specifically, how the upstream running acoustic wave interacts with the airfoil and boundary layer to create convective disturbances is still not clear.

Broadband noise is usually generated by turbulent flow travelling past the sharp trailing edge, acting to increase the radiating efficiency of the random, turbulent eddies as they pass.

Methodologies to predict broadband trailing edge noise were reviewed and results using the RANS based Statistical Noise Model (RSNM) were shown. RANS based noise calculation methods are the only practical way industry can accurately predict trailing edge noise during the design process, as other computational techniques (such as LES or DNS) are too computationally expensive in terms of computer infrastructure and time.

Some passive methods of controlling trailing edge noise were reviewed. While effective, porous trailing edges and brush attachments may require too much cleaning to be practicable. Serrations, on the other hand, are larger and hence will have a lower tendency to clog with dirt, but experiments show they are not as effective as theory suggests.

More research is needed to understand why this is the case and see if there are ways to improve the performance of serrated trailing edges.

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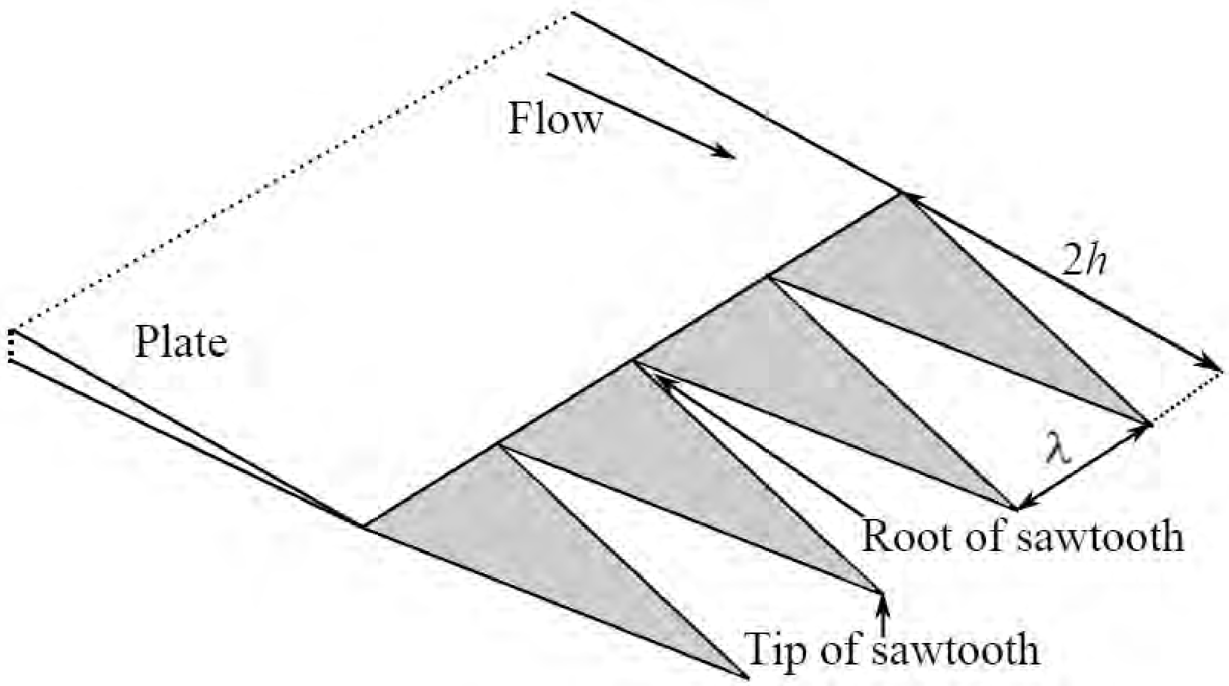

Figure 9: Sawtooth serrations at the trailing edge of a flat plate with root-to-tip amplitude of 2h and wavelength of λ; (Moreau et al. 2012b).

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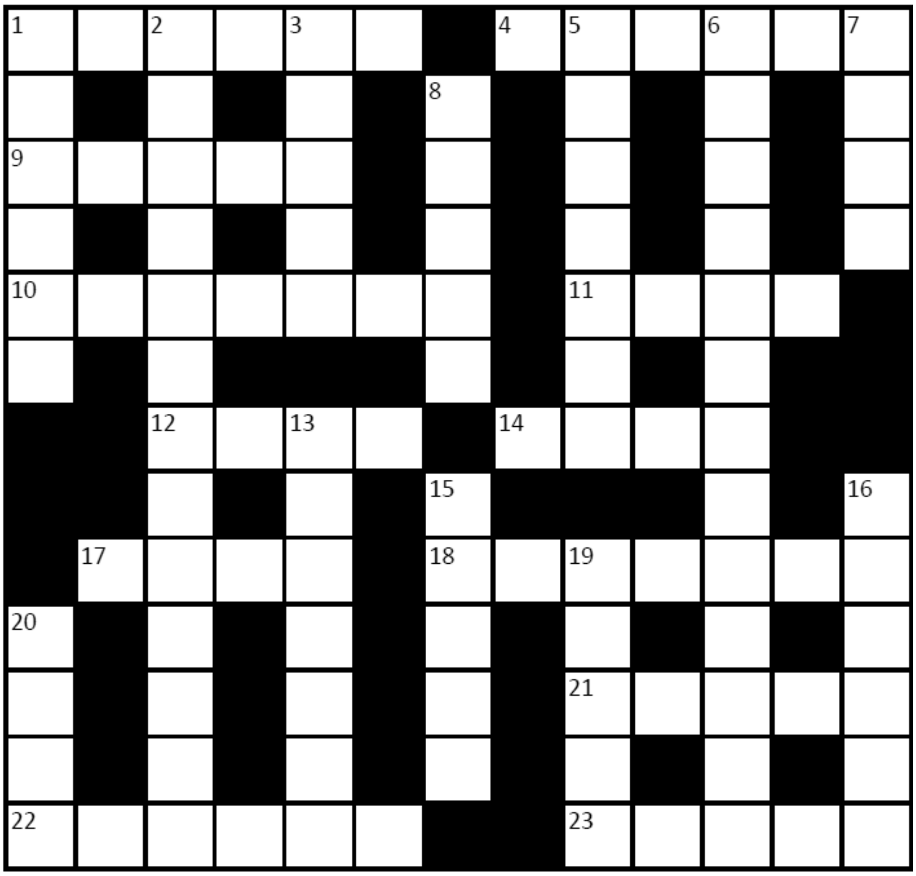
Acoustic Crossword #7



CLUES ACROSS

1. With 13 it's slightly deaf (4,2)
4. When he played, 6 occurred (6)
9. Emotional, they objected to the noise and voted with their feet (5)
10. The smallest instrument allows us to hear (7)
11. These points occur in 21 (4)
12. Inside, we choose to hear again (4)
14. They are our most common units, ten times (4)
17. Over a tad of information (4)
18. A verbal assault results in tearful loss (7)
21. Inspiring villain (5)
22. Mother, to badger the point to deal with construction noise effects (6)
23. Done around small points of minimal movement (5)

CLUES DOWN

1. Radio enthusiast by the French sea, strikes (6)
2. Beater on river stirred up sound (13)
3. Rank of reflections, not chaos (5)
5. Improve perception, hence an alteration (7)
6. A solitary horn played by the royal procession (1,5,7)
7Dn, 20Dn. Space where earplugs are needed (4,4)
8Dn, 15Dn. False leads for recording (5,5)
13. Trial, in a sense (7)
15. See 8 down
16. Warnings about the French appendages (6)
19. On door quoth the seal manufacturer nevermore (5)
20. See 7 down

Crossword submitted by:

A shy mallard

Solutions to Crossword #6

Across:

7. Decade
8. Orated
9. Solo
10. Analytic
11. Bedroom
13. Pitot
15. Frets
16. Bootleg
18. Crotchet
19. Nasa
21. A minor
22. Linear.

Down:

1. Aero
2. Favourite tune
3. Senator
4. Modal
5. Easy listening
6. Semitone
12. Eardrums
14. Portals
17. Chord
20. Scan

A Bigger Speaker

A new study has shown that the Earth's surface and atmosphere act as a giant loudspeaker in both the audible range of hearing and in infrasound. According to the computer modelling of sound recordings and seismic data used in the study, an earthquake "pumps" the surface and the atmosphere above it, sending sound waves radiating from the epicenter.

The infrasound made by an earthquake can provide detailed information about the event. In particular, it can reveal the amount of shaking that is occurring directly above the source of the quake. Accurate analysis of these sound waves could provide information that is typically gathered using an array of seismometers. This could make infrasound detection a key tool for assessing the damage and studying the mechanism behind a seismic event.

In creating their computer models, a team from Los Alamos National Laboratory in Santa Fe, USA assumed the surface and atmosphere would pump like a piston and, during a seismic event, act in the same way as a loudspeaker or subwoofer.

To test this model, the research team collected acoustic and seismic data during a 4.6-magnitude earthquake that occurred on January 3, 2011 near Circleville, Utah. The data was recorded at the University of Utah that maintains seismograph stations equipped with infrasound recording devices. After analyzing the data, they found it closely matched the results produced by their loudspeaker-based computer models.

© Adapted from an article by Brett Smith for redOrbit.com

Cretaceous Acoustics

Global temperatures directly affect the acidity of the ocean, which in turn changes the acoustical properties of sea water. Research from Rhode Island suggests that global warming may give Earth's oceans the same sound qualities they had more than 100 million years ago. This research predicts that by the year 2100, global warming will acidify saltwater sufficiently to make low-frequency (less than 200Hz) sound near the ocean surface travel significantly farther than it currently does.

This work builds on the recent investigation of historic levels of boron in seafloor sediments used to reconstruct ocean acidity for the past 300 million years. Using this data, the group were able to conclude that 300 million years ago, during the Paleozoic, the low frequency sound transmission in the ocean was similar to today. They also found that transmission improved as the ocean became more acidic, reaching its best transmission value around 110 million years ago – allowing low frequency sound to travel twice as far.

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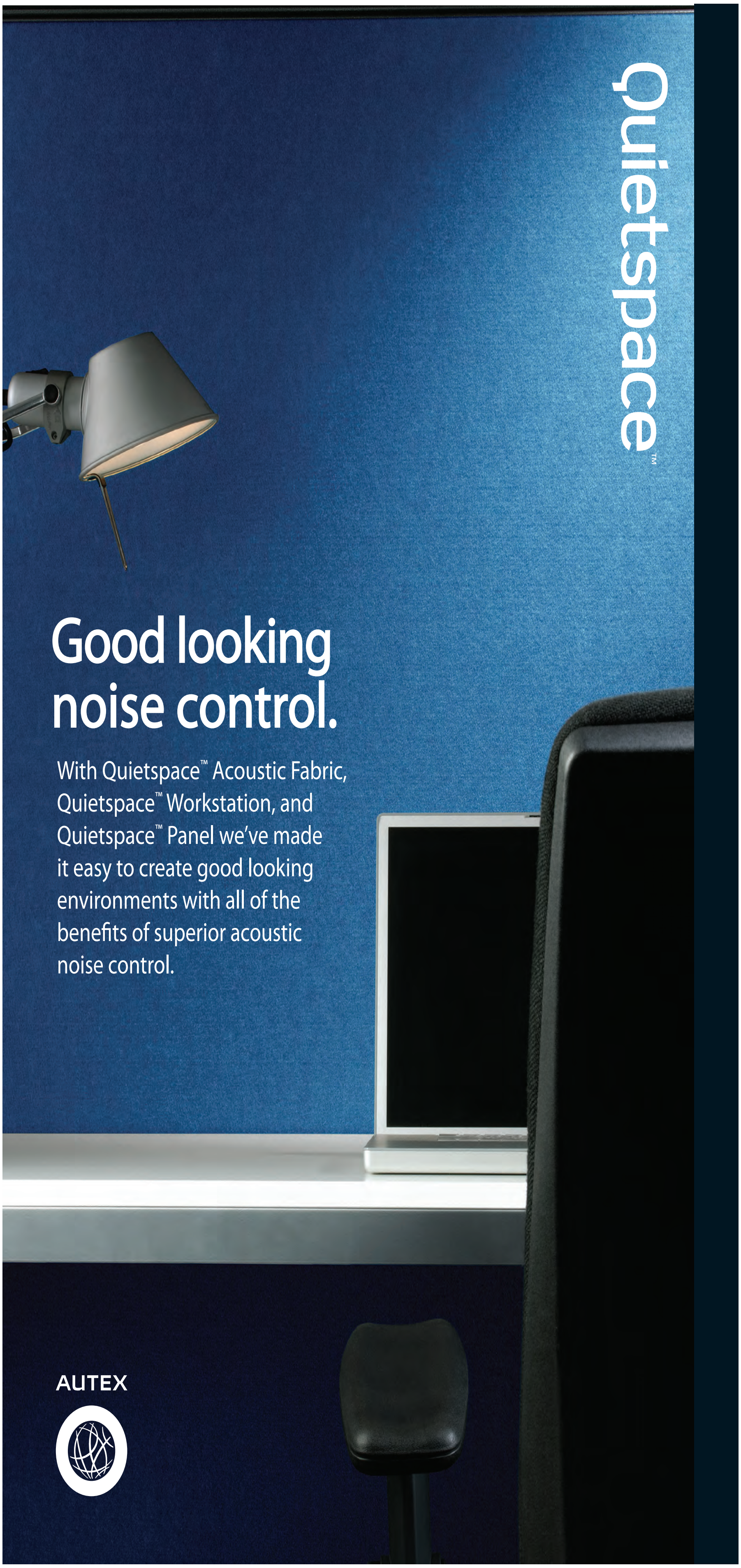
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Sound Snippets: Supervillan Acoustics

For anyone who's ever been tired of listening to someone drone on and on and on, two Japanese researchers have the answer.

The SpeechJammer, a device that disrupts a person's speech by repeating his or her own voice at a delay of a few hundred milliseconds, was named Thursday as a 2012 winner of the Ig Nobel prize – an award sponsored by the Annals of Improbable Research magazine for weird and humorous scientific discoveries.

The echo effect of the device is just annoying enough to get someone to sputter and stop.

Actually, the device created by Kazutaka Kurihara and Koji Tsukada is meant to help public speakers by alerting them if they are speaking too quickly or have taken up more than their allotted time.

"This technology ... could also be useful to ensure speakers in a meeting take turns appropriately, when a particular participant continues to speak, depriving others of the opportunity to make their fair contribution," said Kurihara, of the National Institute of Advanced Industrial Science and Technology in Japan.

Still, winning an Ig Nobel in acoustics for the device's other more dubious purpose is cool too.

"Winning an Ig Nobel has been my dream as a mad scientist," he said.

© Mark Pratt Associated Press

Upcoming Events

2012

21-23 November 2012
AAS2012: Acoustics 2012: Acoustics, Development and the Environment.
I would like to advise that the 2012 Australian Acoustical Society annual conference will be held in Fremantle, Western Australia. We have received a record 154 abstracts to date on a wide range of relevant topics regarding the environment, infrastructure and specialist fields, and will also be running several workshops prior to the event. ASNZ members will be entitled to discounted member rates, and can find out more at the conference web page.

Luke Zoontjens, AAS WA Division Chair

http://www.acoustics.asn.au/joomla/acoustics-2012.html

2013

26 - 31 March, Vancouver, Canada. 2013 IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)
http://www.icassp2013.com

1 - 4 May, Singapore 3rd International Congress on Ultrasonics (ICU 2013) concurrently organized with the 32nd International Symposium on Acoustical Imaging (AI 2013)
http://www.epc.com.sg/PDF%20Folder/ICU%202010%20Phamplet%20v1%20(12%20Jul%202010).pdf

2 - 7 June, Montreal, Canada 21st International Congress on Acoustics(ICA 2013)
http://www.ica2013montreal.org

1-3 July 2013, RASD 2013, International Conference on Recent Advances in Structural Dynamics Colleagues,
RASD will be held at the University of Pisa, Pisa, Italy, 1-3 July 2013. The eleventh in the RASD series, the conference will bring together researchers working in all areas of structural dynamics. The ten previous conferences have been held every three years or so since 1980.

As on prevision occasions, this conference is devoted to theoretical, numerical and experimental developments in structural dynamics and their application to all types of structures and dynamical systems. It will be an opportunity to exchange scientific, technical and experimental ideas.

The Call for Papers will be made in June 2012 with the deadline for the submission of abstracts being 28th September 2012. Submission and Registration to the conference will be done through the University of Southampton Open Conference System (www.ocs.soton.ac.uk/index.php/rasdconference/RASD2013).

Dr Emiliano Rustighi (on behalf of the RASD2013 Organising Committee)

Further information is available at https://www.soton.ac.uk/rasd2013

7-11 July 2013, 20th International Congress on Sound and Vibration (ICSV20), Bangkok, Thailand
The 20th International Congress on Sound and Vibration (ICSV20) will be held 7-11 July 2013 in Bangkok, Thailand. The ICSV20 is sponsored by the International Institute of Acoustics and Vibration (IIAV) and the Faculty of Science; Chulalongkorn University, the Acoustical Society of Thailand and the Science Society of Thailand; the ICSV20 is organized in cooperation with: the International Union of Theoretical and Applied Mechanics; the American Society of Mechanical Engineers International and the Institution of Mechanical Engineers. The ICSV20 Congress will be held at Imperial Queens Park Hotel, Bangkok, Thailand.

Theoretical and experimental papers in the fields of acoustics, noise, and vibration are invited for presentation. Participants are welcome to submit abstracts to www.icsv20.org and companies are invited to take part in the ICSV20 exhibition and sponsorship. For more information, please visit: http://www.icsv20.org

26 - 28 August, Denver, USA NOISE-CON 13
http://www.inceusa.org

27 - 30 August, Denver, USAWind Turbine Noise 2013
http://www.inceusa.org

15 - 18 September, Innsbruck, Austria Internoise 2013
http://www.internoise2013.com

9-11 October, Hangzhou, China 4th Pacific Rim Underwater Acoustics Conference (PURAC 2013)
http://pruac.zju.edu.cn/index.htm

2 - 6 December, San Francisco, USA 166th Meeting of the Acoustical Society of America
http://www.acousticalsociety.org

2014

5 - 9 May, Providence, USA 167th Meeting of the Acoustical Society of America
http://www.acousticalsociety.org

6 - 10 July, Beijing, China 21th International Congress on Sound and Vibration (ICSV21)

27 - 31 October, Indianapolis, USA 168th Meeting of the Acoustical Society of America
http://www.acousticalsociety.org

16 - 19 November, Melbourne, Australia Internoise 2014
http://www.internoise2014.org

CRAI Ratings

Auckland

215, Dominion Rd	(1)	★★★★½
Andrea (form. Positano), Mission Bay	(1)	★★★
Aubergine's, Albany	(1)	★★★★½
Backyard, Northcote	(1)	★★
Bask, Browns Bay	(1)	★★★
Bay (The), Waiake, North Shore	(1)	★★★★★
Bolero, Albany	(1)	★★★★
Bosco Verde, Epsom	(1)	★★★★½
Bouchon, Kingsland	(1)	★★
Bowman, Mt Eden	(1)	★★★★½
Bracs, Albany	(1)	★★★★
Brazil, Karangahape Rd	(1)	★★★
Buoy, Mission Bay	(2)	★★★★½
Byzantium, Ponsonby	(1)	★★★
Café Jazz, Remuera	(1)	★★★★½
Carriages Café, Kumeu	(1)	★★★★
Charlees, Howick	(1)	★★★★★
Cibo	(1)	★★★★★
Circus Circus, Mt Eden	(2)	★★
Cube, Devenport	(1)	★★
Del Fontaine, Mission Bay	(1)	★★★★★
Deli (The), Remuera	(1)	★★★★
Delicious, Grey Lynn	(1)	★★★★★
De Post, Mt Eden	(1)	★★
Dizengoff, Ponsonby Rd	(1)	★★
Drake, Freemans Bay (Function Room)	(1)	★★
Eiffel on Eden, Mt Eden	(1)	★★
Eve's Cafe, Westfield Albany	(1)	★★★½
Formosa Country Club Restaurant	(1)	★★★★★
Garrison Public House, Sylvia Park	(1)	★★★★½
Gee Gee's	(1)	★★★
Gero's, Mt Eden	(9)	★★★
Gina's Pizza & Pasta Bar	(1)	★★★½
Gouemon, Half Moon Bay	(1)	★★
Hardware Café, Titirangi	(1)	★★★★★
Hollywood Café, Westfield St Lukes	(1)	★★½
IL Piccolo	(1)	★★★★
Ima, Fort Street	(1)	★★★★
Jervois Steak House	(1)	★★★
Kashmir	(1)	★★★★
Katsura	(1)	★★★½
Khun Pun, Albany	(2)	★★★★★
Kings Garden Ctre Café, Western Springs	(1)	★★
La Tropezienne, Browns Bay	(1)	★★
Malaysia Satay Restaurant, Nth Shore	(1)	★★★★★
Mecca, Newmarket	(1)	★★★★★
Mexicali Fresh, Quay St	(1)	★★
Mezze Bar, Little High Street	(16)	★★★★
Monsoon Poon	(1)	★★★★★
Mozaike Café, Albany	(1)	★★
Nana Thai, Botany South	(1)	★★★★½
Narrow Table (The), Mairangi Bay	(1)	★★★★½
One Red Dog, Ponsonby	(1)	★★★
One Tree Grill	(1)	★★★
Orbit, Skytower	(2)	★★★★
Pakuranga Thai	(1)	★★★★★
Patriot, Devonport	(1)	★★★½
Pavia, Pakuranga	(1)	★★★★★
Prego, Ponsonby Rd	(2)	★★
Remuera Rm, Ellerslie Racecourse	(1)	★★★★★
Rhythm, Mairangi Bay	(1)	★★
Rice Queen, Newmarket	(12)	★★★★
Sails, Westhaven Marina	(2)	★★★★★
Scirocco, Browns Bay	(1)	★★★
Seagers, Oxford	(1)	★★★★
Shahi, Remuera	(1)	★★★½
Shamrock Cottage, Howick	(1)	★★
Sidart, Ponsonby	(1)	★★★★½
Sitting Duck, Westhaven	(1)	★★★½
Sorrento	(1)	★★½
Spices Thai, Botany South	(1)	★★★★
Stephan's, Manukau	(1)	★★★★★
Tempters Café, Papakura	(1)	★★★★★
Thai Chef, Albany	(1)	★★★★★
Thai Chilli	(1)	★★★★★
Thai Corner, Rothesay Bay	(1)	★★★★★
Tony's, High St	(1)	★★★
Traffic Bar & Kitchen	(1)	★★
Umbria Café, Newmarket	(1)	★★★★½
Valentines, Wairau Rd	(1)	★★★★★
Vivace, High Street	(2)	★★½
Wagamama, Newmarket	(1)	★★★★½
Watermark, Devonport	(1)	★★
Woolshed, Clevedon	(1)	★★½
Zarbos, Newmarket	(1)	★★
Zavito, Mairangi Bay	(1)	★★ ★

Arthur's Pass

Arthur's Pass Cafe & Store	(1)	★★★½
Ned's Cafe, Springfield	(1)	★★★★

Ashburton

Ashburton Club & MSA	(1)	★★★★½

Readers are encouraged to rate eating establishments which they visit by completing a simple form available on-line from www.acoustics.ac.nz, or contact the Editor.
Repeat ratings on listed venues are encouraged.

★ Lip-reading would be an advantage. ★★ Take earplugs at the very least. ★★★ Not too bad, particularly mid-week. ★★★★A nice quiet evening. ★★★★★The place to be and be heard. (n) indicates the number of ratings.

Robbies	(1)	★★★
RSA	(1)	★★★★
Tuscany Café & Bar	(1)	★★★

Bay of Plenty

Alimento, Tauranga	(1)	★½
Imbibe, Mt Maunganui	(1)	★½
Versailles Café, Tauranga	(2)	★★

Blenheim

Raupo Cafe	(1)	★★

Bulls

Mothered Goose Cafe, Deli, Vino	(1)	★★

Cambridge

GPO	(1)	★★★★★

Christchurch

@Tonys, Ferrymead	(6)	★★½
3 Cows, Kaiapoi	(1)	★★★★
Abes Bagel Shop, Mandeville St	(1)	★★★★
Addington Coffee Co-op	(4)	★★★★
Alchemy Café, Art Gallery	(1)	★★★★★
Anna's Café, Tower Junction	(1)	★★★★
Arashi	(1)	★★
Azure	(2)	★★★
Bamboozle, Sumner	(5)	★★½
Becks Southern Ale House	(11)	★★★★½
Buddha Stix, Riccarton	(1)	★★★★
Bully Haye's, Akaroa	(1)	★★
Cashmere Club	(1)	★★★★★
Cassels & Sons, The Brewery	(5)	★★★★
Christchurch Casino	(1)	★★
Christchurch Museum Café	(1)	★★★★
Cobb & Co, Bush Inn	(1)	★★★
Coffee House, Montreal Street	(1)	★★
Cookai	(3)	★★½
Corianders, Edgeware Road	(11)	★★★
Costas Taverna, Victoria Street	(1)	★½
Decadence Café, Victoria St	(1)	★★★★★
Drexels Breakfast Restaurant, Riccarton	(1)	★★★★
Edisia, Addington	(1)	★★★
Elevate, Cashmere	(1)	★★★
Fava, St Martins	(1)	★★
Flying Burrito Brothers, Northlands	(12)	★★½
Foo San, Upper Riccarton	(1)	★★★½
Fox & Ferrett, Riccarton	(1)	★★★★★
Gloria Jean's, Rotheram St	(1)	★★★★
Golden Chimes	(1)	★★★★★
Governors Bay Hotel	(1)	★★★★
Green Turtle	(1)	★★★★
Harpers Café, Bealey Ave	(1)	★★★★★
Holy Smoke, Ferry Rd	(1)	★★
Indian Fendalton	(2)	★★
JDV, Merivale	(2)	★★★★
Kanniga's Thai	(1)	★★★
La Porchetta, Riccarton	(4)	★★½
Little India	(2)	★★★★★
Lone Star, Riccarton Road	(6)	★★★
Lyttleton Coffee Co, Lyttleton	(1)	★★★★
Manee Thai	(6)	★★½
Mexican Café	(6)	★★★
Myhanh, Church Corner	(4)	★★★½
Number 4, Merivale	(2)	★★★★
Oasis	(1)	★★★★½
Old Vicarage	(2)	★★★½
One Good Horse, Parklands	(4)	★★★★
Phu Thai, Manchester Street	(1)	★★★
Pukeko Junction, Leithfield	(1)	★★★★
Red, Beckenham Service Centre	(1)	★★★★
Red Elephant	(1)	★★★★
Retour	(1)	★★★
Riccarton Buffet	(2)	★★★★½
Robbies, Church Corner	(2)	★★★★½
Route 32, Cust	(1)	★★★★
Saggio di Vino (2012)	(1)	★★★★½
Salt on the Pier, New Brighton	(6)	★★★½
Speights Ale House, Tower Junction	(1)	★★★★
Spice 'n' Life, Church Corner	(4)	★★★★½
The Bridge, Prebbleton	(1)	★★★★★
The Bicycle Thief	(1)	★★★★½
The Sand Bar, Ferrymead	(2)	★★★½
Tokyo Samurai	(1)	★★★★★
Tutto Bene, Merivale	(2)	★★
Untouched World Cafe	(1)	★★★★★
Wagamama, Oxford Terrace	(6)	★★★
Waitikiri Golf Club	(1)	★★
Waratah Café, Tai Tapu	(1)	★★★

Clyde

Old Post Office Cafe	(1)	★★★★★

Dunedin

A Cow Called Berta	(1)	★★★½
Albatross Centre Cafe	(1)	★★★★★
Bennu	(1)	★★★★
Bx Bistro	(1)	★★★★
Chrome	(1)	★★★★½
Conservatory, Corstophine House	(1)	★★★★★
Fitzroy Pub on the Park	(1)	★★★★★
High Tide	(2)	★★
Nova	(1)	★★★★★
St Clair Saltwater Pool Cafe	(1)	★★★★½
Swell	(1)	★★
University of Otago Staff Club	(1)	★★

CRAI Ratings (cont.)

Feilding

- Essence Cafe & Bar0 (1) ★★★★

Gore

- Old Post (1) ★★★
- The Moth, Mandeville (1) ★★★★★

Greymouth

- Cafe 124 (1) ★★★

Hamilton

- Embargo (1) ★★★★★
- Gengys (1) ★★
- Victoria Chinese Restaurant (1) ★★★★★

Hanmer Springs

- Laurels (The) (2) ★★★★★
- Saints (1) ★★★★½

Hastings

- Café Zigliotto (1) ★★★

Havelock North

- Rose & Shamrock (1) ★★★½

Levin

- Traffic Bar & Bistro (1) ★★

Masterton

- Java (1) ★★

Matamata

- Horse & Jockey (1) ★★★★★

Methven

- Ski Time (2) ★★★

Napier

- Boardwalk Beach Bar (2) ★★★★★
- Brecker's (1) ★★★★★
- Café Affair (1) ★★
- Cobb & Co (1) ★½
- Duke of Gloucester (1) ★★★★½
- East Pier (1) ★★
- Estuary Restaurant (1) ★★★★★
- Founder's Cafe (1) ★★★★★
- Napier RSA (1) ★★★★★
- Sappho & Heath (1) ★★

Nelson/Marlborough

- Allan Scott Winery (1) ★★★★★
- Amansi @ Le Brun (1) ★★★★★
- Baby G's, Nelson (1) ★★★★★
- Boutereys, Richmond (1) ★★★★
- Café Affair, Nelson (1) ★★
- Café on Oxford, Richmond (1) ★★★
- Café Le Cup, Blenheim (1) ★★★
- Crusoe's, Stoke (1) ★★★
- Cruizies, Blenheim (2) ★★★★½
- Grape Escape, Richmond (1) ★★★★★
- Jester House, Tasman (1) ★★★★★
- L'Affaire Cafe, Nelson (1) ★★
- Liquid NZ, Nelson (1) ★½
- Lonestar, Nelson (1) ★★★★
- Marlborough Club, Blenheim (1) ★★
- Morrison St Café, Nelson (1) ★★½
- Oasis, Nelson (1) ★★★★★
- Rutherford Café & Bar, Nelson (1) ★★★★★
- Suter Cafe, Nelson (1) ★★
- Verdict, Nelson (1) ★★
- Waterfront Cafe & Bar, Nelson (1) ★★★
- Wholemeal Trading Co, Takaka (1) ★★★★★

New Plymouth

- Breakers Café & Bar (1) ★★★
- Centre City Food Court (1) ★★★★
- Elixer (1) ★★★★
- Empire Tea Rooms (1) ★★★★½
- Govett Brewster Cafe (1) ★★
- Marbles, Devon Hotel (1) ★★★
- Pankawalla (1) ★★★★★
- Simplicity (1) ★★★
- Stumble Inn, Merrilands (1) ★★★
- Yellow Café, Centre City (1) ★★★
- Zanziba Café & Bar (1) ★★★

Oamaru

- Riverstone Kitchen (1) ★★★★★
- Star & Garter (1) ★★★
- Woolstore Café (1) ★★★★

Palmerston North

- Café Brie (1) ★★★
- Café Esplanade (2) ★★★★
- Chinatown (1) ★★★★
- Coffee on the Terrace (2) ★★★
- Elm (1) ★★★★½
- Fishermans Table (1) ★★★★★
- Gallery (3) ★★★★
- Rendezvous (1) ★★½
- Roma Italian Restaurant (1) ★★★
- Rose & Crown (1) ★★
- Tastee (1) ★★★
- Thai House Express (1) ★★★★★
- Victoria Café (1) ★★★★

CRAI Ratings (cont.)

Queenstown

Bunker	(1)	★★★★
The Cow	(1)	★★★
Sombreros	(1)	★
Tatler	(1)	★★★★
Winnies	(1)	★★★★★

Rotorua

Cableway Rest. at Skyline Skyrides	(1)	★★★★★
Lewishams	(1)	★★★
Woolly Bugger, Ngongotaha	(1)	★★★
Valentines	(1)	★★★★★
You and Me	(1)	★★★★★
Zanelli's	(1)	★★

Southland

Lumberjack Café, Owaka	(1)	★★★★★
Pavilion, Colac Bay	(1)	★★
Village Green, Invercargill	(1)	★★★★★

Taihape

Brown Sugar Café	(1)	★★★★½

Taupo

Burbury's Café	(1)	★★★
Thames		
Thames Bakery	(1)	★★★
Waiheke Island		
Cortado Espresso Bar	(1)	★★★★
Cats Tango, Onetangi Beach	(1)	★★★★

Timaru

Fusion	(1)	★★★★★

Wanganui

3 Amigos	(1)	★★★½
Bollywood Star	(1)	★★★½
Cosmopolitan Club	(1)	★★★★
Liffiton Castle	(1)	★★½
RSA	(1)	★★★½
Stellar	(1)	★★★★½
Wanganui East Club	(1)	★★★★

Wellington

162 Café, Karori	(1)	★★★★★
180º, Paraparaumu Beach	(1)	★★
88, Tory Street	(35)	★★
Anise, Cuba Street	(1)	★★
Aranya's House	(1)	★★★★★
Arbitrageur	(2)	★★★
Arizona	(1)	★★
Astoria	(2)	★★★
Backbencher, Molesworth Street	(1)	★★★
Bordeaux Bakery, Thorndon Quay	(1)	★★
Brown Sugar, Otaki Railway Station	(1)	★★★
Buzz, Lower Hutt	(1)	★★½
Brewery Bar & Restaurant	(5)	★★★★
Carvery, Upper Hutt	(1)	★★★★★
Chow	(1)	★½
Cookies, Paraparumu Beach	(1)	★★★½
Cosa Nostra Italian Trattoria, Thorndon	(1)	★★★★
Dockside	(1)	★★★★
Gotham	(6)	★★★½
Great India, Manners Street	(2)	★★★★★
Habebie	(1)	★★
Harrisons Garden Centre, Peka Peka	(1)	★★★★
Hazel	(1)	★★
Katipo	(1)	★★★★★
Kilim, Petone	(4)	★★★★½
Kiss & Bake Up, Waikanae	(1)	★★★
La Casa Pasta	(1)	★★★★½
Lattitude 41	(3)	★★★★
Legato	(1)	★★
Le Metropolitain	(1)	★★★★★
Loaded Hog	(5)	★★★★½
Manhatten, Oriental Bay	(1)	★★★★
Maria Pia's	(1)	★★★
Matterhorn	(1)	★★★
Meow Café	(1)	★★
Mungavin Blues, Porirua	(1)	★★★★★
Olive Café	(1)	★★★★★
Olive Grove, Waikanae	(1)	★★★½
Original Thai, Island Bay	(1)	★★★★
Palace Café, Petone	(1)	★★½
Parade Café	(1)	★★
Pasha Café	(1)	★★★★
Penthouse Cinema Café	(2)	★★★½
Pod	(1)	★★½
Rose & Crown	(1)	★★★★★
Shed 5	(1)	★★
Siem Reap	(1)	★★
Speak Easy, Petone	(1)	★★
Speights Ale House	(1)	★★
Sports Bar Café	(1)	★★★★
Stanley Road	(1)	★★★
Stephan's Country Rest., Te Horo	(1)	★★★★★
Wakefields (West Plaza Hotel)	(1)	★★★
Windmill Café & Bar, Brooklyn	(1)	★★
Yangtze Chinese	(1)	★★★★½
Zealandia Café, Karori Sanctuary	(1)	★★★½

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NCS Acoustics

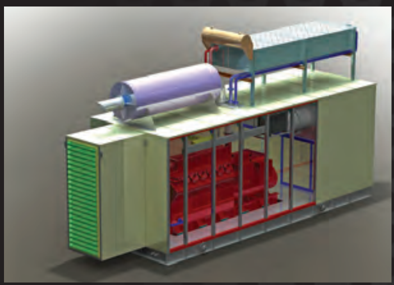
DESIGN • MANUFACTURE • INSTALL

PERFORMANCE GUARANTEED — Designed, manufactured and tested in New Zealand

ESTABLISHED SINCE 1981 — Formerly NOISE CONTROL SERVICES LTD

DESIGN

Got a commercial or industrial noise problem? Our acoustic engineers will design an economical, innovative solution to your exact requirements.



MANUFACTURE

Operating from a 2000m^2 purpose built factory in Auckland, we are able to meet the production requirements, large or small, of clients throughout New Zealand and internationally.

INSTALL

We offer installation, testing, monitoring and maintenance services, to ensure you receive optimum performance from our products.

We provide custom made acoustic solutions

- Attenuators: Rectangular, Cylindrical, Compact Cylindrical, Crosstalk, Curb
- Silent Supply/Extract Systems
- Acoustic Louvres
- Sound Enclosures, Canopies and Acoustic Containers
- Absorptive and Reactive Mufflers
- Blower, Vent and Specialist Diary Industry Silencers
- Acoustic Doors and Plugs
- Acoustic Barriers and Screens
- Absorption Panels
- Audiometric Booths

"If it's noisy we can fix it!"

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www.ncsacoustics.co.nz

FORMERLY... NOISE CONTROL SERVICES — ACOUSTIC PRODUCTS AND DESIGN

Leaders in design, manufacture and installation of acoustic solutions.