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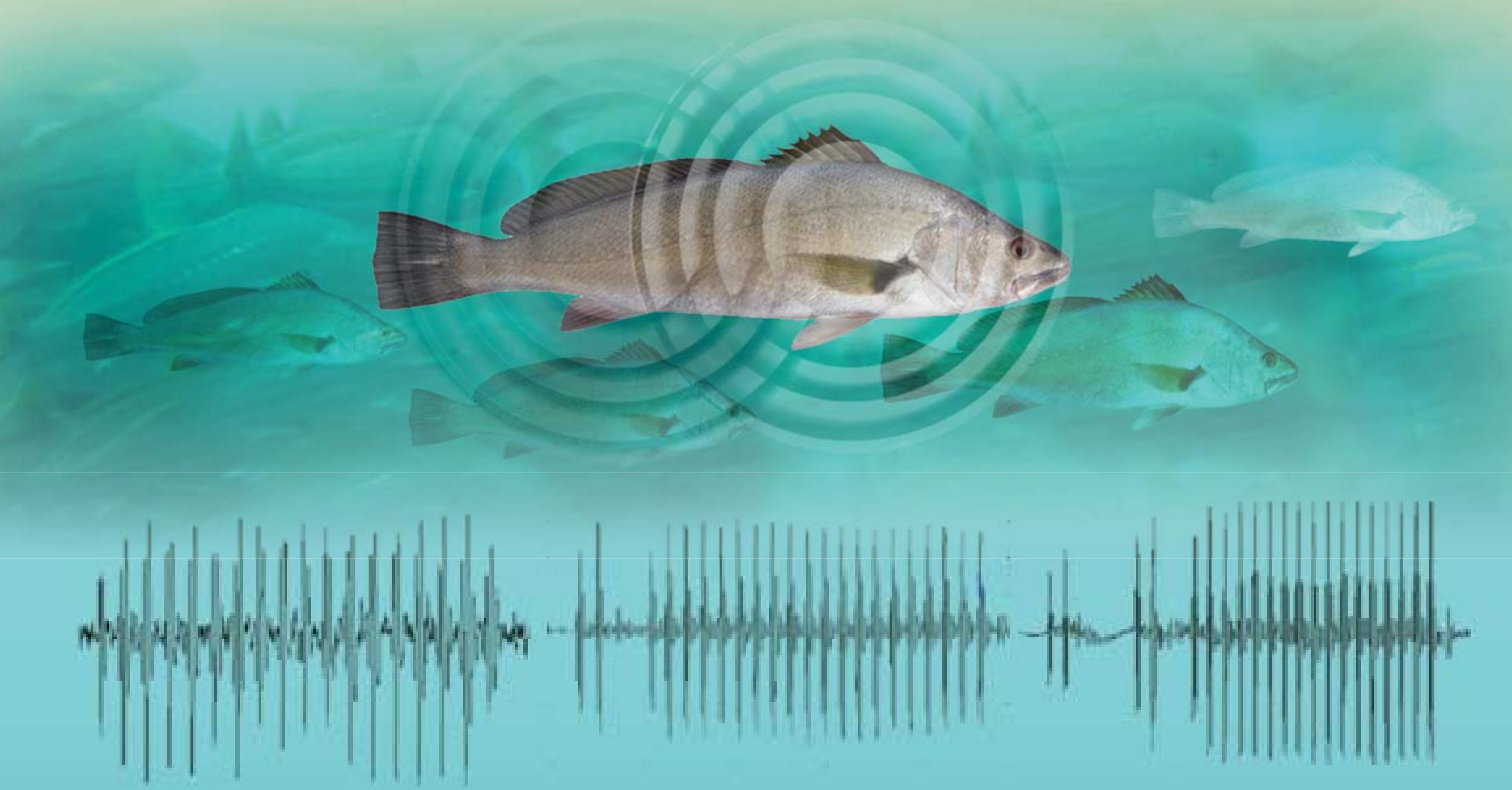

Noise from personal players
Road noise barriers
Airfoil trailing edge noise
Microperforated materials
Transmission loss in panels
Fish calls
Accents of world English
Preventing a deaf generation
Restaurant noise

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Acoustics Australia General Business
(subscriptions, extra copies, back issues, advertising, etc.)
Mrs Leigh Wallbank
P O Box 70
OYSTER BAY NSW 2225
Tel (02) 9528 4362
Fax (02) 9589 0547
wallbank@zipworld.com.au

Acoustics Australia All Editorial Matters
(articles, reports, news, book reviews, new products, etc)
The Editor, Acoustics Australia
c/o Nicole Kessissoglou
School of Mechanical and Manufacturing Engineering
University of New South Wales
Sydney 2052 Australia
61-2-93854166 (tel)
61-2-96631222 (fax)
AcousticsAustralia@acoustics.asn.au
www.acoustics.asn.au

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PAPERS

TECHNICAL NOTES

Cover design: Heidi Hereth

Message from the President

Well, this is my last note to you all as the current President. And what a way to go! We had a very successful ICA in Sydney thanks to the efforts of Marion Burgess and her team and then very successful satellite conferences thereafter. Reports about all of these are in this edition of our journal. I also had the pleasure of the Company of the Victorian Governor, Professor David de Kretser and Dr Leo Beranek at the ISRA banquet and what a treat that was too!

President of AAS presenting Dr Leo Beranek his Honorary Fellowship of the AAS at the 20th ICA

It is clear that Australia is no slouch when it comes to our acoustic contributions to the world. It was great to see so many overseas visitors at our conferences but it was really good to some very impressive Australian contributions.

Governor of Victoria, Professor de Kretser with Dr Leo Beranek and Dr Norm Broner, President AAS at the ISRA banquet.

As I hand over the reins to our next President, Peter Heinze, I want to thank the Federal Council and the Divisions for their support during my Presidency and I urge you all to give Peter your full support. There are some potentially exciting developments afoot so watch this space!

Overall, I think that everyone has had a very good year this last year. Best wishes to all for the season and a safe holiday. Let's all return refreshed next year and let's all have an even better New Year!

Norm Broner

Message from the Editor

This year has been a significant year in acoustics in Australia. We've had the pleasure of hosting the 20th International Congress on Acoustics (ICA) in Sydney and its associated meetings, the International Symposium Musical Acoustics (ISMA) in Sydney and Katoomba, the International Symposium on Room Acoustics (ISRA) in Melbourne and the International Symposium on Sustainability in Acoustics (ISSA 2010) in New Zealand. I was especially lucky to be able to attend ICA2010 since it was held in my home town of Sydney, as travelling these days is increasingly limited due to my young family. Attending acoustic meetings is such an enjoyable experience, it's such a great treat to catch up with colleagues from interstate and overseas, as well as learn about so many different and interesting topics in acoustics. My highlight of the year was attending the lectures by Dr Leo Beranek, particularly the one at the Sydney Conservatorium of Music. It was fascinating to learn of Beranek's background thanks to an introduction by Fergus Fricke, after which we were treated to an excellent talk on concert hall acoustics. I hope I can be forgiven for getting on the bandwagon and posting a photo with the famous acoustician.

I am sure you will enjoy reading the range of articles in this issue as much as I have. In addition, the technical notes describe two very different and important campaigns that are raising awareness of noise in our society and some of the ill effects that go with it. Before I sign off I would like to thank Marion Burgess and her team for all the hard work in bringing ICA2010 to Australia. I would also like to give a special thanks to the reviewers for this issue, many of whom were asked to review articles in a very short time.

L-r: Dr Leo Beranek, Mr Peter Karantonis (Renzo Tonin & Associates), Mr Nicholas Tselios (Renzo Tonin & Associates), A/Prof. Nicole Kessissoglou (UNSW)

I wish you the best for the holiday season and look forward to receiving lots of articles in the New Year.

Nicole Kessissoglou

THE STATISTICAL DISTRIBUTION OF EXPECTED NOISE LEVEL OUTPUT FROM COMMONLY AVAILABLE PERSONAL STEREO PLAYERS

W. Williams[1] and J. Purnell[2]

[1]National Acoustic Laboratories, Chatswood, NSW 2067

[2]Chatswood High School, Chatswood, NSW 2067

This work presents a summary of the equivalent at-ear sound levels that can be expected to be experienced by users of personal stereo players. Estimates of inter-device and inter-earphone variability are also provided along with variations in performance and maximum output levels. This variation in acoustic output levels may mean that attempts by users to control noise exposure by monitoring the electrical output may not be as simple as first envisaged. A simple method is provided for the estimation of PSP output level with respect to the volume setting.

INTRODUCTION

Since the introduction of personal stereo players (PSP) there has been increasing discussion and speculation concerning the possible levels of overall noise exposure from excessive listening by users (Rice, Breslin & Roper: 1987; Waugh & Murray: 1989; Passchier-Vermeer: 1999; Fligor & Clarke Cox: 2004; SCENIHR: 2008). Acoustic output levels from devices and their associated earphones have been measured in the laboratory (Waugh & Murray: 1989; Turunen-Rise, Flottorp & Tvete: 1991; Passchier-Vermeer: 1999; Fligor & Clarke Cox: 2004; Portnuff & Fligor: 2006; Keith, Michaud & Chiu: 2008), in situ in common use settings (Williams: 2005; Williams: 2009) and in a mixture of the laboratory and in situ (Rice, Breslin & Roper: 1987). The conclusions from this work agree that given the available levels of acoustic output there is a distinct possibility of noise injury and subsequent hearing loss with excessive use (Lonsbury-Martin & Martin: 2007; Morata: 2007).

Laboratory measurements produced by six compact disc players and a range of nine commercially available headphones were carried out by Fligor and Clarke Cox (2004) using specifically recorded 'white' noise and a selection of CDs from eight music genres. The A-weighted output levels at maximum volume setting with the white noise ranged from around 94 to 115 dB. Keith et al (2008) specifically measured the A-weighted output levels at maximum volume setting from various combinations of portable digital audio players and headphones with results ranging from 101 to 107 dB for headphones when worn as would be normally expected with a 'loose' fit. If the headphones were fitted with a 'tight' fit, such as having ear phones under a head ('sweat') band or a greater clamping force on earmuffs, it was observed that the output level could increase on average by 16 dB to a maximum in one case of 120.4 dB.

A combination of laboratory and in situ measurements found maximum A-weighted levels extended over 100 dB for 5% of users with one reaching a maximum of 107 dB (Rice, Breslin & Roper: 1987). From the presentation of the data it is unclear how these values were distributed between laboratory and in situ measurements. In another study of 139 participants in situ, the maximum A-weighted output level was recorded as 110 dB (Williams: 2009).

Currently social research examining PSP use and possible problems of over exposure to noise and subsequent noise injury frequently makes use of interviews and questionnaires. Rather than attempt the time-consuming task of an on-site measurement of PSP acoustic output level users are asked to rate the volume setting they typically set on their device. This is usually expressed either as a single figure rating from one to ten or as a percentage of maximum output. In contrast, this project looked at what acoustic output level could be expected in relation to the volume setting. Social researchers can then estimate the approximate noise exposure of PSP users within a given confidence interval.

METHOD

Ten different PSP devices and 17 different earphones were tested. Samples were gathered after a request for volunteers to lend their PSPs for measurements. All testing was carried out at the National Acoustic Laboratories, Chatswood. As it was not logistically possible to have all of the PSPs and headphones assembled simultaneously during the testing period the most desirable situation of testing all devices and earphone combinations was not possible. Hence the following combination of devices and headphones were measured: a) 10 devices with as many compatible/available headphones as possible making a total of 45 combinations; b) one device with each of 12 earphones and three devices with each of eight earphones to examine earphone variation; and c) one earphone with each of six devices and three earphones with each of four devices to examine device variation. A comprehensive list of device – earphone combinations tested is supplied in the attached Appendix.

The acoustic output level measurements were carried out using a previously utilised system (Williams: 2009) consisting of a lightweight manikin head fitted with a Zwislocki artificial ear simulator including pinna. The artificial ear simulator was in turn fitted with a B&K 4134 pressure response microphone, supported by a B&K 2639 preamplifier and B&K 2804 microphone power supply leading to a B&K 2231 Integrating Sound Level Meter. The system was calibrated using a B&K 4230 calibrator. The output levels under earphones are expressed as the equivalent diffuse field, A-weighted equivalent continuous sound levels (LAeq) as per AS/NZS 1269.1: 2005.

The measurements were performed using one of the earphones from the PSP by placing it around, over or in the measurement ear depending on whether it was a circum-aural, supra-aural or an insert earphone, while the PSP was playing. The noise level under the earphone was measured in accordance with the recognised procedure as per AS/NZS 1269.1 (2005), Appendix C (Informative), *"Recommended procedures for measurement of sound pressure levels from headphones or insert earphones"*. The measurement parameter was the L_{Aeq} taken over a two minute (120 sec) period. This sample time was selected so as to adequately 'average' the representative noise level of the PSP and in line with previous practice (Rice, Breslin & Roper: 1987; Williams: 2005; Williams: 2009).

The song or music playing was 'pseudo-randomly' selected to represent that typically used by owner of the device. For example, this may have been a frequently listened to or favourite selection. In this way it was intended to sample the range of outputs experienced by a large number of users. The acoustic output levels were measured at the 35%, 50%, 65%, 80%, 90% and 100% volume setting as judged by the 'volume indicator' on all of the devices used. These levels were selected as representative of the range of typical listening conditions.

RESULTS AND DISCUSSION

a) Overall

Figure 1 presents a specific example of the output from a well-known, good quality device with matching 'ear-bud' earphones together with a line of best fit between the volume settings and measured outputs. This particular device was tested with volume settings from 10% to 100%. As would be expected of a well-engineered player there is good linearity with a clear, linear relationship between the measured output level and the indicated volume setting and 100% output corresponds to an LAeq of about 100 dB. Unfortunately this is not the case with all device – earphone combinations.

The acoustic output levels measured from the 45 device – earphone combinations are presented graphically in Figure 2 along with the mean output level (solid line). As can be seen there is a wide range of output levels for a selected volume setting. These vary with an overall average of 34 dB, from a minimum of 23 dB at 35% volume setting to 45 dB at the 100% volume setting. The range increases roughly proportional to the selected volume. Overall there is an increase in output level with increase in volume setting however this is not the case with all device – earphone combinations. One combination resulted in an almost flat response with higher outputs for lower settings (see Figure 3). There is a general tendency for non-linearities to occur at low volume settings.

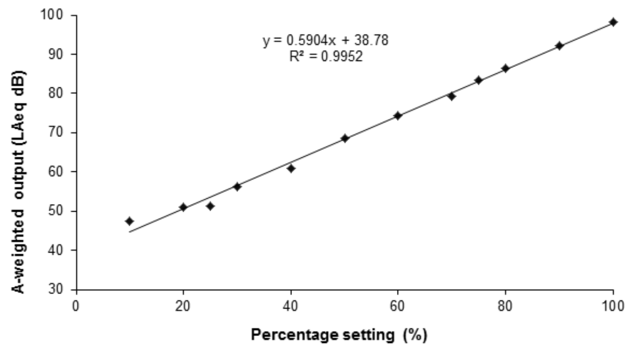

Figure 1: The relationship between measured acoustic output (L_{Aeq}) and volume setting (L) of a combination of a good quality PSP and matched earphones.

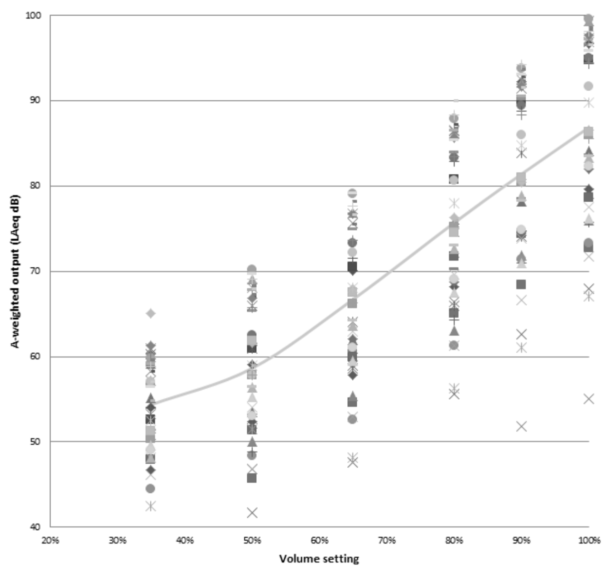

Figure 2: Measured acoustic output (L_{Aeq}) and volume setting (L) for all 45 PSP – earphone combinations tested. The solid line represents the expected (mean) value.

The general relationship for all devices is provided by the trend line, viz: expected output = 0.53 L% + 34 (R2 = 0.99). The average standard deviation (SD) for all volume settings is 8.8dB monotonically increasing from 5.3 dB at 35% to 10.9 dB at 100% output. The upper 95% confidence interval for the output level at 100% volume setting is 108 dB.

The variation in performance has two main sources discounting any variation that may arise from music or song selection. The two obvious sources are the devices and the headphones.

b) Earphone variation

One device was tested with six different devices and three sets of earphones were tested with each of four devices. The device tested with each of six different earphones gave an average SD of 7.3 dB. Four of these earphones were the same as used with the subsequent three devices. The devices tested with each of the same four earphones produced average SDs of 8.0 dB, 9.2 dB and 9.8 dB. The average SD across all tests of 8.6 dB could be considered the between-earphone variation.

c) Device variation

One PSP was tested with each of 12 earphones while three devices were tested with each of eight different earphones. These eight earphones were included in the testing with the 12 earphones tested with the first device. The SD for the test with 12 earphones was 6.0 dB while the other three tests produced SDs of 4.9 dB, 6.9 dB and 8.5 dB with an average value of 6.6 dB. This is representative of the between-device variation.

General discussion

The implication of the SDs for the earphones and devices is that more variation should be expected between earphones as compared to the variation between devices. Figure 3 illustrates the variation possible showing two different device earphone combinations with their volume settings. One well behaved combination (solid line) behaves reasonably as would be expected, while the second (broken line) shows very irregular and poor performance.

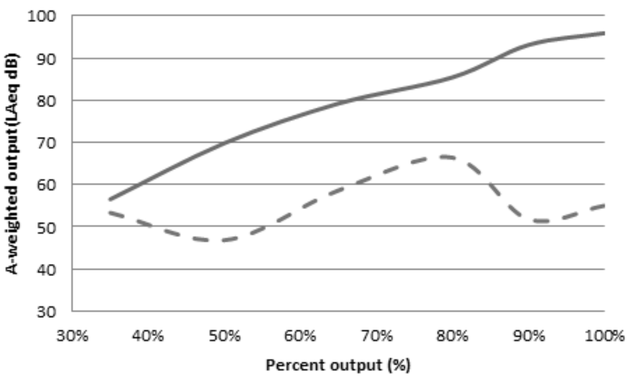

Figure 3: The acoustic output – volume setting for two device – earphone combinations showing good performance (solid line) and poor performance (broken line).

From an engineering perspective this variation of acoustic output levels is to be expected and can arise from many sources including impedance mismatch between device and earphone; variation in electrical signal sensitivity between earphones; quality control during production; ageing and wear of players and earphones; power supply (battery) variations; and device amplifier and power supply design and performance criteria. All devices are not designed or produced to the same specifications or criteria.

While Figure 3 clearly shows the differences in performance possible, it is observed that the more well-known and popular device – earphone combinations tend to provide higher output levels compared to those not so well known or as popular. Devices combined with their supplied earphones also tend to have more regular performance compared to mixed combinations. Measured maximum outputs greater than 90 dB are more common (20) compared to those measuring less than 80 dB (11) at maximum volume setting.

If comparisons are made to regulated workplace noise exposure standards where an eight hour, equivalent continuous A-weighted sound pressure level (LAeq,8h) greater than 85 dB is deemed to be hazardous, then users with outputs of 97 dB, using the equal energy 3 dB exchange rate, will reach their allowable exposure with only 30 minutes of use. In the current survey 13 of the 45 device – earphone combinations provided outputs at or greater than 97 dB. It is a reasonable conclusion to draw that regular use of PSPs at these levels does have the potential to cause a predictable and significant hearing loss over the long term (ISO 1999: 1990).

One notable consequence arising from the wide variation in acoustic output relates to suggestions frequently made to legislatively limit PSP output to 'safe' levels (Hellström, Axelsson, Costa,: 1998; Vogel, Brug, Hosli, van der Ploeg, & Raat: 2008; Vogle, Verschuure, Ploeg, Brug & Raat: 2009; Snowden & Zapala: 2010). The only reliable method of regulating acoustic output levels would be to actually monitor the acoustic signal in the ear. If exposure control is attempted by simply monitoring the electrical signal to the earphones then this will be unreliable as demonstrated above. This unreliability could be due to such causes as different electrical sensitivities between earphone types and impedance mismatching.

Exposure prediction

If general users, social researchers or anyone with an interest needs to estimate the potential noise exposure of individuals who regularly use PSPs the graph presented in Figure 4 would be of some use. For example, if a user states that they regularly have the volume set at around 80% an exposure estimate of 76 dB can be made with a 95% confidence interval of about 58 dB to 94 dB. This can provide typical, best- and worse-case estimates for possible noise exposures from PSP use.

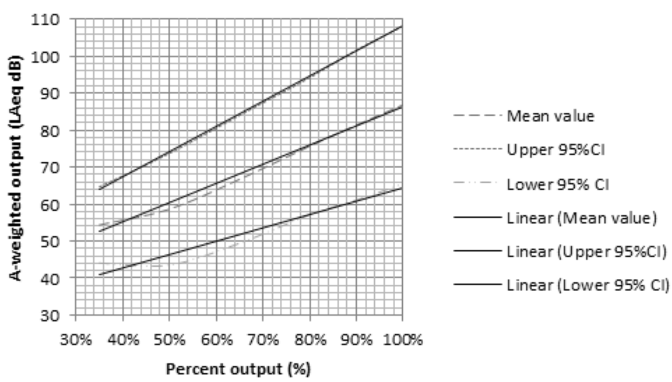

Figure 4: The estimation of expected and range of acoustic output levels from commonly available personal stereo player and earphone combinations with linear approximations for the mean and upper and lower 95% confidence interval value.

CONCLUSION

It was found that there is significant variation in acoustic signal output level from PSP use dependent on the device – earphone combination. At upper volume settings these variations can be in the order of 40 dB. While the level of the acoustic output has the potential to cause noise injury and hearing loss with extended exposure, the obvious solution of controlling exposures by electrical monitoring of the output signal may not be as simple to implement as first envisaged.

ACKNOWLEDGEMENTS

Many thanks are due to Elizabeth Beach and Megan Gilliver for assistance with gathering sufficient devices and earphones.

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THE ACOUSTIC PERFORMANCE OF NOVEL NOISE BARRIER PROFILES MEASURED AT THE ROADSIDE

Jeffrey Parnell[1], Stephen Samuels[2] and Con Tsitsos[3]
[1]Noise Specialist, NSW Department of Planning, Sydney, Australia
[2]Visiting Research Fellow, University of NSW, Sydney, Australia. Director, TEF Consulting, Sydney, Australia
[3]Environmental Officer – Noise, NSW Roads and Traffic Authority, Sydney, Australia

As part of continuing investigation into noise barrier optimisation, a research and development study to conduct insitu empirical testing of several full size prototype barrier designs was funded by the NSW State Government. Of particular interest to this study was a design known as a random edge profile barrier. Literature research had found that there was a body of evidence indicating that a barrier with an edge irregularity can cause a substantial degradation of the diffracted signal. It is generally accepted that an increase in insertion loss occurs because the jagged edge causes a reduction in coherence of the diffracted signal being transmitted to the shadow zone as compared to a conventional straight edge barrier [1-3]. It has been suggested that the mechanism for this is that the jagged geometry on the top of a barrier alters the sound pressure level in the shadow zone by causing the region of the barrier nearest the receiver to admit multiple paths with variable phase [4]. The direct waves from the diffracting edges of the barrier and waves subsequently reflected from the ground plane are superimposed at the receiver causing constructive or destructive interference at the receiver. The present study followed a methodology that included construction of an 80m long by 2.4m high barrier that served as the base for an additional conventional top as well as a random profile and T-top novel cap. Empirical data collected showed that for the receiver locations investigated, a random edge barrier will out-perform a conventional barrier of the same nominal height for most frequencies associated with broadband tyre/road noise. A T-top barrier was found to perform better than a conventional barrier of similar height for most frequencies whilst a conventional barrier offered the most practical solution for attenuation of low frequency noise.

INTRODUCTION

In reviewing developments in the design, construction and performance of roadside noise barriers, researchers found that barriers with novel cappings appeared to be capable of providing considerable increases in attenuation, particularly in the higher acoustic frequency regions [5, 6]. The implications of these findings were twofold.

- Capped barriers of the same height as conventional barriers could potentially provide greater noise reductions than the conventional barriers.
- A specified noise reduction could potentially be provided by a capped barrier of lower height than a conventional barrier.

In NSW, barrier designs that do not deliver at least a 10 dB(A) reduction are generally not considered economically viable. Therefore, the potential benefits were considered sufficient enough to warrant further investigation and a research and development study to conduct in situ empirical testing of several full size prototype barrier designs was subsequently funded.

Of particular interest to this study was a design known as a random edge profile (or jagged edge) barrier such as that presented in Figure 1. The available evidence was that a barrier with such an edge irregularity can produce increased insertion loss because the jagged edge causes a reduction in coherence of the diffracted signal being transmitted to the shadow zone compared to a conventional straight edge barrier [3].

Figure 1: Representation of a random edge barrier used in the study

Researchers have reported enhanced performance for random edge barriers at higher frequencies but reduced performance at lower frequencies [1, 7]. In particular, it has been indicated the cross over point in performance occurs around 2000–5000 Hz [2, 3]. This suggested that whilst there would be some benefits to reducing broadband road traffic noise, the critical areas of maximum acoustic energy which lie below 2000 Hz would not experience any improvement. Moreover, in most cases there would be degradation in performance as compared to a conventional straight edge barrier in this frequency range. Studies such as those cited above also indicated that these types of jagged edge barriers tend to perform better when the noise source is closer to the barrier. However, these studies were mostly conducted on small scale models or by using the boundary element method and the authors have been unable to find any reports of full scale testing of random edge profile barriers under normal traffic conditions.

THE EMPIRICAL STUDY

The Study Set-up

The objective of the empirical study reported in the present paper was to undertake a full scale experiment to determine the insertion loss of a random edge barrier and to compare these results with those of conventional straight edge barriers and with that of a barrier with a T-top configuration. A conventional 2.4m high barrier was constructed at the study site and was subsequently fitted with a T-top which maintained the height but added 0.6m horizontally to each side. The T-top was later removed and the conventional barrier was then increased in height to 3.0m, from which the upper 0.6m was later replaced with a random edge top as shown in Figure 1. Thus the performance of four barriers were investigated in the study.

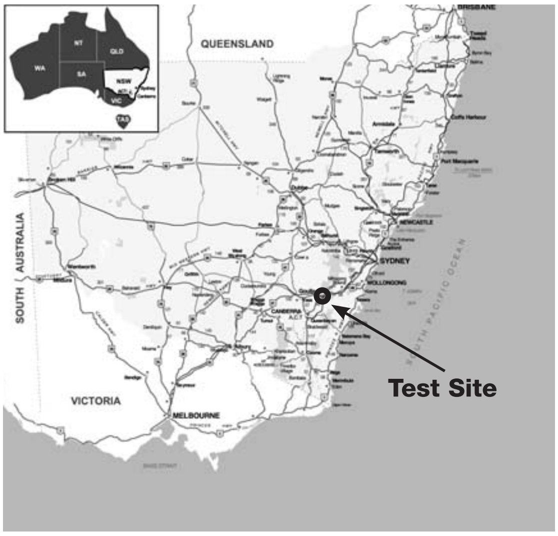

Figure 2: Location of test site

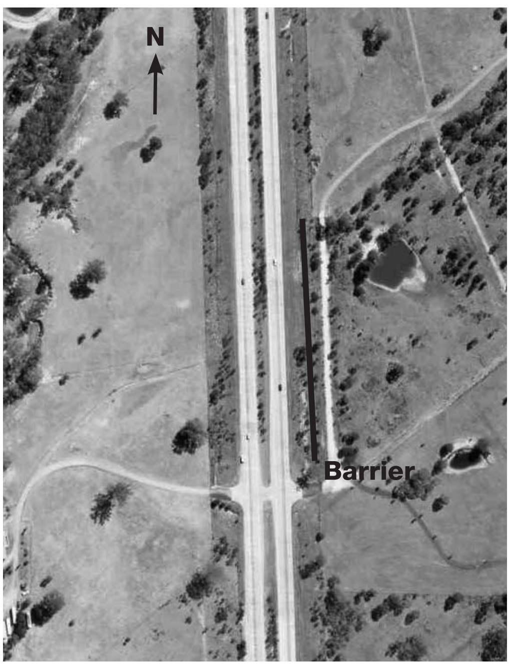

Figure 3: Barrier location

The study site was located on a section of the Hume Highway in NSW between Marulan and Goulburn. The barriers were constructed of a 28 mm timber laminate developed exclusively for use as a noise barrier. This laminate was provided in sheets that were 2.4 x 1.2m and were fixed between galvanized H beams. The barriers are shown in Photos 1 - 4. The various extensions and tops were also constructed of the 28 mm laminate and any gaps were suitably filled to eliminate any leakage. Researchers [8] have quantified the reduction of insertion loss resulting from air gaps in less substantial timber noise barriers, however in the case of this barrier, the authors have confidence that there was no potential for any leakage. As finally constructed, the barrier was 80m long with an average setback of 22.3m from the south bound carriageway of the Hume Highway. CoRTN algorithms [9] indicate that to prevent contributing leakage around barrier requires the barrier to subtend an angle of around 160° to the road. To comply with this therefore restricted measurements to no more than 7m behind the barrier. Whilst it would have been preferable to obtain measurements at distances further behind the barrier, this would have required a much longer barrier which was not an option within the study budget.

Photo 1. Section of highway (from Gipsicam)

Photo 2. Conventional barrier (2.4m)

Photo 3. T-top barrier (2.4m)

Photo 4. Random edge barrier (3.0m)

Data Collection and Analysis

Three precision (Type 1) microphones were set up at various locations in front of, and behind each barrier configuration (including the no barrier scenario). Designated A, B, and C these microphones captured traffic noise data simultaneously at various combinations of the measurement points shown in Figure 4 and listed in Table 1. Extensive sets of data were collected for each barrier configuration and were also duplicated in the absence of any barrier. A 01dB Metravib Harmonie four channel analyser capable of collecting data from three microphones simultaneously at a sampling rate of 51.2 kHz was used to collect and analyse the road traffic noise data. Synchronised video footage of the roadway was also collected to allow identification and characterisation where necessary. The analyses involved determining noise indices such as the Leq and producing various frequency spectra of the traffic noise signals.

An assessment of potential barrier reflection to measurement point 1(MP1) did not indicate it would be a significant feature of the experiment. This conclusion was supported by the 'no barrier' measurements and as a result, barrier reflection was not considered further.

Figure 4: Cross section showing microphone positions A, B & C and barrier position

Table 1: Measurement points

Position	Measurement Point	In front or behind barrier	Location of measurement point relative to base of barrier	
			Height (m)	Distance from barrier (m)
At the barrier Microphones A,B & C	1	Front	1.2	2.4
	2	Behind	1.2	2.4
	3	Behind	1.2	4.8
	4	Behind	1.8	2.4
	5	Behind	1.8	4.8

As indicated in Table 1, there was a substantial set of data collected during the course of the investigation and subsequently a vast range of results ensued. Only the key results are summarised in the present paper. Firstly, the measured traffic noise Leq levels at the five measurement points, averaged over replicate samples at each measurement point, are set out in Table 2. Because road traffic is not a controllable steady noise source it is normally difficult to compare one monitoring period against another (although this site provided extremely reproducible conditions). However, use of a carefully configured experimental design involving sequential, simultaneous monitoring at various combinations of the four shielded measurement points ensured that the data of Table 2 could all validly be compared against one another and presented in Table 3 [9].

Importantly, this experimental design also ensured that the data differential in Table 3 were, in effect, independent of the influences of factors such as fluctuations in the traffic volume, composition and speed during the measurements.

Table 2: Average traffic noise levels at the 5 measurement points

Barrier Type	Averaged L_{eq} Traffic Noise Level (dB(A))				
	MP1	MP2	MP3	MP4	MP5
Conventional 2.4m	75.4	63.1	63.1	64.1	64.5
Conventional 3.0m	75.9	60.9	61.5	61.8	62.9
T-top	76.3	62.1	62.6	64.3	65.7
Random edge	75.6	60.9	60.4	62.1	61.1
No barrier	75.5	71.7	69.8	73.1	71.3

Table 3: Average measured attenuations

Barrier Type	Averaged attenuation between MP 1 and MPs 2 to 5 L_{eq} dB(A)			
	MP 2 (std dev)	MP 3 (std dev)	MP 4 (std dev)	MP 5 (std dev)
Conventional 2.4m*	12.8 (0.34)	12.5 (0.39)	11.3 (0.38)	11.0 (0.44)
Conventional 3.0m*	15.0 (0.06)	14.4 (0.06)	14.0 (0.29)	12.9 (0.25)
T-top*	13.9 (0.21)	13.2 (0.21)	12.2 (0.19)	10.7 (0.28)
Random edge*	14.7 (0.11)	15.2 (0.21)	13.5 (0.19)	14.4 (0.39)
No barrier*	3.2	5.0	1.5	3.3
TNM predicted	1.6	2.0	1.4	2.0

* 2.5kHz band pass filtered

Observations

In the initial reporting of this study [10, 11], offsets for the distance attenuation between MP1 and the 'behind barrier' positions MP2 to MP5 were estimated using the US FHWA traffic noise prediction model TNM. Measurements made following the removal of the barrier have shown that actual distance attenuation for this study site to be much higher than expected, most likely as a result of ground impedance effects. These effects can be difficult to quantify [12, 13] and whilst these findings warrant further investigation, the effects over such short distances are generally restricted to the less important higher frequency bands and are outside the scope of the current study. Based on confidence in the scientific method used, the high signal to noise ratio, appropriate study area and the good repeatability of measurement, anomalies with higher frequency data have been addressed by band pass filtering the signal to 2.5 kHz which is consistent with other researchers who have chosen to limit their data to similar upper frequencies [14, 15].

Whilst ground effects behind the barrier would be important in quantifying site specific absolute levels of insertion loss, the objective of the study was rather to compare the performance of the various barrier types. Therefore to eliminate uncertainty associated with determination of absolute levels of barrier insertion loss and the need to account for the variation in distance setbacks between the measurement points, this paper presents the performance of the trial barriers relative to the performance of the conventional 2.4m barrier.

Review and Re-Presentation of Data

Some data collected as part of this study has previously been presented [10, 11, 16, 17] and the authors have benefited from reviews, comments and requests for additional details. The authors are thankful for this feedback and have refined the presentation of data in this latest paper in line with comments received. Notable improvements to the presentation of data include: removal of frequency data (>2.5 kHz) which were outside the range of frequencies of interest and which tended to introduce higher sample variance without improving understanding of the mechanisms under investigation; provision of some statistical assessment of the reported results; use of the conventional 2.4m barrier as reference for assessing the performance of the other test barriers.

SUMMARY OF THE KEY OUTCOMES ACROSS THE FREQUENCY SPECTRA

Typical outcomes of the study across the frequency spectra have been reproduced in Figures 5 and 6 which show relative attenuation of the test barriers at MP2 and MP5. Before interpreting what appears in these figures it should be noted that road traffic noise is relatively broadband in nature and that the majority of acoustic energy, which is generated by tyre/road interaction, lies in the 250 Hz to 4 kHz range and sometimes down to 50 Hz [18, 19]. The Portland cement concrete pavement in place at the study site tended to exhibit more discrete frequencies than some other types of pavements such as dense graded asphalt, however it provided traffic noise levels with an excellent signal to noise ratio for the measurements of the study. Table 4 presents the performance of the conventional 3.0m, T-top and random edge barriers relative to the performance of the conventional 2.4m barrier at the various receiver points behind the barrier.

Table 4: Attenuation performance relative to conventional 2.4m barrier

Barrier Type	Change in attenuation relative to conventional 2.4m barrier L_{eq} dB(A)				Average Change
	MP 2	MP 3	MP 4	MP 5	
Conventional 3.0m*	2.2	1.9	2.6	1.9	10.8
T-top*	1.1	0.7	0.9	-0.3	9.3
Random edge*	1.9	2.7	2.2	3.4	11.2

* 2.5kHz band pass filtered

It is apparent in Table 4 that relative to the reference barrier, the conventional 3.0m and T–top barriers were found to perform better at MP 2 (setback 2.4m, height 1.2m) and MP 4 (setback 2.4m, height 1.8m) than they do at further distances from the barrier. Conversely the relative performance of the random edge barrier was seen to increase in comparisons of less shielded positions, either at greater setbacks or more elevated positions. At the least shielded position MP5 (setback 4.8m, height 1.8m) the random edge barrier was found to out-perform the conventional 2.4m barrier by 3.4 dB(A) and the conventional 3.0m barrier by 1.5 dB(A). This result indicates destructive interference mechanisms are occurring, particularly where angles of diffraction are low. In retrospect, it would have been valuable to have undertaken more detailed measurements in shadow zone to determine if the improved attenuation is a result of when the signal grazes over the barrier edge and diffraction angles are low or if it is related to an optimised reflection behind the barrier.

Whilst the T-top barrier shows performance improvements over the conventional 2.4m barrier at points in close proximity to the barrier, it shows little or no advantage at the more exposed receiver points. At MP 5 the T-top barrier was found to perform slightly worse overall (0.3 dB(A)) than the conventional 2.4m barrier, however this result is within the margins of error.

Earlier analysis of the T-top barrier [10, 11] concluded that this barrier performed better at higher frequencies. Band pass filtering the data to <2.5kHz has reduced this advantage and indicates little benefit for receivers not in close proximity to the barrier. This conclusion may however be different if the T-top was larger or the barrier was close enough to the road that the T-top overhung the road.

The low performance of T-top barrier in the low and mid frequencies at this study site may be one reason other researchers are sometimes able to report they are able to gain significant improvements by the addition of absorptive material, quadratic residue diffusers and primitive root diffusers [20, 21]. At sites where T-top barriers are reported to be performing well, the addition of these covers appears to perform below expectations [22].

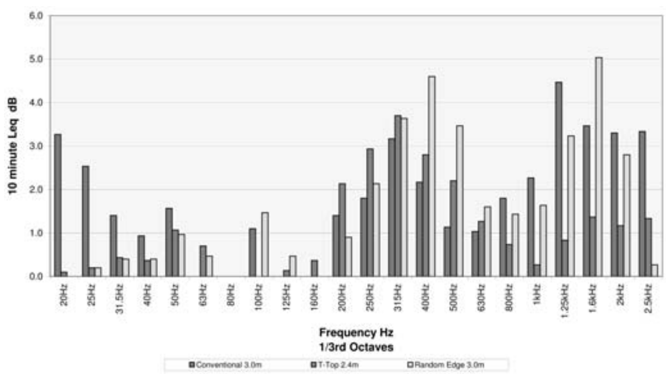

Figure 5: Comparison of spectral data of test barriers to the conventional 2.4m reference barrier at MP2

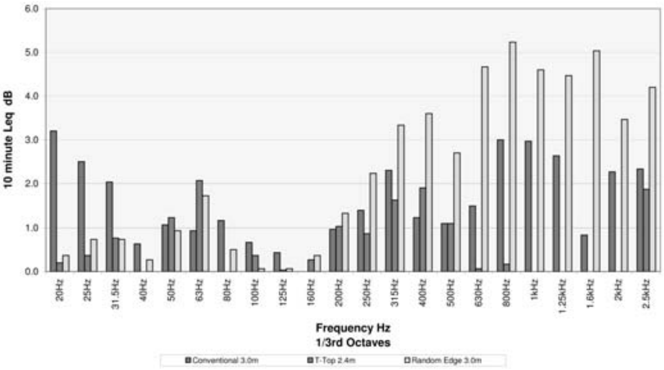

Figure 6: Comparison of spectral data of test barriers to the conventional 2.4m reference barrier at MP5

These results, along with those from the various other measurement points, appear to be consistent with theoretical evidence that the random edge disrupts the coherence of the acoustic waves as they are diffracted by the barrier edge. This conclusion was also supported by the observations that the greatest differential improvement in insertion loss occurred at those locations close to the shadow/bright zone interfaces (MP 3 and 5).

Future Areas of Research

Comments have been received regarding the use of absorptive material and devices on the barrier surfaces. Investigation of improvements resulting from these surface modifications is worthy of study of its own however these options were discounted as this study focused on barrier types that had a realistic chance of being incorporated into highway projects. The literature contains a plethora of acoustically interesting barrier designs, however it is highly unlikely that absorptive type of barriers would ever be built because of urban design, maintenance and cost considerations. Furthermore studies have shown actual performance is often much less than predicted.

One area worthy of further research is to quantify the extent of the zone of destructive interference behind the random edge barrier. It is unknown whether the benefits indentified in this study would extend indefinitely or are optimised at some set distance.

CONCLUSIONS

Overall, the following conclusions ensued from the study and are reported in the present paper.

- The overall acoustical performances of the conventional noise barriers used in this study, which was limited to receivers being no further than 4.8m behind the barriers, were improved by introducing the novel barrier cappings.
- The random edge barrier was found to out-perform the other noise barriers tested in this study over the frequencies that generally make up broadband road traffic noise. In close proximity to the barrier and from 160 Hz to around 630 Hz the T-top barrier was able to out-perform both conventional barriers, thereafter it continued to out-perform the conventional 2.4m barrier. For the lower frequencies below around 50 Hz, the conventional 3.0m barrier was found to afford superior attenuation. Low frequency noise can be generated by heavy vehicle engine compression brakes, therefore there may be no real advantage in utilising novel barrier tops in an attempt to address this particular issue.
- Earlier investigations reported in the literature had suggested that the crossover point for performance improvement between conventional barriers and random edge barriers typically occurred somewhere between 2 kHz and 5kHz [2, 3]. The conclusion of the present study is, however, that this crossover point is closer to 250 Hz for the barriers investigated. The implication of this finding is that random edge barriers of the type studied may provide significant improvements in attenuating road traffic noise within the critical frequency bands of maximum acoustic energy.
- Care must be taken in reporting absolute values for insertion loss for noise barriers as site specific variables can significantly influence the attenuation measured, particularly if assumptions are being made regarding the ‘no barrier’ scenario.
- The random edge barrier provides significant advantage over the other designs for the less shielded receiver locations behind the barrier, however it is unknown how far the area of influence extends.

ACKNOWLEDGEMENTS

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A REVIEW OF TRAILING EDGE NOISE GENERATED BY AIRFOILS AT LOW TO MODERATE REYNOLDS NUMBER

E.J.G. Arcondoulis, C.J. Doolan, A.C. Zander and L.A. Brooks
School of Mechanical Engineering, University of Adelaide, SA 5005

This paper contains a detailed literature review of research findings regarding the cause of flow-induced noise created by airfoils operating at low to moderate Reynolds numbers. There are many important engineering applications that operate at these conditions. More investigation is required to understand why airfoils in this range of Reynolds numbers produce high levels of tonal noise. As discussed in this paper, there are still many uncertainties surrounding the nature of the source.

INTRODUCTION

Airfoils produce tonal and broadband noise at low to moderate Reynolds number flow conditions (50,000 < Re < 200,000; Re = UL/v, where U is the freestream velocity, L is the airfoil chord and v is the kinematic viscosity of the fluid). Many important engineering applications (including micro-wind turbines, compressor and cooling fans, small unmanned air vehicles and submarines) operate at this flow condition and hence it is important to understand and control this undesired noise.

The tonal and broadband noise is produced in the vicinity of the trailing edge of an airfoil [1]. Although there is no consensus, various explanations for the trailing edge noise mechanism have been proposed. Quadrupole noise sources in the boundary layer and near wake are made more efficient through a diffraction process at the sharp trailing edge, forming a cardioid directivity pattern [1], [2]. Sound at certain acoustic frequencies is thought to be amplified, via an acoustic feedback mechanism near the trailing edge [3], [4], [5], [6]. There exists some disparity in the explanations for this mechanism and where the origin of the feedback loop is located. A schematic diagram illustrating the fluid flow and cardioid directivity pattern is provided in Figure 1.

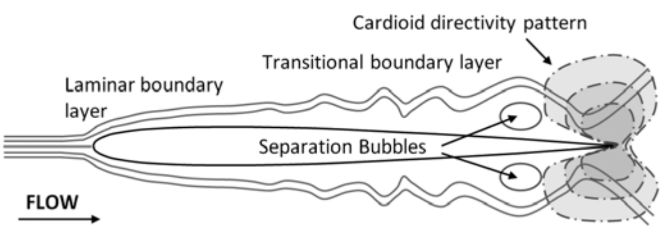

Figure 1: Schematic diagram of low to moderate Reynolds number and 0° angle of attack airfoil fluid flow and cardioid directivity pattern.

This aim of this paper is to provide a review of airfoil trailing edge noise mechanisms at low to moderate Reynolds number. The flow structure around an airfoil in this flow regime is described, followed by an explanation of the diffraction and acoustic scattering observed at the trailing edge and the nature of the trailing edge noise. The postulated feedback mechanisms causing this trailing edge noise are then discussed and summarised.

FLOW STRUCTURE

At low Reynolds number, the flow about airfoils has different characteristics from that found at high Reynolds number. Sandberg et al. [2] show that at Re = 50,000 and 0° angle of attack, laminar boundary layers form initially on the airfoil surfaces but unsteady disturbances appear (Tollmein Schlicting or T-S waves) that are the first stages of transition to a turbulent state. Depending on local flow conditions, the boundary layer may also separate, creating an oscillating shear layer. These unsteady flow fields are on each side of the airfoil and interact at the trailing edge, forming a complex wake [7].

At non-zero angles of attack, the flow structure is asymmetric about the airfoil chord. The boundary layers on each side of the airfoil grow and become more unstable at different rates relative to the distance from the airfoil leading edge. The boundary layer on the suction side of the airfoil becomes highly unsteady and generally separates from the airfoil, forming an unstable shear layer. The separation takes place further upstream than the 0° case, resulting in a turbulent shear layer at the trailing edge. The pressure side boundary layer generally remains laminar along the entire chord for relatively low angles of attack.

DIFFRACTION AND ACOUSTIC SCATTERING

A more complete description of the edge diffraction process is given in Figure 2, which replaces the airfoil with a semi-infinite half plane. The noise sources in the boundary layer are now represented as quadrupoles [8] that can be considered as a pair of dipoles whose major axes are orthogonal. Five quadrupoles are drawn so that the major axis of one of the dipole pairs is oriented towards the sharp edge. When a wave from a dipole encounters the edge, a diffracted wave is produced that travels back towards the quadrupole with opposite phase. This diffracted wave combines with outgoing waves from the other side of the dipole (that has similar phase to the diffracted wave) to create an efficient source of sound. In this way, one side of the quadrupole is made an efficient radiator of sound and results in the cardioid directivity pattern commonly associated with trailing edge noise [1], [9].

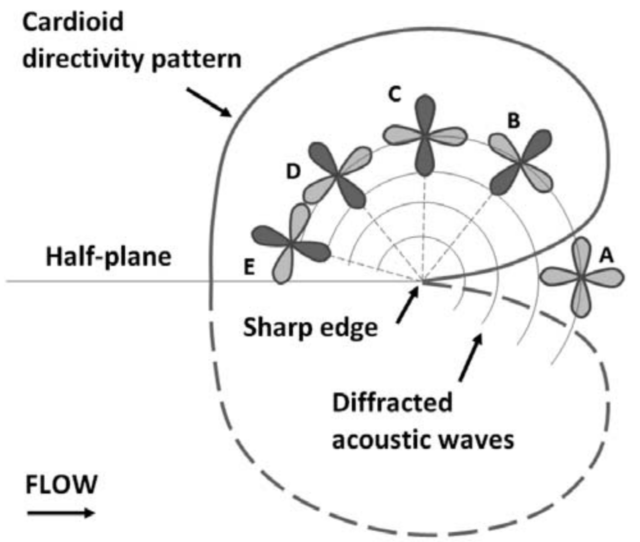

Figure 2: Cardioid directivity pattern of the noise emitted from eddies in various locations relative to a sharp edge.

THE NATURE OF TRAILING EDGE NOISE

The noise generated by airfoils at low to moderate Reynolds number can be generally classified as either tonal or broadband. The noise is observed to contain a superposition of discrete tones on a broadband hump [3], [10]. This is demonstrated in Figure 3 which presents the noise spectra generated by a NACA0012 airfoil at a Reynolds number of 75,000 and 0° angle of attack. Figure 3 shows a primary tone (*fn,max*) and a series of secondary tones (*fn*) [3]. The broadband hump (*fs*) is also evident in Figure 3 and is defined as the centre frequency of the broadband noise component.

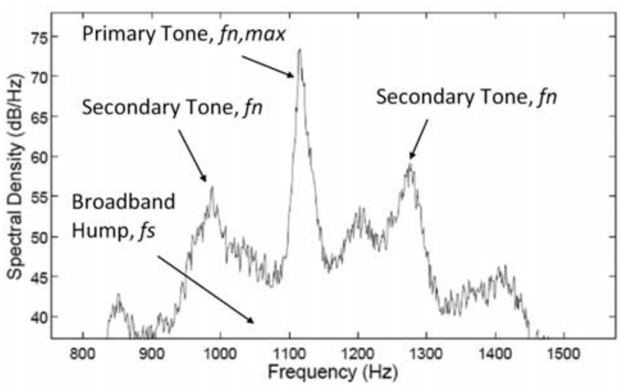

Figure 3: Noise Spectra for a NACA0012 airfoil at a Reynolds number of 75,000 and 0° angle of attack [10].

Broadband noise is due to a large number of incoherent eddies with a variety of sizes and strengths. The tonal noise however is due to reasonably coherent and strong eddies in the trailing edge region. The questions of how tonal noise is generated and why some eddies are more coherent and stronger than others remain unsolved. Many studies have attempted to answer these and other related questions regarding low Reynolds number trailing edge noise.

The first comprehensive study of airfoil self-noise at low to moderate Reynolds numbers was performed by Paterson et al. [11]. They presented the measured tonal noise frequency for each flow velocity case and observed that for a small increase in flow velocity, U, the primary tonal noise frequency (*fn,max*) would increase by $U^{0.8}$. At certain flow velocities, the tonal frequency was seen to instantly "jump" to a higher frequency, forming a new 0.8 power relationship with velocity. This overall pattern of increasing frequency with respect to $U^{0.8}$ for a given velocity range forms a "ladder structure" [3], [12], [13]. Looking at a range of Reynolds numbers and angles of attack, there are many $U^{0.8}$ power curves. If a line is fitted through all these data points, the overall frequency dependency will fit a $U^{1.5}$ curve, given by

$$f = \frac{0.011U^{1.5}}{\sqrt{Cv}} \qquad (1)$$

where f is the frequency of the primary tone, U is the fluid freestream velocity, C is the airfoil chord length and v is the kinematic fluid viscosity. Figure 4 shows the results of Arbey and Bataille [3], displaying this ladder structure.

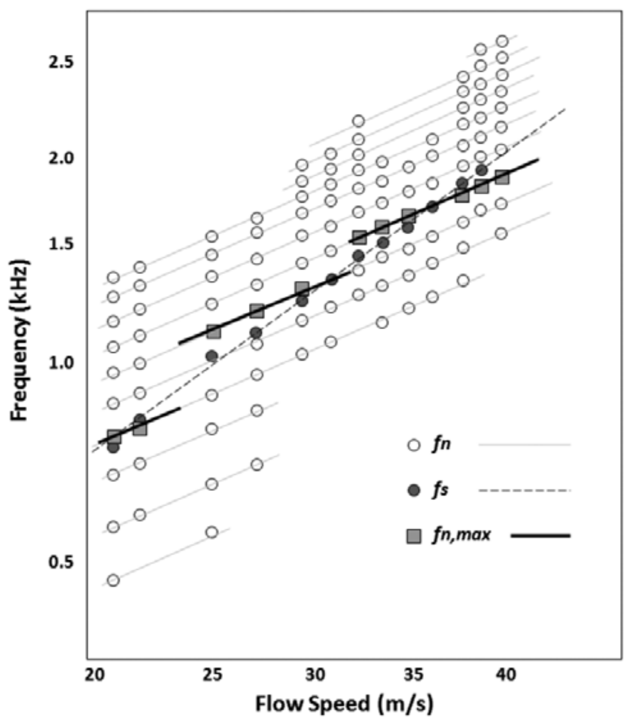

Figure 4: Ladder-type evolution of the dominant discrete frequency, *fn,max*, for a NACA0012 airfoil with 160mm chord. Adapted from [3].

Arbey and Bataille [3] show that for the same airfoil profile at 0° angle of attack, increasing the Reynolds number (by increasing the freestream flow speed and/or airfoil chord) results in a decrease in the primary tonal noise amplitude

($f_{n,max}$). This implies that there exists a Reynolds number for a given airfoil and angle of attack that results in the greatest tonal noise amplitude. Note that the quantity and amplitude of the secondary tones (f_n) are also influenced by the increase in Reynolds number. The main frequency (f_s) was observed to have a Strouhal number dependence, based on the boundary-layer thickness at the trailing edge. Arbey and Bataille [3] also confirmed that the broadband contribution is a result of the diffraction of pressure waves at the trailing edge.

Preliminary investigations show that the primary tonal noise frequency can be estimated using a parametric fit to empirical data [11], but there is still no formal method for determining which angle of attack and Reynolds number causes the greatest tonal sound pressure level for an airfoil under low to moderate Reynolds number flow conditions.

FEEDBACK MECHANISM

Although there have been many investigations into the causes responsible for the trailing edge noise of airfoils in low Reynolds number flow regimes, there is no general consensus amongst the acoustic community for the cause of tonal trailing edge noise. Further, insufficient experimental measurements have been performed to confirm the mechanisms proposed in the literature. The following is a discussion of the various proposed causes of tonal noise.

Paterson et al. [11] postulated that the observed ladder structure behaviour was due to a vortex shedding phenomenon, located at a distance downstream of the trailing edge. Tam [12] disputed Paterson et al.'s [11] explanation of the cause of the tonal noise, arguing that vortex shedding noise is Strouhal number dependent, which is inconsistent with the data of [11]. Tam [12] recognised the $U^{1.5}$ increase of the tonal noise frequency; however, he claimed that this was only an empirical fit over a large frequency range and did not capture the detail of the ladder structure.

Tam [12] proposed that the ladder structure of tonal noise was due to a self-excited feedback loop of aerodynamic origin. Acoustic disturbances originating at the sharp trailing edge propagate downstream along the airfoil wake. When these disturbances are of sufficient magnitude they induce lateral oscillations in the wake, resulting in the emission of acoustic waves. A portion of the acoustic wave energy is propagated upstream to the pressure side of the airfoil near the trailing edge, forcing the boundary layer to oscillate, thereby completing a feedback loop.

Arbey and Bataille [3] agree in some aspects with Tam [12], in that the existence of regularly spaced discrete tonal frequencies is linked with an aeroacoustic feedback mechanism. However, they propose that hydrodynamic fluctuations (which generate acoustic waves as they are diffracted at the trailing edge) propagate upstream to a point on the airfoil where the hydrodynamic instabilities are formed. This explanation differs from that of Tam [12] in both the location at which the acoustic feedback loop closes and the distance from which the acoustic source is located relative to the trailing edge.

Arbey and Bataille [3] suggest that the location of the hydrodynamic instabilities is the point of maximum flow velocity in the laminar boundary layer. If both the acoustic wave and the hydrodynamic fluctuation frequency are in phase at this location, the hydrodynamic fluctuation will become amplified [12], [14]. This fluctuation then propagates downstream, thus closing the feedback loop.

Nash et al. [13] disagreed with others ([3] and [12]) and proposed that the feedback mechanism responsible for the tones is based on a vortex shedding process. As the unstable boundary layer forms, T-S waves continue to grow as they propagate toward the trailing edge of the airfoil and begin to roll up into a vortex. The interaction of this vortex with the trailing edge generates a scattered oscillating field around the airfoil which oscillates at the same frequency as the T-S wave. This oscillating field extends upstream to approximately half the chord which is close to the point at which the boundary layer becomes unstable.

Nash et al. [13] hypothesise that the oscillating mean flow provides an upstream feedback mechanism for the most amplified instability, resulting in the narrow-band acoustic tones observed. However, McAlpine et al. [15] suggest that the vortex shedding at the pressure side owing to the separation bubble acts in a similar way to the vortex shedding behind a cylinder. They propose that there is a small region of instability close to the body, which explains why the vortex shedding is a self excited mechanism. Nash et al. [13] also identify that previous work has neglected the influence of a laminar separation bubble near the trailing edge and its influence on the tonal noise generating mechanism.

Nash et al. [13] agree with Arbey and Bataille [3] in that there exists a point upstream of the trailing edge which is responsible for the activation of an acoustic instability via the amplification of T-S waves. While Arbey and Bataille [3] identify this location as the maximum boundary layer velocity on the airfoil, Nash et al. [13] do not refer to the maximum boundary layer velocity and estimate its location as half the airfoil chord.

Nakano et al. [4] indicate from their experimental results of a NACA0018 airfoil that the tonal noise source is distributed on the trailing edge region of the pressure surface. The periodic variations of the velocity field are observed in the separating region on the pressure surface, which is followed by upwash and downwash motion at the trailing edge of the airfoil. This separating region is also observed by Nash et al. [13] for a NACA0012 airfoil. These flow phenomena over the airfoil surface result in the periodic formation of vortex streets in the wake of the airfoil. The tonal noise appears when the adverse pressure gradient on the pressure surface is sufficiently small to allow instability waves to grow slowly along the surface. They then scatter as sound when they travel past the trailing edge and propagate upstream toward the point of boundary layer instability, initiating a feedback loop.

Nakano et al. [4] and Desquesnes et al. [16] observed that a separation bubble forms near the airfoil trailing edge on the pressure side of the airfoil under non-zero angle of attack flow conditions. The existence of this recirculation bubble had already been identified as a necessary condition for the tonal noise phenomenon to occur [17]. This periodical oscillation is amplified as it approaches the trailing edge, due to the upwash and downwash motion in the downstream of the airfoil.

Desquesnes et al. [16] propose that a secondary feedback loop exists. They explain that a laminar boundary layer is formed near the leading edge of an airfoil when the flow is steady and continues along the airfoil chord until boundary layer separation occurs, leading to an unstable shear layer with T-S instability waves. The T-S waves interact with the trailing edge, forming a dipolar acoustic source. They suggest that the acoustic waves then travel upstream along the airfoil chord and generate an acoustic feedback loop, as depicted in Figure 5.

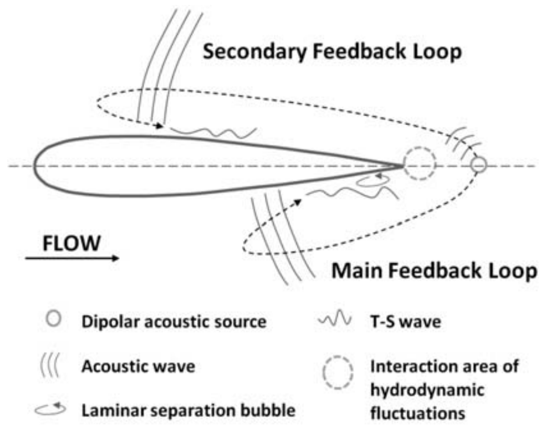

Figure 5: Schematic of the tonal noise mechanisms proposed by [16].

Desquesnes et al. [16] further explain that if the flow onto an airfoil is fast enough, or if the airfoil is located at a sufficient angle of attack, a turbulent boundary layer may form on the airfoil surface. The acoustic waves generated within the turbulent boundary layer are diffracted at the trailing edge, similar to the laminar boundary layer case, forming a dipole-like acoustic source with cardioid directivity [1]. Due to the hydrodynamic fluctuations in the immediate vicinity of the trailing edge and the turbulent nature of the flow, the noise emission is broadband. If the flow onto the airfoil is sufficient to generate a turbulent boundary layer, then the tonal noise is not observed.

The secondary feedback loop proposed by Desquesnes et al. [16] does not contradict the work of Arbey and Bataille [3]. Arbey and Bataille [3] only investigated airfoils at 0° angle of attack and Desquesnes et al. [16] only investigated non-zero angle of attack cases. It is possible that the secondary feedback loop exists in conjunction with the model proposed by Arbey and Bataille [3] at angles of attack greater than zero. It is also possible that Arbey and Bataille's [3] model could be the secondary loop shown by Desquesnes et al. [16]. A comparison of each model and their ability to predict the discrete tones of airfoil self noise for varying angles of attack has not been investigated.

Chong and Joseph [6] investigated a NACA0012 airfoil for both zero and non-zero degree angles of attack. Similar to others ([3] and [16]), they show that acoustic waves travel upstream to complete a hydrodynamic and acoustic feedback loop. They do, however, disagree with others ([3],[5],[12],[13] and [16]) and argue that the location which "closes" the feedback loop is the point at which the boundary layer instabilities on the airfoil profile originate (consistent with Nakano et al. [4]). This may not coincide with the location of maximum velocity on the airfoil profile [3] or half the airfoil chord length [13].

It should be noted that differences in the experimental results discussed may be due to varying testing conditions, such as freestream turbulence, vibration of the airfoil or other factors that can influence boundary layer transition at low to moderate Reynolds number.

OCCURENCE OF TONES

Desquesnes et al. [16] furthered previous work [3], [11], [13], [17] and generated plots of angle of attack against Reynolds number, identifying regions of the plot surface which exhibited tones or no tones. Some of these results, including some results from Arcondoulis et al. [10] are provided in Figure 6. The proposed tonal noise envelope [17] shown in Figure 6 conflicts with some of the presented data. Charts of this type for other NACA airfoil profiles are not known to the authors.

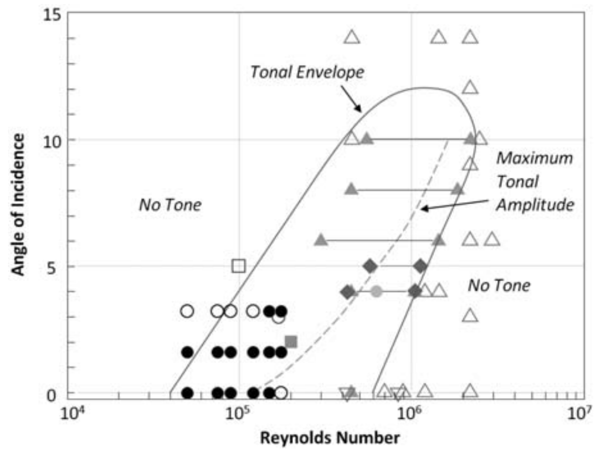

Figure 6: Pattern showing where tonal noise is likely to occur for a NACA0012 airfoil (adapted from [17]). Filled markers represent that a tone was present, whilst unfilled markers represent that a tone was not present. Data sources: shaded/unshaded circles [10], shaded/ unshaded triangles [11], unshaded inverted triangles [3], shaded/ unshaded squares [16], shaded diamonds [17]. The tonal envelope and the maximum tonal amplitude lines are from [17].

INFLUENCE OF AIRFOIL PROFILE

The aforementioned research provides a detailed investigation of specific airfoil sections with varying flow conditions. Sandberg et al. [2] identified a reverse flow region for the NACA0012 airfoil which is not displayed by the thinner airfoils. They explain that the flow oscillates around the trailing edge at the wake frequency; however they are unclear as to why there is a unique behavioural flow pattern for the NACA0012 airfoil profile. This finding suggests that the airfoil profile has a significant effect on the flow in the wake. Many of the theories suggest that the hydrodynamic instabilities in the wake are important in the structure and physics of the acoustic feedback loop. Thus it can be deduced that the airfoil profile influences the nature of the acoustic feedback mechanism.

SUMMARY

This paper has reviewed previous work on trailing edge noise generated by airfoils at low to moderate Reynolds number. The flow structure around an airfoil is reasonably well established; however, the physics of the feedback mechanism which results in the production of tonal noise is still unclear. Understanding the processes which cause this tonal noise is important, as this will allow advancements in quieter designs of engineering applications involving airfoils. There are many unresolved areas in this field of research, which are summarised in the text below and where appropriate, in Figures 7 and 8.

- There are limited mean and unsteady velocity data for various NACA airfoil profiles, for various angles of attack and at low Reynolds number.
- A comprehensive understanding of tonal noise production at various Reynolds numbers, angles of attack and for different airfoil profiles (obtained in an anechoic environment) has not yet been obtained.
- The effect of the airfoil profile on the tonal and broadband noise components for various Reynolds numbers and angles of attack has not been comprehensively investigated.
- There is no consensus on the location and physics of the activation of the acoustic feedback loop(s). Also, the position on the airfoil chord where the acoustic feedback loop(s) is (are) closed on the airfoil chord is not resolved. These require investigation.
- There does not yet exist an accurate model which predicts the magnitudes of the primary and secondary tones and the broadband noise.

FUTURE WORK

It is the intention of the authors to further pursue this ongoing study at the University of Adelaide, via the use of more refined experimental methods, including the use of aeroacoustic beamforming in conjunction with hot-wire anemometry. It is anticipated that a greater understanding of the acoustic feedback mechanism for the trailing edge noise of airfoils at low to moderate Reynolds number will be obtained.

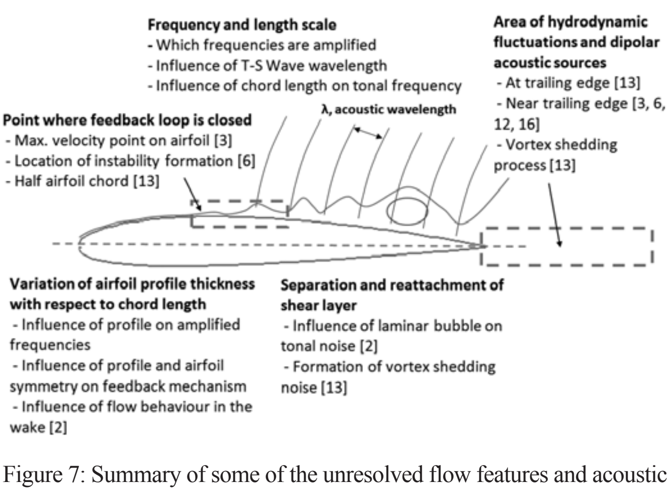

Figure 7: Summary of some of the unresolved flow features and acoustic feedback mechanism characteristics of an airfoil at 0° angle of attack.

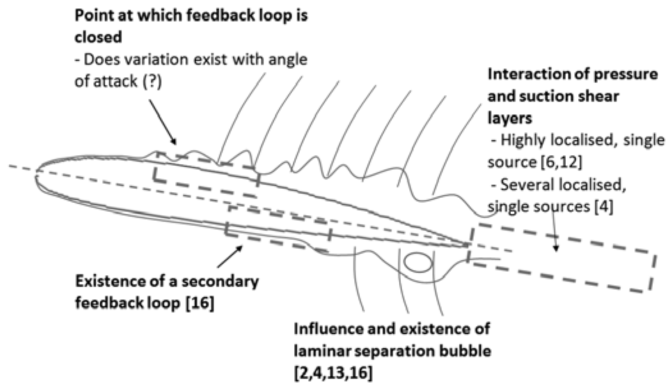

Figure 8: Summary of some of the unresolved flow features and acoustic feedback mechanism characteristics of an airfoil at non-zero angles of attack.

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USE OF CFD TO CALCULATE THE DYNAMIC RESISTIVE END CORRECTION FOR MICROPERFORATED MATERIALS

J. Stuart Bolton and Nicholas Kim
Ray W. Herrick Laboratories, Purdue University, West Lafayette In, USA

The classical Maa theory for microperforated materials was initially formulated for constant diameter, cylindrical holes. Since then, a number of *ad hoc* corrections have been suggested to account for different hole shapes: in particular, rounding of the aperture. Here it is shown that the resistance and reactance of small apertures may be calculated using relatively simple CFD models in which a single hole is modelled. The fluid is assumed to be viscous but incompressible, and the geometry is assumed to be axisymmetric. It will be shown that this approach essentially reproduces the classical theory of Maa for circular, sharp-edged apertures. However, it will also be shown that the resistive end correction, in particular, exhibits a clear dependence on frequency and geometrical parameters that is neglected in conventional microperforated material models.

INTRODUCTION

Microperforated materials are of current interest since they provide a useful alternative to fibrous materials in a number of noise control situations. Thus it is important to be able to calculate the acoustical properties of microperforated materials accurately. The best-known model for microperforated materials is that of Maa [1], which is based on a model of oscillatory, viscous flow in small tubes. The Maa model also features end corrections to account for inertial and resistive effects associated with flow converging into the holes. Those corrections have usually been based on a combination of physical reasoning and *ad hoc* comparisons between measured and predicted results. In the present work, an alternative approach has been adopted. Here a simple computational fluid dynamics (CFD) model of oscillatory, viscous flow through a single hole has been developed, and has been used to calculate the specific acoustic impedance of a microperforated sheet. In particular, the emphasis has been placed on the real part of the specific acoustic impedance (here referred to as the dynamic flow resistance) since the energy dissipation produced by a microperforated panel is proportional to that component of the impedance. It will be shown that the CFD results for the dynamic flow resistance are in generally good agreement with the predictions of existing models, particularly at high frequencies, but that they differ significantly at low frequencies. It is suggested that the latter discrepancy results from the neglect of a static, resistive end correction in conventional microperforated material models. Based on the CFD results, a revised dynamic resistive end correction is proposed. Note finally, that only sharp-edged holes have been considered in the present work, but that the general approach can easily be extended to calculate the specific acoustic impedance of microperforated materials having arbitrary hole geometries.

REVIEW OF THEORY

The Maa [1] model can be separated into two parts, one being a linear component and the other a non-linear component which becomes significant at high incident sound pressure levels. In this study, the focus is on the linear part, only. The linear component of the Maa model is derived from Rayleigh's [2] formulation for wave propagation in narrow tubes. Based on those equations, Crandall [3] modeled dissipation in small diameter channels, and Maa further developed Crandall's model for the case of very small holes in which the oscillatory viscous boundary layer spans the hole diameter. For a circular-hole model, the equation for the normal specific acoustic transfer impedance of a microperforated sheet (without end correction) is expressed as:

$$z = \frac{j\omega t}{\sigma c}\left[1 - \frac{2}{k\sqrt{-j}}\frac{J_1\left(k\sqrt{-j}\right)}{J_0\left(k\sqrt{-j}\right)}\right]^{-1} \tag{1}$$

where ω is the angular frequency, t is a length of the hole (usually the same as the thickness of the perforated sheet), c is the speed of sound, σ is the surface porosity of the sheet (i.e., the fraction of the total surface area occupied by holes), k is the perforation constant defined by $k = d\sqrt{\omega\rho/4\eta}$, η is the dynamic viscosity, ρ is the air density, d is the hole diameter, and J_0 and J_1 are the Bessel functions of the first kind of zeroth and first order, respectively.

A resistive end correction was suggested by Ingard [4], to account for energy dissipation at the surface of the sheet as flow approaches the hole. Ingard called this effect a surface resistance, and the surface resistance on one side of the hole was defined as $R_s = \frac{1}{2}\sqrt{2\eta\rho\omega}$. In the microperforated panel formulation of Guo *et al*. [5], the end correction is added to the real part of the above expression as:

$$r = \mathrm{Re}\left\{\frac{j\omega t}{\sigma c}\left[1 - \frac{2}{k\sqrt{-j}}\frac{J_1\left(k\sqrt{-j}\right)}{J_0\left(k\sqrt{-j}\right)}\right]^{-1}\right\} + \frac{\alpha 2 R_s}{\sigma\rho c} \tag{2}$$

where r is the real part of the specific acoustic transfer impedance, R_s is the surface resistance, and α is a nominally frequency-independent factor which accounts for hole type. It was suggested by Guo *et al*., based on a comparison with measurements, that α should be set to 4 when the hole is sharp-edged, and should be set to 2 when the hole has a rounded edge. Maa also used the surface resistance for the end correction, but he did not include a factor to account for hole shape.

In the present work, it has been found that the value of α in the above formulation is not necessarily independent of frequency. The objective here is to introduce a numerical procedure to identify the value of α that makes Eq. (2) exact for a given hole geometry.

CFD MODEL OF AN ORIFICE

Geometry

To perform the CFD calculations, it was first necessary to create a discretized model of a single, sharp-edged hole, and a corresponding channel. The microperforated panel was modeled geometrically using the software Gambit. The models were classified into 3 groups: one was a group having different panel thicknesses; the second was a group having different hole diameters; and the last was a group having different surface porosities. The mesh interval was chosen to be 0.005 mm in order to ensure accurate results for the smallest hole considered. In addition, the model was made axisymmetric (i.e., two-dimensional) to make the calculation time relatively short. Figure 1 shows the basic perforated panel model. Note that in Fig. 1, the bottom of the figure represents the center-line of the axisymmetric model.

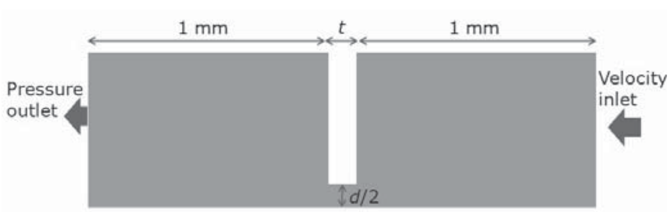

Figure 1. The geometry of the CFD model for a microperforated panel.

CFD Parameters

The CFD calculations were performed by using the commercial software Fluent. Since all model dimensions were very small compared to a wavelength at all frequencies of interest, the flow was assumed to be incompressible, and as a result there was no energy loss by heat transfer. The simulation was a pressure-based, implicit formulation, the Green-Gauss node-based method was selected for the gradient option, and the second-order implicit method was chosen for the unsteady formulation. The options selected were: SIMPLE for the pressure-velocity coupling method, STANDARD for pressure, and SECOND-ORDER UPWIND for momentum. The outlet pressure was set to ambient pressure, and the inlet velocity was chosen to be a Hann windowed, 5 kHz half-sine wave having a maximum value of 1 mm/s in order to cover the frequency range up to 10 kHz. The simulations were run for 200 time steps over a period of 0.1 ms, and the time interval was chosen to be 0.5 μs. The imposed inlet velocity and the resulting inlet pressure for one case are shown in Fig. 2(a), while the spectra of the inlet velocity and pressure are shown in Fig. 2(b). Note that zero tangential velocity boundary conditions were imposed in the hole and on the surface of the plate section, but not at the outer surfaces of the inlet and outlet channel sections. As mentioned above, three sets of models were considered in which the following parameters were changed: panel thickness; hole diameter; and surface porosity. The specific parameters for the three models sets are listed in Table 1.

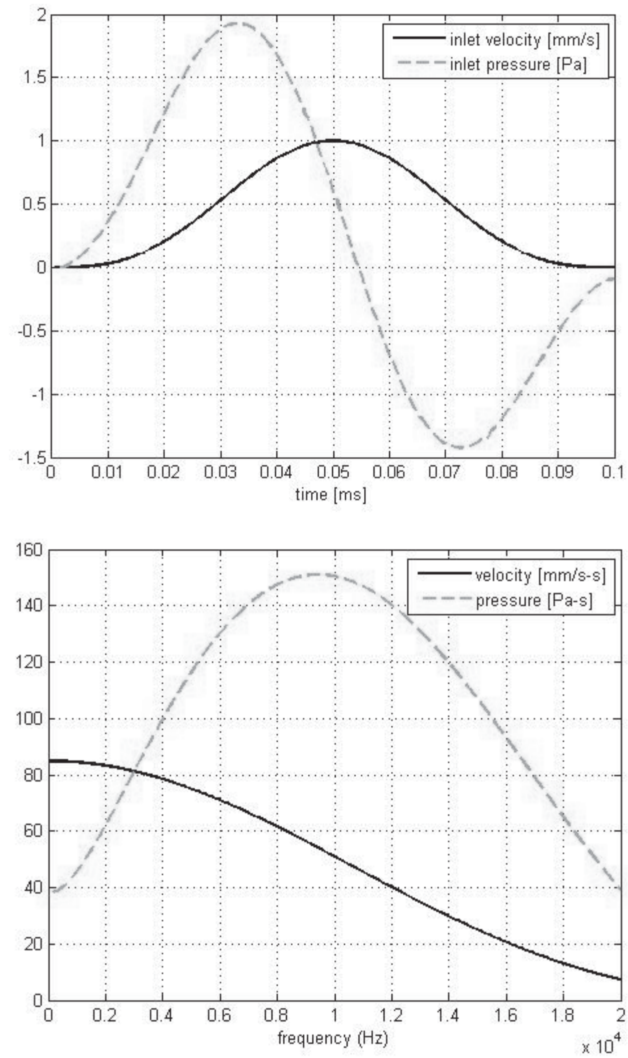

Figure 2. (a) Inlet velocity and pressure vs. time (b) Inlet velocity and pressure magnitude vs. frequency (t = 0.4064 mm, d = 0.2032 mm, σ = 0.02).

Table 1. Parameters of three model sets (t is thickness, d is diameter of the hole, σ is the surface porosity).

Set 1. Thickness			Set 2. Diameter			Set 3. Porosity		
t (mm)	d (mm)	σ	t (mm)	d (mm)	σ	t (mm)	d (mm)	σ
0.1016	0.4064	0.02	0.4064	0.1016	0.02	0.4064	0.2032	0.005
0.2032	0.4064	0.02	0.4064	0.2032	0.02	0.4064	0.2032	0.01
0.3048	0.4064	0.02	0.4064	0.3048	0.02	0.4064	0.2032	0.015
0.4064	0.4064	0.02	0.4064	0.4064	0.02	0.4064	0.2032	0.02
0.508	0.4064	0.02	0.4064	0.508	0.02	0.4064	0.2032	0.025
0.6096	0.4064	0.02	0.4064	0.6096	0.02	0.4064	0.2032	0.03
0.7112	0.4064	0.02				0.4064	0.2032	0.035
0.8128	0.4064	0.02				0.4064	0.2032	0.04
0.9144	0.4064	0.02						

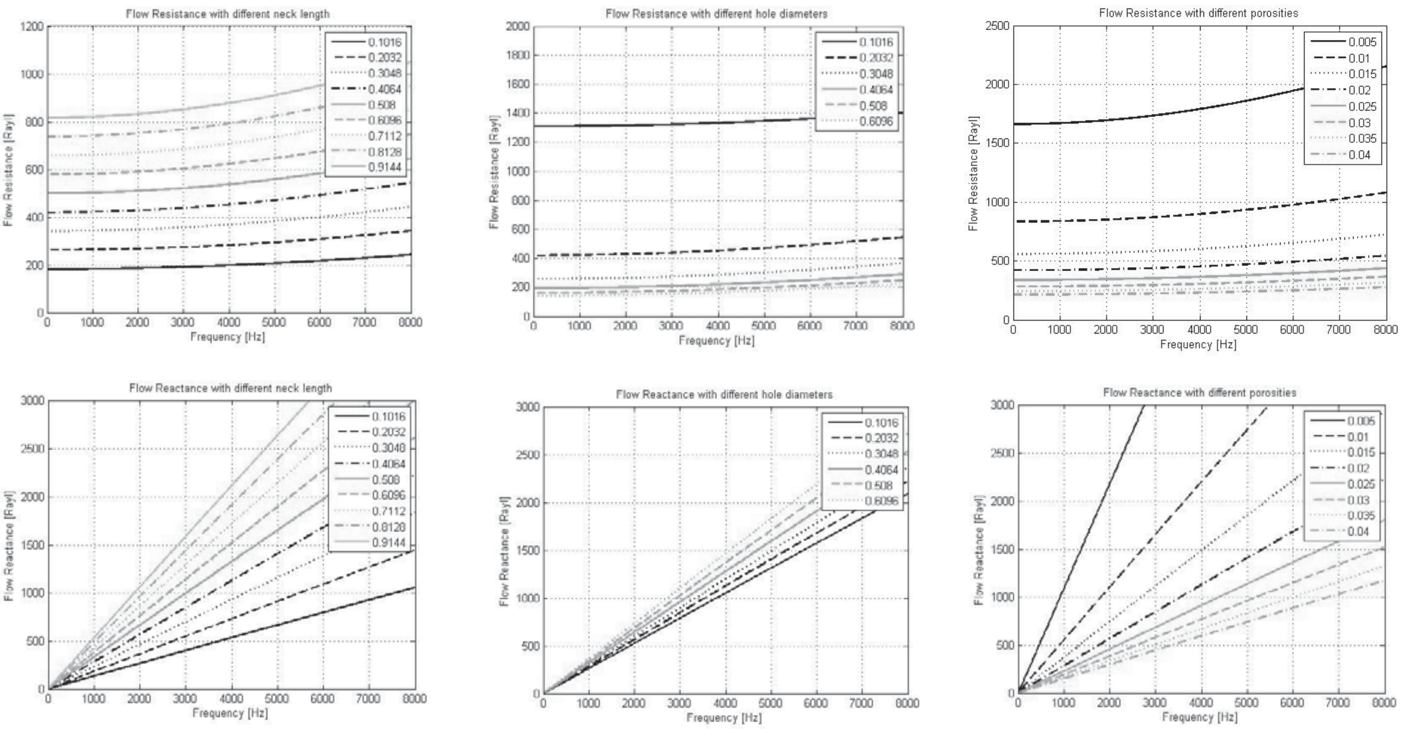

Figure 3. Dynamic flow resistance and dynamic flow reactance of set 1 (left), set 2 (middle), and set 3 (right).

Transfer Impedance

The specific acoustic transfer impedance of the panel was calculated as $Z = (P_1 - P_2)/V$. Here, P_1 is the inlet pressure, P_2 is the outlet pressure (which is the ambient pressure), and V is the inlet velocity; all of these quantities were Fourier transformed in order to obtain the impedance in the frequency-domain. The real part of the specific impedance is referred to here as the dynamic flow resistance, and the imaginary part is referred to as the dynamic flow reactance. Figure 3 shows the flow resistance and flow reactance for the three model sets described above.

As expected, the dynamic flow resistance increases as the thickness increases, the diameter decreases, or the porosity decreases. The dynamic flow reactance, which will not be considered in detail here, shows a pure mass-like characteristic, as expected. To illustrate the difference between the CFD results and the predictions of the Guo *et al*. model, one particular case is considered here: the thickness of panel was 0.1016 mm, the hole diameter was 0.1016 mm, and the porosity was 0.02. In the Guo *et al*. model, the parameter α was set to both 2 (round-edged hole) and 4 (square-edged hole), for the purpose of illustration. The comparison of the impedances is shown in Fig. 4, and Fig. 5 shows the absorption coefficients of the microperforated material for various backing depths calculated by using both CFD-based impedance and the Guo *et al*. model (with $\alpha = 2$). The surface normal impedance of the microperforated sheet and a rigidly terminated air spaces was calculated as $z_p = -j\rho c \cot k_a L$, where k_a is the wave number in air (ω/c), and L is the air layer depth. The normal incidence plane wave reflection coefficient is then $R = \frac{(z_p - \rho c)}{(z_p + \rho c)}$ and the normal incidence absorption coefficient is $\alpha_n = 1 - |R|^2$.

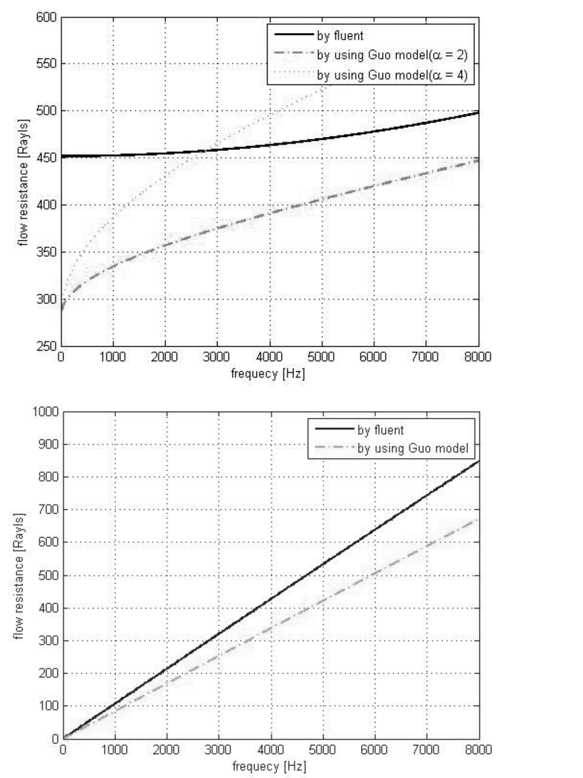

Figure 4. Dynamic flow resistance (top) and flow reactance (bottom) at $t = 0.1016$ mm, $d = 0.1016$ mm, $\sigma = 0.02$.

The dynamic flow resistance calculated from the CFD simulations generally lies between those predicted by the Guo *et al*. model for $\alpha = 2$ and $\alpha = 4$; the CFD reactance is very similar in character but slightly larger. The CFD and

Guo *et al*. flow resistances differ most significantly in the low frequency range. It is suggested that the difference in the dynamic flow resistance at low frequencies results from the neglect of a static, resistive end correction in conventional microperforated material models. The resistive contribution to the hole impedance from flow over surfaces adjacent to the hole (and from shearing within the fluid exterior to the hole as flow converges into the hole) does not vanish at 0 Hz: i.e., under steady flow conditions. However, the assumed frequency dependence of the resistive end correction in the Guo *et al*. model (and in the Maa model on which it is based) necessarily causes the resistive end correction to become negligible at low frequencies (when the parameter α is assumed to be frequency-independent). This effect is believed to be primarily responsible for the difference between the Guo *et al*. and related models and the present CFD results, and this is the major finding of the current work. Since the major difference between the Guo *et al*. impedance predictions and those made using the present approach are in the dynamic flow resistance, the magnitudes of the absorption coefficients predicted using the two approaches will differ in the low frequency range but the peak locations (determined by the dynamic flow reactance) will be approximately the same: this behaviour is illustrated in Fig. 5.

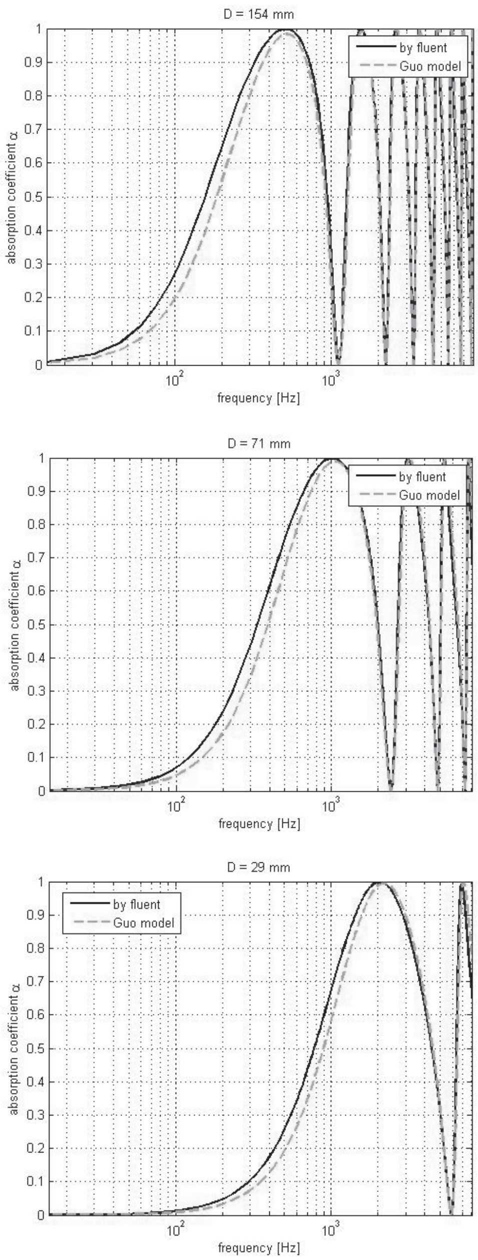

Figure 5. Comparison the absorption coefficient of a microperforated sheet (t = 0.1016 mm, d = 0.1016 mm, σ = 0.02) with air backing (L = 154 mm, L = 71 mm, L = 29 mm).

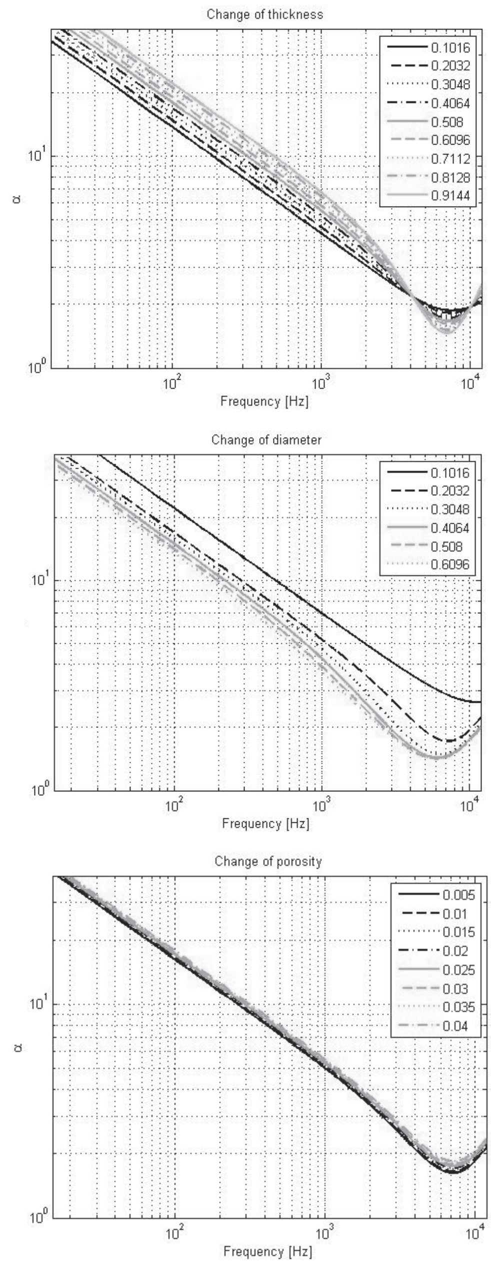

Figure 6. α vs. frequency for different thicknesses (top), different hole diameters (middle), and different surface porosities (bottom).

DYNAMIC RESISTIVE END CORRECTION

As noted above, the difference between the Guo *et al*. model and the CFD simulations results primarily from the resistive end correction. The end correction in the Guo *et al*. model is expressed as $\frac{\alpha 2 R_s}{\sigma \rho c}$, where α equals 4 for a sharp-edged hole. To improve the accuracy of the Guo *et al*. model, it would be necessary to make the parameter α dependent on frequency (as well as on the hole geometry and surface porosity). Here, the value of α has been calculated that would be required to force perfect agreement between the Guo *et al*. model (for the specific resistance) and the CFD results. Figure 6 shows the dependence of α on frequency and on geometric parameters, when defined in this way.

From Fig. 6 can be seen that α is generally inversely proportional to frequency in the low frequency region, but that it appears to be approaching a constant value at high frequencies. The results in Fig. 6 also indicate that as the panel thickness increases, the value of α also increases. In the same way, the value of α increases as hole diameter decreases. In the variable porosity cases, the porosity does not have a strong effect in the range considered here. These results imply that α should, in principle, be treated as a function of frequency, thickness, hole diameter, and porosity. In the Fig. 6, all three graphs show that α is approximately proportional to $f^{-0.5}$. Therefore, α can be conveniently represented as:

$$\alpha = \beta f^{-0.5} \tag{3}$$

Then, a new parameter β, is defined to be a function of thickness, hole diameter, and porosity. Figure 7 shows β for different thicknesses, hole diameters, and porosities at 5 kHz. Figure 7 implies that β is proportional to porosity, and inversely proportional to thickness and hole diameter. Based on the change of dynamic flow resistance at 5 kHz, an approximate expression for the parameter β, as a function of thickness, hole diameter, and porosity, is suggested as:

$$\beta = (14.1 - 0.059\,\sigma)\frac{t}{d} + 117 \tag{4}$$

The constants were determined by a least square method. Note that since the porosity is always smaller than 1 (so that 14.1 is always much larger than 0.059σ), under normal circumstances the porosity term can be neglected. The new parameter β is then simply defined as:

$$\beta = 14.1\frac{t}{d} + 117 \tag{5}$$

Equation (3) shows that α depends on frequency, and Eq. (5) shows that α is function of thickness and hole diameter.

From these results, a new resistive end correction can be defined, based on Guo's end correction but in which the value of α is given as, $\alpha = \beta f^{-0.5}$. Figures 8, 9, and 10 show comparisons of the value of α obtained using the CFD simulations with that predicted using the new parameter β. From these three different cases it can be seen that the suggested form of the parameter β results in reasonable agreement between the CFD results and the approximate predictions over a relatively wide range of hole parameters. Finally, the absorption coefficients calculated by using the three different methods are plotted in Fig. 11, where it can be seen that the results calculated using the parameter β as defined in Eq. 5 are essentially indistinguishable from those calculated using the CFD-based impedance.

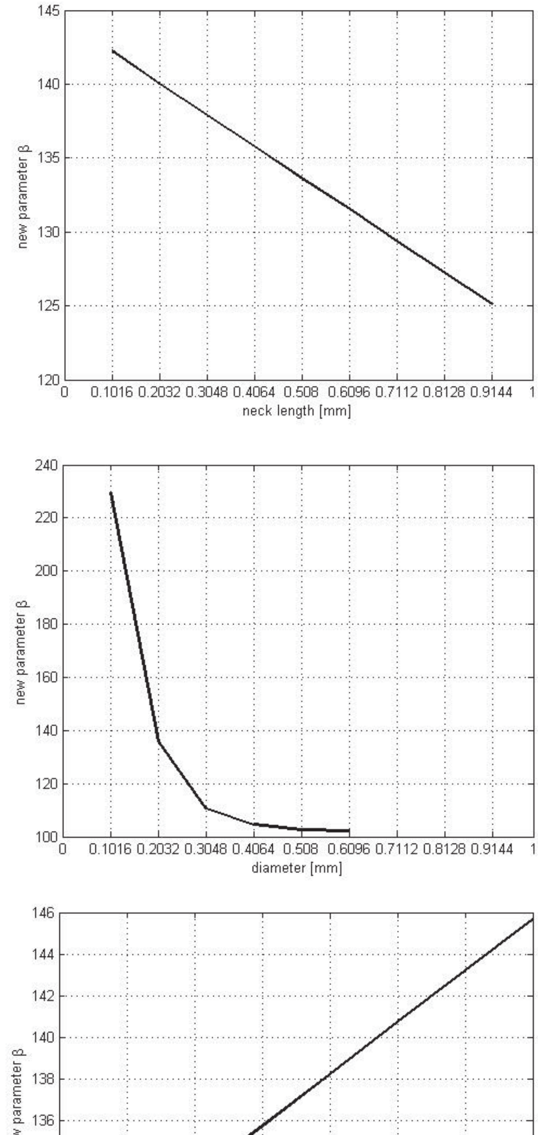

Figure 7. β vs. thickness (top), hole diameter (middle), and porosity (bottom) at 5000 Hz.

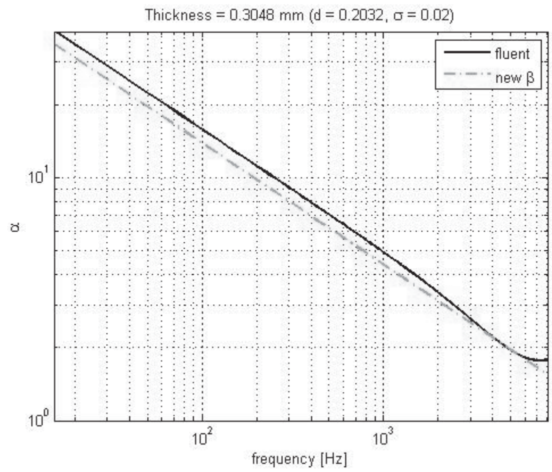

Figure 8. End correction from CFD simulation (solid line) vs. prediction with new parameter β (dash-line) at t = 0.3048mm (d = 0.2032 mm, σ = 0.02).

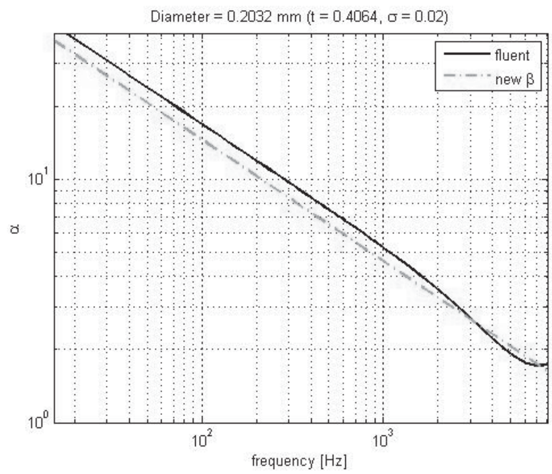

Figure 9. End correction from CFD simulation (solid line) vs. prediction with new parameter β (dash-line) for d = 0.2032 mm (t = 0.4064 mm, σ = 0.02).

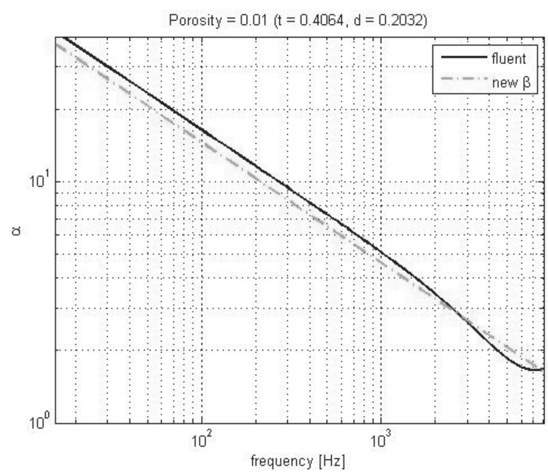

Figure 10. End correction from CFD simulation (solid line) vs. prediction with new parameter β (dash-line) for σ = 0.01 (d = 0.2032 mm, t = 0.2032 mm).

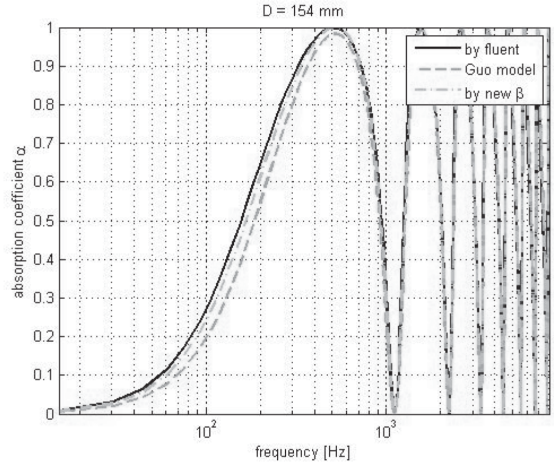

Figure 11. Absorption coefficient calculated by using different impedance values (L = 154 mm, t = 0.1016 mm, d = 0.1016 mm, σ = 0.02).

CONCLUSIONS

In this paper, CFD models of microperforated materials have been considered. It has been demonstrated that those models generally produce results that conform with well-established theoretical models, but may be more accurate at low frequencies. The CFD models have been used to generate corrections which can be applied to existing models to improve the accuracy of their predictions. Here, only square-edged holes have been considered, but the same approach can easily be extended to other hole geometries. An examination of the effect of varying hole geometry will be the subject of future work.

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NUMERICAL PREDICTION OF THE TRANSMISSION LOSS OF LEAKS IN TRIMMED PANELS

Israel Pereira[1], Marcus Guettler[2] and Sascha Merz[3]
[1]Universidade Federal de Santa Catarina, Brazil
[2]Technische Universitaet Dresden, Germany
[3]ESI US R&D San Diego, USA

Small holes and pass-throughs can often have a significant impact on the transmission loss of trimmed panels, particularly at mid and high frequencies. The effect of such "leaks" can be included in modelling methods such as Statistical Energy Analysis (SEA) by using various analytical leak models. Such models typically assume a simple cross-sectional geometry in order to calculate the leak TL. However, for more complex configurations, for example, where a pass-through only penetrates certain layers of a multi-layer noise control treatment applied to the panel, a more detailed model is required in order to determine the TL of the leak. In this paper, Foam Finite Elements have been used to create such local models in order to predict the TL of partially trimmed pass-throughs. This local TL can then be used to update a system level SEA model. In addition, the paper demonstrates the widely known result that the TL of a simple hole does not depend on its cross-sectional shape but only its cross-sectional area and length. Results are presented for a number of examples.

INTRODUCTION

Statistical Energy Analysis (SEA) is an established numerical method for modelling the response of complex vibro-acoustic systems over a wide frequency range [1, 2]. A common application of SEA is prediction of interior noise in a vehicle due to external acoustic excitation, along with the design of the interior "sound package" of the vehicle [3]. A typical airborne SEA vehicle model is shown in Fig. 1. The model consists of SEA subsystems that represent plates, cavities and semi-infinite fluid domains. The subsystems are coupled via point-, line- and area-junctions (the latter typically contain multi-layer noise control treatments or NCTs). Acoustic excitation is applied to the exterior of the vehicle and interest lies in predicting the sound pressure level in the driver and passenger head spaces. The SEA model also typically contains leaks to represent holes and pass-throughs in the structure and sound package. Such leaks are important for higher frequencies, where they can sometimes become the primary transmission path.

In order to represent simple leaks such as circular and rectangular apertures, analytical representations of the leak TL can be included in the SEA model [4]. However, in some instances a more detailed description of a leak is required, for example, to confirm that a simple leak model can represent a hole with a complex cross-sectional shape or to update an SEA model, where the leak only penetrates through certain layers of a NCT. For either case, only the local transmission loss (TL) of the leak is needed. This can be computed using a detailed numerical model and used to update a system level SEA model.

This paper presents numerical results for the TL of various leaks. The impact of cross-sectional shape is investigated, for leaks with the same length and cross-sectional area. The influence of sound package on the TL of a leak is then analysed and results for various local models of the leak are discussed. In order to cover a broad frequency range, the Hybrid FE-SEA method [5-7] has been used to perform the numerical simulations in this paper. In these models acoustic finite elements have been used to model the fluid in the local vicinity of the leak. The noise control treatment has been modelled using Foam Finite Elements [7, 8] based on Biot theory and the acoustic half-space on either side of the panel is represented by SEA acoustic fluids. It has been assumed that for the frequency range of interest (i) leak TL is dominated by local properties and (ii) edge effects are negligible. All models have been created in the commercial software package VA One [7].

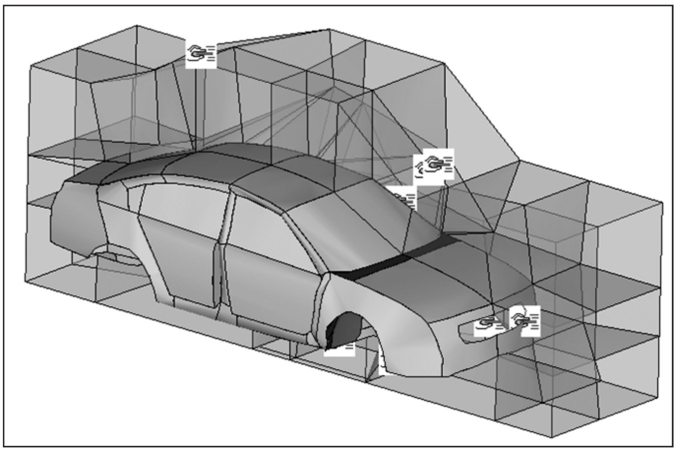

Figure 1. Typical vehicle airborne SEA model.

PREVIOUS STUDIES

A study of the transmission loss of slits and seals for airborne SEA was recently conducted by Cordioli *et al.* [9]. In this work the TL of an automotive door seal was investigated using Hybrid FE-SEA models. It was found that the inclusion of the acoustic "channel" before and after the seal can have a significant impact on the overall TL of the seal. It was also shown that for "slits" a Hybrid FE-SEA model provided a quick way to model the slit TL and that the geometrical complexity of the channel does not have a significant impact on the TL of the slit (the TL scales with the overall length and cross-sectional area of the channel). The current paper uses a similar modelling approach but applied to trimmed pass-throughs.

INFLUENCE OF ACOUSTIC LEAK ON THE TL OF A TRIMMED PANEL

This section provides a simple example of the influence of a leak on the TL of a simple panel. Consider a 1mm thick steel plate between two air filled cavities shown in Fig. 2. A noise control treatment layup consisting of 20mm melamine foam and a 1.5kg/m^2 septum has been applied to the steel plate. A circular leak with a diameter of 10mm diameter is added to the steel plate using an analytical formulation [4]. An SEA model of the system is created that contains two cavity subsystems (with overridden volumes to simulate large reverberant rooms), one plate subsystem and the leak in the area junction between the panel and the cavities.

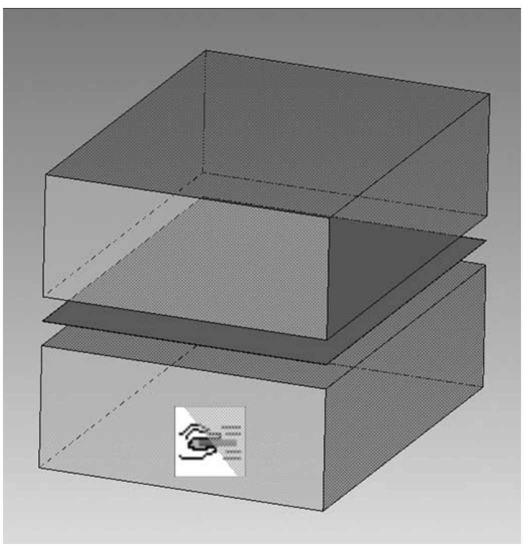

Figure 2. SEA model used to predict TL through a steel plate of dimension 1.64m×1.19m×0.001m with a NCT layup consisting of 20mm of melamine foam, a 1.5kg/m^2 septum and a 10mm diameter "leak".

The predicted TL results are shown in Fig. 3 for four configurations of bare and trimmed panels with and without a leak. It can be seen that, for this model, the leak is the dominant transmission path above approximately 1 kHz when the panel is trimmed. This is not the case with the bare panel where the 'weak' path is still the panel itself. The TL curve for a different leak (with 30mm depth and 10mm diameter) is plotted in Fig. 4. The curve can be used to show typical characteristics of the leak TL. Below approximately 1kHz the TL of the leak is fairly constant and is determined by "aperture" effects. Above approximately 10kHz the local TL of the leak tends to zero and the TL is determined by the "area" of the leak (the TL tends to approximately 44dB in this example since the TL is normalized to the overall area of the panel). Between 1kHz and 10kHz various local acoustic resonances of the leak occur.

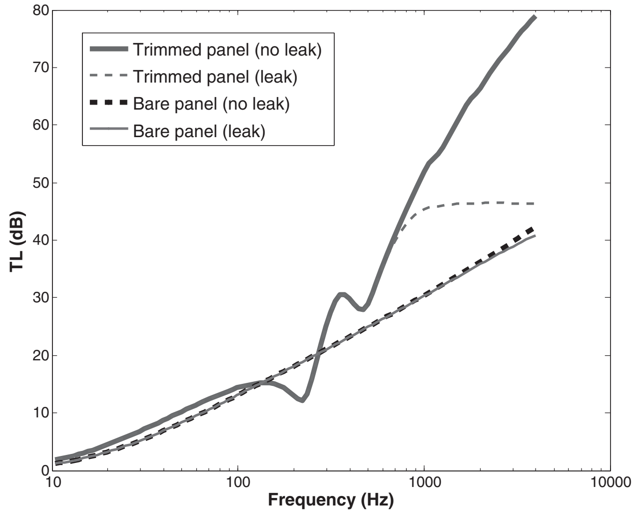

Figure 3. Influence of a leak on the TL of bare and trimmed panels.

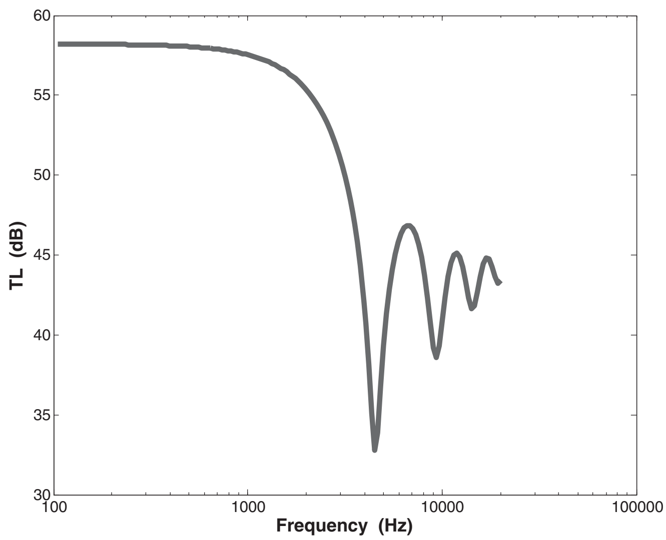

Figure 4. Transmission loss (normalized to panel area) for a rigid panel with a single circular pass-through having 10mm diameter and 30mm depth.

INFLUENCE OF CROSS-SECTIONAL SHAPE ON UNTRIMMED LEAK

The previous examples considered a leak with a simple cross-sectional geometry modelled analytically. This section considers the TL of leaks with more complex cross-sectional shapes. The leaks shown in Fig. 5 were selected; each has the same depth and cross-sectional area but different cross-sectional shapes. Various Hybrid FE-SEA models were created for the leaks as shown in Fig. 6. The leaks are represented by Acoustic Finite Elements (this allows any leak geometry to be investigated, including situations in which the cross-sectional area of the leak varies throughout the depth of the leak). The Acoustic FE subsystems are then connected to SEA semi-infinite fluids (SIFs) using "Hybrid Area Junctions". A "baffled" boundary condition option was selected for these Hybrid Area Junctions. Each SIF then describe a (complex and full) radiation impedance looking into a baffled half space. A diffuse acoustic field was applied to the source side (the DAF is represented by a reciprocity relationship as discussed in [10]). The advantage of the Hybrid FE-SEA models is that they solve very quickly (the models in this example solved in a matter of seconds).

The TL predicted by the various Hybrid models and the TL predicted for a circular leak by an analytical model are shown in Fig. 7. It can be seen that the TL curves are almost identical, highlighting that (for frequencies at which the wavelength is large compared with the dimension of the leak) the TL is insensitive to the cross-sectional shape of the leak. There is close agreement between the Hybrid result and analytical results (the small differences are perhaps due to the simplifying assumption adopted in the analytical model that the pressure within the leak is uniform across the leak cross-section). The results in this section are consistent with the standard SEA practice of using a simplified leak formulation to describe leaks with different cross-section.

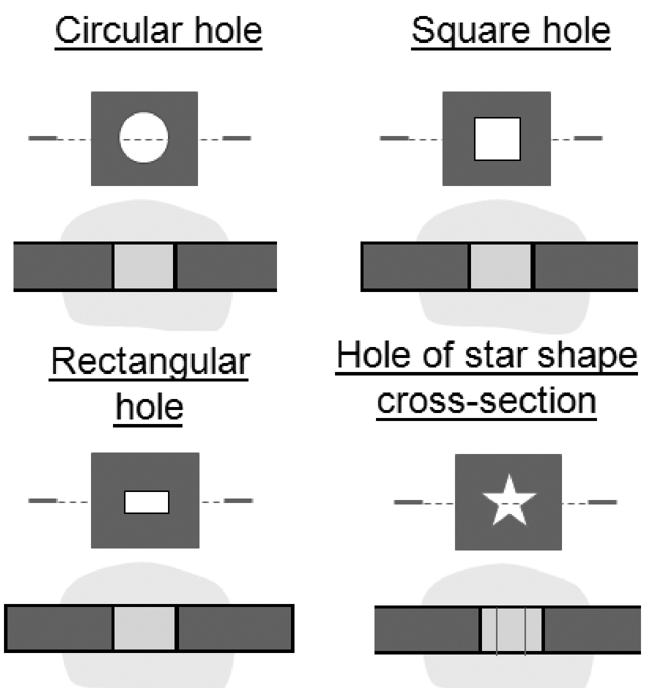

Figure 5. Examples for pass-throughs having simple and complex cross-sectional shape.

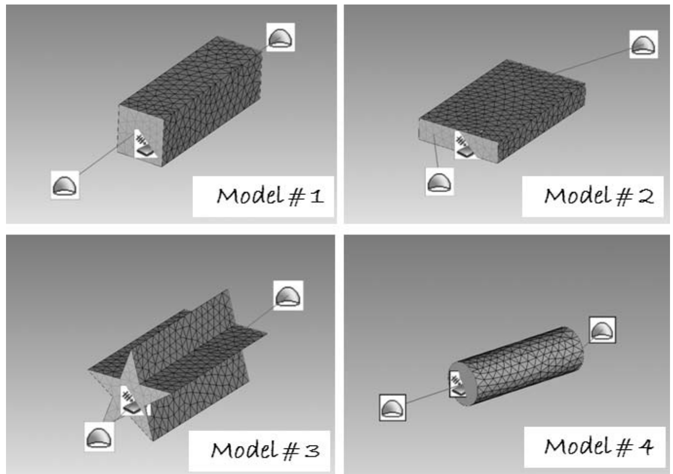

Figure 6. Hybrid FE-SEA models of leaks with the same cross-sectional area and depth but different cross-sectional shapes.

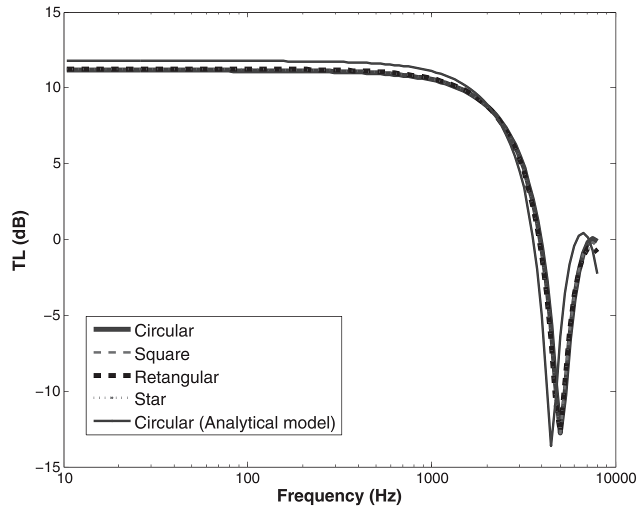

Figure 7. TL of leaks with different cross-sectional shape using a Hybrid FE-SEA model and of a circular leak using an analytical model.

MODELLING A TRIMMED LEAK: FULL PANEL MODEL

Consider now the problem of applying a layered noise control treatment over a given leak. In principle, a model could be created in which the panel is modelled in detail using Structural Finite Elements, the trim modelled with Foam Finite Elements and SEA fluids applied to either side to model the TL. This is investigated in the current section.

A Hybrid model of the previous flat trimmed panel has been developed using foam finite elements to represent the trim and structural finite elements to represent the panel. The air is modelled using SEA semi-infinite fluids on either side of the panel. 700 structural modes have been extracted to represent the response of the steel panel. The foam is represented by approximately 70,000 foam finite elements. The model is shown in Fig. 8. Results for the same configuration have also been obtained using an SEA model, where the air is represented by SEA acoustic cavities, the panel is represented by an SEA plate and the trim is described with the standard SEA transfer matrix approach for poroelastic layups. For the Hybrid FE-SEA model, a frequency range from 10 to 1,000Hz has been considered, where 80 frequency points were computed. For the pure SEA model, a frequency range from 100 to 5,000Hz has been investigated. On a 4 core 64-bit machine with 2.2GHz clock frequency and 8GB of RAM, the detailed Hybrid model required approximately 70 hours to solve, whereas the simple SEA model required 5 seconds. The majority of the computational expense of the Hybrid model was associated with the explicit representation of the trim using foam finite elements (the computational time may be reduced through the use of frequency interpolation but this was not employed in the current example).

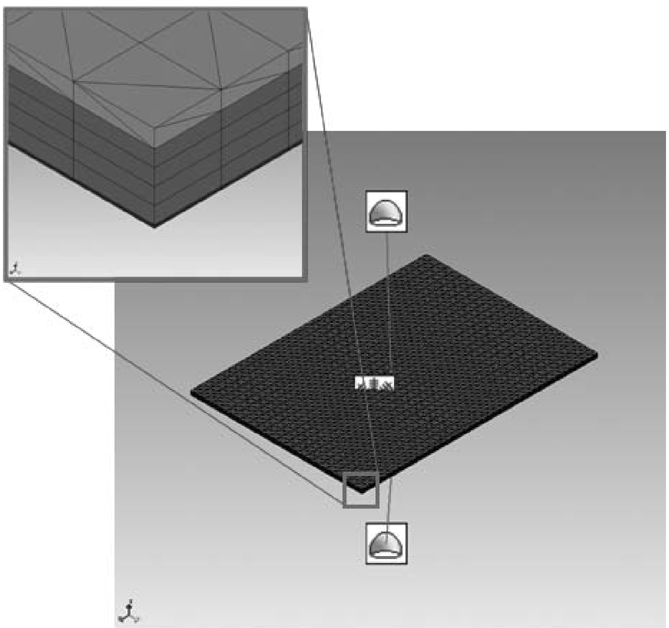

Figure 8. Hybrid FE-SEA-PEM model of a trimmed panel.

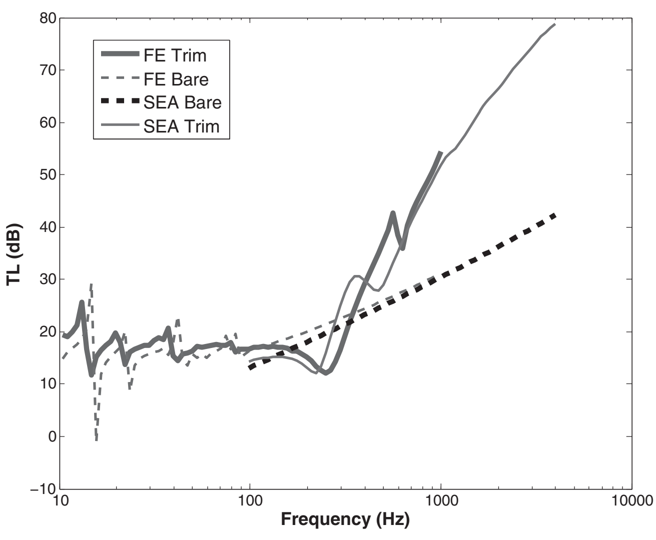

Figure 9. Comparison of the transmission loss obtained from pure SEA and Hybrid FE-SEA-PEM models for an untrimmed and a trimmed panel.

The results for the TL of the trimmed and untrimmed panels are presented in Fig. 9. The models are in close agreement across the common frequency range. However, the example highlights that the use of a detailed finite element model of the entire panel may result in long solve times which may not be practical for quick design studies. It is therefore natural to question whether a detailed model of an entire panel is needed in order to assess the TL of a trimmed leak. The following sections investigate this in more detail.

MODELLING A TRIMMED LEAK: LOCAL MODELS

An alternative approach to modelling an entire panel is to create a local model of a leak that includes the trim in the "local" vicinity of the leak. A question that then arises is *"how much of the surrounding trim do I need to include in a local model to characterise the effect of the trim on a given leak?"*. In this section this question is addressed by comparing the results from two different Hybrid models of a trimmed leak. The models are used to assess the sensitivity of the TL to the amount of foam that is modelled.

The Hybrid models are shown in Figs. 10 and 11. The leak is modelled with acoustic finite elements as before. The foam and septum in the vicinity of the leak are modelled with foam finite elements. SEA SIFs are then added to model the source and receiving sides of the leak. The difference between the two Hybrid models is that the first model is larger than the second model (the first model includes a larger cross-sectional area than the second model).

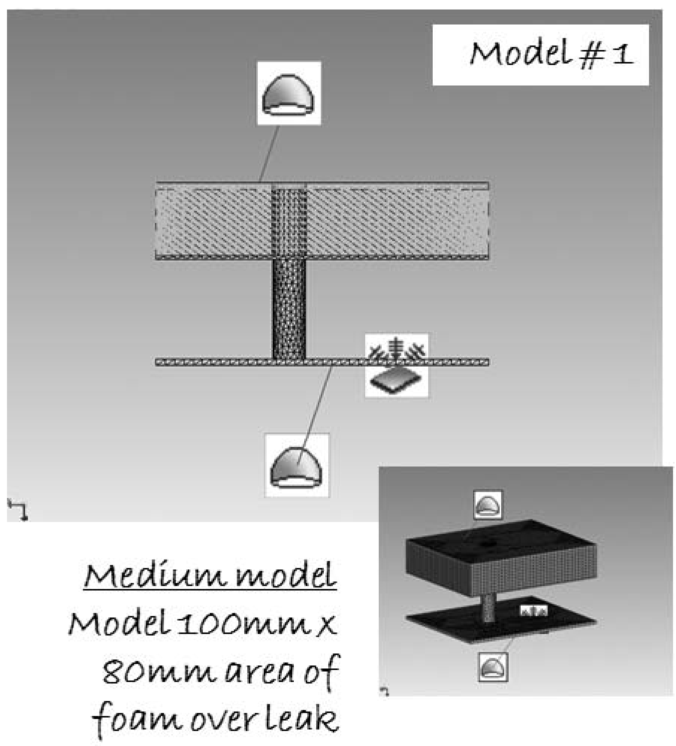

Figure 10. Hybrid FE-SEA model of trimmed leak (medium sized model).

For the two models, the dimensions of the cut-out were chosen to be 100mm×80mm and 50mm×30mm, respectively. The TL from both models is presented in Fig. 12 along with the TL of an "untrimmed" leak. It can be seen that, for this model, above approximately 300 Hz the results from the two models are identical. Below 300 Hz the results are sensitive to finite size effects and the TL depends on the boundary conditions applied to the edge of the foam. At first sight this might suggest that it is necessary to use a larger model to characterize the insertion loss that the treatment applies to the leak TL. However, as discussed in previous sections, the TL of a leak is often dominant at higher frequencies. In such instances it may therefore be possible to use a local Hybrid FE-SEA model to characterize the insertion loss that the trim applies to the leak.

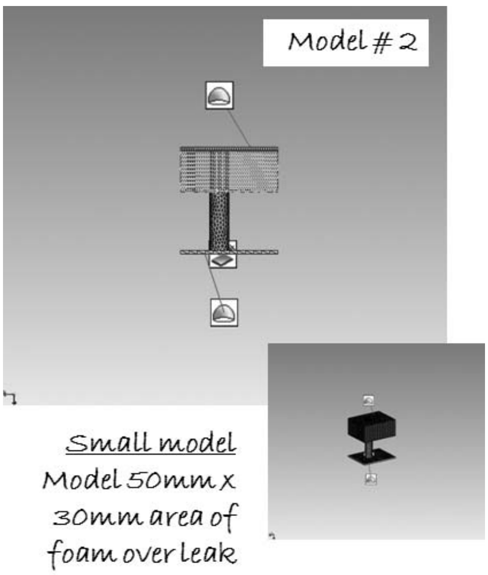

Figure 11. Hybrid FE-SEA model of trimmed leak (small model).

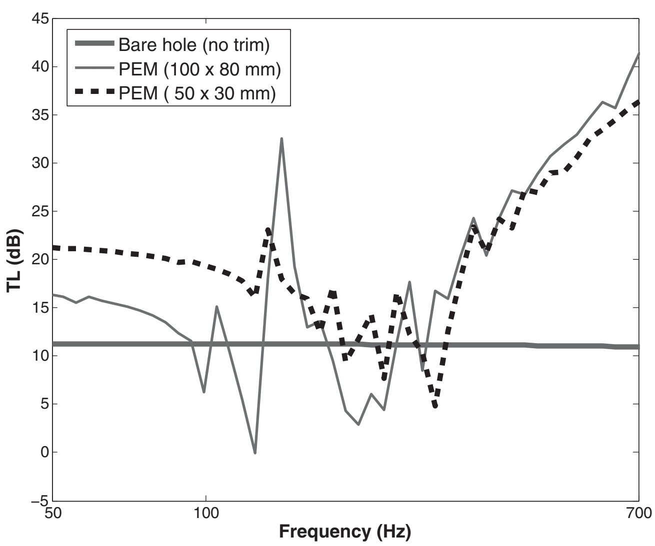

Figure 12. Comparison of the TL of a trimmed leak predicted by Hybrid models (frequencies over 300 Hz of interest for typical leak).

CONCLUSIONS

This paper has presented a number of methods for creating detailed local models of leaks. The main application of the current work is updating system level SEA models with information from detailed local Hybrid FE-SEA-PEM models. It was demonstrated that (at lower frequencies) the TL of an untrimmed leak is insensitive to cross-sectional shape and only depends on overall cross-sectional area and depth. The use of local Hybrid FE-SEA-PEM models was then investigated for modelling the TL of a trimmed leak. For the configurations in the current paper the use of smaller local models provided similar estimates of TL at higher frequencies indicating that it is not necessary to model an entire panel in order to characterize the TL of a trimmed leak. While the current paper focused on simple trim layups, the proposed approach is expected to be applicable to more complex layups involving partial coverage and complex cut-outs within the treatment.

ACKNOWLEDGEMENTS

This work was performed while the first and second authors were research interns at ESI US R&D. Helpful discussions with Vincent Cotoni and Phil Shorter are acknowledged. All models discussed in the current paper were developed using the commercial vibro-acoustics software VA One [7].

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A COMPARISON OF TECHNIQUES FOR RANGING CLOSE-PROXIMITY MULLOWAY *(ARGYROSOMUS JAPONICUS)* CALLS WITH A SINGLE HYDROPHONE

Miles J.G. Parsons[1], Robert D. McCauley[1], Michael C. Mackie[2] and Alec J. Duncan[1]
[1]Centre for Marine Science and Technology, Curtin University, GPO Box U1987, Perth, WA 6845, Australia
[2]Department of Fisheries, Government of Western Australia, PO Box 20, North Beach, WA 6020, Australia

The accurate ranging of sounds produced by fish can provide valuable information on species ecology, and fish calls are being increasingly used to delineate and evaluate spawning grounds. In 2008, a single hydrophone was deployed on the riverbed of the Swan River, Western Australia, to assess the most effective technique for ranging mulloway (*Argyrosomus japonicus*) calls. During this experiment, the ranges of a calling mulloway were calculated using four techniques. These techniques involved comparing the characteristics of the direct and surface -reflected paths using: 1) arrival-time difference; 2) the pressure-amplitude ratios; 3) pulse sound-pressure-level ratios and; 4) a combination of techniques 1) and 2). Technique 1 proved the most consistent ranging technique, with accuracy limited by wave-motion-induced variation in water depth. However, a combination of the tested techniques is recommended when ranging fish.

INTRODUCTION

Overfishing has led to the collapse of numerous fish stocks around the world. It is a particular threat to species prone to exploitation, such as those of the Sciaenidae, known as drums or croakers, e.g. mulloway (*Argyrosomus japonicus*), black jewfish and (*Protonibea diacanthus*) teraglin (*Atractoscion aequidens*) [1-3]. The recent collapse of a black jewfish spawning aggregation in northern Queensland has highlighted the susceptibility of Sciaenidae in Australia and the need to develop more accurate monitoring techniques for sustainable management of the fishery [4, 5].

The observation of fine-scale movement of individual fish facilitates the understanding of interaction within the spawning group and the spatial extents of aggregation movement. For example, some species exhibit mobile spawning rushes where multiple males follow a female in a vertical movement, while other species take part in near stationary pair spawning [6-9]. However, many fish spawn during hours of darkness or in estuarine waters of high turbidity, which can affect the ability of visual techniques to observe behaviour [5, 10]. In addition, some methods of observation may induce behavioural bias (e.g. baited remote underwater video), while extractive techniques such as tagging and biological sampling may not be appropriate for species which are susceptible to barotrauma (over-expansion of the swimbladder) or exhibit high catch-mortality rates. Such species include black jewfish, mulloway, and West Australian dhufish (*Glaucosoma hebraicum*), which are key species of commercial importance in Australia [11-15].

One alternative method of observation is the remote recording of fish calls (passive acoustics). For centuries traditional fishermen around the world have known that many species of fish produce sound, listening to the noise through the hulls of their wooden boats to locate aggregations [16]. Over the past five decades, more than 800 different fish species have been reported to be soniferous [17]. Sounds associated with reproductive behaviour are being increasingly reported [18-24]. Winn [25] and Fine *et al*. [26] summarised these sounds as associated with one of several behavioural functions including: aggressive encounters (usually territorial); reproduction; echolocation; schooling; recognition; feeding; migration; exploration; and distress.

Sound production by fishes can eventuate from diverse methods, such as bubble release from the mouth or vibration of bubbles at the anal cavities [27]. Some species use stridulation, which is the rubbing or knocking of body parts together, creating a noise similar to that of marine invertebrates. This stridulation (high frequency, wide-bandwidth, usually of short duration) may be from pectoral fins (e.g. catfish [28, 29]) or skeletal bones (e.g. pipefish, *Syngnathus louisanae* [30]), but the chief mechanism of fish sound production is via the vibration of the swimbladder (an enclosed gas chamber within the body cavity) [25]. To vibrate the swimbladder, fish contract fast or superfast twitch ("sonic") muscles, which may or may not be connected to the swimbladder [31, 32]. Since the acoustic impedance of the gas inside the swimbladder differs greatly from the surrounding water, the swimbladder is highly effective at generating sound [33] and is therefore an effective means of communication (and observation) over great distances.

Mulloway is a commercially and recreationally important species in Australia [34]. Individuals aggregate during spawning, often in estuaries at night-time high tide, which restricts many traditional data sampling methods [5]. Mulloway produce tonal sounds of varying length, comprising a train of swimbladder pulses [35, 36] (Figure 1). Close-proximity ranging of fish can be achieved non-invasively by recording these calls with a hydrophone [5, 20, 35]. Fine-scale localisation of individual fish from their calls has been achieved [37], but this is non-trivial because it requires an array of hydrophones and regular array synchronisation [35, 37]. Single hydrophones are often used to identify broad-scale movements of cetaceans [38], and on occasion the position of fish [20], but rarely to observe the small-scale movement patterns of individuals.

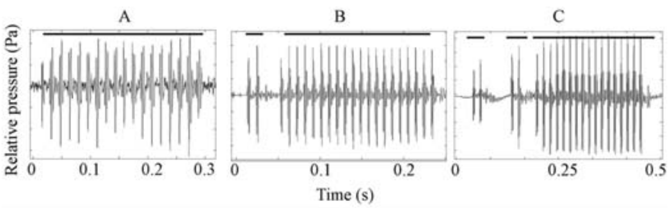

Figure 1. Waveforms of example mulloway (*Argyrosomus japonicus*) calls. Black lines above waveforms denote periods of audible tone.

Understanding local sound-propagation characteristics (e.g. transmission loss) is one of the initial steps towards assessing the numbers of calling fish by comparing the sound-pressure levels (SPL) produced by a single fish with the overall received SPL from the entire chorus [20, 39]. Given that estuarine tidal range, salinity and temperature all vary at different temporal scales (ranging from hours to months), the propagation of sound in estuaries can change significantly over a matter of hours, with considerable effect on the received SPL of fish calls [31]. The ability to range fish calls using a single hydrophone aids the characterisation of local transmission properties at the time of recording, and therefore the contribution of an individual call to the overall SPLs [20, 35]. Once local transmission properties have been determined and accounted for, it is then possible to compare the SPLs of fish calls recorded at different times and potentially to compare estimates of abundance.

The aim of this study was to assess the most appropriate passive-acoustic technique for localising fish under survey conditions by calculating the range of calling mulloway in Mosman Bay, Western Australia using four different techniques.

METHODS

Data collection

A hydrophone array was deployed in Mosman Bay on 8th March 2008 to localise individual mulloway calls. The Mosman Bay channel varies in depth between approximately 18 and 21 m and comprises a sand/silt substrate with a number of artificial reefs (Figure 2).

An HTI-90U hydrophone (Hi-Tech Industries Inc., MS, USA) was attached to a custom-made autonomous sea-noise logger (www.cmst.curtin.edu.au/products/usr.html) developed at Curtin University of Technology and Defence Science and Technology Organisation (DSTO) and deployed on the riverbed at approximately 32° 0.57' S, 115° 46.43' E. The noise logger recorded for twenty five minutes of every half hour at a sampling frequency of 10.416 kHz with a flat (± 1 dB re 1 V^2/Hz) frequency response between ~20 Hz and 1 kHz (confirmed using a -90 dB re 1 V^2/Hz white-noise source).

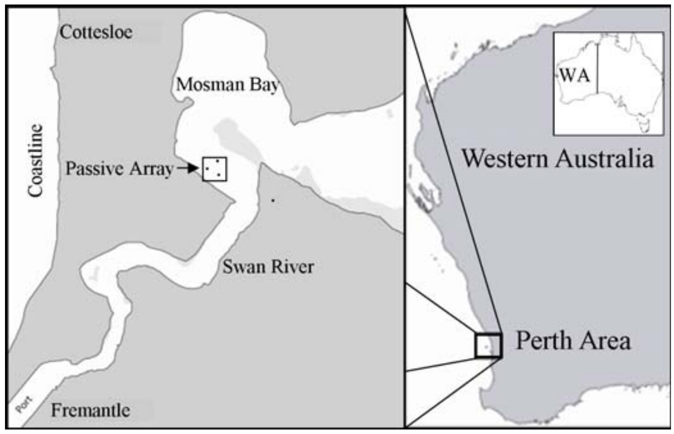

Figure 2. Map of the Swan River in Western Australia and the location of a hydrophone array in the Mosman Bay area.

At the time of the reported calls the hydrophone was positioned in 18.3 m of calm water. The greatest variation in water depth was due the wake of passing vessels, estimated at a maximum of ± 30 cm [40]. Over large distances, the effects of ray bending on path distance and transmission loss can have considerable impact on source-range estimates. However, at the ranges in this experiment (<50 m), the effects of ray bending on source range were considered negligible compared to those of depth variation caused by vessel-generated surface waves [37, 41].

Data analysis

Waveforms and spectral content of the recorded calls were analysed using a suite of Matlab© programs developed by the CMST. The received SPL refers here to root-mean-squared (RMS) pressure measured in dB re 1µPa.

In addition to long calls (Figure 1), mulloway also emit short calls of one or two pulses. These short calls look similar to the first two pulses of the call in Figure 1B. The waveform of an example single pulse mulloway call together with the waveform characteristics of importance to each ranging technique are highlighted in Figure 3A, including the call initiation peak (CIP), peak-peak amplitude of the first pulse cycle and the pulse duration used in analysis. Using these waveform and call spectral-content characteristics, four techniques were applied to determine caller range [20, 37, 42]. These techniques are summarised in what follows.

Technique 1: Arrival-time difference

The difference in distance between the direct path (r_1) and that of the surface reflected path (r_2) is equal to that travelled by the signal during the arrival-time difference (ΔT) at sound speed under survey conditions (c), given as ΔTc. If the caller and the hydrophone are positioned at the same depth (see results section for estimate of caller depth) the path distance difference, combined with the hydrophone depth (d) can be related to the source range in the form of:

$$r_1 = \frac{4d^2 - (\Delta Tc)^2}{2\Delta Tc} \quad (1)$$

where $\Delta T = T_{r2} - T_{r1}$.

Technique 2: Pressure-amplitude ratio

For each call the absolute difference between the first positive and negative peaks in waveform amplitude were measured for the direct (V_1) and surface reflected (V_2) signals. Range was calculated from the ratio of these two pressure differences, combined with the known hydrophone depth and assumed caller depth in the form of:

$$r_1 = \sqrt{\frac{(2d)^2}{\left(\frac{V_1}{V_2}\right)^2 - 1}} \quad (2)$$

Technique 3: Energy ratio

The received SPLs of the direct (SPL_1) and surface-reflected (SPL_2) pulses were calculated as per the techniques standardised in McCauley [20] and Madsen [43]. In this technique, transmission loss for both paths was assumed to be close to spherical spreading 20log(r). Therefore the two calculated SPLs were related by:

$$SPL_1 + 20(\log(r_1)) = SPL_2 + 20(\log(r_2)) \quad (3)$$

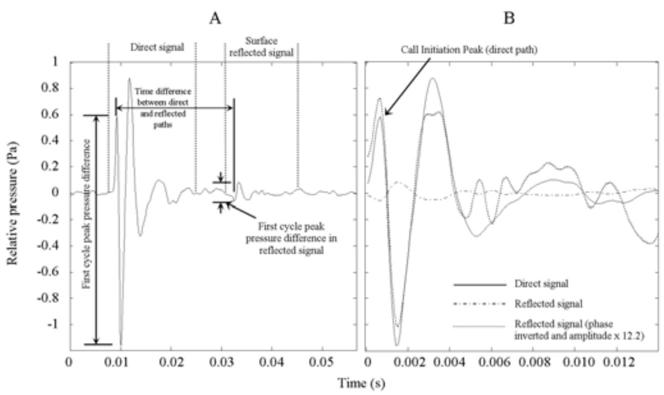

Figure 3. Waveform of an individual *A. japonicus* single pulse call with the direct signal, reflected signal, time difference and pressure amplitude points taken in analysis (A). An expansion of the direct (continuous line) and reflected (dotted line) pulse waveforms from A with the reflected waveform phase inverted and scaled to match the amplitude of the direct waveform (dot-dash line) with both waveforms synchronised to the call initiation peak (B).

Technique 4: Arrival-time difference + pressure-amplitude ratio

Range was calculated using a combination of techniques 1 and 2 by:

$$r_1 = \frac{\Delta Tc}{\frac{V_1}{V_2} - 1} \quad (4)$$

This technique removed the assumptions of caller depth. To confirm position in the water column, the azimuth of the fish from the vertical and centred at the hydrophone was given by:

$$\cos\theta = \frac{r_1^2 + 4d^2 - r_2^2}{4r_1 d} \quad (5)$$

where ghost range, r_2 was calculated by:

$$r_2 = r_1 \frac{V_1}{V_2} \quad (6)$$

Assumptions

The carrier frequency of Mosman Bay mulloway calls ranges between 175 and 350 Hz [35, 36]. The height and period of waves generated by passing vessels typically varied by ±30 cm and ~4 s [40]. As such, the acoustic Rayleigh parameter has been considered to be low (P<<1) and direct energy was assumed to be reflected in the specular direction as a coherent wave, with the reflection coefficient taken as -1 [44]. To provide maximum and minimum range estimates, the variation in water depth (d) due to wave height and possible losses in the reflected signal due to scattering (arbitrarily taken as ±10%) was applied to each applicable technique.

The SPL for each complete call was calculated as per methods outlined in Coates [45], McCauley [20]. In previous studies, for a particular call type, source levels of calls from an individual fish have been considered to remain constant [20, 46]. As such, the relative received SPL of a complete call was taken as indicative of the relative caller range. At ranges approximately equal to the water depth, spherical spreading provides a reasonable estimate of geometric losses [38, 39], thus a doubling in range would result in an equivalent decrease in received SPL of approximately 6 dB re 1μPa [47].

RESULTS

A series of short calls (1-5 swimbladder pulses) were observed during the recording period (Figure 3A). Based on the rate of call emission, the similarities of spectral peak frequencies of the calls (Figure 4B) and the similarity with calls of the same type emitted in aquaria by an individual fish [35], it was determined that these calls originated from a single fish. The fish emitted a total of 114 calls over a 32 s period. Due to interference from overlapping calls or surface reflected pulses, not all calls in the series were suitable for analysis with all four ranging techniques (Table 1).

Table 1. Breakdown of short calls in the analysed call series by the number of pulses within a call and the number of calls used in each localisation technique

Number of pulses in call	Number of calls analysed				
	Total	Technique 1	Technique 2	Technique 3	Technique 4
1	37	19	16	16	16
2	41	24	16	16	16
>2	36	n/a	n/a	n/a	n/a

Swimming behaviour

Initial calculations using arrival-time differences (ΔT) of the call initiation peak between the direct and surface waveform for the most intense call (Figure 4A, 15.4 s) showed that for the call to be emitted from within the water column (and not beneath the riverbed) the fish must have been within 1.6 metre range of the hydrophone. At this point the fish must therefore have been swimming on, or close to, the riverbed. It was assumed that the fish behaved similarly to those reported by Parsons *et al*. [37] and continued swimming along the riverbed remaining at the same depth as the hydrophone.

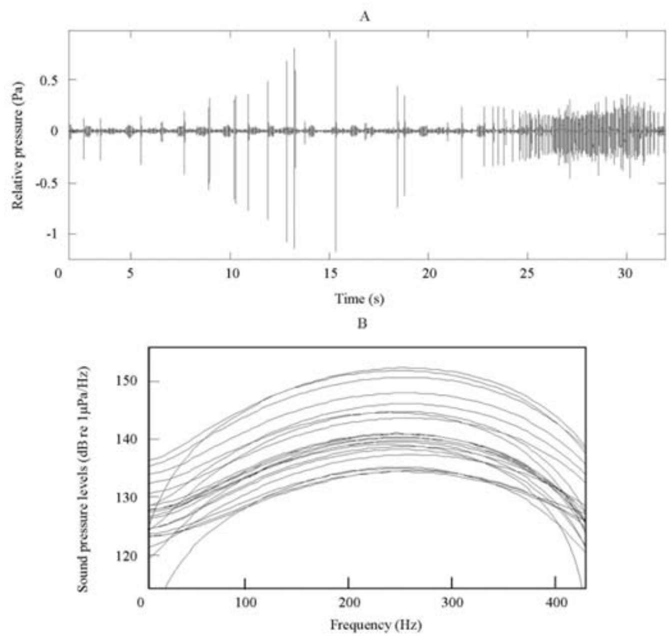

Figure 4. Waveform of a series of short calls recorded in 18.3 m of calm water at 19:35 on March 8th, 2008 (A). Example frequency spectra of the first two waveform cycles from 22 calls to highlight the likelihood of an individual caller (B).

Caller range

Figure 5 displays the caller range as determined by the four techniques, together with the maximum and minimum estimated ranges due to varying water depth from surface waves and possible pressure variation due to scattering. The received SPL of each call are also shown for comparative purposes as an indication of relative range, assuming calls were of constant source level [46]. With the exception of two calls ranged by technique 3, the four ranging techniques positioned the fish between 1 and 16.5 m from the hydrophone (Figure 5). All techniques ranged the fish as approaching and then departing from the hydrophone over time at a comparatively constant rate. Additionally, the mean water-column elevation of the caller to the receiver from the vertical was 96.9° (±7.1° s.d.), confirming that the caller was positioned on or very near the riverbed.

Transmission loss

During the call series, the trend in received call SPL declined by approximately 30 dB re 1μPa. If transmission losses were due only to spherical spreading, this difference in SPL would imply that the range of the farthest call was approximately 30 times that of the nearest. The relationships between the received call SPL and the caller range, as determined by each technique, are shown in Figure 6. This figure displays the least-squares-regression fit curves (and 95% c.l.) for call SPL and log(r) relationships for each technique in the form of:

$$RL \text{ (dB re 1}\mu\text{Pa)} = SL \text{ (dB re 1}\mu\text{Pa)} - TL \quad (7)$$

where RL is the received SPL, SL is the source level and TL is the transmission loss.

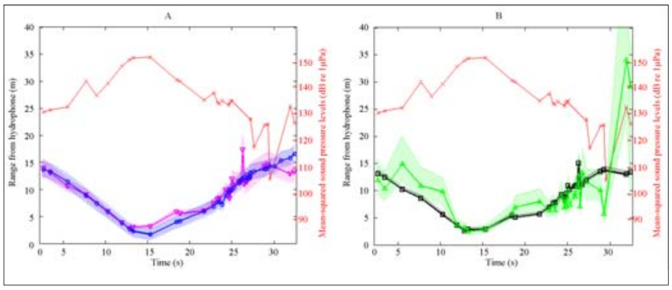

Figure 5. Range variation of recorded calls against time, as calculated by time-arrival differences (○, blue line, A), combined time-arrival/pressure amplitude ratio (△, magenta line, A), pressure amplitude ratios (□, black line, B) and mean squared SPL ratios of direct and surface reflected pulses (▽, green line, B). Maximum and minimum determined ranges caused by variation in water depth (time-arrival, pressure amplitude and SPL methods) or 10% variation in surface reflected pressure amplitude (combined time-arrival/pressure amplitude method) are shown by the shaded regions. SPLs of each call with time are also shown (x, red line).

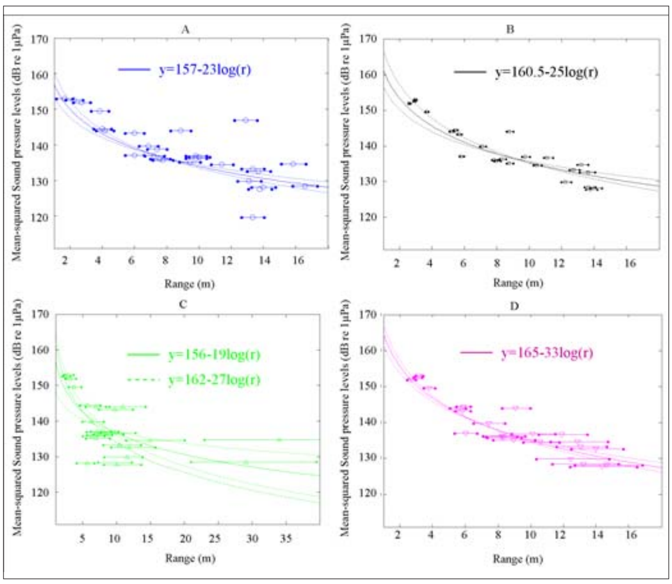

Figure 6. Relationship between mean-squared SPLs and range as calculated using time-arrival differences (A, ○), waveform amplitude ratios (B, □), mean squared SPL ratios of direct and surface reflected pulses (C, ▽) and combined time arrival/pressure amplitude ratio (D, △). Continuous lines show the least squares regression fit (with 95% c.l., dotted lines) for received SPLs with range to illustrate the transmission losses estimated by each technique. Dashed line in C represents the least squares regression fit with two calls of possible interference removed.

These plots illustrate that the relationship between call SPL and range calculated from technique 1 (Figure 6A) displayed the greatest similarity to spherical spreading (20log(r)). Although technique 3 estimated similar losses of 19log(r), once the final two call-range estimations were removed this changed dramatically to 27log(r) with an improved Pearson correlation (r^2 = 0.65, compared with 0.50). Estimated ranges using technique 2 and 4 produced transmission losses of 25log(r) and 33log(r) respectively (Figure 6B and 6D).

Technique 1 positioned the fish at minimum and maximum ranges of 1.6 and 16.5 m, compared with 1.3 and 13.6 m for technique 2, 1.2 and 32.2 m for technique 3 and 2.6 and 14.6 m for technique 4. All techniques displayed estimated transmission losses of greater than spherical spreading, however, only the arrival-time and pressure amplitude methods were within practical limits displaying transmission loss curves of less than 25log$r$ [45].

Surface reflection

The similarity between a swimbladder pulse direct path and the surface reflected signal is shown in Figure 3B by the magnified, phase inverted signal. This similarity indicates that there was no frequency shift in the spectral content of the surface reflection, which was typical of all the analysed calls. However, in calls of greater range there was, on occasion, visible interference between the surface reflection and direct paths of successive pulses.

DISCUSSION

This experiment has shown that for short, close-range (<20 m) signals, which contain a discernible initial pressure peak, all four ranging techniques provided similar estimates of caller range. Over the course of 43 analysed calls, the estimated ranges were similar to that expected by consistent, straight-line movement by an individual fish. The comparison of estimated range and received SPLs of complete calls illustrated that estimated transmission losses, determined using the caller ranges, were within practical working conditions [45].

Technique comparison

The relationship between determined range and complete call SPL illustrated that technique 1 provided range estimates which most closely resembled transmission losses to spherical spreading compared with the other techniques. However, this technique requires an *a priori* estimate of the caller depth not often available when locating fish.

Technique 2 also provided range estimates which varied consistently with time. However, although these ranges displayed high correlation with the least-squares-regression-determined losses (due to interference, likely between the waveform tail of the direct path and the peak of the reflected path), fewer calls could be used to estimate range

Technique 3 displayed greater variation in estimated range from the transmission-loss curve than other techniques, particularly at greater ranges (Figures 5B and 6C, green line). Similar to technique 2, this variation was likely due to interference, with increased effect with range as the path difference between direct and surface reflected paths was reduced.

Transmission loss

McCauley [20] reported minor levels of frequency shift in the surface reflections of Terapontidae calls, possibly due to loss of lower-frequency energy through the reflected path. If present, this scattering or energy loss would have significant effects on the range estimates from the energy techniques, producing a range estimate shorter than the actual position. The similarities between the direct and surface-reflected waveforms (Figure 3B) highlight that frequency shift was not evident in the calls analysed during this study.

Recommendations

Technique 4 eliminates the assumption of caller depth. However, with increased range the likelihood of interference between the direct and surface-reflected paths will still affect the range estimate. Therefore, when using a single hydrophone the authors propose that a number of techniques, applying different acoustic characteristics, are used to estimate the range of fish calls. The inclusion of technique 4 helps provide an estimate of the caller depth to confirm assumptions made using technique 1 alone.

SUMMARY

The calls analysed in this study were produced at close range in shallow water. McCauley [20] employed similar techniques to range the calls of Terapontidae in similar water depths, with sufficient signal-to-noise to estimate range. However, as range or water depth increases it is likely that fish-call signal-to-noise ratios of surface-reflected paths (and possibly the direct path) decrease and are less likely to be sufficient to estimate range. Additionally, the reduced arrival-time difference of calls at greater range results in overlap between the waveform of the direct and surface reflected path of the pulse, causing interference between the two waveforms [35-37]. These limitations mean that the application of ranging fish using call surface-reflection techniques is not only dependent on the call structure and intensity, but also the relative dimensions of caller, receiver and water surface positions.

ACKNOWLEDGEMENTS

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Acoustics 2011

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Authors are encouraged to prepare papers from all areas of acoustics and to submit abstracts by the end of March 2011. The Trade Exhibition will provide an opportunity for the latest technology to be displayed and sponsorship opportunities are available. Details can be found on the conference web site at http://www.mech.uq.edu.au/acoustics2011/.

A series of workshops that will focus on aspects of transportation noise and a short course on fundamental acoustics are also planned.

Congress Plenary speakers will include Dr David Hiller (ARUP) and Professor David Thompson (ISVR, University of Southampton). ACOUSTICS 2011 is shaping up to be a very exciting conference.

For further enquiries, contact the conference chair, Matthew Terlich, at mterlich@savery.com.au

AN AUTOMATED WEB TECHNIQUE FOR A LARGE-SCALE STUDY OF PERCEIVED VOWELS IN REGIONAL VARIETIES OF ENGLISH

Ahmed Ghonim, John Smith and Joe Wolfe

School of Physics, The University of New South Wales, Sydney NSW 2052

J.Wolfe@unsw.edu.au

Because vowels in English are largely distinguished by the frequencies of their first two formants ($F1$, $F2$), the division of the ($F2$, $F1$) plane is an important and quantifiable component of accents. We report results of a web-based study into some of the many accents of English. Participants identified the vowel in h[vowel]d words produced by synthesis from a large set of possible values of $F1$, $F2$ and $F3$, using two different fundamental frequencies and two different durations. Compared to analysing spoken utterances, this approach has a number of obvious disadvantages, which we discuss. It has the significant advantages, however, of low cost, large scale and wide-ranging international participation. It is then possible to use the same experimental protocol to characterise the (perceptual) vowel plane of a substantial number of subjects and accents, thus allowing simple comparisons. From the large data base thus acquired, we present four examples of vowel maps for different Anglophone countries and regions therein. Knowledge of local variations in the perceptual ($F2$, $F1$) map, and the way in which these depend on fundamental frequency f_0, is not only of phonetic interest, but may be useful to those who use synthetic speech in automated communication systems.

INTRODUCTION

In Western languages, the vowels are chiefly distinguished by the frequencies of the low frequency formants, mainly the first two ($F1$, $F2$). The formants or peaks in the spectral envelope arise from acoustical resonances of the vocal tract, which increase the power of the radiated speech at frequencies near those of the resonances. The articulatory and acoustic origins of formants and their properties and roles in phonetics are important and well studied. Fine reviews are given by Fant [1] and Clark *et al*. [2].

The division of the ($F2$, $F1$) plane into vowels is one identifying feature of different accents and one that is readily and objectively quantified. There are many different regional and cultural accents of English, especially if one includes those of regions in which it is spoken as a foreign language. In principle, the different divisions could be determined by recording samples of speakers of each accent under similar conditions and analysing the recordings. This would, however, be difficult and expensive for a single research group. Collating the work of many groups is also a large task, and it could encounter variations in experimental technique.

Here we report an automated routine on a web site that uses synthetic speech to sample the vowel plane and to determine the perceptual vowel plane of volunteer subjects, rather than the produced vowel plane. It has gathered (and continues to gather) a large database of divisions of the vowel plane from regional varieties of English.

The perceptual division of the ($F2$, $F1$) plane is in principle different from the divisions in the space of produced vowels, but this does not make it less interesting. Indeed, in the field of synthesised speech, one is especially interested in how vowels produced with particular values of ($F2$, $F1$) will be perceived among the target listening group. Manell [3] has used perception of synthesised words to study vowel drift over time. Hay *et al*. [4] have used forced-choice perceptual studies of vowels to investigate the effects of age and social class.

The advantages of the method reported here are that it is automated and is available to volunteers around the world at times of their convenience. This has allowed us to accumulate a large and growing data set from about a thousand volunteer subjects. Because the data set is large, this paper includes just a few vowel planes as examples of regional variation, but leaves detailed analysis for other studies.

MATERIALS AND METHODS

Vowels and carrier words

The vowels are presented in the h[vowel]d context because, in English, all utterances thus produced are real words, with the exception of hud, whose pronunciation is reasonably obvious because of anticipated rhymes with the words bud, cud, dud, mud and sud.

The sounds produced in this study are all pure vowels rather than diphthongs. Subjects were, however, permitted to identify these pure vowel words as words that are usually spoken as either pure vowels or diphthongs and to identify sounds as one of the words h[written vowel]rd. This decision was made after some preliminary trials suggested that some respondents might decide that a long version of an utterance on the plane near 'head' sounded like 'haired', or identify a pure vowel with a word spoken in some regions using a diphthong. We could think of no reason to disallow such a choice: we were, after all, interested in their perception. We can justify this decision in retrospect: the h[written vowel]rd and h[diphthong]d words were indeed chosen by some respondents, though less often than the h[written vowel]d words. Conversely, it is possible that speakers of some variants of English might not identify the word 'hard' in this survey because they expect the word to contain a rolled 'r'.

Formant parameters

The ($F2$, $F1$) plane is sampled at a spacing of 50 Hz in both directions. This value was chosen as a compromise between resolution on the plane and the required number of samples. The choice of the boundaries for ($F2$, $F1$) was difficult. It varies among accents [2] and perhaps also according to measurement technique. We used values that include the limits shown in plots of ($F2$,$F1$) for spoken vowels, e.g. [2]. We set:

$$300 \text{ Hz} \leq F1 \leq 800 \text{ Hz},$$
$$800 \text{ Hz} \leq F2 \leq 2200 \text{ Hz}, \text{ and}$$
$$F1 \leq F2 - 200 \text{ Hz} \quad \text{and} \quad F2 \leq 3100 \text{ Hz} - 2F1$$

These boundaries are shown in Fig. 1. $F3$ was determined using the empirical relationship $F3 = 2100 \text{ Hz} + 0.42*F2$ that had been determined by fitting a linear regression to values of $F2$ and $F3$ collected from a range of sources. The bandwidth of all formants is set as a function of $F1$, $F2$ and $F3$ using the equations of Hawks and Miller [5].

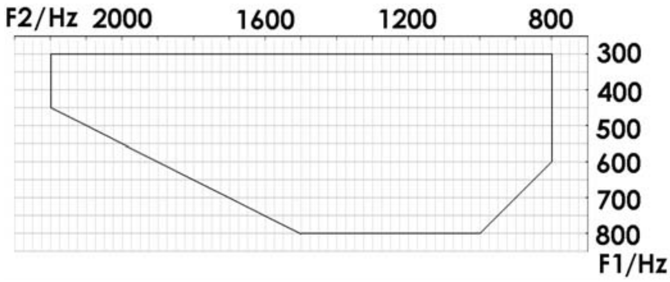

Figure 1. The chosen boundaries of the ($F2$, $F1$) plane investigated resemble those for speech. The plane is sampled at intervals of 50 Hz. The reversed axes are traditional in phonetics.

Jitter and shimmer were applied using the values of Minematsu *et al*. [6]. For each sampling of the vowel plane, tokens were synthesised with two values of initial f_0: 126 Hz and 260 Hz (hereafter 'low' and 'high') and two values of vowel duration: 120 and 260 ms (hereafter 'short' and 'long'). $f_0(t)$ was decreased slightly (by 20 Hz) during each token. The limitation to two values of f_0 and duration was to limit the size of the data base in these two dimensions. Higher resolution of the effects of these parameters may be easily measured in studies that do not aim for such large data sets. Pragmatically, therefore, we chose values of f_0 that were very likely to be identified as man and woman, and durations likely to be identified as short or long vowels in isolated utterances.

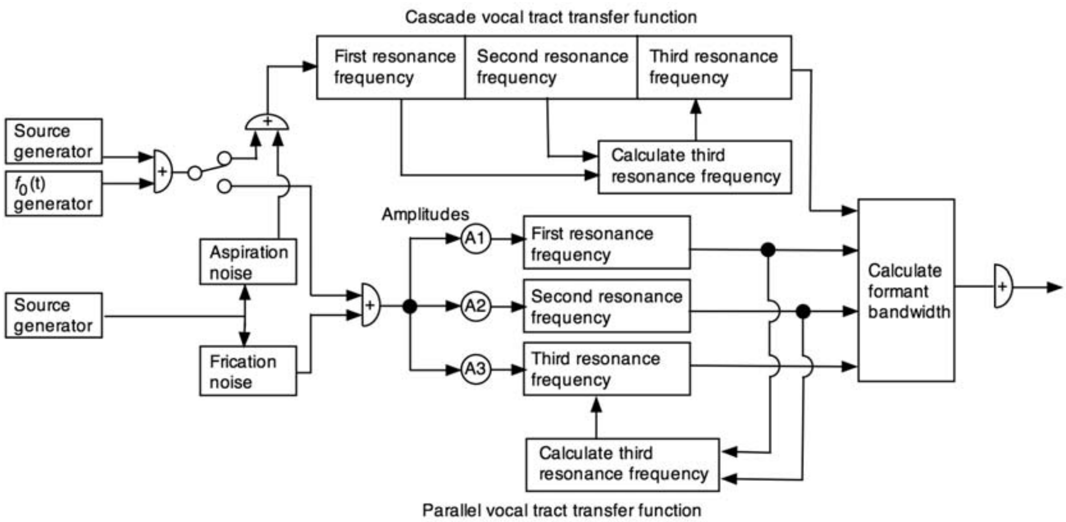

Figure 2. A schematic of the software used to generate the tokens.

Speech synthesis

The synthesis follows the principles of Klatt [7] and Boersma and Weenink [8]. The software is represented schematically in Fig. 2 and details are given elsewhere [9]. A total of 22,488 monaural files in the .wav format were generated and stored with 16 bit precision and sampled at 11 kHz.

The user interface and data acquisition

The web interface is written in PHP and Java and is described in detail elsewhere [9]. Initially, a page asks the user to specify the type of loudspeakers used: headphones, internal speakers or external speakers (subjects are encouraged, but not obliged, to use headphones to improve the frequency response). The software then acquires demographic data on the subject: country and region of origin, country and region of current residence, first and second languages, age and gender. Subsets of data may be subsequently plotted using these demographic data. Any differences attributable to the type of loudspeakers used for the test (headphones, internal or external speakers) may also be examined. Differences between vowels generated with high and low pitch may also be distinguished.

Once those data are recorded, the software displays the data acquisition page, an example of which is shown in Fig. 3. A sound plays three times and the user chooses one of 17 possible words or ‘Vowel unrecognisable’. Additional repeats are available by clicking a ‘play’ arrow. Following this choice, another sound is played three times and the user can either make another choice or go to the ‘Results’ section.

The parameter space is sampled in a pseudo-random routine that repeats once all points in the space ($F2$, $F1$, duration, f_0) have been sampled. Subjects may continue for as long as they wish. At any stage, they may stop and view the results for their own data and return to continue either immediately or later.

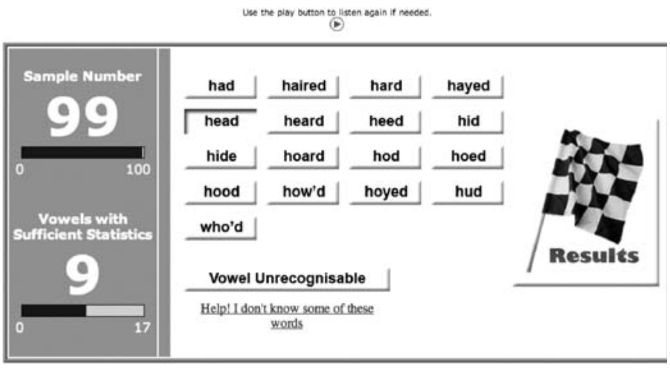

Figure 3. Part of the data acquisition page. The user hears a sound, clicks on a choice and either requests a repeat, proceeds to the next sound or proceeds to the ‘results’ page.

Initially, subjects were recruited by announcing the URL (www.phys.unsw.edu.au/swe) on our own speech and music web sites (www.phys.unsw.edu.au/speech) and by inviting colleagues and friends to participate. An announcement in *Echoes*, a newsletter published by the Acoustical Society of America, also recruited subjects.

RESULTS AND DISCUSSION

At the time of writing, 302 American residents, 112 Australian residents and 71 residents of the UK had been surveyed, along with subjects living in 63 other countries.

On all the displays, $F1$ is plotted in the negative y direction and $F2$ in the negative x direction. This presentation is traditional in phonetics, because it roughly corresponds to the vowel maps in which jaw height is plotted in the y direction and tongue fronting is plotted in the negative x direction [10]. For the benefit of those unfamiliar with phonetics, this rough correspondence is indicated on the display of results in our study and thus also on Figs. 4 and 5.

The coordinates plotted for any word are the mean values of ($F2$, $F1$) for all sounds identified as that word. ‘Short’ printed with a vowel means that more than 75% of our subjects’ selections of that word were from sounds of the short duration class and similarly for ‘long’.

Figure 4 displays the data collected from 346 subjects born in the USA and Australia, selected by origin, but with no constraint on sex or age. (The default display includes ellipses whose semi-axes are the standard deviations in the directions of greatest and least correlation, but these have been omitted here for clarity.)

There are, of course, considerable similarities between the maps for these two countries: Americans and Australians can usually understand each other. Figure 4 confirms that there are, however, differences in detail: for instance, when an American says ‘Bob’ (short for Robert), an Australian may hear ‘Barb’ (short for Barbara).

Figure 5 displays the data for subjects born in two different Australian states; 29 from New South Wales (NSW) and 17 from Queensland. Here, again, there are differences.

Are the differences great enough to lead to confusion? Dowd *et al*. [11] measured a characteristic separation on the vowel plane beyond which vowel sounds cease to be confused. This corresponds to about 170 Hz in the $F1$ direction and 450 Hz in the $F2$ direction, and Pythagorean combinations in any other direction. Some pairs of vowels that fall within this distance for NSW fall beyond it for Queensland (e.g. ‘heard’ and ‘had’) and *vice versa* (‘heed’ and ‘hayed’).

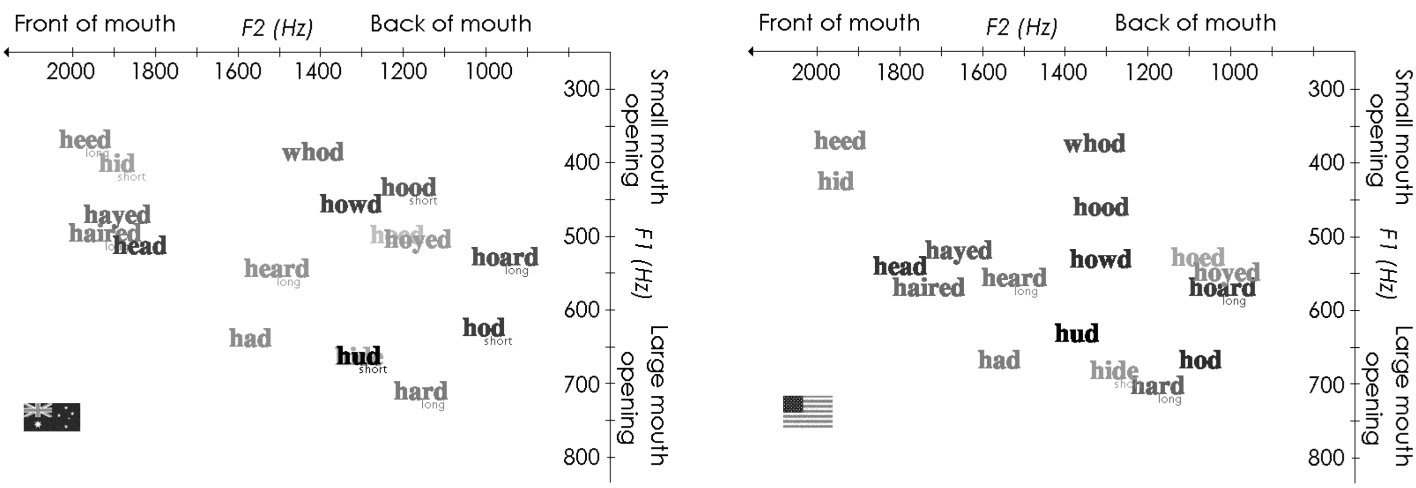

Figure 4. The data for 78 subjects born in Australia and 268 born in the USA. The words are printed so that their centres lie over the mean ($F2$,$F1$). Because this allows printed words to obscure one another, we note that, ‘hud (short)’ coincides with ‘hide’ (on average) for these Australian subjects. The words appear in different colours on the web.

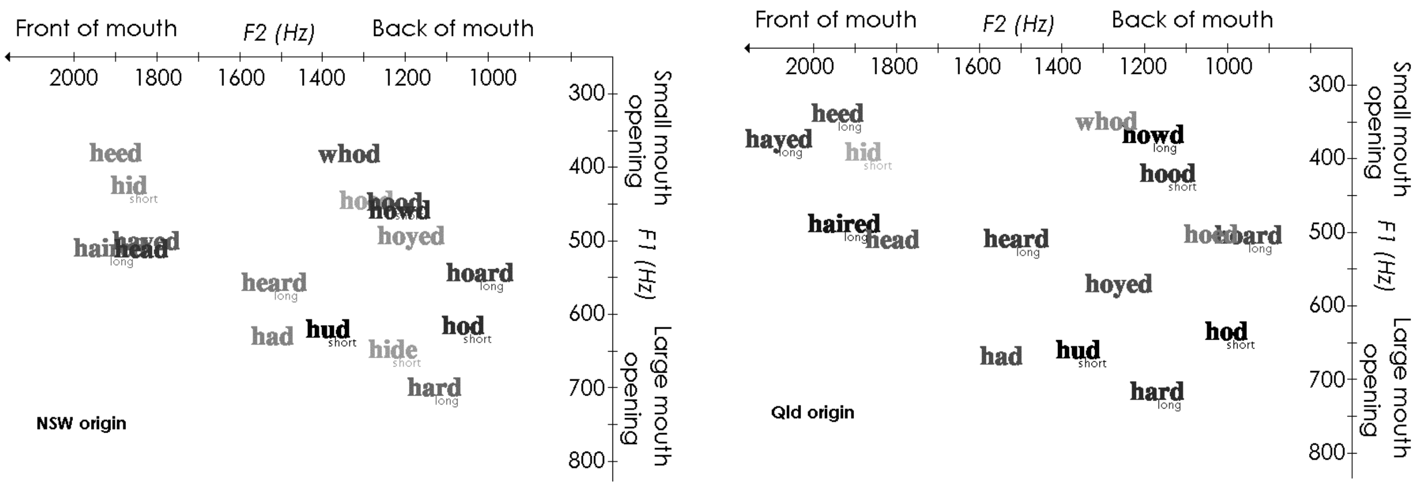

Figure 5. The data for 29 subjects born in New South Wales and 17 from Queensland. We note that 'haired (long)', 'head' and 'hayed' overlap for NSW, as do 'hood', 'howd' and 'hoed', while 'hoard (long)' and 'hoed' coincide for Queensland. (The sample is not yet large enough to give good statistics on 'hide' for the latter.).

It is possible, of course, to produce very many such plots and comparisons for different regions or for different sets of the experimental parameters. Subjects who have finished recording a set of responses are invited to look at their own vowel map, as well as those of various demographic groups, which may be sorted by country and province of birth, region of current residence and/or region in which the subject has previously resided, and/or by first, second or third language, by gender and age and by combinations of these.

CONCLUSIONS

The technique has been demonstrated over three years and the supporting technology proved reliable. It appears that it has not been noticeably vandalised by spurious entries. The data set is large and growing and samples four dimensions. This paper has given only simple examples, illustrating the expected regional variations. Quantitative analysis, however, is left for further studies, possibly involving experts in different areas. In the future, it may also be interesting to compare results gathered in different decades, as Mannell [3] is doing in another study. We do not propose allowing completely free searches of the database, because this might violate the privacy of the subjects. We do, however, propose to make the data available to interested investigators after discussion of any possible ethical issues involved.

ACKNOWLEDGMENTS

We thank the many volunteer subjects who have contributed to the project and the Australian Research Council for support.

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Technical Note

Note: Technical notes are aimed at promoting discussion. The views expressed are not necessarily those of the editors or the Australian Acoustical Society. Contributions are not formally peer-reviewed.

MUSIC TO MY EARS CAMPAIGN: PREVENTING A DEAF GENERATION

Nick Parkyn
Audiologist: Attune

The Music to My Ears Campaign was established in 2010 to raise awareness of the potential risk of permanent hearing damage as a result of over-exposure to loud music. It's no secret to most people that working around power tools and heavy industry can damage your hearing, which is why we have a Noise Code of Practice to set guidelines for prevention of noise-induced hearing loss in the workplace [1]. But young people working in heavy industry today are wearing their earplugs and ear muffs all day at work, only to take them off on a Friday to bombard their ears with high intensity sound at nightclubs and pubs, often exceeding their weekly safe noise dose in one night. There is a plethora of research showing entertainment venues exhibiting sustained and damaging noise levels, including venue decibel tests released in the Sydney Morning Herald (September 16) indicating that most venues tested are playing music over 100dB, causing permanent hearing damage after 15 minutes [2]. Whether or not sound is perceived to be pleasurable or not has no bearing on its damaging effects, although it is human nature to assume so, as studies such as Australian Hearing's Binge Listening Report have shown.

Let's look at the facts. According to Australian Hearing's 2010 Binge Listening report, currently 1 in 6 Australians have hearing loss and this is predicted to rise to as much as 1 in 4 by 2050 [3]. Clubs often average over 100 decibels which can cause permanent damage after 15 minutes. According to the Australian Hearing Health Senate Inquiry 2010, the costs of hearing loss to Australia were estimated at $11.75 billion in 2005, which represented 1.4 per cent of Australia's then GDP [4].

Part of the problem is that noise-induced hearing loss is cumulative, meaning that young people often suffer no immediate adverse affects to social noise exposure at damaging levels. While high noise exposure does cause a shift in hearing thresholds that usually improves within 16 hours (but can take days), it is understood that this temporary threshold shift never recovers absolutely. With repeated exposure to high levels of noise, from music, heavy industry or otherwise, these small increments of hearing loss cumulate insidiously over time. As an audiologist at Attune's Ipswich clinic near Brisbane, the author commonly experiences reports from clients along the lines of "my hearing is fine, I can hear a car down the street before my children can, I just don't tend to be very social anymore because everybody just mumbles these days". After a thorough audiometric examination, these kinds of clients are often found to have a steeply-sloping high frequency hearing loss, often with normal hearing in the low frequencies, which explains why they can hear the hum of a car engine clearly but not high-frequency consonants of human speech. This type of audiometric configuration is typical of a noise-induced hearing loss, and adds to the insidious nature of the problem, meaning that it often goes undiagnosed for far too long. The impact of permanent hearing loss to quality of life is all too obvious to audiologists, the hearing impaired, and their families. Hearing aids can provide some benefit but are by no means a cure.

At Attune, the author commonly sees young patients in their teens and twenties reporting tinnitus, a condition commonly associated with noise-induced hearing loss. Tinnitus may be experienced temporarily by young clubbers, but this often goes away, giving the impression that the damage is temporary. Not so for Daniel Lalor, campaign director of the Music to My Ears Campaign. After a night out, the ringing in his ears, which he had experienced before and expected to stop, never did. While suffering the anxiety and distraction associated with tinnitus, Daniel researched about legislation regarding noise levels in venues, and was shocked to find that while patrons are protected under the same guidelines that protect bar staff, there is almost always no safeguards in place to warn patrons of the risks of hearing damage at venues, let alone to prevent it. It seems that the naïveté regarding the damaging affects of social noise exposure is not just a bugbear of the young party-going population. Through the Music to My Ears Campaign, Daniel hopes to affect positive social change by raising awareness of the nature of recreational noise-induced hearing loss and prevention, allowing availability of free and discreet earplugs at venues, and holding Healthy Hearing Events to provide a safe model for venues to adopt and promote the cause.

The longitudinal studies do not yet exist to alert us to the extent of noise-induced hearing loss from today's pubs and clubs, and with the cumulative nature of noise-induced hearing loss, immediate effects are rarely seen. Do we have to wait until the permanent damage is already done, as has happened so often in the past with health disasters such as cigarette smoking and asbestos? While the campaign has received some support and exposure amongst the audiological community from Attune, Australian Hearing, and the Audiological Society of Australia, more collaboration is needed from professionals, media, and venue and event organisers. Visit www.musictomyearscampaign.org for more information about recreational noise exposure and the campaign, and sign up to the mailing list for up to date information as it happens.

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Technical Note

CREATING RESTAURANT VIBRANCY WITHOUT NOISE

Dr Michael Haywood, Quiet Acoustics

With the majority of existing cafes, restaurants and social venues having had little acoustic input or consideration during construction, we are often faced with having to fix the reverberating noise issues retrospectively.

Noise is now the biggest complaint of restaurant goers worldwide, ahead of service and food, so this is something that needs to be addressed if our social culture is to flourish. Yet when you speak to many restaurant owners, their understanding is that vibrancy attracts crowds, and you need noise to be vibrant!

Perhaps out of fear of acoustical consulting fees, or a perception that it is an easy fix, many proprietors attempt to research the topic themselves, often implementing solutions that destroy the vibrancy, whilst not actually removing the vocal noise, reaffirming their initial beliefs that vibrancy = noise. Here is one theory on how we can fix this.

Figure 1 is a typical noise frequency response for a busy cafe, almost every cafe or restaurant is the same. This recording was taken using a $1 Iphone application. The phones microphone pickup tends to roll of the frequency response under 60Hz, but above this it is surprisingly well calibrated to more expensive equipment that we use, so perfectly useful for this problem.

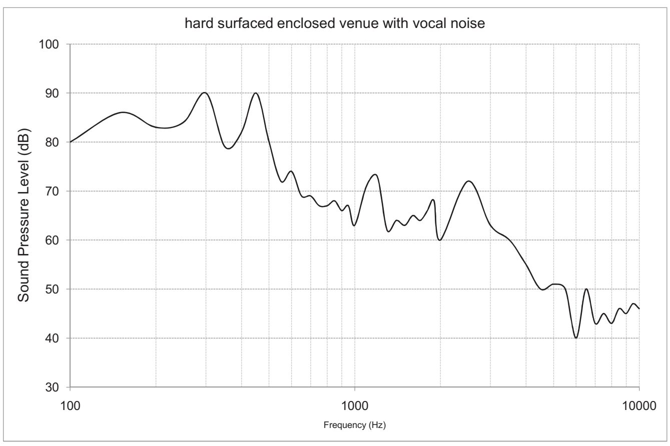


Figure 1. Noise frequency response for restaurant with no acoustic treatments.

What it tells us is that the majority of reverberated noise is coming from the fundamental harmonics of male and female speech (consonants and vowels) 80-500Hz. There are some higher harmonics showing up, but it is the lower frequencies that are reverberating, and dominating the sound pressure level in the room. Reverberation in this lower frequency range inhibits communication, forces patrons to speak louder to be heard, and has been shown to lead to unease, restlessness, anxiety, and stress. None of which is good for café ambience!

What it also tells us is the frequencies above 1000Hz are not reaching noisy levels, yet this is the "vibrancy" that proprietors speak of. The upper harmonics of speech, the syllables, the music, glasses clinking, laughter, the barista, the cutlery, the general background ambience. Reverberation in this mid to high frequency band may actually be good for ambience, and has been shown by audiology groups around the world to be necessary for comprehension in classroom environments.

So is this how we separate vibrancy from noise? and can we treat one without the other?

Current theory is that hard clean lines and a lack of soft furnishings in restaurant design are bad for acoustics, but I'm going to go out on a limb here and say the opposite. Hard clean lines are excellent for social venues, as they amplify the mid to high frequency bands that contribute to ambience and aid comprehension without raising your voice.

Absorbing materials will remove this ambiance, whilst failing to effectively remove the 80-500 Hz vocal noise. If you have ever been in a heavily carpeted fine dining restaurant and felt you had to whisper for privacy, you will understand what I am trying to say. Absorbing materials kill ambience.

The reading in Figure 2 is from a busy social venue with an abundance of soft furnishings and acoustic absorbing tiles. You can see the mid to high frequencies have been removed, which will make the room seem quieter, but the vocal noise remains. This is the opposite of what you want to achieve, and the reason many proprietors are scared of losing their vibrancy with acoustic solutions.

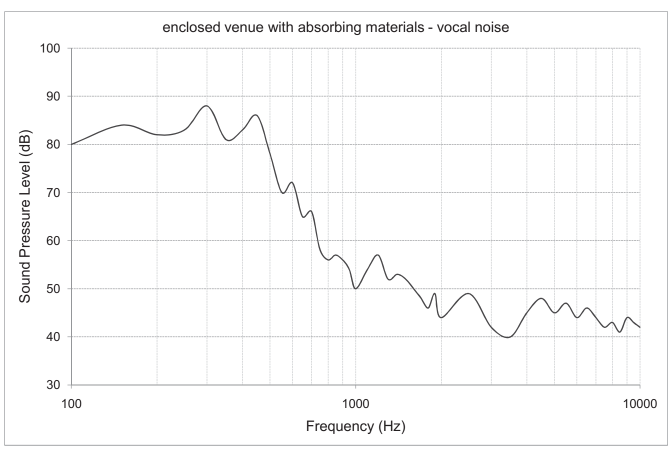


Figure 2. Noise frequency response for restaurant with absorbing and diffusing treatments.

So how do we remove low frequency reverberation without removing mid to high frequency vibrancy? Helmholtz would have a tear in his eye today if his resonators became mainstream in social settings, and as an engineer of these systems I would too. It is 100 year old technology, it can be built by anybody, and we can tune them to the exact frequency bands we want to remove, whilst not absorbing the vibrancy that proprietors keep telling us is so important for trade.

Two examples both commercially available today achieve noise reduction coefficients of 1 within their specific frequency bands. The effect of resonator panels within a hard surfaced, clean enclosed space is to lower the low frequency reverberation, whilst maintaining the mid to high frequency. When you have all frequencies humming in the ear at 70-75 decibels, this is vibrant ambience without noise.

Figure 3 is a recording for a busy venue with wooden resonator panels, tuned to the 100-315 Hz frequency band. You can see the vocal noise has been removed, with minimal effect to the mid to high frequencies.

The education that needs to be delivered to proprietors is that you can indeed have vibrancy without noise, and that there are simple techniques available, even on your phone, that can be used to quickly self diagnose your problem, determine how bad it is, and indicate what steps you need to take to develop perfect vibrant ambience.

To this effect, Quiet Acoustics have started an Australia wide restaurant noise awareness campaign, whereby proprietors can have their venue recorded for free, or take their own recordings, and have the data analyzed, rated, and classified according to current database averages.

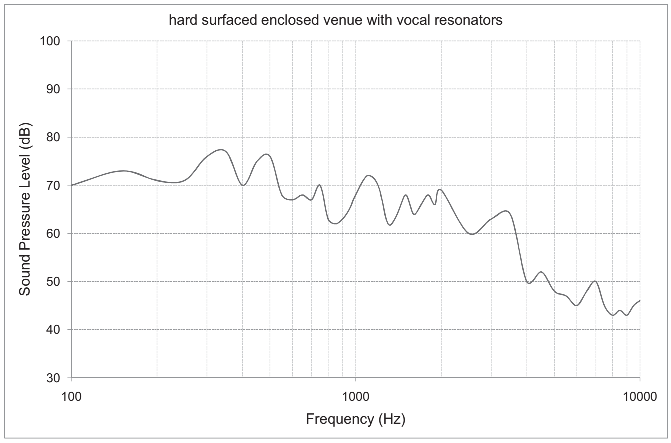


Figure 3. Noise frequency response for restaurant with low frequency vocal resonators.

By providing the restaurant and cafe industry with a simple tool to quantify noise levels, we are in a much better position to build such a database, and in turn make the industry more aware and appreciative of damaging noise levels.

If you would like to get involved with the program, have any ideas for improvement, or wish to understand vocal resonators more, please feel free to get in touch with Dr Michael Haywood from Quiet Acoustics at mike@quietacoustics.com.au.

News Item

Effective Noise Control and Hearing Loss Prevention

Perri Timmins, Safe Work Australia, Canberra

BACKGROUND AND AIM

A Safe Work Australia research project entitled Getting heard: effective prevention of hazardous occupational noise investigated the factors that influence the effective control of occupational noise and prevention of occupational noise-induced hearing loss (ONIHL). The overall aim of the project was to provide stakeholders with a greater understanding of why a preventable condition such as ONIHL occurs among Australian workers despite the regulation of exposure to occupational noise. The project was funded by the Australian Government through the Hearing Loss Prevention Program. The findings are reported in a Safe Work Australia publication, Occupational noise-induced hearing loss in Australia: overcoming barriers to effective noise control and hearing loss prevention, available online at: http://www.safeworkaustralia.gov.au/AboutSafeWorkAustralia/WhatWeDo/Publications/Documents/539/Occupational_Noiseinduced_Hearing_Loss_Australia_2010.pdf.

The project began with literature reviews of common personal, organisational, and economic noise control and ONIHL prevention barriers. This was followed by focus group discussions with workers, managers and employers; nation-wide self-report surveys of over 1100 workers and 1000 managers and employers; and in-depth face-to-face semi-structured interviews with 50 employers, managers, work health and safety representatives and union representatives. The empirical studies focussed on five at-risk industry groups: construction; manufacturing; transport and storage; agriculture, forestry and fishing; and hospitality and entertainment. The surveys also included noise-exposed people from other industries.

MAIN FINDINGS

Overall, the findings suggest that the strongest barriers to effective noise control and ONHL prevention are:

- over-reliance on personal hearing protectors (PHPs)
- infrequent and improper use of PHPs
- lack of prominence of noise as a serious work health and safety issue, and
- lack of consideration of potential benefits of effective noise control.

Other important barriers include:

- business size (small or medium-sized businesses are less likely than large businesses to have effective noise control and ONIHL prevention)
- insufficient knowledge of the effects of loud noise on hearing
- insufficient knowledge of the effects of hearing loss on quality of life
- belief that noise control costs too much
- belief that hearing loss is inevitable (‘fatalism’)
- belief that hearing loss ‘will not happen to me’ (‘optimism’)
- low confidence about being able to do anything about noise (‘self-efficacy’), and
- work cultures that are resistant to change.

In addition to the removal or correction of the above barriers, potential enablers of the adoption of effective control prevention measures include greater economic and regulatory incentives and managerial commitment to work health and safety.

KEY MESSAGES

Although this project did not examine the extent of the occupational noise problem, loud noise and ONIHL were simply not major issues for many participants, especially compared to other more visible and immediate workplace hazards. Even when there was an appreciation of the hazard and an effort to reduce the risk, there were those who were not clear or confident about the solution. These individuals often simply rely on PHPs rather than higher-order risk controls, and workers often remove their PHPs when the devices get uncomfortable or interfere with communication.

A clear message from the research is that both regulatory enforcement and education are vital for achieving more effective noise control and ONIHL prevention. Employers, managers and workers need clear, concise, and readily available information about the real risks and available solutions. Participants’ comments and the literature suggest that the use of opinion leaders and role models (‘safety champions’) might complement existing and future efforts that rely on workplace education, mass media and online resources. Above all, innovative action is needed to correct the apparently common beliefs that noise control is too expensive, too difficult, or simply not worth worrying about.

In 2011, Safe Work Australia will publish a brochure for managers and workers and a condensed version of Occupational noise-induced hearing loss in Australia: overcoming barriers to effective noise control and hearing loss prevention. The brochure will be based on current knowledge and practice and the findings of the Getting Heard project.

Book Reviews

Collected Papers in Building Acoustics: Room Acoustics and Environmental Noise

Edited by: Barry Gibbs, John Goodchild, Carl Hopkins and David Oldham

Publisher: Multi-Science, 2010, 419 pages

ISBN: 978-907132-14-8

This book is the second volume of the book series entitled "Collected Papers in Building Acoustics" containing papers previously published in the journal of building acoustics. The first volume includes a collection of papers on the measurement, prediction and control of sound transmission. The focus of this book is on room acoustics and environmental noise.

Many authors of the collected papers in this book are well known in the field of room acoustics and modelling environmental noise. Their papers were selected because of "their rigor, citation history and contribution to the science and practices of building acoustics".

The book is divided into five parts. The first part is about "Auditorium Acoustics", and opened by Beranek's historical review of the six principle acoustical attributes of a concert hall. His acoustical stories of Philharmonic Hall in Lincoln Centre, New York City, its stimulation to serious psycho-acoustic research and the design attempts from traditional shoebox shaped to vineyard shaped halls, etc. recorded the foot-prints of generations of brilliant acoustics in the field of auditorium acoustics. Following Beranek's paper, Orlowski reviewed detailed acoustical design of concert halls and presented data from objective tests. The paper by Takatsu et al. tackled the acoustical design of a round-shaped multi-purpose event hall based on Ando's subjective-preference theory. Fricke's team contributed two papers to this part. Jeong and Fricke addressed the percentage of correct response of a couple of listeners to discriminate the duration of standard stimuli as a function of reverberation time of the listening environment, and the just noticeable difference in duration as a function of signal to ratio. Fricke in the second paper used a neural network analysis to relate the acoustical quality of concert halls to the six acoustical attributes. This part of the book is completed by Meyer's refreshing discussion about the conductor's spatial impression contrasted to that in the audience area.

The second part contains three papers in "Acoustics in Religious Buildings". Carvalho et al. presented the correlation between subjective and objective acoustic field measurements made in a survey of 36 Catholic churches in Portugal built in the last 14 centuries, while Magrini and Ricciardi examined measurement results and most significant acoustical parameters obtained in 10 historically significant churches in the city of Genova. The last paper by Mijic et al. concluded that the resonators found in medieval Serbian churches had not contributed to their acoustic quality.

The four papers included in the third part of the book are important references in the area of "Acoustics in Schools". The review paper by Shield and Dockrell summarized, based on 124 reference papers, the important factors affecting speech intelligibility (SI) in the classroom. Current acoustical standards for classrooms are also outlined. This part collected two papers from Hodgson's group. The first paper described Hodgson's empirical models, which are reasonably accurate and involve low run time, for predicting total A-weighted speech levels and 1kHz early decay times (which are directly relevant to SI) in classrooms. Yang and Hodgson in the second paper reported their investigation of the optimal reverberation for SI for normal and hearing-impaired adult listeners in non-diffuse sound fields. The editors used Whitelock and Dodd's paper to complete this part, which recommended classroom design based on the children's requirements (which significantly differ than for adults) for SI.

The leading paper in the fourth part (named "Absorption, Diffusion and Reverberation Time") is by Kang, who described an experimental scale-model investigation into the effect of a ribbed diffuser and a Schroeder diffuser on the sound attenuation in long enclosures such as underground station. Waddington and Oriowski's experimental paper, on the other hand, focused the two-microphone technique for the in-situ measurement of acoustical impedance of absorbing surfaces. This part of the book collected another paper from Fricke's group. They used optimal neural networks to predict reverberation time. 15 input variables were required and the prediction accuracy was claimed within the range of subjective difference limen. Ermann's paper looked at the effect of aperture size on the double-sloped decay on the competing qualities of reverberance and clarity in coupled-volume concert halls. The paper by Asdrubali and Horoshenkov presented a Pade approximation model for acoustic properties of loose mixes of expanded clay granulates using the information of porosity, flow resistivity, tortuosity and standard deviation of the pore size.

The final part of the book is entitled "Environmental Noise". The papers by Hothersall and by Menounou and Busch-Vishniac dealt with the noise attenuation by noise barriers from different view angles. The former focused on the assessment of insertion loss spectra and mean insertion loss of barriers with a range of profiles using mathematical modelling. While the latter presented the design and analysis of traffic noise barriers with jagged top edge and claimed that in many cases the new barriers have improved insertion loss by up to 6 dB. In their paper, Ismail and Oldham emphasized the importance of computer simulation of urban noise propagation and discussed a range of modelling techniques in relation to the urban environmental properties. The editors collected two interesting papers from Lam's team. In his first paper, Lam showed that significant error occurred when the methods described in the CONCAWE report 4181 and ISO 9612 Part 2 were applied to calculate outdoor noise propagation in situations where ground cover changed from the assumed types and when the meteorological condition was significant. His second paper with Windle was on the sound reduction index (SRI) of single and double skin profiled metal cladding systems. One of the highlights of the paper is the prediction and explanation the pronounced "dips" in the SRI at mid frequencies caused by the resonance frequencies of the profile geometry.

The most impressive parts of this book are the rich historical information of the research development, vast amount of practical data, and the novel and efficient methods. It is certainly a valuable reference for research, consulting and teaching in the area of room acoustics and environmental noise prediction.

Jie Pan is a Winthrop Professor in the School of Mechanical and Chemical Engineering at the University of Western Australia

Sound Insulation

Author: Carl Hopkins

Publisher: Elsevier 2007, 622 pages

Soft cover ISBN 978-0-7506-6526-1

Although the title of this book is sound insulation, it does cover a wide range of acoustics and vibration. The first and second chapters on sound fields and vibration fields respectively are both 109 pages long. Chapter 3 on measurement is 188 pages long. Direct sound transmission is covered in the 125 page long fourth chapter. The book ends with 75 pages on combing direct and flanking transmission in the fifth chapter.

Because I have worked on the prediction of sound insulation, I immediately turned to the chapter on direct sound transmission. The book tries to provide a consistent approach to the prediction of sound insulation by using statistical energy analysis (SEA) to predict sound insulation whenever possible. Because non-resonant transmission cannot be directly covered by SEA, the standard approach of introducing separate non-resonant paths into the SEA model is followed. The infinite plate non-resonant theory is presented followed by Leppington et al.'s 1987 finite plate formula. Above the critical frequency of the panel, Cremer's 1942 infinite plate theory is presented because it is pointed out that the results are the same as for a finite plate. The important fact that point connected homogeneous plates often have the same critical frequency as the individual plates is mentioned. Orthotropic plates, including profiled plates are covered. Cavity wall systems are also analysed using SEA. Both Crocker and Price's 1970 and Craik's 2003 approach to modelling the cavity are given. I was disappointed that Sharp's model for cavity walls was not mentioned because it provides a good qualitative understanding of the sound insulation of a cavity wall. The presentation on point and line connections between plates is fairly brief. Again, I was disappointed that Sharp's version of Heckl's 1959 theory was not described. The Chapter ends with a major section on impact sound insulation and a very short section on rain noise.

I like this book a great deal, because chapter 1, together with parts of chapter 3, provides a very good introduction to reverberant sound fields and especially their statistical properties. However, equation 3.14, for the ensemble relative variance of bandwidth limited Gaussian white noise which has been passed through a reverberant room, is only correct if the integrating time is long compared to the reverberation time of the room divided by 6.9. The correct formula is given in one of the reviewer's 1986 papers. The factor of two is not needed if the integrating time is short compared to the reverberation time divided by 6.9. Figures 1.43 and 1.44 show good agreement between theory and experiment for the spatial standard deviation of level of third octave bands of random noise in reverberant rooms with volumes of 29 and 34 m3. Readers should beware that Lubman (1974) and the reviewer (2006) have shown that the theory under predicts at high frequencies in reverberant rooms with volumes of 715 and 607 m3.

Chapter 2 gives a good introduction to waves on plates and beams. It points out that there can be significant decrease in vibration level with distance, especially where the propagation is at right angles to the plate ribs (studs or joists). This chapter also covers the input impedance of plates and the radiation of sound from bending waves on plates. Chapter 3 covers a remarkably wide range of topics. This reviewer particularly liked the sections on reverberation time, maximum length sequences (MLS) and sound intensity. As indicated above it also includes signal processing and the variability due to using random noise. The author's discussion on the niche effect was of great interest to this reviewer.

I expected Chapter 5 to open with a discussion of the prediction methods of the EN 12354 series of standards, but this is not the case. After the introduction, the sections are "vibration transmission across plate junctions" using both wave approaches and finite element methods, "statistical energy analysis" and "SEA based model". It is this last section which describes the EN 12354 methods. It has a sub-section entitled "application" which gives a very good discussion of the current limitations of the SEA based model.

This book benefits from the wide variety of the author's knowledge. One of its most important strengths is the author's comments and asides as he develops the subject area. This book deserves a place on the book shelves of anyone whose work covers sound insulation.

John Davy is an adjunct professor at RMIT University and a principal research scientist at CSIRO Materials Science and Engineering. His research includes the prediction of sound insulation.

Additional review from a casual user of the book

A comprehensive understanding of the theory, measurement and application of sound insulation is an essential asset for a competent acoustic consultant. There is a wealth of data available for the individual components of a building construction, but it is only if those components are put together carefully in a building that the full potential of sound insulation is achieved. Reference books with sections on sound insulation tend to cover the more common aspects with generic advice. It's rare to find a book that deals with the details and provides the theory, but is still easy to read. With this book it is possible to 'dip into' the sections of interest without having to read from the first page as the table of contents is very well divided with clear section headings. Indexes are always difficult to construct and while many of topics can be quickly found from the index, for others you need to cross check with the table of contents – for instance there is no entry in the index for 'glass' or 'windows' yet these are dealt with in the text. So this book is not for the person who quickly wants guidance on the performance of a particular type of construction – the manufacturer's data sheets can provide that – but it is for the person who wants to know more about how and why a construction has a particular performance and perhaps guidance on what can be done to improve it.

Marion Burgess is a research officer with the Acoustics and Vibration Unit of UNSW at the Australian Defence Force Academy and involved with various educational activities.

NEWS

New president takes over

The AAS recently held its Federal AGM on Tuesday 7 December 2010. Forty people attended a function at the Malvern East Golf Club in Melbourne. Following the AGM, Dr Carl Howard from the University of Adelaide delivered a fascinating presentation on preventing algae blooms using ultrasound. The next day the Federal Council held a teleconference meeting and ratified the election of the Office Bearers of the Australian Acoustical Society for 2010-2011. These are

President	Mr	PA	Heinze	(SA)
Vice President	Dr	N	Broner	(VIC)
Treasurer	Mr	GA	Barnes	(VIC)
General Secretary	Mr	RJ	Booker	(QLD)
Registrar	Mr	TJ	McMinn	(WA)

I ate the muesli? - Test for hearing loss

Australian Hearing and iconic Aussie recording artist John Paul Young has turned to the phenomenon of mondegreens – the misinterpretation of lyrics – to drive a new public education campaign that encourages Australians to get their hearing checked if they are experiencing loss of hearing. The campaign focuses on the launch of a new online video where mondegreens are shown during John Paul Young's chart topping song "I hate the music". The end result is in marked contrast to the original lyrical intent. The video acts as a humourous reminder to Australians who are experiencing hearing difficulties to get a hearing check.

John Paul Young knows too well what it is like to live with a level of hearing loss. He is one of many Australians who suffer from tinnitus, which can be described as "ringing in the ears" and can occur as a result of age-related hearing loss or exposure to loud noises. Speaking from his own experience with hearing loss, Young says the campaign uses its unusual approach to bring attention back to the importance of maintaining hearing health. "Hearing loss is a very easy condition to ignore. Hopefully this campaign will encourage people to reconsider the importance of their hearing health," Young said. "If you are worried about your hearing or suspect that you have a level of hearing loss, don't waste time and get it checked out."

Check out the video via http://medianet.multimediarelease.com.au/bundles/1e0a57bc-c26b-4d6e-8473-21c127bf1463. More information on hearing tests is available from www.hearing.com.au

On-line free publications in acoustics

Noise News International

You can now subscribe to be alerted to new editions of the free quarterly Noise News

International on-line publication. The latest edition (June) contains a comprehensive report on the discussions held during Inter-Noise 2009 on Low-Noise Machinery and Products.

See: http://www.noisenewsinternational.net/

Technology for a Quieter America

Technology for a Quieter America, by the US National Academy of Engineering, assesses major sources of noise (transportation, machinery and equipment, consumer products, etc), how they are characterised, efforts to cut noise emissions and efforts to reduce noise in workplaces, schools, recreational environments and homes. To buy the book, a PDF or individual chapters or read it online for free, go to www.nap.edu/catalog.php?record_id=12928

Excellence in acoustics award

At the dinner of the International Congress on Acoustics, the CSR Bradford Insulation Excellence in Acoustics Award for 2010 was presented to a team from UNSW: Joe Wolfe, Jer Ming Chen, Paul Dickens and John Smith. Their entry was entitled *Measurement technology for impedance, reflection and transmission spectra and resolution of the 'player paradox' for wind instruments.*

The team reported advances in the technology of measuring impedance and reflection spectra. One consists in using only non-resonant loads for calibration and the other is adjusting the magnitudes and phases of the probe spectrum as a function of the measured load so as to optimise signal:noise ratio. Their original calibrations are acoustically infinite waveguides (from 40 to 200 m long) that traverse the ceiling space of the physics building, but Paul presented a paper at ICA 2010 in which he described a portable version. The team has also been able to measure impedance spectra in the presence of high intensity extraneous signals.

Combining these technologies, the team was able to resolve a scientific puzzle concerning the role of the mouth as a resonator in playing musical wind instruments, a question that has attracted debate over three decades. Jer Ming won the student prize for his presentation of this work at Acoustics08 in Paris. The team's work in this area has been published in a series of papers in *Acoustics Australia, Journal of the Acoustical Society of America and Science.*

NSW Noise Guide for Local Government

A new noise guide for Local Government has been published and is available on the website of the NSW Department of Environment, Climate Change and Water (DECCW) at:http://www.environment.nsw.gov.au/noise/nglg.htm

DECCW has been progressively reviewing the Guide since the Protection of the Environment Operations (Noise Control) Regulation 2008 was made. Updated versions of Parts 2 and Part 4 were e-published on DECCW's website in 2009. The entire Guide has now been revised to provide an easy to use, comprehensive tool to assist with the interpretation of current policy and legislation when dealing with local noise problems. Questions or feedback on the Guide may be directed to Environment Line, Phone 131 555, or Grant Harper, Senior Noise Officer on tel: (02) 9995-5996 or email: grant.harper@environment.nsw.gov.au

Low noise cooling fan technology applied at Queensland Curtis LNG project

Cooling fans are often identified as one of the more significant sources of industrial noise. In order to meet strict environmental noise criteria, best available technology for low noise cooling fans was sought by engineers for the Queensland Curtis LNG project, which involves transporting coal seam gas. For application in the air-cooled heat exchangers, the Howden SX fan was selected for its excellent low noise characteristics. This decision also alleviated the need for excessive use of passive noise control measures such as silencers which could have made the installations less efficient. For more information about the project and low noise fan technology, you can contact acoustic specialist Peter Yallamas of Howden Australia at p.yallamas@howden.com.au.

New website for Pyrotek Noise Control

Pyrotek Noise Control (formerly Soundguard) have revised and renewed their website. The website address is www.pyroteknc.com. The website includes details on the range of products including the new absorber, Reapor, made from recycled glass and suitable for internal or external use. You can register online to receive regular information updates from Pyrotek.

Workplace noise

Safe Work Australia has released the Draft Model Work Safety and Health Regulations and Codes for Public Comment. It is intended that the final versions of these documents are adopted by each of the States. The regulations define the standards and are supplemented by Codes of Practice for management of each type of hazard. This is the opportunity for those who have experience with workplace noise assessment and control to comment on both the Draft Regulations and the Code of Practice for Managing Noise and Preventing Hearing Loss at Work. The documents can be downloaded from follow the link from "Model WHS Legislation" on http://safeworkaustralia.gov.au

NEW PRODUCTS

Sound intensity system

Brüel & Kjær offers a new hand-held sound intensity system: 2270-G. The 2270-G comprises of the hand-held sound level analyser (2270), Sound Intensity Software (BZ-7233) and Sound Intensity Probe Kit. This portable, battery operated system allows one person to make sound intensity measurements complying with the IEC 61043 sound intensity standard. Users simply swap the 2270 meter's microphone for the sound intensity probe to start measuring. The BZ-7233 software transforms the analyser into a powerful measurement tool using the intensity technique to determine sound power levels and locate noise sources using contour maps. A unique phase calibration technique allows users to make all measurements with a 12mm spacer covering a frequency range from 50 Hz to 10 kHz. The sound intensity system is part of Brüel & Kjær's 2270 range, which offers many sound and vibration analysis applications. For more information, visit www.bksv.com/Type2270G or www.bksv.com.au or tel. (02) 9889 8888

Soundproofer handles tough duty

Pyrotek Noise Control has announced a noise absorber called Reapor for challenging environments. Reapor is a soundproofing panel made from recycled glass and is resistant to damage or deterioration from the elements. In addition it is non-combustible, making it fire-safe. It is also free of chemicals harmful to the environment and is recyclable. Being non-combustible and smoke-free makes Reapor suitable for today's tougher fire codes, particularly for schools, hospitals, aged care facilities, plant rooms, substations, exitways, smoking areas, stairwells, airports and railway terminals.

New acoustic product a success in gymnasium

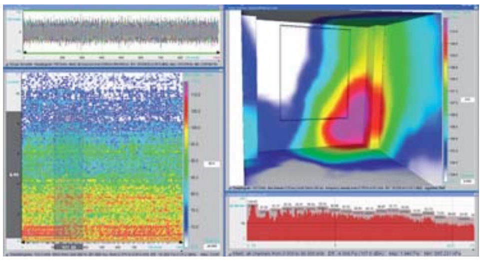
A new acoustic panelling from Pyrotek Noise Control was recently used to control noise level and reverberation in the gymnasium at the Umina Campus of Brisbane Waters Secondary College. Before the acoustic panelling was installed, students and teachers struggled to communicate effectively due to the echo bouncing off the hard surfaces of the gymnasium. Tests conducted in the empty gymnasium revealed a reverberation time (RT) well in excess of the recommended measurements for building interiors as stipulated by the Department of Commerce Schools Facilities Design Standard. According to the acoustic consultant's report, "an excessive RT causes undesirable build-up of sound energy and results in poor speech intelligibility", which is far from ideal in an educational venue such as a college

AC easy

acoustic camera
simply perfect – perfectly simple

acoustic camera

acoustic image 3D
noise emmission via mechanical, external stimulation of the building



AC easy and the high-end system AC pro do not differ software-wise as both use NoiseImage4. Differences only exist in hardware equipment.

Depending on the desired area of application the user can choose from three different microphone arrays. The two offered AC easy basic configurations can be combined with a Sphere32-35 easy, Ring32-75 easy or a Ring33-35 easy Array.

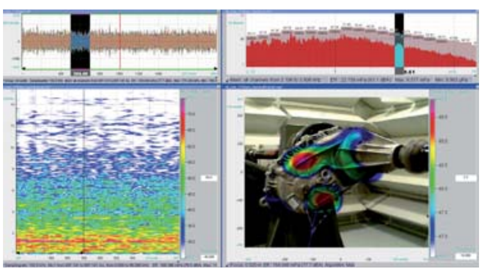
AC easy key features:

- Live streaming (the recorded data is transferred from the data recorder to the PC/ notebook in real-time, a life-analysis is immediately visible)
- High usability, easy and intelligible handling
- Shows sound sources quickly and reliably
- Small, mobile and comapct

Specifications – system with notebook

- Software NoiseImage4 for PCs, starting at Windows XP / 7
- Standard notebook
- Microphone arrays; Sphere32-35 easy, Ring32-75 easy or Ring32-35 easy
- National Instruments NI PXI-1033 Chassis with two microphone measurement cards (NI PXI 6250; 48kHz data recording, 16bit resolution)

acoustic image 2D
sound source of a transmission unit at 1.700 rotations/min



Specifications – system with desktop PC

- Software NoiseImage4 for PCs, starting at Windows XP / 7
- Microphone arrays; Sphere32-35 easy, Ring32-75 easy or Ring32-35 easy
- Standard PC with two National Instruments micorphone measurement cards (NI PCI 6250; 48kHz data recording, 16bit resolution)

Listening with the eyes.

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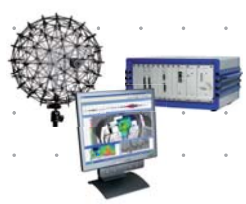
Phone: +61 (0) 2 9872 9995
Mobile: +61 (0) 412 268 541
www.hwtechnologies.com.au
info@hwtechnologies.com.au



gfai tech
gfai tech GmbH
Rudower Chaussee 30
D-12489 Berlin, Germany
Phone: +49/(0)30-6392-1624
Fax: +49/(0)30-6392-1630
www.gfai-tech.com
www.acoustic-camera.com
acousticcamera@gfai.de

gymnasium. An echo-damping acoustic panelling called EchoHush Cosmo, a panel with decorative slots that allow the acoustic cavity infill to absorb noise energy and control reverberation, was used to reduce the RT. In a follow up report, the acoustic consultant confirmed that the reverberation time in the empty gym has been reduced by over 40 percent. Staff and students at the Umina Campus have remarked on the decreased level of noise in the gymnasium.

Meeting Reports

NSW Division

The NSW Division held their AGM on 27 October at the National Acoustics Laboratory, Chatswood. Immediately following the AGM was a technical meeting with a talk presented by Peter Knowland, PKA Acoustic Consulting, on the topic "The evolution of the design for the Al Futtaim Exova sound transmission loss measurement suites in Dubai". This talk described Knowland's experiences with sound transmission suites, including the CSIRO Laboratory at North Ryde, the Lorient laboratory at Banyo in Brisbane and the Rintoul laboratory experiment. In 2009 Peter Knowland was commissioned to design a sound transmission loss suite in Dubai based on the Lorient design. Calibration of the laboratory was also discussed.

On 19 August Dr Leo Beranek gave a talk on concert hall acoustics at the Sydney Conservatorium of Music. In his talk Beranek briefly covered the history of Western music and concert halls, the background to the physical determination of the behaviour of sound in rooms, the principal acoustical attributes of concert halls, and described some famous older concert halls.

Victoria Division

ISRA 2010

The International Symposium on Room Acoustics (ISRA 2010) was held as a satellite conference at the Arts Centre ANZ Pavilion, St Kilda Rd, Melbourne, from 29-31 August 2010. The organising committee comprised of Fergus Fricke (general chair), Charles Don (conference manager), William Martens (program chair), Densil Cabrera (papers chair), Norm Broner (sponsorship and financial manager) and Liz Dowsett (secretarial and administrative services) with assistance from Sheena Don. The local organising committee comprised of Norm Broner, Densil Cabrera, Charles Don, Peter Fearnside, Fergus Fricke, Lawrence Harvey, Sylvia Jones and William Martens. Strong financial and administrative support for ISRA 2010 from the AAS Victoria Division Committee was given. The Victoria Division Committee acknowledges and thanks the work of the organising committee and speakers in making this a most successful symposium, at which there were around 170 participants.

The Symposium banquet was held at the Hotel Melbourne on Flinders Street. The invited speakers were the Governor of Victoria, Professor David de Kretser, and Leo Beranek. Fergus Fricke introduced David de Kretser and referred to his wide interests in medical and health matters. Professor de Kretser expressed his pleasure at being present, welcomed the overseas visitors to Melbourne and acknowledged the original owners of the land. He continued by referring to acoustics as a field of study and practice which, like stem cell work, is important in that it crosses disciplinary boundaries. Acousticians are concerned with oral and aural communication. Yet 20% of people aged over 20 years have a hearing defect through exposure to very loud noise (defined as >80 dB(A)). Some organisations are conscious of the dangers of hearing loss due to constant exposure to very loud noise such that when, for example, he visits a motor manufacturing factory, he is provided with hearing protectors. Because of this wide but unnecessary prevalence of personal hearing loss, he said that governments would soon be made responsible for regulating the production and emission of loud noise. He concluded by commending the work done by the AAS, its members and acousticians generally.

Fergus Fricke then introduced Leo Beranek as a widely known acoustician of long standing. Dr Beranek was born in 1914 in Iowa, USA and has written and published 14 books, of which his autobiography, "Riding the Waves" was quite recent. Leo Beranek, who received a standing ovation, said in reply that he was most happy to be in Australia and hoped that all attending the Room Acoustics Symposium were profiting from it. In his talk he referred to some of his acoustical and other experiences throughout his life. In 1942 he joined the Acoustical Society of America (ASA). In 1944 after his colleague, RH Bolt had earlier received the Bruce Lindsay medal for significant acoustical work, he also received this award. In 1950 he designed the world's largest muffler. However his acoustical design for the New York Lincoln Centre auditorium was not followed, resulting in an acoustically dead concert hall. In 1954 he was elected ASA president; at about this time he learned to enjoy skiing in Switzerland and the USA. He was the president and CEO of a Boston TV station for 11 years until it was sold. As a result he received the Abraham Lincoln TV award in 1976. In 1982 his first wife died. He remarried three years later and learned to sail. In 1984 he was elected for a 6 year term to the Board of Overseers at Harvard University for the physics, biology, theatre and business faculties. In the 1990s he returned to work solely in acoustics and in 1994 published his book on Concert Hall Acoustics.

VIC Division AGM and Technical Meetings

On 15 September the Victoria Division held its AGM at SKM. The invited technical speaker was David Demant, Senior Curator of Information and Communications at Museum Victoria. Demant was invited as the Museum had recently taken over some of the acoustical equipment which had belonged to H. Vivian Taylor, architect and acoustician. Taylor was an AAS foundation member in 1964 and its first national president from 1971. There were 20 members present. On request, Louis Fouvy gave a brief description of these instruments, which comprised a sound level meter (GR model 759), octave band analyser (GR 1550), narrow band sound analyser (GR 760), vibration analyser (GR 762), high fidelity Byer tape recorder and a set of gramophone records for producing tones at various frequencies. In their time (in the 1930s and 40s), the GR instruments were precision instruments.

In his talk, David Demant described devices from Magic Lanterns to Music-on-Wax from earlier times. He illustrated his talk with examples from those at Museum Melbourne. He first demonstrated a magic lantern, the predecessor of the slide projector. He next demonstrated a musical box dating from around 1880. Well known tunes were produced by a clockwork-driven cylinder with appropriately located pins which struck the sprung note metal bars (which extended mostly over two octaves) as the cylinder rotated. Boxes were equipped with a start-stop control, and the cylinder speed was maintained by an air resistance governor. The final demonstration was of an Edison phonograph (or gramophone).

The final Victoria Division technical meeting for 2010 on 7 December took the form of an end-of-the-year dinner meeting at the Malvern Valley Golf and Reception Centre, East Malvern. Dr Carl Howard of the University of Adelaide was the after dinner speaker. There were 41 present, including the AAS general secretary, Richard Booker, several interstate councillors who were also attending the National AGM held prior to the dinner and several ANCE members.

The School of Mechanical Engineering at the University of Adelaide includes numerous aspects of sound and vibration among its subjects for study. Lake Torrens, like rivers and lakes elsewhere, suffers annually from toxic algal blooms. Copper sulfate treatment, though it works, is associated with undesirable environmental problems (as recognized, for example, in China). Carl Howard and his colleagues are checking the suitability of treating the algal blooms with ultrasound. At this stage this is a work in progress, supported by grants from several water authorities throughout Australia.

Western Australian Division

Acoustics Seminar in the West

WA Division held its annual Acoustics Seminar on 18 August at the Perth Zoo Function Room. Divisional Chair Rebecca Donovan facilitated the day's program of wide-ranging topics. Luke Zoontjens (NDY) presented two projects, first describing assessment and design requirements of animal houses in research facilities where excessive audible and ultrasonic noise can interfere with research findings on animal behaviour; then exploring challenges of acoustic places within the driver sleeping berths on interstate freight locomotives. Switching to a different type of train, Conrad Weber (Heggies) explained a retrofit of noise control on a Sydney electric railway where rail-on-concrete and a restriction on the height of structures combined to demand more than a standard approach. Shifting to air transportation mode, Bojan Sevo (AECOM) presented results of investigations into Perth airport community complaints and noise levels at locations well beyond the 20 ANEF contour.

'Submerged sounds' topics included Chris Sorgiovanni (L3-Nautronix) on using a ray tracing model to predict the performance of underwater telephone signalling systems, and Alec Duncan's (CMST) findings from measurement and modelling of underwater noise from pile-driving using hydraulic and drop-hammer machinery. Alexander Gavrilov (CMST) described his work using data from the Cape Leeuwin CTBT (Comprehensive Test Ban Treaty) hydro-acoustic station, that proved reliable detection of Pygmy blue whales up to 50 km. Darryl McMahon (DSTO) then talked us through the principles of sonar noise reduction, using submarine technology examples.

Back in the air once more, 'Noise in the Wind' was the title of John Macpherson's (DEC) explanation of two recent documents; the draft national wind farm development guidelines, and AS 4959 Measurement prediction and assessment of noise from wind turbine generators. The day's finale was 'Acoustics MasterChef' by Michael Haywood (Quiet Acoustics) who described a panel system that incorporated Helmholtz resonators to reduce sound levels in vocal frequencies whilst retaining restaurant ambience. More information on the panel system can be found in the technical note by Haywood in this issue.

A highlight of the seminar was the opportunity to meet and to hear presentations by the three recipients of the ICA student travel grants, Ms Ye Lei, Miss Yanni Zhang and Mr Wei Liu from the University of Western Australia, all of whom studied under the leadership of Prof. Jie Pan.

WA Division AGM, Technical Meeting and Tertiary Prize

WA Division combined a technical presentation with its AGM on 20 October. The Cove restaurant in Attadale was just the place for a pleasant evening, comprising a brisk AGM followed by a meal and technical

Acoustics 2011
BREAKING NEW GROUND
Gold Coast Australia

The Australian Acoustical Society conference in 2011, ACOUSTICS 2011, will be held from 2-4 November at the Holiday Inn in the heart of Australia's favourite holiday destination on the Gold Coast, Queensland. The conference theme, Breaking New Ground, is based on the recent boom in large infrastructure projects. Major infrastructure for transportation, industry and mining present challenges in noise and vibration, whether these are in assessment, modelling or mitigation or in the need to provide appropriate legislative and regulatory frameworks. This conference will break new ground as delegates review recent developments and address the challenges and opportunities presented by the construction and operational phases of such infrastructure. Other major topics for the conference will include Underwater Acoustics and Architectural and Building Acoustics. Authors are encouraged to prepare papers from all areas of acoustics and to submit abstracts by the end of March 2011. The Trade Exhibition will provide an opportunity for the latest technology to be displayed and sponsorship opportunities are available. Details can be found on the conference web site at http://www.mech.uq.edu.au/acoustics2011/. A series of workshops that will focus on aspects of transportation noise and a short course on fundamental acoustics are also planned. Congress Plenary speakers will include Dr David Hiller (ARUP) and Professor David Thompson (ISVR, University of Southampton). ACOUSTICS 2011 is shaping up to be a very exciting conference. For further enquiries, contact the conference chair, Matthew Terlich, at mterlich@savery.com.au presentation. With the arrival of her baby daughter, almost as the AGM was occurring, it was no surprise that Rebecca Donovan has stepped down to support her family. Luke Zoontjens, the new Divisional Chair, thanked Rebecca for her leadership and contribution to the Society in her role as Chair in recent years.

Rebecca's baby Louisa got off to a flying start in acoustics - a hearing check at one day of age

Vice-Chair Dr Alec Duncan presented the AAS WA 2009 Tertiary Prize in Acoustics and Vibration to Mr Brad Walsh of the School of Mechanical Engineering, University of Western Australia. Brad presented a summary of his honours thesis of blade interaction noise of the micro-unmanned aerial vehicle *Mupod*.

Brad Walsh receives the 2009 AAS WA Tertiary Prize in Acoustics and Vibration from Dr Alec Duncan

FASTS

The AAS is a member of the Federation of Australian Scientific and Technological Societies, FASTS. At the 2010 AGM in late November the Board discussed the Strategic Plans for FASTS which identifies clear goals. On this 25th anniversary of the formation of FASTS, the President outlined the growth strategy aimed at improving FASTS impact and influence and to provide a stronger voice for science and technology issues at the government level. The strategic plan takes into consideration the financial limitations of the FASTS funding while striving to meet the needs and expectations of the member societies. The three main problems that stakeholders identified as warranting action were to campaign for better maths and science education, better PR and communication on science and the need to position science as an issue essential to Australia's future.

One outcome of the survey was a suggestion to change the name of the organisation to be more easily recognised. It was intended that the new name would be released at the time of this meeting however consensus on the new name for the organisation has not been reached and it is now open to the member societies to propose a new name. Any suggestions for a name that would be more recognisable and representative of the organisation and its intentions are welcomed.

FUTURE CONFERENCES AND WORKSHOPS

ICBEN 2011

The 10th International Congress on Noise as a Public Health Problem will be held between 24-28 July 2011 in London, UK, organized by the UK Institute of Acoustics on behalf of the International Commission on the Biological Effects of Noise (ICBEN). This congress aims to present the current state of the art in research on the biological effects of noise on health and is suitable for research scientists, policy makers and industry concerned with the effects of noise. Papers and posters will be welcome on topics including noise induced hearing loss, noise and communication, non-auditory physiological effects of noise on health, influence of noise on performance and behaviour, effects of noise on sleep, community responses to noise, noise and animals, interactions with other agents and contextual factors and noise policy and economics.

Deadlines: Abstract submission 14 February 2011; Paper submission 16 May 2011; Registration before 16 May 2011. More information from http://www.icben2011.org//

Inter-Noise 2011

The 40th International Congress and Exposition on Noise Control Engineering (Inter-Noise 2011) will be held in Osaka, Japan from 4-7 September 2011. The Congress is sponsored by the International Institute of Noise Control Engineering (I-INCE) and co-organised by the Institute of Noise Control Engineering Japan (INCE/J) and the Acoustical Society of Japan (ASJ). The organisers extend a warm welcome to all prospective participants world-wide and invite all to join them in Osaka to discuss the latest advancements in noise and vibration control engineering and technology, focusing on the congress theme of "Sound Environment as a Global Issue". Inter-Noise 2011 will feature a broad range of invited and contributed papers, together with plenary lectures by distinguished speakers. There will be extensive exhibitions of noise and vibration control technology, measuring instruments, equipment and systems from all over the world.

Deadlines: Abstract submission 15 February 2011; Full paper submission: 1 June 2011; Early registration: 8 June 2011

More information from

http://www.internoise2011.com

ICSV18

The 18th International Congress on Sound and Vibration (ICSV 18) is to be held in Rio de Janeiro, Brazil, 10-14 July 2011. ICSV is the annual premier world event organized by the International Institute of Acoustics and Vibration (IIAV). The congress includes invited and contributed papers on the range of topics of sound and vibration. Rio de Janeiro is a cosmopolitan metropolis known worldwide for its scenic beauty and its natural resources. The city provides a harmonious and agreeable environment for its inhabitants and visitors, for both leisure and work, which combined with its infrastructure, makes Rio an important centre for commerce and services, with the advantage of a modern and diversified industrial sector. The congress venue is a five-star Hotel with excellent conference facilities located in the Barra da Tijuca neighbourhood, facing its amazing beach. Barra da Tijuca is Rio's most modern living complex and community, offering innumerable attractions.

Deadlines: Abstract submission 20 December 2010; Paper and early registration 31 March, 2011

More information from http://www.icsv18.org

Wind Turbine Noise 2011, Rome, Italy

The fourth international conference on wind turbine noise and its effects on people will be held in Rome, Italy from 12-14 April 2011. The conference is organised by INCE/Europe and the previous conference in 2009 involved more than 160 delegates from 25 countries representing manufacturers, developers, researchers in noise and vibration, environmentalists, pressure groups and consultants. There is an introductory course on noise to be held in the afternoon prior to the conference, which has proved to be very popular in previous years. Offers of papers for this conference are invited and prospective authors should send a 200 word abstract by 1 November 2010 to organiser@windturbinenoise2011.org. A template for abstracts can be found on the conference website and those wanting to attend may also register to receiver further information as the organisation of the conference progresses. The CDs of the Proceedings of WTN 2009, WTN 2007 and WTN 2005 are available from the INCE Europe secretariat, contact Cathy@cmmsoffice.demon.co.uk

More information from

http://www.windturbinenoise2011.org

ICA 2010

Summary of ICA 2010 activities

The International Congress on Acoustics, ICA 2010, held in Sydney on 23-27 August, was a major undertaking by the NSW Division on behalf of the AAS with over 1,000 local and international participants. An overview summary of the conference activities is presented in what follows. The executive committee comprised of Marion Burgess as chair, David Anderson as secretary, Chris Schulten as treasurer and Norm Broner as the technical exhibition manager. ICMSAustralia provided the services of professional conference organiser (PCO). The paper management system was via OCPMS with an access key providing the link between the registration and the paper management databases. Members of the local and international advisory committee provided advice and assistance with the technical program. ICA 2010 was held at the Sydney Convention Centre. The technical program comprised of 10 parallel sessions over the 5 days commencing mid morning on Monday and closing mid afternoon on Friday. Over 750 papers were verbal presentations and 150 were poster presentations. There were 5 plenary speakers and 8 distinguished speakers. Two technical tours were organised: one to the Opera House and the other to the National Acoustics Laboratory. The exhibition was organized by Norm Broner with assistance from the PCO. The exhibition was comprised of 34 booths. The ICA-ASA Young Scientist awards of €500 were offered to 30 young scientists and 29 of these attended ICA. The NSW and WA Divisions of the Australian Acoustical Society provided financial assistance for 13 students to attend ICA 2010.

Three associated meetings were held corresponding to the International Symposium Musical Acoustics (ISMA) in Sydney and Katoomba, the International Symposium on Room Acoustics (ISRA) in Melbourne and the International Symposium on Sustainability in Acoustics (ISSA 2010) in New Zealand.

Marion Burgess, Chair ICA 2010

Diary

2011

12 – 14 April, Rome, Italy
Wind Turbine Noise 2011
http://www.windturbinenoise2011.org

22 – 25 May, Prague, Czech Republic
International Conference on Acoustics, Speech, and Signal Processing (IEEE ICASSP 2011).
http://www.icassp2011.com

23 – 27 May, Seattle, USA
161st Meeting of the Acoustical Society of America
http://asa.aip.org/meetings.html

13 - 17 June, Ottawa, Ontario, Canada
Twelfth International Conference on Hand-Arm Vibration
http://www.hav12.org

27 June – 1 July, Aalborg, Denmark
Forum Acusticum 2011
http://www.fa2011.org

4 – 6 July, Leuven, Belgium
Eighth International Conference on Structural Dynamics (Eurodyn 2011)
http://www.eurodyn2011.org

10 – 14 July, Rio de Janeiro, Brazil
18th International Congress on Sound and Vibration (ICSV18)
http://www.icsv18.org

24 – 28 July, Tokyo
19th International Symposium on Nonlinear Acoustics (ISNA)
http://www.isna19.com

24 – 28 July, London, UK
10th International Congress on Noise as a Public Health Problem (ICBEN)
http://www.icben2011.org

1-4 August, Tokyo, Japan
19th International Symposium on Nonlinear Acoustics
http://www.isna19.com

27 – 31 August, Florence, Italy
Interspeech 2011
http://www.interspeech2011.org

4 – 7 September, Osaka, Japan
Inter-Noise 2011 - Sound Environment as a Global Issue
http://www.internoise2011.com

5 - 8 September, Gdansk, Poland
International Congress on Ultrasonics (2011 ICU)
http://icu2011.ug.edu.pl/index.html

31 October – 4 November, San Diego, USA
162nd Meeting of the Acoustical Society of America
http://asa.aip.org/meetings.html

2 – 4 November, Gold Coast, Australia
ACOUSTICS 2011
http://www.mech.uq.edu.au/acoustics2011/

2012

20 – 25 March, Kyoto, Japan
IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2012)
http://www.icassp2012.com

8 – 12 July, Vilnius, Lithuania
19th International Congress on Sound and Vibration (ICSV19)
http://www.iiav.org/index.php?va=congresses

12 – 15 August, New York, USA
Inter-Noise 2012
http://www.internoise2012.com

9 – 13 September, Portland, USA
Interspeech 2012
http://www.interspeech2012.org

2013

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

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

Meeting dates can change so please ensure you check the conference website: http://www.icacommission.org/calendar.html

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For more information about NDY Sound please visit to our website:
www.ndy.com/acoustics

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The following are Sustaining Members of the Australian Acoustical Society.
Full contact details are available from http://www.acoustics.asn.au/sql/sustaining.php

3M AUSTRALIA
www.3m.com

ACOUSTIC RESEARCH LABORATORIES
www.acousticresearch.com.au

ACRAN
www.acran.com.au

ACU-VIB ELECTRONICS
www.acu-vib.com.au

ADAMSSON ENGINEERING
www.adamsson.com.au

ASSOCIATION OF AUSTRALIAN ACOUSTICAL CONSULTANTS
www.aaac.org.au

BORAL PLASTERBOARD
www.boral.com.au

BRUEL & KJAER AUSTRALIA
www.bksv.com.au

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www.csr.com.au/bradford

EMBELTON
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NSW DEPT OF ENVIRONMENT & CLIMATE CHANGE
www.environment.nsw.gov.au

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www.peaceengineering.com

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* Proceedings of annual conferences

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Fax: (02) 9262 5060
Laura.Allison@aecom.com

AAS - Queensland Division
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Sec: Darren Jurevicius
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Fax: (08) 7100 6499
darren.jurevicius@aecom.com

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School of Mechanical & Manufacturing Engineering
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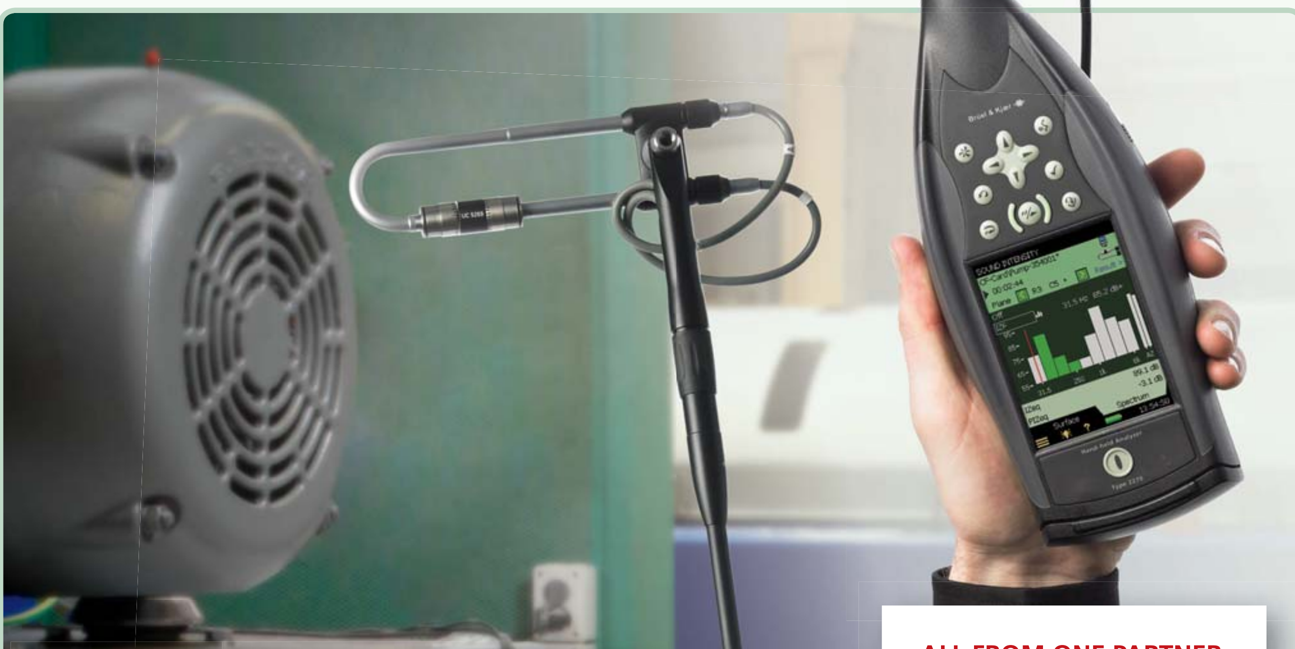

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