Acoustics Australia

Ambulance sirens

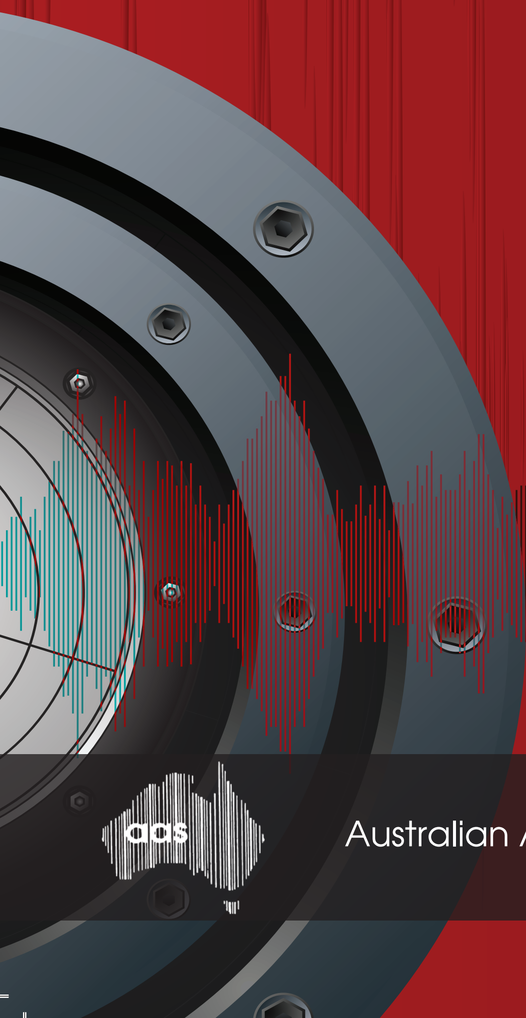
Ultrasound fundamentals

Cocktail party speech extraction

Music studio design

Orchestral occupational noise

Low noise cooling tower fans



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Volume 39 Number 2 August 2011

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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
+61 401 070 843 (mobile)
AcousticsAustralia@acoustics.asn.au
www.acoustics.asn.au

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PAPERS

TECHNICAL NOTES

Cover design: Helena Brusic

MESSAGE FROM THE PRESIDENT

Welcome to this midyear issue of Acoustics Australia. It is with great sadness and sorrow that we were advised that Colin Speakman passed away on Wednesday 6 July 2011. Colin was a stalwart of the Society, a member of the current Federal Councillor team, former AAS QLD Division Chairperson and Vice Chair and was instrumental in organising the Conference on the Gold Coast in 2004, and played a significant role in the organisation of this year's QLD conference too. Colin's input to the Federal Council was highly valued. On behalf of the society I would like to take this opportunity to pass on our gratitude for Colin's services and sincere condolences to his wife and 2 young daughters. Colin's obituary is provided on page 80 of this issue.

The QLD division is well underway with this year's conference, Breaking New Ground, to be held on the Gold Coast from 2-4 November. At our recent midyear Federal Council meeting the report from the Queensland Federal Councillors (Matthew Terlich and Ian Hillock) indicated that it is going to be a large conference with 5 streams occurring over 2 days, some 140 abstracts and 26 booths for exhibitors. They also have some interesting, topical and varied workshops proposed, and great social events. Please refer to the AAS website for further details and note that the more substantial late registration fees kick in on 30 September 2011.

The Federal Councillors recently held their midyear meeting. A large number of agenda items were discussed, with further work on a number of items to be carried out by the councillors and our Federal Secretary – Richard Booker. These midyear meetings are held by teleconference and it is noteworthy to express thanks to the Councillors who provide their time and effort and for those that produced reports beforehand.

Acoustic Australia is a highly valued journal with its varied depth and quality of professional articles published. The team at Acoustics Australia (AA) has a difficult task in producing these whilst balancing funds from advertisements against ever increasing production costs, besides chasing down those allusive technical articles. On occasions the Society has to provide financial interventions to tide the journal over. I trust you all are acutely aware that the AA team is doing their utmost to achieve what is a technically superior and enjoyable journal to read.

Some of you may have remembered the successful joint conference we held with the NZ Acoustical Society in Christchurch in 2006. There are opportunities in the future for the AAS to reciprocate this successful venture and hold it in Australia. Please note that effective Friday 1 July, the New Zealand Acoustical Society (NZAS) changed its name to the Acoustical Society of New Zealand (ASNZ) and enacted a new membership regime.

The VIC division on behalf of the AAS and in conjunction with the Melbourne Convention and Visitors Bureau has submitted a bid document to the IINCE Congress Selection Committee to hold InterNoise 2014 in Melbourne. I have seen the final document and must congratulate Dr Norm Broner (Congress President) and his team (Co-Technical chairs Assoc. Prof. Charles Don and Dr John Davy, Treasurer Geoff Barnes) on producing a formidable bid in such a short time frame. Charles Don will present the bid to the congress selection committee on Saturday 3 September 2011 and we wish him well.

I look forward to catching up with you all at the QLD conference and if you have any questions or issues please contact me or your respective Federal Councillors – our contact details are on our website www.acoustics.asn.au.

Peter Heinze

MESSAGE FROM THE EDITOR

I hope you like the new look of Acoustics Australia. If a change is a good as a holiday, the journal hasn't had a holiday since 1985! I welcome your comments and suggestions for improvement, after all it is *your* journal.

I've now been in this editorial role for just over one year. Since my first issue last August, I'm sorry to write I've had virtually no feedback on the journal and its various articles. It is my wish to make the journal as interesting as possible to you – the reader. I encourage you to write to me with your opinions on any of the articles. I believe the more engagement the journal receives from its members, the more interesting it will be become. So please, don't be shy (or too busy!). Feel free to email me directly on n.kessissoglou@unsw.edu.au. I look forward to your comments as well as case studies that will make an interesting technical note.

The Acoustics 2011 conference on the Gold Coast in November is shaping up to be a great event. I believe the organisers have had an overwhelming response with abstract and paper submissions, and promise a full and exciting program. If you see me around, please come and introduce yourself, I'll be the one with a baby in tow. My expected little one is due in less than two weeks – thankfully he/she is hanging in there long enough to finalise this issue!

My thoughts are with the family and friends of Colin Speakman, a valued member of our Society and a loving family man.

I hope you enjoy this issue (and all issues) and I look forward to your letters, in particular on the technical notes which are aimed at promoting dialogue amongst members.

Nicole Kessissoglou

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ACOUSTIC CHARACTERISTICS FOR EFFECTIVE AMBULANCE SIRENS

Carl Q. Howard, Aaron J. Maddern and Elefterios P. Privopoulos
School of Mechanical Engineering, The University of Adelaide, Adelaide, South Australia

Ambulances involved in collisions with motorists at intersections result in a number of negative outcomes including the inability to respond to the assigned emergency task, injury of people, and sometimes the loss of an operational appliance. The warning siren is perhaps the only non-visible device to alerting motorists approaching intersections of a converging ambulance. Acoustic measurements were conducted on several commercial-off-the-shelf sirens, a motor vehicle, and an ambulance, to characterise the noise transmission system. Tests were conducted in order to provide recommendations to improve the audibility and effectiveness of the warning signal. It is recommended that ambulance operators install sirens that broadcast sideways to the ambulance; that broadcast low frequencies so that the siren sound can penetrate into vehicle cabins; and that have signals with short repetition periods to convey high perceived-urgency.

INTRODUCTION

Emergency vehicles are regularly driven using warning lights and sirens to alert motorists and pedestrians of its approach, with the expectation that the motorist or pedestrian will clear the path for the emergency vehicle. The flashing lights on the emergency vehicle are only effective if the motorist has already directly sighted the lights on the vehicle or from a reflection. The warning sirens on an emergency vehicle are the only means that a motorist or pedestrian is alerted to its approach, without having sighted the vehicle, and hence this warning mechanism is important for the prevention of collisions.

A common factor in many collision incidents is that the motorist was not alerted, or did not recognise, the approach of an emergency vehicle [1]. This is where the warning siren on the emergency vehicle is pivotal in the prevention of collisions with motorists.

A study of insurance claims over a 2 year period (2003-2004) in the United States against emergency medical service agencies showed that the most frequent claims were for emergency vehicle crashes and patient handling mishaps [2]. Statistics indicate that most accidents between emergency vehicles and motorists occur at intersections [3-7]. A counter example is from a study conducted in Houston Texas USA which indicated that most collisions between emergency vehicles and motorist *did not* occur at intersections, and for those collisions that *did* occur at intersections there was no correlation with the severity of the collision [8].

There is an elevated risk of collision and injury when ambulances respond rapidly to emergency call-outs that require the use of lights and sirens, and several papers address the question of whether there is a decrease in travel time to the job site or transport of a patient to a hospital [9-12], and whether there is significant benefit for patient outcomes. The reported statistics indicate that there is only a small decrease in response time for transport in urban areas. Care must be taken when considering the applicability of the results to other cities where road networks, road rules, and driver education standards differ.

In the metropolitan area of South Australia, where this study was undertaken, there are several collisions between ambulances and motorists that occur each year at intersections resulting in vehicles being ‘written-off’ and are replaced at substantial cost. The goal of the investigations was to provide recommendations to improve the audibility of sirens on ambulances to approaching motorists at intersections, with the intention of reducing the number of collisions between vehicles.

FAVOURABLE SIREN CHARACTERISTICS

De Lorenzo and Eilers [13] describe the favourable characteristics for sirens. They note a US Department of Transport report that suggested that “…over a siren’s effective frequency range, the average signal attenuation (through closed-windowed automobile bodies combined with typical masking noise) resulted in a maximal siren effective distance of siren penetration of only 8 to 12 m at urban intersections.” For a vehicle travelling at 50km/hr, this distance would be covered in less than 1.15 seconds, which is insufficient to prevent a collision. The problem is further exacerbated as road users tend to overestimate the distance from noise sources by a factor of two [14], thus causing drivers to assume they have more time to respond. The favourable siren characteristics include: sufficiently loud, wide frequency spectrum (1kHz-4kHz) to overcome ‘masking’ noise, rapid rise in pitch, rapid cycling time. The work conducted here provides additional details about the favourable acoustic characteristics for sirens including findings from psychoacoustic studies and experiments.

Catchpole and McKeown [15] provide a good overview of the favourable characteristics for ambulance sirens that are similar to the recommendations by De Lorenzo and Eilers [13]. They conducted several acoustic measurements and field trials to evaluate the performance of two siren types, a ‘Wail’ and ‘Yelp’ siren and a ‘Localiser’ siren, mounted under the wheel arch and another behind the radiator grill. The wail type of siren sweeps non-linearly between 800-1700Hz with a sweep period of 4.92s [16]. The yelp siren has identical bandwidth to the wail with an increased sweep period of 0.32s [16]. The 'Localiser' siren emits a tonal sweep between 500-1800 Hz with a period of 0.384s, and emits a burst of white noise for 0.256s, every 0.128s, centred at the highest portion of the sweep frequency (see Fig 3. in Ref.[16]), with the highest sound pressure level emitted at 4kHz (see Fig 3 in Ref. [15]). Their conclusion was that a grill-mounted 'Localiser' siren sound had better penetration into vehicles and hence had a better effective range than the standard 'wail' and 'yelp' siren. This result is surprising considering that the Localiser siren has a peak sound pressure level at 4kHz, where most modern vehicle cabins provide high sound transmission loss, and hence is unlikely to be audible above background noise levels in the vehicle. The experimental results presented here quantify these characteristics and show that a better method of achieving sound penetration into vehicles is for the siren to emit low-frequency sound, where a vehicle cabin has poor transmission loss properties, resulting in higher interior noise levels.

NOISE CONTROL FACTORS

Noise transmissions problems can be analysed as three inter-related components: (1) the noise source, (2) the transmission path, and (3) the receiver, and each are described below.

Noise source factors

The siren on an emergency vehicle should be capable of alerting nearby motorists so that they clear the path for it. There are several acoustic characteristics that must be considered:

- Adequate amplitude emitted by the siren.
- Directivity (sound radiation pattern) of the siren loudspeaker. This factor is related to the mounting location of the siren and whether there is an effective reflective 'backing plane' to aid in the radiation of sound.
- Ensuring that the radiated sound pressure level from the siren is not altered due to the added pressure placed on the diaphragm of the siren due to the forward motion of the vehicle.

Transmission path factors

The transmission path is from the siren to the receiver. The factors that should be considered are the:

- Attenuation of broadband noise due to distance, which decreases by a factor of 6dB per doubling of distance from a point source [17]. Attenuation of tonal noise, which is used in sirens, has constructive and destructive interference caused by the reflection from the ground and is more complicated to predict.
- Attenuation of the noise source due to the acoustic transmission loss of the vehicle cabin.
- Diffraction and reflection of the warning sound around vehicles and buildings.

Receiver factors

The receivers in this system include motorists, pedestrians, emergency personnel, patients, and housing residents. Some of the factors to be considered for the receiver can also be attributed to the characteristics of the noise source. For example, the waveform generated by the siren should be perceived by the receiver as urgent. The factors for the receiver that need to be considered include:

- 'Masking' of the siren noise by background noise such as car audio, engine, passengers speaking, fans, and wind noise.
- Localisation of the siren warning signal, such that a person can determine the direction and movement of the noise source.
- Psychoacoustic factors such the correct interpretation of the sound as a warning signal, and the perceived urgency of the noise.
- Limiting the noise exposure to emergency workers to siren noise to prevent hearing loss [18, 19].
- Limiting the interior noise levels inside the ambulance to prevent communication difficulties with crew and radio communications. It is common practice for ambulance crews to switch off the siren when conducting radio communications, during which time there is an elevated risk of a collision.
- An awareness that the emergency transport of patients has been shown to increase their stress levels [20-22] leading to elevated heart rates and blood pressure which is medically undesirable for cardiac and stroke patients.
- Appropriate use of sirens to prevent community annoyance, particularly at night.
- Sufficient time for a motorist to hear and react to the warning signal.
- Awareness of standards that place limits on the noise level and directivity of sirens [23].

Intrusiveness

Robinson et al. [24] commented that many researchers that conduct detection threshold tests to explore the masking curves for human hearing will ask the listener to indicate if they can hear a target tone when a customised masking background noise is played concurrently, where the listener is waiting to hear the target noise (for example see Refs [25-27]). However, a motorist is pre-occupied with a 'foreground' driving task and is not expecting to hear the noise from a siren.

Fidell [28] conducted tests on 24 drivers in driving simulator to examine their reaction time to an emergency siren. Later, Fidell and Teffetellar [29] examined the intrusiveness of a sound on a group of subjects that were playing computer games. In both experiments it was found that the sound level required for the subjects to reliably detect the test sounds was 'considerably' higher than if they were not engaged in the distracting foreground task. In the driving simulator tests, the required sound pressure level of the siren was around 10dB higher than if the subjects were not driving.

The ability to notice a warning sound when preoccupied with a primary task can be been explained by considering the 'spare capacity' of a human mind to monitor unexpected stimuli [30]. The 'spare capacity' of an aviation pilot engaged in the foreground task of flying a plane is important if there is a need to deal with alarms, and this topic has been the focus of a great deal of research.

Localisation

One of the main methods that humans use to determine the direction and movement of a sound source is from the slight difference in the arrival time of sound at the ears on the left and right side of the head, called the inter-aural time difference (ITD).

It has been demonstrated that a driver within a vehicle with closed windows has greater difficulty identifying the correct direction of the source of an ambulance siren, compared to if the person was not within a vehicle [14,31,32]. A vehicle enclosure obstructs the direct path of siren noise and redistributes the acoustic energy over the surface of the vehicle, re-radiating into the enclosed space, which has the effect of altering the apparent direction of an external sound source.

Sounds that are easier to localise have the characteristics of a broad frequency range and uniform sound power density [33]. A siren sound has been designed to improve localisation called 'The Localiser' [33] that is a combination of a traditional 'yelp' with white noise components [16]. This siren sound was evaluated in a driving simulator and also in road trials [34] and motorists were better to identify the direction of the siren signal. However field testing involving the use of the Localiser siren by Catchpole and McKeown [15] indicated that the "… sound pattern was not as easily recognised as a more traditional emergency vehicle siren."

Withington [32] suggested that the reason why many sirens are ineffective is because "… the frequency content of the siren sounds is so poor" to enable localisation. Common warning signals comprise single frequencies that change frequency and amplitude over time, and it has been shown that humans have difficulty in identifying the correct location of the source of pure tones [35,36].

Although the ability for motorists to correctly identify the source direction of a warning signal is important, a precursor is that the motorist has heard the warning signal. It will be shown in the following section that the combined effects of limited siren output, a compromised sound radiation pattern, high noise reduction of a vehicle cabin and background noise means that the siren signal will often be 'masked'.

Catchpole and McKeown measured the Localiser siren radiating into *free-field* at a distance of 11m (Fig 3. [15]) and showed that the highest sound pressure level was between 3kHz-5kHz, and suggested that it would be more likely to be detected than the 'wail' and 'yelp' sirens. However, modern vehicles are acoustically designed to have high transmission loss above 1kHz, and hence will significantly attenuate high-frequency siren noise compared to low frequency noise.

EXPERIMENTAL TESTING

Measurement of siren loudspeaker directivity

Acoustic directivity measurements of a siren were conducted to measure the variation in the off-axis radiated sound compared to the on-axis sound levels. Two siren loudspeakers that are used in the South Australian ambulance fleet were individually tested using a white-noise source. The tests were conducted in an anechoic chamber with a reflecting ground plane, and a backing plane behind the loudspeaker. The measurements were taken at 0, 30, 45, 60, and 90 degrees from the axis of the siren, at a distance of 1.8m, which is in the acoustic 'far-field' at the acoustic wavelengths of interest.

Figure 1 shows the difference between the measured total sound pressure level and the maximum total sound pressure level for one of the sirens, which was directly in front of the speaker at 0 degrees, which shows the attenuation of the sound level with angle.

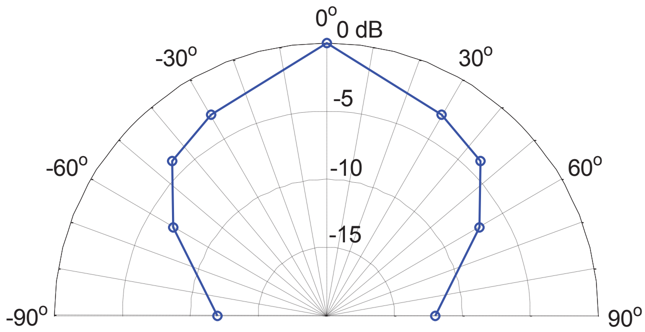

Figure 1: Measured directivity of a siren, displayed as difference from on-axis sound pressure level.

The results for the test on the second siren displayed a nearly identical radiation pattern as the first siren. The results show that there is significantly less (12dB) sound radiated at 90 degrees to the axis of the siren. This would be subjectively interpreted as less than half as loud (p85 Ref. [17]). This is an important finding as collisions between ambulance vehicles and motorists occur when transiting four road intersections, where the warning signal should be projected to the side of the ambulance. For example, when an ambulance approaches a four-way intersection where they are approaching a stop light, there is usually cross-wise vehicular traffic movement. Ambulances will stop before entering the intersections to ensure that vehicles on the cross-wise roads have stopped. Unfortunately, some vehicles do not stop and collide with the ambulance attempting to cross the intersection. Hence, it is recommended that ambulance vehicle operators install additional siren loudspeakers that project sound transverse to motion of the ambulance, or sirens that provide consistent sound radiation over +/- 90 degrees from the axis of the siren.

Sound power measurements of sirens

Most literature quote Sound Pressure Levels (SPLs) for sirens measured at a distance from the siren. However, these values are dependent on the measurement distance and mounting location of the siren. An alternative method used to characterise sound sources is the measured radiated acoustic power, which is independent of measurement distance and mounting location.

Experiments were conducted to measure the total acoustic sound power the systems listed in Table 1.

The Rumbler unit is intended to be installed as a complement to a primary audio warning system. The Rumbler unit obtains the input audio signal from the output of the primary warning system amplifier, then frequency shifts, low-pass filters, amplifies and broadcasts by sub-woofer loudspeakers.

Table 1: Configuration of sirens for sound power measurements.

Hazard Systems	Signals: generated by Hazard Systems unit: 'wail' and 'yelp'. Amplifier: Hazard Systems. Sirens: 2 – Hazard Systems siren model 810-011.
Federal Signal Rumbler	Signals: 'wail' and 'yelp' generated by Hazard Systems unit that the Rumbler frequency shifts and low pass filters. Amplifier: Federal Signal Rumbler Sirens: 2 – Federal Signal Rumbler, sub-woofers.
European	Signals: generated by European Unit: Police (France), Gendermerie (France), Pompiers (France), UMH (France), Ambulance (France), Polizia (Italy), Ambulanza/Vigili del Fuoco (Italy), 2 Ton Police (Norway), 3 Ton Fire Brigade (Norway), Feuerwehr (Fire Brigade) (Germany), Rettungsdienst (Emergency Service) (Germany), Polizei (Germany), Pistensignal (Runway Signal) (Germany), Fire Brigade (UK). Amplifier: European Unit. Sirens: 2 – Hazard Systems horn type.

The sound power measurements were conducted in an acoustic reverberation chamber using the 'absolute method' [17], a traversing calibrated Bruel and Kjaer microphone, and a Larson Davis 2900 spectrum analyser. The results of the one-third octave band sound power measurements are shown in Figure 2, and show that the sirens exhibit similar sound power levels, and broadcast a similar frequency range. The frequency range of the 'Rumbler' siren is distinguishable, emitting between 125Hz-500Hz. This result is important as it will be shown that low-frequency sound can better penetrate a vehicle cabin than high-frequency noise.

Figure 3 shows the A-weighted total sound power of the sirens. The 'Rumbler' siren has a lower A-weighted total sound power than the other siren types, as it emits noise in a lower frequency band compared to the other sirens where the A-weighting reduces the contribution. However this is not necessarily detrimental, as it is the perceived loudness of the sound at the *receiver* that is the important characteristic, which is also dependent on the transmission loss of the vehicle cabin, and in the frequency range of the Rumbler siren vehicle cabins have poor transmission loss, which can lead to a higher interior noise level compared to the emission of a high frequency siren noise.

Noise reduction of a passenger vehicle

The purpose of conducting this experiment was to quantify the noise reduction of a typical passenger vehicle. The vehicle tested was a 2005 Mitsubishi Magna station wagon. The test was conducted by placing a microphone at the driver's seat position. Two large loudspeaker enclosures that emitted white noise were positioned in front of the vehicle, at the rear of the vehicle and to the driver's side of the vehicle, at a distance of 4.2m from the microphone in each case. The doors and windows on the vehicle were closed for the tests. The sound pressure levels at the driver's position were recorded and subtracted from the sound pressure level at the microphone when the vehicle was absent. The difference between these two levels represents the noise reduction of the vehicle.

The results from the experimental testing are shown in Figure 4 and show the expected trend of poor noise reduction at low frequencies, and high attenuation at high frequencies.

Catchpole and McKeown [15] recommended adding high-frequency content "… would improve vehicle penetration…", however as shown in Figure 4 there is high noise reduction at high frequencies. Hence it is unlikely that the addition of high frequency content in sirens will improve vehicle penetration.

The frequency ranges of the Hazard Systems 'wail' and 'yelp', and Rumbler sirens, that broadcasted frequency shifted and low-pass filtered versions of the 'wail' and 'yelp' signals, are highlighted in Figure 4, and shows that the standard sirens operate in the range where the car exhibits high noise reduction and the Rumbler operates where there is less noise reduction. Hence, installation of a siren that emits low-frequency content will have greater vehicle penetration than the same amplitude at higher frequencies. Non-acousticians will be familiar with this effect from the pass-by noise of car audio systems with sub-woofer loudspeakers.

Masking by background noise

The siren noise that is received by the driver of a vehicle must be sufficiently loud to be detected. There are many sources of noise that can mask siren noise such as road traffic, car audio, air-conditioning and ventilation fans [37].

Corliss and Jones [38] have investigated the issue of siren noise penetrating vehicles and the minimum levels that a person can hear a tonal siren noise in the presence of background noise, called the masked threshold levels. They suggest that the sound pressure level of an emergency siren should be about 72dB re 20µPa for quiet interior conditions, and with an assumed 30dB of attenuation provided by a closed car, it must have a level of excess 100dB outside the car.

Robinson and Casali [39] describe two methods used for the prediction of the detectability of a siren in the presence of background noise, namely the 'The Critical Band Method' and the international standard 'ISO 7731-1986: Danger signals for work places -- Auditory danger signals' [40]. The critical band method is based on the physiology of the human ear [41,42]. These methods are used to calculate *masked thresholds*, which basically provide a conservative estimate of the sound levels needed for a signal to be detected, from measured levels of a background noise. In general, a signal is less affected by masking if it is relatively complex in nature and has a relatively large contrast with the background noise. It is stated that signal levels 6-10 dB above the masked thresholds will ensure 100% detectability, and that signal levels approximately 15 dB above the masked thresholds are recommended for ensuring rapid response from the listener.

Robinson and Casali [39] recommend characteristics for auditory danger signals in the context of a workplace. However many of these recommendations are applicable to ambulance sirens warning motorists. Some of the relevant recommendations include:

- The signal should exceed the masked threshold by at least 15 dB above masked threshold across the entire spectrum where possible.

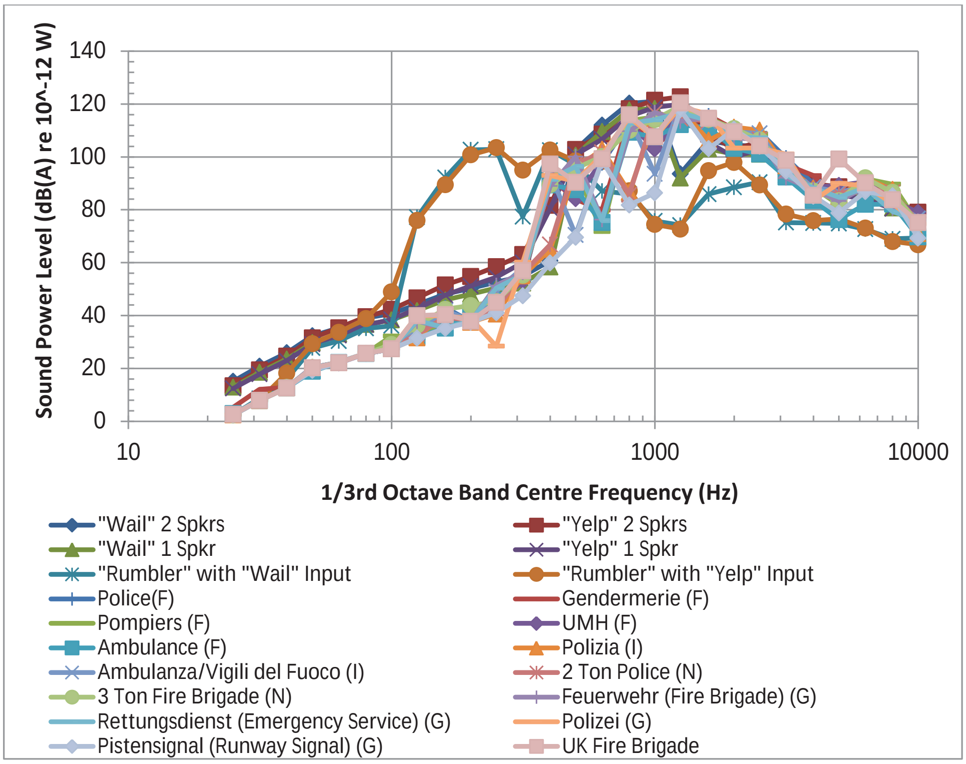

Figure 2: Sound power levels (A-weighted) of all sirens.

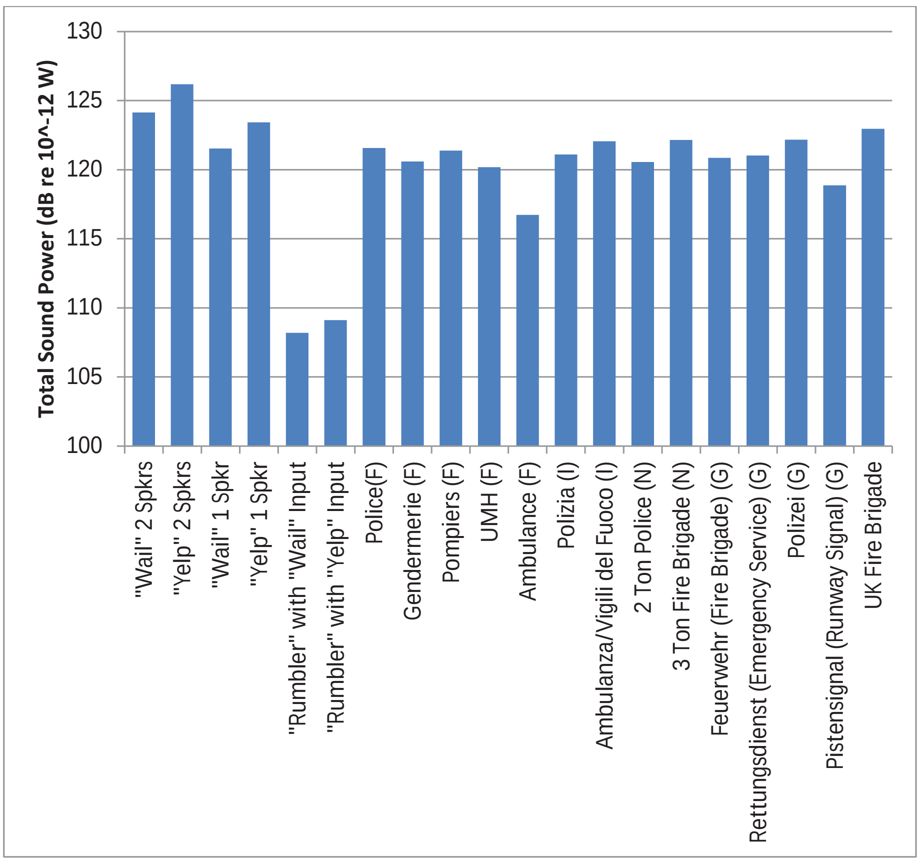

Figure 3: Total A-Weighted sound power levels of all siren

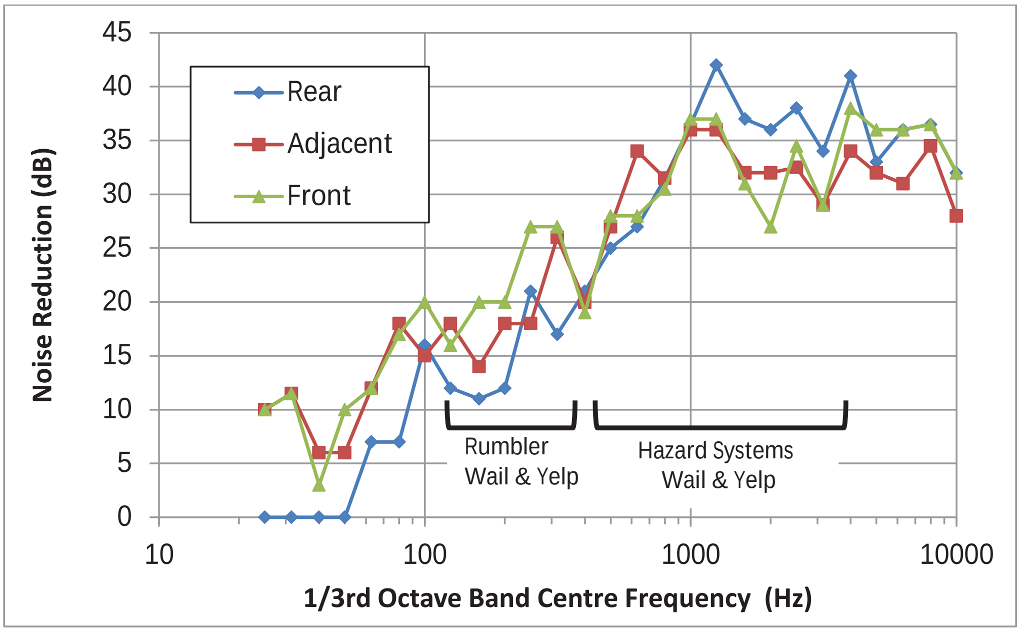

Figure 4: Noise reduction of an average passenger vehicle

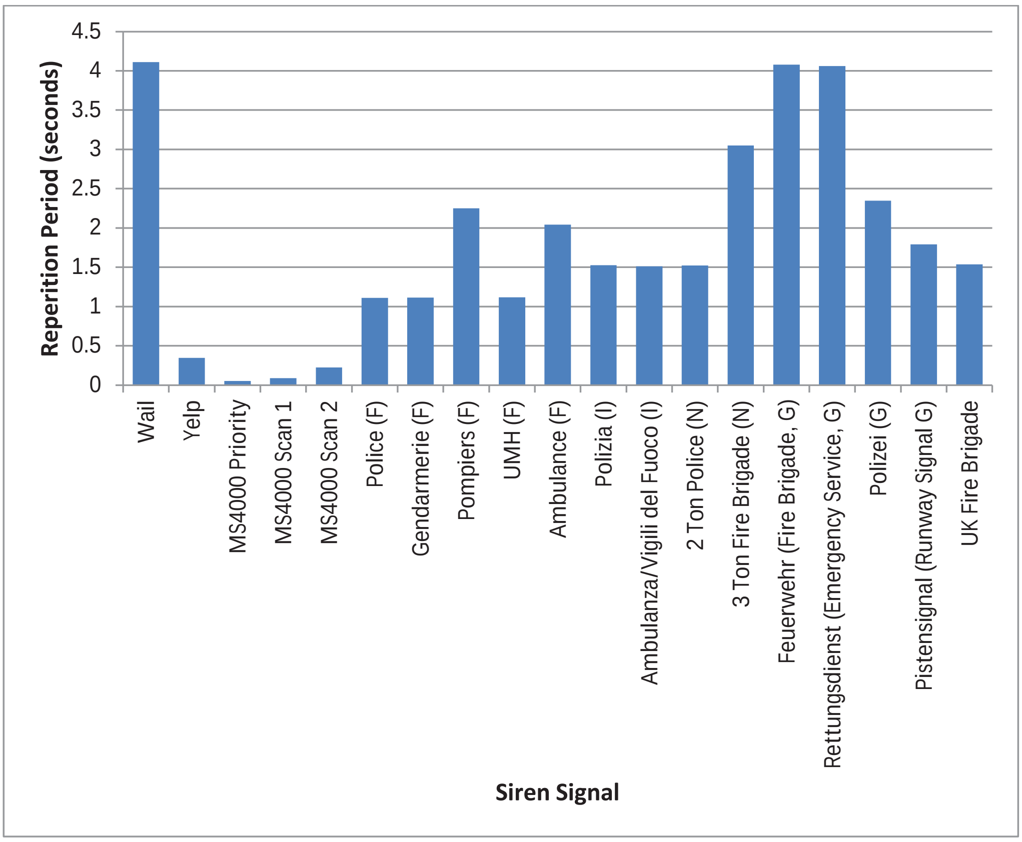

Figure 5: Repetition period of siren signals.

- Frequencies higher than 3000Hz are not recommended as subjects with noise-induced hearing loss are more likely to be disadvantaged by not being able to detect such signals.
- Complex signals with harmonic components with a fundamental frequency below 1000 Hz should be used.
- Signals below 1000Hz should be used for outdoor alarms as such low frequencies are less affected by atmospheric absorption and are more effective in regards to diffraction around barriers, such as vehicles and buildings.

The last recommendation to use low frequency sirens is consistent with the recommendation by Mortimer [43], to use low frequency horns on trains to enhance sound propagation and penetration into vehicles.

The requirements for sirens are described in the standard 'ISO 7731-2003: Ergonomics - Danger signals for public and work areas - Auditory danger signals' [44], in regards to masking as:

- The siren signal should exceed the masked threshold by at least 13dB in one or more 1/3 octave bands.
- A-weighted sound pressure level of the signal should be at least 15dB greater than that of the background noise.

Perceived urgency

The term 'Perceived Urgency' is used to describe the urgency inherent in a warning signal, and is a product of its acoustic characteristics. Hellier and Edworthy [45] conducted human jury testing of various sounds to evaluate perceived urgency where parameters such as pitch, speed, rate of repetition, in-harmonicity and length were altered. Their investigations showed (and confirmed by other researchers [46-47]) that a sound source that repeats quickly was the most important parameter affecting perceived urgency: the shorter the repetition of the sound source, the higher the perceived urgency.

To determine the perceived urgency of the sirens examined in the work presented here, the repetition period of the sirens were measured using the audio editing software Audacity, and the results are shown in Figure 5.

The results show that the 'wail' siren, which is used widely in Australian ambulance fleets, has one of the longest repetition periods of the signals examined. The 'yelp' siren has a faster repetition period than the 'wail' siren and should convey a higher degree of perceived urgency.

The Federal Signal 'MS 4000 Priority' siren exhibited the shortest repetition period, and is likely to convey the highest perceived urgency of the sirens tested. The situations that require conveying a high degree of urgency include approaching intersections, clearing vehicles ahead in the same lane, and lane changing into oncoming traffic, and therefore it is recommended that the 'Priority' signal be broadcast at appropriate situations.

Passenger vehicle background noise masked threshold calculation

Experiments were conducted to measure typical background noise levels inside a moving vehicle. The results were used calculate the masked threshold levels using the critical band method [39]. The one-third octave-band average sound pressure levels (L_{eq} 30 seconds) were recorded using a Larson Davis 2900 sound level meter. The microphone was calibrated before conducting the measurements. The measurements were conducted in a 2005 Mitsubishi Station Wagon, driving through the central business district of Adelaide. All measurements were taken in the front passenger seat of the vehicle at ear height. The test cases are listed in Table 2.

Table 2: Driving field-test cases.

Test No.	Radio	Windows	Overall SPL [dBA]
1	Off	Closed	58
2	Off	Open	66
3	On	Closed	78

Figure 6 shows the one-third octave band masked thresholds using the Critical Band Method [39]. It is observed, that the sound pressure levels with radio turned on exhibited the highest levels for most of the measured frequency range. The second highest levels occurred while driving with the windows open, and the lowest levels were with the windows closed.

Figure 7 shows the masked threshold level for the test with the windows closed and the radio turned on, compared with the predicted in-car sound pressure levels from a wail and Rumbler siren located 20m from the car. The results indicate that it would be difficult to hear the wail siren, and that the Rumbler siren might just be audible. These results are consistent with Ref [37] that stating that the average siren attenuation, through closed-windows and typical masking noise, resulted in an effective distance of siren penetration of only 8-12 m at urban intersections, which is an insufficient distance to alert road users to safely clear the path.

Additional locations for sirens

It is common for sirens to be mounted at the front of an ambulance beneath the front grill or bumper and point forwards. As noted previously, that most collisions between emergency vehicles and motorists occur at intersections [3-7], there is a need to broadcast the warning signal transverse to the ambulance. Two potential locations for installing sirens are shown in Figure 8: in both front wheel arches and on the light bar on the roof on both passenger and driver sides. Measurements were conducted of the Sound Pressure Level at the driver's position when the 'wail' siren was operational at the three locations shown in in Figure 8, and the results are listed in Table 3.

Table 3: Total A-weighted siren sound pressure levels that can be expected within cabin according to different mounting locations

Position	Total Sound Pressure Level (dBA, re 20μPa)
Current Position on Front Bumper	71
Roof Location	79
Front Wheel Arch	72

The results indicate that mounting the siren on the light bar on the roof increases the interior sound pressure level at the driver's ear by about 8dB, which would be clearly perceptible. Although this level of 79dBA is below the recommended

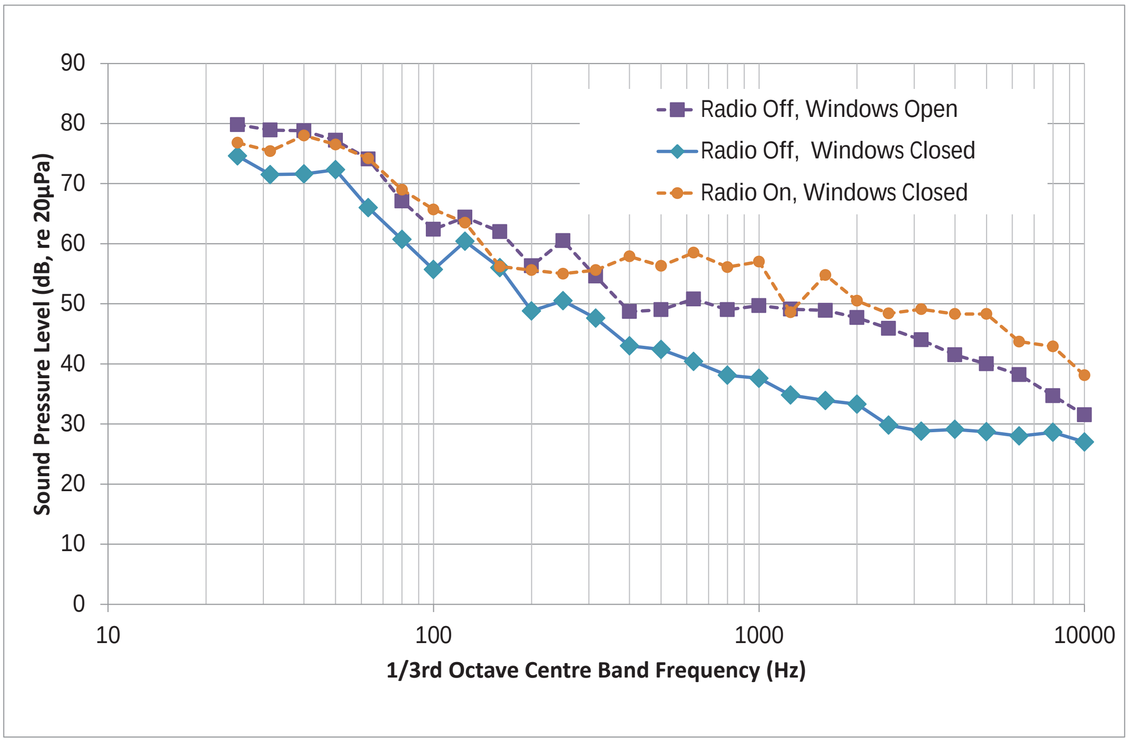

Figure 6: Masked thresholds while driving for three test cases, using L_{eq} levels over 30 seconds.

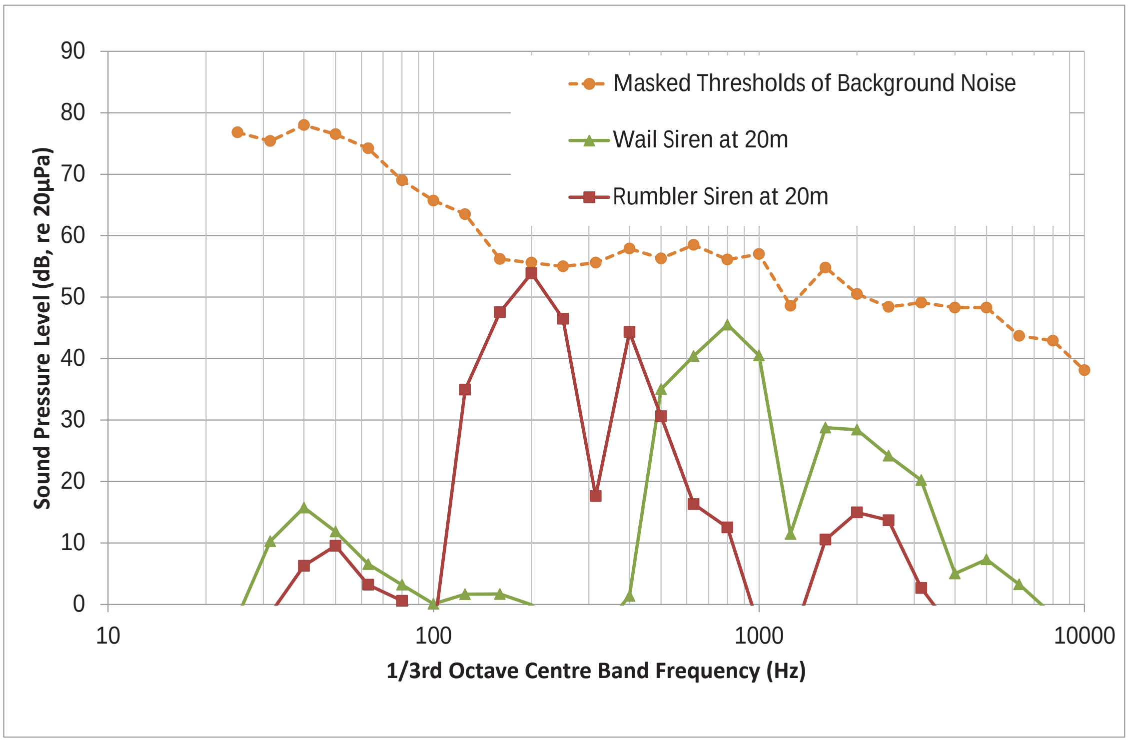

Figure 7: Masked threshold Sound Pressure Levels when driving with the radio on and windows closed, and the predicted vehicle interior SPLs from the Wail and Rumbler sirens.

Occupational Health and Safety guidelines of 85dBA (8-hours), paramedic crews currently have communications difficulties and hence it would not be advisable to install additional sirens on the roof. However installation of additional sirens in the wheel arch only increased the interior noise levels by about 1dB, which is subjectively unperceivable [17].

Figure 8: Potential mounting locations for sirens.

SUMMARY

The study conducted here considered several factors and the summary of the findings are described below.

Intrusiveness

Researchers have found that the human response to an auditory alarm depends on psychoacoustics and whether a subject is occupied with a foreground task. Studies indicate that the amplitude of a warning signal to attract attention needs to be 10dB higher if the subject is involved in a foreground task compared to when the subject is waiting for the signal. This result is applicable to warning driving motorists of an approaching emergency vehicle.

Localisation

Previous studies have shown that when motorists are able to correctly identify the source direction and movement of a warning signal, that they are correctly able to take evasive manoeuvres. Warning signals with high or broadband content improve the Localisation of warning signals. However, it was found that these hybrid signals are not widely recognisable as warning signals [15]. In addition, modern vehicles are designed to provide good "acoustic comfort" to passengers, and one of the key metrics that is minimised is the A-weighted sound pressure level [48,49]. As a consequence, vehicle cabins provide good sound transmission loss in the mid- to high-frequency ranges (1-8kHz), which unfortunately corresponds to the frequency range required to improve the localisation of a warning signal. Also, a vehicle with closed windows has an enclosed semi-reverberant sound field that blurs the direct-path of an external warning signal, which will decrease the ability of a motorist to correctly identify the direction of a sound source.

Directivity

Measurements of the acoustic directivity of a siren used on a fleet of ambulances that showed that there was about a 12dB decrease in sound level at 90 degrees to the axis of the siren, compared to the on-axis sound level. The Society of Automotive Engineers standard for emergency sirens [23] and the California Code of Regulations [50] only provide recommendations for sound levels of sirens within +/- 50 degrees of the axis of the siren. The recommendation from the work conducted here is that emergency vehicles should be fitted with sirens that project a warning signal transverse to the ambulance direction, in order to improve the audibility of the siren to converging vehicles. Alternatively, sirens that have a consistent sound radiation pattern over +/- 90 degrees from the axis of the siren are also suitable.

Sound power

The sound power of several sirens was measured in an acoustic reverberation chamber and they had similar levels. The frequency range was also similar, with the notable exception of the Rumbler siren that is designed to emit low-frequency sound. Although simply increasing the sound power output from sirens well above the masked threshold levels would improve their detection rate, standards exist that prescribe maximum sound pressure level limits and many sirens are designed to operate close to these limits. Currently there is no opportunity to increase the output sound power from sirens, and other methods must be employed to improve the detectability of a siren.

Noise reduction

Modern vehicles are designed to have a comfortable acoustic environment, and as a result of the materials used they provide high sound transmission loss above 1kHz. It was found that the noise reduction of a passenger vehicle is greater than 30dB above 1kHz, and hence warning signals with high-frequency content are significantly attenuated. Vehicles exhibit only moderate noise reduction around 100Hz and hence warning signals with low-frequency content have greater penetration into vehicles compared to high-frequency warning signals. Hence it is recommended that emergency vehicle operators consider using a combination of low-frequency and their current warning signals.

Masking noise

Experiments were conducted to estimate the background noise level in a typical passenger vehicle for three conditions. Driving with the windows closed and a radio playing music at moderate level resulted in the highest background noise levels, with the vehicle cabin providing the highest noise reduction. Research has indicated that the critical band method is a useful tool for predicting the required amplitude of a signal to be detected. However this estimated level must be increased as motorists are engaged in a foreground task and are not expecting a warning signal.

Perceived urgency

The acoustic characteristic of a signal that has the greatest influence in conveying the importance of an alarm is the period of repetition. Several warning signals were examined and it was found that the Federal Signal 'MS 4000 Priority' had the shortest period and hence conveys a high degree of urgency.

Mounting locations

Although many emergency vehicles have sirens that face forwards, it is important to ensure that the acoustic radiation pattern of the siren adequately broadcasts transverse to the motion of the vehicle, to ensure that converging motorists can hear the warning signal. Mounting additional sirens near the front wheel arches and facing transverse to the vehicle can improve the radiated sound field.

CONCLUSIONS

The desirable acoustic qualities for warning signals broadcast by emergency vehicles result from a system of noise transmission, psychoacoustics, standards, and practicalities. The selection of an effective warning signal involves many competing factors that ultimately requires making compromises.

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THE FUNDAMENTALS OF POWER ULTRASOUND – A REVIEW

Thomas Leong, Muthupandian Ashokkumar and Sandra Kentish*
Department of Chemical & Biomolecular Engineering and School of Chemistry,
University of Melbourne, VIC 3010
sandraek@unimelb.edu.au

The principal method behind applications of power ultrasound is that of acoustic cavitation. This paper aims to provide an overview of bubble behaviour during acoustic cavitation, including phenomena such as transient and stable cavitation, rectified diffusion, coalescence and sonoluminescence. Application of these effects to processes such as nanomaterial synthesis, emulsion formation and waste water treatment is then described.

INTRODUCTION

Power ultrasound refers to the section of the sound spectrum from 20 kHz through to around 1MHz. The basis of many applications of ultrasound in this frequency range is acoustic cavitation, which is the formation, growth and collapse of microbubbles within an aqueous solution [1] resultant from pressure fluctuations that occur in the applied sound field. The event of a collapsing bubble is a microscopic implosion that generates high local turbulence and the release of heat energy. The consequence is a significant increase of temperature and pressure of up to several thousand degrees Kelvin and several hundred Bar. These physical phenomena are the same as those reported in hydrodynamic cavitation which results in damage of mechanical items such as pumps and propellers [2].

These effects can be exploited in a vast array of beneficial applications [3]. Elevated temperatures [4] in the vicinity of collapsing bubble "hot spots" can be utilised to enhance the chemical reaction rates of some processes, due to the increased heat and the formation of free radicals. Strong disturbances of pressure resultant from shockwave emissions lead to mechanical effects such as mixing and shearing which, for a chemical reaction, can serve to increase encounters between reactants, accelerate dissolution or aid the renewal at the surface of a solid reactant. These conditions, generated by the collapse of bubbles, are the basis for most aspects of sonoprocessing and sonochemistry. Examples of significant applications of acoustic cavitation developed for commercial use include wastewater treatment [5], food and beverages processing [6], and the formation of protein microbubbles which can be used for image contrast agents [7] or drug delivery vehicles [8].

The current review briefly covers the main concepts which are vital to the understanding of the cavitation phenomena followed by an overview of some of the current applications of ultrasound induced cavitation and some thoughts on what will be in store for the future. On the subject of acoustic cavitation, Neppiras [9] has written an excellent review that covers the important physics of cavitation in sound fields. Other invaluable sources of information can be found in the books by Young [1], Brennen [10] and Leighton [11] which detail the mathematical derivations of the basic theories of cavitation and bubble dynamics along with experimental data for these theories. A more recent review by Lauterborn [12] is another excellent reference for those wishing to gain an insight to the fundamental behaviour of bubbles in an acoustic field.

HISTORY

Cavitation was first reported in 1895 by Thornycroft and Barnaby [2] when they observed that the propeller of their submarine became pitted and eroded over a relatively short operation period. Their observation was the consequence of collapsing bubbles due to hydrodynamic cavitation that generated intense pressure and temperature gradients in the local vicinity. In 1917, Lord Rayleigh [13] published the first mathematical model describing a cavitation event in an incompressible fluid. It was not until 1927 when Loomis [14] reported the first chemical and biological effects of ultrasound, that workers recognised that cavitation could be a useful tool in chemical reaction processes. One of the first applications reported in the literature was the use of ultrasound induced cavitation to degrade a biological polymer [15]. Since then, applications of ultrasound induced cavitation have increased in popularity, particularly as novel alternatives to processes such as the production of polymer [16], for the enhancement of chemical reactions [17], emulsification of oils [18] and degradation of chemical or biological pollutants [19]. The advantage of using acoustic cavitation for these applications is that much more mild operating conditions are utilised in comparison to conventional techniques and many reactions which may require toxic reagents or solvents are not necessary.

ACOUSTIC CAVITATION AND BUBBLE FORMATION

In acoustic cavitation, a sound wave imposes a sinusoidally varying pressure upon existing cavities in solution [1] (see Figure 1). During the negative pressure cycle, the liquid is pulled apart at sites containing such a gaseous impurity, which are known as "weak spots" in the fluid. The number of bubbles that are produced during this rarefaction cycle is proportional to the density of such weak spots present in the fluid [10].

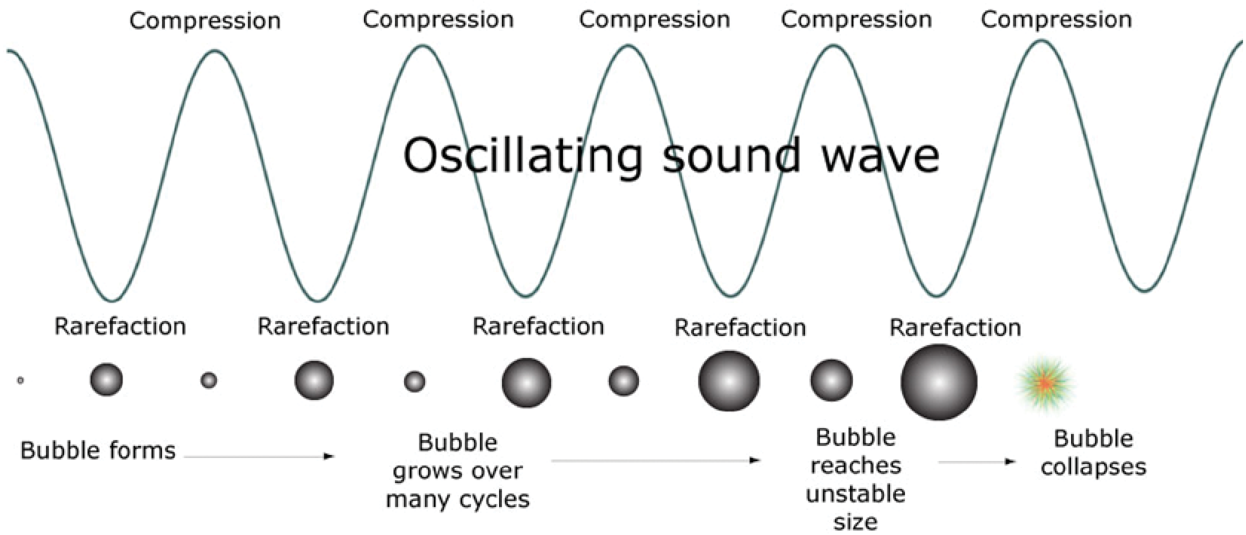

Figure 1: Graphical summary of the event of bubble formation, bubble growth and subsequent collapse over several acoustic cycles. A bubble oscillates in phase with the applied sound wave, contracting during compression and expanding during rarefactions.

There are two known mechanisms for cavity or bubble formation [1]. One mechanism involves pre-existing bubbles in the liquid which are stabilised against dissolution because the surface is coated with contaminants such as a skin of organic impurity. A second mechanism relies on the existence of solid particles (motes) in the liquid with gas trapped in these particles, where nucleation takes place. There can also be tiny crevices in the walls of the vessel or container where gas is trapped. The pressure inside a gas crevice is lower than the outside liquid pressure. Consequently, gas diffuses into the gas pocket, causing it to grow. A bubble is then created as the gas pocket departs from the crevice under the influence of a radiation force.

As can be seen in Figure 1, a bubble formed in one of these ways may then grow until it reaches a critical size known as its *resonance* size. The *resonance* size of a bubble depends on the applied frequency of the sound field. When bubbles reach their *resonance* size due to growth by processes called *rectified diffusion* or *coalescence*, two possible events may occur. The bubble may become unstable and collapse, often violently, within a single acoustic cycle or over a small number of cycles. This is termed *transient* cavitation. The other possibility is that the bubble oscillates for many cycles at, or near, the linear resonance size. This is termed *stable* cavitation. The terms *transient* and *stable* cavitation are also used to define whether or not the bubbles are active in light emission (sonoluminescence) or chemical reactions [20].

A simple relationship that can relate the resonance size of the bubble with the frequency is given by equation (1):

$$F \text{ x } R \approx 3 \tag{1}$$

where F is the frequency in Hz and R is the bubble radius in m. Note that this equation gives only a very approximate theoretical resonance size [1, 11].

A more accurate version of equation (1) is the linear resonance radius which can be calculated using the following equation [1]:

$$R_r = \sqrt{\frac{3\gamma p_\infty}{\rho\omega^2}} \tag{2}$$

where γ is the specific heat ratio of the gas inside the bubble, p_∞ is the ambient liquid pressure, ρ is the liquid density and ω is the angular frequency of ultrasound (all in SI units). In practice, the size for an active bubble is usually smaller than this radius due to the nonlinear nature of the bubble pulsation [21].

At 20 kHz ultrasound frequency, the bubbles generated in the sound field are relatively large and their collapse results in strong shockwaves which can be useful for mechanical shearing applications such as emulsification [18]. Between 100 to 1000 kHz, the bubbles generated are much smaller. However, their collapse induces a higher increase in temperature which can be more useful for sonochemical purposes [22]. At above 1 MHz frequency, cavitational effects are much weaker. However, there are some industrial applications in this frequency range such as the gentle cleaning of electronic parts and the nebulisation of liquids to create fine sprays. This higher frequency range is also commonly used for medical and industrial imaging purposes.

BUBBLE BEHAVIOUR IN AN ACOUSTIC FIELD

Gas bubbles in liquids under the influence of a sound field can do several things, as can be seen in Figure 2. A bubble can meet another bubble in solution, combining to form a larger bubble. This is termed *coalescence*. In a gas saturated solution such as water above a certain threshold pressure, individual bubbles can also grow with time over several acoustic cycles. This is termed *rectified diffusion*. If gas bubbles grow large enough, they can leave the system entirely due to buoyancy. This is termed *degassing*. Bubbles of a certain size can also become unstable and collapse, often violently. The range of bubble radii at which this occurs is very wide, and is usually much lower than the linear resonance radius [21]. Bubble collapse can sometimes be accompanied by fragmentation into smaller bubbles. Under suitable conditions, light emission can be observed, and this is

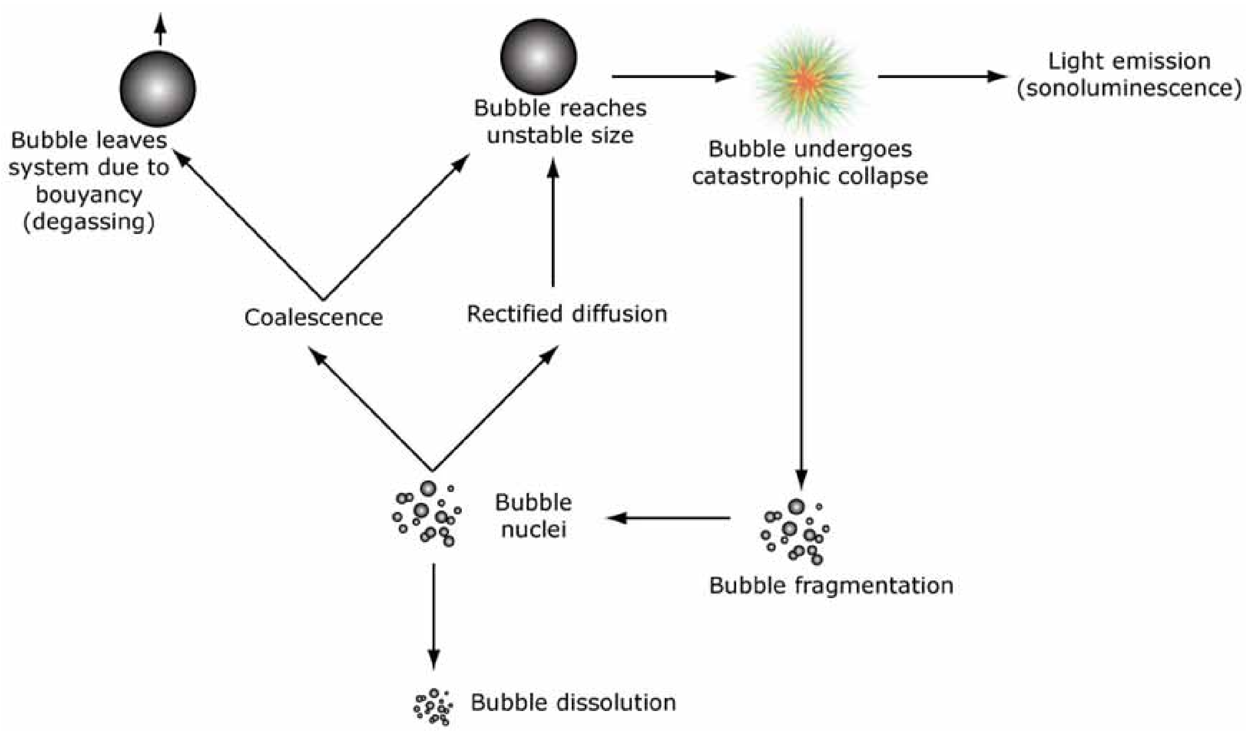

Figure 2: Bubble nuclei under the influence of an acoustic sound field can grow via either coalescence or rectified diffusion. Upon reaching an unstable size, the bubble will collapse, possibly fragmenting to form smaller bubbles accompanied by an emission of light if conditions are suitable. Bubbles that become bigger than the resonance size will leave the system by buoyancy.

termed *sonoluminescence*. Bubbles below the threshold pressure for rectified diffusion can dissolve into solution.

It is possible to predict the behaviour of a single gas bubble provided knowledge is known about the radius, the driving frequency, the driving pressure and the dissolved gas concentration. Each of these phenomena is described in more detail in the following sections.

The onset of stable and transient cavitation

Apfel [23, 24] has used equations for bubble growth thresholds developed by Safar [25] to produce a series of cavitation prediction charts. An example of these charts, for a 10 kHz frequency system is shown in Figure 3 and illustrates the areas of different cavitation activity:

Region A – The bubbles are under inertial control and bubble growth only occurs via rectified diffusion. Upon reaching resonance ($R/R_r = 1$) the bubbles undergo more violent behaviour and collapse.

Region B – Growth by rectified diffusion and/or by mechanical means may occur although the bubble is not initially transient. Upon fragmentation, the microbubbles formed may exist in region C.

Region C – This region is the transient region for cavitation and the border with region B indicates the transient threshold, also known as the *Blake threshold* [26].

Safar's equation enables the prediction of the rectified diffusion pressure threshold P_D for a bubble of radius R_D (Equation (3)) and indicates the threshold between Regions A and B:

$$\frac{P_D}{P_0} = \frac{[3\eta(1+2\sigma/P_0R_D) - 2\sigma/P_0R_D]\,[1 - \omega^2/\omega^2 r]\,[1+2\sigma/P_0R_D - C_i/C_0]^{1/2}}{[6(1+ 2\sigma/P_0R_D)]^{1/2}} \quad (3)$$

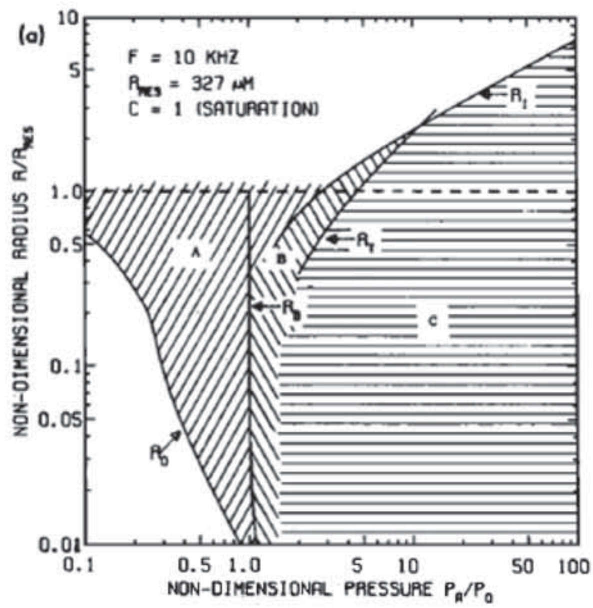

Figure 3: Cavitation prediction chart for a 10 kHz system in a 100% gas saturated system taken from Apfel [24]. Region A is for a bubble under inertial control, B the region for growth by rectified diffusion and C the region for transient cavitation.

Here, η is the solution viscosity, σ is the surface tension, ω and ω_r the driving and resonance frequency respectively, P_0 the ambient pressure, and C_i and C_0 are the concentrations of dissolved gas in the liquid far from the bubble and at saturation, respectively. The *Blake threshold pressure* P_B is defined as:

$$P_B = P_0 + \frac{8\sigma}{9}\left\{\frac{3\sigma}{2[P_0 + (2\sigma/R_B)]\, R_B^3}\right\}^{1/2} \tag{4}$$

Neppiras [27] developed similar predictions for the transient thresholds based on Apfel's criterion for a bubble at the radius of the transient threshold and Blake's threshold pressure. He used another expression from Safar [25] which included a multiplying factor that extended the formula so that it applied for bubbles through to resonance, not just $R_0 < R_r$. More recently, computer simulations performed by Yasui [28] for various acoustic frequencies have been used to show different regions of bubble behaviour, namely *dissolving* bubbles, *stable* and *unstable* bubbles which may emit SL under the correct conditions, and *degas* bubbles, which oscillate radially at a low amplitude and do not emit SL.

In a multibubble system, the behaviour of bubbles is more complex due to the multiple pathways in which a bubble can enter or leave the system and also different pathways in which it can grow or collapse. It is both difficult to predict theoretically and monitor experimentally the precise bubble behaviour in such systems. In order to understand bubble behaviour in an acoustic field, it is prudent to begin from the simplest case of a single bubble that is oscillating in an acoustic field.

Dynamics of a single bubble

The *Rayleigh-Plesset* equation is commonly used to model the fundamental motion of a bubble in an acoustic field. Those looking for an in depth derivation of the equation can find it in the book by Young [1].

For motion of the bubble wall we have the result derived by Besant [29]:

$$\frac{P_L - P_\infty}{\rho} = R\ddot{R} + \frac{3}{2}\dot{R}^2 \tag{5}$$

where R is the radius of the bubble wall at any time, $\dot{R}$ is the wall velocity, P_∞ is the pressure in the liquid at infinity, P_L is the pressure in the liquid at the bubble wall and ρ the liquid density.

Noltingk and Neppiras [30, 31] extended this fundamental equation to include the effects of surface tension due to the Laplace pressure of the bubble (Equation (6)). To take this into account, at $R = R_0$ the gas pressure in the bubble is $P_0 + 2\sigma/R_0$ where P_0 is the ambient pressure in the liquid and σ is the surface tension. Adiabatic heat transfer is assumed with γ being the ratio of specific heats of the gas.

$$R\ddot{R} + \frac{3}{2}\dot{R}^2 = \frac{1}{\rho}\left[\left(P_0 + \frac{2\sigma}{R_0}\right)\left(\frac{R_0}{R}\right)^{3\gamma} - \frac{2\sigma}{R} - P_\infty\right] \tag{6}$$

A viscosity term for the liquid was later added by Poritsky [32] and he showed that this term arises only in the boundary conditions rather than through the Navier-Stokes equation. The equation then becomes

$$R\ddot{R} + \frac{3}{2}\dot{R}^2 = \frac{1}{\rho}\left[\left(P_0 + \frac{2\sigma}{R_0}\right)\left(\frac{R_0}{R}\right)^{3\gamma} - \frac{2\sigma}{R} - \frac{4\eta\dot{R}}{R} + P_\infty\right] \tag{7}$$

where η is the viscosity of the liquid. Equations (5), (6) and (7) are often referred to as the *Rayleigh-Plesset* equation and are fundamental in the analysis of bubble behaviour.

We usually subject the bubble to a sound field such that the pressure P varies as

$$P = P_0 - P_A \sin\omega t \tag{8}$$

where P_0 is the steady state pressure (usually atmospheric pressure), ω is the angular frequency and P_A is the amplitude of the driving pressure. When we add this pressure term into Equation (6), we obtain

$$R\ddot{R} + \frac{3}{2}\dot{R}^2 = \frac{1}{\rho}\left[\left(P_0 + \frac{2\sigma}{R_0}\right)\left(\frac{R_0}{R}\right)^{3\gamma} - \frac{2\sigma}{R} - (P_0 - P_A \sin\omega t)\right] \tag{9}$$

which is the fundamental equation of a single gas bubble under the influence of an oscillating sound wave.

Rectified diffusion – growth of a single bubble

The fundamental equations from the previous section have been applied to model the process of bubble growth or dissolution known as rectified diffusion. This phenomenon relates to an unequal transfer of mass across the bubble interface during the rarefaction and compression of the sound wave cycle. Above the threshold pressure for rectified diffusion, this unequal mass transfer causes the bubbles to slowly grow. Below this pressure, the bubble dissolves due to the greater influence of the Laplace pressure exerted on the bubble wall by surface tension. Those looking for an elegant review of the history of the developments of the theory behind rectified diffusion should refer to the work by Crum [33].

Eller and Flynn [34] developed a theory to account for this uneven mass transfer by two main effects. These are known as the *area* and *shell* effects. The *area* effect refers to the fact that diffusion of gas into the bubble occurs when the bubble is larger during the expansion phase, whilst diffusion out of a bubble occurs when the bubble is smaller during the compression phase. As the rate of diffusion across an interface is proportional to the surface area available for mass transfer, more gas diffuses into the bubble than out. Over a number of acoustic cycles, a net inflow of gas into the bubble results, leading to bubble growth.

The *shell* effect refers to the mass transfer boundary layer through which mass transfer occurs. As the bubble shrinks in the compression phase, this shell thickness increases. In contrast, as the bubble expands, the shell thins as depicted in Figure 4. The concentration gradient is thus lower when the bubble is in compression, thereby resulting in a lower driving force for mass transfer.

The solution to the rectified diffusion problem is an interesting one, as it is complicated by a moving boundary layer as the bubble oscillates. This problem has been solved in two different ways by both Eller and Flynn [34] and Hsieh and Plesset [35,36], and details of their approach can be obtained in their papers.

Figure 4: A depiction of the change in mass transfer boundary layer (shell) thickness of a bubble during the expansion and compression cycles of an acoustic wave. The concentration gradient is thus enhanced during bubble expansion.

In the case of Eller and Flynn, they showed that the change in the number of moles n of a gas in a bubble is given by

$$\frac{dn}{dt} = 4\pi D R_0 C_0 \left[\left\langle \frac{R}{R_0} \right\rangle + R_0 \left(\frac{\langle (R/R_0)^4 \rangle}{\pi D t} \right)^{1/2} \right] H \tag{10}$$

where H is defined by

$$H = \frac{C_i}{C_0} - \left\langle \left(\frac{R}{R_0}\right)^4 \left(\frac{P_g}{P_0}\right) \right\rangle \bigg/ \left\langle \left(\frac{R}{R_0}\right)^4 \right\rangle \tag{11}$$

The pointed brackets in this case imply time average, where t is the time. C_i is the concentration of dissolved gas in the liquid far from the bubble, C_0 is the saturation concentration of gas in the liquid and D is the diffusivity of the gas.

Crum [33] later used Eller's derivation and extended it by taking into account the thermodynamics of the process. The end result for the change in bubble radius for a spherical bubble as a function of time is

$$\frac{dR_0}{dt} = \frac{Dd}{R_0} \left[\left\langle \frac{R}{R_0} \right\rangle \left(1 + \frac{4\sigma}{3 P_0 R_0}\right)^{-1} \left(\frac{C_i}{C_0} - \langle (R/R_0)^4 (P_g/P_0) \rangle / \langle (R/R_0)^4 \rangle \right) \right] \tag{12}$$

where $d = R_g \, T \, C_0 / P_0$. Here R_g is the universal gas constant and T is the temperature.

An alternative mathematical analysis was presented by Fyrillas and Szeri [37-39] in a series of papers to analyse the phenomena of rectified diffusion. Their derivation utilised Lagrangian coordinates rather than spherical coordinates in order to account for the moving boundary condition. The Henry's Law boundary condition describing the gas concentration at the surface of the bubble wall was also split into a smooth and oscillatory solution to the problem.

Bubble coalescence

In a single bubble system, the only growth pathway possible is via rectified diffusion. To investigate the behaviour of a multibubble system, we must also consider the process of bubble coalescence. The bubble coalescence process can be described in three steps [40,41]:

1. The bubbles come into contact to form a film of thickness between 1 to 10 μm
2. This film reduces in thickness
3. When the film becomes sufficiently thin, rupture occurs and the bubbles coalesce.

Studies of coalescence behaviour in the absence of ultrasound have been performed by various workers [40-43]. The review by Chaudhari and Hofmann [44] provides a comprehensive overview of the coalescence behaviour of gas bubbles in liquids.

Studies by Lee [45] and Sunartio [46] have found that coalescence behaviour is similar to that reported in the absence of ultrasound. An improved understanding of coalescence behaviour in ultrasound systems will ultimately improve the efficiency of a range of sonoprocessing applications where bubble population and sizes are important.

Sonoluminescence

The violence of a transient collapse can sometimes be characterised by the emission of light, termed sonoluminescence. Sonoluminescence was first observed in the 1930s by two different groups of workers; Marinesco and Trillat [47] in 1933 and Frenzel and Schultes [48] in 1934. Paounoff [49] validated these observations in 1947 by showing that the exposure of photographic plates occurred at locations of pressure maxima (antinodes) of the standing wave. It became clear to workers in the field that the gas bubbles generated during acoustic cavitation were responsible for the emission of light.

The high temperatures and pressures generated with the onset of inertial cavitation also serves to induce a range of chemical reactions within and surrounding the bubble [50]. The extreme conditions enable the transduction of acoustic energy into light energy that has a very short emission lifetime.

Sonoluminescence can be produced in the case of a single bubble (see Figure 5) undergoing extremely nonlinear pulsations, termed single-bubble sonoluminescence (SBSL) and also in the case of a field of bubbles undergoing cavitation, termed multibubble sonoluminescence (MBSL). In the former case, a single intensely bright dot suspended in a standing wave can be observed [22]. The intensity of the emitted light is dependent on various factors that include the amount and type of dissolved gases in the liquid [51], the frequency of the applied ultrasound [52], the applied sound pressure amplitude, hydrostatic pressure and addition of particular solutes [53-56]. Multibubble sonoluminescence can often be used as a probe for cavitation activity in a solution.

There are a number of theories as to the mechanism for sonoluminescence. These are discussed by Finch [57] and Jarman [58]. During the compression phase of the oscillating bubble, the contents of the bubble are heated [1]. This causes excitation of the gas in the bubble, promoting the formation and recombination of excited species. Recent numerical simulations by Yasui et al. [21] showed that the main mechanism of the light emission in sonoluminescence is actually electron-atom bremsstrahlung that occurs in the weakly ionised plasma formed inside the heated bubble. Bremsstrahlung radiation is light that results from an electron being accelerated by the collision with an ion or a neutral atom.

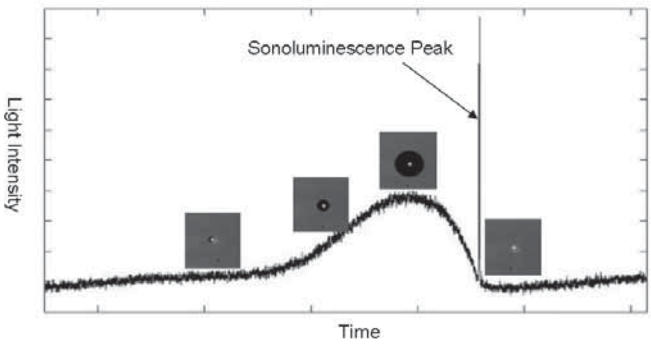

Figure 5: Sonoluminescence response of a single bubble in degassed water. The curve corresponds to the scattered laser light intensity of a levitated bubble undergoing non-linear oscillation in a standing wave. Still images show the corresponding bubble expanding from approximately 5 μm radius to 60 μm radius during one acoustic cycle at a frequency of 20 kHz. The sharp peak corresponding to the point of bubble collapse, with a lifetime of several picoseconds, is the sonoluminescence emitted by the bubble and is visible by the naked eye as a bright glow.

The relative intensities of the sonoluminescence from many different gases dissolved in water have been studied [51]. The general trend found was that as the thermal conductivity of the gas increases, the sonoluminescence was found to decrease and this correlated (for the series of noble gases) with the size of the atom. If sonoluminescence is due to an adiabatic compression during rapid collapse of the cavitation bubble, then energy loss due to thermal conduction will indeed lower the final temperature. Other factors that influence the bubble temperature include the amount of bubble vapour that becomes trapped inside the bubble [59] and the concentration of gas as the sonoluminescence intensity is related to the number of bubbles [60].

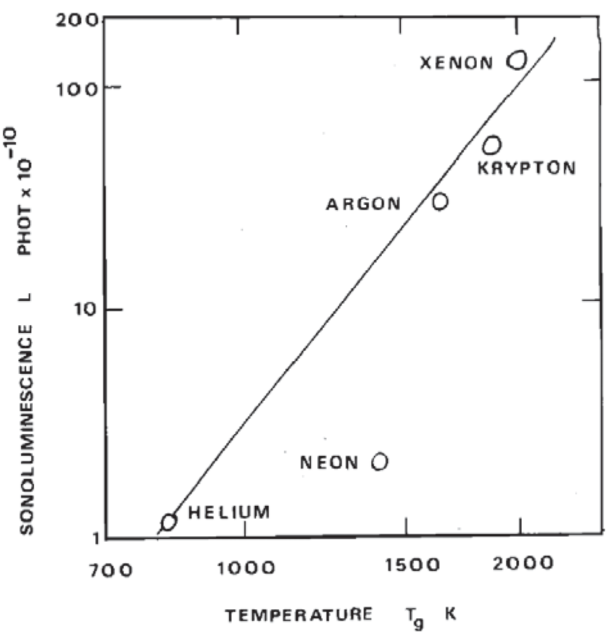

Figure 6: Experimental data taken from Young [51] showing the fit of experimental sonoluminescence intensity data with that of the theoretically determined cavitation temperature for the noble gases.

Hickling [61] explained that if bubbles are sufficiently small, loss of heat from the bubble into the liquid can significantly reduce the temperature of the collapse, resulting in lower sonoluminescence intensity. He demonstrated his theory analytically by means of solution of the equation of motion of gas in the collapsing bubble and good agreement between theory and experimental measurements were confirmed.

Figure 6 (taken from Young [51]) compares the experimental data points for the noble gases of the SL intensity as a function of the theoretical temperature of the gas. This correlation between the predicted temperatures and the SL intensity supports the hot-spot theory for SL.

The intensity of the emitted light can be approximated by the following equation from Yasui et al. [21]:

$$P_{Br,atom} = 4.6 \times 10^{-44} n_e nT/V \tag{13}$$

where n_e is the number of free electrons inside the bubble, n is the total number of neutral atoms inside a bubble, T is the temperature inside the bubble, and V is the bubble volume.

It is possible to determine the temperature of the gases inside the bubble during cavitation, by correlation with the sonoluminescence emission spectra. This is quite readily achieved in multibubble systems, where the emission spectra consist of detailed line structures. Temperatures of approximately 5000 K were determined by Flint and Suslick [4]. However, in the case of a single bubble, free from disturbances of other bubbles, the emission spectra normally obtained are featureless, as shown from the comparison by Matula et al. [62]. Work by Suslick [63, 64] has recently overcome this hurdle, by using xenon and argon filled bubbles in sulfuric acid. They were able to obtain good spectral details, from which a temperature of 15,000 K was deduced – a temperature as high as that found on the surface of bright stars [65].

SONOCHEMISTRY

Ultrasound induced cavitation is an extremely useful and versatile tool to carry out chemical reactions. Sonochemistry refers to the area of chemistry where chemical reactions are induced by sound. The range of ultrasound frequency commonly used in sonochemistry range from 20 kHz to ~ 1 MHz. A recent review for sonochemistry has been written by Ashokkumar and Mason and forms the basis of the following section [66].

Radical formation

The extreme temperature conditions generated by a collapsing bubble can also lead to the formation of radical chemical species. Ultrasonic waves in water have been shown to form radicals by the following reaction due to homolytic cleavage:

$$H_2O \rightarrow H^{\bullet} + OH^{\bullet} \tag{14}$$

The hydroxy and hydroxyl radical formed in this reaction are highly reactive and rapidly interact with other radical or chemical species in solution. $H^{\bullet}$ atoms are highly reducing in nature and $OH^{\bullet}$ radicals are highly oxidizing. A common product of this reaction in water is hydrogen peroxide.

The generation of $H^{\bullet}$ and $OH^{\bullet}$ radicals, commonly referred to as primary radicals, has been confirmed and quantified by a number of experimental techniques. Common methods include the use of ESR spin traps and dosimeters [67] or the reaction with chemicals such as teraphthalic acid [68] that will lead to the formation of hydroxyterephthalate which can be assayed with spectroscopy. One of the more simple methods to quantify the amount of $OH^{\bullet}$ radicals formed is by use of the "Weissler" method, which involves the oxidation of iodide ions [69]. In this technique, iodine is added to water which has been sonicated which reacts with the hydrogen peroxide formed. The reaction scheme for this method is:

$$\begin{aligned} &2OH^{\bullet} \rightarrow H_2O_2 \\ &H_2O_2 + 2I^- \rightarrow 2OH^- + I_2 \\ &I_2 + I^- \rightarrow I_3^- \end{aligned} \tag{15}$$

The quantity of I_3^- can be measured by ultraviolet spectrophotometry at 353 nm.

Suslick [70] has suggested that sonochemical reactions can occur at two sites of a bubble. The first is the bubble's interior gas phase, and is suggested as the dominant site for sonochemical reaction due to the intense temperatures attained during collapse (~5000 K). The second is the liquid shell surrounding the bubble, which can reach temperatures of up to 1900 K. In addition to these two primary reaction sites on the bubble, solutes in bulk solution beyond the bubble itself can react with the radicals formed inside or on the surface of the collapsing bubble.

Nanomaterial synthesis

Due to the reducing and oxidizing potential of the primary radicals generated during acoustic cavitation, sonochemistry has been used extensively in materials synthesis. The radicals are useful in initiating certain chemical reactions in organic and organometallic chemistry, as well as initiating polymerization [71]. They can also be used as a means to cross link proteins and this is an important mechanism for the synthesis of protein microspheres. A comprehensive review by Suslick and Price [72] gives examples of many applications of material synthesis using ultrasound.

A simple example of metal synthesis in an aqueous medium is that of the reduction of gold from Au(III) nanoparticles to Au (0) [73]. Under an inert atmosphere, the only reducing species in water are $H^{\bullet}$ atoms and these act to reduce the Au (III) ions to produce Au(0) by the following reaction:

$$AuCl_4^- + 3H^{\cdot} \rightarrow Au + 3H^+ + 4Cl^- \tag{16}$$

Ultrasound processing has generally been found to provide selectivity in the reaction product. For example, under ultrasonic irradiation, switching from an ionic pathway to a radical pathway is often observed. An example is the reaction of styrene with lead tetra-acetate in acetic acid [74].

In recent years, ultrasound generated radicals have been widely used as a novel technique for polymer synthesis [71]. The advantage of ultrasound induced polymerization has several advantages, namely that no chemical initiators or costabilisers are required, reaction temperatures are lower, polymerization rates are faster, conversions of reactant are greater and larger molecular weights can be produced. Teo et al. [75] for example, has used ultrasound to initiate emulsion polymerization of methacrylate monomers. Their results show that the mechanism involved is very similar to that of conventional polymerization processes.

Shear and mechanical mixing

Ultrasound-driven growth and collapse of bubbles is accompanied by the generation of shock waves, microstreamers, and microjets which lead to increased turbulence and shear forces which can facilitate mass transport. These physical phenomena can be used for a range of shearing and mixing applications. Cavitation can be used to induce emulsification of two immisible liquids such as oil in water. The jetting behaviour from transient collapse can be used to disperse fine drops of one liquid into the other when cavitation occurs at the interface between the two liquids. Leong et al. [18] showed that oil emulsions with mean particle sizes as low as 40 nm could be generated using a 20 kHz ultrasound frequency and an appropriate surfactant/co-surfactant system. These results were comparable to those generated from homogenization with a Microfluidizer™ [76], with the advantage that the ultrasonic horn would be easier to clean and more efficient due to lower equipment wear rates.

Mason [77] provides an example of the use of ultrasound as an alternative to phase transfer catalysts, which are compounds that enable the transfer of a water-soluble reagent into an organic phase. The use of ultrasound produces fine emulsions that can be used to disperse the aqueous phase into the organic phase. An example is the formation of dichlorocarbene which has been reported to achieve a much higher conversion in the presence of ultrasound in comparison with the case where the reagents were simply stirred.

Medical applications

More recent advances of sonochemistry are in the field of microbubble synthesis. Grinstaff and Suslick [78] developed an ultrasonic technique whereby cavitation induced radical formation and emulsification were used to synthesise air or liquid filled proteinaceous microspheres. In this procedure, proteins dissolved in a liquid are irradiated with ultrasound to form a stable foam-emulsion. The stability of this foam is caused by cavitation induced radicals that cause the protein molecules to cross-link, generating a spherical protein shell. The principal cross-linking agent is the superoxide ion created by the extremely high temperatures produced during acoustic cavitation. The mechanism proposed by Suslick suggests that disulfide cross-linkages form, although other workers [79] suggest that the presence of SH groups is not necessary for successful microsphere formation.

Air-filled microbubbles are in clinical use as echo-contrast agents for sonographic applications. Many articles and review articles are available in the literature for those interested in the medical applications available [7, 8]. Commercial microbubbles such as Definity™ and Optison™ are marketed for *in vivo* use where these spheres are injected into the bloodstream of a patient. The application of ultrasound to the affected area causes bubbles to vibrate in response to the pressure changes of the sound wave. Bubbles of an appropriate size range will vibrate very strongly at resonance, making them several thousand times more reflective than normal body tissues. The result is improved image resolution of tissues and organs. In some cases, a liquid can be encapsulated inside these protein spheres. This ability to encapsulate liquids can be used for targeted or time released drug delivery [80]. Figure 7 taken from Zhou et al. [81] shows lysozyme protein microbubbles filled with various types of organic oils. Care must be taken however when generating sonicated protein products intended for *in vivo* use or as food ingredients. Stathopulos et al. [82] have recently reported that the sonication of proteins can lead to the formation of amyloid aggregates. It is possible that such aggregates can give rise to immunogenicity, toxicity or even disease responses in the subject.

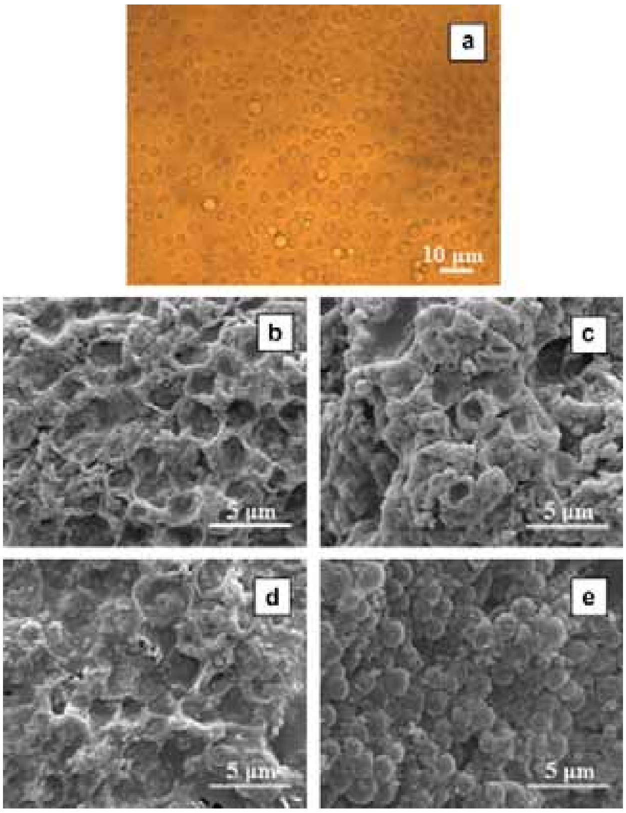

Figure 7: (a) Optical microscopic image and SEM images of (b) tetradecane, (c) dodecane, (d) sunflower oil and (e) perfluorohexane-filled lysozyme microspheres taken from Zhou et al. [81].

Sonochemical degradation of pollutants

Another useful application of sonochemistry is in the field of wastewater treatement. Articles by Colarusso and Serpone [83] and Adewuyi [84] provide a comprehensive overview of sonochemistry for use in environmental applications such as the degradation of pollutants. The hydroxyl radicals generated during cavitation can be used for the oxidative degradation of organic pollutants in an aqueous system. The heat produced in the cavitation process can also be used to remove volatile pollutants by pyrolytic decomposition. Singla et al. [19] recently reported that sonochemical degradation of various organic pollutants could be achieved by both oxidative and pyrolytic mechanisms.

Destruction of microorganisms by power ultrasound is also possible [85]. However, ultrasound has been shown to have no direct impact on spores or gram positive organisms and so is often used in conjunction with more conventional techniques such as chlorination or treatment with heat and pressure, such that increased effectiveness is achieved with lower requirements for chemical or energy usage.

CONCLUSIONS, FUTURE DEVELOPMENTS AND EXPECTED ADVANCEMENTS

Ultrasound induced cavitation is an effective tool to induce mechanical shear and to perform a variety of chemical reactions. This approach has been available for some decades but deployment is now rapidly increasing due to the recent availability of industrial scale ultrasonic horns and ultrasonic reactors.

Ultrasound can be energy intensive and hence emerging applications are likely to be where high value can be added. There exists a diverse range of applications that are well established or have exciting future potential that meet this criterion. The development of effective drugs for treatments of disease by ultrasound is one of the areas which could have widespread health benefits. Another emerging area is the use of ultrasound to provide novel food ingredients and our work is focused in particular on the production of novel dairy products. The need for more sustainable processing of consumer goods will be satisfied in part by such continuing developments in ultrasound processing and sonochemistry.

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TARGET SPEECH EXTRACTION IN COCKTAIL PARTY BY COMBINING BEAMFORMING AND BLIND SOURCE SEPARATION

Lin Wang[1,2], Heping Ding[2] and Fuliang Yin[1]

[1] **School of Electronic and Information Engineering, Dalian University of Technology, P. R. China**
[2] **Institute for Microstructural Sciences, National Research Council Canada**

wanglin_2k@sina.com, heping.ding@nrc-cnrc.gc.ca, flyin@dlut.edu.cn

Due to the ambient noise, interferences, reverberation, and the speakers moving and talking concurrently, it is a challenge to extract a target speech in a real cocktail-party environment. Emulating human auditory systems, this paper proposes a two-stage target speech extraction method which combines fixed beamforming and blind source separation. With the target speaker remaining in the vicinity of a fixed location, several beams from a microphone array point at an area containing the target, then the beamformed output is fed to a blind source separation scheme to get the target signal. The fixed beamforming preprocessing enhances the robustness to time-varying environments and makes the target signal dominant in the beamformed output and hence easier to extract. In addition, the proposed method does not need to know the knowledge of source positions. Simulations have verified the the effectiveness of the proposed method.

INTRODUCTION

Extracting a desired speech signal from its corrupted observations is essential for tremendous applications of speech processing and communication [1]. One of the hardest situations to handle is the extraction of a desired speech signal in a "cocktail party" condition - from mixtures picked up by microphones placed inside a noisy and reverberant enclosure. In this case, the target speech is immersed in ambient noise and interferences, and distorted by reverberation. Further more, the environment may be time-varying. Generally, there are two well-known techniques that may achieve the objective: blind source separation (BSS) and beamforming.

Assuming mutual independence of the sources, BSS is a technique for recovering them from observed signalss with the mixing process unknown [2, 3]. Nevertheless, BSS may not appropriate for target signal extraction in a cocktail-party condition. First, under-determined situations can result from the fact that there is only a limited number of microphones. Second, BSS processes the target signal and interference equally; it can be difficult to separate many signals simultaneously and also a waste of computational power if we want only one target. Third, BSS performs poorly in high reverberation, where the mixing filters are very long.

With a microphone array, beamforming is a well known technique for target extraction. It can be implemented as a data-independent fixed beamforming or data-dependent adaptive one [4, 5]. Fixed beamforming is more preferred in complicated environments due to its robustness. It achieves a directional response by coherently summing signals from multiple sensors based on a model of the wavefront from acoustic sources. It can enhance signals from the desired direction while suppressing ones from other directions. Thus, fixed beamforming can be used for both noise suppression and dereverberation. However, its performance also degrades in cocktail-party conditions. First, the performance is closely related to the microphone array size - a large array is usually required to obtain a satisfactory result but may not be practically feasible. Second, beamforming cannot reduce reverberation coming from the desired direction.

Because of the reasons above, few methods proposed in recent years have good separation results in a real cocktail-party environment. In contrast, a human has a remarkable ability to focus on a specific speaker in that case. This selective listening capability is partially attributed to binaural hearing. Two ears work as a beamformer which enables directive listening [6], then the brain analyzes the received signals to extract sources of interest from the background, just as blind source separation does. Stimulating this principle, we propose to extract the target speech by combining beamforming and blind source separation. In fact, the idea of combining both technologies has been proposed by several researchers [7, 8]. In [8], the beamforming as a preprocessor of BSS, forms a number of beams each pointing at a source. This makes subsequent separation easier. However, it requires that prior knowledge of all source positions, which is seldom available in real life. We extend the work in [8] by applying it to a special case of blind source extraction problem in noisy cocktail party environments, where only one source is of interest. Instead of focusing on all the sources, the proposed method forms just several fixed beams at an area containing the target source. The beamforming enhances the robustness of the algorithm to time varying environments. After that, the

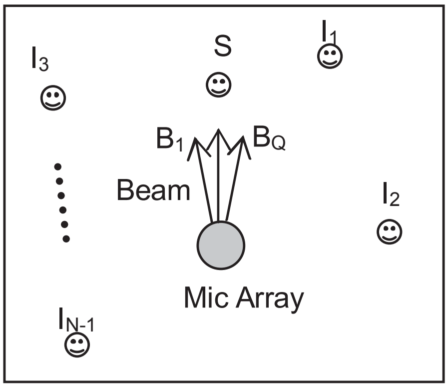

Figure 1. Illustration of the proposed method

target source becomes dominant in the beamformed output and it is easier for a blind source separation algorithm to extract it. Since the proposed method only needs the position of the target to do beamforming, it can be more practical.

PROPOSED METHOD

In a cocktail party, each speaker may move and talk freely. While this is a most difficulty for source separation, it is often in such case that the target speaker stays in a position or moves slowly and the noisy environment around it is time-varying, *e.g.*, moving interfering speakers and the ambient noise. For this specific situation, a target speech extraction method with a microphone array is proposed. It is illustrated in Fig. 1, where the target source *S* and *N*-1 interfering sources $I_1, \cdots, I_{N-1}$, are convolutively mixed and observed at an array of *M* microphones. To extract the target, *Q* beams ($Q \leq N$) are formed at an area containing it, with a small separation angle between adjacent beams; then the *Q* beamformed outputs are fed a blind separation scheme. Using beamforming as a preprocessor for BSS, the method possesses the advantages of both while complementing their weakness. In particular,

1) the residuals of interference at the output of beamforming are further reduced by BSS;
2) the poor separation performance of BSS in reverberant environments is compensated for by beamforming, which deflates the reflected paths and shortens the mixing filters;
3) the beamformer enhances the source that is in its path and suppresses the ones outside. It provides a cleaner output for the BSS to process; and
4) the fact that there are fewer beams than sources reduces the dimensionality of the problem and saves computation.

In a word, the target signal becomes dominant in the beamformed output and is hence easier to extract. Meanwhile, as seen in Fig. 1, the beams are pointing at an area containing the target, as opposed to the interfering sources. This is very important for operation under a time-varying condition, because

1) when the target speaker remains in a constant position while others move, it is impractical to know all speakers' positions and steer a beam at each of them;
2) there is no need to steer the beams at individual speakers since only the target speaker is of interest;
3) the target signal is likely to become dominant in at least one of the beamformed output channels if the beams point at an area containing the target speaker. Thus, it is possible to extract it as an independent source even if the number of beams is less than the sources [1]. This feature is very important for the proper operation of the proposed method; and
4) a seamless beam area will be formed by several beams with each covering some beamwidth. It is possible to extract the target signal even if it moves slightly inside this area. This feature may improve the robustness of the proposed method.

In a nutshell, beamforming makes primary use of spatial information while BSS utilizes statistical information contained in signals, and combining both technologies may help get a better extraction result. The signal flow of the proposed method is shown in Fig. 2. The implementation details are given in the two subsections to follow.

Beamforming

A superdirective fixed beamformer is designed in the frequency domain, using a circular microphone array. The principle of a filter-and-sum beamformer is shown in Fig. 3. Suppose a beamformer model with a target source *r*(t) and background noise *n*(t), the components received by the *l*'th sensor is $u_l(t) = r_l(t) + n_l(t)$ in the time domain. In the frequency domain the term is $u_l(f) = r_l(f) + n_l(f)$. The beamformer's output in the frequency domain is

$$x(f) = \sum_{l=1}^{M} b_l^*(f) u_l(f) = b^H(f) u(f) \tag{1}$$

where $b(f) = [b_1(f), \cdots, b_M(f)]^T$ is the beamforming weight vector composed of beamforming weights for each sensor, and $u(f) = [u_1(f), \cdots, u_M(f)]^T$ is the vector composed of outputs from each sensor, and $(\cdot)^H$ denotes conjugate transpose. The $b(f)$ depends on the array geometry and source directivity, as well as the array output optimization criterion such as a signal-to-noise ratio (SNR) gain criterion.

Suppose $r(f) = [r_1(f), \cdots, r_M(f)]^T$ is the source vector composed of the target source signals picked up by the sensors, and $n(f)$ is the noise vector composed of the spatially diffused noises also picked up by the sensors. Being a measure of improvement in signal-to-noise ratio, the array gain is defined as the ratio of the SNR at the output of the beamforming array to that at a single reference microphone. The reference SNR is defined, as in [9], to be the ratio of average signal power spectral densities over the microphone array, $\sigma_r^2(f) = E\{r^H(f) r(f)\}/M$, to the average noise power spectral density over the array, $\sigma_n^2(f) = E\{n^H(f) n(f)\}/M$. By derivation, the array gain at frequency f is expressed as

$$G(f) = \frac{b^H(f) R_{rr}(f) b(f)}{b^H(f) R_{nn}(f) b(f)} \tag{2}$$

where $R_{rr}(f) = r(f) r^H(f)/\sigma_r^2(f)$ is the normalized signal cross-power spectral density matrix, and $R_{nn}(f) = n(f) n^H(f)/\sigma_n^2(f)$ is the normalized noise cross-

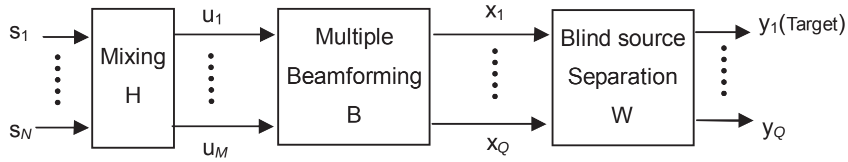

Figure 2. Signal flow of the proposed method combining beamforming and BSS

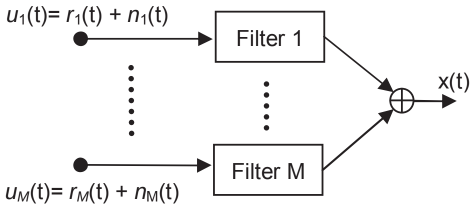

Figure 3. Principle of a filter-and-sum beamformer

power spectral density matrix. Provided that $R_{nn}(f)$ is nonsingular, equation (2) is maximized by the weight vector

$$b_{opt}(f) = R_{nn}^{-1}(f)r(f) \tag{3}$$

$R_{nn}(f)$ and $r(f)$ in equation (3) depend on the array geometry and the target source direction. Readers may refer to [8] for details on calculating $R_{nn}(f)$ and $r(f)$ for a circular array.

After calculating equation (3) at all frequency bins, the time-domain beamforming filter $b(n)$ is obtained by inverse Fourier transforming the $b_{opt}(f)$.

Blind source separation

Frequency-domain BSS is employed here due to its fast convergence and low computation. The mixed time-domain signals are converted into the time-frequency domain by short-time Fourier transform (STFT); then instantaneous independent component analysis (ICA) is applied to each frequency bin; after permutation alignment and scaling correction, the separated signals of all frequency bins are combined and inverse-transformed to the time domain.

For instantaneous ICA, we use a complex-valued Scaled Infomax algorithm, which is not sensitive to initial values, and is able to converge to the optimal solution within 100 iterations [10]. The scaling ambiguity problem is solved by using the Minimum Distortion Principle [11].

Permutation ambiguity inherent in frequency-domain BSS is a challenge problem. Generally, there are two approaches to solve it. One is to exploit the dependence of separated signals across frequencies [13, 12], and the other is to exploit the position information of sources: the directivity pattern of the mixing/unmixing matrix provides a good reference for permutation alignment [14]. However, in the proposed method, the directivity information contained in the mixing matrix does not exist any longer after beamforming. Even if the source positions are known, they are not much helpful to permutation alignment in the subsequent blind source separation. Consequently, what we can use for permutation is merely the first reference: the inter-frequency dependence of separated signals. Ref. [13] proposes a permutation alignment approach based on the power ratio measure. Bin-wise permutation alignment is applied first across all frequency bins, using the correlation of separated signal powers; then the full frequency band is partitioned into small regions based on the bin-wise permutation alignment result. Finally, region-wise permutation alignment is performed, which can prevent the spreading of the misalignment at isolated frequency bins to others and thus improves permutation. This permutation alignment algorithm is employed here.

EXPERIMENT AND ANALYSIS

We evaluate the performance of the proposed method in simulated conditions. A typical cocktail party environment with moving speakers and ambient noises is shown in Fig. 4. The room size is 7m $\times$ 5m $\times$ 3m, and all sources and microphones are 1.5m high. Four loudspeakers S1-S4 placed near the corners of the room play various interfering sources. Loudspeakers S5, S6 and S7 play speech signals concurrently. S5 and S6 remain in fixed positions, while S7 moves back and forth at a speed of 0.5 m/s. As the target, S5 is placed at either position P1 or P2. S5 simulates a female speaker, while S6 and S7 simulate male speakers. An 8-element circular microphone array with a radius of 0.1 m is placed as shown.

In blind source separation, the Tukey window is used in STFT, with a shift size of 1/4 window length, which is 2048 samples. The iteration number of instantaneous Scaled Infomax algorithm is 100. The permutation alignment algorithm in [13] is employed. In beamforming, a beamformer is designed with the algorithm presented in Section 2.1, using the circular array in Fig. 4. Three beams are formed towards S5, with the separation angle between two adjacent beams being 20°. The room impulse responses are obtained by using the image method, with the reverberation time controlled by varying the absorption coefficient of walls [15]. The test signals last 8 seconds with a sampling rate of 8 kHz. The extraction performance is evaluated in terms of signal-to-interference ratio (SIR) for where the signal is the target speech.

With so many speakers in such a time-varying environment, BSS alone fails to work. Now we compare the performance of beamforming alone and the proposed method with reverberation RT_{60} of 130 ms and 300 ms respectively. The results are given in Table 1. As an example, for the close target case (P1) under RT_{60} = 300 ms, the input SIR is around -9 dB – the target is almost completely buried in noises and interference. The enhancement by beamforming alone is minimal. On the other hand, the proposed two-stage method improves the SIR by 15.1 dB. In the far target case (P2) of RT_{60} = 300 ms, the target signal received at the microphones is much weaker with an input SIR around only -11 dB. The proposed method is still able to extract the target signal with an output SIR of 3.3 dB and a total SIR improvement of 13.5 dB.

For the close target (P1) with RT_{60} = 300 ms, Fig. 5 shows the waveforms at various processing stages: sources, microphone signals, beamformer outputs, and finally the BSS outputs. It can be seen that, the target signal S5 is totally buried in noises and interference in the mixture signals; it is enhanced to a certain degree after beamforming but is still difficult to tell from the background; and after blind source separation, the target signal is clearly exhibited at the channel Y2. In addition, an interference signal (S6) is observed at the output channel Y1, and the noise-like output Y3 is mainly composed of the interfering speech S7 and other noises. The extraction result also verifies that the validity of the proposed method in noisy cocktail-party environments.

The good performance of the proposed method in such time-varying environments is due to two reasons. First, fixed beamforming can enhance target signals even in time-varying environments. Second, the spectral components of the target and (moving or static) interfering signals are still independent after beamforming; besides, the target signal becomes dominant in the beamformed output. This helps the subsequent blind source separation.

The proposed method is under the assumption that the target source stays in a fixed position. For a moving target, it is possible that time-varying beamforming and sample-by-sample blind source separation algorithms are better choices. This can be a topic for future research.

CONCLUSIONS

It is challenging to extract a target speech in a time-varying, noisy, and reverberant environments. Emulating the human auditory system, the paper proposes a target speech extraction method for such a difficult condition by combining beamforming and blind source separation. The proposed method integrates the advantages of both technologies and complements their weakness. In addition, a special beamforming processing style is employed to deal with time-varying environments. Simulations verify that, the proposed method performs well in a time-varying cocktail-party-like situation where any of the two methods alone fails to work efficiently.

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Table 1. Comparison of beamforming and the proposed method in terms of signal-to-interference ratio (SIR)

Target S5	P1 (close)		P2 (far)	
RT_{60}	130 ms	300 ms	130 ms	300 ms
Input SIR	-8.2 dB	-9.1 dB	-10.7 dB	-10.8 dB
Beamforming	4.6 dB	0.6 dB	2.5 dB	-2.3 dB
Proposed method	11.9 dB	6.0 dB	9.1 dB	3.3 dB
SIR improvement	20.1 dB	15.1 dB	29.8 dB	13.5 dB

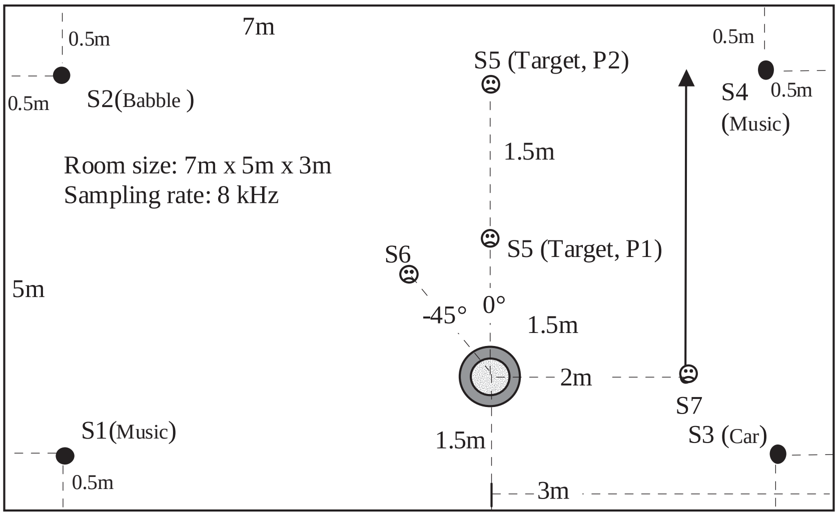


Figure 4. Simulated room environment

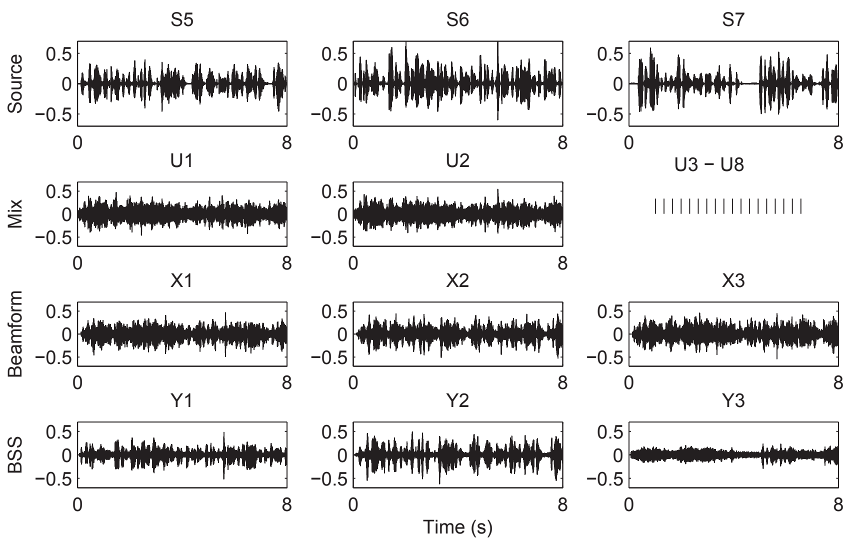


Figure 5. Waveforms at various processing stages

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.

COST EFFECTIVE DESIGN FOR A MUSIC REHEARSAL STUDIO

Redevelopment of Victoria Police Bands' Green Street Studios

Derek Thompson, AECOM

The Victoria Police Bands perform at formal police events, official State functions, in schools, for charities, and at community events throughout Victoria. From their permanent base – in an almost forgotten corner of Melbourne's inner northern suburbs – the bands often host school groups, provide music education workshops, conduct master classes, and even record and produce their own CD releases for sale. This month the band moves into a dedicated new rehearsal facility, recently completed on their existing site. This brief note summarises the vision and constraints driving the project, and traces the broader design process behind the acoustic design.

BACKGROUND

The Victoria Police Bands are comprised of three distinct musical ensembles, and perform a wide-range of musical styles and repertoire. Together, the bands are made up of nearly 50 musicians and include a 25-piece Showband, a 16-piece traditional Scottish bagpipe band and a 5-piece rock/pop band. The bands have a long history, dating back to 1891. The original band has evolved over time with various permutations as brass band, concert band, through to its current form as a Showband.

A Pipe Band was first formed in 1936 to complement the concert band of the time, and has since represented Victoria Police both nationally and internationally. The Pipe Band has performed at prestigious international events, including the Edinburgh Military Tattoo. In international competition events, their highest achievement has been winning the title of World Pipe Band Champions, in 1998 in Glasgow.

PREVIOUS FACILITIES

All groups share the same rehearsal complex, consisting of a ramshackle former drill hall and a collection of small out-buildings. The buildings had never been designed or retrofitted for musical purposes. The main band room, located in the drill hall, was not capable of accommodating all members of the three bands together, much less with any degree of acoustic comfort. The room had a floor area of barely 90 m^2 and a ceiling height of just 3.6 m. Ventilation in the space relied on natural airflow through a pair of louvre windows in one wall. Token acoustic treatment was limited to thin, perforated wood fibre panels direct-fixed to the upper walls. Poor ensemble conditions and oppressive loudness were unsurprising complaints about the space.

Rooms being used for individual and small ensemble practice had no pretence of acoustic isolation. Any internal acoustic treatment was limited to off cuts of carpet hung to cover the basic fibro partitions. As well as the assortment of rooms within the drill hall and out-buildings, a number of disused shipping containers on the site were frequently used for individual practice. The acoustically untreated buildings were also affected by noise of trains passing by on the suburban railway line every few minutes.

Figure 1: Previous band room.

PROJECT BRIEF

The bands' requirements could be summarised into a relatively succinct list of design priorities, forming the essence of a project brief:

- create a more usable space for the musicians;
- introduce acoustic separation between spaces;
- improve internal acoustic quality;
- provide for flexible use of spaces;
- adhere strictly to the modest budget available.

DESIGN CONCEPT

Despite the existing drill hall's many shortcomings, it did offer one concession towards redesign for music – a large central space, which was being used for general storage, vehicle parking and home to the band's music library and historical records.

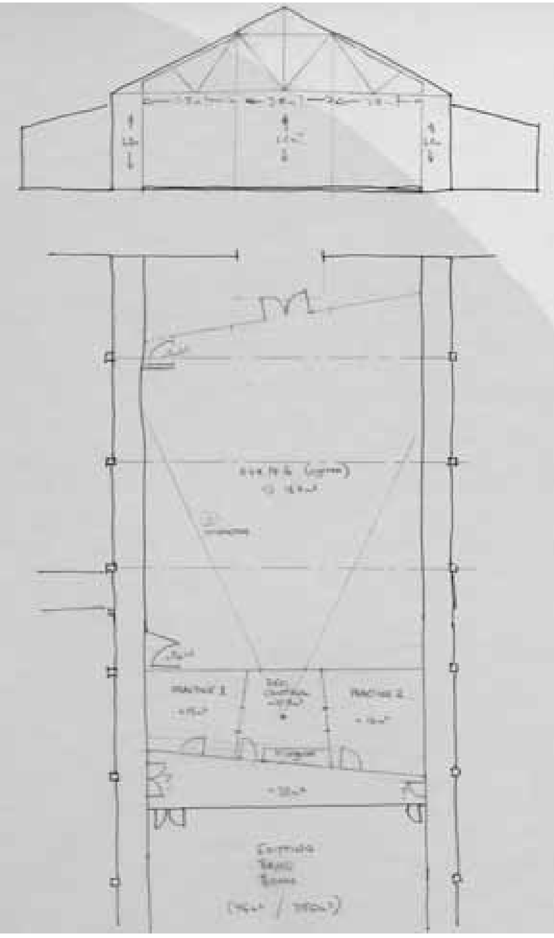


Figure 2: An early concept sketch.

The architectural direction immediately moved towards exploiting the existing space with the insertion of a new, freestanding rehearsal studio within the drill hall. As the concept developed, a conscious decision was made to retain the exterior of the drill hall without significant modification, and to avoid any obvious exterior clues as to the significant changes being proposed underneath the unassuming facade. This design concept has since been described by band members as creating a precious acoustic gem, encapsulated within the raw materials of the old drill hall. There was also a strong desire from the bands for their new rehearsal studio to be adjoined by quality individual practice rooms and if possible for the whole facility to double as a satisfactory recording studio.

THE PROCESS

A collaborative approach evolved during design of the studios, underpinned by a design mantra of '*refining the best possible design - within the available budget*'. Three distinct options representing defined cost points were maintained throughout design development. This allowed the client to understand and contribute to key decisions around budget costs, always being aware of not only the projected project cost, but the associate design limitations and outcomes for any given cost ceiling. The designs were tested, tweaked and costed, then tested again, tweaked again and re-costed. This approach inevitably required ongoing engagement between architect, acoustician, quantity surveyor and other engineering consultants. However the payoff was clear, with immediate control of projected costs possible from very early on in the design process.

Figure 3: Studios under construction.

DESIGN DETAILS

The main studio is designed as a freestanding structure, supported by a steel portal frame hidden entirely within new wall and ceiling cavities. An existing tongue and groove hardwood floor over original concrete slab was retained throughout the main rehearsal space, with individual practice rooms receiving a new carpet floor finish where the existing timber flooring could not be salvaged. A dedicated new air conditioning system serves the new studio spaces. Designed as a top-down system, air is supplied into the main studio at ceiling level via a duct that is tucked into a convenient void under the apex of the roof. Associated machinery is located in a new enclosure, at grade and outside of the drill hall. The system is designed to achieve NR 20; sufficiently quiet to enable periodic recording sessions without needing to isolate the air conditioning (although isolation is possible).

In order to maximise internal room volume, the new studio ceiling follows the form of the drill hall roof, without penetrating or altering the external roofline. Construction of the new ceiling as a double-skin system provides control of rain noise, mitigates external noise (e.g. from train movements), and maintains acoustic isolation between the new studio and surrounding rooms.

New wall partitions are detailed as lightweight, multi-layer constructions to maximise acoustic isolation whilst also minimising material and construction costs. Design of the partitions was critical due to the high sound levels produced by many of the instruments being designed for (especially bagpipes and snare drums), and the substantial cost implications of adding any unnecessary partition layers. Numerous partition designs were assessed for predicted transmission loss and also costed in detail, in order to arrive at an optimal balance of cost and acoustic performance.

Isolated glazing details are used to create visual connections between the main studio and an individual practice room designed to double as a recording control room.

The internal acoustic treatment scheme adopted throughout makes extensive use of custom fabricated, modular panels. This approach provides a well controlled room acoustic solution, and also allowed significant economies during design optimisation, as well as control of fabrication and installation costs. The acoustic panels themselves are relatively simple broadband panel absorbers, consisting of perforated front facings over an air cavity containing glass wool insulation. The panels were designed with an angled front face to enable a single panel type, when installed in different orientations, to produce variations in face angle and depth between adjacent panels. This surface variation not only provides visual interest, but also creates the necessary acoustic diffusion within each room.

The broadband panel design, used for the majority of panels, is supplemented by a proportion of tuned low frequency panels. The low frequency panels use a similar construction method as the broadband panels and incorporate the same angled front face; however a different perforation pattern is used to assist tuning.

Together, these two panel types form the basis of the room acoustic treatment for both the main studio, and the new individual practice rooms. The predictable acoustic properties of the panels contributed to straightforward and reliable room acoustic predictions, with minimal impact on the acoustic design when panel layouts required inevitable adjustment to co-ordinate with alterations in room geometry or the location of services.

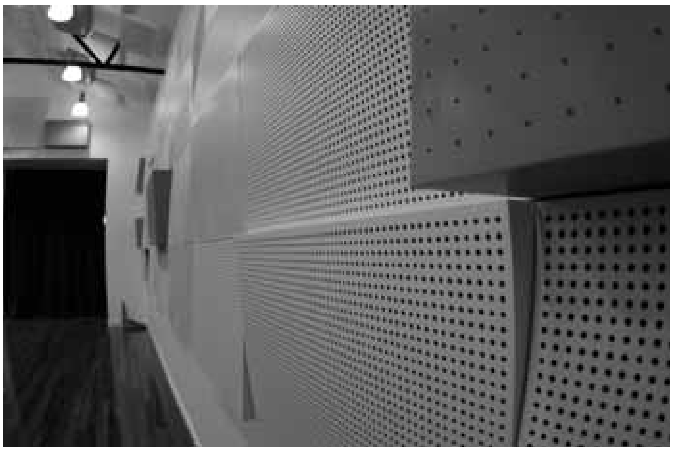


Figure 4: Close-up of modular acoustic panels.

BUILT RESULT

The result is a dedicated rehearsal studio, spacious enough to accommodate any of the bands in proper formation, or even accommodate all three police bands together in relative comfort. Loudness is managed in the main studio without compromising ensemble playing conditions or tonal balance.

In addition to the main studio, band musicians now also have three new individual practice rooms – including one which doubles as a quality recording control room including direct visual connection into the main rehearsal studio. The individual rooms provide neutral acoustic conditions for instrumental practice, and sufficient control of loudness to enable extended practice sessions. Audio and data tie lines connect all the new spaces together, enabling recording in any room; or in any combination of rooms together.

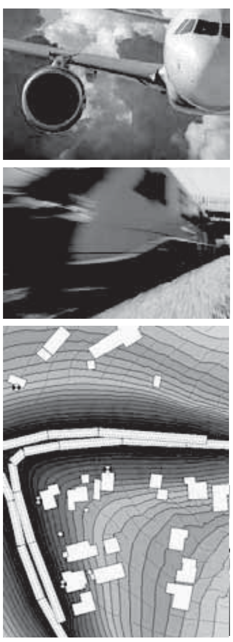
Figure 5: An individual practice room.

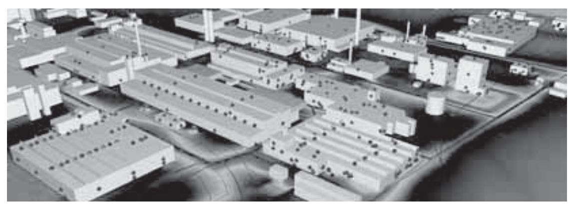
The bands are currently moving into their new rehearsal complex and have already tried out each of the new rooms. Initial feedback has already been very positive on the appearance, quality and acoustic design of the new spaces.

PROJECT CREDITS

Client: Victoria Police
Acoustic Designer: AECOM
Architect: BVN Architecture, Michael McKenna architects
Services Engineer: PCE
Quantity Surveyor: Currie Brown
Builder: Devco

Figure 6: Main studio nearing completion.





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NOISE EXPOSURE REDUCTION FOR ORCHESTRAL MUSICIANS

W. Williams and G. Stewart
National Acoustic Laboratories, Chatswood, NSW

INTRODUCTION

When we think of musicians exposed to loud noise or music, we tend to imagine a heavy metal rock band on stage with special effects from lighting, fog and amplified music. This genre of music tends to be loud with limited dynamic range. Many rock musicians do use a form of personal protective equipment in the form of communication earplugs with the primary intention of receiving foldback to enable them to control and coordinate the sound coming from the stage, not to reduce the effects of noise [1].

At the other end of the musical spectrum are the classical musicians who may be playing Mahler, Wagner or Adams, music with a wide dynamic range and at times very loud depending on the player's location within the orchestra [2]. For example in the horn section during Gustav Mahler's Symphony No 3 the average continuous A-weighted sound pressure level (L_{Aeq}) sits around 94 dB while the C-weighted peaks reach 131 dB [3].

The use of ear plugs has been suggested as a possible solution however, the inherent distortion of the resultant perceived sound spectrum due to the non-linear attenuation characteristics of ear plugs means that plugs are often rejected by musicians. Even 'musicians' ear plugs introduce some non-linearities and this coupled with the occlusion effect makes their use problematic [4].

Hence musicians in large orchestras need some form of occupational noise management if their hearing health is to be maintained. This is why the *National Acoustic Laboratories* in conjunction with the *University of Technology, Sydney* - industrial design department - and the then Symphony Australia (now *Symphony Services International*), the organisation that provides services to Australia's major symphony orchestras, developed the Goodear.

The Goodear is an acoustic shield designed for use in an orchestral setting intended to reduce the noise exposure of the musician sitting in front of the shield from particularly loud playing from instruments to the rear. Unlike the majority of current acoustic shields it is not made of a hard, transparent plastic but rather a more robust material with a sound absorbent surface that prevents sound reflection. One difficulty with sound reflection from hard surfaced plastic or acrylic barriers is that they create spurious sound sources within the orchestra and can increase the sound exposure of adjacent musicians.

When the original version of the Goodear was produced, in 1997, NAL carried out a series of tests gauging the acoustic performance. More recently a second series of tests has been carried out on a slightly modified production model aimed at verifying performance. The results of these tests are presented here.

TEST METHOD

The testing was carried out in the large anechoic test room at the NAL facilities in Chatswood, NSW, as shown in Fig. 1. This room provides excellent sound isolation from external noise and a sufficiently low noise floor that guarantee the acoustic test results. The shield is approximately 280 x 500 mm and 50 mm thick, formed in a shallow 'V' shape and is positioned, when in use, with the offending sound source located to the rear of the apex of the 'V' and the musician's head located in front of the 'V' opening.

The shield was set up with the 'V' opening facing away from and 1.0 m in front of a loud speaker that provided the source test noise of wideband 'pink' noise at a level of around 80 dB. Measurements were taken at microphone positions 0.01 m, 0.10 m and 0.20 m inside the 'V' to account for various head positions. The usual position would be between 0.20 m and 0.10 m with the possibility of moving closer to increase attenuation when particularly loud passages are due to be played. Measurements were taken with and with-out the shield present, the difference in levels being the attenuation in sound level. The parameter used was L_{Aeq}.

A measurement position was set up at approximately 1.0 m to the right of the sound source to explore any change in exposure experienced by an adjacent musician. In this case the change in level measured with the shield present represents the variation in noise exposure for the adjacent musician. Measurements were made with the Goodear and also with a hard surfaced, plastic shield of similar dimensions to the Goodear to represent existing generic clear shields.

Figure 1. Experimental set-up of the Goodear test.

RESULTS

The attenuation test results using various spectral weightings for the various test positions are presented in Table 1. From the results in Table 1 it can be seen that there are only small differences between the attenuation performances at different locations except for the adjacent position. Here the use of the hard surfaced shield provides a reflection which significantly increases the level and hence exposure, at the adjacent position of up to 4 dB.

Table 1: Attenuation test results with various spectra weighting for various measurement positions (dB)

Distance	1.01		1.10		1.20		Adjacent Position	
Goodear/Plastic	G	P	G	P	G	P	G	P
A-weighted	8	8	8	7	7	6	0	-4
C-weighted	5	4	4	4	4	3	0	-2
Unweighted (Z)	5	5	5	4	4	4	0	-2

DISCUSSION

The attenuation provided by the shields was about 7 or 8 dB when measured directly behind the shield in the normal use position. A 3 dB reduction in level represents a 50% reduction in overall exposure. Because of the non-linear nature of the decibel scale an attenuation of 8 dB results in an 84% reduction in the sound exposure. This reduction in exposure is quite significant in terms of future hearing health as the risk of noise injury is proportional to the exposure level. Thus there is an obvious advantage for musicians in high noise locations using a barrier to reduce their exposure risk.

Measurements taken adjacent to the sound source in a position where an accompanying musician would be located showed that the use of an equivalent sound shield made of a hard, plastic material increases the sound level in the adjacent position by roughly 3 dB. In real terms this is equivalent to doubling the sound exposure for the adjacent musician(s). So using a shield with a non-reflecting surface such as the Goodear reduces exposure for more musicians.

Some commentators have mentioned the fact that the Goodear is not transparent and hence could interrupt the line-of-sight to the conductor or other musicians. This has not generally been found to be a problem as the Goodear is situated below the top of the player's head and hence the line-of-sight remains clear. This is also the case when the musicians to the rear are situated on risers.

The use of the Goodear as an acoustic barrier has specific advantages for orchestral musicians by reducing the overall noise exposure without affecting the sound quality of the performance for the musicians, the conductor or the audience. The noise exposure levels of musicians may not be extremely high on one particular occasion, however over the course of a full musical career there is a degree of risk of noise injury and subsequent hearing loss from noise exposure. The use of barriers such as the Goodear seeks to solve the exposure problem without involving significant cultural change to the orchestral setting.

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LOW NOISE FANS FOR UK COOLING TOWERS

Martin Huis in 't Veld
Sales Manager Retrofit, Howden Netherlands b.v.

Connah's Quay is a 4x345MW combined-cycle power plant situated on the River Dee estuary in Wales, United Kingdom. The plant has been operational since 1996. It has hybrid cooling towers to reduce visible plume and special routines for cooling water makeup withdrawal. Each generating unit is supported by two adjacent cooling towers comprised of five cells above a common pond, making 10 cells per unit. Figure 1 shows a schematic diagram of the hybrid cooling tower and the cooling cycle of the Connah's Quay power plant.

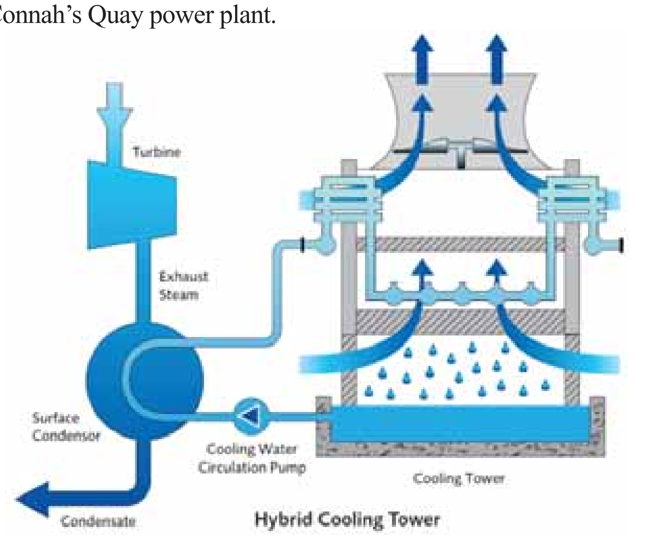


Figure 1.Schematic diagram of the hybrid cooling tower and cooling cycle.

The cooling tower air flow was severely restricted by noise attenuation, due to the environmental constraints imposed during the construction of the plant because of the close proximity of local residents. The noise attenuation equipment adds static pressure loss to the system and reduces the thermal efficiency of the tower, leading to the generation of low level plume and contributing to major failures in the fan drive trains. The detrimental effects on plant and performance due to the restriction of the airflow can be summarized as follows:

- The water/air ratio required to achieve optimum performance is not being achieved.
- At times the tower operates very close to the point where low level plume will be generated.
- The restriction to air flow in the fan outlet stack induces mechanical stress in the fan drive train, contributing to a high level of failures especially during start-up of the fan. The repairs often require the removal of the attenuation, the fan and the gearbox. This leads to major production losses. The engineers are therefore reluctant to shut down the fans as a way of controlling the cooling tower during hours of reduced ambient temperatures. Instead, they maintain 100% fan speed at all time leading to unnecessary low water temperatures, power consumption and noise emission.

The major goal was to improve the power plant's efficiency and reduce the visible plume of the cooling tower, without increasing the existing noise emission. To achieve this goal, the following actions were recently taken:

- The fan outlet attenuation baffles were removed, increasing the air flow through the cooling tower pack and reducing the mechanical stresses during start-up.
- The existing fans were replaced by Howden ultra low noise SX-Series fans in order to operate within the constraints set by the Environment Agency without the attenuation equipment.
- With the Howden SX fans in place, the existing gearboxes became the dominant noise source at the fan outlet. To operate within the constraints set by the Environment Agency, they were refurbished to a new low noise specification.
- The lower sound power level of both the fan and the gearbox allow adaptation of the dry section attenuation, increasing the warm air flow to the mixing plenum. This increases the outlet air temperature while reducing the outlet air humidity and subsequently reducing the visible plume generation.

Since the fan noise is primarily related to operating speed, it was decided that the original fan drive and gear box ratio would be maintained. Although the air supply increased with the installation of the SX fans, the aerodynamic performance remained almost unchanged as the static pressure loss was reduced due to the removal of the noise attenuation baffles. Figures 2 and 3 respectively show the previously existing noise attenuation baffles at the fan outlet, and with the installation of the low noise SX fan instead of the attenuation baffles. Table 1 illustrates the improved airflow and noise reduction achieved through the use of Howden's ultra low noise SX fans. The total sound power was improved even with the removal of the noise attenuation baffles.

Figure 2. Noise attenuation baffles at fan outlet.

Figure 3. SX fan instead of the attenuation baffles.

Table 1. Fan data before and after installation of the SX fans.

		
Fan Type	**Original Fan**	**SX Fan**
RPM	89.9	89.9
Volume flow (m^3/s)	465	500
Static pressure (Pa)	163	147
Sound power level fan (dB(A))	101.3	93.7
Attenuation baffles (dB(A))	-7	Baffles removed
Total sound power level (dB(A))	94.3	93.7

With the introduction of the new cooling fans, the temperature of the cooling water system was improved by 1.4˚C. This improved efficiency by 0.13%, which equates to a combined cycle output improvement of 0.8MW. The efficiency figures may appear low, but in reality they represent a significant improvement. The projected results are as follows:

- The steam-turbine will be more efficient, and consequently the gas-turbine consumes less gas.
- The reduction in gas consumption will reduce CO2 production by 7,500 tonnes per year.
- The incidence of low level plumes will drop from ± 142 days to ± 23 days due to the improved water distribution alone. The fan exchange will further reduce this to ± 6 days.
- Maintenance costs are expected to drop dramatically. Savings will also be made by preventing unnecessary power consumption.
- Production losses because of repairs will be reduced to a minimum. As a consequence, the reliability of the plant will rise significantly.

In summary, the benefit of the installation of the super low noise fans is twofold. The SX impeller performs a similar duty with a significantly lower sound power output. Improved airflow and noise reduction was achieved without any need for changing the fan speed or gear box ratio. It is expected that the entire cost of the modification will be recovered in seven years through efficiency gains alone. In addition, there will be additional savings arising from other factors. The fans can now be shut down whenever required without the risk of stress failure when they are restarted, avoiding unnecessary power consumption. The modification also eliminates the cost of major repairs and production losses.

ACKNOWLEDGEMENTS

This case study is a publication of Howden Netherlands. Special thanks are due to the Plant Manager, Mr Pacey, and to the Project Engineers, Mr Stevens and Mr Barrow of Connah's Quay Power Station for making this publication possible.

For further details on Howden fans, please contact
Peter Yallamas, Howden Australia
Email: p.yallamas@howden.com.au

BOOK REVIEW

Hearing and the perception of sound

Authors: David Alais, Virginia Best, Paul D. Niall, Carolyn Semmler and Donald H. Woolford

Chapter 145 in Expert Evidence, Editors: Ian Freckelton and Hugh Selby

Publisher: Lawbook Co., Australia

Also available from Thomson Reuters as a separate chapter purchase for $39.60 from

www.thomsonreuters.com.au/catalogue/ProductDetails.asp?id=8205

This is one chapter in Expert Evidence, a major subscription based service offering coverage of over 75 expert witness fields. The editors of the service are Dr Ian Freckelton SC, a leading member of the Victorian Bar, and Associate Professor Hugh Selby in the Legal Workshop, Law Faculty of the Australian National University. The description of the series is that "contributing experts are drawn from accredited laboratories, respected consultancy firms and highly regarded individual academics and practitioners" and the content is used "for preparation and case presentation by litigation lawyers (both civil and criminal), forensic specialists, and any expert drawn into investigations or hearings".

This chapter addresses hearing and the perception of sound in approximately 50 pages, plus 8 pages of references mostly to journal articles. As well as the usual introduction to the ear and noise induced hearing loss, the chapter summarises some interesting aspects not usually covered in general acoustics reference books for noise control engineers. These include cognitive psychology, memory for sound, voice and speech, the impact of context in sound identification; audition in the multisensory brain: visual influences on speech perception; ventriloquism, individual differences, auditory perception and blindness, and ambiguity in audition; abnormal hearing and deafness: hearing impairment: oto-toxins, combinations of different sources of hearing damage, supra-threshold characteristics of damaged hearing, plus a section on compensation assessments of noise-induced hearing loss. It has been the challenge for the authors to over such a broad range of topics in a single chapter and to distill the information to be concise and comprehensible.

The chapter is certainly easy to read and there are many references to the papers underlying the comments. It is a little disappointing that conflicting views have not been presented particularly in relation to topics that could be the basis for a legal case. For example, it is stated that speech comprehension is impaired by hearing protectors. This may well be true when compared with listening in a quiet environment but other researchers have shown that wearing hearing protection can improve speech comprehension in noise (as discussed in Earlog 3 Elliot Berger). While the reference listing is quite long, there are no references giving the full titles for the national or international standards that are quoted in the chapter by number only.

Overall the chapter is easy to read and covers interesting material. The chapter would undoubtedly be a valuable reference for anyone seeking more information on hearing and for those preparing for a legal case relating perception of a sound or for hearing loss compensation.

Marion Burgess

Marion Burgess is a research officer in the Acoustics and Vibration Unit of UNSW, Canberra

NEWS

Senate enquiry on wind farms

The Australian Senate enquiry into Social and Economic Impact of Rural Wind Farms was released on 23 June. This enquiry was quite extensive and covered controversial aspects of wind farms, mostly related to the effects on health of low frequency noise and vibration. The full report can be downloaded from

http://www.aph.gov.au/Senate/committee/clac_ctte/impact_rural_wind_farms/report/index.htm Seven recommendations from the report are summarised as follows:

1) The Committee considers that the noise standards adopted by the states and territories for the planning and operation of rural wind farms should include appropriate measures to calculate the impact of low frequency noise and vibrations indoors at impacted dwellings.

2) The Committee recommends that the responsible authorities should ensure that complaints are dealt with expeditiously and that the complaints processes should involve an independent arbitrator. State and local government agencies responsible for ensuring compliance with planning permissions should be adequately resourced for this activity.

3) The Committee recommends that further consideration be given to the development of policy on separation criteria between residences and wind farm facilities.

4) The Committee recommends that the Commonwealth Government initiate as a matter of priority, thorough adequately resourced epidemiological and laboratory studies of the possible effects of wind farms on human health. This research must engage across industry and community, and include an advisory process representing the range of interests and concerns.

5) The Committee recommends that the NHMRC review of research should continue, with regular publication.

6) The Committee recommends that the National Acoustics Laboratories conduct a study and assessment of noise impacts of wind farms, including the impacts of infrasound.

7) The Committee recommends that the draft National Wind Farm Development Guidelines be redrafted to include discussion of any adverse health effects and comments made by NHMRC regarding the revision of its 2010 public statement.

NATA Rules

NATA Rules – November 2010 are currently under review and NATA has invited feedback on the current Constitution and the Regulations. It has been necessary to issue a revised version of the Rules prior to the review having been completed. The revised issue does not incorporate any feedback received so far. Changes made to the Rules were necessary as it was identified that the mandatory statements that comprise the NATA endorsements in the Second Schedule of the NATA Rules do not comply with clause 8.3.1 of ISO/IEC 17011 Standard 'Conformity assessment – General requirements for accreditation bodies accrediting conformity assessment bodies'.

The ISO/IEC 17011 Standard requires NATA's accreditation symbol to have, or be accompanied with, a clear indication as to which activity the accreditation is related (clause 8.3.1). For this reason, previously mandatory statements such as 'This document is issued in accordance with NATA's accreditation requirements' for facilities accredited in a laboratory accreditation program field of testing, have been replaced with a new mandatory statement which clearly indicates as to which activity the accreditation is related to.

Councillors, Members and Stakeholders are advised that the complete review of the Rules which includes any feedback and comments received is currently still being undertaken. The Transition Statement also advises of the changes and the rationale behind it. As stipulated in the Transition Statement, a transition period of two years will apply.

For more information or to comment on the complete review, visit

http://www.nata.com.au/phocadownload/publications/info_about_nata/NATA-Rules.pdf

WorkSafe inspection program in Western Australia

A WorkSafe WA inspection program on noise management in workplaces has revealed that noise remains a widespread hazard in WA workplaces. Inspectors visited 94 workplaces in the metropolitan, Bunbury and Karratha regions last year, identifying potential noise hazards in almost a third of the workplaces visited. Of these, 30 per cent were in the construction sector and 27 per cent in manufacturing, with the remainder spread over eight industry sectors – services, local government, mining services, transport, agriculture, education, retail and wholesale. The most common problem inspectors found was that many employers had not had the risk adequately assessed by a competent person, and so had no basis for formulating an effective noise control and management program. In other workplaces, although the noise hazards had been identified, the only action taken was the provision of personal hearing protectors. In many cases, a higher order of control could have been put in place, for example, at a manufacturing factory, there was scope for using quieter saw blades and silencers on air guns and to relocate a compressor away from workers. At two other workplaces, inspectors were pleased to see that a 'buy-quiet' policy had been introduced, resulting in very quiet welding machines and a quieter tyre change machine. Other areas of concern were the lack of provision of noise-related information and training to workers and their managers, and the failure to provide annual hearing tests. For more information visit

http://www.commerce.wa.gov.au/Corporate/Media/statements/2011/March/Inspection_program_on_noise_ma.html

David Bies Prize in Acoustics

The SA Division has established a David Bies Prize in Acoustics to recognize the contributions of David Bies to the science and practice of and education in acoustics. The prize is available each year and may be awarded to a member(s) of the AAS who is/are an acoustical practitioner(s) in South Australia, or has/have made a meritorious contribution to the discipline in South Australia. Nominations can be made via written correspondence to the AAS SA Division.

NEW PRODUCTS

JetVent fans

The release of the new EC (Electronic Commuted) series of Fantech JetVent fans has thrust forward energy efficiency in car park ventilation. Fantech's Market Development Engineer, Daniel Tan, said the brushless DC technology used in the EC motor was highly efficient, and when combined with integrated speed control could reduce noise and lead to massive power savings. When performing within AS2107:2000 noise requirements, the fan has the greatest thrust of all similarly sized JetVent fan units.

In addition to the high efficiency motor and speed control of the new EC units, the entire JetVent range utilises small, high speed fans which are more efficient than those used to push air around traditional ducts. The impulse fans are strategically located and thrust a high speed jet of air which in turn causes movement of large volumes of air through a process known as entrainment. The JetVent range can also help reduce construction costs, provided the decision to use a ductless system is made early in the building design. For more information, visit www.fantech.com.au

Vibration controllers

Brüel & Kjær has released its next generation of vibration test controllers, Type 7541 and Type 7542. PC connectivity is via a LAN interface that allows wireless operation and centralised control of multiple controllers remote from the vibration table test stations. In addition to reducing cabling, the controller can be placed close to the shaker and the entire system can be supervised and analysed remotely. The Type 7542 controller offers up to 64 input channels for control and limiting, while Type 7541 is suitable for applications that require from two to four input channels.

Both of the two new vibration test controllers promise to save set-up time and simplify testing procedures by virtually guaranteeing that input signal under-ranges and overloads are eliminated. This is attributed to dual, parallel A/Ds that deliver an exceptionally wide 130 dB dynamic range for the input channels without the need for multiple-input voltage range circuitry. For more information, visit www.bksv.com.au

MEETING REPORTS

NSW Division

The NSW Division technical meetings have been presented by Paul Mitchell from EMGA Mitchell McLennan on the topic of 'Regional Planning Panels (JRPP) and noise assessments' (May); Mark Latal, a senior noise policy officer in the Noise Policy Section of the Office of Environment and Heritage (OEH), on the new NSW Road Noise Policy (June); and Steven Cooper from The Acoustic Group on the topic of 'Aircraft noise measurements can be fun' (August).

The NSW Division have awarded travel grants to six PhD students to attend the Acoustics 2011 conference in November.

Victoria Division

The recent AAS Victoria Division 2011 technical meeting took the form of site visit to the Autex factory in West Heidelberg on 6th July to see and learn about the manufacture and properties of their variety of acoustical and thermal insulating materials. The Autex management warmly welcomed the nine members who attended.

The only material used in these products is polyester fibre made from PET plastics. Polyester, whether in fibrous or other form, is used in bedding and clothing, and is non-toxic, food-safe and fire-safe, as tested according to AS/NZS and ISO standards and BCA requirements. Autex obtains its material as extruded fibre, most of which has been recycled, such as from bottle flake. It is 100% recyclable at the end of its life. The different fibre types (denier and shaped fibres) are blended and processed to create basic sheets (mostly around 5 mm thick) which are further engineered into higher performance materials using heat rather than adhesives to create multiple layer products of various thicknesses and densities. Their almost zero VOC levels make them fully recyclable. In the factory tour, those of us present were shown these processes.

Of the absorptive panels, the 'Quietspace' panels are available in 25 and 50 mm thicknesses. Their NRC values, as test data supplied by Autex, vary from 0.85 to 1.0, with 0.85 for the 25 mm panel, 0.90 for the 25 mm panel with 6 mm air gap, and 1.0 for the 50 mm panel. With the 25 mm panel, the air gap provides slightly greater absorption overall, but with almost double the absorption (0.20 compared with 0.12) around 125 Hz. These Quietspace panels, though of not high TL when tested in isolation, can, when used in conjunction with usual wall constructions, increase the TL of an uninsulated reference wall with STC of 36 to an STC of 48 for an insulated wall with Quietspace panels on each side.

The 'QuietStuf' absorption blanket comes in a variety of densities and thicknesses from 25 to 100 mm. NRC values, depending on material density and thickness, vary from 0.55 to 1.10. For all these products, Autex provides a 50 year durability warranty against product failure in normal use situations.

Following the factory tour, refreshments were served, after which Geoff Barnes (VIC Division chairman) thanked the Autex staff who had conducted the factory tour, explained the various manufacturing processes and provided the refreshments: a vote of thanks confirmed by the group's applause.

South Australia Division

In early 2011 the SA Division offered financial sponsorship for final year university undergraduate projects that involve acoustics or vibrations. This sponsorship was set up to encourage students to undertake interesting and useful projects in this field. Sponsorship of $850 was awarded to the following group of students from the University of Adelaide: Yann Frizenschaf, Siobhan Giles, Jack Miller, Christopher Stapleton and Thomas Pitman, who are undertaking a project entitled *Levitating magnet vibration isolation device*. This funding has allowed the students to purchase specialised components required for their prototype design.

Western Australia Division

The WA Division met at Curtin University on 9th February to hear Pam Gunn talk about the noise and vibration aspects of the draft National Work Health and Safety Regulations and Codes of Practice that had been released for public comment in December 2010. Those present proposed and discussed ways to improve the drafts and decided to submit them to Safe Work Australia. These included: wording to make it clear that the exposure standard does not take into account any protection that may be afforded by a worker wearing personal hearing protectors; recommending that people competent to undertake detailed noise assessments be eligible to be Members of the AAS or employees of firms that are members of AAAC; additional training topics and review criteria; adding reporting of uncertainty of measurement to noise reports; and more appropriate cover illustrations for the Code. The group also supported the inclusion in the Code, information about other effects that noise can have on worker health and safety and the effects that ototoxic chemicals and vibration can have on hearing; and the Ready Reckoner for calculating noise exposure levels. The submission was made in early April and can be viewed at the website:

http://www.safeworkaustralia.gov.au/Legislation/PublicComment/Pages/PublicSubmissionsA.aspx

Standards Australia

Alarm Systems for Hearing Impaired

This new standard addresses a critical safety issue for the hearing impaired and the broader community with the objective to provide design and performance specifications for warning equipment that acts with smoke alarms and detector to alert people with hearing impairment of potential danger. Standards Australia said there are a variety of means to alert hearing impaired people of fire hazards and these include vibration, low frequency sounds and visual alarm devices.

Future Conferences

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). Conference sessions will include 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.

More information from

http://www.internoise2011.com

ACOUSTICS 2011

The annual conference of the Australian Acoustical Society will be held in the Gold Coast 2-4 November 2011. This provides the opportunity for all those working in acoustics around Australia to meet and discuss recent work. The theme for this conference is "Breaking New Ground" and many of the papers will be highlighting the role of acoustics in the recent boom in large infrastructure projects around Australia. In addition to papers on this theme, papers on all aspects of acoustics will be welcomed including Underwater Acoustics and Architecture and Building Acoustics. There will be a technical exhibition, workshops and a great social program.

Registration and submission of final versions of all papers 30 September 2011

For more information see

http://www.mech.uq.edu.au/acoustics2011/

Railway Technology

The First International Conference on Railway Technology: Research, Development and Maintenance (Railways 2012), will be held in Las Palmas de Gran Canaria, Spain, from 18-20 April 2012. The purpose of this conference is to provide opportunities for scientists and engineers to meet and to discuss current research, new concepts and ideas and to establish opportunities for future collaborations in all aspects of Railway Technology.

More information from

http://www.civil-comp.com/conf/railways2012.htm

ICSV19

The 19th International Congress on Sound and Vibration (ICSV19) will be held at Vilnius University in Vilnius, Lithuania, 8-12 July 2012. ICSV is the annual conference organised by the International Institute of Acoustics and Vibration (IIAV). Theoretical and experimental research papers in the fields of acoustics, noise, and vibration are invited for presentation. Vilnius is the historical capital of Lithuania and dates back to the 14th century. Vilnius has since been awarded the status of World Cultural Heritage by UNESCO and Vilnius University, the congress venue, is one of the oldest universities in Eastern Europe.

Abstract submission 19 December 2011

More information from

http://www.icsv19.org

ISMA 2012

The 25th edition of the international ISMA Noise and Vibration Engineering Conference (ISMA2012) will be held in Leuven, Belgium, from 17-19 September 2012. It will be organised in conjunction with the 4th International Conference on Uncertainty in Structural Dynamics (USD2012).

Abstract submission 15 January 2012

More information from

http://www.isma-isaac.be/conf/

NOVEM 2012

Noise and Vibration: Emerging Methods (NOVEM) 2012 will be held in Sorrento, Italy, from 1-4 April 2012. NOVEM 2012 is the 4th in the conference series. The goal of the conference is to promote significant discussion and exchange of scientific information. The conference is targeted specifically at persons from research establishments and from industry who are responsible for developments in the field of noise and vibration control. The emphasis of the conference is on new and emerging methods, techniques and technologies in acoustics and vibration, focusing on specially selected thematic areas which represent today's major scientific challenges.

Abstract submission 14 October 2011; Registration 18 November 2011; Paper submission 14 January 2012

More information from

http://www.novem2012.unina.it

Colin Graeme Speakman

1964-2011

The Society mourns the recent loss of one of our most active and well known members. Colin Speakman passed away on 6th July 2011 due to a complication of medical treatment. Colin joined the Queensland Division of the Australian Acoustical Society in 1996, becoming a member of the Division Committee in 1998 and of Federal Council in 2004. Colin served as Division Treasurer for many years and was Congress Treasurer for Acoustics 2004. He became Division Chairman in 2005. At the time of his passing, Colin was a Federal Councillor and Vice-Chairman of the Queensland Division, and Congress Chairman of Acoustics 2011.

Colin's professional career as a Mechanical Engineer and Acoustician commenced with his honours degree from the University of Tasmania (1991) and subsequently as a Research Officer at the University of New South Wales in the Australian Defence Force Academy Noise and Vibration Unit (1992-1996). He was a design engineer at Sound Control Pty Ltd (1996-2005) and a principal acoustics and vibration engineer at Parsons Brinckerhoff Pty Ltd (2005-2011). Colin was a diligent and ethical practitioner of acoustics and mechanical engineering and worked tirelessly for his employers and the Australian Acoustical Society.

We will always remember a quiet modest gentleman who was friendly and willing to help and had a great sense of humour. His presence and influence in the Society will be sorely missed. Colin is survived by wife Kate and daughters Madeleine and Georgia.

Dave Davis

Diary

2011

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

20 - 22 September, Buxton, UK
46th Annual UK Conference on Human Response to Vibration
http://www.hsl.gov.uk/health-and-safety-conferences/UKHRV2011/home.aspx

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

1 – 4 April, Sorrento, Italy
Noise and Vibration: Emerging Methods (NOVEM) 2012
http://www.novem2012.unina.it

18 – 20 April, Las Palmas de Gran Canaria, Spain
Railways 2012
http://www.civil-comp.com/conf/railways2012.htm

13 – 18 May, Hong Kong, China
Joint meeting of the 163rd meeting of the Acoustical Society of America, the 8th meeting of the Acoustical Society of China, the 11th meeting of the Western Pacific Acoustics Conference and the Hong Kong Institute of Acoustics.
http:// acoustics2012hk.org

2 – 6 July, Edinburgh, UK
11th European Conference on Underwater Acoustics (ECUA 2012)
http://www.ecua2012.com

8 – 12 July, Vilnius, Lithuania
19th International Congress on Sound and Vibration (ICSV19)
http://www.icsv19.org

22 – 27 July, Porto, Portugal
15th International Conference on Experimental Mechanics (ICEM15)
http://paginas.fe.up.pt/clme/icem15

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

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

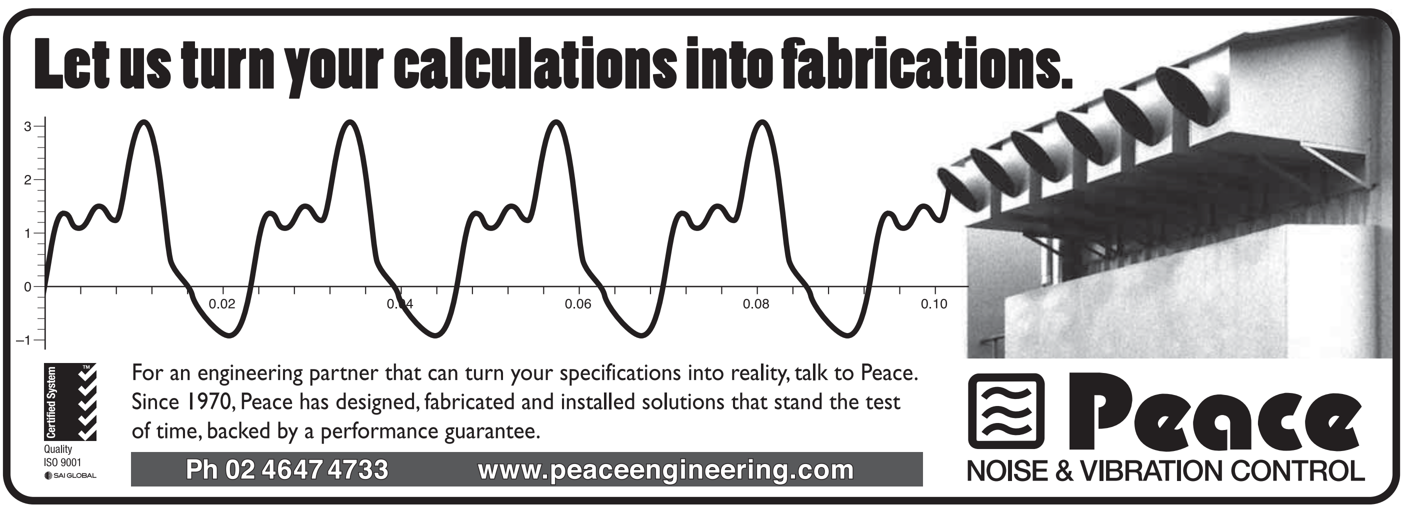
17 – 19 September, Leuven, Belgium
ISMA Noise and Vibration Engineering Conference (ISMA2012)
http://www.isma-isaac.be/conf/

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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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/plasterboard

BRUEL & KJAER AUSTRALIA
www.bksv.com.au

CSR BRADFORD INSULATION
www.bradfordinsulation.com.au

EMBELTON
www.vibrationisolation.com.au

AERISON PTY LTD
www.aerison.com

HOWDEN AUSTRALIA
www.howden.com.au

IAC COLPRO
industrialacoustics.com/australia

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

PEACE ENGINEERING
www.peaceengineering.com

PYROTEK NOISE CONTROL
www.pyroteknc.com

SINCLAIR KNIGHT MERZ
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Richard Booker - General Secretary
Australian Acoustical Society
PO Box 1843 Toowong DC QLD 4066
Tel: (07) 3122 2605
email: GeneralSecretary@acoustics.asn.au
www.acoustics.asn.au

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Enquiries regarding membership and sustaining membership should be directed to the appropriate State Division Secretary

AAS - NSW Division
Laura Allison
c/- AECOM
Level 21, 420 George Street
Sydney, NSW 2000
Tel: (02) 8934 0035
Fax: (02) 8934 0001
Laura.Allison@aecom.com

AAS - Queensland Division
PO Box 760
Spring Hill Qld 4004
Sec: Richard Devereux
Tel: (07) 3217 0055
Fax: (07) 3217 0066
rdevereux@acran.com.au

AAS - SA Division
AECOM,
Level 28, 91 King William St
ADELAIDE S.A. 5005
Sec: Darren Jurevicius
Tel: (08) 7100 6400
Fax: (08) 7100 6499
darren.jurevicius@aecom.com

AAS - Victoria Division
c/- Simon de Lisle
Arup Acoustics
Level 17, 1 Nicholson Street
Melbourne VIC 3000
Tel: (03) 9668 5580
Fax: (03) 9663 1546
simon.delisle@arup.com.au

AAS–WA Division
Unit 3
2 Hardy Street,
SOUTH PERTH 6151
Sec: Norbert Gabriels
Tel (08) 9474 5966
Fax (08) 9474 5977
gabriels@iinet.net.au

ACOUSTICS AUSTRALIA INFORMATION

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The Editor, Acoustics Australia
c/o Nicole Kessissoglou
School of Mechanical & Manufacturing Engineering
University of New South Wales
NSW 2052 Australia
Mobile: +61 401 070 843
acousticsaustralia@acoustics.asn.au

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