# Using Wind Farm Noise Auralisations for Effective Community Consultation

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## ABSTRACT

Two of the most common questions that wind farm developers face during community consultation are 'what will the wind farm look like' and 'what noise will it make?' A lot of work has been undertaken recently to develop 'visualisations' or 'photomontages' to answer the first question. However, there has not been an equivalent tool available to enable local communities to understand what a wind farm actually sounds like. Arup and Hydro Tasmania have jointly developed a tool that will accurately and effectively communicate what a wind farm sounds like under different wind conditions and from a range of distances and orientations. This auralisation tool provides a practical and affordable means for the industry to effectively communicate what a wind farm will sound like to the community.

This paper looks at how auralisation techniques used in other sectors (such as transport and aviation) have been adapted for the renewable wind energy sector and serve as a valuable tool for increasing transparency, minimising risk and building trust within local communities early in the wind farm development process. It shows how a comprehensive field measurement program at Studland Bay Wind Farm, Tasmania has enabled a wind turbine sound library to be developed for future use in wind farm acoustic models and how calibrated auralisations can be presented at community settings.

Keywords: Wind turbine, Auralisation, Community.   I-INCE Classification of Subjects Number(s): 14.5.4

## 1. INTRODUCTION

Hydro Tasmania is Australia's leading renewable energy business that generates hydropower and wind power in Tasmania and trades electricity and energy-related related environmental products in the Australia market. TasWind is a concept that involves building around 200 wind turbines on suitable areas of King Island, in Bass Strait. If it proceeds, it would generate approximately 2400 GWh of renewable energy. The project would connect to the National Electricity Market in Victoria via a high-voltage underwater cable across Bass Strait.

Noise, vibration and low frequency sound can pose significant environmental concerns for the community during the development, planning and operation of wind turbines. These potential effects can be reduced at the planning stage by undertaking noise assessments during site selection and turbine layout design. Some wind-farm developers, including Hydro Tasmania, have sometimes taken potentially affected residents at newly planned sites on tours of existing wind-farm developments in order for them to experience sound from real wind farms for themselves.   However such study tours are necessarily limited in the number of people who can attend, and more importantly, and subject to the particular weather conditions that exist at the time of the tour.

Auralisations of wind farm sound have the benefit that they can be shown to a wide range of the

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potentially affected community, they allow a wide range of 'virtual weather conditions' to be experienced, and they allow direct 'back-to-back comparison between various operational scenarios, so that subtle aural characteristics can be more easily compared.

Arup is a pioneer in the field of auralisation, having established ten (10) SoundLabs around the world. The Arup SoundLabs have facilitated greater stakeholder input into acoustic design and have had significant impact on the design of numerous architectural, environmental and transportation projects.

Arup's SoundLab provides an intuitive understanding of specific acoustic parameters, allowing them to be heard during the acoustic design and planning phase. It allows for difficult acoustic terminology to be demonstrated, listened to and easily understood for various wind farm configurations at various locations, to a range of environmental conditions including inside buildings.

Hydro Tasmania engaged Arup to produce auralisations which would accurately represent and reproduce wind turbine sound from field recordings undertaken at Studland Bay, Tasmania for the purpose of community consultation and education.

## 2. UNDERSTANDING THE BRIEF

This project required Arup to undertake calibrated field recordings, develop a process so that the community of King Island and others could experience the sounds of wind turbines and to develop an understanding of wind turbine sound for a potential future wind farm development.
Hydro Tasmania was interested in using auralisation, or accurate sound renderings, of wind farm noise as part of the community consultation process for the proposed TasWind project on King Island. Auralisations have the potential to reduce misunderstanding and risks associated with noise exposure. It also assists with keeping the discussion of wind farm sound, simple, factual and representative of the proposed development. The use of the Arup SoundLab, and a portable alternative would be used in the approvals and community consultation process for the TasWind project.

## 3. ENVIRONMENTAL NOISE

Noise, and in particular low frequency sound and amplitude modulation, can be a significant environmental concern for the nearby community and to wind farm developers. For the community, misinformation and fear of sound from wind farms is a significant contributor to the opposition to wind farm developments. For developers, the uncertainty of the community consultation and planning application process can be concerning.

Arup has been providing acoustic advice in Australia for nearly two decades and have significant international and local experience in environmental impact assessments, community consultation and auralisation on a full range of types of projects from multi-billion dollar infrastructure projects to much smaller developments both onshore and offshore for both land and aquatic acoustics. Arup has provided noise assessments, predictions, and mitigation design; direct discussion with the community about noise and auralisations for residents to listen to many of these projects. The benefit is that clients themselves hear what they are proposing and the community and stakeholders are also well informed about the noise aspects of the project creating better community engagement.

### 3.1 Auralisation and the SoundLab

When combined with film of operational turbines the use of auralisation (the acoustic equivalent of visualization or visual rendering), particularly when combined with visualisation (such as films), is a very powerful medium for community consultation. Allowing the community to listen to the noise from (and to see) the proposed development provides a transparent, simple and direct aural demonstration of the potential noise impacts. It allows the listener to understand what is proposed without having to try to understand technical terminology. This is particularly powerful for wind farm developments where there is significant stigma associated with their noise. Many people may fear noise emission from wind farms without having ever listened to the noise emission from a wind farm. The auralisation process assists in to gain a clear understanding of what the noise levels are likely to be.

## 4. AURALISATION METHODOLGY

For the wind-farm auralisations we Arup measured real wind turbine sound levels using a Soundfield© ST350 Ambisonic microphone. This special microphone has four separate capsules arranged in a tetrahedron, which allows the three-dimensional character of the sound to be captured. The sound is recorded in a four-channel ambisonic format called ‘B-Format’ which separates the sound into distinct orthogonal X, Y, Z and omni-directional channels. This *B-Format* recording is then played back via a spatialisation engine to accurately recreate the recordings through the specially arranged ambisonic loudspeaker array. The way this is recreated is determined through the use of spherical harmonic mathematics and the sound through each loudspeaker is determined based specifically on its orientation and physical location relative to the listener to recreate the original recording as accurately as possible. Wind farm noise played back through a spatialisation engine (*Ambisonic Decoder*) which separates the sound from the different directions and directs it to the right balance of loudspeakers to make it sound like it is coming from the direction it originated from allowing accurate localisation. This process is called *Ambisonics* and creates a very immersive and highly realistic listening experience.

### 4.1 Equipment

The noise measurement process required the following equipment. The data was captured in the presence of the engineer, the following equipment was used:

- Four Channel 3D SoundField® audio recordings (B-Format) microphone and associated media recorders.
- Hand held sound level meter noise levels Brüel & Kjær 2250 and Brüel & Kjær 2260
- Local weather stations (wind speed and direction and temperature)
- Unattended measurements using four (4) Nigara loggers. These were assembled at pre-selected locations to monitor noise and record lower quality audio continuously using outdoor noise logging equipment and an accompanying data logging weather station. The following was measured at the *unattended* locations.
- Omni-directional audio recordings (lower quality and not 3D format)

Since it is so windy around the wind turbines Arup have developed foam microphone windshields to minimise the low-frequency interference from turbulent wind pressure acting on the microphone capsule. The custom wind-shields for both the noise loggers and the SoundField® microphone assisted to minimise the impact of low-frequency wind noise. These enormous foam windshields are based on a design by Schomer[5], and are designed to reduce low-frequency wind noise on the microphone capsule by around 30 dB. An image of the microphone and wind shields are presented in Figure 1.

Figure 1: Schomer Windshields and SoundField® microphone

Data supplied by the wind farm operator included the following:

- Weather data at wind turbine hub during measurement period for each turbine
- Details turbine operating conditions during the measurement period
- Noise data for existing wind turbines (ie manufacturer data) which was used to validate and confirm measurements

### 4.2 Studland Bay Wind Farm

Studland Bay Wind Farm is one of two wind farms near Woolnorth along the North-West coast of

[5] [1] ISVR Consulting Services, *Noise Measurements in Windy Conditions*, Final Report June 1996

Tasmania, Australia. The wind farm development was commissioned in 2007 with 25 3 MW Vestas V90 turbines[6]. The calibrated recordings were obtained from the Studland Bay Wind Farm over a period of 14 consecutive days in March 2013. A comprehensive matrix of scenarios was developed to capture wind turbine sound under various environmental conditions. A single turbine[7] was isolated as far as practical from the cluster of turbines and presented in Figure 2 as Turbine HE.


Figure 1: Studland Bay Wind Farm

Measurements of Turbine HE allowed sound levels dominated by a single turbine to be captured from distances of 100 m, 250 m, 500, 1000 m, 1500 m and 2000 m. Recordings were obtained for each of these distances for wind speeds in the following ranges 2 – 6 m/s, 6 – 10 m/s and 10 – 14 m/s[8] and under a range of different wind shear conditions. These wind speeds were considered critical areas of interest with respect to linking turbine noise levels with background conditions. Furthermore the orientations of the turbine were noted these included upwind, downwind, crosswind up (upstroke side) and crosswind down (downstroke side). In excess of 80 recordings were obtained. This information was the basis for further post production analysis and the development of the auralisations.

In addition to wind turbine noise at various distances, under a range of wind speeds and blade positioning, back ground noise recordings were also captured. These include the following scenarios:

- Calm conditions – Wind speed at ground level (0 – 2 m/s).
- Light wind near pine trees – Wind speed at ground level (2 – 6 m/s)
- Gusty conditions near pine trees – Wind speed at ground level (6 – 10 m/s)

The wind speed detailed above is the wind speed at ground level.

## 4.3 Calibration

The calibration process is complicated and has, to the best of Arup's ability, maintained accurate representative calibrated ambisonic recordings of wind turbine noise. There are two major calibration corrections which have been applied to the recordings digitally using audio editing software Audacity:

1. Frequency response of the ambisonic microphone
2. Frequency response attenuation due to the windshield

The calibration filters have been implemented using Fast Fourier Transforms and Finite Impulse

[6] http://www.hydro.com.au/energy/our-power-stations/wind-power 20 August 2014
[7] HE Turbine. This turbine was located to the South West of the Studland Bay Wind Farm.
[8] The wind speeds are an indication of the wind speed at hub height.

Response (FIR) Filters. The FIR filter frequency responses have been determined by comparing the Equivalent Continuous Noise Level ($L_{eq}$) of the calibrated reference measurement instrumentation to our ambisonic recording equipment.

To enable auralisation of different conditions, recordings of turbine sound with good signal to noise (recordings where the sound from the turbine is significantly greater than the natural ambient noise) have been used, combined with separate recordings of ambient environments with no turbine noise (eg wind in trees, grazing fields, the ocean, typical domestic sounds such as television and the dishwasher). These recordings have then been layered in different combinations to create the desired virtual aural environments.

To simulate the effect of sound propagation attenuation at large distances from the turbines, FIR filters have been used to attenuate the recordings to account for the change in noise level and frequency spectrum as the distance from the turbine increases. The losses due to sound propagation that have been applied have been calculated using International Standard 9613-2[9] which is the accepted industry standard for modelling sound propagation losses for wind turbines and other environmental noise sources.

In addition, the spectrum change and sound level differences due to being indoors with either an open or closed window has been recreated based on the differences between simultaneous indoor and outdoor measurements of sound.

Each of these alterations to the recordings has been implemented using FIR filters determined from the energy spectrum of recordings and measurements. A flow diagram describing the process is provided Figure 3.

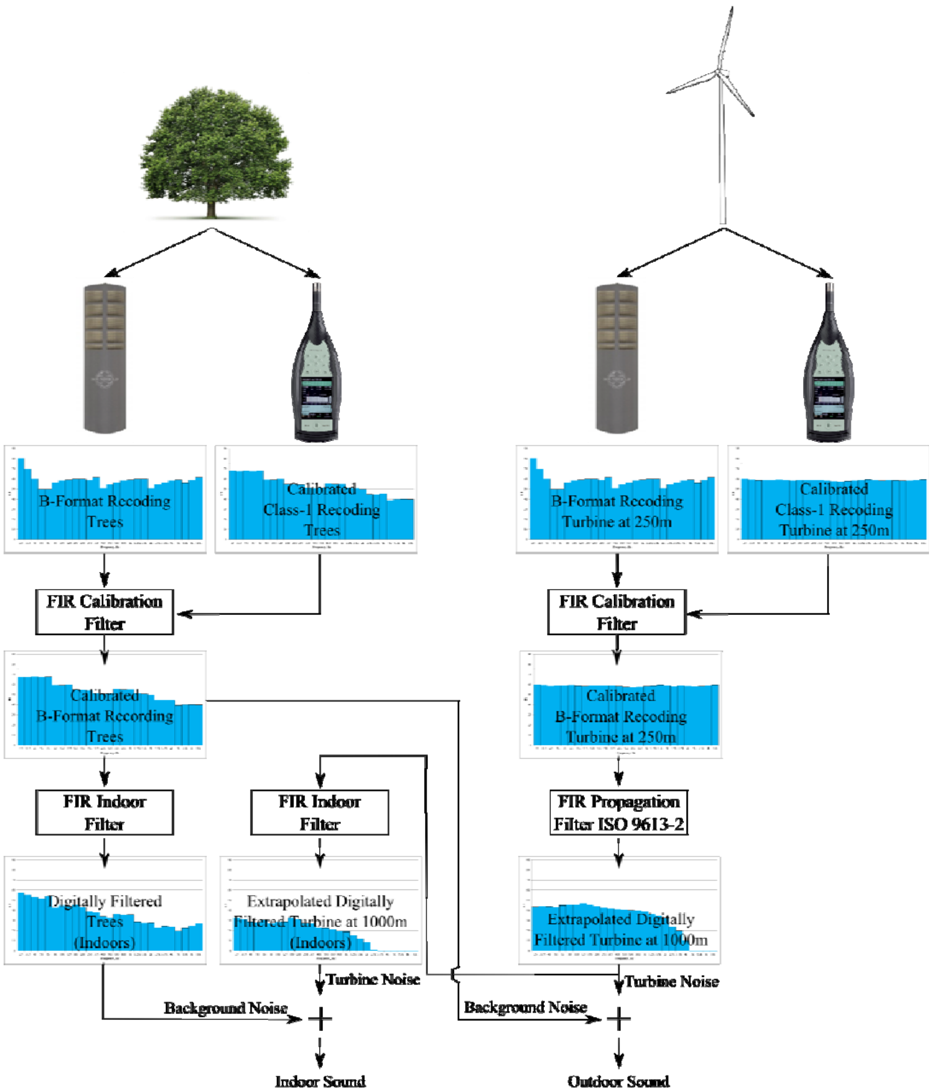


Figure 3 Calibration process

[9] [2] ISO 9613-2:1996 *Acoustics - Attenuation of sound during propagation outdoors – Part 2: General method of calculation.*

### 4.4 Calibration Filters

Due to the arrangement of the multiple microphone capsules within the SoundField microphone, it is not possible to calibrate it using a conventional sound level calibrator or pistonphone. Therefore, a ‘back-to-back’ calibration with a pre-calibrated Brüel & Kjær 2250 SLM has been adopted. Two stages of calibration filter were created to correct for two different aspects of the recording process and the windshield insertion losses and the frequency response of the SoundField microphone. The result is that there are two stages of filter:

- Determination of windshielded Brüel & Kjær 2250 to an unwindshielded Brüel & Kjær 2250 frequency response correction filter
- Determination of windshielded SoundField microphone to unwindshielded Brüel & Kjær 2250 frequency response correction filter

### 4.5 Brüel & Kjær 2250 Windshield Insertion Loss Correction Filter

The insertion loss of the custom windshield on the Brüel & Kjær 2250 was determined by measuring 12 channels (+ sub) of uncorrelated pink noise through the Arup Melbourne SoundLab sound system. The SoundLab speakers are arranged in 3 stacked squares of loudspeakers. Each square has a loudspeaker at each corner of the square. The centre plane is rotated by 45°. It is approximately 3 m wide, 3 m deep and 2.4 m high.

The sound level difference with and without the windshield was determined at 3 separate locations within the room (multiple locations were selected to reduce error due to locations with unusual modal response).

From these three sets of measurements the median differences of the three spectra pairs was determined. From the median difference, a rationalised, smoothed curve was selected manually. This was used as the insertion loss correction filter to account for sound level losses due to the windshield.

This filter was then applied to the SoundField recordings. It should be noted that the SoundField was corrected as a single system combining the frequency response of the microphone with the windshield attenuation

A correction for the SoundField frequency response including the effect of the SoundField windshield has been determined by using the windshield corrected Brüel & Kjær 2250 (unwindshielded) recordings as a reference spectrum and comparing this to the windshielded SoundField spectrum. The SoundField recorded spectra (after correction) and the Brüel & Kjær 2250 spectra were then compared to see how effective the filter was. The differences were typically within 2 dB at lower-mid to mid frequencies (larger at high frequency due to noise), and larger at lower frequencies in one particular recording. The largest variation in any given third octave band (excluding the high frequency) was 7 dB at 31 Hz, however, the smallest at this frequency was 2 dB. On this basis it is felt that the filter is a good representation of the spectrum difference between the Brüel & Kjær 2250 and the SoundField. Note that high frequency (above approximately 3.15 - 4 kHz have been ignored due to the low signal to noise ratio on the Brüel & Kjær 2250 recordings).

## 5. COMMUNITY CONSULTATATION – KING ISLAND, TASMAINA

In the Arup SoundLab wind turbine noise is played back through a ‘spatialisation engine’ which separates the sound from the different directions and directs it to the right balance of loudspeakers to make it sound like it is coming from the direction it originated from. Commonly known as ‘ambisonics’, this creates a very immersive and highly realistic listening experience.

For the TasWind demonstrations, a portable loudspeaker array has been used. This comprises a 6.1-channel hexagonal loudspeaker array, using Genelec studio monitor loudspeakers and subwoofer. The whole system was calibrated prior to any auralisation demonstrations to ensure that the sound level received by the audience was comparable to that which was measured on site. These audio files are then played back and if required several files may be layered to generate the appropriate scenario being investigated.

This allows the listeners to compare what the wind farm sounds like on, for example, a windy day as opposed to day with no wind. The listeners can experience the wind farm at its noisiest when high wind shear allows the turbines to operate in strong wind at hub height, while conditions at ground level remain calm, and background noise levels are lowest. Presented in Figure 4 is an image of the presentation at King Island Council chambers where the auralisation demonstrations were conducted.

The Council Chambers experienced intermittent intrusive noise due to rain and wind events, mostly due to the light weight roof construction. However, low background noise levels were possible, ambient conditions were measured at 25dBA.

Figure 4 King Island Auralisation Presentation

### 5.1 Community Feedback

Arup completed 11 community consultation sessions at the Council Chambers at Currie on King Island between 13 – 15 November 2013. The sessions were presented and guided by the authors. Each session lasted approximately 20 minutes with 20 – 30 minutes of questions and discussion. Questionnaires were completed by participants at the completion of each session.

The presentation included the following:

- An introduction by Hydro Tasmania explaining the context of the presentations and emphasising that work to date has focused on the audible spectrum.
- Overview of Arup's credentials in the field of "auralisations" citing work on rail and road infrastructure projects
- Explanation of methodology used to capture recordings at Studland Bay and post processing undertaken
- Playback of aural/ visual recordings (with and without headphones) at 500m, 1000m and 2,000m and from various directions
- Demonstration of relative impact of various background noise environments under various ground level wind conditions
- Demonstration of attenuation of wind turbine noise inside a home with windows open and closed
- Multiple wind turbine simulation of Studland Bay Wind Farm
- Comparison of Vestas V90 wind turbine with Siemens SWT-3.0-113
- Explanation of future modeling capability made possible by this foundation work (whole wind farms, substitution of various wind turbine makes/ models)
- Demonstration of other compliant infrastructure noises such as rail and road traffic
- Questions and answers
- Invitation to complete feedback survey form

### 5.2 Feedback and Questionnaire summary

A total of 103[10] residents attended the sessions feedback was received from 94 attendees and was overwhelmingly positive with regard to:

- Effectiveness of Speaker Communication
- Subject Matter
- Quality of Material and
- Facilitation (even those not supportive of TasWind).

A summary to the questionnaire is presented below:

***Q: How effectively did the speaker communicate with you?***

Attendees rated speaker communication very highly with 88% rating it as either "good" or "excellent".

***Q: How easy was the presentation to understand?***

[10] Approximately 10% of the population of King Island

Most (82%) of the attendees found the presentation easy to understand and delivered at an appropriate technical level.

***Q: How well did the presentation meet your expectations?***
35% of attendees considered the presentations meet their expectations "very well", 43% "well" and 11% "satisfactorily".

***Q: If you have not visited an operational wind farm before, was the sound recording worse, different, as expected or better than you had imagined it to be ?***
A large number of those attending the auralisation sessions commented that the wind turbine noise presented was "quieter" than they had expected or "not as loud as expected". Results indicate that 35% considered the sound "better" than expected, 26% "as expected" and 13% "different" to expectations.

***Community Discussion and general feedback***

A large number of respondents thought the sound recorded was *"Better than expected"*. A typical comment was *"Quieter than I thought it would be"* or *"Not as loud as expected"*.

There was a high level of interest in hearing turbines at different separation distances and directions and the impact background noise has on audibility of wind turbine noise. One attendee observed: "*The background noise of the birds seemed unrealistic. This would only occur in the morning, therefore the background noise would be lower. Maybe with cattle more realistic on island*". Many attendees asked what the turbines proposed for King Island would sound like (in comparison to Studland Bay Wind Farm) and some were interested in comparative recordings of the existing Huxley Hill Wind Farm as well. Some were interested to learn that larger turbines are not necessarily noisier. Participants suggested further background noise recordings be presented such as barking dogs / cows / loud rhythmic bass music or a chainsaw all at various distances. Some were also interested in other domestic appliances (i.e. other than TV as shown)

## 6. SUMMARY

Arup and Hydro Tasmania have jointly successfully demonstrated that wind turbine sound can be accurately reproduced and presented to community groups. This approach has provided Hydro Tasmania with a planning instrument suitable for demonstrating project noise levels during the feasibility phase of the project. The auralisation reproduced for TasWind has kept the community of King Island engaged with the project, and it has also provided useful insight to the concerns of resident groups. In the opinion of the authors and feedback received from the King Island community wind noise auralisation significantly assisted with the introduction of the TasWind project.

## REFERENCES


1. ISVR Consulting Services, *Noise Measurements in Windy Conditions*, Final Report June 1996
2. ISO 9613-2:1996 *Acoustics - Attenuation of sound during propagation outdoors – Part 2: General method of calculation.*