The Acoustic Group
CONSULTING ACOUSTICAL & VIBRATION ENGINEERING

ACOUSTIC REVIEW

PROPOSED RYE PARK WIND FARM

44.5133.R1:MSC

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CONTENTS

APPENDICES

INTRODUCTION

1. I Steven Edwin Cooper, the Principal of The Acoustic Group Pty Ltd, Consulting Acoustical and Vibration Engineers, provide this review in relation to acoustic matters with respect to the proposed Ryde Park Wind Farm to be located in the vicinity of the township of Ryde Park, approximately 12 km north east of Yass and 42 km west of Crookwell in New South Wales.

2. The proposed wind farm was the subject of an environmental impact statement and is available for viewing on the Department of Planning website under Major Projects.

3. The EIS contained an acoustic assessment from SLR Consulting Australia Pty Ltd identified as "Rye Park Wind Farm, Noise Impact Assessment", Report Number 640.0108/R1 dated 2nd August, 2013.

4. The acoustic report identifies that the manufacture and model of turbines to be used has not yet been finalised but the report has considered the use of a Vestas v112 3.0MW turbine as the turbine to be used for prediction of noise emission levels.

5. Section 4.1 of the acoustic report identifies that the layout that has been assessed is for 126 wind turbines making up the wind farm.

6. The report indicates background noise levels were undertaken at 20 reference locations around the proposed wind farm site to provide ambient background data in the form of a regression line that plots the noise level at each receptor location versus the wind speed at a height of 80 m above ground level on the proposed wind farm site.

7. The report identifies that the predicted noise levels have been assessed with respect to the relevant criteria prescribed by the South Australian EPA guideline and the World Health Organisation (WHO) goals where appropriate.

8. The report also refers to a draft guideline issued by the New South Wales Department of Planning and as such has conducted an evaluation of night time impacts.

9. Section 2 of the acoustic report identifies the environmental assessment requirements issued by the Director General (DGRs) in relation to noise impacts. One would assume all of those matters have been addressed in the subject assessment.

10. The first acoustic requirement under the DGRs is to identify that the assessment must include a comprehensive noise assessment of all phases or components of the project including turbine operation, substation, transmission line noise, construction noise and vibration generating activities during construction and operation.

11. It would appear that the acoustic report has addressed the first noise component of the DGR.

12. The second component in relation to noise states:

> *"In relation to wind turbine operation, determine the noise impacts under operating meteorological conditions (i.e. wind speed to cut into rated power) including impacts under meteorological conditions (including varying atmospheric classes, van den Berg effect for wind turbine). The probability of such occurrences must be quantified."*

13. I am unable to find where in the acoustic assessment is it identified the noise impact that will occur as a result of the wind turbine operation including the different meteorological conditions and wind speed that would exacerbate such impacts. **Therefore from the outset it is identified that the acoustic report has failed to address all of the noise related DGRs specified for the project.**

14. The third DGR requirement is to include monitoring to ensure there is adequate wind speed data and ambient background data that is representative of sensors of which the material indicates there is monitoring to satisfy the 14 day period out in the SA EPA guideline.

15. The fourth DGR requirement concerning noise is to provide the nominated background level used in the assessment process and considering significant differences between day and night time background levels higher than 30 dB(A). The SLR report indicates by way of a series of regression lines with respect to the ambient noise level and the methodology used by the South Australian EPA guideline, that background levels are regularly below 30 dB(A) and on the basis of the limitation of the instrumentation used would suggest at times less that 20 dB(A).

16. The next DGR requirement is to identify the risk from low frequency infra-sound, in which Section 7.6.2 of the report appears to dismiss the issue of infrasound by reference to a number of documents.

17. The SLR report does not actually assess the DGR requirement as to the risk from low frequency and infra sound noise, but simply identifies that infrasound noise emissions from modern wind turbine are significantly below the threshold of perception.

18. The report has failed to identify whether that threshold of perception means a physical perception or an audible perception and has failed to identify any matters in terms of the risk of infrasound level generated by the proposed wind farm.

19. In Section 9.2.1 reference is made to the assessment of low frequency noise under the draft NSW wind farm Guidelines using dB(C). This assessment is in terms of external noise. There is no assessment of internal noise or impacts as a result of low frequency noise.

20. Accordingly it would seem that the acoustic report has failed to identify any risks associated with low frequency or infra-noise. The remaining acoustic DGR's relate to matters of potential noise mitigation, monitoring, noise agreements and contingency strategy which if having failed to identify the impacts of the turbines and the risks with respect to low frequency and infra-sound cannot therefore be addressed.

21. As the SLR Consulting Australia Report failed to identify the actual impact that the turbines will have on residents, failed to identify any risks associated with low frequency or infra-sound, and failed to identify the matter of sleep disturbance for persons subject to the proposed wind farm these are matters that need to be addressed with respect to the subject application and the responsibility of the wind farm operators and consultants to ensure there is no adverse impact.

22. In dealing with the acoustic assessment for the subject application it is noted that in the SLR Consulting report there is no identification of infrasound levels that would be expected external to and inside residential dwellings, and no discussion on the physical effects of turbines on residents in relation to headaches, nausea and sleep disturbance.

23. SLR Consulting Australia has not provided any guarantee of there not being any adverse noise/vibration/sensation impacts associated with the development.

24. The fundamental question in assessing the acoustic impact of the proposed wind farm that before the approval authority is whether the noise levels permitted by the SA EPA guidelines are adequate to protect the amenity of the community.

25. From my measurements at operating wind farms and discussions with residents that are impacted by the wind farms (but are not impacted when removed from the wind farms) it would appear that there is a fundamental problem with the criteria set out in the SA EPA guidelines and the core objectives set out in the third paragraph of the introduction to the 2009 guidelines where the guideline states:

> *The core objective of the guidelines is to balance the advantage of developing wind energy projects in South Australia with protecting the amenity of the surrounding community from adverse noise impacts.*

26. On the basis that operating wind farms comply with the guideline criteria, material provided by residents in proximity to the wind farms of Waterloo, Cape Bridgewater and Hallett provide a different perspective to that provided by SLR Consulting Australia which is the matter that should have been addressed in complying with the DGR's acoustic requirements.

27. I have conducted measurements at a number of residential premises in proximity to wind farms including the Waterloo Wind Farm that was the subject of "testing" by the SA EPA last year. There are matters from that testing program that are relevant to the subject application in that the community has clearly identified adverse impacts for a wind farm that "complies" with the SA EPA Guidelines.

WATERLOO WIND FARM TESTING

28. The noise testing conducted in April – June, 2013 in relation to the Waterloo wind farm came about as a result of residents' complaints concerning noise emission from the wind farm.

29. The EPA gave an undertaking to the community to provide monitoring at various residential locations, where testing was to be carried out both indoors and external to residential dwellings. The results of some of that material were posted on the SA EPA's website late last year where the data includes the results of unattended noise logging at the various monitoring locations and summaries of resident's diaries. The monitoring locations used in the EPA Waterloo study are identified in Appendix B.

30. A number of versions of the EPA Waterloo Study report have appeared that contain or omit data or conclusions that are relevant in undertaking a detailed review of the report(s) on the EPA Waterloo Study.

31. The measurement material and community response re Waterloo Wind Farm is relevant for this application because:

- There are similar set back distances from the turbines to residential receivers.
- The ambient noise levels (without the wind farms) are similar.
- The winds farm is predicted to comply with the SA EPA guidelines, and both wind farm assessments have ignored the impact of infrasound.

32. The outcome of the 2013 Waterloo EPA noise testing raises a number of additional matters that are relevant to the subject wind farm, including:

- what constitutes acoustic compliance,
- averaging techniques,
- inaccurate data,
- wind direction,
- ambient background levels, and
- the perception of turbines versus audibility.

33. During the EPA Waterloo test program I conducted attended and unattended monitoring at the location identified as the west monitoring location, the north-east monitoring location and the east monitoring location, together with additional locations not identified on the EPA map.

34. With respect to the EPA west monitoring location this occurs at the property of Mrs Julie Quast, at which I have done extensive attended monitoring during the day and night time periods, in addition to the unattended monitoring at that location.

INTERNATIONAL CONFERENCE ON WIND TURBINE NOISE

35. In late August 2013 there was a conference held in Denver Colorado, USA in relation to wind turbine noise.

36. A number of papers were presented by persons from Australia in relation to wind farm noise.

37. I presented 2 papers at the conference which were technical in nature as they discussed appropriate measurement procedures, problems in the measurements/reporting of wind farm noise and instrumentation issues. The papers appear as Appendices C and D (being relevant to paragraphs 30, 31 and 32).

38. The two papers in Appendices C and D were prepared in May 2013. The actual presentation included additional material that was not available at the time of the preparation of the papers.

39. The paper from Appendix C raised an issue as to the suitability of regression curves conducted only over a 2 week period that is then used for the determination of noise compliance purposes of a wind farm.

40. Appendix E provides a paper from Dr Paul Schomer, a world leading acoustician with no equal in Australia. Dr Schomer has been responsible for the development of many dose-response curves for community noise used throughout America. His involvement in wind farm assessments has led him to propose that there is a perception of the operation of turbines.

41. Dr Schomer's paper identifies the potential for a motion sickness like affect that can be perceived by some people (inside buildings) and proposes undertaking controlled experiments to assess his hypothesis.

ADDITIONAL MATERIAL FROM ADELAIDE UNIVERSITY

42. As identified above Adelaide University conducted measurements in and around Waterloo Wind Farm during the aforementioned EPA testing program. Members of the monitoring team presented papers in the Denver conference one paper highlighting the results of their work at Waterloo concerning wind screens for infrasound measurements.

43. At an Acoustical Society conference in Victor Harbour (in November, 2013) members from the School of Mechanical Engineering at Adelaide University provided a paper "Analysis of un-weighted low frequency noise and infrasound measurement at a residence in the vicinity of a wind farm." (paper available at

    http://www.acoustics.asn.au/conference_proceedings/AAS2013/index.htm).

The wind farm in question was the Waterloo Wind Farm and the majority of the paper relates to measurements inside a house south west of the wind farm (the actual house is not identified in the paper).

44. The paper is a stand-alone paper and identifies that there are a number of issues in relation to low frequency and infrasound which simply do not get picked up in the A-weighted concept used in the EPA guidelines. The Conclusions set out in the paper are relevant to the subject application and the inadequacy of the SLR report to identify the impacts that will occur.

CONCLUSIONS

Several spectral characteristics have been identified in this study which may be overlooked in an analysis that considered time-averaged third-octave levels exclusively. The existence of two tones around 28 Hz and 46 Hz that have corresponding rms sound pressure levels close to the threshold of audibility (for most people) for single frequency tones, has been established. It has also been shown that these tones are amplitude modulated at approximately 0.8 Hz, which corresponds to the blade-pass frequency. The 15 dB of amplitude modulation makes this noise much more noticeable and annoying than would be the case for the steady tonal sound used to establish the thresholds of audibility. Peaks at the blade-pass frequency and its harmonics have also been measured.

Vibration results indicate that acceleration levels measured in the 16 Hz third-octave band are close to the recommended upper limit for building vibrations in AS 2670.2 (1990). The presence of amplitude modulation at this frequency in the narrowband results suggests that the housing structure is excited by noise that originates at the wind farm.

Analysis of four representative cases based on times where the wind farm power output, wind speed, wind direction and stability were different has shown that the measured sound pressure level and degree of amplitude modulation is highly dependent on these variables. The worst case conditions for the tonal peaks corresponded to the cases where the residence was located downwind from the wind farm. In terms of amplitude modulation, the worst case occurred in stable, downwind conditions where the wind farm was operating at a capacity greater than 50%. These characteristics were observed for a number of 10-minute averages for a given condition but all results are not presented in this paper due to space restrictions. The nature of the observations suggests that there is a possible aeroelastic phenomenon associated with the tower and blades or a problem with the wind turbine drive system.

It has also been shown that low-frequency indoor noise levels are highly variable with room position and could differ by as much as 20dB from one position to another. This occurred at frequencies in the range where room resonances would be expected to exist. A possible structural resonance was identified at 16 Hz, where the vibration levels were relatively higher. The sound pressure level at this frequency was also found to increase indoors relative to outdoors for one of the measurement cases.

> For the different windshield configurations, there is good agreement in the measurements of the blade-pass frequency, tonal noise and amplitude modulation. However, there are some discrepancies in the infrasonic range for the broadband noise component, which is due to differences in the secondary windshield geometry and location. This would affect the strength of turbulence incident on the microphones.

45. Further work being undertaken in Canada (private communication) is looking to the first paragraph in the above conclusion as a result of the physical distance between the swept path of the blades and the tower by setting up a standing wave. The second paragraph of the above conclusion ties in with the SERI paper (discussed later).

46. The third and fourth paragraphs in the above conclusion identify similar issues to matters contained in my peer review and have expanded on a number of the issues with respect to the noise floor instrumentation and microphones (similar to my Denver papers). The authors in the above paper were quite specific as to ensuring the capability of their instrumentation to measure the noise of concern rather than just a noise floor of the instruments, being relevant matters that I have raised in a number of papers and reviews.

47. The University researchers identify in the paper a number of audible components, which the EPA in their report on Waterloo is unable to identify. The results indicate that there is clearly an impact generated by the subject wind farm at Waterloo and there is evidence to show the presence of low frequency noise and infrasound generated by the wind farm, which is contrary to the statement in the EPA guidelines that a well maintained wind farm does not produce infrasound.

48. At the conclusion of the EPA Waterloo testing, and after the University's equipment had been removed from the area (and also after my equipment had been removed), there was a cable outage problem at the wind farm that resulted in all turbines being off for more than 7 days.

49. The community that had been trained in relation to reporting of noise monitoring and effects (for the EPA Waterloo study) were able to continue reporting with the wind farm off. I have been advised that members of the community noticed a difference with the turbines off in terms of the audible characteristics that they perceive at their dwellings, matters in terms of lack of sleep disturbance and resumption of normal health.

50. In the last 2 months I have been conducting testing at 3 houses in proximity to Cape Bridgewater wind farm being in the south west corner of Victoria. The testing has been undertaken at the request of the community and the wind farm operator, where I have been given free range to conduct measurements internal and externally to the 3 houses and at any point on the wind farm that I desire.

51. In the course of that survey I have also had the residents fill out diaries for the purpose of identifying any impacts that the operation of the wind farm may generate whilst monitoring is being undertaken.

52. In the first instance I sought to utilise the diary concept provided by the South Australian EPA with respect to the Waterloo study but it soon became apparent when trying the system with residents that they found the concept in the diary recording to be ambiguous and difficult to address.

53. During the course of discussions with the residents it was apparent that whereas the South Australian EPA diary comments identified that they were addressing noise it was established that the residents in Cape Bridgewater experience not only noise impacts but experienced impacts associated with vibration and sensation. Accordingly the diary was modified to separate the observations into those 3 different categories and a simpler description in terms of sensitivity of each of these issues was drawn from a UK wind farm report.

54. On obtaining data from the residents after 2 weeks of diary notes and comparing that material with the noise monitoring it was established that the residents were actually responding to changes in the wind farm where the comments correlated to changes in wind speed or power output of the wind farm.

55. Discussions with the residents revealed that was their understanding of the diary and those complaints that they had lodged with the wind farm operated were related to changes that they had detected during the course of their normal daily activities.

56. Each of the 6 residents involved in the study were presenting the diaries in the same format and as such the diary undertakings were then changed to provide regular notation of the perceived impact of the wind farm during operation and a shutdown period, where there was a request to see if the diary notations could be done at a regular pattern at say every 1 or 2 hours.

57. Having ascertained that the observations in the diary by the Cape Bridgewater residents were not of an ongoing basis but only changes I contacted some of the residents involved in the Waterloo EPA study and put the position to them that that was what they were doing in all of their diary notations, to which I received an affirmative.

58. As a result of changing the diary recording procedure and then plotting the noise levels with the power output of the wind farm it has been established that there is some relationship between the wind farm operation and the noise levels external residential premises. This situation is expected by way of the analysis that has been provided for the subject wind farm where the noise level is predicted at residential locations to increase as the wind strength increases.

59. However whereas the SA EPA guidelines and the NSW draft Guidelines nominate an external noise level (and would appear to have been derived from an internal noise target) there is no assessment of the internal noise levels.

60. To this end my monitoring at Cape Bridgewater has included internal monitoring to look at the relationship between the turbines and internal noise levels.

61. My preliminary results and findings were presented to a public meeting in Portland that is contained to the Pacific Hydro website with respect to the Cape Bridgewater wind farm identifying that material that is in the public domain.

62. A simultaneous monitoring of external and internal levels at various houses has identified the presence of discrete narrow band frequencies associated with the blade pass frequency of the turbines and multiple harmonics of that frequency to be evident inside houses.

63. Comparison of that material with respect to the external and the internal measurements reveals that at times there is only a minor increase above their ambient background level with respect to the infrasound narrowband frequencies, whereas in the internal locations there is a noticeable increase above the background levels.

64. The material that was provided to the residents and subsequently placed on The Waubra Foundation website compares internal and external measurements for a wind speed near maximum for the turbines operating regime but occurring during the wind farm shut down. The results show that with the wind farm shutdown and the wind at the speed associated with maximum power output there were no specific infrasound peaks associated with the blade pass frequency and multi harmonics in the internal or the external narrow band spectra.

65. The data also reveals that if one seeks to compare infrasound with turbines operating versus turbines not operating, or the natural environment, using 1/3 octave band material will not provide any difference, but using narrow band analysis shows a significant difference, i.e. sticking to an analysis of dBA or even 1/3 octave bands does not identify the discrete infrasound frequencies associated with the operation of turbines.

66. There is other material that has been obtained from the study that shows changes in power settings of the turbine are related to high levels of disturbance/adverse impacts inside residential dwellings which is a matter that should have been reported by SLR Consulting Australia if they were compliant with the DGR's specified for the subject wind farm.

67. I now go to the relevant matters noted above concerning the acoustic assessment of wind farms.

WHAT CONSTITUTES ACOUSTIC COMPLIANCE?

68. In dealing with industrial noise situations, acoustic criteria are generally specified in a noise limit measured over time, and where the basis of the noise limit relates to an ambient background level.

69. Non-compliance is where the noise emitted by the industrial premises exceeds the nominated limit. A question arises what is the extent of the exceedance and how often that exceedance occurs, leading to what form of action that may be taken by the regulatory authority.

70. In the case of wind farms the current EPA assessment procedure has a number of issues that relate to the measured levels and the impact that such levels have on the community. One issue is the use of the A-weighted level which is an overall noise level and does not take account of low frequency noise and infrasound that is evident in the acoustic signatures of wind farms.

71. The second issue in terms of acoustic compliance is related to the basis of a varying ambient noise level that is dependent upon the wind.

72. The terminology in relation to the background noise set out in Section 3.1 of the 2009 SA wind farm guideline identifies that background noise can mask noise effects and for new developments such as wind farms, the wind generates noise that can provide a masking effect. The guideline can be taken in one way to suggest that the ambient background noise level is determined by the wind when in actual fact the background level can be generated by other noise sources that in themselves may be influenced by the wind, particularly being trees, grass and shrubs.

73. Measurements conducted of noise generated by the wind passing across a microphone can be significant if the microphone does not incorporate a windscreen (whose purpose is to reduce the pressure generated by the wind passing across the microphone). There are different size windscreens available with the general trend being that the larger the windscreen the less effect the wind has on the microphone.

74. For the purpose of my noise loggers I have a wire mesh screen cage around the microphone that has a rain shield above the microphone. There are two foam rubber windscreens around the wire mesh screen (one windscreen inside another windscreen). The entire microphone mesh screen/windscreen installation is contained in an external wire cage. The testing that I have conducted in relation to that instrumentation set up reveals that the noise as a result of wind (at locations removed from trees, grasses and shrubs) is a linear curve such that the wind generated levels are relatively low when compared to levels at receiver locations generated by the wind farm.

75. On some instrumentation used for monitoring I have seen a standard 50 mm windscreen, a 100 mm windscreen, a 175 mm windscreen and windscreens up to 300 mm in diameter which therefore can give rise to different attenuation of the pressure generated by the wind on the microphone.

76. However the major variation that occurs in relation to the noise levels at residential receivers, even if using the larger windscreens, is the proximity of trees, grass and shrubs that generate noise levels as a result of wind passing through those trees, shrubs and grass.

77. If one chooses to locate monitoring microphones next to or in bushes then the resultant noise level when compared with a wind speed determined at the hub height of the wind farm will be appropriate for that position (in the bushes) but may not be representative of the noise level at the residential dwelling.

78. In terms of considering the “wind noise“ I mean that to refer to the ambient noise of an area in proximity to the microphone that is subject to a variation in noise as a result of the wind impacting upon the surrounding vegetation or obstacles.

79. If a residential dwelling has trees around it then the acoustic environment for the dwelling will be different to that for a dwelling where there are no trees or shrubs (and is simply a dwelling exposed to the surrounding area).

80. With respect to the above comments I note that on page 6 of the 2009 SA wind farm guidelines under a heading of "background noise measurement position" there is a greyed-in box that states:

> *The property boundary of the receiving premises is generally not considered a valid measuring position for large rural properties unless a house is located near the boundary or the development plan clearly envisages noise sensitive development at such a location.*
>
> *In general, any area within 30 metres of a house and in the direction of the wind farm would be a valid measuring position. Care should be taken to ensure that the area is not screened from the wind farm by house, shelter or other elements.*
>
> *Background noise levels can be significantly affected by local conditions, such as the presence of trees nearby.*
>
> *Photographs from multiple directions are to be taken showing the noise measurement position and associated surroundings, such as buildings, trees and topography. This will ensure that no significant physical changes have been made to the locations since the time of the initial background noise measurements.*
>
> *Care must be taken when using a measurement position to represent other receivers in the locality. Trees, grass and shrubs should be representative of the local area that is being assessed. Background noise measurements should represent the natural background in the immediate vicinity of the relevant receiver; extraneous noise sources (water pumps, air conditioning units, electrical transformers, etc.) should not influence the data. In case selection of the representative point is not straightforward a conservative approach should be taken by placing the microphone in the quieter location.*

81. Page 8 of the guidelines indicate that for the purpose of determining background noise data corresponding to the operation of wind speed, approximately 2000 measurement intervals (or the equivalent of 2 weeks' worth of data) are required where at least 1500 points are collected for the worst-case wind direction.

82. Whether 2 weeks of data is a sufficient representation of the ambient background over the year is dubious, in that my monitoring with respect to the above comments I note that on page 6 of the guidelines over an extended period (3 months) at Waubra reveals on two week periods there can be different regression curves. Similarly one expects differences in ambient levels in each season.

83. The use of a regression line basis for wind farms means that the compliance is based over a small period of time (two weeks) and an average level, and therefore cannot cater for individual hours/days of excessive noise.

AVERAGING TECHNIQUES

84. The greyed-in box at the end of Section 3.1 (in the guideline) indicates the compliance checking will require a similar noise data collection process to be repeated when the wind farm is operational.

85. Therefore that means that the acoustic compliance is determined as an average over 2 weeks of data and is not looking at the same scenario as to an exceedance above a limit that applies for other industrial sources.

86. Use of an averaging technique that compares the noise versus the wind speed at the hub height (and not the wind at the residential receptor) the wind farm could generate at times a significant degree of noise disturbance. However, the compliance method set out in the guideline only considers average level for different wind speeds.

87. If for example let us consider an analogy to the EPA's compliance method by way of legal and illegal driving on the road between Yass and Canberra.

88. Assume for the purpose of the exercise that the distance from the outskirts of Canberra to Yass is 100 km. If we were to drive a car at a speed of 100 km constantly for 1 hour then we would travel a distance of 100 km and have an average speed of 100 km per hour.

89. If the speed limit is taken as 100 km then the trip would be compliant with the laws for motor vehicles and would achieve such an average speed of 100 km/hr.

90. If we now consider that at the same time another vehicle left the same location outside of Canberra and travelled at a speed of 200 km for 20 minutes then the driver pulled the car over and had a 30 minute sleep and then continued the remainder of the journey at 200 km an hour for 10 minutes. That scenario would still have an average speed of 100 km/h for the trip but the person driving that vehicle would have exceeded the speed limit and would be considered to be a dangerous driver.

91. If we had a third vehicle that commenced driving at 200 km an hour for 20 minutes alongside the second vehicle doing the same speed but when the second driver pulled over to have a rest the third driver turned around and drove back towards Canberra for 15 minutes at 200 km an hour, then turned around and headed back to Yass at 200 km an hour for 15 minutes to then pick up vehicle 2 so they could have a race to Yass for the last 10 minutes at 200 km an hour. The third driver despite speeding at 200 km an hour for an entire hour would under an average method from Canberra to Yass still only have 100 km/h as the average speed over that specific distance.

92. The operation of the wind farm and the method of monitoring the noise falls under the same averaging technique and completely disregards the noise at times that is significantly above what may be deemed to be a noise limit that can give rise to disturbance to the community.

INACCURATE DATA

93. With relevance to the matter of 'deemed' acoustic compliance I now refer to Appendix F that provides a compliance letter in relation to the Quast property (at Waterloo) which suggests that the noise level generated by the wind farm from cut-out to maximum wind speed will vary from 30 to 43 dB(A).

94. The post-construction noise monitoring result suggests that the worst case wind direction is in the range of 53-143°.

95. Appendix F3 indicates the location of the noise logger used for monitoring purposes (by Marshall Day Acoustics for the Applicant) was on the southern side of the residence. The compliance report does not append "**Photographs from multiple directions are to be taken showing the noise measurement position and associated surroundings, such as buildings, trees and topography"** as required by the SA wind farm guideline (see page 6).

96. However having attended the Quast residence and having had the MDA monitoring location being identified to me it is relevant to note that the monitoring position shown in the post-construction noise monitoring results summary does not truly reflect the acoustic environment at the dwelling or the noise from the wind farm.

97. Appendix F4 identifies in the upper figure the relationship of the Quast dwelling to a large bank of trees to the south (of the dwelling) and the position of a trailer which contained monitoring equipment used by the South Australian EPA.

98. If the post-construction noise monitoring report had provided a view from the house across the noise monitor in a southerly direction it would have revealed the trees that are shown in the bottom figure of Appendix F4. Furthermore the MDA logger location is not in a position between the residence and the wind farm but to the side of the house, close to large trees.

99. However, it is not just the MDA logger that didn't comply with the SA Guidelines, the EPA noise logger position shown in Appendix F4 contradicts the EPA's wind farm guideline and is closer to the large gum trees that the MDA logger location.

100. If there is wind at the Applicant's/EPA monitoring location the noise levels will be influenced by the rustling of the leaves and thereby give either a false reading in relation to the measurements or would require by some form of (unidentified) adjustment to the levels to determine the noise contribution from the wind farm. The MDA compliance report does not indicate any such adjustment.

101. Appendix F6 provides a photograph from the EPA noise monitoring trailer through the aforementioned trees towards the nearest turbine and indicates the inappropriateness of the monitoring location used by the EPA.

102. For the purpose of my monitoring at the Quast residence I installed equipment more than 20 m from the residence by locating it on the driveway where it was free of major trees, although there were some bushes along the driveway. My monitoring location is shown in Appendix G7 together with identification of the monitoring positions used by Adelaide University for the second set of measurements by that organisation (see Appendix F7).

103. I note that the first set of measurements for Adelaide University at the Quast residence were carried out directly in front of the residence above the metal fence shown in upper figure of Appendix F4. That location was between the residence and the wind farm and free of trees (in accordance with the guideline).

104. The matter of acoustic compliance testing that is accurate and relative to any conditions of consent is therefore somewhat of a concern by examination of the position utilised by Marshall Day Acoustics and even the South Australian EPA. If the SA EPA permits incorrect monitoring locations how can the residents expect accurate compliance results?

105. To place the results of such monitoring in context, Appendix G provides the results of monitoring from my logger position where the results are not influenced by the rusting of leaves.

106. Appendix G identifies that there was a generally steady output of the wind farm on Saturday 27th April, 2013 and that during the day the background level was around 47 dB(A) with an Leq level in the mid-50s, whereas at night the background level reduced to the upper 30s with an Leq in the low 40s.

107. The South Australian EPA procedure permits the use of a background level measurement with a minor adjustment to account for the Leq level from the wind farm. As I know the wind induced noise on my system is below 35 dB(A) for the wind speeds so shown then the measurements reveal a wind farm noise level greater than the compliance levels provided by MDA.

108. Of concern as to the position of a regulatory environmental authority and the accuracy of their monitoring is the material set out in Appendix H1 being the EPA external measurements at the Quast residence including 27 April 2013, obtained from the EPA's website. Appendix I reveals that monitoring for the same time period (that appears in Appendix G), being the A-weighted level, is seen in the middle of the day to be above 60 dB(A). However my measurements in Appendix G for the same time period recorded noticeably lower levels. As the wind at my logger was subject to a wind in the order of 3 m/s (and therefore at the EPA position) suggests that the EPA monitor was recording noise from the trees.

109. To provide a direct comparison without having to turn the page Appendix H3 places an extract of the EPA graph for 27th April 2013 at the Quast house directly above my results for the same time but on the driveway (not under trees).

110. Appendix I shows my results (whilst Appendix J provides the EPA charts) for the same time at a location identified to the NE of the range. My logger measurements near the EPA logger reveal similar results and the attached photo shows there were no tall trees near either of the logging microphones.

111. Appendix J4 provides a direct comparison of the EPA results versus my results, thereby revealing the EPA results at the Quast residence are affected by the large trees adjacent to the microphone.

112. The MDA compliance report provided for the Quast residence suggests that the maximum noise level contribution is 40 dB(A) at the residence as determined by Marshall Day Acoustics with a maximum contribution of up to 43 dB(A) for a hub-height wind speed 15 m/s.

113. In the computer model and the International Standard upon which the calculations have been based (ISO9613 – 2:1996) there is a tolerance allowance in terms of the predictions. However Marshall Day Acoustics made no mention of a tolerance on their predicted levels. Even allowing for that tolerance under a 'worst case scenario' the predicted levels for Waterloo Wind Farm do not agree with reality.

114. If one takes the data set out in Appendix G where the wind at the receiver location is relatively low in terms of noise impact on the microphone then the Leq level in the mid-50s is well above the predicted level as is the background level that is in the order of 48 dB(A). Unfortunately the wind information pertaining to the wind farm itself (hub-height wind speed and direction) has not been provided despite requests for such material.

115. If the predicted levels are reported as a 'worst-case' scenario then the use of the regression process must obtain an average level below the 'worst-case' scenario. However actual measurements at the Quast residence have revealed errors in the predictions.

116. If one accepts the 'predicted' noise level from Marshall Day Acoustics for the Quast residence to show that the noise level with the wind farm operating is at or around 40 dB(A) or even as low as 30 dB(A) near the cut in speed then the logger graphs for the 27th April, 2013 indicate that in the early hours of the morning the ambient background level at that residence is below 15 dB(A). The noise floor of the sound level meter I used for logging purposes whilst having a specified limit in the lower 20s bottoms out at 15 dB(A), and therefore indicates that the ambient background level measurements are below 20 dB(A).

117. The Leq level which can be used to describe the ambient noise in terms of an amenity concept is still below 20 dB(A). Therefore the concept of an intrusive noise level of 30 dB(A) being well above the ambient background level presents a problem if one claims there is <u>no noise impact</u>.

118. However if one uses instrumentation that cannot measure say below 25 dB(A) then the data so presented is inaccurate in identifying the actual ambient background levels that exist in rural areas. The matter of not identifying the low frequency and infrasound components will be discussed later.

119. If one goes to the EPA logger charts for the Waterloo study and looks to the outside measurements at the same dwelling (identified as outside west) the outside level appears to have a lower noise limit of around 22 dB(A) and possibly a slightly lower limit for the inside location.

120. I note that this does not mean that the EPA ambient background levels at these residential properties are limited to 20 dB(A) but it is simply that the instrumentation that was used by the EPA does not have the capability of recording levels below 20 dB(A) by reference to the specifications for the instrumentation used by the EPA.

121. I have measurements conducted inside the Quast residence during the course of the EPA monitoring period (using superior instrumentation) to reveal background levels significantly lower than that nominated by the EPA, even when I have conducted measurements in the same room as the EPA's internal measurements.

122. Despite assurances by the EPA that information pertaining to the operation of the wind farm during the EPA 2013 Waterloo study, including the power output and hub height wind information, would be made available to consultants working for the residents, that material has not been provided.

123. Therefore in the absence of hub-height wind data I am unable to identify the relationship of the wind of the turbine on the measurements identified on 27th April, 2013 so as to correlate the relationship between the wind speed and wind direction at the turbines versus the wind speed and direction obtained at the residence, and compare the measured levels with Marshall Day Acoustic’s Certificate of Compliance.

124. Normally conditions of consent relate to the hub-height wind speed versus the noise level at residential receivers. The hub-height wind speed information is not available for the community. Therefore whilst I can measure the noise at residential receivers and the wind at the microphone I am unable to determine the relationship of the actual measurements versus the “regression” graph. As such the consent conditions related to hub height wind data already mean any noise data at residential receivers is automatically “inaccurate” as the hub-height wind data is not available.

WIND DIRECTION & BACKGROUND LEVELS

125. The wind speed and direction becomes relevant in that on returning to Appendix B to identify the location of the Quast residence with respect to the wind farm (the west location) it can be seen that in one concept if wind is blowing from the wind farm towards the residence (from the east) then there is an expectation that the 3 turbines opposite the residence would be the major noise source with a lower contribution coming from other turbines.

126. However if the wind at the Quast house is to originate from the south the noise impact at the residence will be governed by a large number of turbines to the south of the house, not necessarily the nearest turbines.

127. This is an issue of concern in terms of the matter of acoustic compliance in that the weather conditions at the turbine can be entirely different to that at residential dwellings. Without material pertaining to the wind speed and direction at the turbines then there is difficulty in independently establishing acoustic compliance when conditions of consent are expressed in terms of the hub height wind speed.

128. If the approval condition is expressed in terms of hub-height wind speed and that material is not provided, then there is an issue of how one determines compliance with conditions of consent that may be handed down by the Determining Authority.

129. At the present point in time the regression line curves that are typically provided for a wind farm (as in the SLR assessment of Rye Park) refer to a median level which would mean an averaging. Accordingly there will be noise levels above and below the average curve.

130. If one considers a constant noise source generating noise 24 hours a day then at distances of 2 or 3 km from that source there will be a variation in noise level dependent upon the temperature, relative humidity, and wind direction and speed which will alter the propagation of noise to the receiver location. One would expect that in a situation of wind blowing from the noise source to the receiver there will be an enhancement of the noise level at the receiver locations compared to that of a neutral weather condition, whereas if a wind is blowing from a receiver to the source then one would expect to experience a lower noise level.

131. The concept of an averaging of noise from the source gives rise to noise levels both above and below the average level which therefore will give rise to greater (and also lesser) noise impact.

132. Generally in terms of developing noise criteria for a sound source (i.e. road traffic, air traffic and rail traffic) a dose-response curve is developed to determine a noise level that is based upon 10% of the population being highly annoyed or affected and that for levels below that then more than 90% of the population will be satisfied (e.g. Appendix A to Australian Standard AS2021 – 2000 "Acoustics – Aircraft Noise Intrusion – Building Site and Construction").

133. In a Technical Note in the April 2012 Journal of the Australian Acoustical Society, the Noise Specialist NSW Department of Planning and Infrastructure (Mr Parnell) in discussing the "Draft NSW Planning Guidelines: Wind Farms" identified they were based on the SA EPA 2009 guidelines with some amendments. Under a discussion for the Development of noise criteria:

> **Development of noise criteria**
> When developing noise criteria, there are two aspects that need to be considered:
> - What is the level of noise acceptance that is considered appropriate for the area? and;
> - What is the noise amenity that one is trying to establish for the area?
>
> In response to the first aspect, it is a general NSW objective to set where possible noise goals that will ensure at least 90% of the population are protected from being highly annoyed for at least 90% of the time [4]. To establish the noise levels at which these impacts may be expected, reference was made to dose/response studies. In particular, the studies presented in the following three figures were used to gain a perspective of annoyance levels. Note: the noise levels in all figures are measured or predicted outside of the residence.
>
> Acknowledging that an Lden noise metric incorporates an evening and night time penalty into this single noise descriptor, Table 1 shows the approximate dose response compared to a Leq using a 6.4 dB reduction from the Lden for a constant noise source and extrapolation from the source studies. From data contained in Table 1 it can be shown that 90% of the population can be expected not to be very or highly annoyed at 40 dB(A). In examining the second aspect of noise criteria development, reference is made to the amenity noise goals established in the INP [4] for various land use classifications. From Table 2 it can be seen that 40 dB(A) is an accepted night time noise level for a rural area.
>
> It can therefore be concluded that both contemporary dose/response relationships and acceptable amenity noise goals identify a level of 40 dB(A) as meeting NSW noise objectives for protection of the community and maintaining the amenity of a rural area. Notwithstanding, it was determined that the threshold criteria set in the *Draft* should be discounted by 5 dB to a level of 35 dB(A) to allow for any other industrial noise sources and to ensure that NSW objectives were easily met.

134. A problem with the reference material in the above extract is the combination of rural and urban locations in the survey quoted and the use of wind turbines much smaller than proposed for Rye Park.

135. In the SA guidelines there is no distinction between night time ambient background versus the day. In the draft NSW Guidelines the regression curves have been separated into night and day.

136. There is a fundamental problem with the regression curve system used for wind farm assessments is that there is no data in terms of social surveys to determine the appropriate noise level. Furthermore the use of the averaging concept without taking in account the wind direction gives rise to different impacts.

137. One can take the wind data at a receiver point to determine both the direction and speed over time and evaluate such material with respect to the noise levels so as to determine the regression line relative to the wind at the receiver point.

138. When there is sufficient data that is available one can take the measurement data grouped into 0.1 m/s wind bands to then provide an analysis that would identify the upper 10 percentile, the 50 percentile, and the 90 percentile level in each of those wind speeds from which one can derive appropriate curves.

139. The 90th percentile curve obviously is noticeably lower than the median/average curve and in terms of normal environmental noise can be the basis for determining background. With sufficient data by such an analysis one can determine the actual background level versus the wind speed at the receiver location. One then has a basis of assessing the noise level at the receiver location versus the true background level.

140. The DOPI suggestion that the nominated regression curve addresses 90% of the population for 90% of the time is incorrect as the regression line is about 5 dB above the 90th percentile line.

141. Considering the criterion of 35 dB(A) or background + 5 dB(A) whichever is the greater clearly provides a noise limit that **DOES NOT** protect 90% of the population 90% of the time.

142. My paper in Appendix C raised an issue as to the suitability of regression curves conducted only over a 2 week period that is then used for the determination of noise compliance purposes of a wind farm.

143. I raised the issue as to the averaging technique for the determination of the levels and whether in fact the methodology is providing the true ambient background level.

144. Appendix J1 provides a regression analysis of 3 months of measurement data with respect to the Waubra Wind Farm. From the 3 months of night time data I have determined the regression line in accordance with the procedure in the New Zealand Standard (as Waubra is in Victoria).

145. The results are an average level and do not identify the true ambient background level of the area, particularly as in this case the wind farm is influencing the background level.

146. The NZ Standard used in Victoria nominates an on-off testing to ascertain the wind farm contribution. If there are no on-off tests available during testing for residents, and no information as to the hub height wind speed (or other specified height such as 10m), then the determination of compliance of the wind farm cannot be undertaken, unless some alternative mechanism is available.

147. In the 1998 version of the NZ Standard the background level was based on the L95 parameter whereas in the 2010 version of the NZ Standard the background parameter is the L90 level.

148. In New South Wales ambient background level is for industrial premises is determined as the lowest 10th percentile of the background levels. In NSW the background level is based upon the L90 level.

149. The development of individual regression lines for two week periods reveals different lines that can lead to entirely different noise targets. Clearly the provision of a larger data base would provide a more accurate average level.

150. The regression line in Appendix J1 utilises the L95 parameter to agree with the 1998 NZ Standard referenced in the consent (but for 3 months of data) but utilises the wind speed at the microphone – typically being the appropriate location for residents.

151. From the wind data and noise data I have taken each 0.1m/s wind bin and determined the lowest 10th percentile, the 50th percentile and the upper 10th percentile (for each bin) and then determined the line of fit through those points. The green line represents the lowest 10 percentile of the noise levels to identify the true background level of the noise versus the wind at the receiver location.

152. Appendix J2 identifies in the upper graph the wind direction for the three months of night measurements with the lower graph placing the wind in 90 degree segments centred on the principal wind direction obtained at the residence.

153. The NZ Standard (used in Victoria) identifies in some case the use of separate regression lines for wind direction to provide a greater degree. Appendix J3 shows the different data sets for the four wind quadrants and reveals there are noticeable differences (to be expected) due to the location being at different times upwind, downwind and cross wind to the wind farm.

154. This matter becomes relevant in addressing the SA EPA guidelines in that Section 2 of the 2009 guidelines identifies in the 2nd paragraph that the base noise level is typically 5 dB lower than the level considered to reflect the amenity of the receiving environment. However the guidelines do not reference any studies to identify or define the acoustic amenity of rural residents in South Australia.

155. Similarly there is no information in the Draft NSW wind farm guideline identifying defining the acoustic amenity of rural residents in NSW.

156. On page 2 of the 2009 EPA guideline under a greyed explanation box with respect to other standards states:

> *Most wind farm sites are within or next to areas where low ambient noise levels are a significant component of that areas amenity. These might include rural living zones or zones that are not intended to be subject to any other significant ambient noise sources from adjacent premises.*

157. The residential receivers that are in rural areas free of wind farms experience an amenity which at the present time does not include wind farms. Therefore that is the acoustic amenity that they experience at the moment upon which the impact of the turbines should be assessed. The concept of a sliding background level with wind (generated noise) as identified above provides the base level for determining the amenity of an area upon which one can set either the general concept of 5 dB above the background or a less stringent concept of 10 dB above the background for excessive noise. Such a limit would then have a noise that fits in with the acoustic environment of the area in that as noted above the acoustic environment of rural areas has not been identified in the Wind Farm guidelines.

158. The EPA guideline identifies that low ambient noise levels are a significant component of the area's amenity. Yet the criteria setting a base level that is significantly above the ambient noise amenity that residents experience leads to an acoustic impact as a result of permitting noise level significantly greater than the ambient background level. The attached EPA charts of noise monitoring in Waterloo (see Appendix H1) indicates that the ambient level being the A-weighted level shown in blue on the graphs at night is well below a base level target of 35 dB(A).

159. It therefore follows that if one has noise emission from the wind farm that just complies with the EPA limit then there will be a noticeable impact on the community that is described by members of the community (subject to such noise) as an adverse impact.

PERCEPTION OF TURBINES VERSUS AUDIBILITY

160. The SA EPA guidelines identify an adverse impact (for hosts who are subject to a greater noise level) is sleep disturbance.

161. The complaints register in the Waterloo study published by the EPA reveal residents reported sleep disturbance for internal levels less than 30 dB(A) and other disturbance not necessarily being audible noise. It is noted that not all of the complaints have been identified and complaints associated with sensation have been ignored by the EPA.

162. The SA Guidelines refer to the WHO Guidelines that recommend an internal level not exceeding Leq 30 dB(A) to protect against sleep disturbance, not an averaged level over two weeks. From this figure the WHO Guideline assumed an outside to inside attenuation of 15 dB(A) to suggest an external noise target of 45 dB(A).

163. However in Australian conditions a typical attenuation of 10 dB(A) from outside to inside is nominated for an open window that would lead to a lower external target.

164. The WHO Guidelines threshold was based on traffic assessments in urban areas and noted that if the spectrum contained predominant low frequency that the threshold for sleeping disturbance should be reduced.

165. The majority of residents subject to wind farm noise describe the audible noise as a low frequency noise like a propeller type plane that never lands. For a predominant low frequency noise the attenuation of a building for an open windows situation will be much lower than 10 dB(A).

166. The WHO Guideline internal limit of 30 dB(A) to protect sleep whilst being a Leq level is the level not to be exceeded. Hence to protect against the adverse impact of “sleep disturbance” the internal target must be less than 30 dB(A) the majority of the time. A more appropriate internal target would be say 25 dB(A) for 50% of the time using the regression analysis method if broad band noise and even lower if inside the bedroom the noise is predominately low frequency.

167. The SLR report seeks to place the context of low frequency and infrasound noise with respect to the perception without defining perception of what. If the perception is meant to be audible noise in the infrasound region then it is necessary to note that the testing to determine thresholds is of a short sample noise where participants in such a study determined the threshold of audibility (similar to a hearing test). What if sleep disturbance is also influenced by infrasound that is not audible?

168. The audibility concept for infrasound has a number of flaws in terms of determining the acoustic impact by reason of the testing generally occurring in a very solid structure and having sound for a short duration rather than that experienced over a period of time at residential properties

169. The concept of threshold of audibility external to a dwelling has no meaning in terms of noise received by residents in proximity to wind farms in that the energy from the wind farm gives rise to vibration of building elements which can lead to a perception of the operation of the turbines and not necessarily the audibility of the noise or the very low frequencies described as infrasound.

170. In December 2012 a report from four Acoustical Consulting Firms in relation to the Shirley Wind Farm (in the USA) was issued the main report stating:

> *"The four investigating firms are of the opinion that enough evidence and hypotheses have been given herein to classify LFN and infrasound as a serious issue, possibly affecting the future of the industry. It should be addressed beyond the present practice of showing that wind turbine levels are magnitudes below the threshold of hearing at low frequencies."*

171. One of the authors of the joint report was Dr Paul Schomer.

172. Dr Schomer has no equivalent person in Australia who can compare to his technical capabilities and achievements in acoustics. Dr Schomer's volume of work in the aspect of acoustic research is way beyond that of any member of the AAS.

173. Each of the four firms provided an appendix to the report, setting out the results of their measurements/observations. Of importance to addressing the inadequacy of the dB(A) measurements for wind farms and the aspect to look at infrasound using different parameters, Dr P. Schomer states:

II) Implications of the measurements:

1. *The measurements support the hypothesis developed in (I) that the primary frequencies are very low, in the range of several tenths of a Hertz up to several Hertz. The coherence analysis shows that only the very low frequencies appear throughout the house and are clearly related to the blade passage frequency of the turbine. As Figure 5 shows, the house is acting like a cavity and indeed at 5 Hz and below, where the wavelength is 200 Ft or greater, the house is small compared to the wavelength.*

IV) Descriptors for Wind Turbine Emissions

1. *Currently the wind turbine industry presents only A weighted octave band data down to 31 Hz. They have stated that the wind turbines do not produce low frequency sound energies. The measurements at Shirley have clearly shown that low frequency infrasound is clearly present and relevant. A weighting is totally inadequate and inappropriate for description of this infrasound. In point of fact, the A weighting, and also the C and Z weightings for a Type 1 sound level meter have a lower tolerance limit of 4.5 dB in the 16 Hz one third octave band, a tolerance of minus infinity in the 12.5 Hz and 10 Hz one third octave bands, and are totally undefined below the 10 Hz one third octave band. Thus, the International Electro technical Commission (IEC) standard needs to include both infrasonic Measurements and a standard for the instrument by which they are measured.*

174. The above comments from Dr Schomer agree with the factual material I provided in my submission on the NSW draft wind farm guidelines some 12 months prior to the release of the Shirley wind farm report.

175. A report on the MOD-1 turbine was issued by NASA in April 1985 (Wilshire W, "Long Range Downwind Propagation of Low-Frequency Sound" – NASA Technical Memorandum 86409) that confirms the earlier work I had carried out as to the Wind Turbine Signature and evidence of that signature detected 8km from the Waterloo Turbines.

176. During the course of noise monitoring at Waterloo in early 2013 whilst in attendance at residential properties I sought to ascertain from the residents the situation as to when they were able to identify the turbines were operating and giving rise to an impact.

177. On the basis of enquiring with various residents (Quast, Faint and Schaefer) as to whether they are able to detect an impact as a result of the turbines it would appear that as a generalised concept and using the narrow band measurements, where the level at 2-4 Hz was above 45 dB for those residents who are sensitised to the wind farm they reported a perceptible impact. This would appear to be in general agreement with measurements that I have conducted previously at Waterloo (Quast, Schaefer and Dixon) where residents have indicated disturbance to their sleep in cases where the narrow band levels below 5 Hz was in the order of 45 to 50 dB when measured inside residences.

178. At the above houses in proximity to the Waterloo wind farm where the narrowband infrasound levels associated with harmonics of the blade pass frequency of the turbines were less than 35 dB (due to the prevailing weather conditions), there did not appear to be any disturbance from the wind farms on those occasions as expressed by the residents.

179. This investigation whilst only preliminary in nature provided the possibility that the impact as a result of wind farms was of perception, not audible noise.

180. However in the monitoring that I have conducted inside dwellings I have not found audible infrasound levels – if one uses 85 dBG as the assumed threshold of audibility of the infrasound region. However audibility of infrasound is not the same as perception of the presence of infrasound energy.

181. The possibility of impact from turbines being one of a perception that people feel or receive rather than audibility was a matter raised in a technical meeting of the Australian Acoustical Society held in Sydney in March, 2013 where extracts from a recording of the questions at that meeting are contained in Appendix L. Unfortunately the Acoustical Society has not posted a video of the meeting, and as such the extracts in Appendix L are not complete.

182. After my testing as part of the Waterloo 2013 study I was provided a report from the Solar Energy Research Institute (SERI) prepared for the US Department of Energy in February, 1985 in relation to an experimental wind turbine identified as MOD – 1 (http://waubrafoundation.org.au/resources/kelley-et-al-1985-acoustic-noise-associated-with-mod-1-wind-turbine/). This turbine was the subject of extensive testing by a number of organisations with appropriate qualifications and expertise to undertake testing of the various components associated with turbine impacts. Relevant extracts from the SERI report appear in Appendix M and identify that there is a matter of perception, not audibility for the infrasound components of turbines.

183. Appendix M identifies perception levels both in terms of faint perception and threshold perception contained in the SERI report that is directly compared with the audibility threshold level nominated by NASA. The nominated LSL criterion is from a Japanese study in a controlled environment where the infrasound energy did not go as low as that recorded in proximity to win farms in Australia.

184. I note that the sound pressure levels set out in Appendix M are peak sound pressure levels and therefore have pressure levels which are higher than I have recorded in that my measurements where I utilised the RMS level rather than the peak level. As the graph presented in the SERI report related to a background level determined inside a dwelling, Appendix M10 super imposes the threshold levels with respect to that background so as to place the levels in the context of measured levels utilising one third octaves.

185. Utilising Appendix M10 identifies the matter of perception determined in the SERI report being well below the audibility levels attributed to infrasound.

186. Professor Salt and Assistant Professor Lichtenban (both of Washington University) have published an article 'How Does Wind Turbine Noise Affect People?' in the Journal of the Acoustical Society of America where they highlight the results of their systematic research into the response of the human ear to low frequency and infrasound (reproduced as Appendix N).

187. Appendix N identifies common issues raised by residents affected by wind turbines and the common response from applicants in the current debate (paragraphs 2 and 3). After discussing the results of different types of studies the Conclusions and Concerns are compelling bearing in mind the article appears in the Journal of the Acoustical Society of America.

188. Dr Schomer and I had a meeting after the Denver conference where we discussed the results of our individual testing and the perception issue for the frequencies below 0.63 Hz, and between 2 and 4 Hz. There is some relevance between the sensitivity of people to low frequency vibration in the body. Reference to Australian Standard AS 2670-2 *Evaluation of human exposure to whole-body vibration, Part 2: Continuous and shock-induced vibration in buildings (1 to 80Hz)* and AS 2670-3 *Evaluation of human exposure to whole-body vibration, Part 3: Evaluation of exposure to whole-body z-axis vertical vibration in the frequency range 0.1 to 0.63 Hz*.

189. AS 2670-2 shows for the foot-to-head vibration using the acceleration parameter is more sensitive in the 4 - 8 Hz region, whilst in the side-to-side and back-to-chest vibration using the acceleration parameter is more sensitive for the frequencies below 2 Hz.

190. AS 2670-3 refers to motion sickness for frequencies below 0.63Hz. The introduction to the Standard states:

> ISO 2631/1 covers vibration in the frequency range 1 to 80 Hz only, although referring to the "special problem in the frequency range below 1 Hz associated with symptoms such as motion sickness". Appreciable vibration in this frequency range occurs in many forms of transport. It causes undesirable effects ranging from discomfort to acute distress due to motion sickness and allied symptoms and interference with activity due to sickness and/or the fluctuating inertial forces it produces in the body.

191. The presence of vibration in a building that gives rise to disturbance and motion sickness as identified in AS 2670 warrants investigation in buildings affected by turbines and may align with the observations of Dr Schomer.

192. Vibration measurements I conducted at the Quast residence in May 2013 show vibration levels in the regions of concern identified in AS 2670-2 and warrants further investigation as a basis for motion sickness described by Mrs Quast and is similar to the material presented by Dr Schomer.

CONCLUSIONS

193. The SLR Consulting Australia report into the proposed Rye Park Wind Farm did not address the impact of the proposed wind farm nor identify the occurrences of such impacts or the audibility frequency of such noise (as required under the DGRs).

194. The SA EPA guidelines do not meet their own core objectives. Both the 2003 and 2009 guidelines claim they are "not aware of infrasound being present at any modern wind farm site." As such the guidelines require amendments to address such errors and quantification of adverse sleep and health effects.

195. Monitoring of the Waterloo Wind Farm in 2013 by Adelaide University clearly shows the presence of infrasound and vibration inside residential dwellings.

196. Additional monitoring was undertaken by Adelaide University during the cable outage at Waterloo wind farm to identify the ambient noise in the valley without the operation of the wind farm. Material in relation to the impact residents experienced during the unplanned shutdown of the wind farm (versus operation of the wind farm) and the measurements that were undertaken by Adelaide University would be of assistance to the Determining Authority in obtaining first-hand accounts of the impact provided by existing wind farms.

197. Affidavits and testimony from the residents in proximity to Waterloo and Hallet wind farms that experience different effects with the wind farm off versus on is consistent with the experience from residents in New South Wales and Victoria that have experienced similar unplanned shutdowns and changes in their daily activities, and in particular sleep patterns.

198. Residents near the Cullerin Wind Farm (Edwards M) have reported dramatically improved sleep patterns after the audit testing of the Cullerin Wind Farm in New South Wales where at the end of the completion of the testing there was a problem with the substation (basis of problem unknown) that led to the entire wind farm being off-line for some 10 days.

199. The evidence from residents in proximity to wind farms not only in Waterloo and Hallet (being in South Australia) but residents in proximity to Waubra, Cape Bridgewater, Glen Thompson and Macarthur Wind Farms in Victoria, Capital Wind Farm and Cullerin Wind Farm in New South Wales all identify that there is an adverse impact generated by wind farms that purportedly comply with their noise conditions of consent.

200. Not all persons are affected by the wind farms in that there is a different sensitivity for various individuals which is a similar pattern for all various environmental impacts. However whereas residents may become habituated to road, aircraft or rail traffic over time it appears that residents exposed to wind farms noise do not habituate to the noise but in fact become more sensitised to the noise over time.

201. The use of the dB(A) parameter with respect to determining noise limits for a wind farm does not in any way shape or form address the low frequency noise and the infrasound that is generated by the wind farms.

202. There is more evidence coming forward from researchers and communities around the world that there is something when the turbines are in operation that gives rise to an impact. The Cape Bridgewater study that I have undertaken has identified a number of significant factors that lead to adverse impacts.

203. The NSW Department of Planning and Infrastructure has a fundamental requirement to protect the health and well-being of communities that are subject to various environmental pollutants. In relation to the matter of noise/vibration and other perceived impacts the use of the SA guideline for wind farms and the draft NSW guideline do not satisfy that requirement.

204. I can accept that the SA guidelines as originally developed some 10 or 12 years ago related to smaller turbines, had larger separation distances to residential dwellings and there was insufficient data to look at the health impacts on communities or the potential degradation of the acoustic amenity that those rural communities could experience.

205. Even on a dB(A) basis there is still no material to determine the appropriate level that relates to a rural acoustic amenity under the guidelines. Using a base level that is significantly above what is deemed to be a relatively quiet amenity, must automatically start from the wrong position.

206. I have previously issued papers identifying a periodic pattern in the infrasound region that I identified as the "wind turbine signature". That material was subsequently found to be supported by investigations undertaken by NASA in the late 1970s.

207. There are measurements conducted by other acousticians in Australia (Huson L in Cherry Tree Wind Farm VCAT hearing and Hansen K private communication) and overseas (Willshire W NASA Technical Memorandum 86409 and Kelly ND Solae Energy Research Institute 1985) show that the infrasound energy continues well past the nominated threshold setbacks of 1 – 2km, with residents up to 10 km from wind farms, where there are an elevated situation such as the Waterloo Wind Farm, identifying such impacts.

208. From a measurement basis with the appropriate gear some researchers are able to identify infrasound frequencies at distances much greater than 10 km. Whether those levels of infrasound are at a level that would interfere with individuals becomes more of an examination of the interaction of such energy with natural resonances of building elements. More research is required in this area to provide a quantitative assessment.

209. There is enough material to identify that modern day wind farms can generate an environmental "noise" impact pertaining to residential premises.

210. My recent work at Cape Bridgewater has revealed noise impacts for internal levels above the Danish EPA target of dBALF of 20 (being 10H to 160Hz only) and sensation impacts for internal levels above 50 dBC and 50 dB for the 4 Hz 1/3 octave band.

211. The SLR Consulting Australia report submitted with respect to the Rye Park Wind Farm is titled Noise Impact Assessment, yet I find nothing in the report that identifies what level of impact will occur as a result of the proposal.

212. The basis of the SLR Consulting Australia acoustic report appears to assess noise with respect to an external average noise target without necessarily identifying the tolerance in terms of the noise levels and more importantly the impact that would occur.

213. To date there is no material from the Applicant to guarantee there will be no adverse impacts from the proposed wind farm. In fact there is no identification of what impacts (adverse or acceptable) that residents will receive as a result of the proposed wind farm.

214. The planning authority needs to establish/guarantee what levels of noise and infrasound are acceptable in terms of the community and will not give rise to noise impacts or sleep disturbance before granting any consent.

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- Standards Australia, "AS 2670-2 Evaluation of Human Exposure to whole-body vibration, Part 2: Continuous and shock-induced vibration in buildings (1 to 80 Hz)", 1990
- Standards Australia, "AS 2670-3 Evaluation of Human Exposure to whole-body vibration, Part 3: Evaluation of exposure to whole-body z-axis vertical vibration in the frequency range 0.1 to 0.63Hz", 1990
- Salt A & Lichtenhan J "How Does Wind Turbine Noise Affect People?" Acoustics Today, Winter 2014.

APPENDIX A:

CURRICULUM VITA

STEVEN E. COOPER - DIRECTOR

DATE OF BIRTH: 15 June 1952

QUALIFICATIONS:

Bachelor of Science Engineering (Electrical) 1978, University of NSW

Master of Science (Architecture) 1990, University of Sydney

MEMBERSHIPS:

Fellow, Institution of Engineers, Australia
Chartered Professional Engineer

Member, Institute of Noise Control Engineering
Member, Australian Acoustical Society
Member, Acoustical Society of America

Member of Standards Association of Australia Committee AV/10 – Whole Body Vibration (1986 to 2013), Committee EV/11 – Aircraft & Helicopter Noise (1986 to 2013), AV/4 – Architectural Acoustics (1996 – 2000), and Committee EV/10/4 – Railway Noise (1998 to October 2007)

NSW Division, Australian Acoustical Society Membership Committee 1978 to 1997

EXPERIENCE:

The Acoustic Group Pty Ltd
Incorporated in 2003

Steven Cooper Acoustics Pty Ltd
Incorporated in 1995

James Madden Cooper Atkins Pty Ltd
Incorporated in 1981

James A. Madden Associates Pty Ltd
Appointed Associate Director 1980
Appointed Associate 1979
Appointed Engineer 1978

The Acoustic Group was formed to provide specialised services and research in Acoustics and Vibration and draws on the considerable experience of Mr. Cooper from his position from 1982-1995 as Principal and Partner of James Madden Cooper Atkins and from 1995-2003 as Principal of Steven Cooper Acoustics. His particular areas of acoustical expertise include machine and vibration monitoring, acoustical design of auditoria, studios and entertainment venues, traffic and helicopter noise, laboratory instrumentation, precision analysis system, legal assignments and expert witness.

He has considerable experience in vibration measurement and assessment in industry for both Machinery Operating Condition and Occupational Exposure Levels.

His experience in the measurement and assessment of noise emission from industry and licensed premises is extensive having produced numerous assessment reports and noise control designs for clients, statutory bodies and courts. He has been an invited Guest Lecturer on Noise Assessment to NSW Policy Academy for their Noise Familiarisation Course run by the State Pollution Control Commission, a guest lecturer for the Faculty of Architecture at the University of NSW, and a lecturer on noise issues for seminars/workshops run by the Australian Industries Group, the Australian Environment Network and NEERG Seminars.

He is the acknowledged leader in the measurement, assessment and design of helipad/heliport operations, military aircraft noise assessments, and is a major contributor to various Australian Standards. Mr. Cooper is the recipient of an Engineering Excellence Award in the Environment Category from the Institution of Engineers in 1997 for the TRW No. 2 Forge Project.

Projects in which he has been involved include the ICI Botany Complex (Noise and Vibration), APM Matraville Paper Mill (Site noise control), Manildra Flour Mill, Sydney CBD, Granville & Gosford Heliports, ANEF Validation and NPD testing for F111, FA-18, JSF aircraft, Iroquois, Squirrel, Sea King, Sea Hawk, Blackhawk, Super Seasprite, Tiger and MRH90 helicopters, acoustical assessments for Licensed Premises, Studios, Auditorias etc.

PAPERS & PUBLICATIONS

"Design for Noise Reduction – Dual Occupancies" 5th Annual Conference, Local Government Planners Association of NSW, November 1979

"Is Exposure to High Levels of 'Rock' Music a Major Health Hazard to Patrons and Staff" 10th International Congress on Acoustics – Sydney, July, 1980

"Hornsby Shire's General Sound Insulation Code for Residential Flat Buildings" 10th International Congress on Acoustics – Sydney, July, 1980

"Archiving Reproducing Piano Rolls" 10th International Congress on Acoustics – Sydney, July, 1980

"Road Traffic Noise and Local Government Controls", Graduate School of the Built Environment, University of NSW, February, 1981

"Noise Levels of Rock Music and Possible Effects on Young People's Hearing" Scientific Meeting NSW Division, Australian Acoustical Society, April, 1981

"Noise Assessment of Licensed Premises" NSW Police Noise Familiarisation Course, Policy Academy Sydney, July, 1981

"Noise Effects on Staff in Entertainment Venues" Australian Live Theatre Council, May, 1983

"Noise Pollution" Shout – August 1987, Journal of the Registered Clubs Association of NSW

"The Roles and Needs of Expert Witnesses", Development, Local Government and Environmental Seminar for Sly & Russell, Sydney, November, 1987

"Noise Limits for Helicopters", "Helicopters Noise and the Community", "Flight Techniques to Reduce Noise", Helicopter Noise Seminar – NSW Branch of the Helicopter Association of Australia, April, 1988

"Intensity Measurements of the Ampico/Duo Arts Parts 1 & 2" The AMICA News Bulletin (USA), Vol 25 No. 4, July, 1988

"Community Perceptions, Case Studies and Control of Noise" – Australian Conservation Foundation – Sydney Branch, September, 1988

"Helicopter Noise Assessment", Australian Acoustical Society Conference, Victor Harbour, South Australia, November, 1988

"Noise Considerations for the Establishment of Helipads/Heliports", Rotortech '89, Sydney, October, 1989

"An Investigation of the Alternatives to Sabine's Equation in the Determination of Absorption Coefficients using the Room Method", Master of Science Thesis, University of Sydney, March, 1990

"Noise Control – Decibels per dollars. A Practical Approach", The Stock Feed Manufacturers', Association of Australia Conference, Canberra, March, 1990

"Community Response to Aircraft & Helicopter Noise – Proposed PhD Research", Technical Meeting of the Australian Acoustical Society, NSW Division being a Review of Acoustics Research at Sydney University, May, 1991

"A Practical Method for the Assessment of Noise Controls for Aircraft Noise Intrusion", Second Sydney Airport Coalition Public Meeting, Petersham Town Hall, Sydney, September, 1991

"Are Regulatory Noise Limits in Australia Exterminating the Helicopter Industry?", Inter-Noise 91, Sydney, December, 1991

"Consideration of Alternative Acoustic Criteria for Assessment of Aircraft Noise in Wilderness & National Park Areas", Progress Report of Noise Criteria Working Group, Blue Mountains Fly Neighbourly Advice, July, 1994

"Are Regulatory Noise Limits in Australia Exterminating the Helicopter Industry?", Second Pacific International Conference on Aerospace Science & Technology, Melbourne, March, 1995

"Sound Proofing of a Forge", Acoustics Australia, Vol 26 (1998), No 2

"AS2021 – What Does it Mean Now?", Australian Mayoral Aviation Council Conference 1998

"Upgraded Plants and Retrospective Application of Modified Noise Criteria – Case Studies", Australian Industry Group, January, 1999

"Revision of Australian Standard AS2021", Airport Operators Conference, Melbourne, May, 1999

"Living with Your Neighbour's Noise", Neighbourhood Disputes Seminar, LAAMS, Sydney, May, 2000

"What Triggers the New EPA Noise Policies – Tips & Traps", Australian Environment Business Network Noise Pollution Seminar, June, 2001

"Practical Environment Management – Noise Issues", Australian Environment Business Network Environment Management Practitioners Workshop, August 2002, November 2002, February 2003, May 2003, August 2003

"Environmental Issues Management – Noise", Australian Industries Group Practical Methods and Technologies Seminar, October, 2002

"The INM Program is a much better program than HNM for helicopter modelling, but ….", SAE A-21 Helicopter Noise Working Group Meeting, Las Vegas, March, 2004

"Noise Certification, is the Helicopter Industry selling itself short?", HeliExpo 2004, Las Vegas, March, 2004

"Derivation & Use of NPD Curves for the INM", Helicopter Noise Workshop, American Helicopter Society Conference, June, 2005

"Problems with the INM: Part 1 – Lateral Attenuation", Noise of Progress Acoustics Conference 2006, New Zealand

"Problems with the INM: Part 2 – Atmospheric Attenuation", Noise of Progress Acoustics Conference 2006, New Zealand

"Problems with the INM: Part 3 – Derivation of NPD Curves", Noise of Progress Acoustics Conference 2006, New Zealand

"Problems with the INM: Part 4 – INM Inaccuracies", Noise of Progress Acoustics Conference, 2006, New Zealand

"Reviewing the Role of the Expert in Land & Environment Court Cases", NEERG Seminars, Sydney, August 2007

"JSF Aircraft Noise Issues for Australia", F35 ESOH Working Group Meeting, Washington, September 2007

"Acoustic Experts - Noise Under Pressure?" Getting it Together in the Land & Environment Court: Compiling Joint Expert Reports, NEERG Seminars, Sydney, October 2007

"What can go wrong acoustically", NEERG Seminar Dealing with DAs in 2009, Sydney, May 2009

"Community Response to Impulse Noise & Vibration", Training Area Noise & Vibration Workshop, Department of Defence, Canberra, June 2009

"Acoustics & Noise". Regulations & Implementation of DAs & SEPP65, NEERG Seminars, Sydney, March 2010

"INM Getting it to work Acoustically", 20th International Congress on Acoustics, Sydney, August 2010.

"Military Aircraft Noise in the Community", 20th International Congress on Acoustics, Sydney, August 2010.

"Sound Therapy Restores hearing – Fact or fiction? A personal experience of an acoustician", 20th International Congress on Acoustics, Sydney, August 2010.

"Alternative Aircraft Metrics – Useful or like moving the deck chairs on the Titanic", 20th International Congress on Acoustics, Sydney, August 2010.

"Issues arising from Incorrect Acoustic Conditions", Getting it Just Right, NEERG Seminars, Sydney, September 2010

"Avoiding/repairing acoustic disasters in DAs", Managing the DA Process from Go to Whoa, NEERG Seminars, Sydney, March 2011

"Aircraft Noise Measurements can be fun", Australian Acoustical Society NSW Division, August 2011

"INM Problems, Military Operations and AS2021 and the JSF", Australian Acoustical Society Victorian Division, September 2011

"Wind Farm Noise – An ethical dilemma for the Australian Acoustical Society?", Acoustics Australia, Vol 40, No. 2, August 2012

"Are Wind Farms too Close to Communities?", Australian Environment Foundation 2012 Annual Conference, October 2012

"Noise", OLGR Compliance Branch Symposium, Sydney June 2013

"The Measurement of Infrasound and Low Frequency Noise for Wind Farms (Amended)", 5th International Conference on Wind Turbine Noise, Denver 2013

"Hiding Wind Farm Noise in Ambient Measurements – Noise Floor, Wind Direction and Frequency Limitations", 5th International Conference on Wind Turbine Noise, Denver 2013

SPONSORED TECHNICAL REPORTS (Brief Selection only):

Noise Radiation and Reduction on a Fibreglass Minesweeper – HMAS Rushcutter for Carrington Slipways P/L, JMCA Report 16.1650.R1

Occupational Vibration Exposure Levels on Euclid Dump Trucks and Coal Haulers at Utah Blackall Mine Queensland, JMCA Report 16.1648.R1-R3

Thermal Expansion and Misalignment on a Gas Turbine Alternator at Shell Clyde Refinery, JMCA Report 17.1716.R1-R3

Acoustic Appraisal and Control – ABC Perth TV & Radio Studio Complex, JMCA Report 17.1607.R3

Southern Arterial Route – Pyrmont to St. Peters for NSW Department of Main Roads, JMCA Report 16.1647.R1

Building Structure Vibration Department of Social Security, East Point Centre Computer Installation, JMCA Report 15.1542.R2

Blower House Acoustic Controls (Building and Silencer Designs) St. Marys, Quakers Hill, Glenfield, Macquarie Fields and Hornsby Heights Pollution Control Plants, JMCA Reports 10.1014 & 14.1416

The Application and Use of ANEF Contours for Aircraft Noise Control, SCA Report 25.3127.R3 for Submission to the Senate Inquiry into Aircraft Noise at KSA

An Acoustical & Vibration Investigation into Freight Rail Operations in the Hunter Valley, SCA Report 26.3387.R1-R41

TRW No 2 Forge Noise Minimisation Study, SCA Reports 26.3314.R12-R19

Acoustical Assessment, Proposed Extension of Dock Hours, Westfield Shoppingtown, Parramatta SCA Reports 28.3766.R8-R12

Noise Impact Assessment, Proposed Service Centre, Cnr Cowpasture Road & Hoxton Park Road, Hoxton Park, SCA Report 30.3934.R1

Acoustical Assessment, Proposed Extension of Operating Hours, Westfield Shoppingtown Hornsby, SCA Report 30.3928.R3

Acoustical Assessment Aircraft Operations, RAAF Williamtown and Salt Ash Weapons Range, SCA Report 32.4190.R6

Acoustical Assessment Pollution Reduction Program No. 7, Shoalhaven Starches Plant, Bombaderry, SCA Report 32.3849.R17

HMAS ALBATROSS 2013 ANEF, Derivation of NPD Curves, SCA Report 33.4185.R11

Acoustical Assessment, Proposed Residential Development, Glenning Valley, Wyong, SCA Report 33.4303.R1

Acoustic Assessment, Proposed Groundwater Cleanup Project, Botany Industrial Park, TAG Report 34.4372.R3

Acoustic Design Report, Stage 1 Development Application for Bathurst Hospital, TAG Report 35.4477.R2

Acoustic Assessment, SCT Freight Complex - Stage 1, Brolgan Road, Parkes, TAG Report 36.4523.R1

Noise Disturbance in Residential Apartments as a Result of Building Expansion/Contraction, Bluewater Point Apartment Complex, Minyma, Queensland, TAG Report 36.4578.R1

Acoustic Design Report, Westfield Centrepoint Refurbishment, TAG Report 37.4472.R5

Construction Noise and Vibration Impact Assessment, Westfield Sydney City Refurbishment, TAG Report 37.4472.R6

Proposed Shao Lin Temple Development Site Near HMAS Albatross: Noise Assessment Report, TAG Report 37.4586.R1

TIGER ARH NPD Curves, TAG Report 37.4510.R15

Acoustical Assessment, Point Piper Marina, TAG Report 38.4705.R9

Rail Traffic Noise Impacts, Residential Sub-division, Isedale Road, Braemar, TAG Report 40.4865.R1

Acoustic Compliance Testing, New Buildings, RMAF BASE Butterworth, TAG Report 40.4386.R3

Acoustic Compliance Assessment, RAAF Base Williamtown – Off Base NMT Calibration, TAG Report 40.4421.R18

Acoustic Compliance Assessment, Royal Crown Hotel, Dudley, TAG Report 41.4902.R12

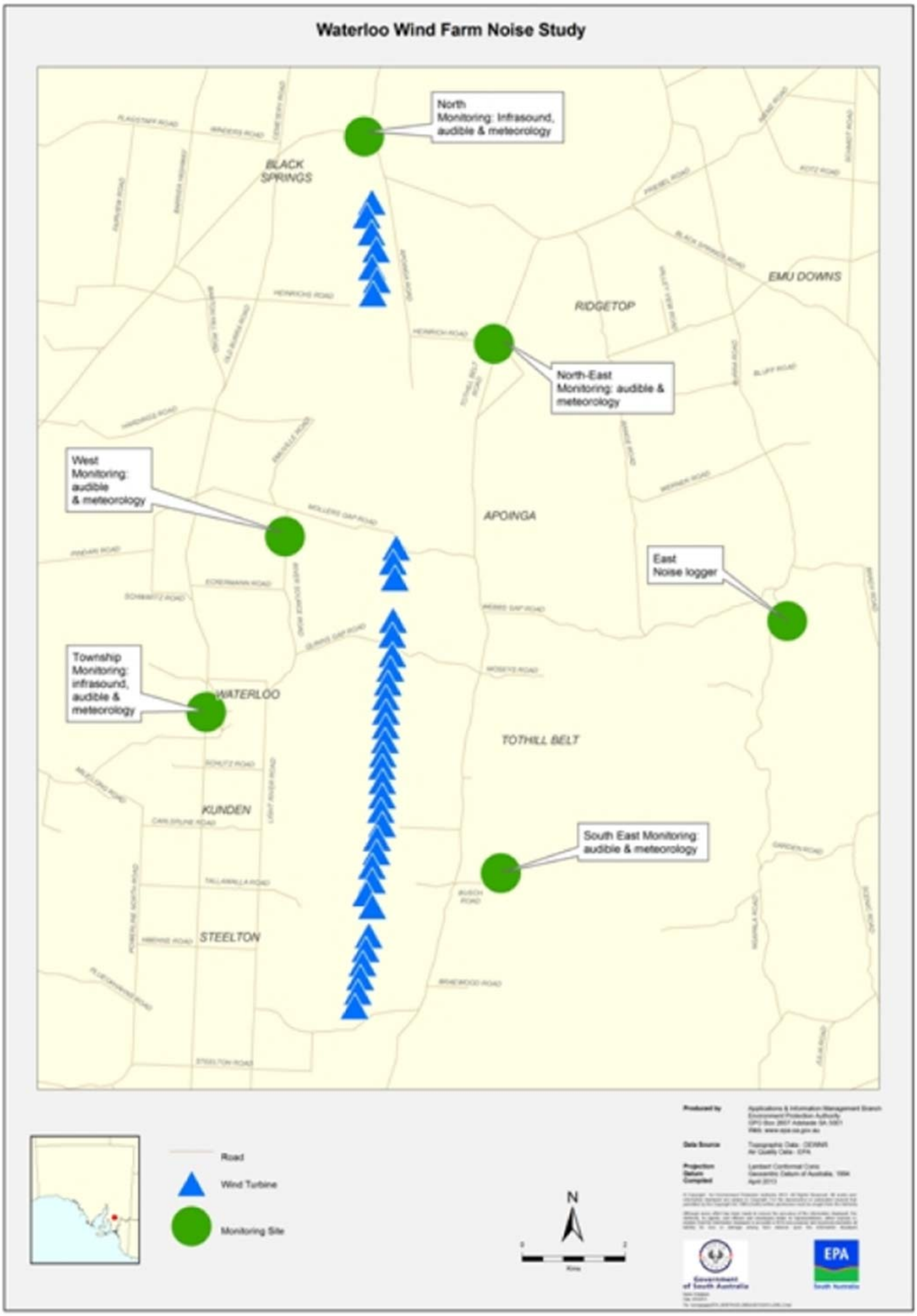
Occupational Noise Assessment, Qantas Freight Terminal, Sydney Airport, Mascot, TAG Report 41.4934.R1

Southern Highlands Regional Shooting Complex, Wattle Ridge Road, Hill Top, TAG Reports 40.4883.R1-12

Submission to the Senate Environment and Communications/Legislation Committee in the matter of Renewable Energy (Electricity) Amendment (Excessive Noise from Wind Farms) Bill 2012, 42.5006.R2

Supplementary Submission in the matter of Renewable Energy (Electricity) Amendment (Excessive Noise from Wind Farms) Bill 2012, 42.5006.R4

<u>APPENDIX B</u>: EPA Monitoring Locations



<u>APPENDIX C:</u> **Cooper Denver Paper 1**

5th International Conference On Wind Turbine Noise Denver 28-30 August 2013

The Measurement of Infrasound and Low Frequency Noise for Wind Farms (amended version)

Steven Cooper The Acoustic Group Pty Ltd, Sydney, NSW, 2040.

E-mail: drnoise@acoustics.com.au

Summary

The use of dB(A) for the assessment of large industrial wind turbines does not address low frequency noise (LFN) or infrasound due to the filter characteristics of the A-weighting curve. In seeking to address infrasound noise (typically identified as between 1Hz and 20Hz) some acousticians for the wind industry have used dB(G) and dB(Z) results. Both of these weighting curves exhibit significant roll offs in the frequency domain below 6Hz that renders the use of such descriptors of no real value in addressing infrasound of wind turbine noise. In my opinion the correct procedure is to use Linear (unweighted) levels in both constant percentage 1/3 octave bands (to agree with current acoustical data) and narrow band analysis to identify the wind turbine signature. For infrasound noise it would appear consideration of the linear result over the bandwidth of 1Hz – 20Hz is appropriate and low frequency noise when considered as a separate exercise should be expressed as a linear level restricted to the bandwidth of 20 – 200Hz.

1. Introduction

Wind farm approvals in Australia to date have used the dB(A) parameter with limits typically specified at 35/40dB(A) or background +5dB(A) whichever is the greater. The dB(A) parameter when used as the sole acoustic descriptor is inadequate for low frequency noise and infrasound. The use of other acoustic parameters has been proposed to discover low frequency noise and infrasound.

Various wind developers and industry lobby groups both in Australia and around the world have been claiming that the report issued by the South Australian EPA and Resonate Acoustics [1] is a scientifically valid document that has confirmed infrasound associated with wind turbines is a non-event. A cursory examination of the document as set out below suggests that it is a document that provides incorrect conclusions to the wind industry and the community that are not supported by the data.

The primary function of the document was to compare the levels of infrasound measured within different environments including locations adjacent to wind farms. The report provides dBG result and Linear octave band levels over the infrasound region of 0.25Hz to 20Hz. The report did not quantify the human perception of

infrasound from wind farms but provided measured levels of infrasound near wind farms.
The report indicates that the use of the dB(G) parameter is an appropriate measurement of infrasound from wind farms. After selective testing of a number of sites, there is a claim that both rural and residential areas experienced dB(G) levels higher than that associated with wind turbines.
As wind farms are normally placed in rural areas (and similarly in the US so are scattered individual turbines) where ambient noise levels are relatively low, then there is a fundamental problem with utilising noise criteria issued for suburban environments where such environments are significantly higher than the background soundscape experienced in rural areas.

2. dB(G)

The authors claim in Section 2.1 (of the Resonate Acoustics report) that the dB(G) parameter is used to quantify sound that has a significant portion of its energy in the infrasonic range.
Immediately following the first paragraph of Section 2.1, a figure is provided showing the weighting characteristics of the G-filter, obtained from the ISO Standard 7196 [2]. The G-weighting function (see Figure 1) follows the procedure in the ISO Standard of referencing the attenuation with respect to a level of 0dB at 10Hz. The filter shows that there is amplification above the region of 10Hz to 25Hz, with a maximum of +9dB at 20Hz. Between 1Hz and 20Hz the filter drops off at 12dB per octave, whilst below 1Hz and above 20Hz the filter drops off at 24dB per octave.

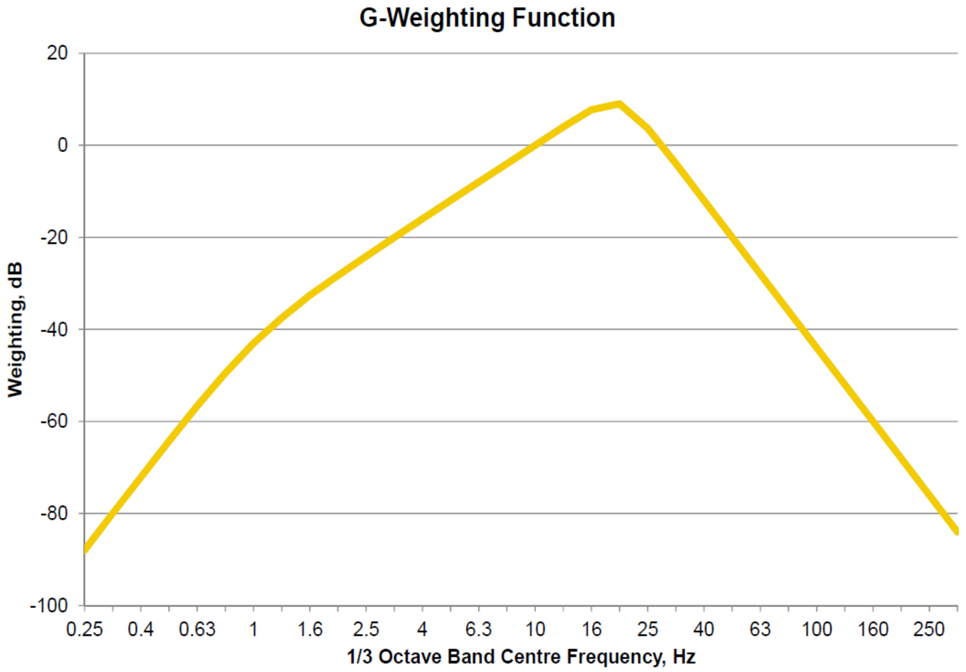


FIGURE 1: G-Weighting Filter from reference 1

At 6.3Hz, being a typical lower limit of some sound level meters that can provide 1/3 octave band results, the dB(G) filter has a value of 8dB below the reference level at 10Hz. Similarly at a frequency of 1Hz (that is typically near the blade pass frequency of modern day turbines) the filter exhibits an attenuation of 43dB below the 10Hz 0dB reference level.

Using dB level expressed in a Linear (un-weighted) format, the frequency spectrum from modern day wind turbines is predominantly elevated in the 0.7Hz to 6Hz region. For example, later in the Resonate Acoustics report (Figure 29) there is a 1/3 octave band spectrum chart limited to the frequency range of 0.25Hz to 20Hz (shown as Figure 2). With the G-weighted response placed over the measurement results it is clearly apparent from Figure 2 that the dB(G) value **does not cover the majority of the infrasound region generated by turbines**.

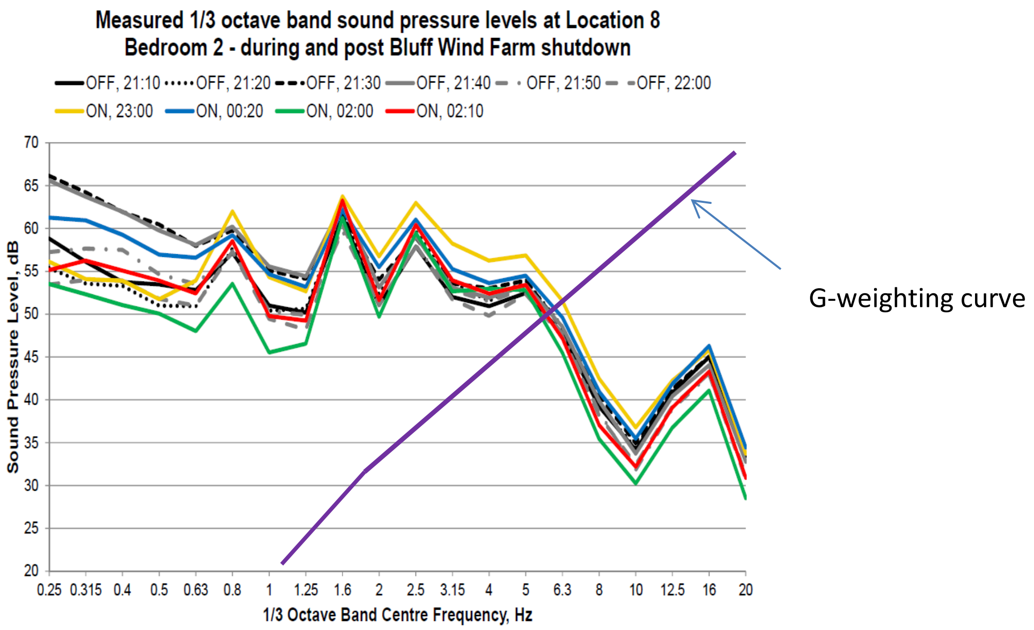


Figure 29 – Measured sound pressure levels with wind farm on and off, Bedroom 2 at house near Bluff Wind Farm

FIGURE 2: Figure 29 from reference 1

Examination of Figure 2 clearly indicates a significant degree of energy in the lower portion of the infrasound band. When the spectrum is corrected by the dB(G) function (Figure 1), the claim as to the dB(G) being a suitable descriptor for infrasound noise for wind farms is incorrect.

Using the linear (un-weighted) data in Figure 29 of the Resonate Acoustics report, that covers only the infrasound region of 0.25Hz – 20Hz, it can be seen that the peaks associated with the blade pass frequency and the first few harmonics (when measured in 1/3 octave bands) are higher than the peak at 16Hz.

Using the red line for ON at 2.10 AM inside the bedroom 2 for location 8 the data appears to provide the results set out in Table 3 to reveal a Linear level of 67 dB, whilst the dB(G) level is 53dB.

TABLE 1: Weighted Results for Figure 2

Weighting	1/3 Octave Band Centre Frequency (Hz)														
	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20
Linear	58	49	49	63	57	60	53	52	53	45	35	33	38	43	33
Z weight	28	24	26	43	40	46	41	41	48	38	31	30	36	42	32

Comparison of the Linear spectrum versus the G-weighted spectrum in Figure 2 (from the Resonate Acoustics report) and Table 2 shows the inadequacy of the dB(G) value to address infrasound from wind turbines.
The use of an overall level using Linear weighting over the infrasound region of 1 – 20Hz for the measurement of turbine noise covers the energy produced by turbines in the infrasound region, whereas the dB(G) result does not reflect the significant portion of the energy in the very low frequency infrasound range as shown by the comparisons having little difference in the dB(G) value, whereas on a Linear basis there is a significant difference.

Impulse response durations for 90% magnitude 1/3-octave filters in time domain		
Center frequency	4^{th}-order	6^{th}-order ANSI S1.11
1.00 Hz	3294 ms	4989 ms
1.25 Hz	2616 ms	3963 ms
1.60 Hz	2078 ms	3148 ms
2.00 Hz	1651 ms	2500 ms
2.50 Hz	1311 ms	1986 ms
3.15 Hz	1042 ms	1578 ms
4.00 Hz	827 ms	1253 ms
5.0 Hz	657 ms	995 ms
6.3 Hz	522 ms	791 ms
8.0 Hz	415 ms	628 ms
10.0 Hz	329 ms	499 ms
12.5 Hz	262 ms	396 ms
16.0 Hz	208 ms	315 ms
20.0 Hz	165 ms	250 ms
25.0 Hz	131 ms	199 ms
31.5 Hz	104 ms	158 ms
40.0 Hz	82.7 ms	125 ms
50 Hz	65.7 ms	99.5 ms
63 Hz	52.2 ms	79.1 ms
80 Hz	41.5 ms	62.8 ms
100 Hz	32.9 ms	49.9 ms
125 Hz	26.2 ms	39.6 ms
160 Hz	20.8 ms	31.5 ms
200 Hz	16.5 ms	25.0 ms
250 Hz	13.1 ms	19.9 ms
315 Hz	10.4 ms	15.8 ms
400 Hz	8.28 ms	12.5 ms
500 Hz	6.57 ms	9.96 ms
630 Hz	5.23 ms	7.91 ms
800 Hz	4.16 ms	6.28 ms
1000 Hz	3.30 ms	4.99 ms
1250 Hz	2.62 ms	3.96 ms
1600 Hz	2.09 ms	3.15 ms
2000 Hz	1.67 ms	2.50 ms
2500 Hz	1.32 ms	1.99 ms
3150 Hz	1.06 ms	1.57 ms
4000 Hz	0.84 ms	1.25 ms
5000 Hz	0.68 ms	1.00 ms
6300 Hz	0.51 ms	0.79 ms
8000 Hz	0.40 ms	0.63 ms
10000 Hz	0.33 ms	0.50 ms
12500 Hz	0.26 ms	0.40 ms
16000 Hz	0.22 ms	0.31 ms
20000 Hz	0.16 ms	0.25 ms

TABLE 2: Impulse response durations from reference 4

In light of the above, the claim that the G-weighting function **"is used to quantify sound that has a significant portion of its energy in the infrasonic range"** is wrong for turbine noise. That position and a number of issues relating to the Resonate Acoustics report were discussed at a technical meeting of the NSW Division of the AAS in March 2013 [3].
The G-weighting filter impulse response time is only about 120ms which is adequate for measuring around 1Hz but the time constants for 1/3 octave bands below 6.3Hz are much longer (see Table 2). Using 1/3 octave band results to derive a dB(G) value is automatically incorrect due to the too long a time constant for industrial wind turbines with blade-passing periods of approximately 1 second (BT=1). Similarly G-weighting when derived from 1/3 octave band results is completely inappropriate when coupled with longer integration times (of 10 seconds) [4] [5].
At the present time ISO 7196 indicates the dBG may be appropriate for the measurement of infrasound, although the Standard does not refer to wind turbines in the bibliography. Swinbanks [5] has suggested that the overall slope of the G function below 10Hz does reflect the sensitivity of the inner hair cells to initial external pressure excitation at the eardrum and therefore follows the threshold of hearing perception referenced in the bibliography of ISO 7196.

Whether the dB(G) scale, which is based on single steady tones and not fluctuating levels with harmonics, is suitable for wind turbines is not addressed in Resonate Acoustics report as it was not a study into the perception of infrasound or specifically wind farm noise.

However, residents detect the impact of turbines (presence of pressure in various parts of the body) at levels below the “threshold of hearing”. Salt and Lichtenham [6] have highlighted the outer hair cells, which are connected through a separate nervous path, are not associated with “direct” hearing. Professor Salt has argued (and has measured) the response of the outer hair cells and found they are more sensitive to infrasound than the inner hair cells, particularly to very low-frequency sounds [7].

As the dB(G) function significantly attenuates the majority of the energy produced by turbines in the infrasound region the use of the overall Linear level for 1 – 20Hz bandwidth is an appropriate measure of turbine infrasound levels and may be the appropriate mechanism to address the inability of the dB(G) “hearing threshold” to correlate with complaints re turbine noise (Appendix D of reference [8]).

3. dB(Z)

The April 2012 issue of the Acoustics Australia was a special issue on wind turbine noise [9].

In relation to infrasound commencing on page 45 of reference 9 is a paper *Measurement and Level of Infrasound from Wind Farms and Other Sources* (“the Sonus paper”) [10]. Statements have been regularly made by wind industry representatives in Australia that the Sonus paper is a peer reviewed paper and as such has been fully reviewed for its technical content [11].

The material contained in the paper is extracted from a report prepared in November 2010 by Sonus for Pacific Hydro [12] (the “infrasound report”) in that the graphs set out in the paper are direct extracts from that report. My review [13] of the infrasound report has identified a significant number of errors and omissions that cannot be expanded upon in this article. Examination of Figure 3 (from reference 12) identifies turbine 27 and a ‘cliff’ measurement location that is suggested to be a natural infrasound environmental location. However Figure 4 is a Google earth map for 3 months before the measurements in reference 12 that identifies a significantly greater number of turbines near the ‘cliff’ measurement location than shown in Figure 3 contained in the infrasound report. Attendance in the ‘cliff’ measurement location found the location impacted by turbines not identified in Figure 3 yet as shown in Figure 4 existed at the time of the ‘cliff’ measurements.

Map 1: Cape Bridgewater Wind Farm Measurement Locations

Figure 3: Sonus report identifying one turbine

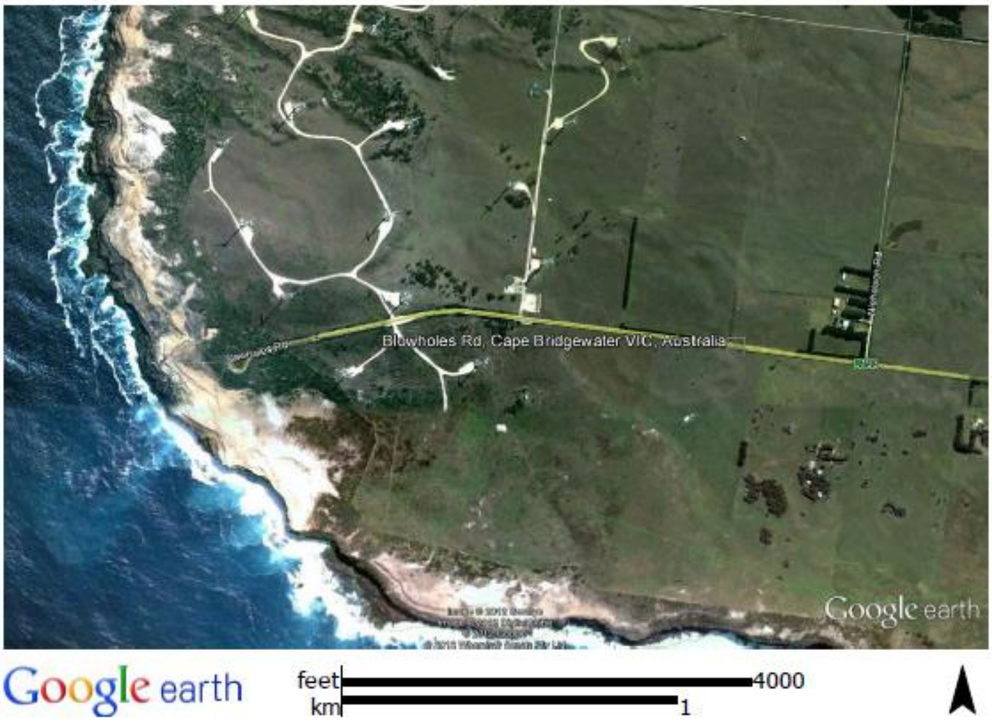


Figure 4: Google Earth, Map 1 three months prior to Sonus measurements

To identify the errors in describing what was tested, where and under what conditions as well, as the above photos that do not show all the turbines that exist at one wind farm, the reader is referred to reference [13].

On page 47 of the Sonus paper measured levels utilising the G-weighting curve are provided. The paper claims (as does the infrasound report) that there are various natural and man-made sources which give rise to higher levels of infrasound than that of wind farms when utilising the dB(G) curve.

However on going to the actual infrasound report it can be established that is not the case by examining the 1/3 octave band results that have been graphed (to identify individual frequencies) with some locations presented in tables.

If one plots the inside and outside noise levels set out in Tables 8 and 9 respectively of the infrasound report (on the basis of the material that has been provided) it can be seen that for frequencies below 3Hz the inside noise levels are **greater** than the outside noise levels (see Figure 3), yet on a dB(G) basis it is claimed that the outside level of 56dB(G) is reduced to an inside level of 50dB(G). The graphs indicate that there are frequencies below 20Hz inside the dwelling where a significant portion of the energy is below 6.3Hz. Utilising the reported results from Table 8 and 9 the 1/3 octave band data for 1Hz to 20Hz provides the levels set out in Table 3.

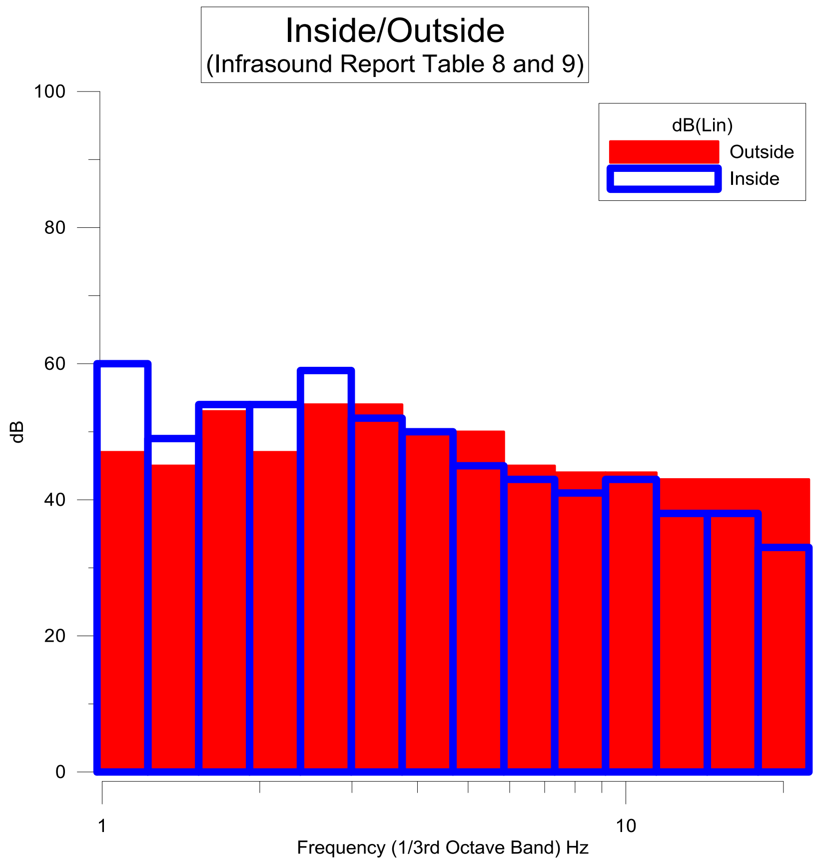


FIGURE 5: Inside/Outside results from reference [12]

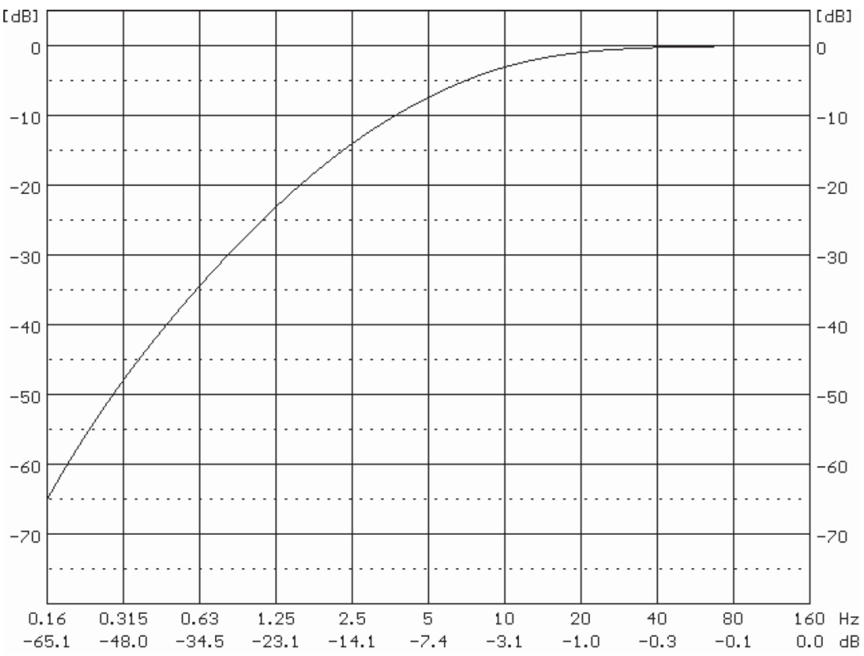
TABLE 3: Calculated levels – Tables 8 & 9 of Infrasound report (Reference 12)

Noise Source	Measured Level dB(G)	Measured Level dB(Lin)	Measured Level dB(C)	Measured Level dB(A)
Inside Dwelling	50	64	35	-14
Outside Dwelling	56	61	41	-6

The report does not identify the blade pass frequency. If one assumes the frequency relates to a speed of 16 - 17 rpm then the blade pass frequency will be below 1 Hz. The above results do not go below 1 Hz as the meter is unable to measure 1/3 octave bands below 1 Hz.

The material provided in the infrasound report and the aforementioned Sonus paper in Acoustics Australia [11] identified the meter was a Svantek 957 meter with a Gras 40 AZ microphone having a frequency response of ±1dB to 1Hz (page 45 of reference 13). Some older Svantek meters (such as the 912 and 912AE) provide a Linear spectrum but not the 957 meter used for the Sonus paper.

The meter used for measurements has the capability for selecting spectra for analysis utilise A-weighting, C-weighting or Z-weighting. For analysis purposes the 957 meter has two Z weighting curves. One curve for the broadband level (figure 6) and a relatively flat curve (Flat) for 1/3 octave band analysis.



Low band frequency characteristics of Z filter implemented in the instrument

FIGURE 6: Z-weighted – characteristics from reference 14

The Z-weighting filter shown in Figure 6 (from reference 14) for the SVAN 957 meter is for the broadband dBZ measurement and provides an attenuation that shows the start of a roll-off around 70 Hz (-0.1dB at f_1 at 80Hz) and whilst only being 1 dB down at 20 Hz, it is 23 dB down at 1.25 Hz. His contradicts the text in the manual (Appendix D9) that indicates the 0.1 dB down point is at 27 Hz.

Therefore if using the dBZ overall value to describe the noise then like the dBG filter curve an overall dBZ value will underestimate the contribution for the blade pass frequency and the lower harmonics of that frequency.

Sonus have advised [15] that the 1/3 octave band graphs from the meter utilise a different curve to that shown in Figure 6 that provides a flat response from about 0.8Hz and required a notation of that fact in the presentation.

There is no identification in either the Sonus paper or the infrasound report of the meter settings.

However there also another set of correction curves in the sound mode to address the sound field and extension cables (as compensation filters) that would appear to change the frequency response curves by an additional "digital filter when compensation filter is engaged" [16].

In other sound level meters there can be a flat Z weighting for a limited frequency range and compensation adjustments for extended frequency response or different microphones. Similarly in using direct analysis processing (such as Pulse) it is necessary to be aware of the High Pass filter settings (22.4Hz, 7Hz, 0.7Hz or DC).

From the above discussion there can be problems in assuming a flat response from the measurement instrumentation. Therefore in reporting on infrasound measurements it becomes necessary to identify the instrumentation setup and any compensation filters that may be used.

The above discrepancy in the response curves leads to an identification that *International Standard IEC 61672-1 Electroacoustics – Sound level meters – Part 1: Specifications* [17] only provides a Z weighting filter correction of 0 dB down to 10Hz. The Standard does not present a frequency response below 10Hz. Furthermore the allowable tolerance of the Z weighting at 10 Hz is larger than at higher frequency.

It is suggested that these aspects of the IEC Standard for the frequency range below 10 Hz for the measurement of wind farms needs to be addressed.

TABLE 4: AAS Paper – Table 2 Data (reference 12)

(Limited 1/3rd Octave Bands 1-20Hz)

Noise Source	Measured Level dB(G)	Measured Level dB(Lin)	Measured Level dB(C)	Measured Level dB(A)
Clements Gap Wind Farm at 85m	75	100	61	9
Clements Gap Wind Farm at 185m	70	97	56	4
Clements Gap Wind Farm at 360m	65	93	51	-2
Cape Bridgewater Wind Farm at 100m	68	89	53	5
Cape Bridgewater Wind farm at 200m	66	83	51	2
Cape Bridgewater Wind Farm ambient	65	83	51	0
Beach at 25m from high water line	78	91	64	13
250m from coastal cliff face	72	90	57	7
8km inland from coast	61	86	47	-5
Gas fired power station at 350m	75	90	60	13
Adelaide CBD at least 70m from any major road	78	91	62	15

Accordingly as the infrasound report concentrated on dB(G), the comparison of man-made and wind farm infrasound will be different as discussed above.
The Sonus paper only provided a table of dB(G) values. If one is seeking to compare infrasound from wind farms, and the dB(G) does not identify the majority of the turbine infrasound, the use of the dB (Lin) parameter band limited to 0.5 Hz to 20 Hz.

In some instances resident complaints attributed to wind farms are related to low frequency noise, which is not a matter that is covered either by dB(G) or dB Linear when the results are just band limited from 1Hz to 20Hz. To address low frequency noise should another measure of wind farm noise cover 20 Hz to 200Hz as a Linear level?

Low frequency noise has recently been shown by Nobbs et al. [17] to be directly associated with specific symptoms under the label of "annoyance" and the severity of those symptoms correlated precisely with the "dose" or SPL of sound energy present in those frequencies at the time. It is noted that reference [17] provides levels in dB(Z) but limited to above 10Hz.

A repeat exercise but to include frequencies below 10Hz was being undertaken at the time this paper was being prepared.

4. Narrow Band Spectra

It is noted that in relation to the matter of addressing infrasound and low frequency noise from wind farms, other acoustic consultants both here and in Australia have looked to narrowband measurements to identify the signature of the turbines to find a fundamental frequency associated with the blade pass frequency and multiple harmonics all to lie in the infrasound region.

A report issued in late 2012 with respect to the Shirley Wind Farm in Wisconsin [8] confirms the results of similar measurements conducted in Falmouth, Massachusetts [19] and measurements in Australia [7]. The Shirley Wind Farm monitoring involved a number of acoustical consultancy firms where assessments were conducted both in terms of 1/3 octave's and also narrowband analysis.

The Wisconsin report identifies residents were able to perceive low frequency noise being below the nominal threshold of hearing and the penultimate paragraph of the conclusion states:

> "The four investigating firms are of the opinion that enough evidence and hypotheses have been given here in to classify LFN and infrasound as a serious issue, possibly affecting the future of the industry. It should be addressed beyond the present practice of showing that wind turbine levels of magnitude is below the threshold if hearing at low frequencies."

One of the firms involved in the Wisconsin study included Dr Paul Schomer, who for experienced practitioners in acoustics would be well aware of his experience in acoustics, particularly with respect to socio-acoustics and regression analysis for various forms of noise sources.

Dr Schomer in his report (attached as Appendix D to the main Wisconsin report) identifies that the implications of the measurements (of the Shirley Wind Farm) are:

1. The measurements support the hypothesis developed in (I) that the primary frequencies are very low, in the range of several tenths of a Hertz up to several Hertz. The coherence analysis shows that only the very low frequencies appear throughout the house and are clearly related to the blade passage frequency of the turbine. As Figure 5 shows, the house is acting like a cavity and indeed at 5Hz and below, where the wavelength is 200 ft or greater, the house is small compared to the wavelength.

In the section of Descriptors for Wind Turbine Emission, Dr Schomer states:

1. Currently the wind turbine industry presents only A-weighted octave band data down to 31Hz. They have stated that wind turbines do not produce low frequency sound energies. The measurements at Shirley have clearly shown that low frequency infrasound is clearly present and relevant. A-weighting is totally inadequate and inappropriate for description of this infrasound. In point of fact, the A-weighting, and also the C and Z-weightings for Type 1 sound level meter have a lower tolerance limit of -4.5dB in the 16Hz one-third octave band, a tolerance of minus infinity in the 12.5Hz and 10Hz one-third octave bands, and are totally undefined below the 10Hz one-third octave band. Thus, the International Electro-technical Commission (IEC) standard needs to include both infrasonic measurements and a standard for the instrument by which they are measured.

5. Filter Limitations

The preceding extract identifies the levels below 10Hz are undefined for the normal filter curves. It would appear that there are different “Linear” frequency responses for different meters and there are different Z filter responses for various meters. Many Type 1 sound level meters do not cover the full range of the spectrum needed for assessing turbines.

Our measurements have utilised the full spectrum capabilities of the Bruel & Kjaer Pulse system with early measurements using the default 22.4Hz high pass filter, then measurements using the 7Hz high pass filter (-3dB @ 0.7Hz), and now 0.7Hz filter (-3dB at 0.07Hz) with unfiltered data being obtained for real time and post-processing.

We have found the frequency response of the microphones has been the first limitation, then the dynamic range of the microphones. This had led to extensive testing of noise floors and frequency range of the various microphones for the Pulse system and comparison with other meters to confirm the measurement results (particularly indoors) are above the thermal/electrical floor of the instrumentation. Such testing has identified a “sensitivity” floor of the microphone (above the electrical noise floor) where the microphone starts to provide an output having overcome the mechanical inertia of the diaphragm.

Swinbanks [5] identifies wind-turbine infrasound can be impulsive with a well-defined array of tonal harmonics below 10Hz. He notes that, *“for impulsive sound, the harmonics are all phase-correlated; so that they do not add together randomly in mean square to form the maximum amplitude, but rather they add together in a linear fashion, with their individual maxima all coinciding. Thus, for an impulse having 10 equal amplitude harmonics each of unity amplitude (say), the mean square level is +10dB, but the peak level is +20dB”.*

Because the peak levels for wind turbine noise could be considerably higher than for wind noise, Swinbanks [5], James & Bray [4] and Rand & Ambrose [19] utilise unweighted time waveforms as an essential part of their assessment where significant crest factors can be identified.

6. Conclusions

The concept of utilising dB(G) to describe infrasound levels associated with wind turbines at residential receivers has a fundamental flaw due to the definition of the G-weighting curve which can be obtained by reference back to International Standard ISO 7196:1995.

Due to the specific frequency weighting characteristics of the G function, whilst the proportion of energy below 6.3Hz is evident in a linear format for such measurements, such energy in not reflected in the dB(G) value.

The relevance of using dB(G) to determine the human perception of infrasound from turbines has not been established or whether in fact the suggestion of a hearing threshold based on dB(G) is appropriate for turbine noise.

There is danger in utilising or presenting material as Linear levels when using instrumentation that has a dB(Z) weighting that may have different frequency responses below 5Hz and potentially different compensation filters that need to be identified.

Not all meters have the same dB(Z) filter or even true Linear spectrum results, nor do most consultants or calibration facilities have the ability to calibrate complete systems across the full infrasound spectrum.

It would therefore appear that in seeking to investigate infrasound measurements the appropriate method is to present the linear (unweighted) results. In our experience in addition to generalised 1/3 octave band information, narrowband analysis should be provided which by its very nature is able to identify the presence of tones at a lower level than one can see by use of 1/3 octave band analysis.

Investigations into the infrasound issue associated with the wind turbines also require consideration of the noise levels inside buildings. In some cases the internal noise levels are higher than external, whilst for other sites the internal levels are marginally below that recorded externally – but not to the extent as the reduction in dB(A) values.

Apart from the issue of secondary windscreens or microphones in holes in the ground, there is an issue in terms of the instrumentation that is used for measurements where matters have been raised by various parties as to the noise floor of the microphone (and the instrumentation) and also the frequency response for the levels being measured. The frequency response of microphones is usually tested at levels much higher than encountered inside residences. Testing in our anechoic room showed the frequency response is not linear across the dynamic range [21] and one has to ensure the system can measure the actual noise – hence requiring specialised instrumentation.

Investigation and measurement of infrasound is for most acousticians a new area of investigation and as well as being somewhat expensive to investigate, it is also quite interesting. It is hoped that the above matters lead to further discussion as to the appropriate measurements and consistency in terms of methodologies so as to permit the health studies and similar that would enable investigating noise from wind turbines can be undertaken from a more solid and consistent basis with respect to the noise level measurements.

7. Acknowledgements

The author acknowledges the contribution from Rob Rand, Rick James, Stephen Ambrose and Les Huson for technical editing of the article, and in particular the material provided by Dr Malcolm Swinbanks to educate us all about filters.

The amended version of the original paper is different to that contained in the conference proceedings following advice from Mr Turnbull of errors in the original paper concerning the Z weighting of the 1/3 octave bands in the SVAN 957. The author in the presentation acknowledged the error and gave an undertaking to those present to re-issue the paper.

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APPENDIX D: Cooper Denver Paper 2

5th International Conference
on
Wind Turbine Noise
Denver 28-30 August 2013

Hiding Wind Farm Noise in Ambient Measurements - Noise Floor, Wind Direction and Frequency Limitations

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Summary

Apart from inadequacy of dB(A) measurement to identify the acoustic signature of wind farm noise the provision of averaging techniques by use of regression curves related to hub height wind speeds are of no assistance to the community in determining acoustic compliance. Furthermore the frequency limitation of various sound level meters automatically restricts the provision of appropriate noise data related to turbine operations. A further issue of concern relates to the noise floor of the measurement system that by the (intentional or unintentional) selection of microphones can render the measurements of no assistance. Examination of different analysis parameters, instrumentation frequency response and microphone noise floors is provided to identify the above anomalies

1. Introduction

The selection of acoustic descriptors used for general community noise assessments do not specifically address or cater for unique characteristics that may be exhibited in the acoustic signature that alter the subjective response to the noise. It is in response to unique characteristics to the noise that leads to a more detailed assessment to quantify the subjective impact. To the modern day acoustician, with the advantage of sophisticated instrumentation and advanced measurement techniques, utilisation of the more detailed analysis is readily available yet often times ignored.

The use of limited capabilities of instrumentation (intentional or unintentional) does not assist in providing the technical basis of measuring let alone understanding the acoustic impacts associated with the operation of wind farms.

For acousticians who are also involved in the assessment of machine vibration their thought processes give rise to different forms of analysis that do not necessarily occur on a regular basis in the acoustic domain. The analogy of machine vibration may assist in identifying different analysis processes that occur for persons involved in such investigations that could directly relate to some of the unique acoustic issues associated with wind farm noise.

2. Vibration Analysis

When there is a significant level of velocity or acceleration recorded on a machine then in a simplistic nature the justification of vibration problem can be identified on an audible basis when the machine doesn't sound right.

The use of octave band information for vibration work is generally of no real assistance with a preference (for vibration measurements using sound level meters) to utilise one third octaves so as to identify specific operating components generally related to the main driveshaft speed of the machine under investigation.
However looking to identify problems that may occur in a machine, which do not necessarily show up in an overall vibration level or 1/3 octave band analysis, the general procedure is to consider narrowband analysis to determine individual frequencies associated with various operating parameters/elements of the machine.

The vibration engineer is used to looking at a narrowband analysis (for machines that in general terms can be expressed as operating at low speeds) they also consider the frequency analysis in terms of a linear domain rather than a logarithmic domain normally applied to acoustic assessments.

For more complex vibration problems such as gearboxes and bearings there are more complex analyses that are available which look to time history and modulation of the signal (such as Cepstrum analysis and Kurtosis analysis) to extract detailed information such as gearmesh frequencies and bearing resonance effects.
Similarly in dealing with the wide range of vibration levels that can occur for different types of signals the vibration engineer may utilise extremely small accelerometers that will not affect the operation of unit under test and at the same time are normally associated with high shock values. For general machine vibration measurements the accelerometers are typically increased in size and the output sensitivity is increased, whereas for low level vibration, such as that associated with seismic investigations, the accelerometers themselves are much larger and have a much greater sensitivity so as to produce a useful output.

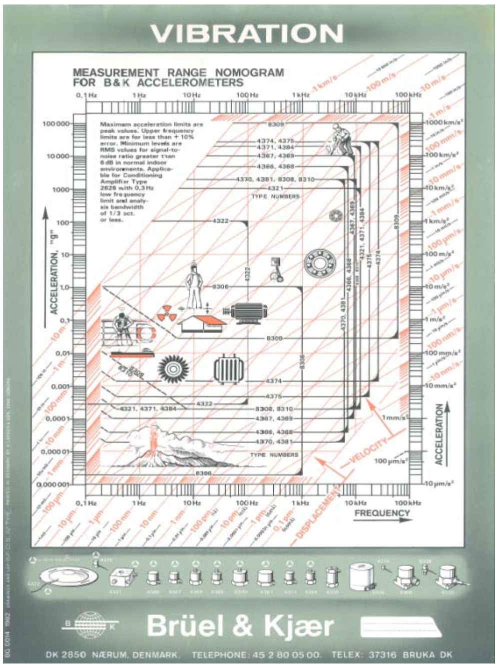

Figure 1 shows a typical accelerometer selection chart from Bruel and Kjaer and indicates that the use of very small accelerometers with low sensitive outputs will be unable to record seismic vibrations, whereas the seismic detector would be overloaded when dealing with high level accelerations such as encountered on the handle of a jackhammer.

In other words in the vibration domain there are different accelerometers for the different types of measurements being undertaken. Furthermore the frequency assessment is predominantly in the linear domain and generally of a lower bandwidth than that encountered in the acoustic domain.

FIGURE 1: Vibration Nomogram

3. dB(A) Levels

The general concept for environmental criteria in relation to the emission of noise from wind farms has been to utilise the A-weighted value when assessed at residential properties.

Whilst dB(A) is appropriate for general environmental noise assessments it is common for the regulatory authorities to include corrections to the measured value to take account of the audible characteristics that may be contained in the subject noise. For example where a noise contains tonal, impulsive or intermittent characteristics various regulations and standards in Australia look to add penalties to the measured level although some penalties do not operate during the night time period.

The presentation of material in simply the dB(A) value has limitations in understanding noise emitted from wind farms in that the A-weighting filter significantly attenuates low frequency noise.
In acoustic matters it is common to provide noise data in terms of octave bands or 1/3 octave bands so as to indicate potential spectral characteristics of the noise.

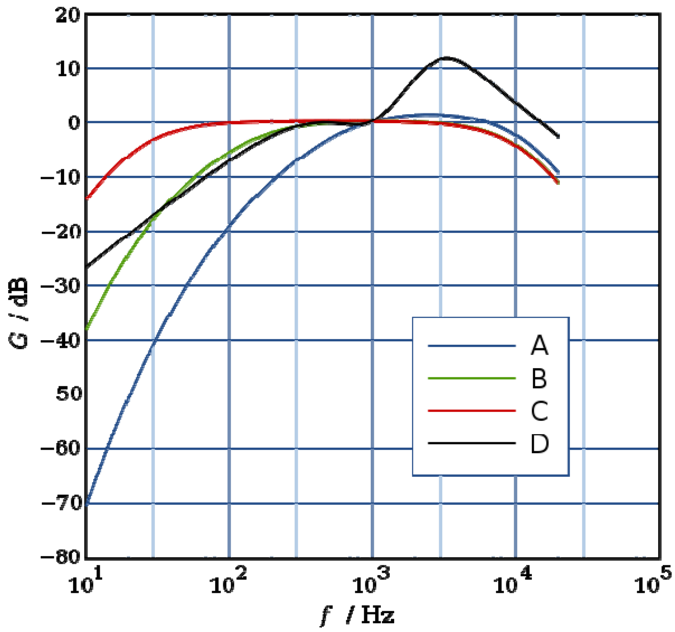

Figure 2 – Common Frequency Weightings

Older acousticians will be used to dealing with octave band information in a linear format whereas there is a general trend in today's digital era to utilise A-weighted spectral information. If one considers low frequency noise to occupy the bandwidth of 20Hz to 200Hz and the infrasound region to be below 20Hz then the significant degree of attenuation provided by the A-weighted curve provides incorrect information as to infrasound energy generated by wind farms (see Figure 2).

Figure 3 provides noise levels measured at distances in excess of 500m from turbines where a sound power level on the basis of hemispherical radiation has been derived for a number of wind farms.

The graph in Figure 3 presents the data in relation to power levels attributed to the turbines in both a linear format and an A-weighted format, where the difference in the spectral shape for the time different frequency weighting is obvious [2].

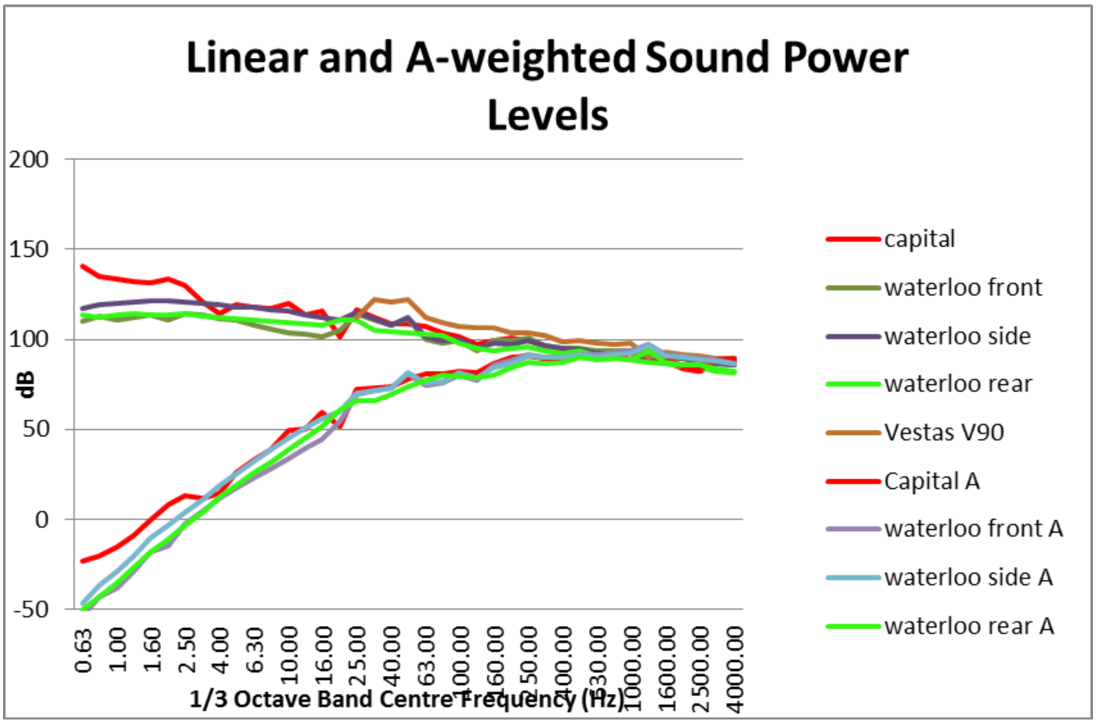

FIGURE 3 Turbine Sound Power Levels (Linear versus A-weighted)

3.1 Audible Characteristics If one is reporting dB(A) Leq levels, adjustments need to be made to account for the subjective nature of the noise. Generally there is a claim there are no subjective characteristics to the noise. If one only utilises Leq and L90 dB(A) levels from noise loggers then there is no attempt to ascertain other characteristics.

Amplitude modulation is one characteristic that can be detected but will not show up in a Leq or a L90 measurement result. The variation in the A-weighted level emitted from a turbine in some cases is identified as a modulation that occurs at the blade pass frequency rate as shown by the time signal in the A-weighted value apparent at a residential locations removed from the turbines – dependent upon the wind direction.

Figure 4 identifies spectral characteristics attributed to operational turbines for a measurement conducted approximately 150m from the base of the turbine with the analysis conducted using a 10 minute time sample to accord with the standards utilised in Australia. The results whilst normally being presented as an L_{eq} level have in the example shown in Figure 5 show there are statistical variations in the noise over the 10 minute sample for all of the 1/3 octave bands.

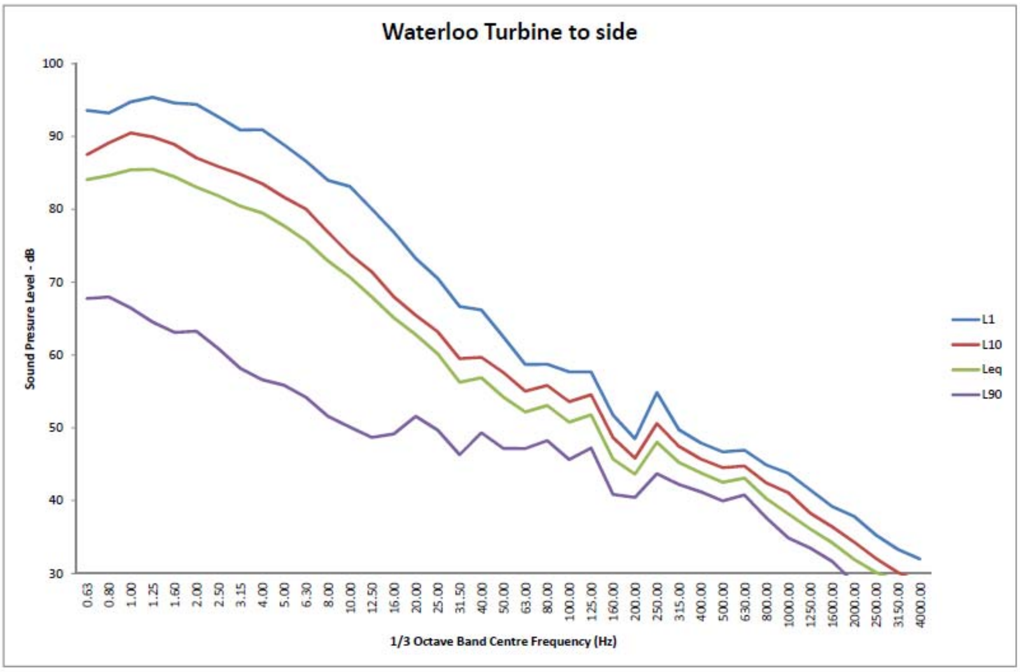

FIGURE 4: 1/3 Octaves at 150 metres from turbine

When the spectrum at residential receivers contains tones that are clearly audible at the location the use of the typical adjustments with a 1/3 octave band levels, either as a 1 sided or 2 sided assessment procedure, tend to identify that the sound is non-tonal despite narrowband analysis showing tones to be present.

As in the vibration analogy discussed earlier, when one looks to specific components associated with wind farm noise emission there are a series of different narrowband components associated with the emission that do not necessarily show up in 1/3 octave band analysis yet such narrow bands may be present.

If one considers the low-frequency region, and in particular the infrasound region, examination of the 1/3 octave bands may not reveal the presence of any discrete components due to a merging of the harmonic pattern associated with the blade pass frequency and its harmonics and other tones that becomes clearly evident if one uses narrowband analysis over the infrasound region as shown in Figure 5.

3.2 Infrasound The use of narrowband analysis permits one to identify the peak frequency components in the wind turbine signature that occur in the infrasound region that by definition will not be contained in the A-weighted level.

For the purpose of considering wind turbine noise in Australia we have utilised the descriptor of *Wind Turbine Signature* where the pattern associated with the blade pass frequency and the first 5 harmonics can be detected both near the turbines and at residential dwellings on a regular basis. None of these low-frequency patterns can be detected by use of the A-weighted parameter and therefore are hidden in the assessment.

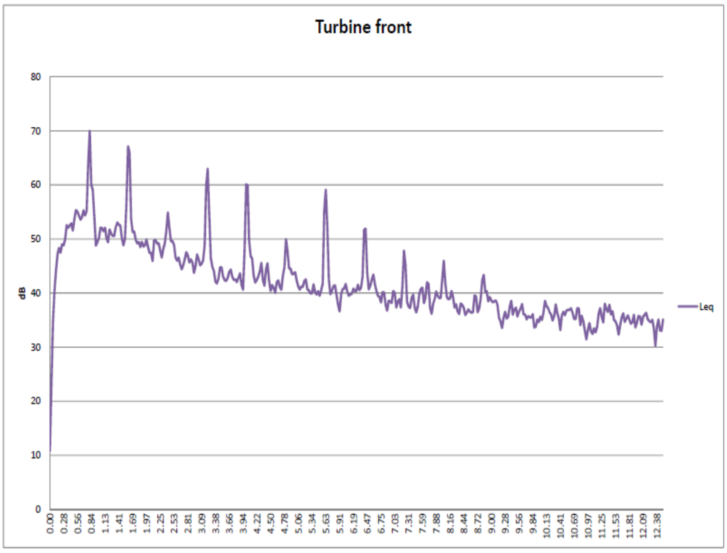

FIGURE 5: At 150 metres from turbine

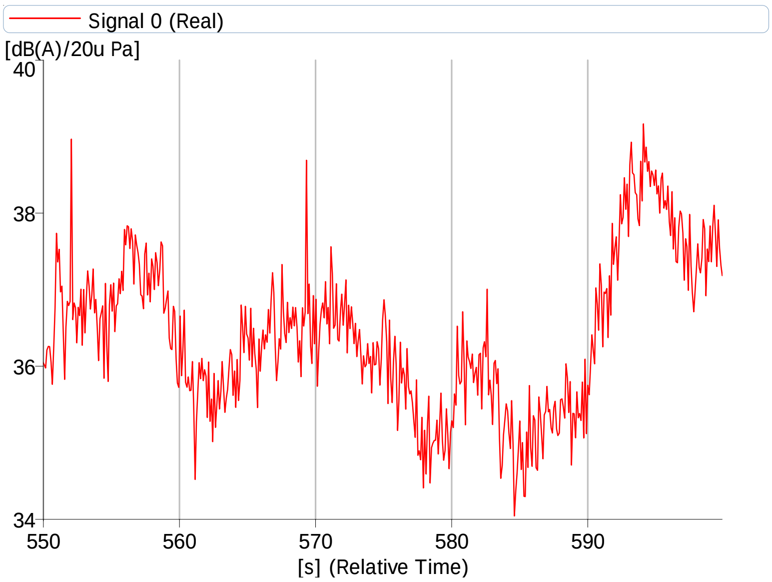

FIGURE 6: dB(A) over time

3.3 Amplitude Modulation

One proposed criterion to address amplitude modulation [3] is if there is a variation of greater than 4 dB(A) at the blade passing frequency then modulation will be considered as an excessive level requiring a 5dB(A) penalty to the predicted or measured level from the wind farm. The modulation characteristic penalty applies only if the modulated noise from the wind turbine is audible at the relevant receiver.

What does that definition of excessive modulation mean? Is it peak to peak of individual waves? Is it the peak to peak of the modulation or the extremities of the overall level?

Figure 6 provides an expanded view of a 10 minute sample of the wind farm noise at a residential property 2.6 km from an operational wind farm. The noise from the wind farm was audible as was a modulation.

Figure 7 is the narrow band analysis of the 10 minute sample (from which Figure 4 was extracted) and identifies a number of distinct peaks in the low frequency region. Whilst Figure 8 covers the infrasound region with the main peak being the second harmonic of the blade pass frequency.

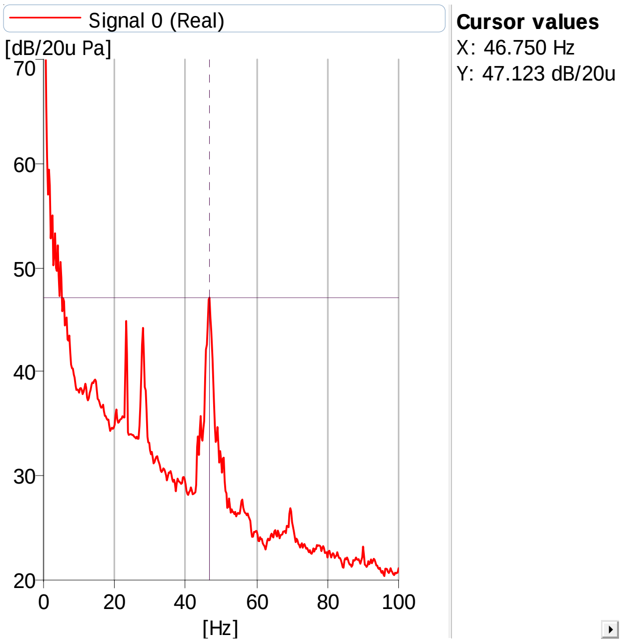

FIGURE 7: FFT 0-100Hz

The modulation is not apparent for noise logger measurements shown in Figures 10 and 12, unless one undertakes wave file recordings then amplitude modulation is not detected. Note the Wind Turbine Signature evident in Figure 5.

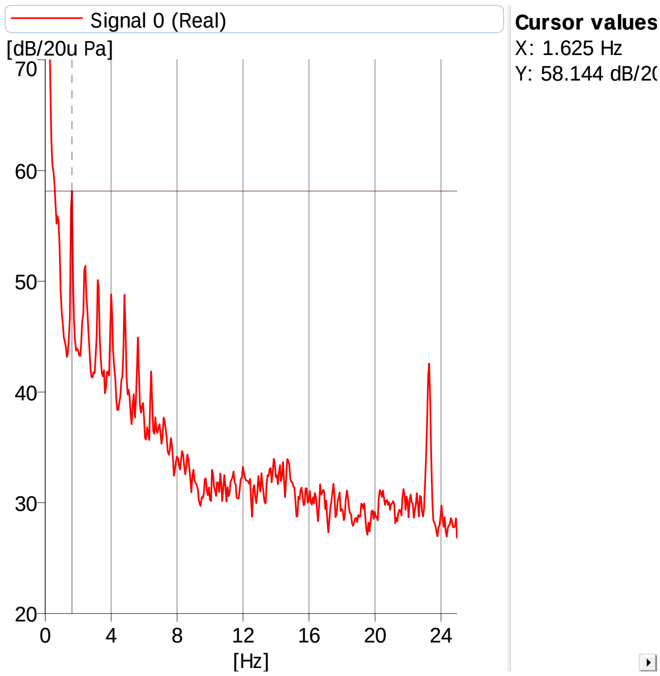

FIGURE 8: FFT 0 -25Hz

3.4 Hearing the infrasound modulation Acousticians may remember that in early days of vibration analysis instrumentation did not go low enough to measure the signature of operating machinery and by use of variable speed instrumentation recorders one could measure the signal at one speed and play back at a higher speed (typically 10 times speed) to conduct the analysis. A similar procedure has been used in relation to acoustic scale modelling of concert halls.

One can take wave files and modify the parameters so as to increase the speed 100 fold so as to then be able to audibly hear the blade pass frequency and the harmonic relationships from the infra sound region.

Similarly by the use of wave file measurements recorded on site one can, without increasing the speed of the signal listen to the audio as a post processing method where additional gain can be supplied and identify acoustic signals in the receiving location even though at the time the persons in attendance may not necessarily be able to detect the noise.

Another issue that has come to light in relation to hiding wind farm noise in ambient measurements has been the selection of averaging times used in the analysis, particularly when looking at modulation and narrowband components. When dealing with constant percentage bandwidth filters the analysis time required to have a valid signal must agree with BT=1. If one looks to frequencies below the audible band then the time period for analysis automatically increases.

For an assessment in Australia was suggested that the averaging time of the analysis be increased to 10 seconds to cater for low-frequency infra sound components in assessing the G-weighted level or the linear levels from which the time signal of the event bears no relationship to what actually occurs.

Similarly for narrowband analysis one can select the number of averages that under linear averaging can lead to different results.

4. Hub Height Wind Speed versus Background Level and Regression Analysis

The procedure used in Australia for determining the criteria to apply at residential receivers uses ambient background level measurements at residential locations referenced back to the wind speed recorded at the wind farm site for either a position 10m above ground level or (now) more commonly at the hub height. The regression analysis does not identify wind direction or wind speed at the residential receiver. The regression analysis reveals a spread of results with derived line representing an average background level rather than the repeated minimum background level used for industrial noise assessments in Australia.

What does the difference between the wind speed and direction at the receiver location versus the hub height?

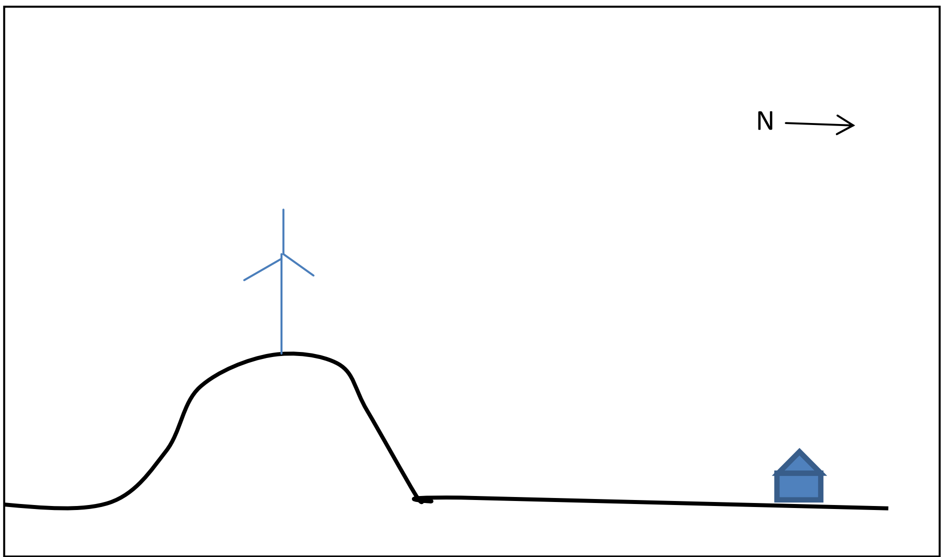

FIGURE 9: Wind Direction Example

Consider the situation in Figure 9 of a residential location located on the northern side of a hill upon which is located a turbine. If one assumes at the present point in time that the wind has a constant speed for different heights then for a wind direction blowing from the south to the north the turbines will be subject to wind but the residence being in the lee of the hill may not receive any wind. In this situation the residential premises would be downwind of the turbine and therefore could be expected to have a higher noise level than if one considered a stationary noise source under still wind conditions.

For the reverse situation of a wind blowing from the north to the south the residents could experience, depending upon the wind strength, an increase in the background level but would also be expected to have a reduction in the turbine noise level emitted under neutral conditions by reason of the residence now being upwind of the noise source.

Therefore for the same hub height wind speed the background level at the residential dwelling can be different for the 2 different wind directions depending upon the strength of the wind, as can the noise emission from the turbine under the different wind directions and wind speeds.

If one was to undertake wind speed and direction measurements at residential locations when the ambient noise level was being recorded, and that material was presented then there could be a correlation between the ambient background level at the residence unclear different prevailing weather conditions with that at the hub height.

Figure 10 provides a graph of noise level over time at a residence depicted in the concept in Figure 9 where the author was in attendance at the time. If one looks to the time around 5pm the ambient background level outside the residence was 30dB(A) and there was no wind at the residential property, nor was there any apparent wind at the turbines in that the turbines were not operating [4].

The noise graph shows an increase in the ambient background level when expressed as an L_{90} level utilising 10 minutes samples and correlates with the nominal power output of the wind farm that is provided from an engineer who collates wind farm power output data and publishes the material in the public domain, i.e. the wind industry does not provide any readily readable material in a graphical format for the output of wind farms, nor do they provide the hub height wind speed.

At 9pm the ambient background level is found to be 43dB(A) for which there was no wind that could be detected at the residential property. On a subjective basis the ambient background level was as a result of the operating turbines.

The application of that wind farm nominated for maximum power output of the turbines the noise level generated by the wind farm would not exceed 34dB(A) at the residential location (shown on a contour map), or 32 dB(A) specified in a Table (in the Environmental Assessment).

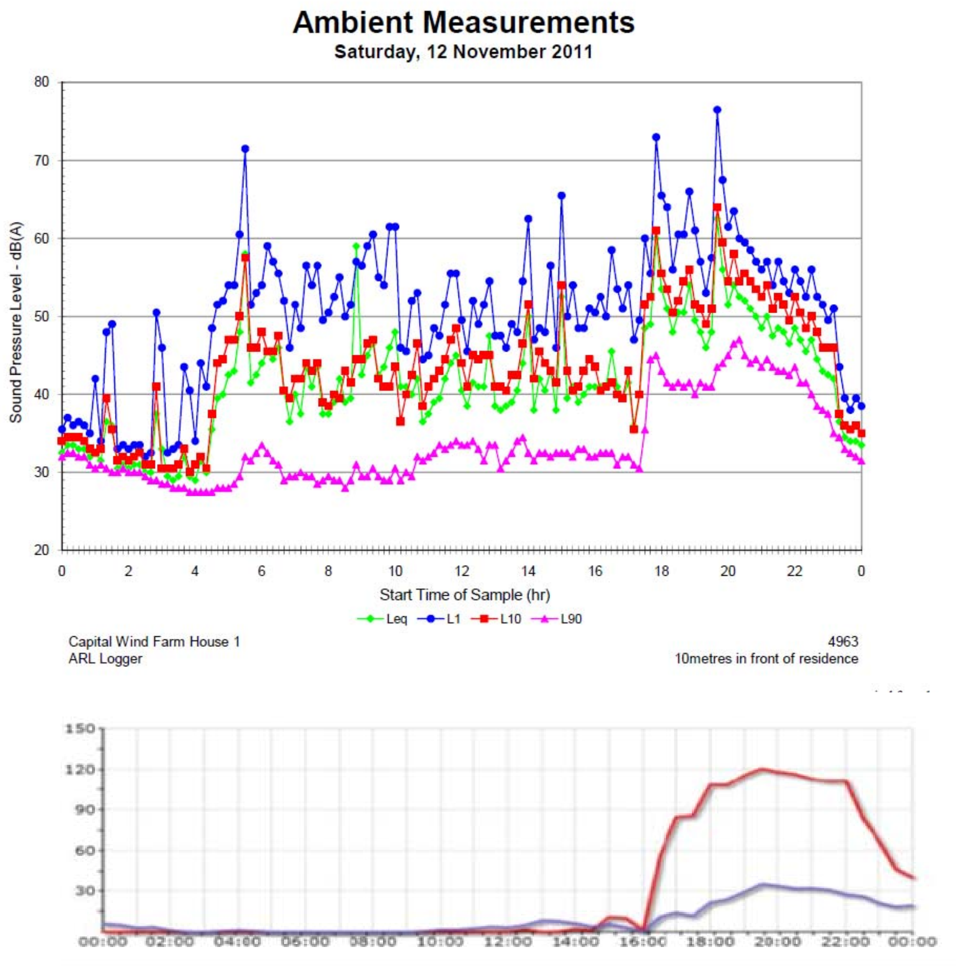

FIGURE 10: Residence in Figure 9 – downwind situation

It would therefore follow that the noise detected at the residential location exceeded that predicted by the applicant and a breach of the conditions of consent – that were based on a regression line analysis.

However the wind farm operator disputed there was a matter of non-compliance, by reason of the noise level measured at the residential receiver not being correlated with the hub height wind speed [5]. The simple explanation as to why one cannot correlate the hub height wind speed data with the measurements is that the wind farm operator does not provide in the public domain any hub height wind speed data. Therefore it would appear impossible for any independent monitoring to ascertain compliance with the conditions of consent because one of the key components for determining compliance is not available.

Arising from the claim of not being able to establish compliance we conducted continuous monitoring over some 4 months at another residence near the residence shown in Figure 9 where wind speed measurements were conducted at the microphone throughout that period, and for a portion of the time also at 10m above the microphone location. The results when correlated with the power output of the wind farm again indicated noise levels significantly greater that nominated in the environmental assessment.

If the true assessment criterion is reacted to the noise emission contribution from a wind farm versus the ambient background level at a receiver location then it must be acknowledged that wind at any assessment location will affect the background level.

But how much will the background level be affected?

To this end utilising the subject monitoring system that is being used at a number of wind farms the system was located on the side of an exposed hill being a residence in proximity to a proposed wind farm. There were no trees within 500m of the monitoring location and as the hillside was fully exposed we were able to determine the regression line applicable to the monitoring system for wind speed at the microphone versus the background level (see Figure 9). This permits us on utilising the same system for monitoring purposes and recording the wind speed at the microphone height to then take any of the measurement results that have been obtained in the presence of wind farm noise and logarithmically subtract the background level attributed to the wind at the time, to then end up with the noise contribution from the wind farm.

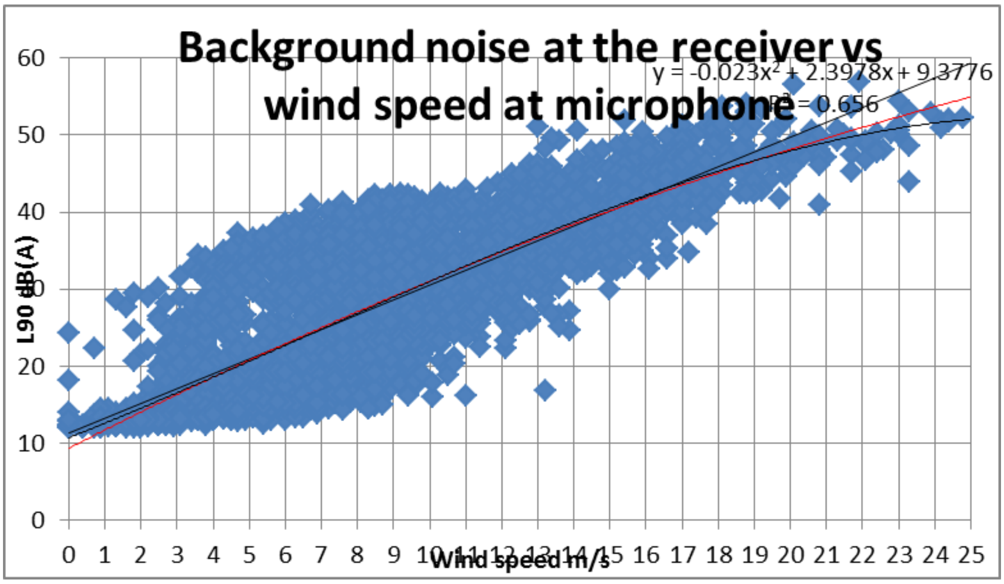

FIGURE 11: Exposed Hillside (furrowed ground) – No Turbines, No Trees within 500 metres

Therefore if we have been able to determine a regression line at the residential location showing the background versus the wind at that residential location one has a base level for assessing (when the wind farm is operational) the actual impact of the wind farm and the matter of compliance with a criterion of a base level or background +5dB being the true background recorded at residential dwellings. Therefore for a number of proposed wind farms we have measurement data that identifies the regression curve for the ambient background versus the wind at the residential location. This curve is completely independent of the hub height wind speed. With such information to hand it then becomes a relatively easy process to identify the noise impact of the wind farm in the environment in which it occurs without the obstacle of (deliberately not) having access to hub height wind speed.

In considering the above information it is apparent that for different wind directions there will be different levels of noise obtained at residential locations both in terms of the A-weighted value and the spectral components

Figure 12 provides a series of graphs recorded at a residential location 2.6km from an operating wind farm showing the noise levels over a 24-hour period. Superimposed on the A-weighted noise levels (that are the statistical 10 minute parameters) is the wind speed at the microphone position, with the graph below that showing the direction of the wind speed and the bottom figure being the power output of the wind farm available for that day.

The results indicate an ambient background level in the early hours of the morning with relatively little wind and little power output to be in the order of 12dB(A) for the monitoring system used with a noticeable increase in the background noise level following the increase in the wind and the increase in the power output.

The grouping of the various plots in Figure 12 shows for the majority of the day a relatively steady power output from the wind farm. However one can see the changes in the background level as there is a difference in the wind direction, yet the wind speed is relatively steady at the microphone until around 8pm when the microphone wind speed drops.

Use of a calibrated monitoring system versus the wind speed at the microphone permits one to determine the noise emission from the wind farm without the need for the hub height wind speed. The graphs show the concept that different wind direction for the same wind speed will give rise to different noise levels at residential properties and therefore different impacts. Following the completion of these measurements a certification letter as to acoustic compliance of the wind farm appeared that apparently is a result of 'extensive testing' (no test results provided) but a simple curve in terms of power output of the wind farm nominated noise levels at the subject residents. The noise level is versus the hub height wind speed and without the hub height wind speed one is unable to challenge that material.

However the results in Figure 12 indicate noise levels greater than that predicted for even the maximum output of the turbines. Figure 12 highlights the differences in terms of the noise emission on just using a dB(A) basis and how one can undertake averaging to determine (or downgrade) the actual noise impact.

But the L_{eq} level of the wind farm will be higher than the background level and may also require adjustments for modulation and tonality.

Wave file analysis of the same time period reveals an audible modulation of the wind farm noise was apparent which is not been included in the raw measurement data.
At the time of the paper being written the hub height wind speed information is not available but is expected to be available for the presentation to then place this material in its correct context.

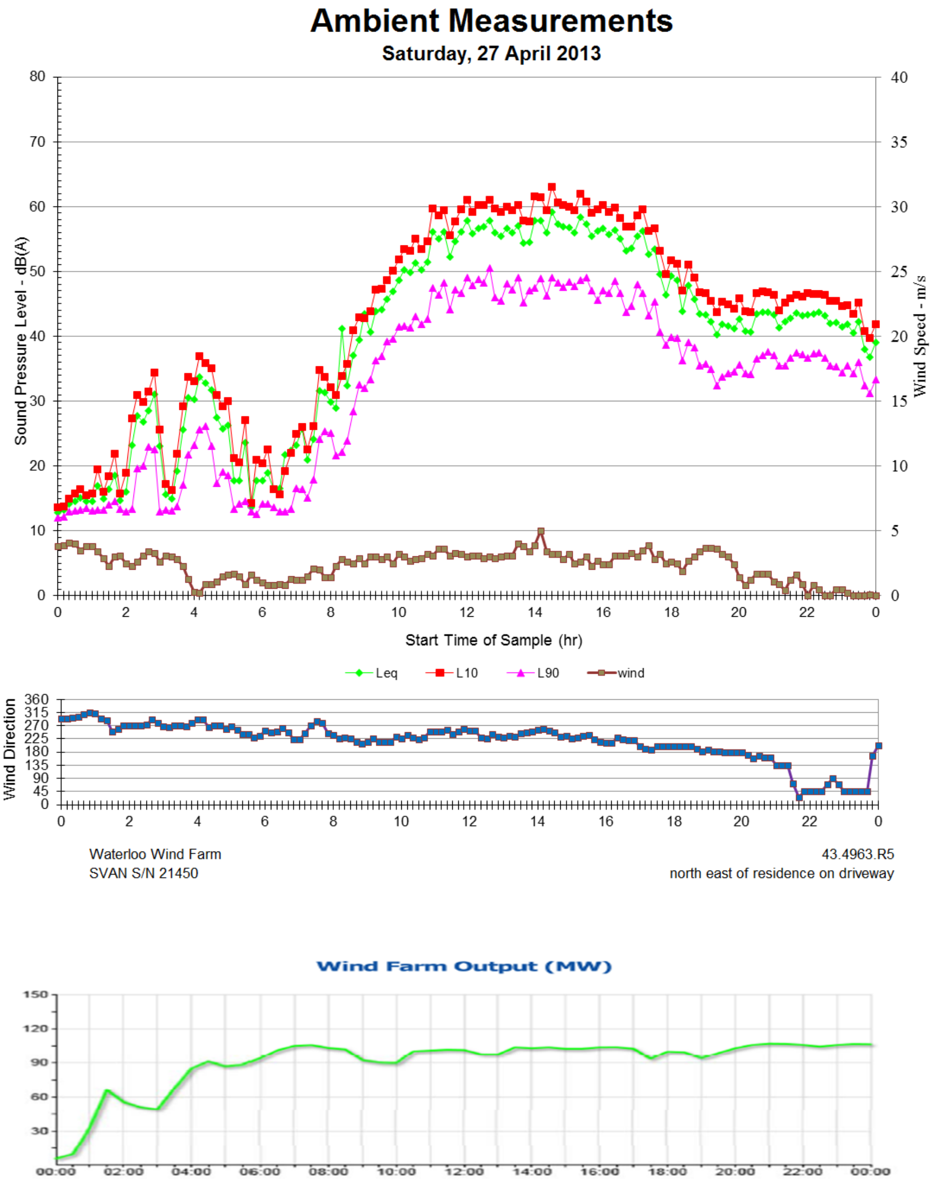

FIGURE 12 Waterloo Wind Farm Monitoring

5. Microphone Selection

Utilising the above vibration analogy one can establish there are different microphones that in themselves will have different frequency responses and different dynamic ranges that in turn require careful consideration in the selection of such equipment.

As experienced acousticians in terms of typical environmental measurements will be aware that there is an upper limit to the dynamic characteristics of a microphone such that in the general course of assessments one reduces the size of the microphone so as to permit the measurement of higher levels. For example one may consider a typical 1 inch microphone to have an upper dynamic limit in the order of say 145 dB with an open circuit sensitivity typically expressed as 50mV/Pa, whereas a quarter inch microphone is capable of measuring levels in the order of 160 - 185 dB and has an open circuit sensitivity at or below 4mV/Pa.

It is also generally acknowledged that typical ½ inch and 1 inch environmental microphones may have an open circuit frequency response varying from a few Hz to 10 kHz or 20 kHz, whilst the ¼ inch and 1/8 inch microphones have a much higher frequency response sometimes extended up to 140 kHz.

Utilising the general concept as expressed in the dynamic range of accelerometers then there must be a limit in terms of the dynamic range of the microphone so as to respond to the measured pressure levels.

Just as one would not use a typical 1 inch microphone in seeking to record a sound pressure level in the order of 170 dB it therefore must follow that a 1/8 inch microphone would be not suitable for recording general community acoustical measurements where background levels are less than 40 dB(A).

Just as in vibration measurements specialised accelerometers are required for the measurement of very low vibration levels, then in dealing with very low sound level measurements such as those encountered in test laboratories there are specialised microphones and preamplifiers to permit low level measurements.

The majority of our equipment is based around Bruel and Kjaer but it is acknowledged that there are other manufacturers who produce both low level sound measurement microphone/preamplifier combinations, and also at the other end of the dynamic spectrum high level sound measurement microphones for blasting.

There is no doubt that the measurement of noise at either the very low level or high sound levels is a lot more expensive than general purpose microphones. To obtain accurate results for even general-purpose sound requires a different classification of a microphone (and expense) to that obtained from a low-cost omnidirectional microphone that may be purchased in a typical electrical outlet store.

Having identified that there are different microphones for different purposes (and those microphones will have different dynamic capabilities) then one needs to expand the consideration of microphones to the fact that they will have different noise floors and also different frequency responses.

Our earlier investigation into wind farm noise utilised our general purpose microphones but with a Bruel and Kjaer Pulse system permitted to undertake both constant percentage bandwidth and narrowband analysis.

Our measurements revealed the presence of narrowband components in the acoustic signature of noise emitted from turbines as external to an inside residential dwellings removed from the wind farm. With any new investigations found a number of limitations in our analysis method it in pulse system by default incorporated a 22.4Hz filter which may be appropriate for general acoustic matters but not specifically for wind farms.

The electrical noise floor of the microphone was an issue that in turn led to extensive testing in our small anechoic room to evaluate the different noise floors of general purpose meters, microphones and our more specialised systems. We are able to determine the threshold of the microphones with respect to the introduction of both white noise and narrowband tones to find that a number of our general purpose meters were unable to measure the full spectrum inside residential dwellings, i.e. their noise floor was not low enough.

To this end we used as a control microphone a Bruel and Kjaer 4179 low noise microphone with a 2660 pre amp with the specification by Bruel and Kjaer indicating a capability to measure down to -2.5dB(A). The microphone has a flat specification to 10Hz and a curve to show the roll off below 10Hz to be 10 dB down at 1Hz.

We have established that the use of 200v polarised Bruel and Kjaer microphones give us a lower noise floor than for non-polarised microphone and with a specialised low-frequency extended range calibrator we can determine the frequency response of our microphones to 1Hz but limited to a measurement at 1 Pascal. What happens at lower SPLs can be tested by the use of signals but at the moment we do not have a low frequency calibrator with adjustable SPLs.

We have seen the trend in some measurements in Australia to nominate use of the Bruel and Kjaer low-frequency microphone type 4193 with the low frequency adapter to extend frequency response down to 0.05Hz. The problem that we have found is that the microphone has a relatively low sensitivity and that with the use of the UC adapter there is a 9 to 13dB increase in the noise floor (i.e. less sensitivity) than without the adapter. In this regard we have found the microphone to be of no assistance in measuring indoors where the ambient background levels are below 20dB(A) – to be expanded upon in the presentation.

On conducting multichannel measurements in the one room on a simultaneous basis we have sought to use our reference 4179 microphone and either 200v polarised microphones that at valid down to 1 or 2Hz.

For the measurement of infrasound we have found it necessary to look carefully into the microphone threshold levels and the selection of microphone used for such measurements, as the issue that has become apparent in Australia is not a matter of audibility of infrasound but the threshold of perception by residents that occurs at levels well below the threshold of hearing.

6.0 Conclusion

The conduct of measurements of wind farm operations, on behalf of communities in Australia, has identified that the dB(A) noise levels specified by Regulatory Authorities do not protect the acoustic amenity of residents and that there are a number of fundamental issues in relation to your the criteria so nominated.

Another paper presented by the author during this conference [6] identifies issues with respect to the dB(G) parameter and the use of Z weighting, suggesting consideration of the use of Linear (un-weighted) levels from 0 – 20 Hz for infrasound measurements.

Whilst the dB(A) provides the basis of assessment for wind farms then the characteristics of the A- weighting curve and the use of Leq or L90 levels does not identify the special characteristics associated with Industrial Wind Turbines.

Regulations in Australia are currently expressed in terms of noise level versus the hub height wind speed. When one evaluates site-specific locations one finds the criteria to be inappropriate.

Furthermore as the community is unable to obtain the hub height wind speed then the matter of acoustic compliance testing on behalf of the community is doomed to failure.

The regression curve used for general assessment purposes of wind farms in Australia does not address the relationship of the acoustic environment at the receiver locations versus the wind at those locations, nor does the relationship of the ambient background levels of residential dwellings take into account the direction of the wind.

Residents report sleep disturbance and other impacts at noise levels less than that nominated by regulatory authorities which has led various acousticians to investigate both low-frequency sound and infrasound as a potential source of the disturbance.

These investigations have revealed difficulties in conducting measurements when incorrect instrumentation is used. If the instrumentation is unable to actually measure the noise that occurs at residential properties, by either limitations in frequency response of the instruments, low sensitivity of instrumentation (dynamic range) and simply relying upon dB(A) measurements, then all the results of such investigations must lead to incorrect conclusions as to noise emission from wind farms.

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[1] Bruel & Kjaer (1982) *Vibration – Measurement Range Nomogram for B&K Accelerometers*, BG 0014.

[2] Cooper S (October 2012) *Are Wind Farms too Close to Communities?* Australian Environment Foundation Annual Conference.

[3] NSW Planning & Infrastructure (December 2011) *Draft NSW Planning Guidelines Wind Farms*.

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[5] The Acoustic Group (November 2012), *Supplementary Submission, Renewable Energy (Electricity) Amendment* (Excessive Noise from Wind Farms) Bill 2012.

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APPENDIX E: Schomer Denver Paper

5^{th} International Conference

on

Wind Turbine Noise

Denver 28-30 August 2013

A proposed theory to explain some adverse physiological effects of the infrasonic emissions at some wind farm sites

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Summary

For at least four decades there have been reports in scientific literature of people being made ill by low-frequency sound and infrasound. In the last several years there have been an increasing number of such reports with respect to wind turbines, which corresponds, obviously, to their becoming more prevalent. A

study in Shirley, WI has lead to interesting findings that include: (1) for major effects, it appears that the source must be at a very low frequency, about 0.8 Hz and below with maximum effects at about 0.2 Hz; (2) the largest, newest wind turbines are moving down in frequency into this range; (3) the symptoms of motion sickness and wind turbine acoustic emissions "sickness" are very similar; (4) and it appears that the same organs in the inner ear, the otoliths may be central to both conditions. Given that the same organs may produce the same symptoms, one explanation is that the wind turbine acoustic emissions may, in fact, induce motion sickness in those prone to this affliction. Finally, It is shown that the probability that sensitivity to motion sickness and sensitivity to wind turbine acoustic emissions are unrelated is less than 2 in 1,000,000.

1. Introduction

For at least four decades there have been reports in the scientific literature of people being made ill by low-frequency sound and infrasound. (Dawson 1982; Tesarz 1997)

Currently, these same problems are appearing in the vicinity of wind farms, and as in 1982 and earlier, nobody understands how these problems come to be; nobody understands why only a fraction of the population is affected; ***nobody understands how the sound can be below the threshold of hearing and be affecting people***.[i]

2. Data from a problem site

2.1 Observations from people affected by the installation of wind turbines

One wind farm that is experiencing these problems is in Shirley, WI. Here three families have abandoned their homes because family members who became ill after installation of the turbines could not acclimate to the problems.[ii] Because of these problems in Shirley, a study was conducted with the proposed test plan calling for the wind farm owner, Duke Energy, to cooperate fully in supplying operational data and by turning off the units for short intervals so the true ON/OFF impact of turbine emissions could be documented. Duke Energy declined this request citing the cost burden of lost generation from the eight turbines at the Shirley site.

Four acoustical consulting firms cooperated to jointly conduct this study: (1) Channel Islands Acoustics (ChIA); (2) Hessler Associates, Inc.; (3) Rand Acoustics; and (4) Schomer and Associates, Inc. This study was conducted during a three day period in December, 2012. The first task accomplished was to meet with residents having problems with the wind turbine acoustic emissions including members of the three families who had abandoned their homes. These discussions with the residents yielded the following observations:

1. At most locations where these various symptoms occurred, the wind turbines were generally not audible. That is, these problematic symptoms are devoid of noise problems and concomitant noise annoyance issues. The wind turbines could only be heard distinctly at one of the three residences examined, and they could not even be heard indoors at this one residence during high wind conditions.
2. The residents reported that at least some of them could sense when the turbines turned on and off; this was independent of hearing or seeing the turbines. This assertion by the residents is readily testable.
3. The residents reported "bad spots" in their homes but pointed out that these locations were as likely to be "bad" because of the time they spent at those locations, as because of the "acoustic" (inaudible) environment. The residents did not report large changes from one part of their residences to another.
4. The residents reported little or no change to the effects based on any directional factors. Effects were unchanged by the orientation of the rotor with respect to the house; the house could be upwind, downwind, or crosswind of the source.
5. The residents were asked if they were susceptible to motion sickness, and all of the residents who reported motion sickness like symptoms as major adverse effects associated with the wind turbines, were also sensitive to motion sickness.[ii]

Two of the major implications of these five findings are: (1) Because these residents largely report wind turbines as inaudible, it seems that suggestions some have made that these conditions are being caused by extreme annoyance can be ruled out, and (2) the lack of change with orientation of the turbine with respect to the house and the lack of change with position in the house suggest that we are dealing with very low frequencies; frequencies such that the wavelength is a large fraction of the wind-turbine diameter (i.e., about 3 Hz) or lower.

It should be mentioned that there are about 120 residences within about 5000 ft of the closest turbine, which suggests that there are about 275 residents. Of these 275 residents, 50 have described adverse effects that they have experienced after the introduction of the wind turbines. The most common complaints are feelings of pressure and pulsations in the ears. A sub-subset of 2 of the 5 people exhibiting motion sickness symptoms fit the following search criteria: about one half or more of their symptoms must be motion sickness symptoms, the overall symptoms must be severe enough that the people abandon their homes (or equivalent), the motion sickness symptoms must include nausea, and the motion sickness symptoms must play a prominent role in the subjects overall response to wind turbine noise. Only 2 of the 50 residents reporting any type of symptom meet these rather selective criteria. .[iii] It is not known how many of the 120 residences are "participating," but most agreements for participating residences include some form of confidentiality and non-complaint clauses.[iv]

2.2 Physical Measurements

Figure 1 is an aerial photo of the Shirley wind farm. This figure shows the positions of five of the eight wind turbines that make up this site, Nordex N-100s, and the position of the three abandoned residences. Primary measurements were made at residences 1, 2, and 3 on consecutive days. Each of the four consulting firms contributed to the overall study.

Figure 1: Aerial photograph of the site showing the 3 residences, and the 5 closest wind turbines

Bruce Walker of Channel Island Acoustics employed a custom designed multi-channel data acquisition system to measure sound pressure in the time domain at a sampling rate of 4,000/second where all signals are collected under the same clock. The system is calibrated to be accurate from 0.1 Hz thru 10,000 Hz.

At each residence, a multi-channel recorder was connected to an outside wind-speed anemometer and a microphone mounted on a ground plane covered with a 3 inch hemispherical wind screen that in turn was covered with an 18 inch diameter and 2 inch thick foam hemispherical dome (foam dome). Other channels of the recorder were connected to microphones inside each residence that were situated in various rooms including basements, living or great rooms, office/study, kitchens and bedrooms. The objective of this layout was to gather sufficient data for applying advanced signal processing techniques.

Robert Rand of Rand Acoustics observed measurements and documented neighbor reports and physiological effects including nausea, dizziness and headache.

Paul Schomer of Schomer and Associates, Inc. observed all measurements. Among other things the following observations are made based on the results of the physical measurements. In particular, these observations are based upon the coherence calculations by Bruce Walker. He produced both amplitude, frequency and coherence plots and 10-minute coherence charts showing only amplitude and frequency. While both types of plots show the same thing, this analysis concentrates on the latter, 10-minute coherence charts, because the amplitude, frequency and coherence plots have only a 30 dB dynamic range. Figures 2 shows the coherence between the outdoor ground plane microphone and 4 indoor spaces at Residence 2: the living room, the master bedroom, behind the kitchen, and in the basement. The data collected at Residence 2 were measured with only 58% of turbine power, although the wind conditions were optimal for turbine operation, and the power was much less than 58% during the measurement periods at R1 and R3.

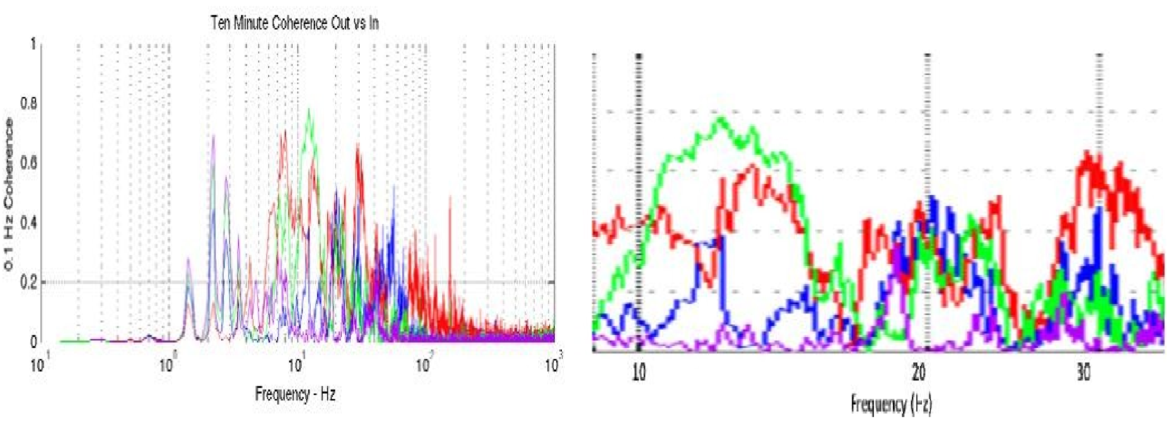

Figure 2a,b: R2-5T212420--coherence with outdoor-ground plane microphone; Living Room-Blue, Master Bed Room- Red, Behind Kitchen- Green, Basement-Purple, b is an expanded view from 9 Hz to 35 Hz

It is inferred from the residents' observations that the important effects result from very low frequency infrasound of about 3 Hz or lower. We can test this assertion with the data collected at the three residences at Shirley. Only Residence 2 was tested during a time when significant power was being generated, so it is the only source of data used herein. Figures 2 shows the coherence between the outdoor ground plane microphone and the four indoor spaces listed above. All of the four spaces exhibit coherence at 0.7 Hz, 1.4 Hz, 2.1 Hz, 2.8 Hz and 3.5 Hz, and in this range there is no coherence indicated except for these five frequencies. The basement continues, with coherence exhibited at these higher harmonically related frequencies of 4.2 Hz, 4.9 Hz. 5.6 Hz, 6.3 Hz and 7 Hz. The coherence in the basement drops low from 10-18 Hz and is more or less random and low above 18 Hz.

Figure 2b shows the coherence just for the frequency range from 10 Hz to 35 Hz, and essentially this figure exhibits random patterns with no correlation from one room to the next. For example, coherence with the microphone behind the kitchen is high from 10-14 Hz and the master bedroom is high from 12-14 Hz while the other two spaces exhibit low coherence, and again the master bedroom is high from 28-35 Hz with the others being low, and the living room is high from 50-58 Hz with the other spaces low; no pattern. In contrast, all four spaces are lock step together in their coherence with the outdoor microphone below about 4 Hz.

As an analysis that is complementary to the coherence plots of Figure 2, Figure 3 shows spectral plots of data collected at Residence 2. As in the coherence plot, we see the first several harmonics of the wind-turbine blade-passage frequency, 0.7 Hz, and nothing notable above about 7 Hz. Two channels of measurement are shown on Figure 3, the outside, ground plane microphone (green), and the indoor microphone in the living room. Note that the pressures that result from the acoustic emissions of the wind turbines, when measured indoors, keep growing as the frequency goes lower, because the entire house is behaving like a closed cavity.

Residence 2, and indeed all three residences, exhibit classic wall resonances in about the 10-35 Hz range which are different for each room and exposure, so it is reasonable to suppose that the randomness in the 10-35 Hz region in the above ground rooms is the result of wall resonances. The basement, which has no common wall with the outside, generally exhibits the lowest coherence in the 10 to 35 Hz region. Thus, we conclude that the only wind turbine-related data evident in the measurements at Residence 2 are the very low frequencies ranging from the blade passage frequency of 0.7 Hz to up to about 7 Hz. This conclusion is consonant with the residents' reports that the effects were similar from one space to another but a little to somewhat improved in the basement, the effects were independent of the direction of the rotor and generally not related to audible sound.

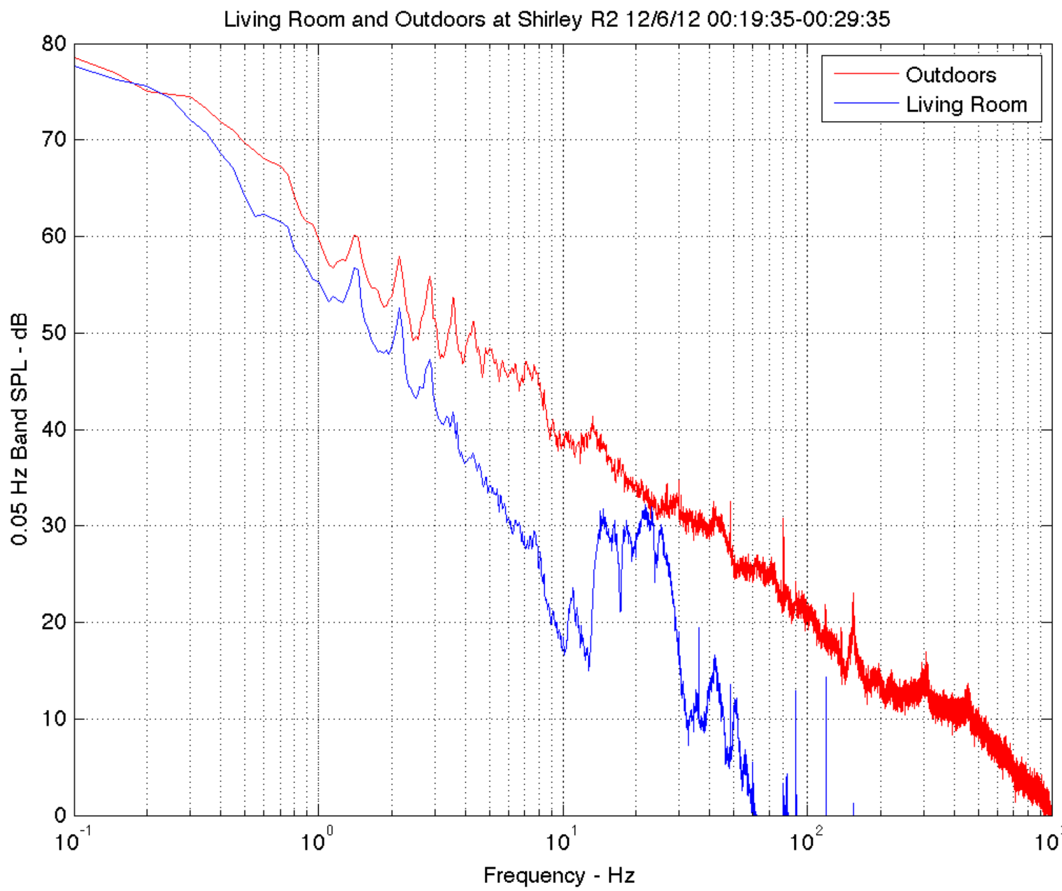

Figure 3: Spectral plot of the ground-plain outdoor microphone data and indoor data measured in the living room of Residence 2.

Figure 4 shows the sound pressure level for the first minute of the 10 minutes represented on Figure 2, above. This figure, which is sensitive to the lowest frequencies, shows that at these very low frequencies the sound pressure level in all four spaces is quite similar. The small changes from different positions in the house also suggests that the house is small compared to the wavelength so that the insides of the house are acting like a closed cavity with uniform pressure throughout being driven by very low-frequency infrasound.

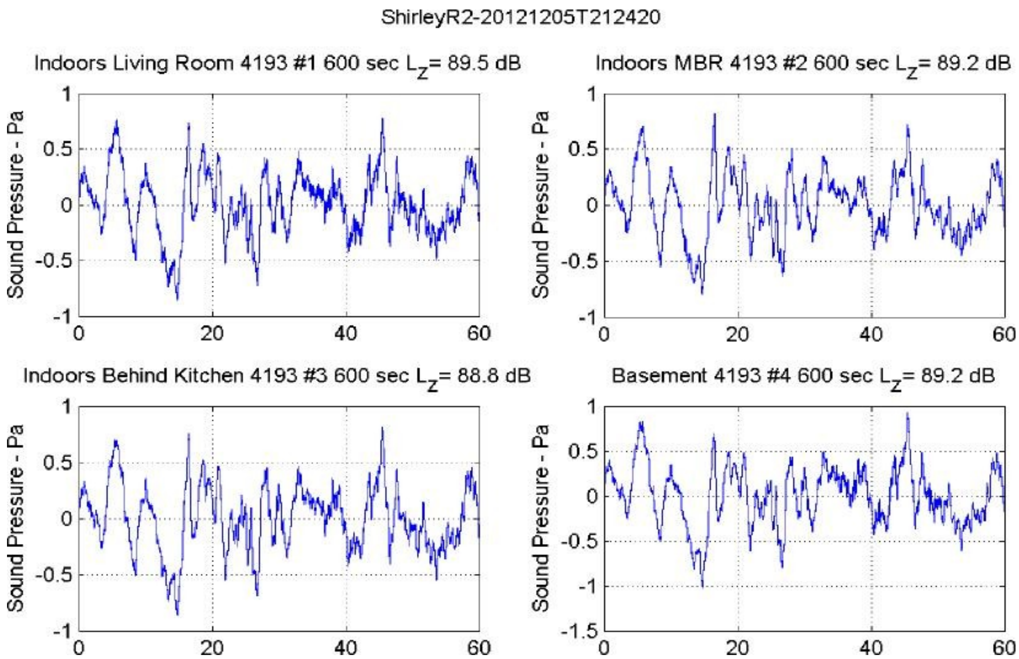

Figure 4: First of the ten minute period of 5T212420. Note that the SPL is very similar for all indoor locations.

Figure 5 is for Residence 3 which was 7000 feet from the nearest turbine, in contrast to Residence 2, which was only 1100 feet from the nearest turbine. Even here, with much reduced amplitude, there seem to be several frequencies where the four spaces have peaks together beginning at 0.7 Hz. While only a slight blip is evident at 0.7 Hz in Figure 5, clear peaks are evident at 1.4 and 2.1 Hz, and a couple of the microphones also show peaks at 2.8 Hz. It is somewhat surprising that we can even measure these considering the low power setting on the day R3 was measured.

The measurements support the hypothesis developed above that the primary frequencies are very low, in the range of several tenths of a Hz up to several Hz. The coherence analysis shows that only the very low frequencies appear throughout the house and are clearly related to the blade passage frequency of the turbine. As Figures 4 shows, the house is acting like a cavity and indeed at

5 Hz and below, where the wavelength is 60 m or greater, the house is small compared to the wavelength.

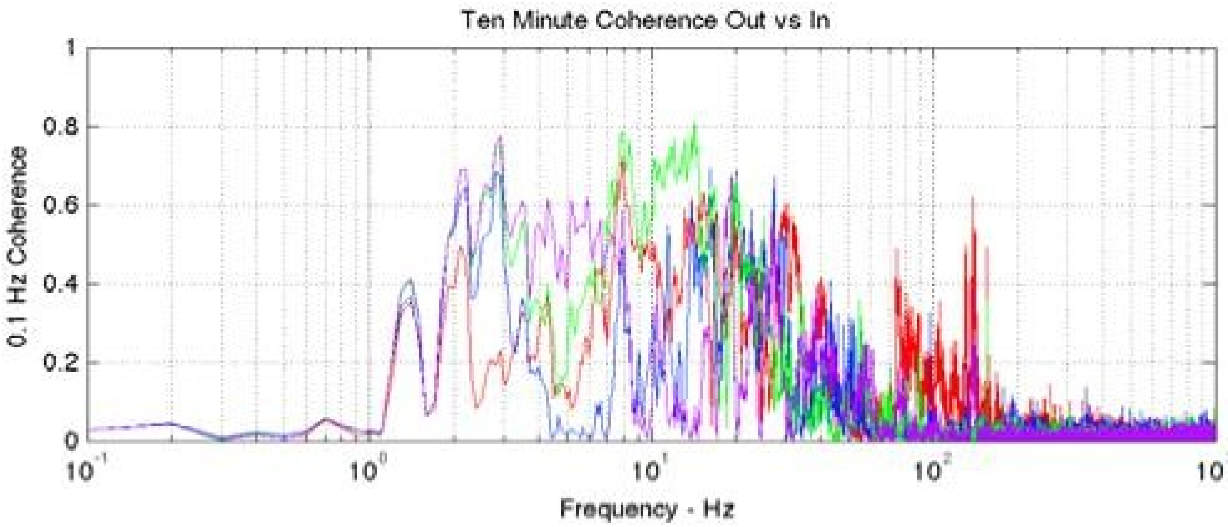

Figure 5: R2-5T204657- coherence with outdoor-ground plane microphone;; Living Room-Blue, Upstairs Bed Room- Orange, Family Room- Turquoise, Basement-Purple

While we would have liked to have been able to draw conclusions on measurements at all three sites, that was not possible because Duke Energy was not generating much power during the measurements of R1 and R3, and even just over 50% during the measurements at R2.

3. The motion sickness hypothesis

3.1 The Navy's Nauseogenic Region

As a starting point we consider a paper by Kennedy *et al*. (1987) entitled: "Motion Sickness Symptoms and Postural Changes Following Flights in Motion-Based Flight Trainers." This paper was motivated by Navy pilots becoming ill from using flight simulators. The problems encountered by the Navy pilots appear to be similar to those reported by 5-6 of the Shirley residents. This 1987 paper focused on whether the accelerations in a simulator might cause symptoms similar to those caused by motion sickness or seasickness. Figure 6 (Figure 1 from the reference) shows the advent of motion sickness in relation to frequency, acceleration level and duration of exposure. To develop these data, subjects were exposed to various frequencies, acceleration levels and exposure durations, and the Motion Sickness Incidence (MSI) was developed as the percentage of subjects who vomited. Figure 7 show two delineated regions. The lower region is for an MSI of 10%. The top end of this region is for an exposure duration of 30 minutes and the bottom end is for eight hours of exposure. The upper delineated region has the same duration limits but is for an MSI of 50%.

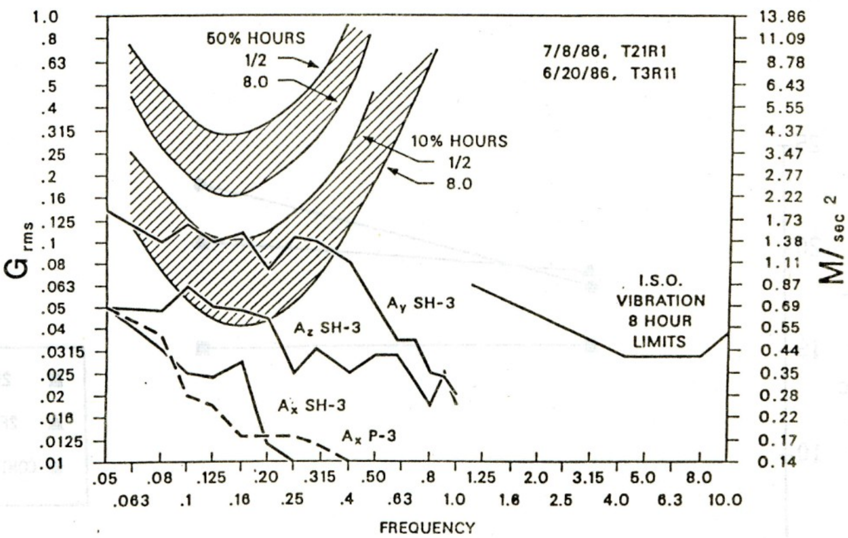

Figure 6: The Navy's nauseogenic region

What is important here is the range encompassed by the delineated regions of Figure 6. Essentially, this nauseogenic condition occurs below 1 Hz; above 1 Hz it appears that accelerations of 1G would be required for the nauseogenic condition to manifest itself. While the Navy criteria are for acceleration, in Shirley we are dealing with pressures in a closed cavity, the house. The similarity between force on the vestibular components of the inner ear from acceleration and pressure on these from being in a closed cavity suggests that the mechanisms and frequencies governing the nauseogenic region are similar for both pressure and acceleration.

As the generated electric power of a wind turbine doubles the sound power doubles and the blade passage frequency decreases by about 1/3 of an octave (Møller and Pedersen, 2011). The wind turbines at Shirley have a blade passage frequency of about 0.7 Hz. This suggests that a wind turbine producing 1 MW would have a blade passage frequency of about 0.9 Hz, and on Figure 6, a change from 0.7 Hz to 0.9 Hz requires a doubling of the acceleration for the same level of response. Thus, it is very possible that this nauseogenic condition has not appeared frequently heretofore because older wind farms were built with smaller wind turbines. However, the 2.5 MW, 0.7Hz wind turbines clearly have moved well into the nauseogenic frequency range.

3.2 Motion Sickness Like Symptoms, and their Implications

Motion sickness, or kinetosis (from the Greek to move) is generally related to the vestibular, visual, and somatosensory systems. (cf. Griffin, 1990). A common theory of the cause of kinetosis is that of sensory conflict: the information received from two or more sensory systems conflict (eg., visual inputs in a closed room and vestibular inputs from a rolling boat) producing symptoms similar to that of ingesting a poisonous substance. The result is an evolutionary protective response to rid the body of a harmful foreign substance. Thus, motion sickness is not really a sickness, but rather is a natural reaction to unusual input information.

At the start of this study the working hypothesis was that wind turbine noise somehow, because of the nauseogenic regions similarity, created symptoms that were similar to those of motion sickness. We now have a much simpler hypothesis--like movies and videos, wind-turbine acoustic emissions trigger motion sickness in those who are susceptible; it is another form of *pseudo-kinetosis.*

At Shirley, of the50 people who reported symptoms after the introduction of wind turbines to the area, 5 of those 50 people reported symptoms similar to motion sickness. We simply have no information on other area residents, except for these 50, and do not know how many of the other residents are participating. Based on the sample of 5 out of 50, we can say that the incidence of motion sickness symptoms at Shirley is 10% or less, a figure that is clearly in line with the expected percentage of those in the general population affected by motion sickness. In fact, Montavit (**2013**) indicates that "about 5 to 10 percent of the population is extremely sensitive to motion sickness; 5 to 15 percent are relatively insensitive; and about 75 percent are only subject to it to a 'normal', i.e. limited degree."

In our meeting with affected residents discussed above, it was stated that each person affected by the wind farm noise in the form of motion sickness symptoms was also motion sickness sensitive

The same is true for Rob Rand and Steve Ambrose who are two acoustical researchers who have themselves reported suffering strong symptoms from low-frequency wind-turbine emissions. It appears individuals who exhibit motion sickness symptoms in response to infrasound, the motion sickness symptoms play a prominent role, and the motion sickness symptoms (listed in Table 1) account for about one half or more of a person's total symptoms, and the total symptoms are sufficiently strong such that these residents abandon their homes, also suffer from motion sickness. The count is two of two people, the father and son at

Shirley, who exhibit motion sickness symptoms to the degree indicated above to wind-turbine acoustic emissions; both are sensitive to motion sickness.

Assume that sensitivity to motion sickness and sensitivity to wind-farm acoustic emissions in the form of motion sickness like symptoms to the degree indicated above are totally uncorrelated and that the probability of sensitivity to motion sickness is 15 percent, a rather high estimate.[v] The probability of finding four people in succession who each reports sensitivity to both motion sickness and wind-turbine emissions to the degree indicated above is (15/100) to the 4th power, which is 0.0005. This is just about 1 in 2,000. Said another way, the probability that sensitivity to wind-farm emissions in the form of motion sickness like symptoms that are so strong that these people abandon their homes and sensitivity to motion sickness are unrelated is just about 1 in 2,000. The clear conclusion is that these four people are affected by wind turbine acoustic emissions, and this particular form of sensitivity to wind-farm emissions and sensitivity to motion sickness are directly related.

The implications of finding a group of people sensitive to wind turbine emissions are important. Therefore we decided to search for more cases. Searching the United States, Canada and Australia yielded three more cases (two from Australia and one from the USA), and all three were sensitive to motion sickness. The probability of finding just three cases in succession is about 1 in 300 which is statistically very significant by itself, but the probability of finding 7 individuals who meet the criteria given above is (0.15) to the 7th power; less than 2 in 1,000,000. Our conclusion stands.

It has been suggested that people's fears create their reactions. At least for those sensitive to motion sickness, this does not appear to be the case. Rather, psychological factors, e.g. fear, is endemic to motion sickness and can amplify its effects significantly. Just the thought of going on a boat or in a plane can trigger motion sickness symptoms in a sensitive person; symptoms that exacerbate the problem. Aversion to the sources of motion sickness is a normal reaction in individuals who are sensitive to motion sickness, so it is not surprising that people who are sensitive to motion sickness and are adversely affected by wind farms, have an aversion to being near wind farms. This is a normal reaction in motion sensitive people that goes with motion sickness and is not unique to wind turbines or related to "not liking" wind turbines, so, it can be expected that those who become ill due to low-frequency noise from wind turbines will have an aversion to wind turbines that is more complex than simply "disliking" the sound or appearance of the turbine[vi].

As noted above, unaccustomed motions and accelerations confuse the brain. For example, during a car trip, nerves and muscle receptors don’t register any movement, since the body itself is sitting still. The eyes, on the other hand, send the brain a message of fast motion. The equilibrium organ in the inner ear delivers information of curves, acceleration and/or ascents which contradict the messages from the other two sources. This contradictory flood of impulses and information overburdens a healthy sense of equilibrium which the brain, in turn, interprets as a danger situation. It then releases stress hormones, which in turn create symptoms of dizziness and nausea.

So to induce a sense of motion where none exists and thereby create the sensory conflict that is requisite to induce motion sickness requires that the acoustic signal cause the vestibular system to "tell the brain" it is accelerating when the ocular system is telling the brain there is no motion.

4. Excitation of the otolith

4.1 The middle ear and inner ear

This main question relates to the fact that the Navy criteria are based on acceleration, while the wind-turbine acoustic emissions are very low-frequency acoustic pressure waves.

In the following, we show only that it appears that an acoustic wave at 0.5 to 0.7 Hz can generate a similar signal in the brain as the signal generated by an acceleration at 0.5 to 0.7 Hz.

The following discussion analyzes the linear motion sensing function of the ear, and explains how the ear could respond to wind turbine emissions. Figure 7 shows the ear (Obrist 2011). We are concerned primarily with the inner ear which is shown in blue in this figure.

Figure 8 shows just the inner ear which contains the cochlea, the organ that divides a sound wave into frequencies ranging from about 10 Hz to about 20 kHz (Obrist 2011). The inner ear also contains the vestibular system which controls and facilitates balance and motion. The system of semicircular canals appears to have evolved in order to be able to sense rotational movements of the head while remaining rather insensitive to forces arising either from translational acceleration of the body or gravity: the cupulae normally have a similar specific gravity to that of the endolymph. The vestibular perception of translational forces is thought to originate normally from sensory systems (maculae) located within the utricle and saccule. The maculae consists of flat gelatinous masses (otollithic membrane) covered with minute crystals (otoconia) connected to an area of the utricle and saccule by cells, including hair cells. A suitably oriented translational force will cause the mass to exert a shear force, resulting in a variation in the firing rate of the hair cells. The maculae cover an area of a few square millimeters. They are located on the floor and lateral wall of the utricle and, in an orthogonal plane, on the anterior wall of the saccule (Griffin 1990).

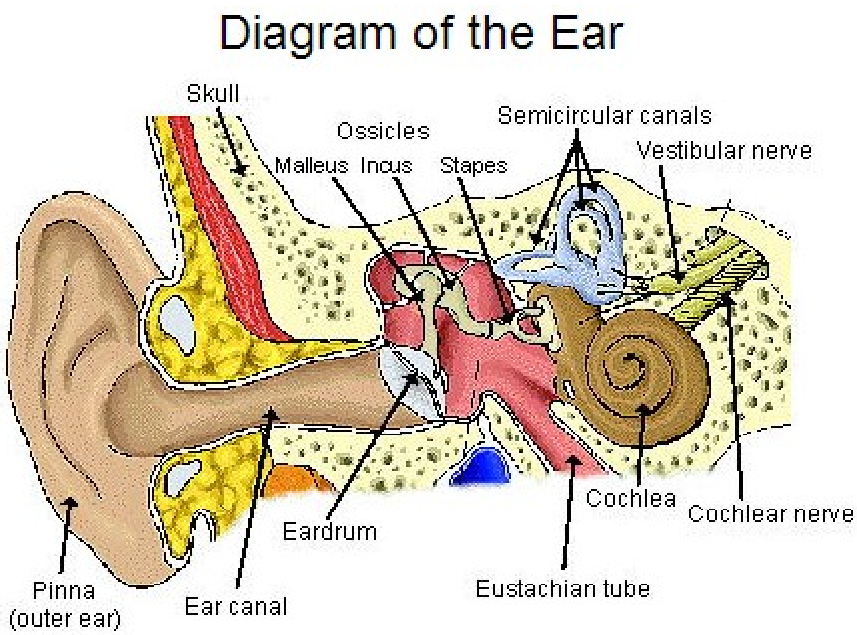

Figure 7: The three parts of the ear

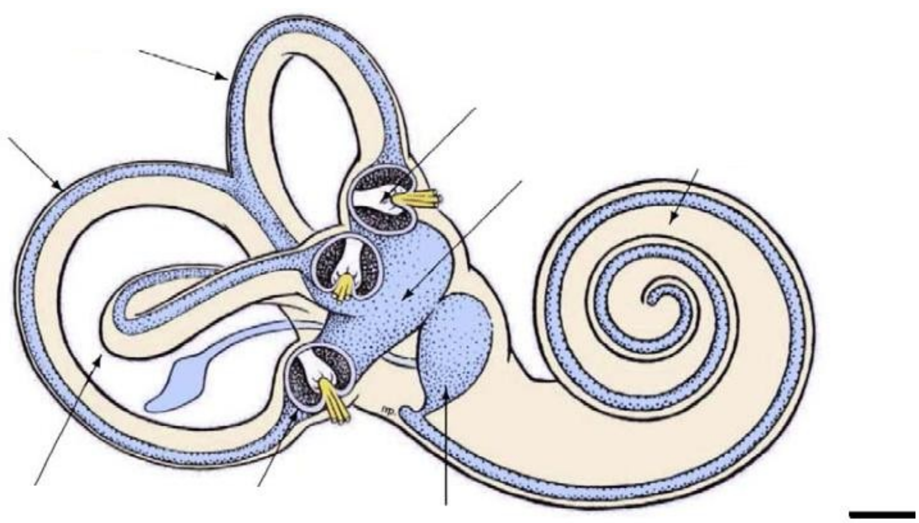

Figure 8: The inner ear

These six inner ear organs, the cochlea, the three SCCs, the saccule, and the utricle, open into the inner space of the inner ear termed the vestibule. The inner part of the inner ear is filled with endolymph which has properties similar to water (Obrist, 2011; Grant and Best, 1987). A hard bone surrounds the inner ear and the only openings to the "outside" are two windows, the round window, which separates the air-filled middle ear from the fluid-filled inner ear by a thin membrane, and the oval window, which connects to the stapes, and also separates the inner ear from the middle ear by means of a thin membrane (Obrist, 2011). The difference between the impedance of air and the impedance of the perilymph would produce a loss of about 29 dB at the air/fluid interface. To match the impedances, the middle ear consisting of the area of the tympanic membrane, the three middle ear ossicles and the area of the footplate of the stapes provides a mechanical transformer that matches this discontinuity. At high frequencies the tympanic membrane develops modes that affect the transmission of sound across the middle ear. Low frequencies do not create these vibration modes and the membrane vibrates as a "plate." The lower limit to the auditory range is limited by the length of the basialar membrane of the cochlear which, in turn, affects the length of the travelling wave on the membrane and, consequently, the lower limit of hearing.

The round window is compliant and responds to the pressure wave that travels up the scala vestibuli and down the scala tympani to create shear forces in the cochlea. These two "tunnels" surround the basilar membrane. Additionally, there is a communication between the scala vestibuli and the vestibular system by means of which acoustic pressure might be transmitted to the otoliths.

4.2 Classical model of the otolith

We have shown there is a plausible path for the infrasound pressures to reach the inner ear and in particular the otoliths. The classical model of the otolith is shown pictorially in Figure 9 (McGrath, 2003). The otoconial layer is a rather dense, firmer layer of the otolith. It thickens at the surface. The otoconial layer gets its density from embedded calcium carbonate crystals (otoconia). The otoconial layer creates an inertial force when accelerated owing to its mass. This force is transferred to the gel layer (cupula) as a shear force which then bends the hair cells causing them to transmit signals to the brain. So the fundamental measurement by the otolith is the inertial force of the otoconial layer (Grant and Best, 1987); the otolith is measuring force.

4.3 Calculations of forces acting on the otolith

In this section we approximate and compare two potential forces acting on the otoliths: (1) inertial forces due to accelerations, and (2) forces due to the instantaneous pressure in an acoustic wave.

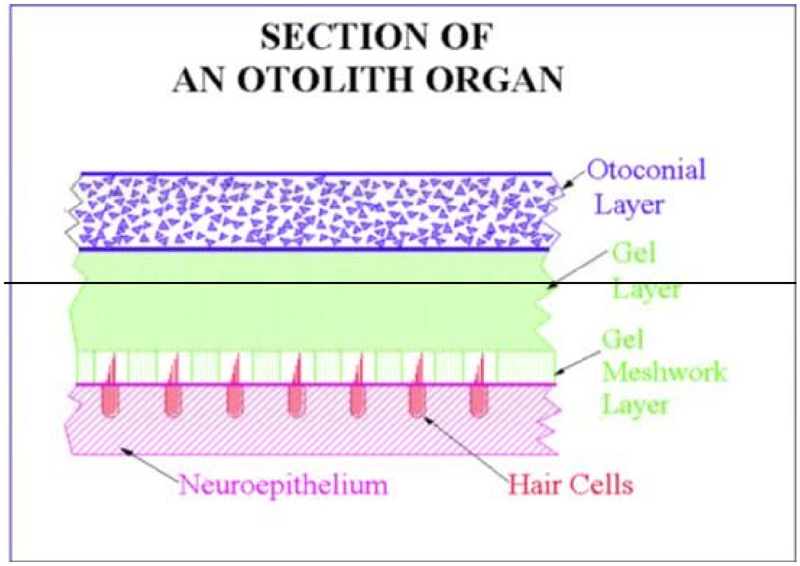

Figure 9: Section of a model otolith organ

Although the more complete solution for modeling the motion of the otolith is given by a parabolic partial differential equation (Grant and Best, 1987), the frequency response of the otoliths is flat from DC to about 10 Hz (McGrath, 2003), the position of the poles in the response being functions of assumptions for values of certain parameters describing physical attributes of the layers and their constituents. For an order of magnitude calculation, we simply consider F= ma, where the acceleration is precisely the acceleration of the head, and the mass is the differential density of the otoconial layer minus the density of the surrounding fluid and the copular membrane times the volume of the otoconial layer. Although calcium carbonate has a density of 2.7 gm/cm^3, the density of the otoconial layer is taken to be 2 gm/cm^3, since it is a combination of the dense calcium carbonate and the less dense gel material. The density of the copular membrane and of the endolymph fluid, which has properties given as being similar to water, is taken as 1 gm/cm^3, so the differential density is 1 gm/cm^3, or 1000 kg/m^3. As can be seen in Figure 8, the otoliths are approximated as round and their diameter is about 1 mm. The reader should note that the exact area encompassed by the otoconial membrane, its size, is not as important as one might think because we are comparing 2 forces, the force due to acceleration of the otoconial layer and the force due to the acoustic pressure on the otoconial layer, each of which is proportional to the same area; the area of the otoliths. The thickness of the otoconial layer has been given as 15 to 20 μm (Grant and Best, 1987). Therefore we calculate: the mass = density*thickness*area or,

mass(kg) = $1\ (\text{kg/ m}^3)*18*10^{-6}\ \text{m}*\pi*0.5*10^{-3}*\text{m}*0.5*10^{-3}*\text{m} = 18*\pi/4*10^{-9} \approx 1.4*10^{-8}$ kg.

With reference to fig. 6, we take the acceleration to be 1 m/s^2, so the acceleration force,

$$F_{accel} = 1.4*10^{-8} \text{ N.}$$

In terms of the pressure of an acoustic wave, we take the SPL to be 74 dB which corresponds to 0.1 Pa. Therefore, the acoustic force, $F_{acous} = 0.1* \pi /4*10^{-6}$ N ≈ $8*10^{-8}$ N.

4.4 Excitation of the otoliths

More recent research tends to confirm the model presented above for the excitation of the saccule. It is shaped similarly to a hemi-sphere with the base of the hemi-sphere rigidly attached to the temporal bone and the otoconial layer on the top where under the force of acceleration shear forces can be set up in the cupula. However there is radically new information about the utricle. Uzun-Coruhlu *et al.* (2007) have used x-ray microtomography and a method of contrast enhancement to produce data revealing "that the saccular maculae are closely attached to the curved bony surface of the temporal bone as traditionally believed, but the utricular macula is attached to the temporal bone only at the anterior region of the macula"(see Figure 10). This radically changes the model for excitation of the utricular macula. According to Uzun-Coruhlu *et al.* in the classical view of the utricular macula "... the sub-surface of the utricular macula is implied (if not actually stated) to be rigid; these models do not accommodate the ‘‘floating’’ utricular macula which we have shown and which is consistent with other anatomical evidence (e.g. Schuknecht, 1974). Since the hair cell receptors on the utricular macula are stimulated by forces there would be a major difference in modeling the sensory transduction of the macula to such forces if the forces acted on a tenuously supported flexible membrane or acted on a membrane which is rigidly attached to bone. As an example, modeling the magnitude of utricular hair cell displacement to an increased dorso-ventral g-load during centrifugation will be quite different if the whole membrane is deflected by the g-load or if it remains fixed in place. The latter rigid attachment has been explicitly or tacitly assumed, whereas our results show the macula is not rigidly attached to bone.

> "The key information which is now required for realistic modeling of utricular transduction is information about the flexibility of the utricular membrane to determine the extent to which it would be deflected by such forces."

Essentially, Uzun-Coruhlu *et al.* are saying that the excitation of the otolith in the utricle depends on the flexibility of the utricular macula. Since the macula is not rigidly attached to the temporal bone, the classical model for excitation of the otolith by an acceleration does not work. One way for inertial forces on the otolith to create bending forces is if the stiffness of the utricular membrane varies with position. Then inertial forces on the otolith will make the otolith "bulge" where it is less stiff and contract where it is stiffer, producing bending forces that will trigger the hair cells. Precisely the same thing will happen if the force is externally applied through the endolymph as when the force is internally applied through the otoconial layer. In this model, if there is external force on the utricle, it will expand where it is less stiff, and contract where it is stiffer. In particular, the pathway described earlier should cause the utricular macula to signal the brain in virtually identical fashion to signals generated by inertial forces.

4.5 An example that indicates these theories may be correct

The pressure in the endolymph is a scalar; its "direction" is everywhere normal to the surface. Therefore, in contrast to true inertial forces which are vectors, the acoustic pressure will always excite the same hair cells independent of the orientation of the head. So, one who experiences this effect should always feel the same motions. And this is exactly what both Steve Ambrose and Rob Rand, who are both acoustical consultants, each experienced. Rob Rand, one of the acoustical researchers on this project, the one who is sensitive to wind turbine acoustic emissions, said of his work in Falmouth, MA in April 2011: "I went outside hoping to feel better. I looked straight at a tree with my eyes, and my brain said the tree was about 20 to 30 degrees elevated and about 20 to 30 degrees to the right. Then I tried to focus on a bush looking straight at it, and again my brain said the bush was off to the right and elevated at about the same angle as before; and the same for the house. For everything I looked at, immediately my brain would say it was elevated and off to the right." Steve Ambrose had exactly the same experience, only not the same angles.

5. Conclusions

The wind turbine clearly emits acoustic energy at the blade passage frequency, which for the Nordex N100 is 0.7 Hz and about the first 6 harmonics of 0.7 Hz. This very low infrasound was only found at R2, but that was the only day in which significant power was being generated (about 58%).

Most residents do not hear the wind-turbine sound; noise annoyance is not an issue. The issue is physiological responses that result from the very low-frequency infrasound and which appears to be triggering motion sickness in those who are acoustic pressure that reaches the otolith through the eardrum and middle ear

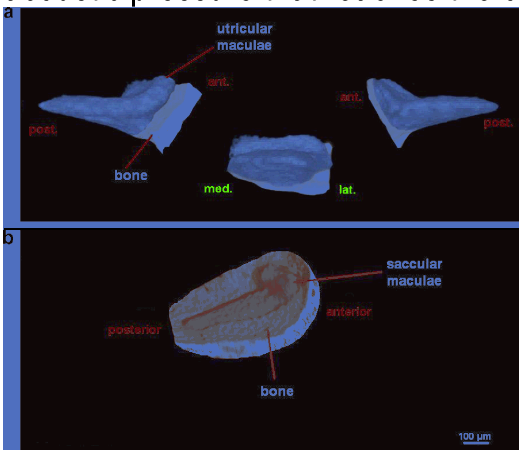

Figure 10: 3-D rendered images of the utricular and the saccular maculae of guinea pig. (a) Illustrates the 3-D rendered images of the three views of the macula as it rotates around a dorso-ventral axis to show the attachment of the macula to the bony wall of the utricle which occurs only at the anterior-most region. (b) Shows the 3-D rendered image of the saccular maculae clearly bound to curved bone.

susceptible to it. It has been shown that the probability that sensitivity to motion sickness and sensitivity to wind turbine acoustic emissions are unrelated is less than 2 in 1,000,000. This statement is sufficient to make clear a relation between wind turbines and motion sickness symptoms in what appears to be a small fraction of those exposed. This finding does not prove our hypothesis that the otoliths are responding to the wind turbine infrasonic emissions. Rather, we can say that the pathway for inducing this condition appears to be the same as airborne transmission through the middle ear and thence to the vestibular sensory cells, but confirmatory research of the pathway is recommended.

Finally, it is shown that the force generated on the otoliths by the pressure from the infrasonic emissions of the wind turbines is perhaps 1.5 to 3 times larger than the force that would be generated by an acceleration that was in accordance with the US Navy's Nauseogenic Criteria (Figure 7 herein). That is, a 0.5 to 0.7 Hz "tone" at 74 dB produces about the same to 1.5 times the force as does a 2 m/s^2 acceleration.

6. Additional research and data collection recommendations

The questions raised by this paper require answers. With the possible exception of study A below, a test facility is required to accomplish the research outlined below, and it probably could be used for study A. The facility would be a small room, perhaps 10 ft by 12 ft by 8 ft high, and, depending on location, would need to be in a soundproof enclosure. Excitation would be with special transducers;

possibly an air-modulated loudspeaker. The main requirement is that the facility extend down to very low frequencies (0.05 Hz or lower). Some of the potential testing is very briefly described below. Potential tests:

- **A.** Perform the "sensing" tests outlined in Appendix A of this paper.
- **B.** Demonstrate electric signals going to the brain that emanate from the otoliths; signals that are in sync with the wind turbine emissions. This testing would need to be done on an animal such as a cat or Guinea Pig.
- **C.** Develop an understanding of why this phenomenon seems to affect residents near only a small minority of wind farms.
- **D.** Establish who is and who is not affected by wind turbine infrasonic emission in various ways, and why.

Results from the type of research indicated above will facilitate development of methods to mitigate and/or prevent these types of problems. Prevention and mitigation may not be so difficult. In particular, the eight-turbine installation in Shirley is very spread out; R1 and R3 are near two turbines while R2 has one turbine that should be 6 dB higher in level than the next nearest turbine. Another place where these seasickness like problems are known to have occurred is in Massachusetts with a one-turbine installation. These findings begin to suggest that having several asynchronous turbines at roughly the same level might preclude the motion sickness problem by breaking up the regular repetition rate inherent when there is just 1 nearby turbine or when there is synchronous operation. This would suggest that in a site with many turbines, only some residences on the perimeter would have the potential for only one nearby turbine.

Currently the wind turbine industry presents only A-weighted octave band data down to 31 Hz, or frequently 63 Hz, as a minimum. They have stated that the wind turbines do not produce low frequency sound energies. The measurements at Shirley have clearly shown that low frequency infrasound is clearly present and relevant. A-weighting is inadequate and inappropriate for description of this infrasound. In point of fact, the A-weighting, and also the C and Z-weightings for a Type 1 sound level meter have a lower tolerance limit of -4.5 dB in the 16 Hz one-third-octave band, a tolerance of minus infinity in the 12.5 Hz and 10 Hz one-third-octave bands, and are totally undefined below the 10 Hz one-third-octave band. Thus, the International Electro-technical Commission (IEC) Wind Turbine measurement standard needs to include both infrasonic measurements and a standard for the instruments by which they are measured.

7. Endnotes

i. The wind farm dialogue has been marred by misstatements on all sides. This quotation of Tesarz *et al.*, (1997) brings to mind one notable misstatement: "If you can't hear it, it can't hurt you." This paper shows that quotation to be a misstatement.

ii. The family in the closest dwelling, R-2, reported that the wife and their then 2-year old son had the problems; the husband did not have problems. The husband would not sell the house because he did not want to stick someone else with the problems, was making payments on the loan because he would not default, and they have purchased a second, smaller house that they also make payments on. These residents reported that their baby son, then 2 years old, would wake up 4 times a night screaming. This totally stopped upon their leaving the vicinity of the wind turbines, and he now sleeps 8 hours and awakens in a normal state for a 2 year old, basically happy. The couple in the middle-distance house, R-1, were living in their camper because they had nowhere else to live that they could afford. Of course the camper is kept several miles from the wind farm. They and two or their adult children, a son and a daughter, were all sensitive to motion sickness and had motion sickness symptoms. The son and daughter each lived in a nearby community and visited very often.

iii. These were the four family members discussed in note ii, above. The mother and father moved from their house because the problems they were experiencing, the majority of which for the father are contained in the Table 1 list. The son and daughter each apparently lives far enough away that the emissions are not a problem to them where they live, but the son reports on two trips to the parents abandoned house to use a shop area there to work on his car. Both times he developed strong motion sickness symptoms and only goes "there for very short periods of time now, and only when absolutely necessary." This is taken to be essentially equivalent to abandoning a home in that his parent’s home is nearby and could readily be used by him, but he chooses to only go there "when absolutely necessary" because he feels so bad when he goes there. The two residents that were selected from the 50 at Shirley with symptoms are the father and the son. About one half of the father's symptoms are in the Table 1 list, they are strong and include nausea, and they have abandoned their home. The son is included because nearly all his symptoms are from the Table 1 list, they are very strong, and he no longer goes to or uses a house that is available to him except when absolutely necessary. In contrast, the mother's major problem centers on pain in the ears, and the daughter's situation is less clear.

iv. Participating households are those that receive a share of the proceeds in exchange for agreeing to not complain about the wind turbines; additional monies are paid to participants who have wind turbines or ancillary facilities or equipment on their property.

v. Montavit (2013) states that 5 to10 percent of the population are "extremely sensitive," and that 5 to 15 percent are "relatively insensitive." So 5 to 10 percent of the population is probably closer to the percentage that we should be using rather than 15 percent.

vi. The effect shown here for wind-turbine emission is certainly not unique to wind turbines. Rather, it appears that these effects would occur with any low infrasonic source. This finding may explain some of the reports that have been present in the literature for over 40 years.

8. Acknowledgements

The authors wish to acknowledge the extraordinary effort and trust that went into making the testing at the Shirley wind farm possible. First, there is the extraordinary efforts of David and George Hessler and their client, Clean Wisconsin, that made the testing happen at the Shirley wind farm. Coupled with this effort was the extraordinary efforts by Glen Reynolds and Forest Voice who also made this testing happen. The real acknowledgement is to trust and to the will to work together in the search for truth and for honest solutions to real problems; not the least of which is determining what the problem is. The Wisconsin Public Service Commission listened and trusted and put in funds, and the town of Forest put in funds, the residents of Shirley trusted and helped and, in particular, the three families who had abandoned their homes trusted and helped and made these properties available. And the four consulting firms trusted and helped one another. And a great deal was accomplished because of all the cooperation and trust. But more could have been accomplished and learned if all parties had participated, cooperated and trusted. We can only hope that next time they will.

Additionally, our acknowledgement goes to George Hessler for repeated reviews of the paper with helpful inputs and questions, and much credit is due to Bruce Walker for his development of a custom multi-channel time-domain very low frequency, 0.1 Hz, measurement system necessary for advanced signal processing and analysis between and among channels, and is custom reprinting of the coherence and spectral plots herein from Shirley. Additionally, credit goes to Robert Rand for repeatedly being a firsthand source of knowledge about the effects of wind turbine emissions and for general thoughts and ideas.

Our acknowledgement goes to Dr. Sarah Laurie (Southern Australia), Dr. Robert McMurtry (Ontario, Canada), and Dr. Jay Tibbitts (Central Wisconsin, USA); three physicians from around the world who searched their records to provide information on symptoms and histories.

And finally, acknowledgements, Alec Salt for providing key references about the otoliths that led us in the right direction, Sumuk Sundarum, MD Ph. D. Internal Medicine for review of an early draft, Stephen Chadwick, MD Otolaryngology for initial ideas and review of an early draft, Paul Schomer's good friend Michael Rosnick, MD Family Medicine for correcting a misconception about the Eustachian Tube, and to Paul Schomer's daughter Beth Miller, for initial lessons and information on the anatomy and physiology of the ear.

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APPENDIX F: Waterloo Acoustic Compliance

EnergyAustralia

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8 October 2012

Mrs. Julie Quast
RMD Waterloo via Saddleworth 5413

Dear Mrs Quast,

TRUenergy Waterloo Wind Farm
Post-Construction Noise Monitoring Result Summary

Please find attached a summary report of the noise monitoring that was conducted at your residence between 25 November 2010 and 19 April 2011. The report has been prepared by Marshall Day - Acoustic consultants & noise control engineers. If you believe that a conversation with a representative of Marshall Day would assist in understanding some of the detail in the report I would be pleased to make the necessary arrangements.

I take this opportunity to apologise for the time that has passed between the noise monitoring and the provision of this information.

Yours sincerely

Steve Brown
Manager, Asset Services
Operations & Construction
EnergyAustralia

POST-CONSTRUCTION NOISE MONITORING RESULT SUMMARY

Waterloo Wind Farm

House reference 24
Resident Name: Quast
Stakeholder: No
Nearest Turbine: BH

Relevant Standard: SA EPA Guidelines 2009
Period: 25 November 2011 to 19 April 2011

Distance to Nearest Turbine (m): 2,493
Worst case Wind Direction: **53-143°**

Noise monitoring periods	Easting	Northing	Make	Model	Serial Nb.
25.11.10 – 07.12.10	305,077	6,239,818	ARL	316	16-306-029
25.02.11 – 20.03.11	305,077	6,239,818	ARL	316	16-306-030
25.03.11 – 05.04.11	305,077	6,239,818	ARL	316	16-306-031
08.04.11 – 19.04.11	305,077	6,239,818	ARL	317	16-306-032

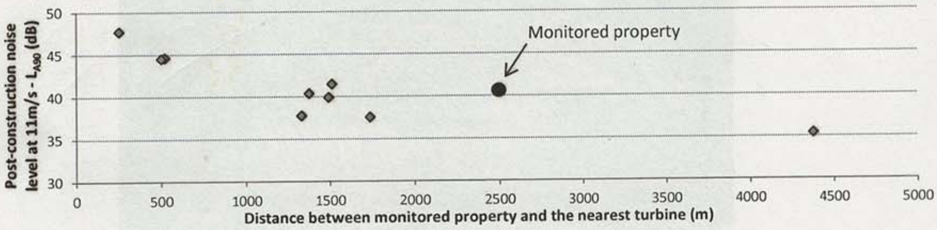
Total number of valid data points collected	7,617
Number of data points used for analysis (worst case wind direction)	3,775
Wind speed range used for analysis (worst case wind direction)	3.5 to 17.7m/s
Post-construction regression line of best fit R^2	0.19

Wind Speed	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Minimum Noise Limit	40	40	40	40	40	40	40	40	40	40	40	40
Post-construction noise	30.3	32.3	34	36	37	39	40	41	41	42	42	43
Derived wind farm noise	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Compliance	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-	-	-

Compliance with the SA EPA Guidelines 2009 achieved? Yes (See comments)

Presence of tonality+? No Presence of annoying characteristics+? No

+ based on subjective assessment by a qualified acoustic consultant

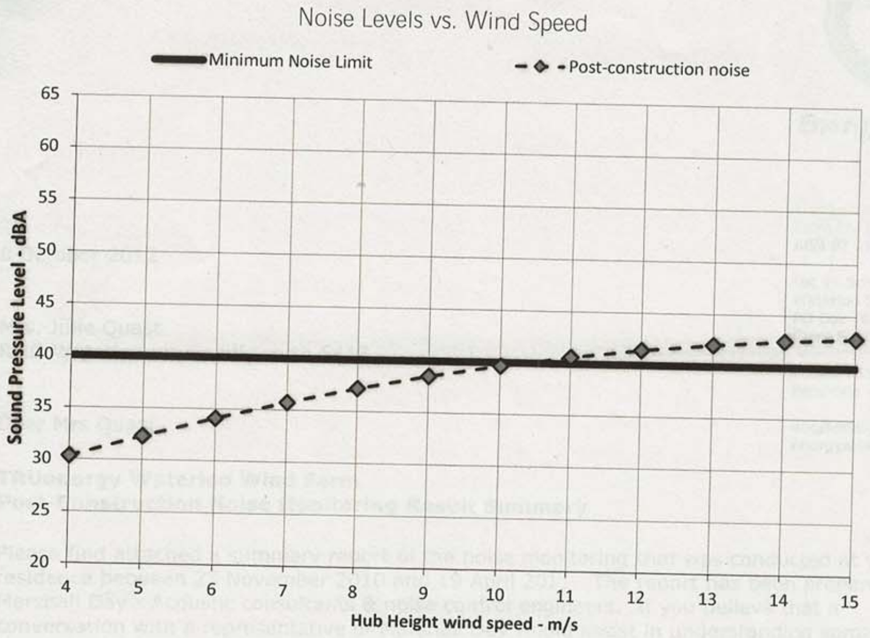


General Comments

Wind farm noise levels could not be derived at this property due to the lack of pre-construction backround noise levels.
Further investigations by MDA and the South Australian EPA demonstrated that post-construction levels were highly affected by background noise levels and that compliance with the SA Guidelines was deemed to be achieved.

Comments from Relevant Authority

Conclusions accepted ☐ Further assessment required ☐


Noise Levels vs. Wind Speed
Minimum Noise Limit
Post-construction noise
Sound Pressure Level - dBA
Hub Height wind speed - m/s
65
60
55
50
45
40
35
30
25
20
4
5
6
7
8
9
10
11
12
13
14
15

Monitoring Locations at Quast residence – Waterloo

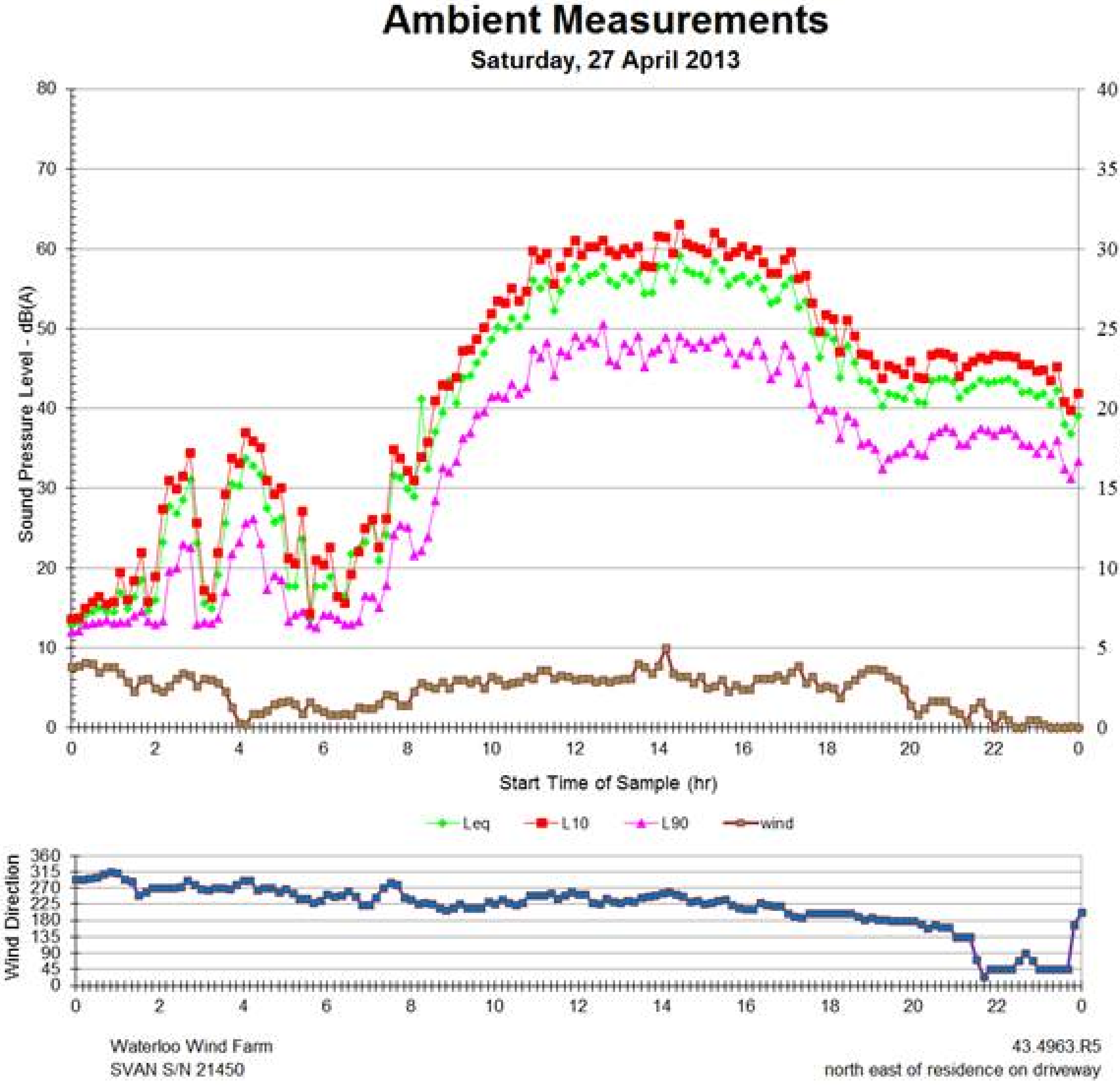
EPA Monitoring Location

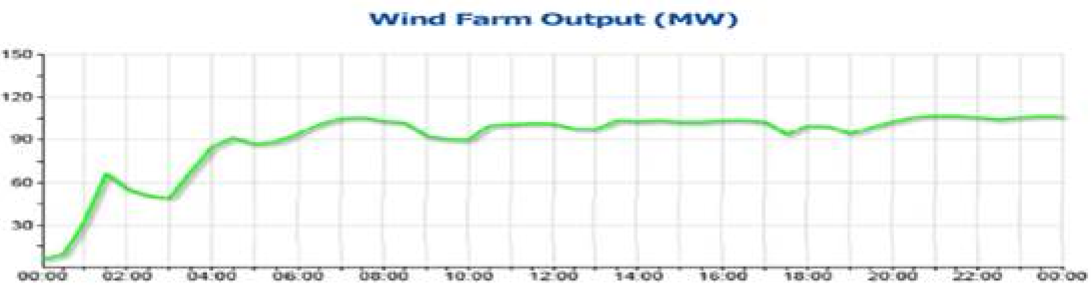
Approximate location of MDA monitor

View through trees from EPA monitor

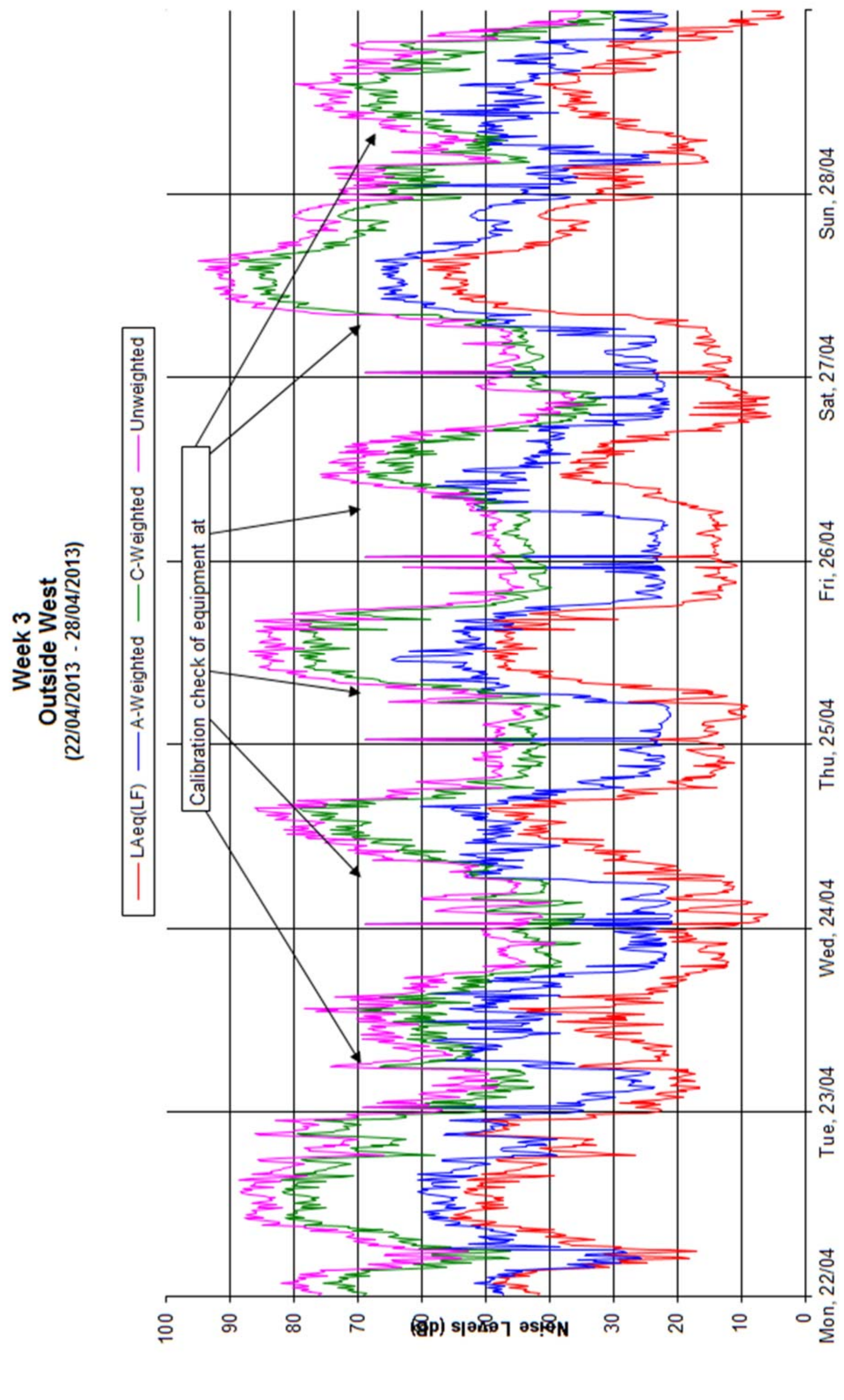
Cooper monitoring position Adelaide University (team 2) monitoring position

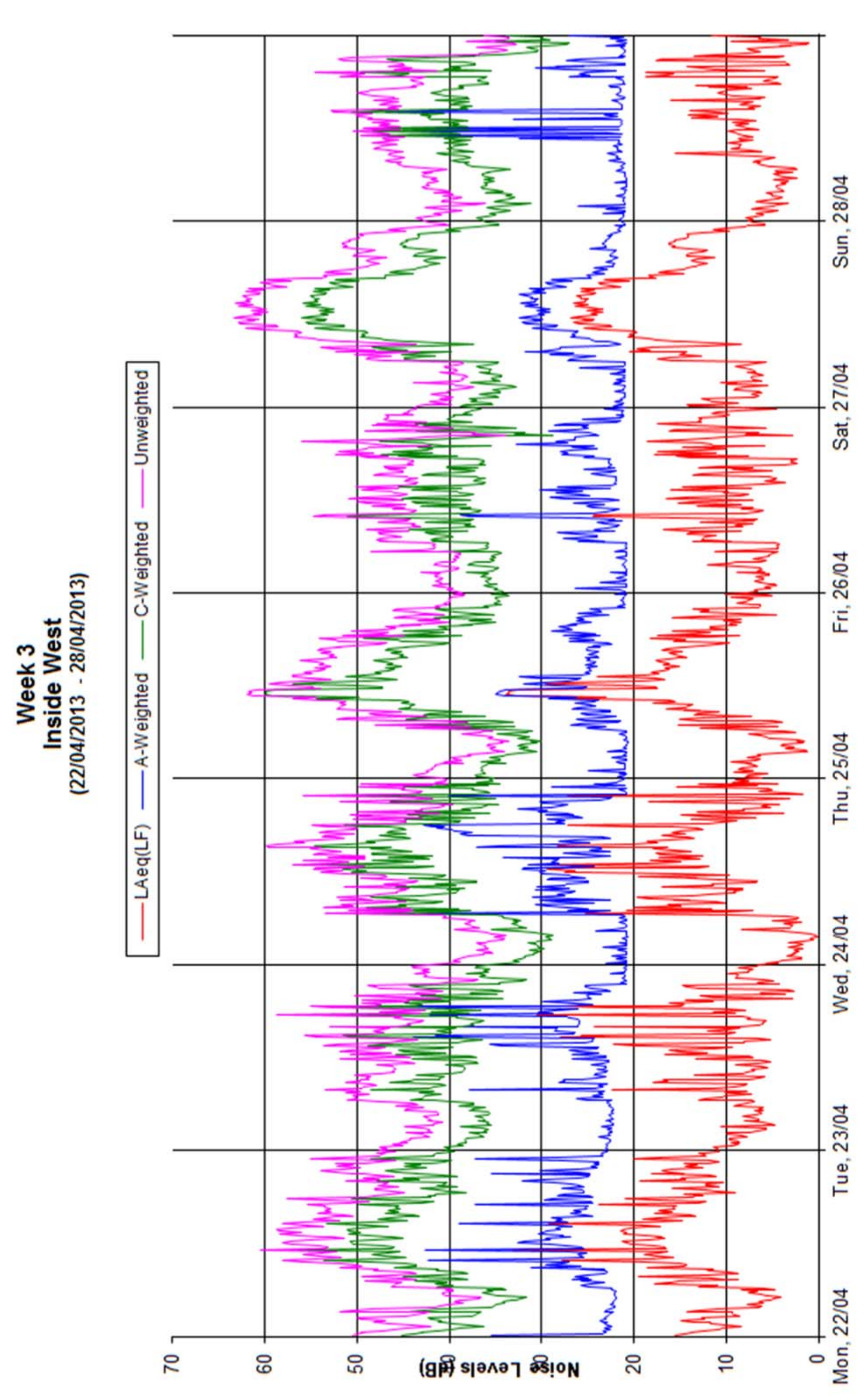
<u>APPENDIX G:</u> Cooper Measurements at Quast

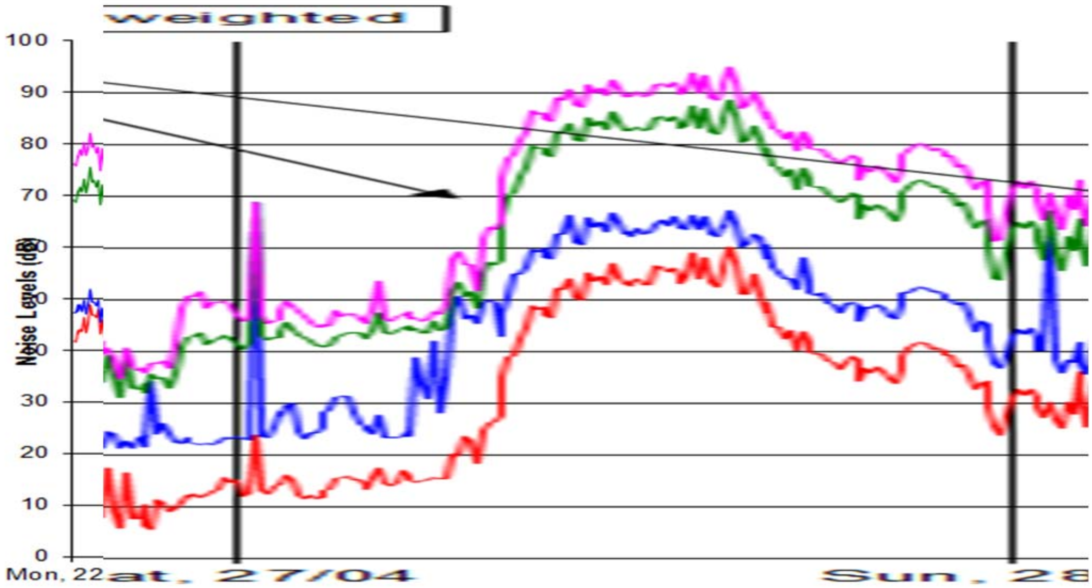


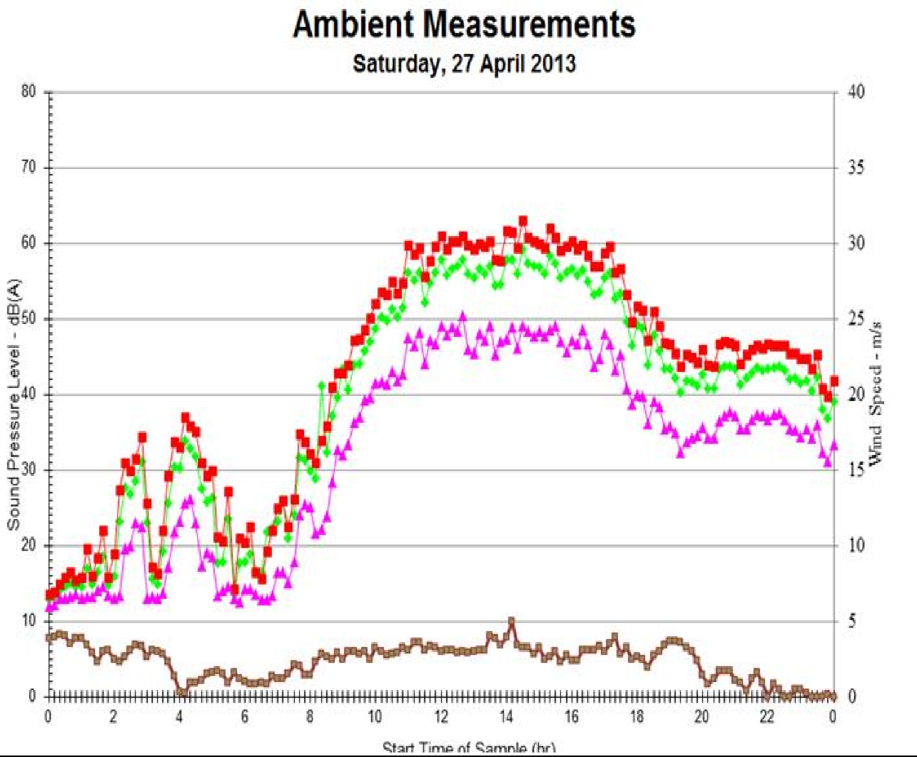


APPENDIX H: EPA Measurements At Quast Residence
(http://www.epa.sa.gov.au/page.php?page=889#north)




Week 3
Inside West
(22/04/2013 - 28/04/2013)
LAeq(LF)
A-Weighted
C-Weighted
Unweighted
Noise Levels (dB)
70
60
50
40
30
20
10
0
Mon, 22/04
Tue, 23/04
Wed, 24/04
Thu, 25/04
Fri, 26/04
Sat, 27/04
Sun, 28/04

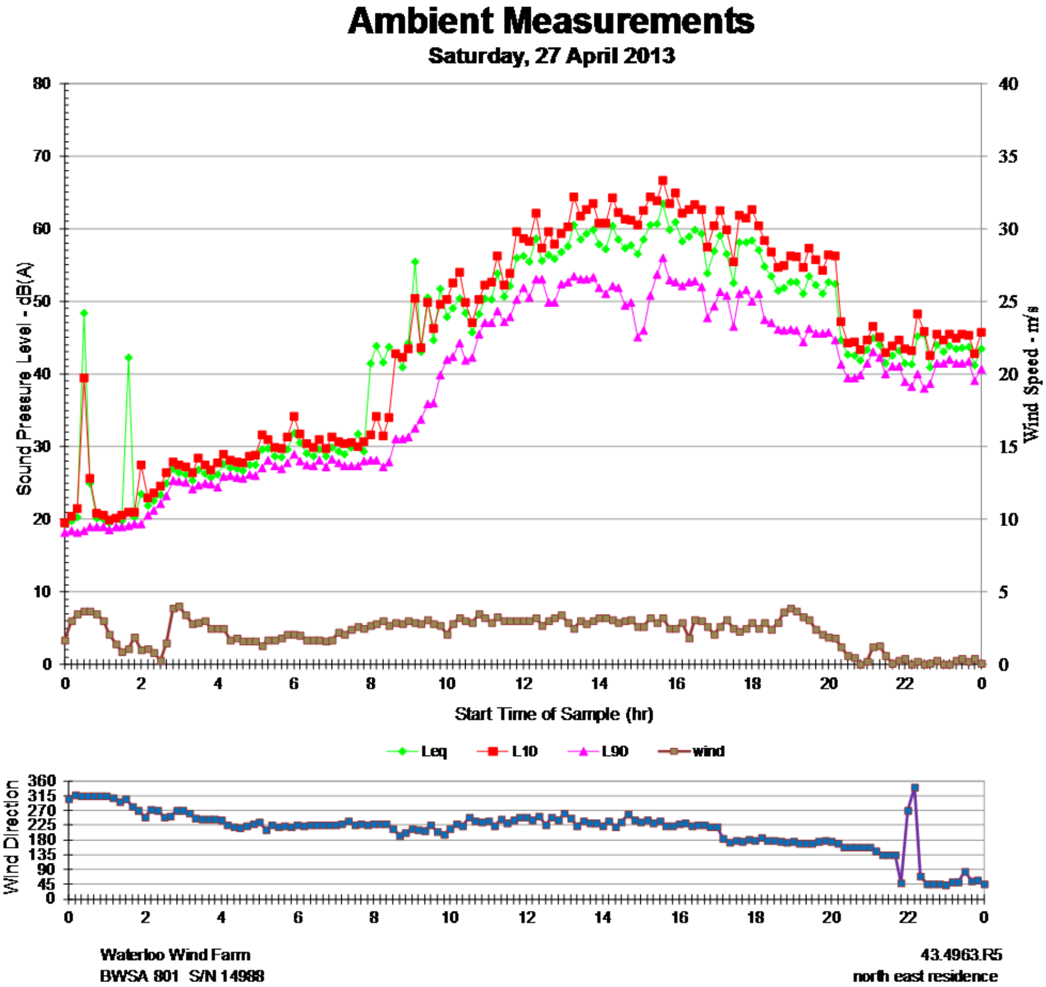


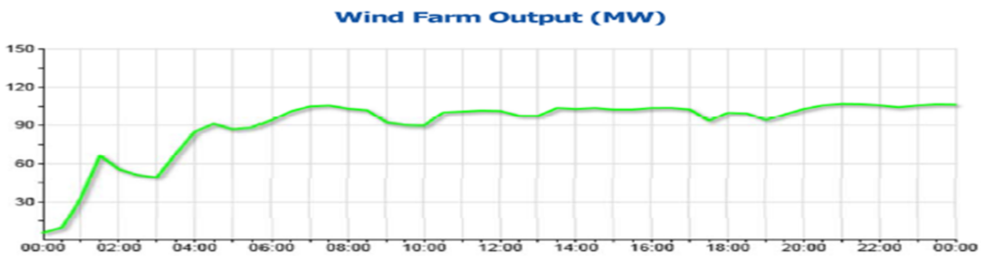


Upper graph is EPA logger – compare blue line being dB(A) L90 or Leq with

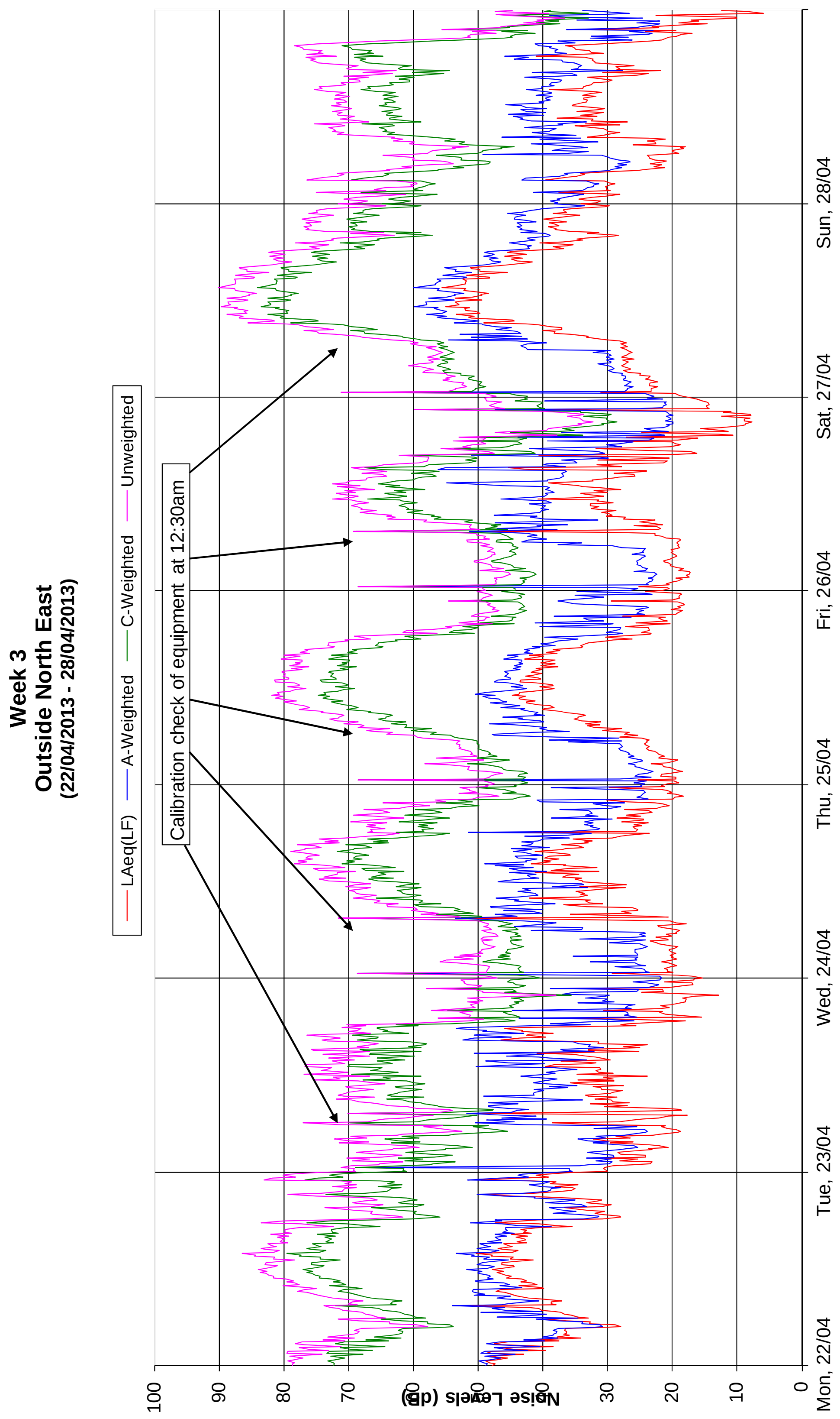
Lower graph purple line is L90 and green line is Leq

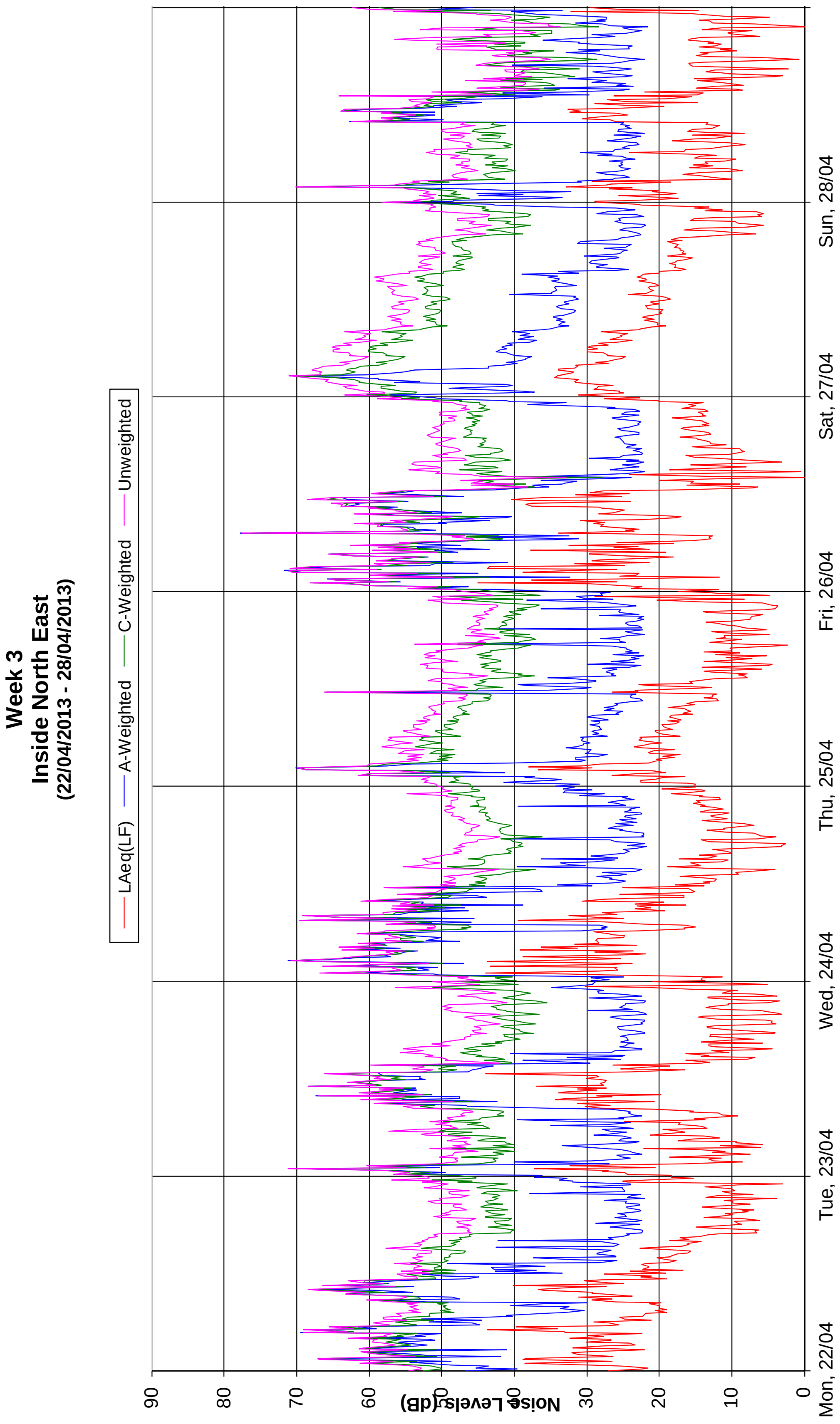
APPENDIX I: Cooper Measurements at NE Location

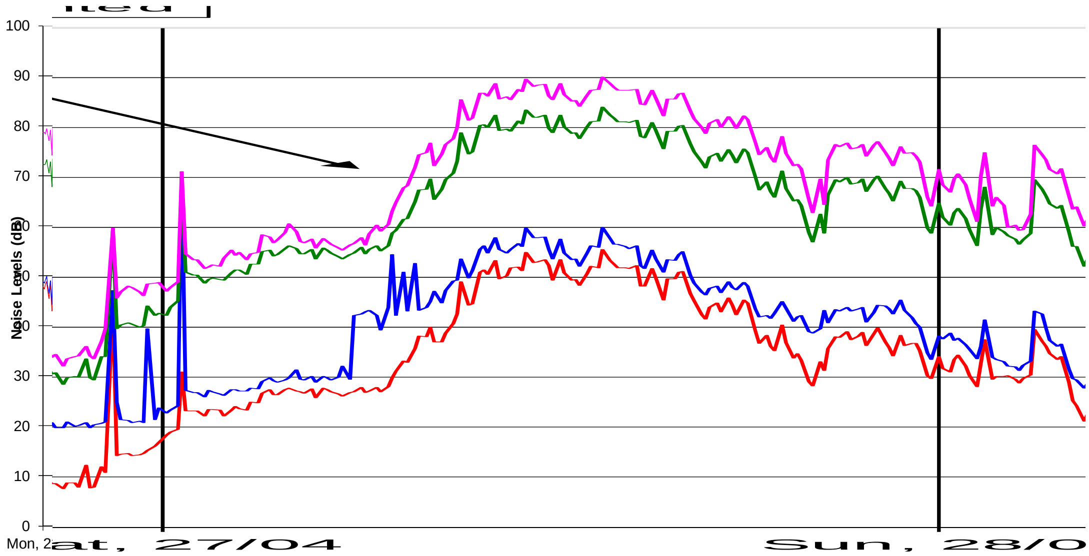


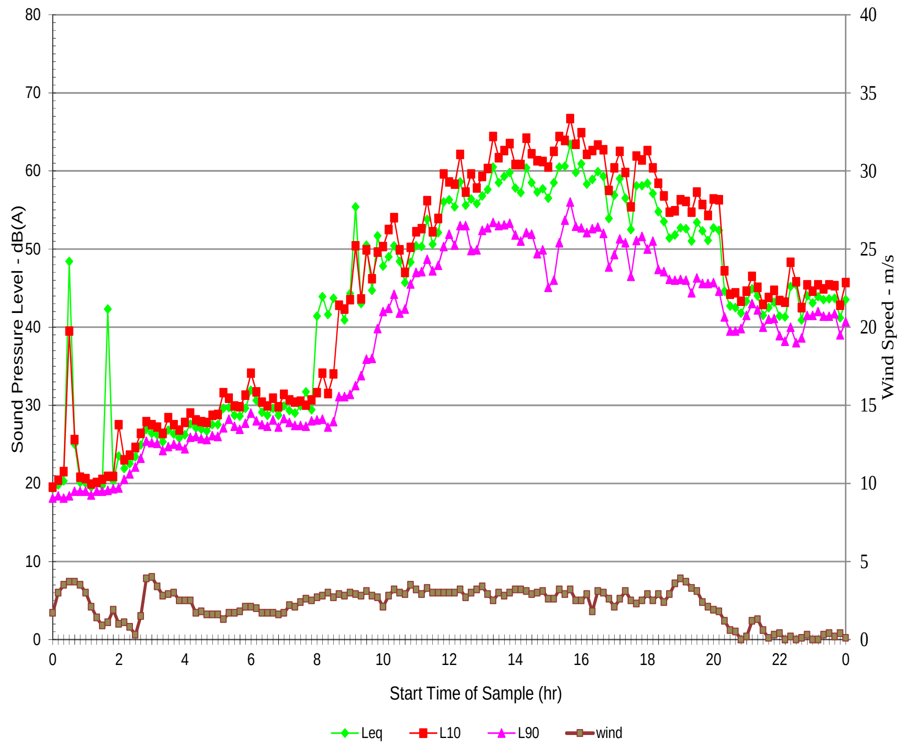


<u>APPENDIX J:</u> EPA Logger Results for NE Location

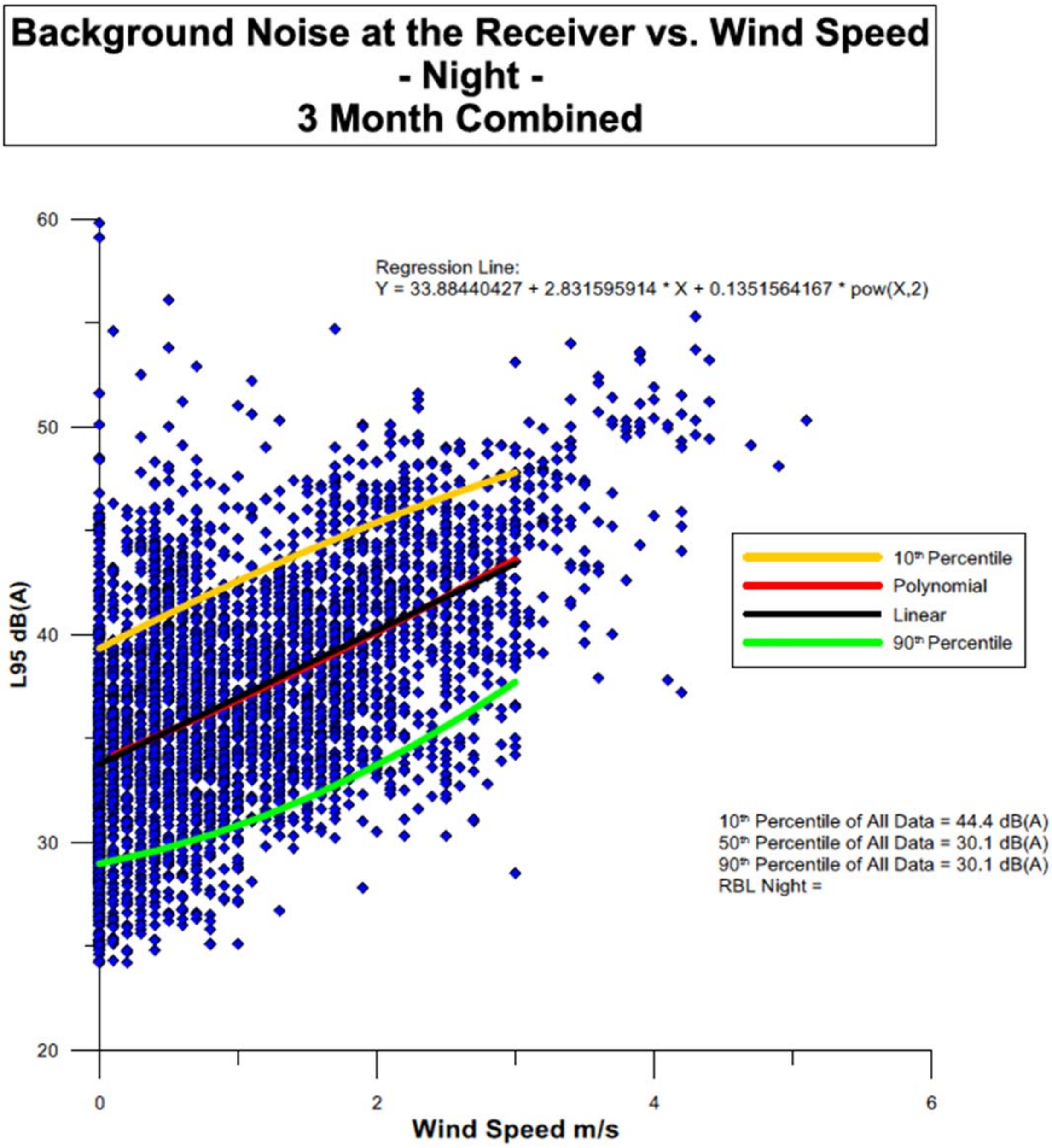


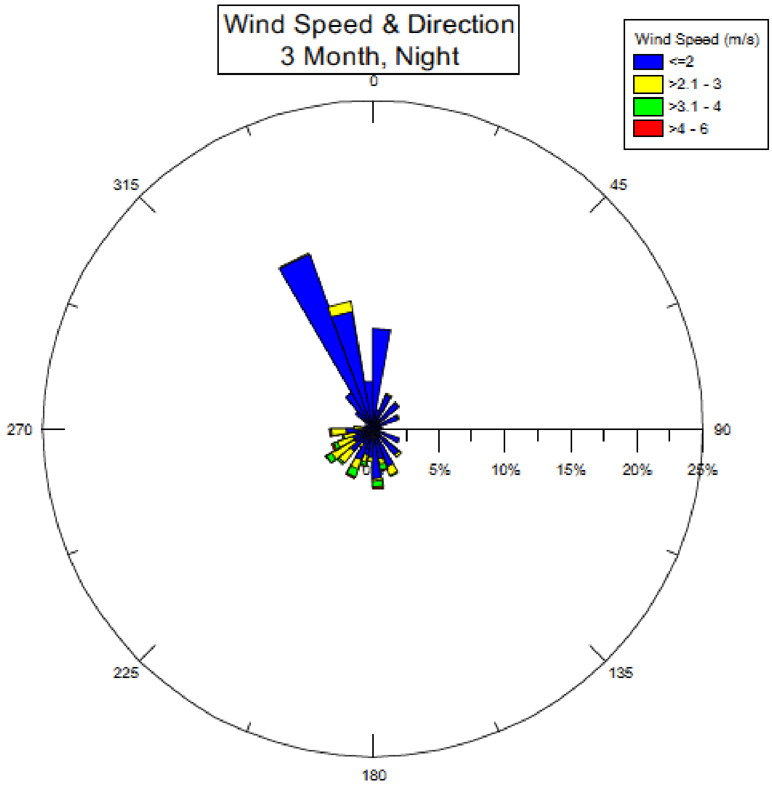

Week 3
Inside North East
(22/04/2013 - 28/04/2013)
LAeq(LF)
A-Weighted
C-Weighted
Unweighted
Noise Levels (dB)
0
10
20
30
40
50
60
70
80
90
Mon, 22/04
Tue, 23/04
Wed, 24/04
Thu, 25/04
Fri, 26/04
Sat, 27/04
Sun, 28/04

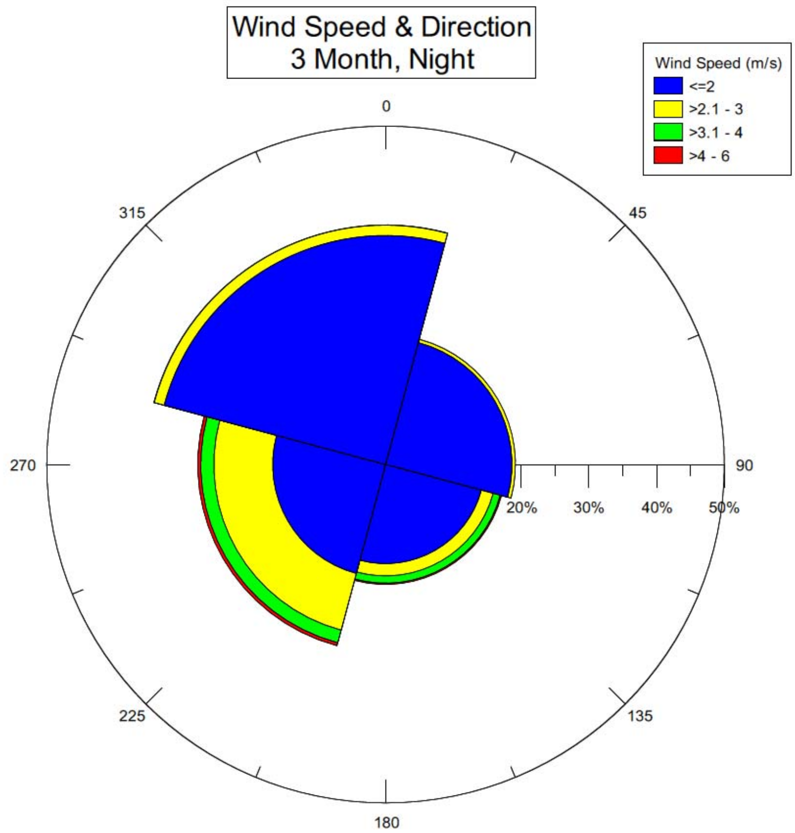

Noise Levels (dB)
100
90
80
70
60
50
40
30
20
10
0
Mon, 2
at, 27/04
Sun, 28/0

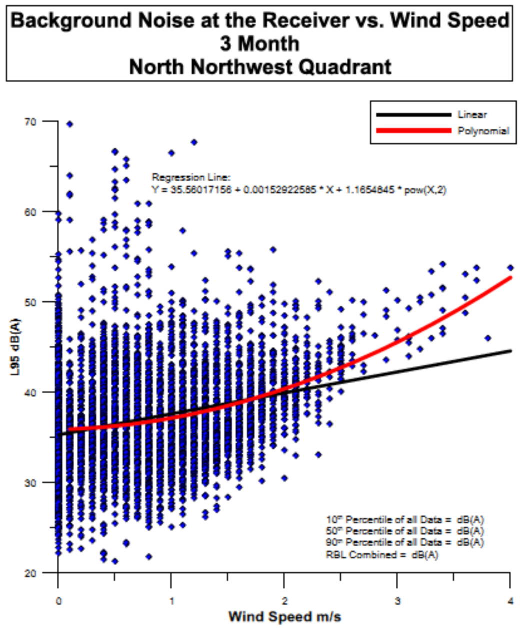

Sound Pressure Level - dB(A)
Wind Speed - m/s
Start Time of Sample (hr)
Leq
L10
L90
wind

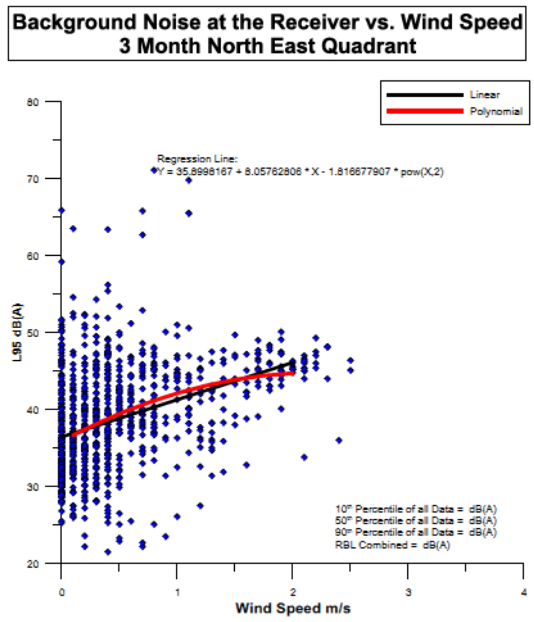
APPENDIX K: Waubra Wind Farm Regression Data

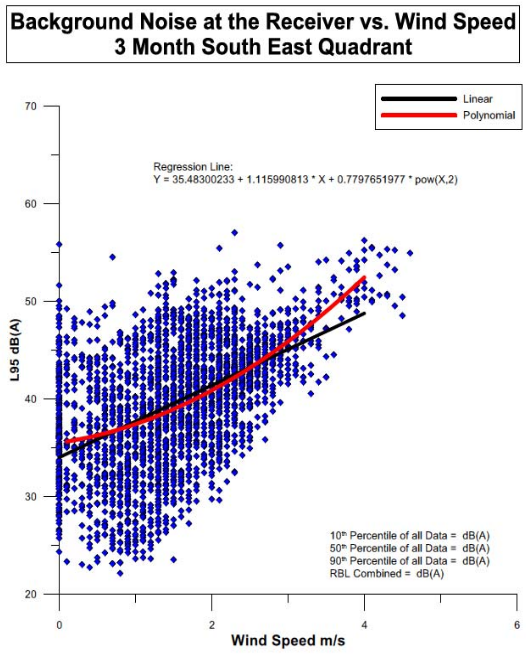


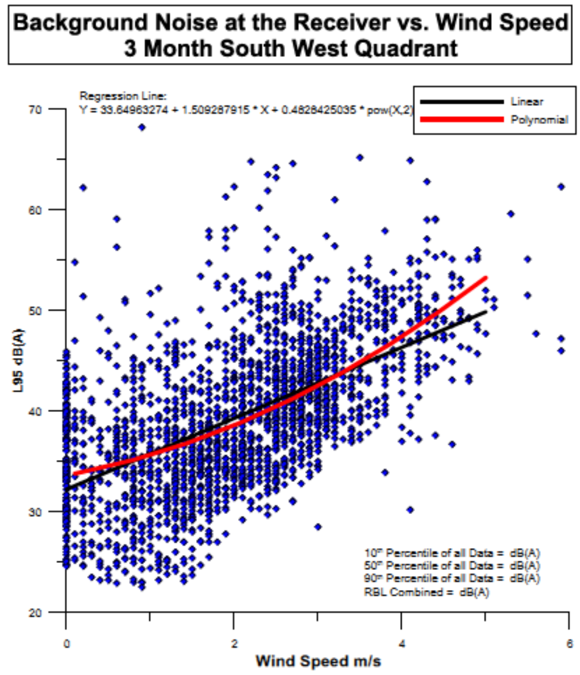

Wind Speed & Direction
3 Month, Night
Wind Speed (m/s)
<=2
>2.1 - 3
>3.1 - 4
>4 - 6
0
45
90
135
180
225
270
315
5%
10%
15%
20%
25%


Wind Speed & Direction
3 Month, Night
Wind Speed (m/s)
<=2
>2.1 - 3
>3.1 - 4
>4 - 6
0
45
90
135
180
225
270
315
20%
30%
40%
50%


Background Noise at the Receiver vs. Wind Speed
3 Month
North Northwest Quadrant
Linear
Polynomial
Regression Line:
Y = 35.56017156 + 0.00152922585 * X + 1.1654845 * pow(X,2)
L95 dB(A)
Wind Speed m/s
10th Percentile of all Data = dB(A)
50th Percentile of all Data = dB(A)
90th Percentile of all Data = dB(A)
RBL Combined = dB(A)


Background Noise at the Receiver vs. Wind Speed
3 Month North East Quadrant
Linear
Polynomial
Regression Line:
Y = 35.8998167 + 8.05762806 * X - 1.816677907 * pow(X,2)
L95 dB(A)
Wind Speed m/s
10th Percentile of all Data = dB(A)
50th Percentile of all Data = dB(A)
90th Percentile of all Data = dB(A)
RBL Combined = dB(A)


Background Noise at the Receiver vs. Wind Speed
3 Month South East Quadrant
Linear
Polynomial
Regression Line:
Y = 35.48300233 + 1.115990813 * X + 0.7797651977 * pow(X,2)
L95 dB(A)
Wind Speed m/s
10th Percentile of all Data = dB(A)
50th Percentile of all Data = dB(A)
90th Percentile of all Data = dB(A)
RBL Combined = dB(A)


Background Noise at the Receiver vs. Wind Speed
3 Month South West Quadrant
Regression Line:
Y = 33.64963274 + 1.509287915 * X + 0.4828425035 * pow(X,2)
Linear
Polynomial
L95 dB(A)
Wind Speed m/s
10th Percentile of all Data = dB(A)
50th Percentile of all Data = dB(A)
90th Percentile of all Data = dB(A)
RBL Combined = dB(A)

APPENDIX L: Questions at AAS NSW Division Meeting March 2013 (as best as can be ascertained off the recording supplied by others)

46:42 Question: Peter Alway

Thank you for that. The first thing that occurred to me immediately we are really trying to look at the effect on people. I don't think that we were able to see what we were looking for. I think that all the measurements were too consistent. To try and to take a measurement, and get a 5 to 8 dB difference of 2 Hz. I think it's wrong.

I wonder about the calibration of the instrumentation and what was actually measured and what I mean by that is, I myself would be measuring 5K with a linear mic in reverberation rooms in good conditions. I have tried and failed to measure below 100 Hz in a very good quality anechoic room. These measurements to me aren't consistent so I don't know what they really mean. So, can I ask you and as a start how did you know that the levels you were measuring were actually correct? What was calibrated? Were the microphones calibrated? And if they were, how were they calibrated at 0.25Hz? How was the SLM calibrated and those sort of things.

48:41 Answer:

I'll do my best. It was my understanding that ….the calibration was very consistent. So that was done just before the testing was carried out. We got a sound system from B and K mics and it was calibrated. The B and K microphones were new…obviously along the way were very cautious and we did a number of back to back measurements and testing…you saw the testing, we did the wind speeds we did the wind shields, so I am very confident that the measurements are correct. In terms of the closeness of spacing…a few of them were averaging longer time periods.

Question: Charlie Arnott

Matthew thank you for your presentation I have a query or two quick questions. You might be familiar with the Australian market operator they collect data of the electricity output of all wind farms in Australia are you aware of that?

Answer:

I am very aware of that.

Question Continued:

What we can ascertain from that data is whether a wind farm is spinning or whether it has been shut down, so whether it is producing power or not.

The interesting thing is, we can create graphs from this data, the interesting thing is that on the 5th October at the Bluff house there was inconsistency between the graphs that are created from the AEMO data and in the shutdown period reported in your presentation. So basically could you explain that anomaly in that correlation there is no correlation?

51:30 Answer:
I cannot answer…as explained earlier, John was there when the measurements were taken and he was there at the time of the shut down and it was given power data to back it up. I am confident in what has happened. I can't explain that. I'm happy to take the information. I can ask them that and get back to you.

52:10 Question: Steven Cooper

Thank you Matthew. The presentation you gave tonight is slightly different from the report in a number of areas.

One of the issues, it's not my questions though, is that the 10 second time you talked about events was identified in the report as 10 second averaging, that is the response time was slowed down for the measurements and therefore it gives you different readings than if you went along and measured fast response.

That's actually not my question, my thing in reading in the report is that you have in the report linear figures, which you showed tonight, and you gave parts of what is figure 29 at the Bluff house. In Section 2.1 you give the G-weighted curve and the G-weighted curve dramatically drops off the energy below 10 Hz as you show and the blade pass frequency is 43 dB down under the ISO Standard.

Your report makes the statement that the G-weighting result covers all the energy associated in the infrasound for region turbines and therefore is suitable. Your results don't show that because if you look at that figure you'll see that there is a lot of energy below 6.3 Hz yet the dB(G) drops out and that gives some problems in doing comparison measurements and yes I used the 945A and other instruments in terms of it. However I just can't get the dB(G) is actually suitable for turbines to go all the way down to 1 Hz ,or less if the blade pass frequency is actually 0.8.

53:46 Answer:
So there are a couple of points there and so I will try and answer the question. So I think you're right. The G-weighting does attenuate the blade pass frequency. There are no questions about that at all, and that's why I showed this one here, which was the equivalent levels at 1.6 Hz in 1/3 octave band un weighted level There is no G-weighting applied to these and compared that to all the other locations.

So I guess, when we started off on this journey we didn't know what we were going to find and so we started off. OK the IEC Standard suggests G-weighting, if there is an idea that there might be infrasound and we went down that path and there have been other studies that I have referenced that have shown a correlation between human perception and the G-weighting. So that's what we did, we were reporting on what we measured. I'm not sure if any of this fixes the problem.

55:45 Question: Renzo Tonin

Matthew, I've seen a number of studies like this where there is a comparison of infrasound and in typal urban situations and also wind farm and they compare the two situations and they show that the low frequency, the infrasound levels are comparable and that the conclusion has always been two things, one is that the infrasound levels are similar so why are these people in rural areas near wind farms complaining, and the second conclusion is that the infrasound levels are 50 dB below the hearing threshold.

The problem with those comparisons and all of the studies included in yours and Sonus and other international studies, you're all coming to the same conclusion.

For what I see is a fundamental issue with the experimental methodology are the assumption made is that if you can't hear the sound it can't hurt you. I think that needs to be explored a little bit more because there is no indication anywhere that the way in which the ISO curves are derived which is usually a 0.5 or 2 second energising of the sound level and the person says yes I can hear it or no I can't hear it. How that can be compared to someone who is living in a situation, experiencing infrasound day and night and experiencing a much lower level? The question is not can you hear it, but do you feel something?

None of the ISO's standard curves, there is no ISO curve which relates to, can you feel something can you hear it. So it's not surprising that the levels are very high. Therefore the comparison you're saying that the measurement is 50dB below the ISO curves don't necessarily support your conclusion or maybe not your conclusion but the implied conclusion that there is not a problem. I think much more attention needs to be given to whether we should be comparing infrasound levels to the threshold level of audibility.

The second thing is, that in terms of experimental procedure, comparing site A and comparing a site B and saying that infrasound levels are similar, and leaving it to the reader to draw the conclusion well what are people complaining about …therefore there is a bit of a trail to the conclusion of the report which leaves one to draw a conclusion that there can't be a problem. I think that needs to be explored as well. The normal way or the fundamental way of approaching the experiment is to create a hypothesis and to prove that that's right or wrong and comparing the infrasound levels of two locations is like going to Japan and comparing radiation in one place and radiation in Tokyo, they're both the same so what are you complaining about? I think the experimental procedure needs to be really thought out.

And finally, measuring sound pressure levels at very low frequencies requires really careful procedures. If you're measuring 1Hz and you're looking at the FFT of a 1 Hz in a 1/3 octave band, it takes a long time for that energy in the 1/3 octave band to stabilise. So what you might be doing when you have random noise and looking at the 1 Hz FFT like you have shown is that you might be scampering past the filter and not really registering the true levels. You said yourself that you got to, you need 10 seconds of a sample to get the Leq of that sample. Well no one has looked that 1 Hz and a half a Hz how long it takes to get the peak to come up to a true level. So there are a lot of cautions there I want to put out to you people who are all experts in this field. I'm not saying there is a problem, I'm not saying there isn't a problem……look at your instruments, when you say look at your calibrators. I know for a fact without dealing in a laboratory .. nowhere near 1 Hz and I know I've calibrated at 1Hz and it is really really hard.

You need not … you can't.. your information you've got there is another part of the problem. But I can see the press releases everywhere that people are drawing inaccurate conclusions from your very good work but it's not the be all and end all.

Answer:
…I'll try and touch on a few of them. The answer, is funnily enough was to try and get more information out there to to further the knowledge and to help understand the issue. Some people……

The 10 second thing, the octave band measurements, that was… and we had a few chats with Bob. I'm not sure if you want to say something now if you're free but, there are a few questions around that but as it stands…In the report there are some other references which might be useful really. …maybe people agree with and maybe people don't… study done on deaf people and actually sensed the levels were higher than the threshold of perception …. We have no expertise in health. That was a study done to ……

I guess that we just took the measurements, said how we did it and shared our results, I can't really explain the blade passing stuff, it didn't really make sense to us. We thought it was best to put that in the public domain so that people can debate it and have discussions.

Question: Bob Randall

I just should say that if you are trying to measure say 1/3 octave levels in very low frequencies, I saw one graph you had go down to a 0.25Hz and the bandwidth of 0.25 again so you've got a bandwidth of 1/16th of a hertz where just the filter response time is 16 seconds if you are to have a BT=1 that you need for a deterministic signal for an average of 16 seconds.

If there are any random issues your need 16 time that again to get a reasonable … error, you get a 1 dB standard deviation in the error. So your talking about 216 seconds for a reasonable measurement of the randomness in the signal yet alone in the deterministic part. That's just one point.

I really only just heard about infrasound again recently in connection wind turbines from first having heard about it when I was working for Bruel & Kjaer in the late 70s and early 80s and then Dr Bruel did some work in that area with a lot of other people and at that time there was no suggestion that infrasound would be doing any harm through being able to hear it. It was just assumed you couldn't hear it and it was assumed at that time that the effects of the bad, the infrasound if you like that were due to feeling in some other way like the resonance of the stomach at I think at 5 or 6 Hz or the eyeball at 12Hz or similar and they were even talking about the sub 1 Hz region 0.1 – 0.63 range, the sea sickness range, and then maybe that could affect the balance mechanism of the ears. That was not hearing it but coming through the ears.

But the idea at time was the damage was not coming through not being able to hear it but it was affecting the body in some other way. Has that been lost? I mean to say I have been away from it 30 years or something and it seems you assume now you are getting affected by infrasound by hearing it and not by something else through the body.

The 10 second thing, the octave band measurements, that was… and we had a few chats with Bob. I'm not sure if you want to say something now if you're free but, there are a few questions around that but as it stands…In the report there are some other references which might be useful really. …maybe people agree with and maybe people don't…and I actually sensed the levels were higher than the threshold of people…we took it as an opportunity to share our results, I can't really explain the blade passing stuff, it didn't really make sense to us. We thought it was best to put it in the public domain so that

APPENDIX M: Extract from Seri Report

SERI/TR-635-1166
UC Category: 60
DE85002947

Acoustic Noise Associated with the MOD-1 Wind Turbine: Its Source, Impact, and Control

N. D. Kelley
H. E. McKenna
R. R. Hemphill
C. L. Etter
R. L. Garrelts
N. C. Linn

February 1985

Prepared under Task Nos. 1066.70 and 4803.10
WPA No. 171A

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Prepared for the
U.S. Department of Energy
Contract No. DE-AC02-83CH-10093

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- Engineering Dynamics, Inc.
- Fairchild-Weston
- Cornell University, Sibley School of Mechanical and Aerospace Engineering
- The General Electric Company
- Massachusetts Institute of Technology, Department of Aeronautics and Astronautics
- NASA Langley Research Center, Structural Acoustics Branch
- NASA Lewis Research Center, Wind Energy Program Office
- Pacific Northwest Laboratories, Atmospheric Physics Department
- Pennsylvania State University, Departments of Meteorology and Mechanical Engineering
- The Portland General Electric Company
- Rocky Flats Wind Energy Research Center
- University of Colorado-Boulder, Departments of Mechanical and Aerospace Engineering
- University of Virginia, Department of Environmental Sciences

Special thanks are extended to the residents of Boone, North Carolina, particularly those near the MOD-1 site who aided us in this investigation. Some parts of the program could not have been accomplished without the help of SERI staff members Stan Thues, Bob McConnell, and Jane Ullman. Benjamin Bell was responsible for developing much of the computerized, time-domain analysis technique. University of Colorado-Boulder (UCB) engineering undergraduates Robert Wooten, David Dill, and Daniel Schell were responsible for supporting the testing at the Rocky Flats Research Center and provided the bulk of the support and planning for the testing in the UCB wind tunnel. This work was supported by the DOE Wind Energy Technology Division under contracts EG-77-C-01-4042 and DE-AC02-83CH10093.

SUMMARY

This document summarizes the results of an extensive investigation into the physical factors surrounding noise complaints related to the DOE/NASA MOD-1 wind turbine operating near Boone, North Carolina. The work reported here presents the results of investigative efforts of staff members of the Solar Energy Research Institute (SERI) and its subcontractors: the Fluid Dynamics Research Laboratory of the Massachusetts Institute of Technology (MIT), the Departments of Meteorology and Mechanical Engineering of Pennsylvania State University, and the Departments of Mechanical and Aerospace Engineering of the University of Colorado-Boulder.

Complaints of noise emanating from the operating MOD-1 were confined to about a dozen families living within a 3-km radius of the turbine, about half of whom were annoyed frequently. These families represented a very small fraction of the total households within this radial distance, a number exceeding 1000 homes, including most of the town of Boone itself. In summary, the complaints centered on the following perceptions:

- The annoyance was described as an intermittent "thumping" sound accompanied by vibrations.
- A "feeling" or "presence" was described, felt rather than heard, accompanied by sensations of uneasiness and personal disturbance.
- The "sounds" were louder and more annoying inside the affected homes.
- Some rattling of loose objects occurred.
- In one or two instances, structural vibrations were great enough to cause loose dust to fall from high ceilings and create an additional nuisance.

The primary objectives of SERI's investigation have been (1) to identify the physical mechanisms responsible for the generation, propagation, and human response (impact) of the annoying "sounds" related to the operation of the MOD-1 turbine and (2) to develop suggestions for its amelioration.

A definitive set of physical measurements that document the characteristics of the MOD-1 acoustic emissions, the vertical structure of the atmospheric velocity and thermal fields controlling the sound propagation, and the internal acoustic pressure variations and structural vibrations of two of the affected homes has been obtained through a series of field surveys. In addition, a number of supporting wind tunnel and full-scale tests using a small, downwind turbine have been conducted to enhance our basic understanding of the suspected physical processes involved. To aid in the investigation, a numerical model of the noise generation process has also been developed. These field measurements and model results allowed us to conclude the following:

- The annoyance was real and not imagined.

- The source of the annoyance was aerodynamic and involved the passage of the turbine blades through the lee wakes of the large, 0.5-m cylindrical tower legs.
- The coherent characteristics of the radiated acoustic impulses (produced by the leg wake-blade interaction) were responsible for the annoyance of the complaining residents.
- The responsible acoustic impulses were being propagated through the air and, in some instances, being focused on the complainants' homes as a consequence of ground reflection and refraction by the atmosphere.

Using a SERI-developed impulse waveform/energy analysis technique, we tested significant differences in the generation processes associated with the wakes from two of the support legs in the data taken during the June 1980 field survey. The impulses produced during this period were far more intense than those observed during our earlier survey in March-April 1980. The impulse analysis demonstrated that the severity of the intermittent impulses was not a unique function of the leg wake momentum deficit and that other factors were also involved. The analysis further demonstrated that slowing the rotor rotational speed from 35 to 23 rpm would reduce but not eliminate the annoyance.

Our analysis of field studies conducted at the MOD-1 strongly suggests that the leg wake-blade interaction was the ultimate source of the annoying acoustic impulses and that the physical process responsible was aerodynamic in origin. Through both controlled wind tunnel testing and experiments performed using a small, downwind turbine in the natural airflow, we determined that vortex-dominated circulations in the cylinder wakes can cause transient lift fluctuations and therefore be a source of acoustic impulses. In particular, the leg wake influences the severity of the impulses generated by

- providing a spatial coherency parallel to the cylinder's major axis and the spanwise direction of the rotor blade;
- its lateral dimensions;
- its turbulence characteristics (whether broadband chaotic or narrowband discrete);
- its time-varying (dynamic) properties as opposed to mean quantities.

The wake characteristics are externally influenced by conditions in the free-stream that reach the cylindrical tower legs, including embedded perturbations containing turbulent length scales equivalent to the Strouhal shedding frequency. Other important variables are the freestream velocity, the vertical wind shear and hydrodynamic stability of the layer between the surface and hub height, the upwind fetch characteristics, and the wind direction controlling the orientation of the rotor plane with respect to the tower structure.

We have found that a number of turbine design parameters influence the severity of the acoustic impulses, including the rotor airfoil shape (close to stall), the operating angle of attack, and the leg-to-blade distance downwind of the tower. The airfoil shape may be a primary contributor to the impulse generation, particularly when the incidence approaches the stall angle. Factors in the impulse generation at the intersection of the blade and wake are spatially organized turbulent perturbations that simultaneously affect the lift generating portion of the blade span and incorporate length scales ranging from less than a chordwidth to several chords.

Perturbation pressure distributions, resulting from vortex core pressure deficits in the leg wakes, have been shown to adversely influence the blade leading edge pressure gradient, resulting in a transient separation of the blade boundary layer as it passes through the wakes. This is a consequence of the characteristic chordwise pressure distribution of the 44xx-series airfoil shape. Because of a forward shift (towards the stagnation point) in the peak negative pressure with an increasing quasi-steady incidence angle, transient leading edge separation and reattachment, as well as airfoil hysteresis, apparently become more severe when the upwash circulation and core pressure deficits created by the embedded vortices in the leg wakes are encountered. Wind tunnel tests have shown, and comparisons of full-scale field data have confirmed, the existence of a critical turbulent scale defined by the reduced frequency parameter k and covering the range $0.5 \leq k \leq \pi$ or, expressed in terms of a perturbation length scale, $2\pi c > \lambda_p' > c$ (where c is the chord dimension at 80% span). Turbulent structures in these ranges that are spatially coherent in a direction parallel to the span impart the most severe lift fluctuations through an interaction with the blade and account for not only the intense, impulsive acoustic radiation but the generation of strong aeroelastic stresses in the blade structure as well. Critical, unsteady aerodynamic parameters, which have been identified as exerting control over these unsteady processes, include the reduced frequency k (or, equivalently, the perturbation wavelength λ_p'), the quasi-steady incidence angle $\bar{\alpha}$, the perturbation spanwise coherence (with respect to the blade span), and possibly the vortex core pressure deficit Δp_v , all of which are stochastic with narrowband (critical) sensitivities.

An investigation into the role atmospheric propagation plays in the MOD-1 annoyance has shown that surface and ground propagation are negligible in comparison with a combination of terrain reflection and atmospheric refaction. Strong focusing (25 dB or more) of the emitted MOD-1 acoustic impulses as a result of these processes can account for local, far-field enhancements (caustics).

Acoustic and seismic (vibration) measurements taken in two of the affected homes near the MOD-1 site revealed that the structures had been undergoing transient elastic deformation under the periodic acoustic loadings from the turbine's operation. The excitation of lightly damped structural modes has also been responsible for summarily exciting cavity (Helmholtz) and air volume resonances within the rooms of the homes and producing secondary acoustic emissions from loose objects. Possibly very important, however, are the strongly oscillatory (harmonic), low-frequency pressure fields created within the smaller rooms and their relation to annoyance of the residents. A measurement of the indoor threshold perception (audible stimuli but no sensation of vibration) at one of the homes undergoing excitation by the MOD-1 impulsive noise led us to suggest the design goal of limiting peak coherent emission in the 8, 16, 31.5, and 63 Hz standard octave frequency bands (measured on-axis 1.5 rotor diameters upwind or downwind of the subject turbine) to band intensity levels of 60, 50, 40, and 40 dB (re 1 pW m^{-2}), respectively, under all atmospheric and operating conditions. The sensitivity of these threshold levels measured in a Boone home compares favorably with documented cases of human annoyance known to be associated with industrial sources of low-frequency noise.

A number of ways to ameliorate the MOD-1 impulsive noise were investigated. Because the leg wakes were found to be ultimately responsible, the abatement of coherent noise emissions has been targeted towards techniques that convert the offending 2-D, discrete wakes to 3-D chaotic by minimizing the spatially organized wake energy in the critical turbulent length scales. Three aerodynamic spoiling devices designed to be placed around the large, cylindrical tower legs were investigated in terms of their ability to achieve the desired transformation of the wake characteristics. We found that installing a helical strake or fence or covering the leg's cylindrical surface with square vortex generator elements or turbulators, placed over most of the leg's surface extending above and below the rotor disk, provided the necessary wake modification. Tests of a perforated shroud-type spoiler indicated it is unusable when the blade plane is less than three cylinder diameters downstream, but it may be adequate at distances beyond that (cylinder far wake). Additional analysis and testing of this type of spoiling device will be necessary before it can be considered as a solution to the problem.

106

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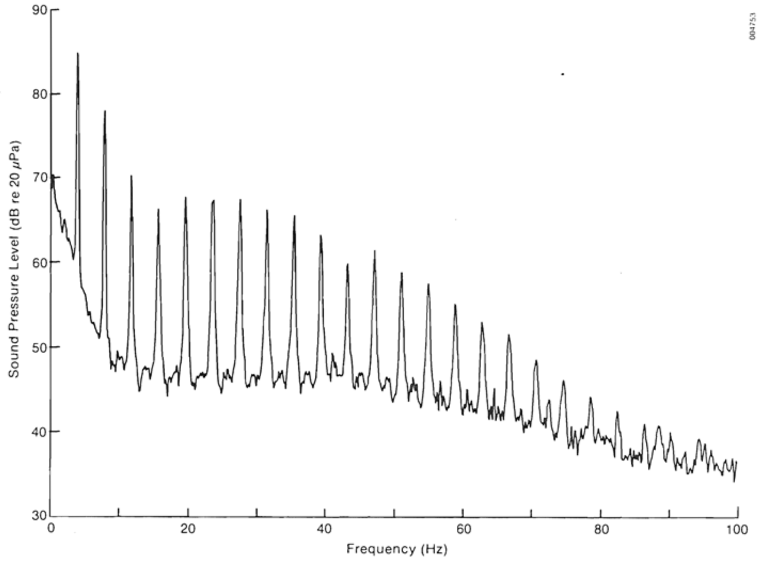

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Figure 5-17. Averaged Acoustic Spectrum as Measured by a VLF Microphone Mounted at the Base of the Cylindrical Test Section (See Figure 5-16)

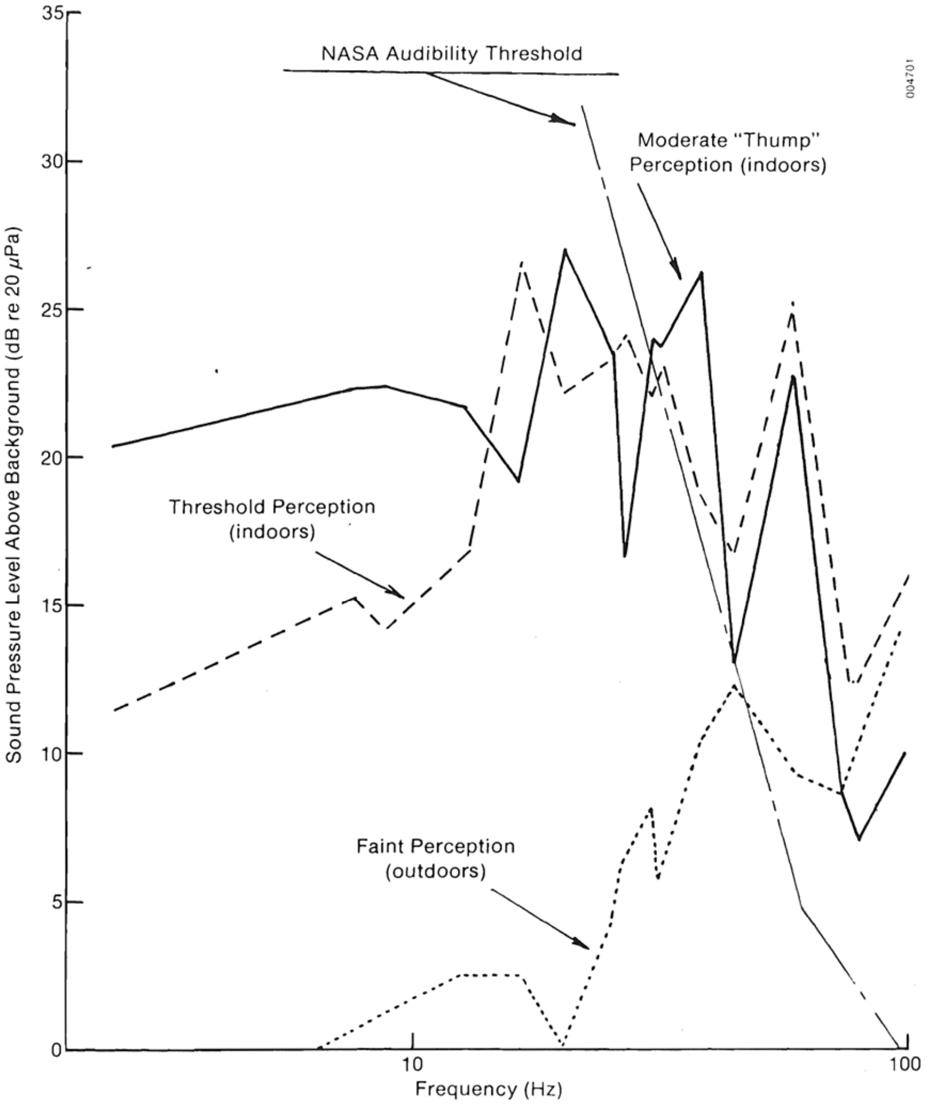


Figure 7-5. Peak Sound Pressure Levels Existing above Background for Moderate Impulsive Excitation (Outdoors and Indoors, House #8) and Threshold Perception (Indoors, House #7) (B_e = 1.25 Hz)

Figure 7-8 plots the details of the outdoor, indoor, and indoor-background 1/3-octave band pressure levels for 100-MW operation of the turbine. It is important to note that while the peak of the external excitation is in the 31.5 Hz band, the indoor peak occurs between the 12.5 and 20 Hz bands and is about 30 dB, on the average, and is higher when the turbine is operating than when it is shut down. The quasi-steady dynamic overpressure for this home is compared with those measured in the two Boone homes in Figure 7-9. Here, the gas turbine and moderate MOD-1 impulse excitation are roughly equivalent up to about 20 Hz, but the former spectrum exhibits a very sharp resonant peak, more than 15 dB greater than the wind turbine, at 25 Hz, followed by a very rapid fall-off--which agrees well with Figure 7-8.

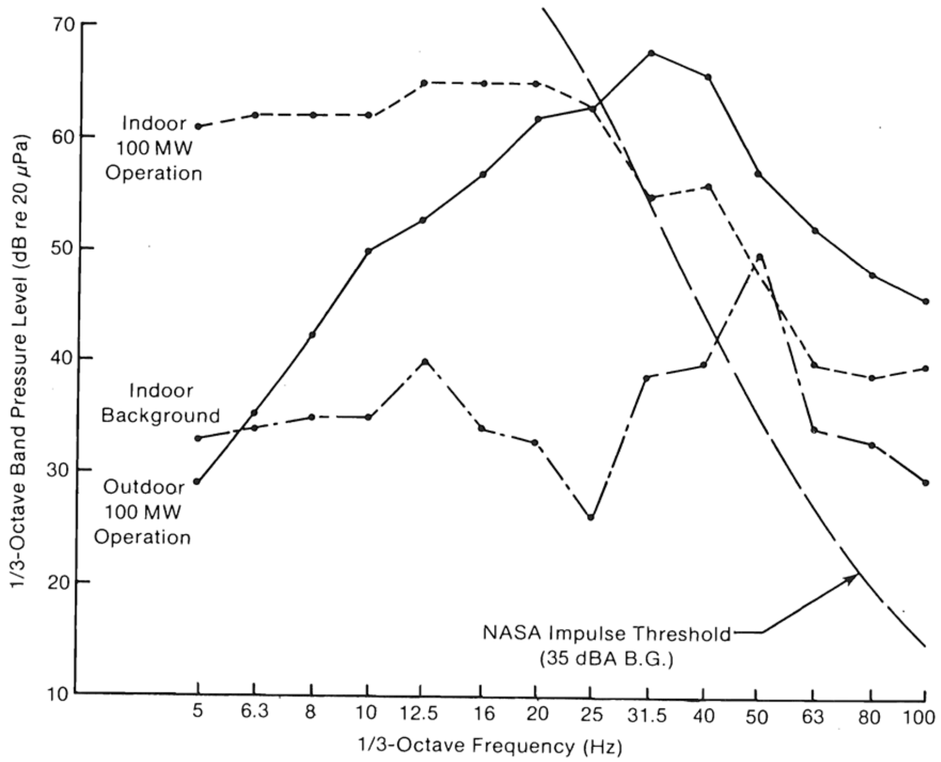
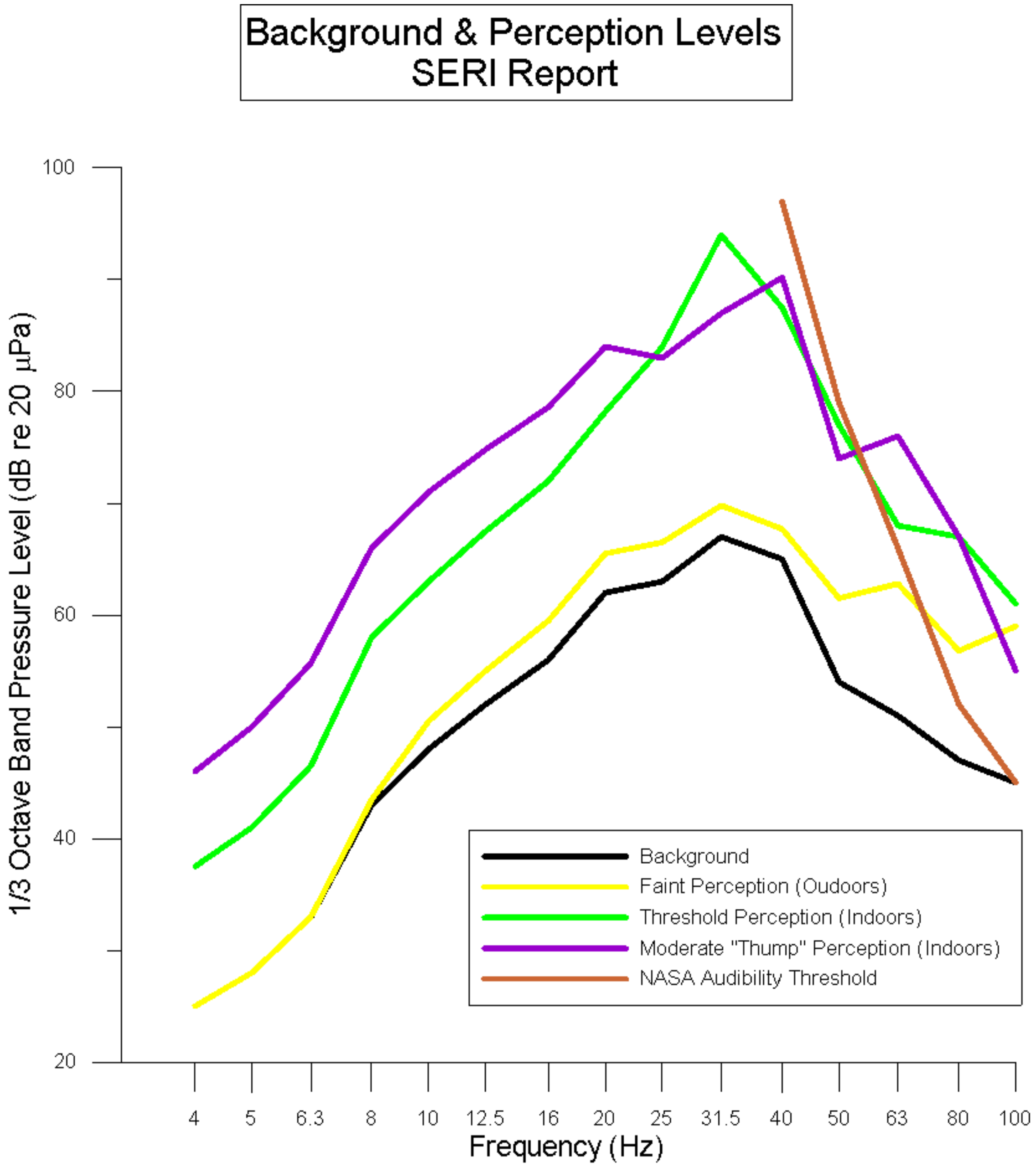


Figure 7-8. Comparison of Averaged External and Internal Acoustic Pressure Fields Associated with Low-Frequency Annoyance from 100-MW Gas Turbine at a Distance of 1 km (B.G. = background)


Background & Perception Levels
SERI Report
1/3 Octave Band Pressure Level (dB re 20 µPa)
100
80
60
40
20
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
100
Frequency (Hz)
Background
Faint Perception (Oudoors)
Threshold Perception (Indoors)
Moderate "Thump" Perception (Indoors)
NASA Audibility Threshold

APPENDIX N: Article from Professor Salt

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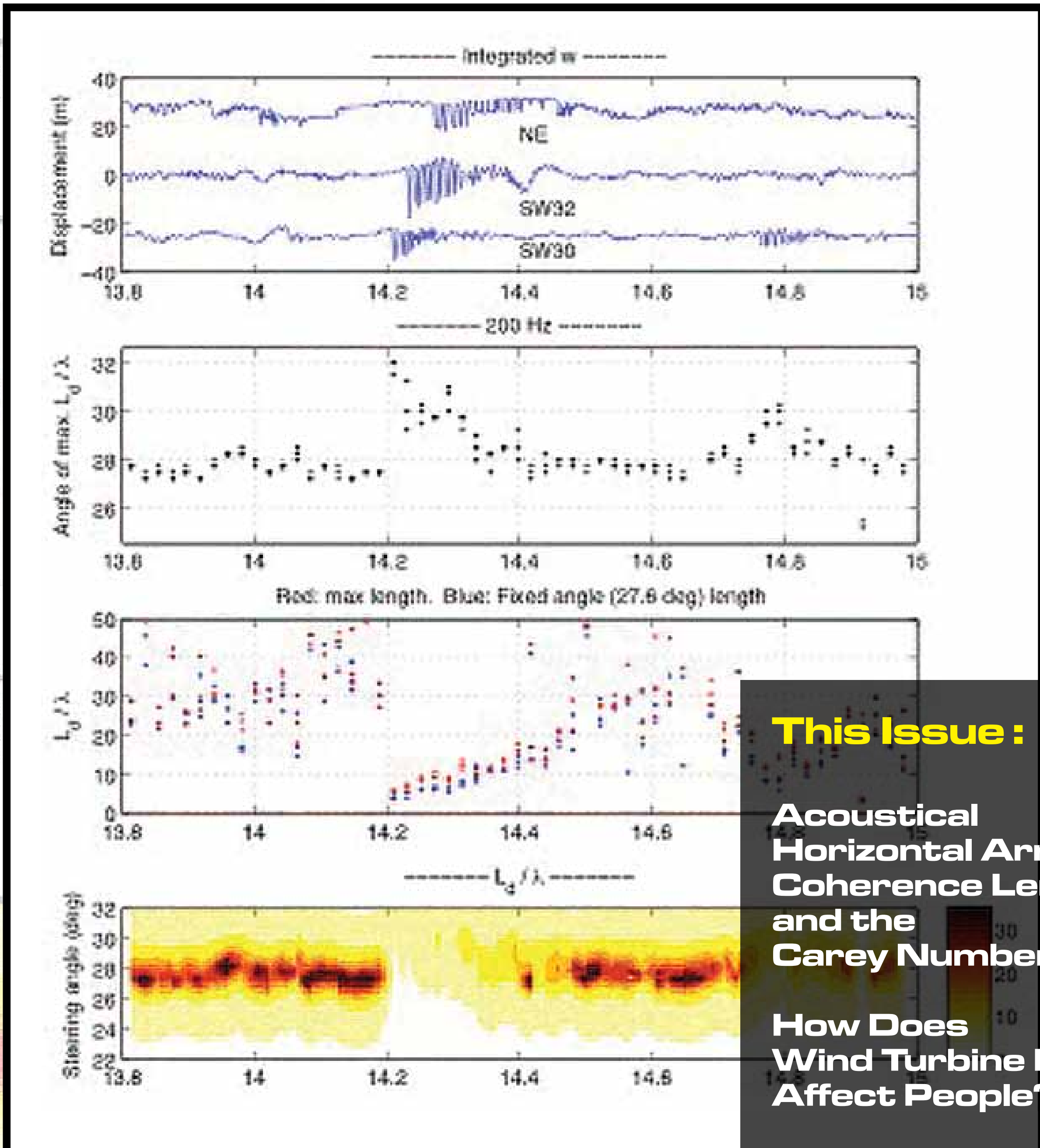

This Issue :

Acoustical Horizontal Array Coherence Lengths and the Carey Number

How Does Wind Turbine Noise Affect People?

Exploring Our Sonic Environment Through Soundscape Research & Theory

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How Does Wind Turbine Noise Affect People?

The many ways by which unheard infrasound and low-frequency sound from wind turbines could distress people living nearby are described.

Introduction

Recent articles in *Acoustics Today* have reviewed a number of difficult issues concerning wind turbine noise and how it can affect people living nearby (Leventhall 2013, Schomer 2013; Timmerman 2013). Here we present potential mechanisms by which effects could occur.

The essence of the current debate is that on one hand you have the well-funded wind industry **1.** advocating that infrasound be ignored because the measured levels are below the threshold of human hearing, allowing noise levels to be adequately documented through A-weighted sound measurements, **2.** dismissing the possibility that any variants of wind turbine syndrome exist (Pierpont 2009) even when physicians (e.g., Steven D. Rauch, M.D. at Harvard Medical School) cannot otherwise explain some patients' symptoms, and, **3.** arguing that it is unnecessary to separate wind turbines and homes based on prevailing sound levels.

On the other hand you have many people who claim to be so distressed by the effects of wind-turbine noise that they cannot tolerate living in their homes. Some move away, either at financial loss or bought-out by the turbine operators. Others live with the discomfort, often requiring medical therapies to deal with their symptoms. Some, even members of the same family, may be unaffected. Below is a description of the disturbance experienced by a woman in Europe we received a few weeks ago as part of an unsolicited e-mail.

"From the moment that the turbines began working I experienced vertigo-like symptoms on an ongoing basis. In many respects, what I am experiencing now is actually worse than the 'dizziness' I have previously experienced, as the associated nausea is much more intense. For me the pulsating, humming, noise that the turbines emit is the predominant sound that I hear and that really seems to affect me.

While the Chief Scientist [the person who came to take sound measurements in her house] undertaking the measurement informed me that he was aware of the low frequency hum the turbines produced (he lives close to a wind farm himself and had recorded the humming noise levels indoors in his own home) he advised that I could tune this noise out and that any adverse symptoms I was experiencing were simply psychosomatic."

“Almost all measurements of wind turbine noise are A-weighted, making the unjustif ed assumption that hearing is the only way by which infrasound generates physiologic effects.”

We asked how she felt when she was away from the wind turbines, to which she replied:

“I did manage to take a vacation towards the end of August and for the two weeks we were away I was perfectly fine.”

The goal of our work in this field is to understand whether the physiology of the ear can, or cannot, explain the symptoms people attribute to wind turbine noise. As it is generally the case when debate influences a specific industry's financial interests and legal well-being, the scientific objectivity of those associated with the industry can be questioned. Liability, damage claims, and large amounts of money can hang in the balance of results from empirical studies. Whether it is a chemical industry blamed for contaminating groundwater with cancer-causing dioxin, the tobacco industry accused of contributing to lung cancer, or athletes of the National Football League (NFL) putatively being susceptible to brain damage, it can be extremely difficult to establish the truth when some have an agenda to protect the status quo. It is only when sufficient scientific evidence is compiled by those not working for the industry that the issue is considered seriously.

Origins of Our Involvement in Infrasound from Wind Turbines

What is the evidence leading us to conclude that unheard infrasounds are part of the wind turbine problem, and how did we become involved in this debate? We are small group of basic and applied scientists, which means that our work addresses fundamental questions on how the ear works in normal and diseased states. While developing paradigms for our studies, we had been using a classic technique called “low-frequency biasing” – measurement of auditory responses to a test sound within the range of audibility, while simultaneously presenting a low-frequency tone (e.g., 4.8 to 50 Hz) to displace the sensory organ of the inner ear. Some auditory responses saturate when displaced by the bias tone, which can be used to establish whether the sensory organ is vibrating symmetrically or whether a fluid disturbance has displaced it to one side. A condition called “endolymphatic hydrops,” which is found in humans with Ménière's disease, can displace the sensory organ as the space containing the fluid called endolymph swells. In our animal experiments we initially used 20 to 50 Hz bias tones, but for many reasons, and in large part based on a study in which we found that the ear responded down to 1 Hz (Salt and DeMott, 1999), we started using the lowest frequency our hardware could generate, 4.8 Hz, a frequency considered to be infrasound. Over the course of hundreds of experiments, we have found numerous biasing effects with 4.8 Hz tones at levels of 80 to 90 dB SPL (i.e., -13 to -3 dBA). We also found that the ear became about 20 dB more sensitive to infrasonic bias tones when the fluid spaces in the cochlear apex were partially occluded, as occurs with endolymphatic hydrops.

In late 2009, the first author received a report of a woman with Ménière's disease whose symptoms – primarily dizziness and nausea – were severely exacerbated when she was in the vicinity of wind turbines. From our animal data, we knew this woman was likely hypersensitive to very low-frequency sounds. Our subsequent review of the literature on wind-turbine noise revealed two aspects that were absolutely astounding:

1. Almost all measurements of wind turbine noise are A-weighted, making the unjustified assumption that hearing is the only way by which infrasound generates physiologic effects. The few studies that reported un-weighted measurements of wind-turbine noise, or recalculated spectra by removing the A-weighting from published A-weighted spectra, clearly demonstrated increasing energy towards low frequencies with highest energy levels in the infrasound region. We were surprised that objective full-frequency measurements showed that wind turbines generate infrasound at levels capable of stimulating the ear in various ways. Under such circumstances, A-weighting measurements of turbine noise would be highly misleading.

2. Literature and websites from the wind industry often contained strong statements that wind turbine infrasound was of no significance. This view was largely based on publications by Leventhall (2006; 2007). Wind turbine noise was described as comparable to rustling leaves, flowing streams, air-conditioned offices or refrigerators heard from the next room. If wind turbine noise really was comparable to such sources then complaints would not be expected. But the turbines sounds are only comparable to these sources if the ultra-low frequencies emitted by the turbines are ignored through A-weighting. Stations that monitor infrasound or low frequency seismic (vibrational) noise for other purposes (for the detection of explosions, meteors, volcanic activity, atmospheric activity, etc.) are well-aware that low frequency sounds emanating from distant wind farms, or coupling to the ground as vibrations, can influence their measurements. The UK, Ministry of Defense has opposed wind turbines cited within 50 km of the Eskdalemuir Seismic Array. We have seen no reports of the Ministry opposing the presence of refrigerators in the region, suggesting they appreciate that sounds emitted from wind turbines and refrigerators are quite different. It was thus quite astounding to see the vast majority of wind turbine noise measurements excluding the low frequency noise content. Given the knowledge that the ear responds to low frequency sounds and infrasound, we knew that comparisons with benign sources were invalid and the logic to A-weight sound measurements was deeply flawed scientifically.

The Ear's Response to Infrasound

Experimental measurements show robust electrical responses from the cochlea in response to infrasound (Salt and DeMott, 1999; Salt and Lichtenhan 2013). This finding was initially difficult to reconcile with measures showing that hearing was notably insensitive to such sounds but the explanation became clear from now-classic physiological studies of the ear showing that the two types of sensory cell in the cochlea had very different mechanical properties (Cheatham and Dallos 2001).

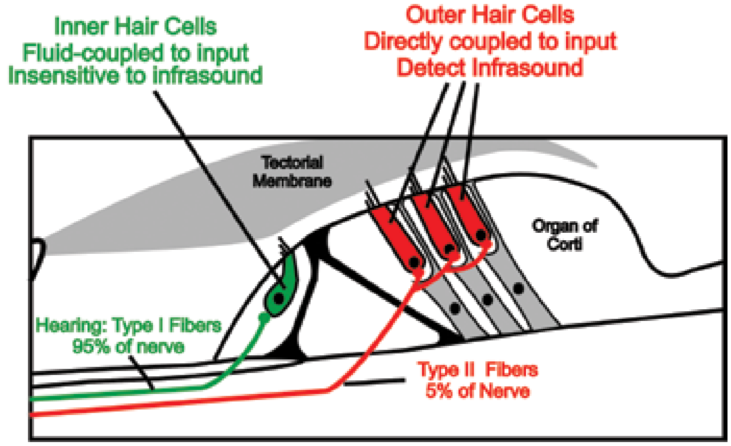


Figure 1 : *T e sensory organ of the cochlea, showing inner and outer hair cell and neural anatomy.*

The auditory portion of the inner ear, the cochlea, has two types of sensory cell. The inner hair cells (IHC; shown green in *Figure 1*) are innervated by type I afferent nerve fibers that mediate hearing. The stereocilia (sensory hairs) of the IHCs are free-floating and do not contact the overlying gelatinous tectorial membrane (shown gray). They are mechanically displaced by fluid movements in the space below the membrane. As their input is fluid-coupled to the vibrations of the sensory organ they exhibit "velocity sensitive" responses. As the velocity of motions decreases for lower-frequency sounds, their fluid-coupled input renders the IHC insensitive to very low-frequency sounds. The other type of sensory cell, the outer hair cells (OHC; shown red in *Figure 1*) are innervated by type II afferent nerve fibers that are not as well understood as type I fibers and probably do not mediate conscious hearing per se. In contrast to the IHC, the stereocilia of the OHCs are inserted into the tectorial membrane. This direct mechanical coupling gives them "displacement sensitive" properties, meaning they respond well to low–frequency sounds and infrasound. The electrical responses of the ear we had been recording and studying originate from the sensitive OHCs. From this understanding we conclude that very low frequency sounds and infrasound, at levels well below those that are heard, readily stimulate the cochlea. Low frequency sounds and infrasound from wind turbines can therefore stimulate the ear at levels well below those that are heard.

The million-dollar question is whether the effects of wind turbine infrasound stimulation stay confined to the ear and have no other influence on the person or animal. At present, the stance of wind industry and its acoustician advisors is that there are no consequences to long-term low-frequency and infrasonic stimulation. This is not based on studies showing that long-term stimulation to low-level infrasound has no influence on humans or animals. No such studies have ever been performed. Their narrow perspective shows a remarkable lack of understanding of the sophistication of biological systems and is almost certainly incorrect. As we consider below, there are many physiologic mechanisms by which long-term infrasound stimulation of the cochlea could have effects.

One important aspect of wind turbine noise that is relevant to its physiological consequences is that the duration of exposure can be extremely long, 24 hours a day and lasting for days or longer, depending on prevailing wind conditions. This is considerably different from most industrial noise where 8 hour exposures are typically considered, interspersed by prolonged periods of quiet (i.e., quiet for 16 hours per day plus all weekends). There are numerous studies of exposures to higher level infrasound for periods of a few hours, but to date there have been no systematic studies of exposure to infrasound for a prolonged period. The degree of low-frequency cochlear stimulation generated by wind turbine noise is remarkably difficult to assess, due to the almost exclusive reporting of A-weighted sound level measurements. It certainly cannot be assumed that cochlear stimulation is negligible because A-weighted level measurements are low. For example, with 5 Hz stimulation cochlear responses are generated at -30 dBA and stimulation is sufficient to cause responses to saturate (indicating the transducer is being driven to its limit) at approximately 20 dBA (Salt and Lichtenhan, 2012; Salt et al., 2013). We have also shown that 125 Hz low-pass filtered noise at just 45 dBA produces larger responses than wide band noise with the same low-frequency content presented at 90 dBA (Salt and Lichtenhan 2012). We conclude that low frequency regions of the ear will be moderately to strongly stimulated for prolonged periods by wind turbine noise. There are a number of plausible mechanisms by which the stimulation could have effects:

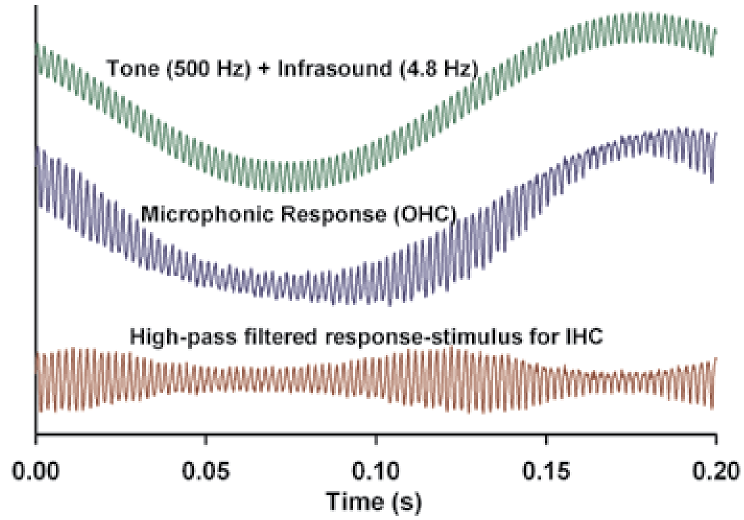


Figure 2 : *Demonstration of biologically-generated amplitude modulation to a non-modulated stimulus consisting of an audible tone at 500 Hz tone summed with an infrasonic tone at 4.8 Hz. The cochlear microphonic response, which is generated by the OHC, includes low and high frequency components. The IHC detect only the high frequency component, which is amplitude modulated at twice the infrasound frequency for the stimuli in this example.*

1. Amplitude Modulation: Low-Frequency Biasing of Audible Sounds

Modulation of the biological mechano-electric transducer of the inner ear by infrasound is completely different from the amplitude modulation of audible sounds that can be measured with a sound level meter near wind turbines under some conditions. This can be demonstrated in low-frequency biasing paradigms in which a low-frequency tone and higher-frequency audible tone are presented simultaneously to a subject.

OHCs respond to both low- and high-frequency components and modulate the high-frequency components by either saturation of the mechano-electric transducer or by cyclically changing the mechanical amplification of high frequencies. IHCs, being insensitive to the low-frequency tone, see a high pass-filtered representation of the OHC response – an amplitude modulated version of the audible probe tone, as shown in *Figure 2*. As hearing is mediated through the IHCs that receive approximately 90-95% of afferent innervation of the auditory nerve, the subject hears the higher-frequency probe tone varying in amplitude, or loudness. A similar biasing influence on cochlear responses evoked by low-level tone pips was explained by the low-frequency bias tone changing OHC-based cochlear amplifier gain (Lichtenhan 2012). This same study also showed that the low frequency, apical regions of the ear were most sensitive to low-frequency biasing. Studies like this raise the possibility that the amplitude modulation of sounds, which people living near wind turbines report as being so highly annoying, may not be easily explained by measurements with an A-weighted sound level meter. Rather, the low-frequency and infrasound levels need to be considered as contributing to the perceived phenomenon. Subjectively, the perceived fluctuation from an amplitude modulated sound and from a low-frequency biased sound are identical even though their mechanisms of generation are completely different. For the subject, the summed effects of both types of amplitude modulation will contribute to their perception of modulation. Acousticians therefore need to be aware that the degree of modulation perceived by humans and animals living near wind turbines may exceed that detected by a sound level meter.

2. Endolymphatic Hydrops Induced by Low Frequency Tones

As mentioned above, endolymphatic hydrops is a swelling of the innermost, membrane bound fluid compartment of the inner ear. Low-frequency tones presented at moderate to moderately-intense levels for just 1.5 to 3 minutes can induce hydrops *(Figure 3)*, tinnitus (ringing in the ears) and changes in auditory potentials and acoustic emissions that are physiological hallmarks of endolymphatic hydrops (Salt, 2004, Drexl et al. 2013).

Unlike the hearing loss caused by loud sounds, the symptoms resulting from endolymphatic hydrops are not permanent and can disappear, or at least fluctuate, as the degree of hydrops changes. Return to quiet *(as in Figure 3)* or relocation away from the low-frequency noise environment allow the hydrops, and the symptoms of hydrops, to resolve. This which would be consistent with the woman's description of her symptoms given earlier. As hydrops is a mechanical swelling of the membrane-bound endolymphatic space, it affects the most distensible regions first – known to be the cochlear apex and vestibular sacculus. Patients with saccular disturbances typically experience a sensation of subjective vertigo, which would be accompanied by unsteadiness and nausea. As we mentioned above, an ear that has developed endolymphatic

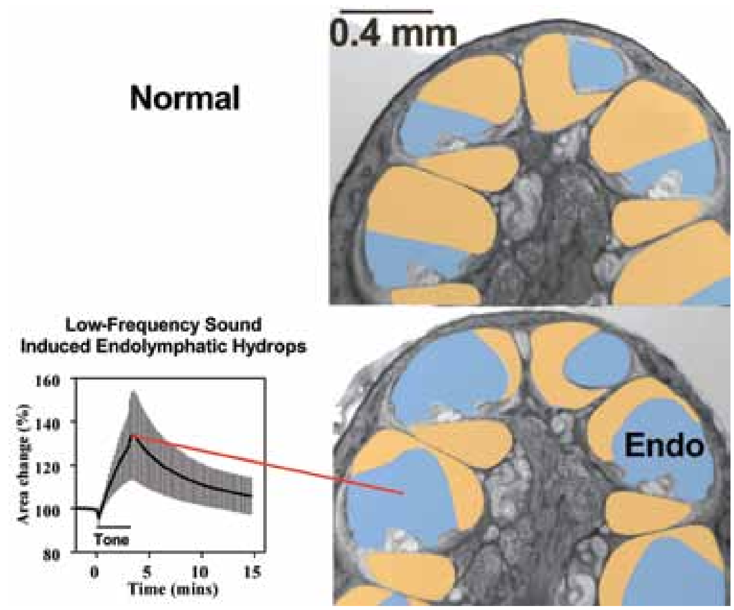


Figure 3 : *Brief exposures to low-frequency tones cause endolymphatic hydrops in animals (Salt, 2004) and tinnitus and acoustic emission changes consistent with endolymphatic hydrops in humans (Drexel et al, 2013). The anatomic pictures at the right show the difference between the normal (upper) and hydropic (lower) cochleae The endolymphatic space (shown blue) is enlarged in the hydropic cochlea, generated surgically in this case.*

low frequencies – has to be considered. To date, all studies of low-frequency tone-induced hydrops have used very short duration (1-2 min) exposures. In humans, this is partly due to ethical concerns about the potential long-term consequences of more prolonged exposures (Drexel et al., 2013). Endolymphatic hydrops induced by prolonged exposures to moderate levels of low-frequency sound therefore remains a real possibility.

3. Excitation of Outer Hair Cell Afferent Nerve Pathways

Approximately 5-10% of the afferent nerve fibers (which send signals from the cochlea to the brain - the type II fibers mentioned above) synapse on OHCs. These fibers do not respond well to sounds in the normal acoustic range and they are not considered to be associated with conscious hearing. Excitation of the fibers may generate other percepts, such as feelings of aural fullness or tinnitus. Moreover, it appears that infrasound is the ideal stimulus to excite OHC afferent fibers given what has been learned about these neurons from *in vitro* recordings (Weisz et al, 2012; Lichtenhan and Salt, 2013). *In vivo* excitation of OHC afferents has yet to be attempted with infrasound, but comparable fibers in birds have been shown to be highly sensitive to infrasound (Schermuly and Klinke, 1990). OHC afferents innervate cells of the cochlear nucleus that have a role in selective attention and alerting, which may explain the sleep disturbances that some people living

"The million-dollar question is whether the effects of wind turbine infrasound stimulation stay confined to the ear and have no other influence on the person or animal."

near wind turbines report (Nissenbaum et al. 2012). The likelihood that OHC afferents are involved in the effects of low-frequency noise is further supported by observations that type II innervation is greatest in the low-frequency cochlear regions that are excited most by infrasound (Liberman et al. 1990, Salt et al. 2009).

4. Exacerbation of Noise Induced Hearing Loss

Some years ago we performed experiments to test a hypothesis that infrasound was protective against noise damage (Harding et al. 2007). We reasoned that low-frequency biasing would periodically close the mechano-electric transducer channels of the sensory organ (reducing electrical responses as shown in the biasing studies above), and consequently reduce the amount of time that hair cells were exposed to the damaging overstimulation associated with noise exposure. The experimental study found that just the opposite was true. We found that simultaneous presentation of infrasound and loud noise actually exacerbated noise-induced lesions, as compared to when loud noise was presented without infrasound. Our interpretation was that low-frequency sound produced an intermixing of fluids (endolymph and perilymph) at the sites of hair cell loss resulting in lesions that were larger. A possibility to be considered is therefore that long-term exposure to infrasound from wind turbines could exacerbate presbycusis and noise-induced hearing loss. Because these forms of hearing loss develop and progress slowly over decades, this could be a lurking consequence to human exposures to infrasound that will take years to become apparent.

5. Infrasound Stimulation of the Vestibular Sense Organs

Recent exchanges in this journal between Drs. Leventhall and Schomer concerning the direct stimulation of vestibular receptors by sound at low and infrasonic frequencies deserve comment. Dr. Leventhall asserts that both Drs. Schomer and Pierpont are incorrect in suggesting that wind turbine infrasound could stimulate vestibular receptors, citing work by Todd in which the ear's sensitivity was measured in response to mechanical low-frequency stimulation applied by bone conduction. Leventhall fails to make clear that there are no *studies* reporting either vestibular responses, or the absence of vestibular responses, to acoustically-delivered infrasound. This means that for all his strong assertions, Leventhall cannot refer to any study conclusively demonstrating that vestibular receptors of the ear do *not* respond to infrasound. Numerous studies have reported measurements of saccular and utricular responses to audible sound. Indeed, such measurements are the basis of clinical tests of saccular and utricular function through the VEMP (vestibular-evoked myogenic potentials). Some of these studies have shown that sensitivity to acoustic stimulation initially declines as frequency is lowered. On the other hand, *in vitro* experiments demonstrate that vestibular hair cells are maximally sensitive to infrasonic frequencies (~1 – 10 Hz). Thus, sensitivity to acoustic stimulation may increase as stimulus frequency is lowered into the infrasonic range. Direct *in vivo* vestibular excitation therefore remains a possibility until it has been shown that the saccule and other vestibular receptors specifically do not respond to this stimulation.

Low-frequency tone-induced endolymph hydrops, as discussed above, could increase the amount of saccular stimulation by acoustic input. Hydrops causes the compliant saccular membrane to expand, in many cases to the point where it directly contacts the stapes footplate. This was the basis of the now superseded "tack" procedure for Ménière's disease, in which a sharp prosthesis was implanted in the stapes footplate to perforate the enlarging saccule (Schuknecht et al., 1970). When the saccule is enlarged, vibrations will be applied to endolymph, not perilymph, potentially making acoustic stimulation of the receptor more effective. There may also be certain clinical groups whose vestibular systems are hypersensitive to very low-frequency sound and infrasound stimulation. For example, it is known that patients with superior canal dehiscence syndrome are made dizzy by acoustic stimulation. Subclinical groups with mild or incomplete dehiscence could exist in which vestibular organs are more sensitive to low frequency sounds than the general population.

"For years, they have sheltered behind the mantra, now shown to be false, that has been presented repeatedly in many forms such as 'What you can't hear, can't affect you.'"

6. Potential Protective Therapy Against Infrasound

A commonly-used clinical treatment could potentially solve the problem of clinical sensitivity to infrasound. Tympanostomy tubes are small rubber "grommets" placed in a myringotomy (small incision) in the tympanic membrane (eardrum) to keep the perforation open. They are routinely used in children to treat middle ear disease and have been used successfully to treat cases of Ménière's disease. Placement of tympanostomy tubes is a straightforward office procedure. Although tympanostomy tubes have negligible influence on hearing in speech frequencies, they drastically attenuate sensitivity to low frequency sounds (Voss et al., 2001) by allowing pressure to equilibrate between the ear canal and the middle ear. The effective level of infrasound reaching the inner ear could be reduced by 40 dB or more by this treatment. Tympanostomy tubes are not permanent but typically extrude themselves after a period of months, or can be removed by the physician. No one has ever evaluated whether tympanostomy tubes alleviate the symptoms of those living near wind turbines. From the patient's perspective, this may be preferable to moving out of their homes or using medical treatments for vertigo, nausea, and/or sleep disturbance. The results of such treatment, whether positive, negative, would likely have considerable scientific influence on the wind turbine noise debate.

Conclusions and Concerns

We have described multiple ways in which infrasound and low-frequency sounds could affect the ear and give rise to the symptoms that some people living near wind turbines report. If, in time, the symptoms of those living near the turbines are demonstrated to have a physiological basis, it will become apparent that the years of assertions from the wind industry's acousticians that "what you can't hear can't affect you" or that symptoms are psychosomatic or a nocebo effect was a great injustice. The current highly-polarized situation has arisen because our understanding of the consequences of long-term infrasound stimulation remains at a very primitive level. Based on well-established principles of the physiology of the ear and how it responds to very low-frequency sounds, there is ample justification to take this problem more seriously than it has been to date. There are many important scientific issues that can only be resolved through careful and objective research. Although infrasound generation in the laboratory is technically difficult, some research groups are already in the process of designing the required equipment to perform controlled experiments in humans.

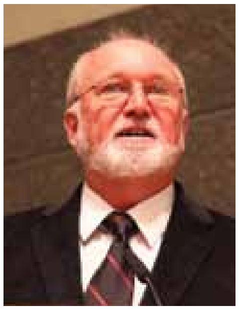
One area of concern is the role that some acousticians and societies of acousticians have played. The primary role of acousticians should be to protect and serve society from negative influences of noise exposure. In the case of wind turbine noise, it appears that many have been failing in that role. For years, they have sheltered behind the mantra, now shown to be false, that has been presented repeatedly in many forms such as "What you can't hear, can't affect you."; "If you cannot hear a sound you cannot perceive it in other ways and it does not affect you."; "Infrasound from wind turbines is below the audible threshold and of no consequence."; "Infrasound is negligible from this type of turbine."; "I can state categorically that there is no significant infrasound from current designs of wind turbines." All of these statements assume that hearing, derived from low-frequency-insensitive IHC responses, is the only mechanism by which low frequency sound can affect the body. We know this assumption is false and blame its origin on a lack of detailed understanding of the physiology of the ear.

Another concern that must be dealt with is the development of wind turbine noise measurements that have clinical relevance. The use of A-weighting must be reassessed as it is based on insensitive, IHC-mediated hearing and grossly misrepresents inner ear stimulation generated by the noise. In the scientific domain, A-weighting sound measurements would be unacceptable when many elements of the ear exhibit a higher sensitivity than hearing. The wind industry should be held to the same high standards. Full-spectrum monitoring, which has been adopted in some reports, is essential.

In the coming years, as we experiment to better understand the effects of prolonged low-frequency sound on humans, it will be possible to reassess the roles played by acousticians and professional groups who partner with the wind industry. Given the present evidence, it seems risky at best to continue the current gamble that infrasound stimulation of the ear stays confined to the ear and has no other effects on the body. For this to be true, all the mechanisms we have outlined (low-frequency-induced amplitude modulation, low frequency sound-induced endolymph volume changes, infrasound stimulation of type II afferent nerves, infrasound exacerbation of noise-induced damage and direct infrasound stimulation of vestibular organs) would have to be insignificant. We know this is highly unlikely and we anticipate novel findings in the coming years that will influence the debate.

From our perspective, based on our knowledge of the physiology of the ear, we agree with the insight of Nancy Timmerman that the time has come to "acknowledge the problem and work to eliminate it".

Biosketches



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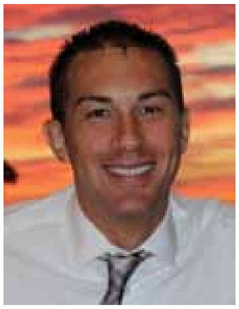

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