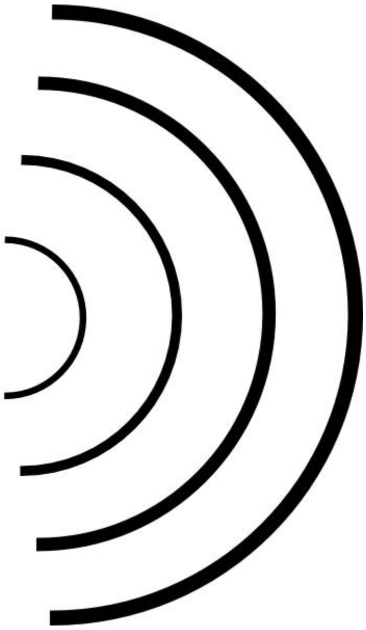
Wind Turbine Noise Impact Assessment Where ETSU is Silent

By: Richard Cox, David Unwin and Trevor Sherman



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Front cover: Site for the proposed Winwick wind farm, Northamptonshire

Foreword

"A rigorous review of how wind turbine noise is assessed is long overdue. The issues raised have far reaching implications for the industry and the entire nation".

Chris Heaton-Harris MP (Daventry, Con)

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The reference documents listed at pages 59 and 60 are available on a CD at a nominal cost. Contact wind-noise@tsp-uk.co.uk

Key Findings

Failure to comply with the intent of ETSU by developers facilitated by the lack of detailed guidance in ETSU has occurred in all the wind farm noise assessments we have reviewed.

- There has been a failure to use suitable microphone wind screens which include secondary wind screens. Measured background noise values are therefore higher than the true values as they include wind noise contamination at the microphone. The consequence of these artificially high measured levels of noise is that the noise limits that apply for the life of the wind farm are calculated to be higher than they should be. The artificially high noise levels have provided justification for significantly reduced separation distances between turbines and residential areas. The failure to use secondary wind screens has probably resulted in measurement errors of significantly greater than 10dB (corresponding to a doubling or more of allowed noise loudness).

- There has been a failure adequately to consider the effects of wind shear during wind farm noise assessments. High levels of wind shear at intermediate wind speeds significantly increase noise intrusion particularly during the night. Either very low levels of wind shear have been factored into the developer's assessments or the effects of wind shear have been totally ignored. However, wind shear was found to be high at the sites in Northamptonshire where wind data was made available to us.

- There has been a failure correctly to analyse the measured background noise data when plotting the average noise curve through the data points. This has resulted in errors, usually in the developer's favour allowing higher levels of turbine noise at wind speeds when complaints are most likely.

- There has been a failure correctly to apply or test the standard turbine noise prediction calculation model resulting in under prediction of turbine noise levels.

- There has been a failure to allow for measurement tolerances and assessment uncertainties arising at each stage of the noise assessment. Excluding wind screen errors, it is estimated that an accumulation of assessment uncertainties of greater than around +/-10dB can occur (resulting in a doubling or halving of noise loudness).

- There has been a failure to address adequately excess amplitude modulation, (EAM) the highly intrusive noise occurring when the normal turbine 'swish' noise changes to a banging or thumping noise. We found that the Salford report [Ref: 30] into EAM was carried out in a less than rigorous way for identifying EAM and noise complaints. The Salford report is also now outdated as turbine sizes have increased significantly since 2007.

These failures of guidance have continued throughout the period since 1997 when Government policy on wind farms closely followed the advice provided by two acoustic consultancies, Hayes McKenzie Partnership and Hoare Lea Acoustics [Ref: Appendix D].

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Contents

Section 1 - Executive Summary and Recommendations

Sections 2 and 3 of this Report examine the *de facto* standard method, ETSU-R-97, used for assessing the likely noise nuisance from wind turbines that was produced in the mid-1990s and is usually referred to as 'ETSU'. The basis of the assessment is that background noise will mask the turbine noise and that both the background noise and turbine noise increase with increasing wind speed. To test whether or not the noise will be within acceptable limits, ETSU requires applicants to measure the background noise at sites at risk, correlate this with the simultaneous wind speeds measured at the proposed turbines' site, make model predictions of the likely turbine noise and then compare these two sets of values with a series of derived noise limits. If the wind farm gains planning consent, the imposed planning conditions include the noise limits and complaints procedure that apply for the life of the wind farm. Although it might be assumed that the science on which the ETSU processes rests is sound and that the data and analyses presented can be relied upon, we demonstrate this is not true.

Section 2 of this Report deals with the background to the ETSU guidance where it shows that it was originally defined by a small group of acoustics consultants (see Appendix D), many of whom have subsequently appeared as authors of the noise assessments embedded in developers' environmental impact statements, and at a time (1997) when the turbines were much smaller than currently being installed. This was also before some of the adverse effects of turbine noise had been fully recognised. Analysis of some 67 planning inquiry decision letters since 2009 [Ref: 17] shows that likely noise nuisance has never been cited as the sole reason to disallow an application and in only a few cases has it been cited as a contributing reason for such a decision. At first sight it would thus seem that the ETSU process is reliable and that concerns about wind farm noise are misplaced. However, this Report adduces evidence to suggest that this view cannot be sustained. Uncertainties that are intrinsic to the process mean that it is far less reliable than has hitherto been assumed. Much of the evidence presented in support of this view relates to parts of the process where the ETSU document does not provide sufficient guidance, in fact to places where it is remarkably 'silent'. Consequently, most if not all wind farm applicants have incorrectly interpreted the ETSU guidance and presented invalid noise assessments.

Section 3 examines sources of uncertainty in the measurement of the background noise upon which the entire process rests. It is shown that there are serious issues of sampling in time (is the period for which data collected truly representative?) and space (have the most at risk locations been adequately monitored or even identified?). An important finding is that, despite early advice to the contrary (see Appendix C) and statements in the ETSU document [Ref: 01] itself, it is likely that possibly all recent noise assessments use data collected from microphones that are inadequately shielded, such that the data are contaminated by the noise of the wind itself. This has two effects. First it raises the level of background noise used as reference and, second, it increases the apparent correlation with wind speed. In planning terms this will allow consents to place turbines that are closer to the nearest at risk properties than ETSU originally intended.

Section 4 and Appendix A examine a second area where ETSU is also silent and where current practice fails to recognise unavoidable intrinsic uncertainty. ETSU asks that a 'best fit curve' is fitted to the background noise data plotted against wind speed in order to determine the average reference background noise over the range of wind speeds. It is from these curves that the noise limits are derived. It is shown that no acoustic theory guides the choice of curve so that typically quadratic, cubic, or even quartic polynomial functions all seem to provide a reasonable statistical fit to the data and are used interchangeably. It is shown that, although it can add an uncertainty of at least +/- 2dB to the values used as reference, the choice of function is more-or-less arbitrary. Almost any curve threaded through the data could have been used. In two real examples the uncertainty is shown to be at least +/- 2dB and it is most evident at moderate winds. As far as the authors are aware, this is the first time this aspect of the ETSU process has been examined and it is additional to issues to do with the establishment of background noise where the variation dominated by some other factor, as for example the time of day at properties close to major traffic routes.

Section 5 deals with uncertainties that arise from hypothetical ('model') calculations of the turbine noise at the 'at risk' locations and times. Typically, developers do not specify which model of turbine is to be installed relying instead on noise emission data for a 'candidate turbine'. Here it is shown that there is uncertainty in the ways by which manufacturers report the emitted noise, between different 'candidate turbines', and in all probability engineering variations between turbines of nominally the same design. These data are then input into a standard noise prediction model defined in ISO9613-2 and used, together with essentially arbitrary assumptions about the absorption of the noise *en route,* to predict the noise at the at risk locations. Even the ISO9613-2 model itself recognises at least +/-3dB of calculation uncertainty in these predictions, but in any specific implementation the engineering and turbine choice variability will add to this perhaps +/- 2dB giving a total uncertainty in this part of the process of around +/- 4dB.

Section 6 and Appendix B looks at the effects of wind shear, which is shown to be higher at some sites than would have been assumed. Wind shear is the change of wind speed and direction with height above ground level caused by a combination of ground roughness and atmospheric stability. Although seemingly aware of the issue, ETSU is silent on how this is to be factored into noise assessments. High wind shear is the condition when the wind speed at upper elevations is much higher than at lower elevations. When using just a single wind speed at some reference height to predict both the turbine and background noise it is necessary to make an assumption about the rate at which this change with height takes place. If high shear is present and not factored into the predictions, the result is to underestimate wind speed at the turbine hub height and to overestimate it at near ground level. The effects are that we have more noise emitted and less masking of this noise near ground level than under low shear conditions. Analysis of the available data for the proposed wind farm at Winwick (Northants) and at nearby sites shows that high levels of shear occur for around 10% of the time, with a particular concentration during the evenings and at night. Noise assessments by wind farm developers have either failed to consider wind shear or applied very low levels of correction such that they consistently under estimate the likely noise nuisance. In common with other recent authors, this Report argues that the so-called 'Article Method' for considering wind shear being promulgated by some acousticians is not only unnecessarily complex but it leads to an even more permissive regime than currently in force. This is being seized upon by the wind power consulting community since it would allow them to demonstrate justification for reduced separation distances between turbines and houses.

Section 7 examines uncertainty. Noise assessment is no different from any other area of science or engineering in that any process requiring measurements and modelling will be subject to error and uncertainty. Recognising that such errors can work in different directions, by adding or subtracting, it is suggested that a sound difference of +/- 10dB from prediction could easily occur that will either double or halve the noise loudness received and is additional to the errors arising from microphone wind induced noise and wind shear.

Section 8 summarises the growing evidence related to excess amplitude modulation (EAM) that also seems to be associated with times of high wind shear. The phenomenon is compared to the well-understood and analogous one of 'blade slap' associated with helicopters. It is concluded that the 'standard' condition applied at planning appeals is ineffective at detecting the pulsing nature of EAM and that only by measuring using a much shorter sampling time period can it reliably be detected.

Finally in Section 9 a summary is presented of some other reasons that have been suggested why ETSU should be reviewed. There are continuing debates about the use of the L_{A90} measurement rather than the others such as the L_{A50}, over the use of the 'A' rather than the 'C' weighting, and over the appropriateness of the levels of the minimum day time noise limit of 35 – 40dB (A) and more particularly the higher night time limit of 43dB (A) that is out of line with World Health Organisation sleep disturbance limits.

Recommendations

The main recommendations that arise from the presented evidence in this report are;

- There is a compelling case for retrospective background noise surveys to be repeated in properly controlled conditions using suitable wind screens to enable more representative noise limits to be established. There is a strong case for commissioning a truly independent controlled study to assess the full magnitude of the effect. We propose that this study is completed at three classes of onshore wind farm site: 1) where permission is granted and the turbines have not been constructed; 2) at sites where there have been noise complaints; 3) at a sample of operating sites.

- It is clear that ETSU as currently defined is simply not fit for the purpose for which it was intended. It should be subjected to independent review from a truly independent multi-disciplinary working group of experts who have no financial interest in wind farm development and under the auspices of a government agency whose objectives do not include the encouragement of renewable energy. The Institute of Acoustics wind farm working group currently preparing technical guidance for DECC on the implementation of ETSU as reported by Charles Hendry MP on 19 June 2012 [Appendix E) clearly does not meet these requirements.

Section 2 - Introduction

The need for this Report

This Report draws on the experiences of the authors [See Biographies] as residents of rural Northamptonshire where we are faced with a flood of wind farm planning applications. Daventry District in the north west of the county is currently seeing the highest concentration of wind turbine development in the UK. This development is taking place despite Northamptonshire experiencing some of the lowest average wind speeds in the UK.

The objective of this Report is to illuminate some of the obscure areas in the process recommended in *Planning Guidance PPG22* for assessing the likely noise nuisance from wind turbines that is enshrined in the work of an expert group that met in the mid-1990s and most commonly referred to as ETSU-R-97 (Ref: 01) or known simply as ETSU. (It should be noted that PPG22 has since been cancelled but the PPS22 Companion Guide has been retained) We began our research on the assumption that, although we might argue about the limits suggested, the process itself rested on firm ground with the backing of sound scientific methods and principles.

Reading wind farm appeal decision letters from the Planning Inspectorate [Ref: 17] since 2009 shows that by and large, planning inspectors have shared this assumption. Yet our work at public inquiries in Northamptonshire over the last five years has shown us otherwise, such that we have come to the view that, although the *process* itself might be sound, the implementation of the measurements and analysis on which it is based leave a great deal to be desired. It is in precisely these same areas that ETSU is silent.

At Local Planning Authority (LPA) determination meetings, and the now almost inevitable ensuing public inquiries, the inherent uncertainties in the acoustic evidence presented by the applicants are routinely ignored. The result has been to allow proposals to be consented when consideration of these uncertainties might well have counselled greater caution regarding the consents themselves, the so-called 'separation distances' of turbines from dwellings, or, failing these, on the planning conditions attached.

The evidence as shown at Appendix D leads us to believe that the technical guidance on wind farm noise assessment over recent years has been dominated by four acousticians, Malcolm Hayes and Andrew McKenzie of Hayes McKenzie Partnership (HMP) and Andrew Bullmore and Mark Jiggins of Hoare Lea Acoustics. These four acousticians were involved in the original ETSU working group and have continued to provide on-going official technical guidance ever since either directly to the Department of Energy and Climate Change (DECC) or indirectly through the Institute of Acoustics (IoA).

However, these same consultants are also actively involved in representing wind farm developers with respect to noise assessments so have a financial interest in the development of wind power. As a result the objectivity and impartiality of their guidance might well be questioned.

Similarly, DECC (formerly the DTI) is the Government department responsible for developing wind power and removing obstacles that may impede its development. DECC is seen by many as playing only lip service to the protection of wind farm neighbours from noise impacts. There is a clear conflict of interest.

Noise is probably the most technically complex issue for planning decision makers to understand. This applies equally to local authority planners, environmental health officers (EHO's) and planning inspectors. These planning decision makers and particularly EHO's seem reluctant to challenge the *status quo* regarding noise assessments from professional acousticians representing developers. There is a serious concern that the unnecessarily complex nature of wind farm noise assessment is creating a 'no-go' area for planning decision makers leaving noise assessments wide open to abuse.

Indeed analysis of 67 wind farm planning appeal decisions [Ref: 17] covering the period Feb 2009 to Feb 2012 shows that no planning appeal was refused solely on noise impact and only three appeals were refused where noise was stated as a joint reason for refusal. Meanwhile, as turbines sizes have increased, (now typically 90m diameter and 80m hub height) we see separation distances between turbines and residential areas being reduced as developers continually push the limit such that less than 500m separation distances are now routinely allowed, (e.g. Watford Lodge and Lilbourne wind farms).

The increased incidence of wind farm noise complaints, the lack of confidence in the existing noise guidelines and the lack of effective noise nuisance enforcement all point to a need for an independent review of wind farm noise assessment guidance. With the apparent conflicts of interest with DECC and the IoA consultants, it therefore became clear to the authors that exposing any failings with the existing noise guidance would have to come from outside the professional acoustics community and from outside of DECC.

Although not qualified acousticians, the authors and contributors to this report are from the scientific, engineering and management consulting professions and are competent to understand the issues, theoretical, practical and social of wind turbine noise assessment.

ETSU-R-97 noise guidelines

The process outlined by the working panel on wind turbine noise [Ref: 01] in ETSU has two key inputs, survey data on the background noise established over a range of wind speeds referenced to wind speed 10m above ground (AGL), V_{10}, using the $L_{A90\ 10min}$ weighted measure and a prediction of the turbine generated noise at selected receptors.

In technical terms, $L_{A90\ 10min}$ is the tenth percentile of the distribution of the A-rated sound level measured over a ten minute period. In non-technical terms, it is calculated by measuring the noise level over a ten minute period, disregarding the noisiest 90% of the time and taking the maximum noise level in the remaining (quietest) 10% of the time. Some acousticians have queried the suitability of this measure. ETSU chose to use V_{10} as the basic reference for wind speed observations because 10 metres is the standard height used in operational meteorology and climatology.

In order to assess the noise impact of a proposed wind farm, a series of measurements of pre-existing background noise and site wind speeds are undertaken and incorporated into a five step process defined in the ETSU guidance as:

1. Measure pre-existing background noise;
2. Measure turbine site wind speeds;
3. Define limits;
4. Predict turbine noise levels;
5. Assess compliance with the limits.

ETSU was published before the current generation of typically 80m hub height turbines with 90m diameter rotors, but, for better or worse, its methodologies are endorsed in the *Companion Guide to PPS22* (Note that PPG22 was the precursor to PPS22, both issued during 2004). However, there are hidden complications in each step in the suggested process. Specifically, the ETSU guidance does not specify how these values are to be obtained, such that it is possible to follow the ETSU guidance as mandated by PPS22, yet still arrive at differing conclusions with respect to the predicted noise nuisance.

This report investigates these areas of the noise assessment process where guidance is either weak or missing from ETSU. They include background measurements and data analysis, wind shear and amplitude modulation. As a result of these gaps in guidance we are seeing noise assessments being conducted by wind power developers leading to planning permissions being granted that claim compliance with the ETSU process and limits yet which fail to provide the protection from noise that was intended when ETSU was written. This report also includes comments on some of the perceived errors in what ETSU does say that the authors believe require further study or investigation.

DECC report dated April 2011

During April 2011 the Department of Energy and Climate Change (DECC) issued a report [Ref: 02] titled, '*Analysis of How Noise Impacts are Considered in the Determination of Wind Farm Planning Applications*' prepared for DECC by Hayes McKenzie Partnership (HMP). The key objectives of the DECC report were:

- "*To investigate the way in which noise impacts for a wind farm are determined in England, including methods used in practice to implement the ETSU-R-97 Guidance.*
- *To provide recommendations to Government on ways in which ETSU-R-97 can be applied in a more consistent and effective manner, taking into account best practice*."

Their report reviewed the way in which noise impacts for wind farms are being determined in England including the methods used in practice to implement the ETSU guidance. The appointment of HMP by DECC to carry out this research contract was controversial at the time since the same company has represented many wind farm developers and produced many of the noise assessments reviewed. We comment throughout this Report on the findings of this DECC report.

Section 3 - Background Noise Measurement

Background noise can help mask the noise effects of wind turbines so the level of masking is a critical factor in assessing the noise impact of a proposed wind farm. Background noise is the ambient noise present when neither the noise being studied nor any intermittent or occasional noises are present. Intermittent noise events such as that from aircraft, dogs barking, mobile farm machinery and the occasional vehicle travelling along a nearby road are all part of the ambient noise environment but should not be considered part of the background noise unless they are present for at least 90% of the time.

Establishing background noise levels provides the foundation of a wind farm noise assessment since it provides the data from which the noise limits are established. These limits are subsequently compared with the predicted noise during the planning application process to determine if the proposed development is acceptable with regard to any potential noise impact. These limits are also used throughout the life of the wind farm, typically for 25 years, to test for compliance when investigating any noise complaints.

In the event of noise complaints where the measured noise levels are found to be within the established limits it is unlikely that any further action would be taken by the LPA against the wind farm operator. It is therefore very important that the limits are appropriate to protect nearby residents so it is essential that accurate background noise level measurements are made.

It was the surprisingly high levels of background noise claimed by developers at several Northamptonshire wind farm development sites that prompted an investigation by the authors of this report to assess whether or not these claimed background noise levels are correct or subject to undisclosed errors and uncertainty.

Sound measuring equipment and wind induced noise

The sound level meters and microphones used for wind farm assessments generally conform to IEC 61672-1: 2002 Class 1 accuracy limits. However, when measuring background noise, the microphone will detect the sum of the background noise we want to measure (including the effects of wind on leaves, bird song, road traffic etc.) plus the effect of the wind directly on the microphone. Wind induced noise at the microphone is not part of the background noise but can corrupt the noise measurement. This is the same effect as the wind noise in ones ears on a windy day or when riding a bicycle. If you turn your head the noise changes and a person standing or riding next to you will not hear the same noise as you.

Most environmental noise measurement involves noise sources such as factories and airports that are not wind speed dependent. It is therefore normal practice in these cases to take noise measurements in low wind speed conditions, typically below 5m/s (11 mph and classified as a gentle breeze). Most noise measuring equipment is designed for these low wind conditions and commercially available windscreens normally provide sufficient attenuation of wind induced noise below 5m/s wind speed to prevent contamination of measurements.

Wind farm noise measurement is an exception since the wind turbine noise source is dependent upon wind speed. Therefore measurement of turbine noise and background noise needs to be made over a wider range of wind speeds and, at speeds greater than 5m/s. Although ETSU states measurements should be taken at wind speeds up to 12m/s, it is generally accepted that with modern wind turbines, noise measurement at V_{10} wind speeds up to 10m/s is adequate. However, the effects of the wind on the microphone must be considered throughout the range of wind speeds during the measurements.

ETSU [Ref: 01] at page 84 warns of this problem where it states: "*there is a risk that measured noise levels can become contaminated by the effects of wind noise on the microphone when using wind shields available commercially*". ETSU also advises at page 52 where it states: "*One should therefore exercise caution to ensure that measurements are not contaminated by wind noise on the microphone and consider the use of secondary wind shields*". This is particularly relevant in low background noise environments such as those encountered at rural wind farm sites.

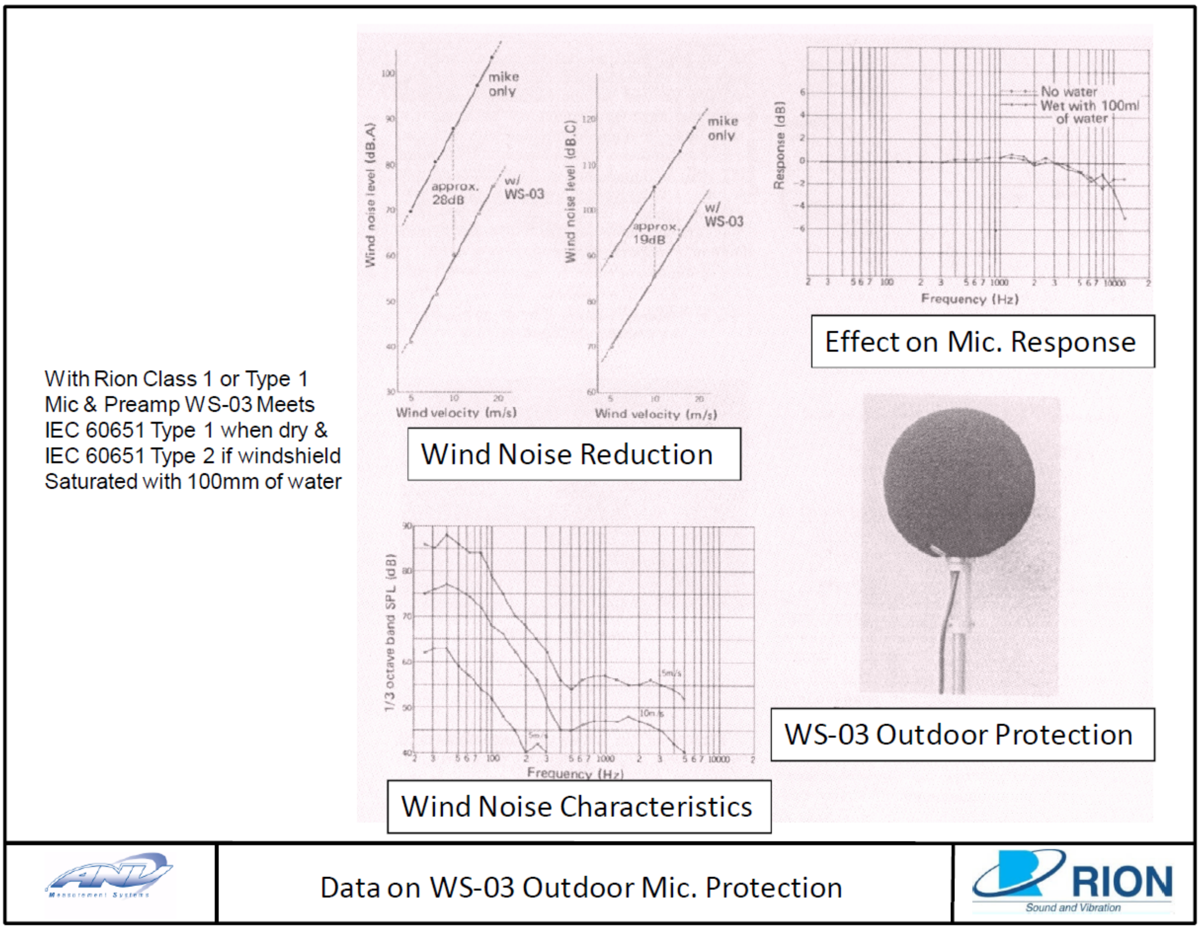
Sound level meter manufacturers provide wind noise reduction data and graphs for their wind screens (also known as wind shields) to assist in evaluating the range of measurements possible without data contamination. Measured values of background noise that are more than 10dB above the wind induced noise curve can be assumed to be free of corruption. Measured values less than 10dB above the induced noise curve will be corrupted to a lesser or greater extent. Note that measured noise can never be less than the wind induced noise value. This limits the range of measurements possible, so making it essential to know the wind induced noise characteristics of the microphone and wind screen being used, the wind speed at the microphone and the approximate noise levels being measured. The importance of using suitable wind screens was highlighted by Malcolm Hayes of HMP, a member of the original ETSU working group in his blog dated 7 July 2000 (see Appendix C).

Although ETSU warns of the effects of wind induced noise and recommends the use of secondary windscreens, it does not provide any detailed guidance. However, detailed guidance is provided by the South Australia EPA [Ref: 18] in the more recent document '*Wind farms environmental noise guidelines*' (the Australian equivalent of ETSU) dated July 2009. Although this Australian guidance is not mandatory in the UK, the acoustic principles are relevant. Page 7 [Ref: 18] clarifies the precautions to be taken to avoid contamination of the measured data and how to validate the data for the three possible scenarios:

- *Where manufacturers' specifications indicate that wind induced noise on the microphone is 10dB(A) or more below the background noise, the data is acceptable.*
- *Where manufacturers' specifications indicate that wind induced noise on the microphone is 10dB(A) to 4dB(A) below the background noise, the affected data may be retained with the wind induced noise subtracted from the measured background.*
- *Where manufacturers' specifications indicate that wind-induced noise on the microphone is within 4dB(A) of the affected data, the affected data should be discarded and the data should be re-analysed. If the procedure causes the regression*

curve to change significantly, then additional data will need to be collected within an improved wind screen.

Figure 1 shows the *Rion WS-03* wind screen data sheet as an example of an outdoor type wind screen widely being used for wind farm background noise surveys. It is described in the manufacturer's specification as being of 200mm diameter and of open cell foam with a nylon non-woven cloth (inner) for water proofing. This type of wind screen is also known as being of two layer construction. The wind noise attenuation (A weighting) is quoted as 28dB. The graph shows the wind induced noise as approximately 41dB(A) at 5m/s and approximately 60dB(A) at 10m/s wind speed. Data for wind speeds below 5m/s are not given. The manufacturers report [Ref: 19] '*Wind screens and their use*' provides additional description of wind screen construction, materials and performance.



Source: Rion

Figure 1: Typical microphone wind screen noise reduction data

Measuring equipment manufactured by Brüel & Kjær offers similar wind noise reduction characteristics. The Brüel & Kjær product data sheet for the outdoor microphone unit type 4188 [Ref: 20 page 4 and Ref: 21 appendix D] shows a 15dB attenuation of wind induced noise (compared to the 28dB for the Rion WS-03) although it does not clarify whether this applies to dB(A) or dB(C) weighted measurement. The Brüel & Kjær *Technical Review No1* dated 1966 [Ref: 21 appendix E] available at the Brüel & Kjær web site provides a report on the effectiveness of windscreens indicating that the wind induced noise effect was well known in 1966.

Measured values of noise that are 10dB or more above the wind induced noise curve can be assumed to be free of contamination. Therefore in the case of the WS-03 wind screen the lowest noise levels free of contamination at 5m/s wind speeds would be 52dB(A) and at 10m/s would be 70dB(A). Since these noise levels are well above the typical background noise levels experienced in rural areas, the need for more effective microphone wind screens in the form of secondary windscreens as advocated by ETSU becomes evident.

Secondary wind screens are intended for use in addition to the primary wind screen and consist of a larger diameter outer screen to slow the wind passing over the microphone and so further reduce the effects of wind induced noise. Figure 2 shows examples of secondary wind screens for both ground use and tripod use.

One acoustics consultant claimed during an inquiry that a two layer primary windscreen is the same as a secondary windscreen when clearly it is not.

Source: Delta

Figure 2: Examples of secondary wind screens

It should be noted that wind turbine manufacturers routinely uses secondary wind screens when measuring turbine noise for type testing and warranty purposes. A typical manufacturer's test report was provided with the Lilbourne SEI dated May 2010 where the secondary wind screen is specified [Ref: 22 appendix C annex 1] and photos provided of the measuring equipment, [Ref: 22 appendix C annex 1 and 5]. In order to further minimise wind induced noise, measurements are taken with the microphone at ground level using a ground board where wind speed will be the lowest. The requirements for measuring turbine noise are also provided by the international standard IEC 61400-11 [Ref: 41] where Para 6.1 specifies the primary and secondary windscreen equipment with Figures 1 and 2 providing details of the ground board measurement arrangement. At Para 6.1.4 it states, "*it could consist of a wire frame of approximate hemispherical shape, at least 450 mm in diameter, which is covered with a 13 mm to 25 mm layer of open cell foam with a porosity of 4 to 8 pores per 10 mm. This secondary hemispherical windscreen shall be placed symmetrically over the smaller primary windscreen*".

Using microphones at ground level during background noise surveys would also serve to minimise the effects of wind induced noise providing the microphone could be adequately protected during the survey period.

Appendix C is copied from a blog by Malcolm Hayes of HMP dated July 2000. In this blog he describes the problems associated with wind induced noise and particularly the effects of turbulence. He states that:

"*When undertaking environmental noise measurements around wind farms we use a double wind shield arrangement, with a B&K UA 0570 type foam shield with a secondary shield of between 300 and 500 mm diameter. Appropriate tri-pod arrangement is required due to increased wind loading from large wind shield*".

Several noise assessments accompanying wind farm planning applications have been reviewed by the authors including the Yelvertoft wind farm noise assessment conducted by HMP during 2008 and none have used secondary wind screens. All have used a primary wind screen only, most often using equipment manufactured by Rion or Brüel & Kjær.

During questioning of the wind farm developer's acoustics consultants at both the Winwick and Lilbourne public inquiries during April and May 2012, it was evident that neither consultant recognised the limitations of the measuring equipment or the characteristics of the wind shields they were using. It is also clear that the recommended practice described by Malcolm Hayes during July 2000 [Appendix C] to use secondary wind screens of 500mm diameter has since been quietly abandoned. The importance of wind screen diameter in attenuating wind induced noise is also reiterated by in the Rion technical report 202 [Ref: 19] where Fig. 1 shows the effect of increasing wind screen dimensions. All the evidence indicates that wind screens of typically 200mm diameter or less (from any manufacturer) will be unsuitable for wind farm noise measurement without the addition of a secondary wind screen.

The implication is that most if not all wind farm background noise surveys conducted recently in the UK will have suffered contamination of the measured background noise due to wind induced noise on the microphone.

As the ETSU target is based on the difference between the turbine noise as measured by the turbine manufacturer and the background noise as measured by the developer it is essential that neither measurement is inflated by microphone-induced noise.

Effects of wind induced noise on the noise assessment

The effect of wind induced noise on the microphone is for the measured data to show higher levels of background noise than is actually the case. The data contamination will be limited to measured values that are less than 10dB above the wind induced noise curve for the microphone and wind screen combination. It is therefore likely that contamination will not affect the data taken at the very lowest wind speeds but the level of contamination will increase gradually with increasing wind speed. The nature of the data contamination is such that its effects are gradual and provide an apparent reinforcement of the correlation between background noise and wind speed whether or not such a correlation actually exists. **This artificial raising of the background noise levels is subtle and virtually undetectable by planning decision makers.** The higher derived noise limit will apply for the life of the wind farm so making it more difficult to obtain resolution to noise complaints. Another effect of these increased noise limits will be to justify reduced separation distances of turbines from residential areas.

Uncertainties regarding the actual characteristics provided by the manufacturers of commercially available wind screens, particularly with regard to turbulence, low frequency induced noise and at wind speeds (at the microphone) of below 5m/s where no data is provided makes it impossible retrospectively to quantify the levels of data contamination on noise assessments previously carried out.

Although we can be confident that data contamination has been a regular feature of most if not all background noise surveys in recent years, the low background noise levels associated with many rural areas combined with the failure to record wind speeds at the monitoring locations must only increase concerns as to the levels of data contamination and uncertainty created.

Unreasonable and unjustifiable increases to derived noise limits resulting from defective assessment practices such as those described above, irrespective of quantum, are considered by the courts to be material prejudice against neighbours in relation to the amenity of wind farm neighbouring households. Such material prejudice, had it been apparent at the time of planning approval, would in all likelihood have led to a requirement for a re-determination of the planning permission. See for example *R (oao Hulme) v S/S Communities and Local Government* shown at Appendix F Para 6, where planning permission was quashed by consent following discovery that noise limits had been set unreasonably high as a result of background noise data processing errors by the applicant for the proposed Den Brook wind farm.

In view of the evidence, there is a compelling case for new background noise surveys (using appropriate wind screens and with turbines shut down) at any wind farm subject to noise complaints. There is also a strong case for commissioning a truly independent

controlled study to assess the full magnitude of the effect on a selection of wind farms including those not yet operational.

DECC study on how noise impacts are considered – wind induced noise

The DECC study [Ref: 02] analysed how background noise was being measured including the requirement for wind screens as part of the noise assessment process for wind farm planning applications. Para 5.19 of the DECC study repeats the requirement stated in ETSU to protect against wind noise.

Para 6.12 makes further comment as to how this subject has been dealt with in the noise assessments analysed when it states: "*The noise measurement equipment was clearly described in 96% of cases and was stated to conform with IEC651 Type 1 or BS EN 61672 Class 1 in 70% of cases. Details of equipment used for field calibration were supplied in 74% of cases. The performance and specification of the wind shields used in the studies corresponding to the design recommended in ETSU W/13/00386/REP (see Paragraph 5.19 (above)) were used in 4% of cases with other high performance wind shield designs being used in 68% of cases and the remainder being unclear or not stated*".

Note that in only 4% of cases is it claimed that appropriate wind screens were used.

The detailed results at DECC report Appendix B fails to clarify what "*other high performance wind shield used*" actually means. It is remarkable that the subject of wind induced noise and the significance of its effect on the overall noise assessment can have received such cursory attention, particularly considering the report's key objectives and the clear need for an independent and impartial review.

Noise measurement methodology

Noise measurement methodologies are often contested at wind farm public inquiries when claimed background noise levels are considered excessive by local residents. The main areas of concern are described below.

Monitoring locations

An assessment is normally made at the likely noise sensitive properties (called *Receptors*) and when selecting the monitoring locations for the background noise survey these should normally be residential properties in closest proximity to the turbines. Practice to date indicates that this selection process can be quite arbitrary with the developer proposing the locations, usually with the LPA EHO agreeing or possibly adding one or two additional ones. Local residents who may be able to suggest suitable monitoring locations are rarely consulted. As an example, during the noise survey for the Lilbourne wind farm, the developer selected a monitoring location at the edge of the village of Lilbourne [Ref: 22] that is within 100m of the M1 motorway embankment resulting in very high measured background noise levels. Had noise been monitored in the centre of the village, 200m or so further away from the motorway, measured background noise levels would have been significantly lower.

ETSU [Ref: 01 Ch. 7] recommends on page 83 that measurements should be taken in free-field positions where the reflection effect from buildings is minimised by locating the microphone at least 10m from a building facade. However, on page 84 it recognises that it may be appropriate to take background noise measurements closer than this if sheltered locations close to the property are frequently used. In this case the measurements should not be taken closer than 3.5m from the façade. Taking the measurements closer to buildings will generally be in more sheltered positions so any wind effects on the microphone will be reduced. Additionally, in sheltered locations the background noise levels may be lower and more representative of the actual background noise levels experienced by the residents. Of the noise assessments reviewed by the authors, most monitoring was carried out in free-field conditions, where generally higher background noise levels and higher wind speeds at the microphone would prevail, and not closer to buildings that would have been more representative.

ETSU recommends the microphone height should be 1.2 to 1.5m above ground level. This recommendation seems to be based solely on it being a convenient working height. However, as we have already shown, wind speed is the lowest at ground level so positioning the microphone at ground level would minimise the effects of wind induced noise at the microphone, and is normal practice by wind turbine manufacturers who have an incentive to demonstrate as low a measured turbine noise value as possible.

Including photographs of the measuring equipment at the monitoring locations is very helpful and has been a feature of some of the noise assessments reviewed by the authors. However, in all cases the few photos included do not allow the suitability of the location properly to be assessed.

Data requirements

The objective of the background noise survey is to obtain simultaneous measurements of noise and wind speed at 10m height (V_{10}). It is therefore essential that V_{10} is measured during the noise survey. This should be an actual 10m height measurements and not a derived wind speed from a different height as has been allowed at some public inquiries. This will avoid any arguments on conversion from other heights.

In most cases there will be a relationship between wind speed and background noise levels. However, at sites affected by other noise sources such as motorways and major roads, the correlation of noise with traffic flows may be stronger than with wind speed. In these cases wind direction and time of the day can have significant effects on background noise levels. Typically traffic noise is at its lowest during the night at a time when wind turbine noise can be most intrusive. Wind direction will also affect receptor background noise levels if shelter is provided from some wind directions but not others. It is therefore important that wind direction is also measured throughout the survey and is factored in during the data analysis. Noise assessments where motorway noise from the M1 was a factor (Yelvertoft, Watford Lodge and Lilbourne) failed to consider the correlation with traffic noise patterns.

Of the noise assessments reviewed by the authors, during the survey wind speed has been measured at just a single location. As we have already seen above, the effects of wind induced noise at the microphone are dependent upon the wind speed at the microphone, not at a distant central location. For this reason wind speed should also be measured close to the microphone at each monitoring location. Additionally, there may well be substantial variation in wind speeds over the area of a large wind farm at any moment in time.

ETSU [Ref 01, page 85] states that data should not be used from periods of heavy rain. The authors have seen noise assessments (e.g. Winwick) where some noise monitoring locations were over a mile from the central rain monitoring location. Rainfall can vary considerably in timing and amount over relatively short distances justifying rain monitoring at most noise monitoring locations.

Survey period

ETSU [Ref 01, page 85] states: "*Background noise measurements should be undertaken over a sufficient period of time to allow a reliable assessment of the prevailing background noise levels to be performed*". ETSU also states: "*The actual duration will depend upon the weather conditions, in particular the strength and direction of the wind that has blown during the survey and the amount of rain*".

In practice we find developers take measurements for typically two to three weeks irrespective of the weather conditions. As a result we find limited data from certain wind directions and often insufficient data at the higher wind speeds.

DECC study on how noise impacts are considered – measurement methodology

The DECC Report [Ref: 02] discusses the measurement methodology at pages 10 to 15. At pages 25 to 28 it provides the results of the analysis where it is clear there has been a high degree of variability in the measurement methodologies implemented. Areas of concern include:

- In only 13% of cases was the LPA involved in the precise positioning of the measurement equipment.
- Photographs of the measuring equipment were provided in only 66% of cases.
- Wind direction information was provided in only 52% of cases with the location of the anemometry equipment generally not provided. There was no evidence of filtering by wind direction in any of the cases.
- Monitoring duration varied from 7 days to 60 days with the average being only 21 days.
- Wind shields with the performance and specification corresponding to the design recommended in ETSU W/13/00386/REP were used in only 4% of cases.
- Reference to rain affecting measurements was vague in most cases and it was difficult to ascertain precisely what data from non-rainfall sources had been excluded and the criteria for exclusion were often not stated.

Conclusions and implications

The failure by wind farm developers to use secondary wind screens has resulted in the background noise data from most if not all wind farm noise assessments carried out over recent years to be contaminated. The nature of the data contamination is such that its effects are to increase the measured noise levels and provide an apparent reinforcement of the correlation between background noise and wind speed whether or not such a correlation actually exists.

This artificial raising of the background noise levels is both subtle and virtually undetectable. The artificially high derived limits are used to assess whether there is likely to be a noise nuisance created by the wind farm and are used throughout the life of the wind farm, typically for 25 years, when investigating any noise complaints. The methodology employed by developers in measuring background noise levels has been shown to be highly variable with significant implications for the measured data. Areas of concern include:

- Selection of the measuring locations
- Positioning of the measuring equipment
- Measurement of V_{10} wind speed and direction
- Failure to monitor for rain at each monitoring location
- Failure to measure wind speed at each monitoring location

The numerous possibilities for error in the noise and associated wind speed data are difficult to quantify, but must be of the order of at least +/- 5dB. This is in addition to the effects of wind induced noise that may be more than 10dB at quiet rural locations.

Section 4 - Background Noise Analysis

When the background noise data have been collected they are plotted in the standard $L_{A90\ 10min}$ version against the simultaneous 10 minute averaged wind speeds at 10m AGL (V_{10}) to give a graph similar to that shown as Figure 3, which was presented at the Winwick public inquiry for the quiet daytime at one at noise receptor, and an 'average curve' drawn through them.

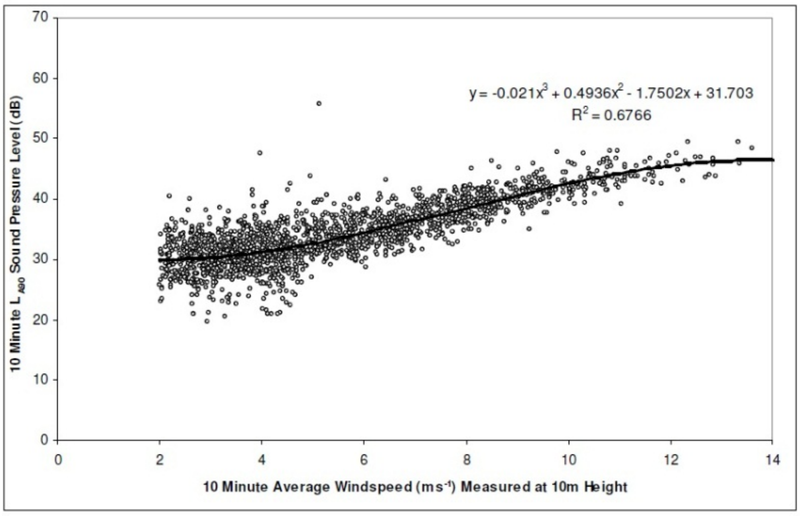


Figure 3: Background noise vs. wind speed for quiet daytime at a receptor, Winwick

This curve is typical of many that we have seen and consists of a degree p = 3 (cubic) polynomial defined by the equation:

$$L_{A\ 90,\ 10min} = -0.021x^3 + 0.4936x^2 - 1.7502x + 31.703$$

In the ETSU process, values predicted by the curve for each whole number wind speed are then used as references against which to set permitted limits of noise and the process is repeated for the agreed at risk noise receptors during times of day defined as 'quiet daytime' and 'night time'. What ETSU is less than clear about is the way in which these curves are to be established. How the ETSU panel expected these average curves for background noise to be obtained is described on page 101 [Ref: 01] as follows:

> *"For each sub-set, a "best fit" curve should be fitted to the data using a least squares approach, usually a polynomial model (of no more than 4th order). Where there is considerable scatter in the data, it may be more appropriate to bin the acoustic data into 1m/s bins before identifying a best fit model. These two curves, referred to as the 'day-time curve' and the 'night-time curve', provide a characterisation of the prevailing background noise level for day-and-night respectively, as function of wind speed from zero to 12m/s at 10m height. Note that whatever model is used to describe the measured data, this should not be extrapolated outside the range of the measured wind speed data."*

Further we are also told that:

> *"The variation in background noise level with wind speed will be determined by correlating $L_{A90,10min}$ noise measurements taken over a period of time with the average wind speeds measured over the same 10-minute periods and then fitting a curve to these data."*

In the guidelines the examples given are quartic or degree *p* = 4 polynomials of the general form

$$L_{a90,\ 10min} = F\ (V_{10})^4$$

in which $L_{A90,10min}$ is the averaged background sound level in dB, V_{10} the wind speed at 10m AGL averaged over the same ten minute intervals, and F denotes 'some function'. Fits to the observed data are usually reported using the *coefficient of determination*, or R^2, a statistic that is probably better thought of as the *percentage of the variance explained by the fitted curve*. For example the polynomial used to characterise the data in Figure 3 had an associated $R^2 = 0.6766$ implying that 67.66% of the variation shown by the original data could be 'explained' by that curve.

These curves are what here we call *models* of the underlying data, but the guidance says very little about why these quite complex polynomials have been used, or any caveats that should be attached to them other than the warning against extrapolation outside the range of the available data. It is worth commenting on five features of this approach and examples:

- First, the approach assumes that the main cause of variation in background is wind speed. This may well be generally true, but we are aware of locations at which the noise environment is determined by some other factor, the most obvious of which is traffic noise close to a busy road that varies more strongly with time of day than it does with the ambient wind;

- Second, the R^2 value refers to a statistical notion of 'explanation' that should not necessarily be equated with scientific causation. Simply chasing a curve that gives the 'best fit' using this measure ignores several issues related to the nature of these data;

- Third, to a statistician, the coefficients arrived at by so-called ordinary least squares (OLS) multiple regression are themselves *estimates* of some *unknown parameters* in the full population from which the sample background ($L_{A90,10min}$) and wind (V_{10}) were sampled and as such are themselves subject to an uncertainty that should be expressed as *confidence intervals* around the plotted line;

- Fourth, the fitted curves and the coefficients that define them have physical implications of which the most obvious is the value of the background $L_{A90,\ 10min}$ (dB) they suggest when $V_{10} = 0$ (m/s). The polynomials given on Figures 2 and 3 of the

ETSU document (page 48) for ‘deep valley’ and ‘partially exposed’ sites suggest still air values of 29.59 and 27.55 dB respectively, whereas the for ‘exposed’ site shown (page 49) it is 44.76 dB;

- Fifth, at no point in the ETSU document can we find any physical justification in acoustics or meteorology for the choice of model to be fitted;

- Finally, although we are advised that polynomials of degree higher than four should not be used, this is also without any additional comment or justification.

All of this would be obvious to any reasonably competent statistician, and leads to the observation that the ETSU panel did not appear to call on such expertise.

In Appendix A we show that, although it is always presented as being certain, this part of the ETSU process is fraught with uncertainty. First, we point out that both the data sets used, for background noise and wind speed, are from time series and exhibit some degree of ‘self’ or autocorrelation, whereas standard OLS analysis assumes that the input data do not show such dependence.

Typically, the effect will be to give an impression of having a better fit, and hence description of the ‘average’, than is in fact the case. Second, we point out that the method by which these data are collected means that the sample size, *n*, that is critical to statistical measures of the confidence that we might have in the fitted lines, is to a large extent arbitrary and can be increased by simply extending the period of observation to collect more data points. Third, and more importantly still, using examples from two wind farm public inquiries for which we have access to either the original data or the summary plots, we show that that the choice of which polynomial model to fit to the data is also more or less arbitrary, with very different curves giving fits that are indistinguishable from each other.

In the case at Winwick, the analysts preparing the Environmental Impact Statement (EIS) are shown to have *over-fitted* their data by fitting more complex curves that the data do not themselves warrant and in one of the examples producing a curve that defies ordinary logic in two ways. First, it implies a background noise with still air of almost $L_{A90,10min}$ = 40dB, which is extremely unlikely for a quiet rural location. Second, at low wind speeds the curve implies that the background noise *decreases* with increasing wind speed, which is physically unlikely. Finally, using the statistical concept of leverage we point out that, although often omitted from the graphs shown, data at both the low and high ends of the range of wind speeds used exert the greatest effect on the fitted curves. The result is that almost any curve through these data can be made to look reasonable, giving modest but important uncertainty in the values chosen as representative of the background.

Conclusions and implications

The question that might well now be asked is ‘does it matter?’ To answer this in Appendix A we use the predicted background at V_{10}=5.0m/s in both examples and show that according to the model used there is a range of background values of around 2.0dB in the $L_{A90,10min}$.

This range is higher at wind speeds below 5.0m/s, but then gets less as winds increase above it. We recognise that it will be argued that such an uncertainty is not perceptible, but observe that it might well be significant in determining limits in cases where the predicted noise is marginal since as we note:

> *… any of these curves could well have been used in determination of an application to build a wind farm and/or in the determination of critical limits for related conditions. That anyone or other of them increases or decreases the reference values at the receptor sites, and so does or does not favour a developer, is in our opinion irrelevant. Just as by manipulation a developer might be able to raise the background by choice of data and function, so could any competent data analyst find a function that would lower it by the same, or an even greater, amount. The difference is that a competent data analyst would be well aware of this fact, report the uncertainty, and allow for it in any decisions based on it*.

We conclude that few, if any, of the consultants used to analyse these data in wind farm proposals are competent or that if they are competent they must be aware of this issue and have chosen to sweep it under the carpet. Moreover, as is shown elsewhere in this report, it is at these relatively low wind speeds that the risk of noise in excess of those usually assigned as a result of the ETSU process is greatest. **Clearly the extent of this effect will vary from time of day to time of day, receptor to receptor, and wind farm proposal to proposal, but the +/-2dB uncertainty we identify is likely to be a reasonable estimate**.

There are at least two ways by which the problem we have outlined can be addressed. First, professional statisticians would undoubtedly suggest alternative ways of fitting that would address issues of model choice and the 'messy' character of the data. Second, referring back to the original ETSU recommendations we find a sentence (page 101) that indicates that the panel were aware of a simpler alternative, which is to smooth the data before undertaking the regression analysis:

> *Where there is considerable scatter in the data, it may be more appropriate to bin the acoustic data into 1m/s bins before identifying a best fit model*

We simply do not understand why all the noise assessments we have seen choose not to follow this simpler and more transparent approach.

Section 5 - Turbine Noise Prediction

ETSU [Ref: 01] does not provide any guidance on how turbine noise predictions should be carried out. The noise prediction methodologies employed include assumed turbine sound power levels and noise attenuation based on distance and other attenuation factors. ISO9613-2 is the most commonly used prediction model and is described by Stigwood and Large of MAS [Ref: 26]. The IoA have also issued unofficial guidance regarding the application of ISO9613-2 in the *Acoustics Bulletin* dated March 2009 [Ref: 03]

This prediction method for outdoor sound propagation has been adopted for wind turbine noise even though the turbine source noise height is much greater than that for which the standard was designed. The standard also highlights the prediction uncertainty of noise attenuation over long distances estimating an accuracy of +/- 3dB for distances in excess of 100m and up to 1000m. Note that most wind farm noise receptors assessed are located within 1,000m of turbines. The standard is not designed for predicting over 1000m and only applies for low wind speeds and sources close to the ground.

Attenuation factors

The predicted turbine noise also depends on absorption conditions factored in to the prediction model. The majority of these are standardised but the amount of ground absorption, either near the source or near the receiver, is often varied. MAS [Ref: 26] advises that under worst case meteorological conditions or other cases where the ground is reflective (e.g. patios, concrete areas or frozen / waterlogged ground) the absorption offered by the ground is minimal and a ground absorption factor of *G=0.0* is appropriate.

Measurements by MAS [Ref: 26] in the field under stable atmospheric conditions have consistently found measured levels are higher than ISO9613-2 predictions when assessed as an L_{A90} or average (L_{Aeq}) value. Other research supports the finding that ISO9613-2 understates noise levels in certain conditions and that the most robust prediction is when using hard ground or an uncertainty value of +/-3dB.

Turbine noise data

Turbine noise emission levels are provided by the turbine manufacturers. These data includes the Apparent Sound Power over the operational range of wind speeds up to typically 12m/s and the Octave Sound Power over a range of frequencies. The noise generated at hub height is standardised to the 10m height using the standard ground roughness length of 0.05m, (equating to a constant shear exponent of 0.16). During the planning application stage of a wind farm it is unusual for the final turbine type to have been decided and the developer normally adopts a ‘candidate turbine’ type from a range of possible turbines for the noise assessment.

The manufacturer’s data can be provided in different formats requiring different treatment during the noise prediction calculation of the noise immission levels at receptors. Comparison of the way manufacturer’s present turbine noise data is examined by Broneske

[Ref: 27] and varies significantly thus presenting difficulties when making comparisons between turbine types and for wind farm noise assessments.

Some manufacturers issue warranted noise levels for use in noise assessments; others state noise levels for information only but attach a noise warranty to their contract with the buyer. Others give warranted sound power levels at hub height and calculated sound power levels referenced to 10 m height for information only. It can also happen that no official document from a manufacturer is available and that noise assessments are based only on a single turbine sound power level test report. If the sound levels from the measurement report are used without adding a measurement uncertainty, there will be no safety margin to allow for measurement uncertainties, uncertainties of the calculation model or variations within a batch of turbines of the same type. In practice most manufacturers would only be expected to provide warranted data with a commercial order and after having assessed the wind farm site and layout. Not all manufacturers' data mentions the 'test conditions' the sound power levels quoted are valid for including:

- Clean blades, no dirt, no ice, no rain on the blades, no damage to the leading edge
- A specified (vertical) wind shear
- A specified (vertical) inflow angle
- A specified turbulence intensity

Also what is not addressed by the manufacturers is what allowances should be made for the non-ideal conditions that in practice will occur for most of the time. Broneske also raises other issues not addressed by the turbine manufacturers including:

- The minimum separation distance needed between wind turbines so that turbulence intensity does not increase to such an extent that the sound power levels increase significantly.
- Amplitude modulation.

The *Acoustics Bulletin* [Ref: 03] advises that a ground absorption factor of *G*=0.5 should only be used where warranted turbine noise data is available. In other cases the hard ground absorption factor of *G*=0 should be used. A review of wind farm noise assessments by the authors shows that where headroom (noise limit above predicted noise) was small, developers have assumed a ground absorption factor of *G*=0.5. In no cases that we reviewed were warranted turbine noise data provided by the turbine manufacturers.

There is a clear case for careful controlled measurement of actual turbine noise to be measured and compared with these ISO9613-2 predicted levels. As things stand we have no means of independent verification of the estimates that are routinely used in the assessment process.

DECC study on how noise impacts are considered – prediction methodology

The DECC report [Ref: 02] discusses the prediction methodologies at pages 16 to 18. At page 17 the report reiterates the recommendation to use a ground absorption factor of *G*=0 where turbine test data, (not warranted data) is assumed for the noise prediction. At pages

28 to 30 the results of the analysis show there has been a high degree of variability in the prediction methodologies implemented. As a result there will have been a high degree of variability in the noise levels predicted.

Conclusions and implications

Use of the ISO9613-2 prediction model and how it is applied is creating at least 3dB of uncertainty and possibly more in the levels of predicted turbine noise at noise receptor locations. The lack of guidance by ETSU in this area is allowing developers a considerable degree of flexibility in how they implement the prediction calculations that LPA planners, Planning Inspectors and third parties are rarely able to challenge.

As a result planning permission is being granted for wind farms that will generate higher levels of noise than claimed during the planning application noise assessment.

Section 6 - Wind Shear

What is wind shear?

Wind shear (vertical shear) can be described as the change in wind speed with height caused by a combination of ground roughness and atmospheric stability. Wind speed differs with height and usually wind speed increases with increasing height in normally a logarithmic relationship. High wind shear is the condition when the wind speed at the upper heights is much higher than at lower ones. Low wind shear is when the wind speeds at upper and lower heights are similar. As Appendix B shows the amount of shear can be quantified by use of an exponent (α) that gives the rate of change of wind speed with height, or gradient of the logarithms of both height and wind speed. From a typical on site meteorological mast this can be estimated from measured winds at two heights using the formula:

$\alpha = Ln(V2/V1)/Ln(H2/H1)$ where:

α is the wind shear exponent
$V1$ is the wind speed at height $H1$
$V2$ is the wind speed at height $H2$
Ln denotes the natural logarithm

As Appendix B shows, if data have been collected at more than two heights the same exponent can be obtained using a best fit linear regression. Similarly wind speed is calculated as: $V2/V1 = (H2/H1)^{\alpha}$.

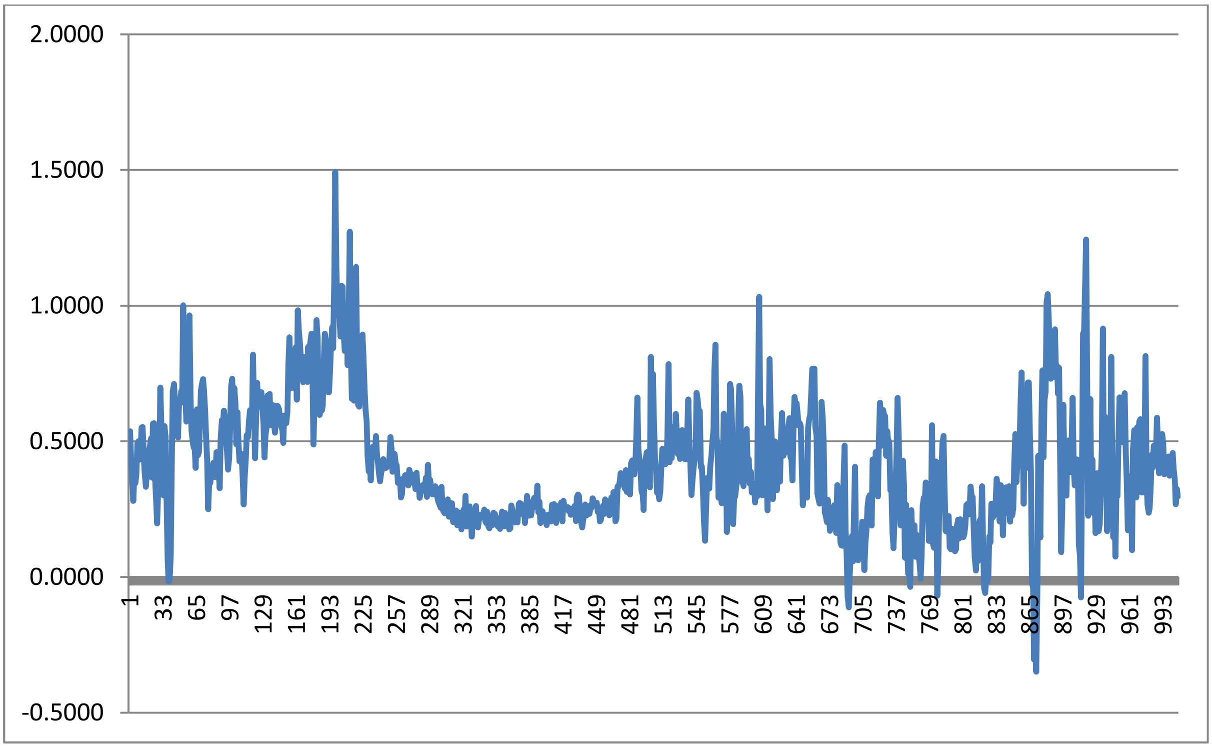


Figure 4: Typical wind shear recorded over a 7 day period

Figure 4 shows wind shear exponent levels calculated for the 10min average wind speeds at the Winwick site during December 2010. Wind shear can be seen to be highly variable, frequently becomes extreme (greater than 1.0) and can briefly become negative when wind speeds higher in the atmosphere are lower than those lower down. The meteorological conditions that give rise to high shear are outlined in Appendix B.

In addition to the vertical shear described above, there can also be a change in wind direction with height known as horizontal shear or 'twist'. There is evidence [Ref: 05 Bowdler] that increasing horizontal shear is associated with increasing vertical shear.

Under high (vertical) wind shear conditions, the higher wind speeds at the heights where modern turbine rotors are positioned, typically 80m AGL, results in high power generation and hence high noise output. Meanwhile, due to the high wind shear conditions there are much lower wind speeds near ground level, which means there is less background noise than expected to mask the turbine noise. Additionally, the high differential wind speeds between the top and bottom of a turbine rotor and increased horizontal shear are implicated in the incidence of amplitude modulation. As a result turbine noise intrusion is most likely to occur under high wind shear conditions.

ETSU and wind shear

ETSU [Ref: 01] makes only minimal reference to wind shear assuming that shear remains constant between two heights. At the time ETSU was written, wind turbines were smaller with lower hub heights and smaller rotor diameters, the effects of wind shear were not observed or fully appreciated. However, ETSU at page 120 outlines the method to calculate wind shear and the existence of wind shear is acknowledged at pages 85 and 87. So, although ETSU does not provide guidance for allowing for the effects of wind shear, it can still be accounted for in keeping with ETSU by adjusting predicted turbine noise levels for wind speed estimates that recognise shear.

The importance of allowing for wind shear is demonstrated by Moroney and Constable [Ref: 06] where their Appendix 1 demonstrates the need to consider actual wind shear in the noise impact assessment. Using data from a wind farm site they show how based on the ETSU 'standard' shear assumption, turbine noise does not exceed the usual ETSU limit (although it does exceed the background noise curve). It may be inferred from this analysis that noise complaints would not arise. However, with the analysis based on actual wind shear, turbine noise is found to be significantly greater than background noise, and that difference is greater than +8dB for 40% of the time. It may be inferred from this analysis that noise complaints are most likely.

Bowdler [Ref: 05] examines wind shear at different times of the day and year at several wind farm sites with the stated objective of examining its shear effect on the relative levels of turbine noise and background noise. He confirms the effect of increased levels of shear is to shift the turbine noise curve to the left at his Figure 3. He also confirms at his Figure 6 that wind shear is highest at low V_{10} wind speeds and decreases as V_{10} wind speed increases and that shear is much higher at night time than during the day time while the differences between summer and winter are small. Bowdler concludes that turbine noise will be at its most intrusive at hub height wind speeds of between 7 and 10 m/s. However, he fails to continue further by examining how much wind shear should be factored into the noise assessment process and how it should be implemented.

Institute of Acoustic Bulletin, the Article Method

The Institute of Acoustics (IoA) in their magazine *Acoustics Bulletin* dated March 2009 [Ref: 03] published an article authored by a group of acousticians that recognises the problem and claims to offer guidance to take account of site specific wind shear (referred to here as the Article Method). Whereas ETSU states that background noise levels should be referenced to V_{10}, the 10m height measured wind speed, allowing predicted turbine noise to be adjusted to reflect wind shear, the Article Method adjusts background noise levels even though the effect of wind shear is on turbine noise.

The Article Method is therefore unnecessarily complicated but should in theory produce similar results. However, it makes it more difficult for decision makers during the planning application stage to assess how close to the limit the predicted turbine noise may be. It also makes noise nuisance enforcement by local authorities virtually impossible.

The original article itself is written in a way that makes it quite difficult to understand and as such it is doubtful if many non-acousticians have understood what it actually implies. This is further complicated by the apparent contradiction in the description of the measurement heights H_1 and H_2. At [Ref: 03] page 35, H_1 is shown as being the upper height and H_2 as the lower height. On page 36, however, H_1 is shown as the lower height and H_2 as the upper height.

Comparison of the Article Method with ETSU is also carried out by Moroney and Constable [Ref: 06]. These authors identify major problems with the Article Method including increased data scatter and high variability depending upon when the wind shear is measured. They demonstrate that using two weeks' worth of shear data recorded only two weeks apart can produce significantly different results.

Moroney and Constable also demonstrate the effect on acceptable separation distances through the use of the Article Method. For the case they analysed, using the Article Method suggests a separation distance of 750m would be acceptable whereas using the ETSU approach the separation distance would need to be 1,150m. Their conclusion is that the Article Method is less protective of wind farm neighbours than the ETSU methodology and as a result allows developers to site turbines closer to homes. It is not surprising then that the wind power industry and its allies in the consulting community are promoting the Article Method.

A comparative analysis of the ETSU and Article Methods is also provided by Stigwood of MAS [Ref: 04] in his report: '*The effect of a common wind shear adjustment methodology on the assessment of wind farms when applying ETSU-R-97*'. He concludes: "*Not only is the article method unlikely to indicate adverse noise impact at the planning stage, but once the* *development is operational the article method virtually removes the ability for local communities to enforce controls over reasonable turbine noise impact*".

Winwick wind shear analysis

Appendix B provides a wind shear analysis performed for the Winwick wind farm from anemometer mast data taken over a 12 month period. Winwick is located in NW Northamptonshire in an area of rolling hills and mixed farmland [See cover photo]. The diurnal wind shear characteristic determined for the Winwick site follows the findings of the NREL authors [Ref: 08]. This analysis formed the basis of evidence presented [Ref: 13] at the Winwick public inquiry during April 2012. The data provided for the Winwick site covering the whole of 2010 provided an opportunity to take the wind shear analysis process further than we believe has been thus far conducted.

The wind shear characteristics of any wind farm site are not expected to change significantly from year to year except insofar as the incidence of wind speeds at which it occurs are represented in each year's weather. Therefore the wind shear levels once determined for a specific site from the measured data can generally be considered to be reliable and predictable for noise assessment purposes.

The methodology adopted for the Winwick wind shear analysis is described at the noise proof of evidence RC1 [Ref: 10] and inquiry presentation notes [Ref: 11]. These presentation notes were requested by the Planning Inspector and accepted as evidence during the inquiry. The methodology for calculating the wind shear exponent follows GP van den Berg [Ref: 07] and that in '*Evaluation of wind shear patterns at Midwest wind energy facilities*' [Ref: 08]. The methodology applied with the Winwick wind shear analysis included:

- Calculation of the shear exponent for each 10min data set.
- Determination of shear characteristics for different wind speeds, times of the day and month of the year.
- Determination of the effects of wind shear and correction for shear on the noise assessment.

Wind shear was calculated using the 23.1m and 60.27m wind speed data for each valid 10min data set. The average wind shear throughout the 12 month period was found to be 0.2548 calculated from 51,943 valid data sets.

Once we had the results of the shear calculations, it was a case of analysing the results to determine the site specific shear characteristics and the levels of shear to be factored into the noise assessment. Analysis of wind shear against wind speed shows that high wind shear is only occurring when V_{10} is less than 5m/s and almost exclusively during the quiet day time and night time periods.

Analysis was then performed to determine the hourly average wind shear throughout the 12 month period. Figure 5 shows the hourly average wind shear exponent with a minimum of 0.11 occurring around mid-day and a maximum of 0.32 occurring around midnight. This shows a similar daily pattern as demonstrated by Smith [Ref: 08].

If we break down each of the hourly averages to show the wind shear exponent spectrum in bands it can be seen at Figure 6 that:

- A shear exponent of greater than 0.4 occurs for more than 19% of the time from 8pm through to 5am. The total time above 0.4 is 167.9 mins.
- A shear exponent of greater than 0.5 occurs for more than 7% of the time from 8pm through to 5am. The total time above 0.5 is 60.9 mins with 54.3 mins of this during the quiet daytime and night time periods.

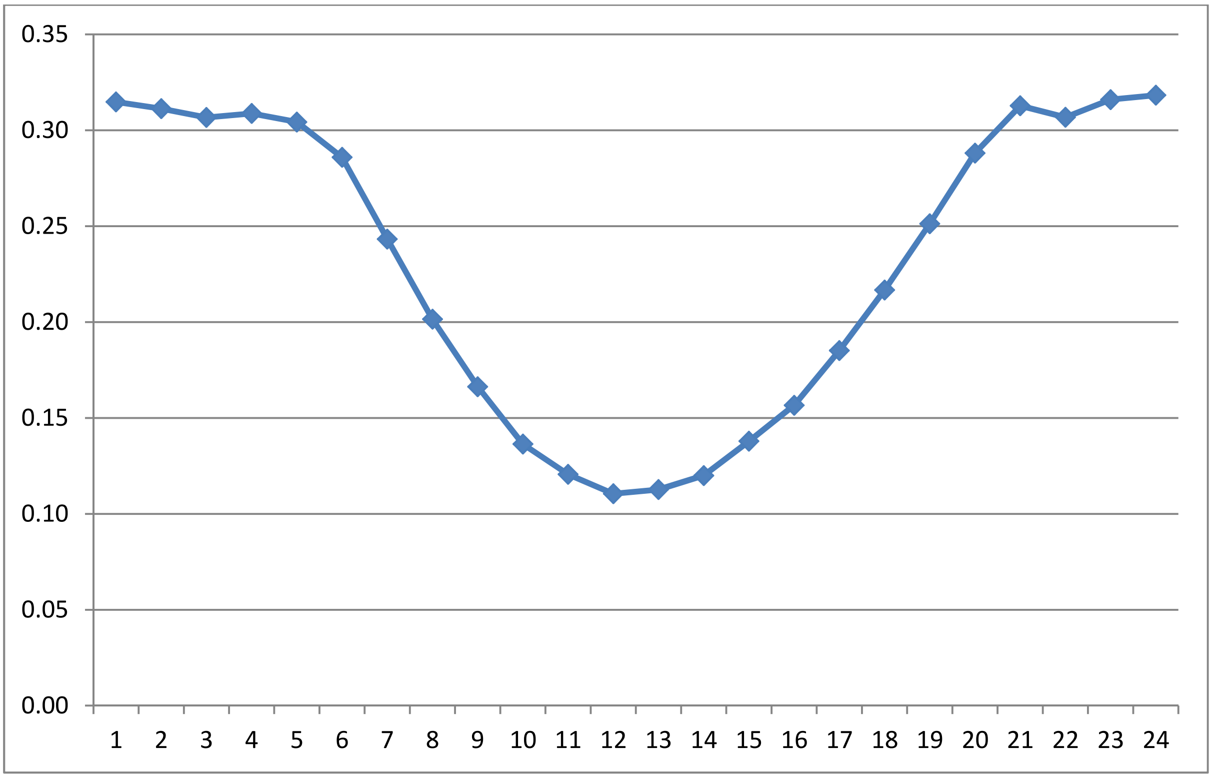


Figure 5: Hourly average wind shear

The wind shear analysis demonstrates Winwick is a high wind shear site and that wind shear exceeds 0.5 for significant periods during both ETSU ‘quiet day time’ and ‘night time’ periods. These hourly average shear levels are precise, predictable and affect this particular site for significant durations on a daily basis. As such they are not extreme events; they are regular events leading to the conclusion that wind shear levels of 0.5 should be factored into noise assessment.

In contrast to these high levels of wind shear identified from the analysis above, the Winwick wind farm developer, E.ON, represented by noise consultant AMEC, chose to apply corrections for the significantly lower average levels of wind shear based on wind speed bands as shown at Table 1. It was recognised by the planning inspector at the Shipdam appeal in her decision, [Ref: 09 Para 29] *"fluctuations in wind shear can be substantial, and averages can hide significant details"*.

Wind turbine manufacturers relate the turbine noise generated at hub height to the typical receptor at ground level by referencing the noise to a 10m height using the 'standard' shear exponent of 0.16 (or the equivalent ground roughness length of 0.05m) in line with ETSU. This is a perfectly reasonable standard to use providing it is understood but corrections need to be made for actual wind shear that exceeds this standard value.

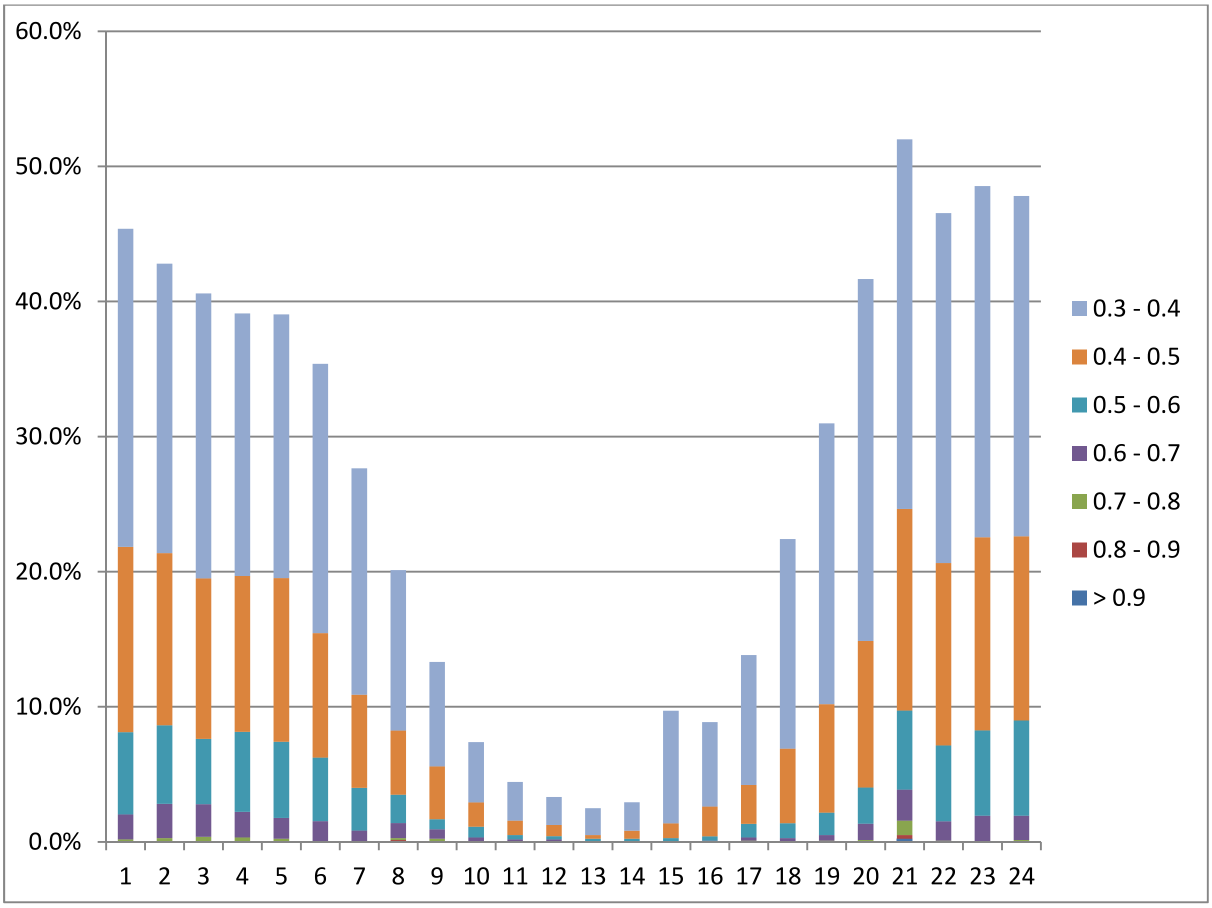


Figure 6: Hourly average wind shear exponent breakdown

Referring to Table 2, column 1 provides a range of V_{10} reference wind speeds. These are in turn referenced to the 80m hub height at column 2 using the 'standard' 0.16 exponent value. These 80m height wind speeds are then used to calculate the corresponding 10m height wind speeds at columns 3, 5, 7 and 9 for a range of shear exponent values of 0.3, 0.4, 0.5 and 0.6. The differences between these calculated V_{10} values and the 'standard' V_{10} wind speed at column 1 is the required offset and is shown at columns 4, 6, 8 and 10 respectively. So in the case of considering the effects of a shear exponent of 0.5 at a standard V_{10} wind speed of 6m/s, referring to Table 2, the actual V_{10} wind speed will be 2.96m/s requiring an offset correction of 3.04m/s.

10m Wind speed bands	2	3	4	5	6	7	8	9	10	11	12
Quiet Daytime (18:00 – 23:00)	0.27	0.26	0.20	0.16	0.12	0.12	0.11	0.10	0.10	0.09	0.09
Night-time (23:00 – 07:00)	0.36	0.29	0.23	0.19	0.15	0.13	0.13	0.12	0.11	0.10	0.10

Source: E.ON, Winwick SEI dated 31 Oct 2011

Table 1: Average wind shear values applied by Winwick wind farm developer

1	2	3	4	5	6	7	8	9	10
Reference Wind Speed	Calculated from V_{10} using α = 0.16	Calculated from V_{10} ref using α = 0.3	Shift from reference required for α = 0.3	Calculated from V_{10} ref using α = 0.4	Shift from reference required for α = 0.4	Calculated from V_{10} ref. using α = 0.5	Shift from reference required for α = 0.5	Calculated from V_{10} ref. using α = 0.6	Shift from reference required for α = 0.6
V_{10}	V_{80}	V_{10}	V offset	V_{10}	V offset	V_{10}	V offset	V_{10}	V offset
	α = 0.16	α = 0.3	Ref - α = 0.3	α = 0.4	Ref - α = 0.4	α = 0.5	Ref - α = 0.5	α = 0.6	Ref - α = 0.6
3.0	4.18	2.24	0.76	1.82	1.18	1.48	1.52	1.20	1.80
4.0	5.58	2.99	1.01	2.43	1.57	1.97	2.03	1.30	2.70
5.0	6.97	3.74	1.26	3.04	1.96	2.47	2.53	2.00	3.00
6.0	8.37	4.48	1.52	3.64	2.36	2.96	3.04	2.40	3.60
7.0	9.76	5.23	1.77	4.25	2.75	3.45	3.55	2.80	4.20
8.0	11.16	5.98	2.02	4.86	3.14	3.94	4.06	3.20	4.80
9.0	12.55	6.73	2.27	5.46	3.54	4.44	4.56	3.60	5.40
10.0	13.95	7.47	2.53	6.07	3.93	4.93	5.07	4.01	5.99
11.0	15.34	8.22	2.78	6.68	4.32	5.42	5.58	4.41	6.59
12.0	16.74	8.97	3.03	7.29	4.71	5.92	6.08	4.81	7.19

Table 2: Wind shear offset calculations

In the case of Winwick we determined that the V_{10} wind speeds when high wind shear occurs as being below 5m/s and that shear values of 0.5 occur for significant periods of time. Referring to Table 2, to the range of shear offsets at column 8 corresponding to V_{10} wind speeds below 5m/s and above the turbine cut-in point, are found to vary from 2.03m/s to 5.07m/s. In the case of Winwick it is believed that an offset of 3m/s to be a modest and reasonable correction to apply to the predicted noise curves.

Figure 7 shows as an example the day-time noise level curves in dB $_{LA90}$ vs. V_{10} 10 min averaged wind speed for the receptor location 'Winwick Warren The Cottages'. The effects of applying shear offsets of 2m/s and 3m/s show that for this location the wind shear correction causes a 'compliant' situation with 2.6dB of headroom to become 'non-compliant' with predicted noise 3.5dB above the limit curve.

We are seeing noise assessments accompanying planning applications where data relating to lower winds often below 4m/s are cut-off on the basis that the turbines will not operate at wind speeds below 4m/s. Table 2 identifies the importance of the lower V_{10} wind speeds when assessing noise impact. Although the turbine cut-in may be activated at around a 4m/s reference V_{10}, the actual V_{10} wind speed can be significantly lower at the cut-in point.

We see a 4m/s standard V_{10} at column 1 represents a V_{80} (hub height) of 5.58m/s at a standard wind shear of 0.16 in column 2. It is of course the hub height wind speed that determines the cut-in point for the turbine. However, at a wind shear of 0.5, this same V_{80} cut-in occurs with V_{10} at 1.97m/s as shown at column 7. Additionally, at a 3.94m/s V_{10} wind speed (column 7 and closest to 4m/s) at a wind shear of 0.5 represents a V_{80} wind speed of 11.16m/s, a doubling of V_{80} wind speed from the 'standard' wind shear condition when turbine noise emission and power output would be close to maximum and masking by background noise close to a minimum.

Bowdler [Ref: 05] concluded that turbine noise would be most intrusive at hub height wind speeds of 8m/s to 10m/s. This corresponds to V_{10} Wind speeds of below 4m/s at wind shear of 0.5.

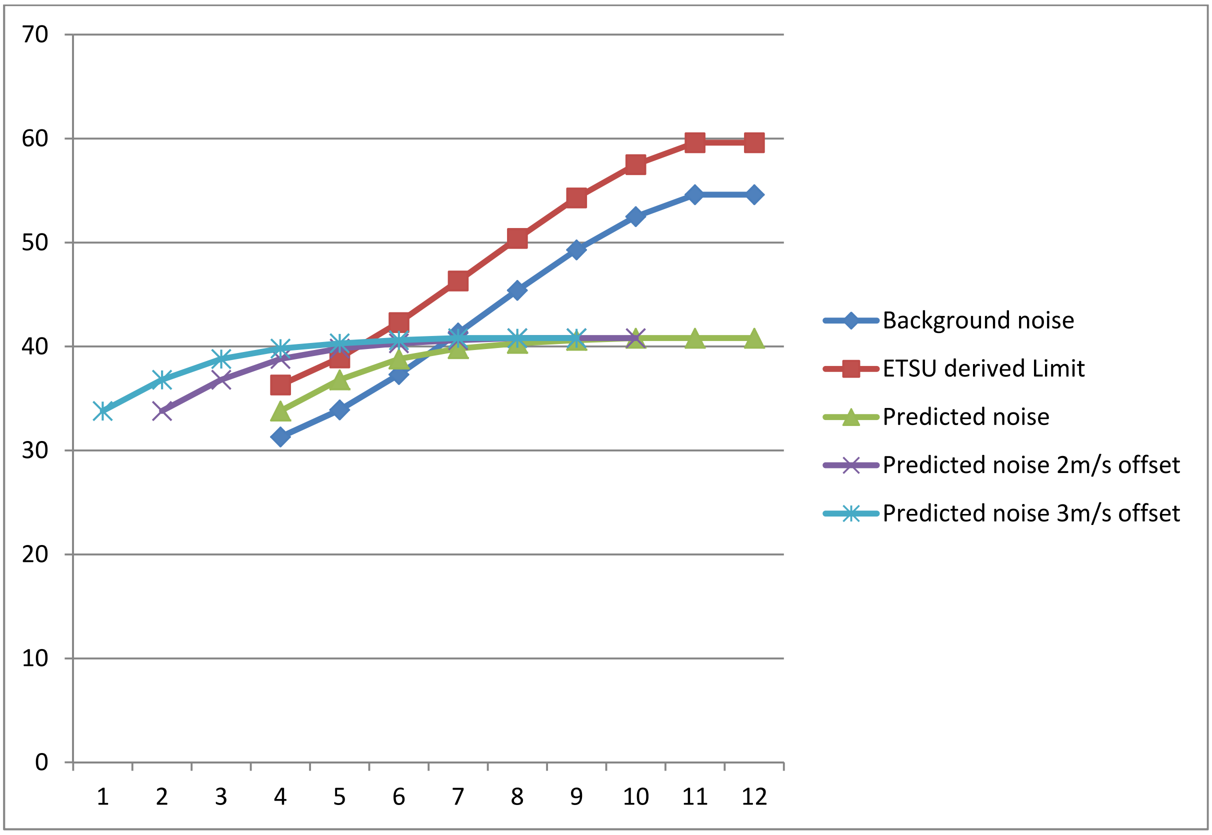


Figure 7: Wind shear correction illustration

DECC study on how noise impacts are considered – wind shear

The DECC study [Ref: 02] conducted by HMP dated April 2011 analysed how wind shear was being considered as part of the noise assessment process for wind farm planning applications. The report concluded that just over half the cases studied (53%) did not address the potential issue of wind shear although where wind shear was addressed, it mostly followed the principles described in the Institute of Acoustics Bulletin Article.

Even more disturbing is that at every wind farm where wind data has been made available and has been analysed by third parties, high levels of wind shear have been identified. High wind shear values in excess of $\alpha = 0.5$ prevail for around 10% of the time at sites analysed in Northamptonshire and mostly during the evenings and night time. With a majority of wind farms having no wind shear correction applied and insufficient correction being applied at the remainder there is a real danger of noise impacts being routinely underestimated.

Conclusions and implications

Noise intrusion is most likely during high wind shear conditions so mainly during the night time and evening (ETSU quiet day time) when wind speeds at ground level are likely to be low but turbine noise at or close to maximum. Noise assessments by wind farm developers have either failed to consider wind shear or applied very low levels of corrections so under estimating the likely noise impact on nearby residents.

A group of acousticians have proposed a methodology known as the Article Method for considering wind shear in the IoA magazine. Analysis of this methodology by Moroney and Constable [Ref: 06] and Stigwood [Ref: 04] shows it to be overly complicated and can lead to an under estimation of the noise impact. Although the Article Method is regarded as unofficial guidance it is being seized upon by the wind power consulting community as it allows them to demonstrate justification for reduced separation distances between turbines and houses.

Section 7 - Assessment Uncertainties

Noise assessment is no different from any other area of science or engineering in that any process requiring measurements will be subject to tolerances or uncertainty. It should be clear that within the ETSU process there are many decisions to be made about precisely how the guidance is to be followed but on which the ETSU document is silent. Yet each and every one of these decisions affects the application of the process by planning authorities. Our research suggests that there is a consequential under-estimation of the likely turbine noise that is critical to the 'safety' of the overall wind farm noise assessment.

Almost invariably, would-be developers present pages and pages of information that appears to be solidly based but that gloss over numerous questionable decisions made in the measurement period. Unfortunately, much of this evidence seems to be accepted without question and only its implications with respect to the limits to be set, usually by planning condition, are subject to scrutiny.

We believe that the way that the noise assessment evidence is presented, which gives the impression of scientific rigour and hides the uncertainties may well generate false impressions of its veracity.

- Measurement tolerance of the sound level meter, typically +/- 3dB for Class 1 SLM over the frequency range applicable;
- The effect of inadequate wind shielding of the microphones used;
- The siting of the microphones and variations in their height;
- Contamination of the data by rainfall, with the possibility of substantial spatial variation in this;
- Use of limited sampling periods and failure adequately to control by time of day variations in background and with respect to wind direction;

We recognise that the effect of these uncertainties could be both to increase or decrease the measured background at specific receptors, but on balance they will most probably lead to an assessment that uses a higher background than it should, resulting in shorter separation distances being applied, or to inadequate planning conditions being imposed. However, in the spirit of making an unbiased assessment we might conservatively rate their cumulative effect as being responsible for a +/- 5dB uncertainty (excluding the effects of inadequate wind screens) in the $L_{A90\ 10\ min}$ values held to represent the background noise at the chosen receptors.

Second, we have also shown that a further source of variation that can be estimated from analyses using data from real noise assessments is:

- Variations due simply to the invariably unjustified choice of polynomial function fitted to the background vs. wind speed data to establish what ETSU choses to call the 'average' curve.

This is shown to be of the order of +/-2dB but could equally be 'for' or 'against' a proposal. Developers, while claiming to assess the worst case scenario, fail to acknowledge that uncertainty can contribute to higher background noise levels which consequently give license to inflict greater noise on wind farm neighbours.

Third, the noise assessments we have examined are conducted assuming a 'candidate turbine' and do not take into account possible variations in the noise output such as:

- Differing actual turbines and the ways by which their manufacturers measure and report the emission data;
- Variations between nominally identical turbines;
- Allowances for non-ideal conditions met in practice but not incorporated into the manufacturer data used;
- Variations due to turbine and blade ageing;
- The methodology used to estimate the noise at each receptor and especially the assumed ground attenuation factor;

ISO9613-2 itself puts a +/- 3dB uncertainty around the estimation of noise at the sort of distances likely to be needed in a noise assessment, so it seems reasonable to add perhaps a further 2dB to this to give a total uncertainty, assessed by the usual rule for combining such figures of +/-3.6dB

So, we have uncertainty in the measurement of the background and in the predicted turbine noise. The third element in the noise assessment is the V_{10} winds used to index both these sets of data. It comes as no surprise to observe that these data too are subject to uncertainty as a result of:

- Use of a single point measure of the V_{10} wind in cases where the proposed wind farm spans a large area;
- Inadequate sampling of the range of both wind speed and direction;
- The ways by which wind shear across the rotor blades is factored into the assessment;
- The simple statistical fact that throughout the ETSU process use is made of average values, such that by definition there will be times and conditions on which the limits must be exceeded unless sufficient 'headroom' is allowed as a safety margin.

Note that in this we do not include the risk of excess amplitude modulation discussed at Section 8 and that again it is difficult to give precise estimates of the total uncertainty.

Conclusions and implications

In summary we have arrived at estimates of the uncertainties in the ETSU process of +/-5dB, +/-2dB, +/-3.6dB and +/-5dB for the basic sound data, the 'average' curve, the predicted turbine noise and the reference wind speeds. Of course some of these will cancel, but by the same token some will be additive. Combining these estimates in the standard way yields a token of +/-8.2dB but how they combine in any specific assessment would have to be dealt with on its merits, but we conclude by observing that **a sound difference of up to**

10dB from prediction could easily occur that will either double or halve noise loudness. This would be in addition to the errors arising from microphone wind induced noise and correction for wind shear.

The simple fact of this uncertainty in the process, about which ETSU is relatively silent and which every consultant report we have read does not mention, might well explain the increasing number of consented and operational wind farms at which the developer can justifiably claim ETSU compliance but at which the complaints data seem to indicate that a nuisance exists. If the suggested uncertainties are at all reasonable, it is difficult to avoid three conclusions about the ETSU process itself:

- The first is that, where there are receptors at risk from noise nuisance, whether or not a specific proposal 'passes' or 'fails' the ETSU process is largely a matter of chance, related to the way that the analysis has been conducted. We have no doubt that some schemes will have been consented that, had the analysis been conducted differently and the uncertainties recognised, should not have been. As we observe at the outset, we can find no scheme that has been rejected solely on noise nuisance grounds, so the converse, that schemes have been disallowed on noise grounds that should have been consented, does not apply.

- The second is that this in turn implies that, whatever the original intention of the ETSU panel, rather than a means of addressing legitimate public concern the entire process has become an expensive, irrelevant and unnecessary pseudo-scientific charade.

- Third, the entire process could be replaced by application of a clear and simple separation distance rule similar to those in place in some jurisdictions or that some English LPA's have attempted to enforce.

Complete safety may well be an impossible goal, but for the English Midlands a 2km separation distance would leave enough 'headroom' to make virtually all planning decisions safe from a noise aspect.

A 2km separation distance is also recommended by Frey and Haddon [Ref: 40] during 2007 who conclude, "*that a safe buffer zone of at least 2km should exist between family dwellings and industrial wind turbines of up to 2MW installed capacity, with greater separation for a wind turbine greater than 2MW installed capacity*."

Section 8 - Amplitude Modulation

Much inquiry time has been devoted to amplitude modulation (AM) with developers tending to talk down the likelihood of it occurring and its severity. However, it is generally agreed that AM is an aerodynamic effect of the turbine blade or aerofoil as it passes through the air.

What is amplitude modulation?

Amplitude modulation is the cyclic variation of sound energy emitted by a wind turbine. These cyclic variations occur at the blade passing frequency (about once per second) and normally give rise to the characteristic 'swish' noise. For much of the time this characteristic noise can be relatively benign but under certain conditions the nature of the noise changes to what is often referred to as excess amplitude modulation (EAM). EAM is generally recognised as being when the swish of the turbine blades changes to a more pronounced thumping or banging noise.

EAM is highly intrusive and can be experienced at receptor locations over 1.5km from turbines [Ref: 07]. It should be considered as being additional to the normal turbine noise and its occurrence at any particular site cannot at present be predicted with a high degree of certainty although it tends to be associated with high wind shear conditions and large wind turbines.

The wind turbine and helicopter comparison

There are many similarities between wind turbine and helicopter rotors with regard to the aerodynamics involved. The equivalent behaviour to EAM on a helicopter is known as *blade slap*. When it occurs it is the loudest and most objectionable form of helicopter noise. Blade slap can, at least to some degree, be found on virtually every type of helicopter, although some are far more susceptible to it and the noise more severe. Helicopter blade slap has been studied for several decades and is now well understood.

Research by Leverton [Ref: 29] during 1972 found that during normal operational manoeuvres and descent the Sea King/SH 3D produces loud blade slap, this is in contrast to the Wessex/S58 which produces only low level intermittent blade slap. Blade slap usually occurs during transient manoeuvres and is often associated with turns, with shallow descents, and with flare approaching a hover associated with the pilot tilting the rotor head.

The cause of helicopter blade slap is generally recognised as being the result of blade vortex interaction (BVI). This is described by Nitzsche [Ref: 30 page 120] as:

"*The most important component of the external noise occurs during manoeuvring flight and landing, when the rotor blades interact more strongly with the vortices shed by the tip of preceding blades, resulting in the phenomenon known as blade vortex interaction (BVI)*".

The sharp bang or slap is due to the sudden change in pressure on the blade surface as it encounters the vortex.

Whereas BVI has been well understood in the aviation industry for decades, the wind power industry is seemingly unable to understand the equivalent behaviour of wind turbines. Helicopter pilots are aware of the flight conditions that cause blade slap so are able to minimise its occurrence. In contrast the wind power industry is telling us AM is not understood and cannot be predicted. Since the aerodynamics involved are very similar we have some difficulty accepting this assertion.

Contributing factors leading to EAM

A description of AM is provided by Stigwood at [Ref: 26] based on measurements at four wind farm sites in the UK. He confirms that AM is dominated by low frequencies and differs from the assumptions in ETSU regarding peak to trough variation and sound energy.

EAM is associated with the high wind shear conditions that occur typically during the night. GP van den Berg [Ref: 07] states at section 10:

"*At night the sound from the wind park contains repetitive pulses, unlike the sound in daytime. According to the long-term auditory observation of residents this pulse-like character or 'thumping', is more pronounced and more annoying at high turbine rotational speed*".

Bowdler at [Ref: 05 page 12] states: "*it may make a difference to the sound characteristics of the turbine in that increased amplitude modulation may take place where the wind direction at the top of the trajectory is significantly different from that at the bottom*".

We know from the research into helicopter blade slap that it can be triggered by tilting the rotor disc as occurs during flight manoeuvres so increasing blade loading. With wind turbines the rotor disc is fixed but the effects of wind shear both vertical and horizontal (known as twist) can bend the rotor blades so effectively tilt the 'rotor disc' with respect to the wind. With a helicopter it is known that high blade tip speed and high blade loading are contributory factors in the generation of the tip vortices. A similar effect is observed with the occurrence of wind turbine AM.

When we consider the effects of wind shear across a typical 90m diameter wind turbine rotor with a hub height of 80m, we see wind speed changes on each revolution typically in the order of a factor of 2 or more under high shear conditions. In Section 6 above and Appendix B we have seen that wind shear exceeds 0.5 for significant periods of time on a daily basis at wind farms in Northamptonshire, is highly variable and regularly exceeds 1.0. High wind shear will create high cyclic forces to be applied to the rotor blades causing blade bending and effectively tilting the 'rotor disc' as occurs with a helicopter. Researchers from Denmark's Risoe DTU National Laboratory for Sustainable Energy have found large wind turbine blades can flex by up to six meters (20 feet) when subjected to strong wind gusts. Additionally, that load is often not evenly distributed along the length of the blade, so it doesn't flex evenly. At Shipdam [Ref: 09 Para 31] the Planning Inspector recognised the problems associated with rapidly changing wind speeds across the turbines swept area where she stated; "*Because of the non-neutral conditions within each turbine's swept area (at least 3,800m2) there would be a significant range of wind speeds. Ecotricity's detailed data show that changes of wind speed can occur from minute to minute*."

For example, under wind shear conditions of 0.5 we may see wind speeds of 6.46m/s at 35m height (blade bottom) and 12.2m/s at 125m (blade top), a ratio of 1.9, while V_{10} would be only 3.45m/s, classified as a 'gentle breeze'. Similarly with a wind shear of 0.9 we may see wind speeds of 4.64m/s at 35m height and 14.59m/s at 125m height, a ratio of 3.1, while V_{10} would be only 1.5m/s, classified as 'light air'. Given what is known regarding blade slap with helicopters it should not therefore come as a surprise that amplitude modulation with its 'thumping' noises frequently occurs with wind turbines.

Incidence of EAM and the Salford study

Stigwood [Ref: 26] states that there is general acceptance that EAM occurrence may be observed at between 10-16% of sites nationally. In public inquiries developers usually rely on the so-called *Salford study* [Ref: 30] from 2007 which found a lower percentage than 10-16%. FOI requests since 2007 have found that they failed to identify a number of sites affected by AM. Moreover other sites have been built since the study and others were missed from the study, including at least one in the original ETSU study.

The Salford report looked at EAM only from the acoustics perspective and failed to look at it from an aerodynamic or audiology perspective. It seems safe to assume that there are aerodynamics experts employed by wind turbine manufacturers who have a much greater understanding of AM and how it could be predicted with greater accuracy. The email survey of turbine manufacturers conducted by the Salford researchers appears to have been a somewhat less than rigorous attempt for obtaining information on AM. Turbine manufacturers are unlikely for commercial reasons to want to share any vulnerability to AM with their turbines.

Finally, the Salford study's survey methodology of LPA's has been widely criticised for being less than rigorous in identifying wind farm noise nuisance complaints arising in the UK. Additionally, during 2007 none of the larger 90m diameter wind turbines now operational and being built had been installed at any UK onshore wind farm. This move to larger turbines has resulted in turbine noise shifting to lower frequencies that by its nature tends to be more intrusive. It is clear to the authors that more research is needed into EAM. Whether a result of EAM noise or simple turbine noise, it is important to note that, although it tried to make light of the facts, even the Salford report acknowledged that about 20% of wind farms had been subject to noise complaints.

EAM planning conditions

A feature of EAM is its highly intrusive nature due to the low frequency content. When it occurs it causes a high degree of noise nuisance and can be experienced at receptor locations over 1.5km from turbines. Additionally, sound proofing measures such as double glazing are ineffective against the low frequency noise associated with EAM. EAM is usually observed when wind conditions at ground level are light and the atmospheric conditions stable, typical of high wind shear. It also tends to occur when the overall turbine noise is less than maximum making a breach of noise limits unlikely. As a result the 'standard' noise conditions based on dB $L_{A90\ 10min}$ noise measurement are ineffective at controlling EAM. Although it has been claimed that Statutory Nuisance Legislation could be used in the event of EAM occurring, experience to date in the UK has shown that obtaining redress from EAM for local residents is extremely difficult and only possible (one known case) following a lengthy, risky and expensive legal process.

To date very few wind farms have an EAM planning condition applied. The only prescriptive conditions the authors are aware of have been applied to just two wind farms (not yet built) at Den Brook, 11 December 2009 located in Devon and the Marston Vale Millennium Country Park, Bedford. 2nd February 2012. The condition [Ref: 31] is supported by a description [Ref: 32] where the key feature is the use of $L_{Aeq\ 125\ milliseconds}$ noise measurement to detect a rise and fall in sound energy levels of more than 3dB occurring within a 2 second period.

This planning condition was reviewed by Moroney and Constable [Ref: 33] who concluded:

"*the Den Brook condition is straightforward and that it is possible for this condition to be employed in a transparent and objective manner to demonstrate the existence of excess AM in wind turbine noise*".

Their report goes on to state:

"*These findings should be welcomed by both wind-farm neighbours, developers, and decision makers in the planning process. AM noise provokes complaints and heated debates, and an enforceable, objective, condition to cap such noise gives all parties clarity, as well as sparing neighbours and developers the trouble, expense, and uncertainty of private nuisance actions. The Den Brook condition appears to be a readily workable solution to this very real problem*".

Despite this the Den Brook wind farm developer, RES, is now challenging the EAM planning condition. The acoustic consultant Dr Bass of RES has written a report, [Ref: 33] where he purports to have thoroughly tested the Den Brook EAM condition. Dr Bass concludes that background noise alone, i.e. without turbines present create significant false positive indications of EAM, so effectively making the condition unworkable. He determined that the measured background noise data contained:

"*energy at a wide range of frequencies, particularly low frequencies. It may be that it is this low frequency 'rumble' which is causing the AM Test Method to fail when clearly no AM is present in the data*".

Amongst Dr Bass's stated reasons for the false positives is that it is caused by wind induced noise at the microphone. As has been shown earlier at Section 3, wind induced noise can be problematic when measuring noise levels if inadequate microphone wind screens are used.

The wind induced noise can contaminate the measured data and turbulence causes high levels of low frequency noise.

Dr Bass in his test of the Den Brook EAM condition used Rion NA-28 and NL-52 sound meters each with wind screens estimated to be around 200mm diameter. Examination of the photos from his report show that the spherical WS-03 wind screen was used with the NA-28 sound meter and the elliptical WS-15 wind screen was used with the NL-52 sound meter. Malcolm Hayes of HMP [Appendix D] confirmed that 200mm diameter wind screens are inadequate due to wind induced noise and wind screens consisting of a primary wind screen surrounded by a secondary wind screen of 500mm diameter are necessary. As a result of the failure to use suitable measuring equipment it can be concluded that Dr Bass's noise data, report findings and conclusions are fundamentally flawed.

DECC study on how noise impacts are considered – amplitude modulation

The DECC study [Ref: 02] conducted by HMP dated April 2011 comments on amplitude modulation at page 23 where it repeats the findings of the Salford report; [Ref: 30] that it; "*does not consider there to be a compelling case for further work into AM"*.

Conclusions and implications

EAM is highly intrusive and can be experienced at receptor locations over 1.5km from turbines. It should be considered as being additional to the normal turbine noise and it tends to be associated with high wind shear conditions, with large wind turbines and due to the interactions of multiple turbines in relative close proximity. Its occurrence at UK wind farms is likely to be significantly greater than the 10% to 16% reported.

The wind power industry claims EAM rarely occurs, is not a real problem and cannot be predicted. However, wind turbine EAM is similar to blade slap that occurs with helicopters, a phenomenon that has been understood for decades and can be accurately predicted. It is clear to the authors that more research is needed into wind turbine amplitude modulation.

The 'standard' noise condition based on dB $L_{A90\ 10min}$ noise measurement is ineffective at detecting the pulsing nature of EAM. Only by measuring using a much shorter time period can EAM be reliably detected. The EAM condition as applied at the Den Brook and Marston Vale wind turbines uses the $L_{Aeq\ 125\ milliseconds}$ noise measurement and is considered by the authors to be appropriate and straightforward meeting the requirements of Circular 11/95.

Statutory nuisance legislation is ineffective at dealing wind turbine noise nuisance requiring a Den Brook type EAM planning condition to be applied to all UK wind farms to ensure protection for nearby residents.

Section 9 - Other Reasons ETSU Should Be Reviewed

The previous sections of this report cover areas of the noise assessment process where ETSU [Ref: 01] is vague or silent. There are however, some areas where a review of the specific guidance provided in ETSU is required in light of the experience since 1996 when it was produced. These have been discussed at numerous public inquiries and the doubts they raise are well known, so this section is essentially by way of a summary.

Noise measurement

ETSU requires noise levels to be measured using the '$L_{A90\ 10min}$' measurement. In this case the 'A' indicates the A weighting measurement that most closely accords with the sensitivity of the human ear. However, given the significant low frequency content of wind turbine noise, the use of the C weighting measurement has been suggested by some acousticians and audiologists [Ref 38] to better indicate the true noise impact.

The '90' indicates the measurement of the noise level exceeded for 90% of the time. This measurement is effective for broadband noise such as traffic noise but not when measuring intermittent noise as produced by wind turbines. Some acousticians have proposed using the L_{A50} measurement [ETSU Ref 1 page 16] that indicates the noise level exceeded for 50% of the time or the L_{AEQ} the measurement indicating the equivalent continuous sound pressure level.

The '10 min' indicates the measurement is averaged over a 10 min period. This may work effectively when measuring broadband noises such as traffic noise but not when measuring intermittent noise as produced by wind turbines. It has already been proposed that the $L_{Aeq\ 125\ milliseconds}$ measurement be used to monitor for excess amplitude modulation.

Noise limits

The principle of the ETSU limits is to control turbine noise to 5dB(A) above the background noise on the assumption that turbine noise less than 5dB(A) above background would be unlikely to cause a nuisance. This assumption may work for similar types of noise but not when the turbine noise is intermittent and when the $dB_{LA90\ 10min}$ measurement is used. For this reason it can be argued that the limit should be lower and possibly set at the actual background noise level.

ETSU proposes minimum limits to apply in low noise environments and sets this limit to be within the range of 35 – 40 dB(A). The justification given at ETSU page 63 being: "*We believe that limits within this range offer a reasonable degree of protection to wind farm neighbours without placing unreasonable restriction on wind farm development*".

Then at page 61 ETSU recommends a higher night time limit of 43dB(A). This recommendation would seem to defy logic and its implementation has frequently been challenged at public inquiries. Its justification was that that most people are indoors at night when the noise indoors will be attenuated by an assumed 10dB(A) through an open window. There seems to be no technical justification for this claimed level of attenuation and most casual observers would estimate the actual attenuation through an open window to be barely perceptible (i.e. around 3dB) indicating that further work is required to assess the noise levels inside homes. The attenuation afforded by a closed window can be highly variable depending on the type of glazing system and frequency of the noise. In the event of low frequency noise as occurs with EAM, no window type, whether open or closed is effective at attenuating the noise. Additionally, there has not been adequate study of the potential adverse health effects of wind turbine noise [Ref: 39].

During 2006 the DTI (now DECC) commissioned a report titled '*The measurement of low frequency noise at three UK wind farms*'. The report [Ref: 35] was produced by HMP under the authorship of Malcolm Hayes. Following the publication of the DTI report, the Den Brook Judicial Review Group, submitted a Freedom of Information (FOI) request asking for copies of draft versions of the HMP study and associated correspondence. This request was refused by the DECC as it was considered not be in the public interest. After an appeal to the Information Commissioners Office, draft versions of the report [Ref: 36] and a limited number of emails [Ref: 37] were eventually released. It was claimed that any other emails that may have been related to the study had been deleted.

The 3rd Draft version of the HMP report [Ref: 36] recommended a reduction in the night time allowed noise level to 38dB $_{LA90}$ (40dB $_{LAeq}$) in order to ensure internal noise levels (with window open for ventilation) is limited to 30dB $_{Leq}$. Then it recommended**, in the event of high levels of aerodynamic modulation then an additional reduction of 5dB in the noise limit should be applied.**

The draft report [Ref: 36 page 35] also included the statement, "*A difficulty in returning to sleep will result in tiredness the next day and all the associated descriptions of ill health which might be associated with a lack of sleep".* An unnamed government official responded with the comment,

"This sentence is dangerous and could be read that wind farms cause ill health which is not the intention. We need the report to stick to the facts that LFN (low frequency noise) *is below the guidelines but that once woken by a car there may be problems getting back to sleep for those with sensitive hearing as a result of the wind farm – something like that*".

These recommendations were removed from the final report [Ref: 35] as were the recommendations that the ETSU-R-97 noise limits be reduced in line with World Health Organisation sleep disturbance limits. Additionally, there is no evidence of audiologists or other medical professionals being included on any of the noise working groups.

Conclusions and implications

There is compelling evidence for an **independent** review of ETSU and particularly regarding the noise limits, sound measurements to be used and health effects. The argument, "to *offer a reasonable degree of protection to wind farm neighbours without placing unreasonable restriction on wind farm development"* should not provide the justification to impose greater levels of wind turbine noise intrusion than would be permitted by other forms of development.

Biographies

Authors

Richard Cox

Prior to joining the power generation industry Richard Cox spent over eight years in the Royal Navy as an electrical artificer working on naval aircraft, predominantly Wessex and Sea King helicopters providing maintenance and operational support for electrical, flight control and weapon systems.

As an electrical engineer in the power generation industry was involved in the construction, commissioning, maintenance and life extension of nuclear and fossil fired power stations for over 30 years in both technical and commercial roles. During this period he was employed by the steam turbine and generator business of a major European manufacturer of power generation equipment for nuclear and fossil fired power stations. In contrast to his engineering career he has enjoyed a lifelong interest in the natural world and protection of the environment.

Now retired he has gained a good understanding of wind turbine technical and environmental issues including noise over the last three years. During this time he has given evidence at four wind farm public inquiries; Yelvertoft, Watford Lodge, Winwick and Lilbourne, all located in Daventry District, Northamptonshire and within 5km of his home.

David Unwin

David Unwin is retired academic geographer resident in Northamptonshire, retaining an Emeritus Chair in Geography at Birkbeck College, University of London. From 1967 to 2002 he taught Meteorology and Climatology to MSc level at several universities in the UK. In research he specialised in the climate change effects of urbanisation, which is arguably the best demonstrated anthropogenic influence on the outdoor climate, and in the application of spatial statistical analysis to environmental issues.

Much of his academic work was been at the interface between geography and computer science and he has considerable expertise in statistics and data analysis including the analysis of large volumes of climatological data. In 2012 he was awarded the Ron F Abler Honor of the Association of American Geographers for distinguished service to the disciple. From 2008 to 2010 he led the residents group opposed to a wind farm at Harrington, Northants and has experience in several subsequent applications. His views on onshore wind farms should not be taken to represent those of Birkbeck College and University to with which he is associated.

Trevor Sherman

Trevor Sherman is a retired management consultant living in rural Northamptonshire. He continues to respond to client requests for senior executive coaching assignments around the globe. Over many years Trevor has immersed himself in projects and campaigns outside of his professional sphere. For the past three years he has been actively involved in opposing a wind farm application in his village and coordinating the communication between the protect groups for the many wind farm applications within Daventry district. He gave evidence on community involvement in April 2012 at the Winwick Warren Wind Farm planning appeal. He has edited and published ‘A Guide to Fighting Wind Farm Locally’ which has been distributed nationally on request to wind farm protest groups.

Trevor started his career as a management trainee with Courtaulds Group followed by ten years’ experience in sales and marketing roles with Olivetti, GEC and Amway. He joined a USA owned marketing services and training agency, Carlson Marketing Group, where he progressed from Account Executive to General Manager. He completed his senior management training at the Sundridge Park Management College. Trevor ran his own management consultancy business for sixteen years up to his retirement two years ago. He initially specialised in quality management and customer satisfaction work. Trevor is a qualified external quality assessor. His consultancy work then extended to training, coaching and assessment when he became licensed to deliver a number of world renowned leadership training programmes.

Peer Reviewers

John Yelland MA DPhil(Oxon) CPhys MinstP CEng FIET BA(1)UEA
Dr Yelland is a consultant physicist and electrical engineer with an unusually wide range of experience. His DPhil thesis was on the acoustic impedance of liquid helium three; he has worked for both large and small Corporations including the Plessey Company and Instruments SA. He has been technical director of Companies in France and in England, having launched several successful Companies himself which continue to trade today.

His experience in physics ranges includes medical acoustics, analytic X-rays and precision temperature measurement and control. His experience in electrical engineering ranges from DC to GHz, including high voltage equipment and high power microwave amplifiers. Dr Yelland is now semi-retired but continues to work as a consultant; his main interest currently lies in multidisciplinary projects.

Rod Greenough
Dr R D Greenough, Emeritus Reader in Physics, was a lecturer in Physics at the University of Hull for more than 36 years with special responsibility for lectures to first year undergraduates in Data Analysis. He supervised numerous PhD students and published in excess of 80 refereed research papers in recognised international research journals and, in turn, refereed papers submitted by authors for publication to several international journals. Presently he is co-director of an SME specialising in the application of audible sound for non-destructive condition monitoring and the application of technologies to cancel audio noise.

Mike Hulme

Mike departed from a teaching career in environmental sciences back in the seventies. "*Our aim was to develop a low impact lifestyle through the application of alternative technologies, self-sufficiency and the re-use of materials wherever possible.*" Having built their home from largely recycled materials, Mike and his wife Barbara set about producing food and fuel from their 10 acre smallholding. What also evolved was a small scale engineering business based very much on the same sustainable principles.

In June 2004, Renewable Energy Systems (RES) applied to construct an anemometer approximately 1Km to the west of their smallholding. "*This was clearly a precursor to a wind farm development which, at the time, seemed to be very much an extension of our own aspirations,*" says Mike. Eight years on, Mike is a lead member of the Den Brook Judicial Review Group (DBJRG) and has been through two Public Inquiries and two High and Appeal Court Judicial Reviews in an effort to gain adequate protection in respect of adverse noise impacts, particularly EAM, from the 9 x 120 meter high turbines proposed for the Den Brook Valley wind farm. "I *realised very early on that ETSU derived noise limits and conditions are not fit for purpose, especially where EAM is concerned*."

Following 4 days of detailed noise and meteorological evidence submitted by experts on behalf of the DBJRG, senior Planning Inspector, Andrew Pykett, imposed an unprecedented stand-alone noise condition for the control of wind turbine EAM noise impacts. The five and a half years, often twisting and turning, debacle was elegantly captured and broadcast in the four part BBC2 documentary, 'Wind Farm Wars'. However, two and a half years on RES, the developer, is now seeking to significantly vary the unprecedented EAM condition for reasons examined in part 8 of this critically illuminating report.

Jon Whitehurst

Dr Jon Whitehurst is currently the Combat Systems Chief Engineer within BAE SYSTEMS Maritime – Naval Ships, responsible for the design integrity and certification of the combat systems supplied by the company, including certification of noise specifications. Previous positions held include Chief Engineer, Technical Integrity within the BAE Systems Integrated System Technologies, and Chief Engineer within the AMS Radar business. Prior to this, Jon was the Head of Engineering within the Radar Systems Division of BAE SYSTEMS Combat and Radar Systems (CaRS) business prior to merger of CaRS and Alenia Marconi Radar businesses. Jon has been the author of 5 peer reviewed papers and is named as inventor or co-inventor on 4 patents. Jon currently holds the roles of the Vice Chair and Honorary Secretary of the IET Solent Network.

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Appendix A: Background Noise Data Analysis

An almost unrecognised source of uncertainty in the ETSU process [Ref 01] arises from the models used in the establishment of an average background noise curve as a function of the 10m AGL wind (V_{10}). In this Appendix we enlarge on and justify the summary given in Section 4 of the report.

Typically, an Environmental Impact Statement (EIS) required by the Local Planning Authority will have an assessment of the likely noise nuisance at selected receptors for both 'quiet daytime' and 'night-time' conditions. This is based on an established curve of background noise plotted usually against measured V_{10} winds using observations collected over at most a few weeks simultaneous recording of both $L_{A90\ 10min}$ (dB) at the receptors and V_{10} (m/s) measured using a meteorologically standard 10m mast.

In spite of the worrying issues with the observed data dealt with in Section 3, the ETSU advice most frequently followed is to fit a *best fit polynomial curve* to these 'background' and wind speed data using the standard ordinary least squares (OLS) criterion of goodness of fit that under some well-understood assumptions provides the best linear unbiased estimates for the coefficients that define this curve. It would seem that the ETSU panel were of the opinion that specification of a polynomial of up to the 4^{th} degree and use of the phrase 'best fit' were sufficient to ensure a reasonably objective and robust result on which the LPA and/or Planning Inspectorate can rely. In the cases to which we have access this is simply not the case and the resulting average background curve values at whole number wind speeds used to assess compliance with the suggested ETSU limits need to be qualified by uncertainty that the ETSU process does not recognise. The arguments we present for this view are both scientific and statistical.

What is almost always forgotten is that this curve fitting procedure, using classical OLS regression that has been known and used since the mid-nineteenth century, assumes that the data are an *independent random sample* from a defined population of possible values. The method was outlined when, rather than being a very large data file downloaded from an automatic recording device, each and every data point was likely to be hard won by careful hand measurement. This is not the place to enter into a long exegesis of the assumptions of linear regression and their impacts on the fitted curves, nor do we argue for complete statistical purism: there are literally millions of successful and useful scientific studies that at some point break one or more of these assumptions. However, two specific features of these data are important and relate to the fact that both numbers come from a time series sampled and then averaged over ten-minute intervals by automatic recording devices.

The first is that these data will to a greater or lesser extent exhibit *auto-* or *self- correlation.* Autocorrelation can be understood by a simple thought experiment. Suppose that at some time the anemometer records a V_{10} of 10m/s, what is the value likely to be in ten minutes time? Given that meteorological elements show persistence in time it is highly unlikely to be either 0m/s or, say, 25m/s. Chances are that it will be fairly close to 10 m/s. In other words successive wind data are correlated with themselves and the same is likely to be true for the background sound pressure. Yet statistical inference assumes that each case is an independent sample that is uncorrelated with the others. The effect on the result is to bias the standard error because the formula is 'tricked into believing' that there is a larger sample than actually exists. Larger samples give smaller standard errors and better statistical significance. In essence this means that the statistical significance of any established fits, and thus the confidence we have in them, is likely to be over-estimated.

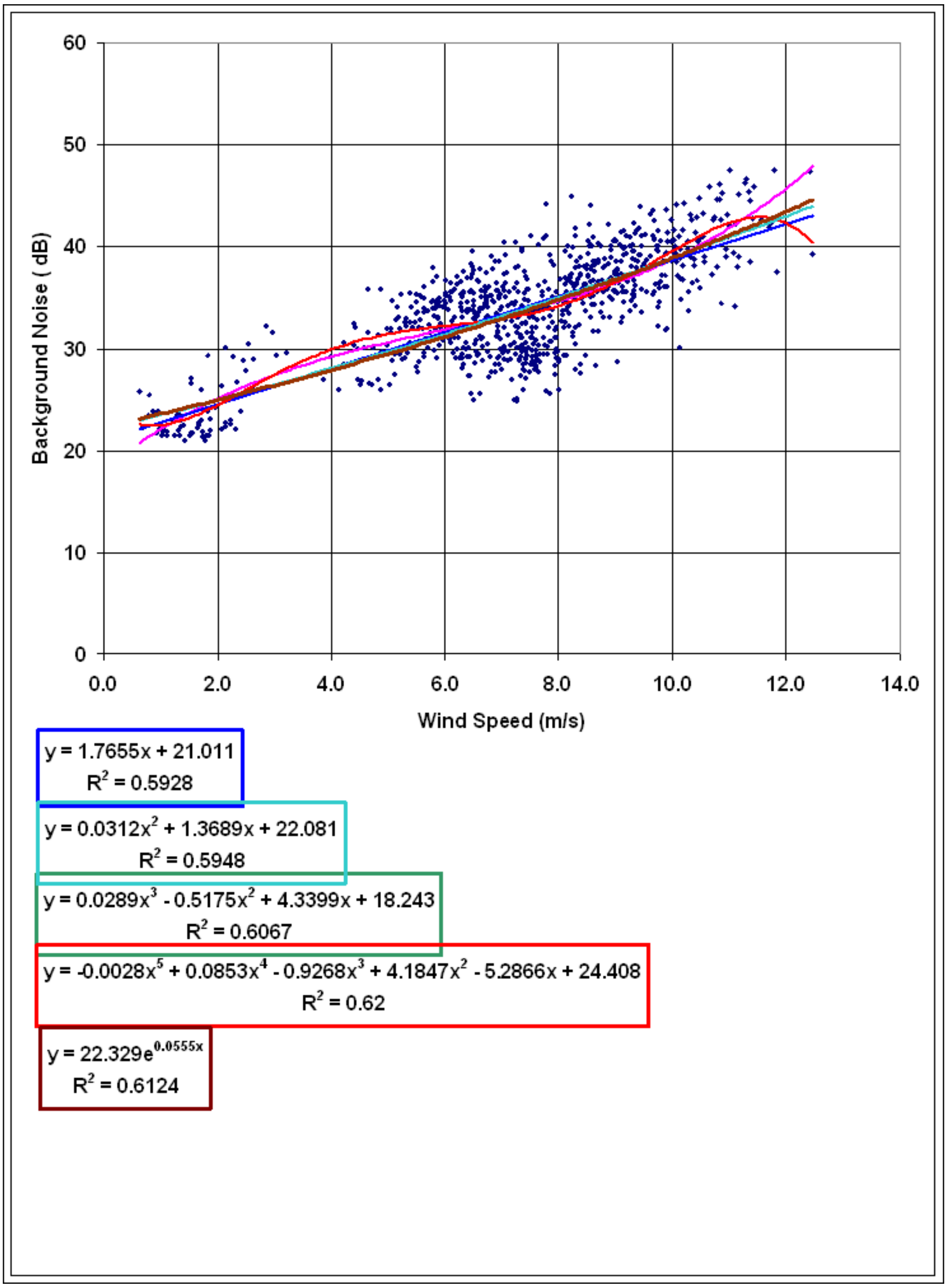


Figure A.1: Models for background noise data as a function of wind speed

The second feature is that the number of sample points (*n*) is not only large but is also to a very large extent *arbitrary*; it can be almost as large as you like (for example by using more weeks data, or decreasing the sampling time interval), but the impact on the statistical significance of any results is to make any change, not matter how small, almost certain to pass the standard tests. There is a real risk here of conflating the statistical notion of 'significance' with the scientific one and it cannot be stressed too highly that they are not the same thing.

The major consequence of these observations is that choosing a "best fit" polynomial curve to summarise the background noise is not easy. In all the environmental impact statements (EIS) associated with wind farm noise assessments we have examined we have yet to see a rationale based in acoustic or statistical theory for the curves that have been presented. Instead, what we find are polynomial curves of degree, p= 2 (quadratic), p = 3 (cubic), sometimes p = 4 (quartic), and in one case a p = 5 (quintic) that even ETSU rules out. ETSU's use of the word 'curve' seems almost universally to have ruled out the use of polynomial 'curves' of degree p = 1 (linear, straight line 'curves') even when, as we will see, Occam's Razor might suggest that this is the most appropriate model at some sites. The occasional commentary in the text shows that the fitting process is almost always driven by an obsession with the idea of ETSU's *best fit* being equivalent to 'highest *coefficient of determination* I can get'.

This coefficient of determination, which is denoted by the standard name "R^2" measure the fit of the curve to the data and varies from 0 (or equivalently 0%) indicating no fit at all up to 1 (100%) indicating that the curve passes exactly through each and every data point. An alternative interpretation is that in percentage form it gives the percentage of the variation in the dependent variable ($L_{A90\ 10\ min}$) that is accounted for by variation in the independent one (V_{10}) when, and only when, this is expressed by the particular curve fitted.

The uncertainty this model choice introduces into an assessment can be illustrated using the real daytime background noise data from a recent wind farm proposal in North Lincolnshire, shown in Figure A.1. There are n= 825 data points and the coloured lines represent five different models fitted to them. We have four polynomial regressions of degree p = 1, 2, 3, and 5 as:

Degree p= 1: $L_{a90\ 10min} = Y = 1.7655x + 21.011$ (dB), $R^2 = 0.5928$
Degree p= 2: $L_{a90\ 10min} = Y = 0.0312x2 + 1.3689x + 22.081$(dB), $R^2 = 0.5948$
Degree p= 3: $L_{a90\ 10min} = Y = 0.0289x3-0.5175x^2+4.3399x +18.243$ (dB), R^2=0.6067
Degree p= 5: $L_{a90\ 10min} = Y = -0.0028x^5 + 0.0853x^4 -0.9268x^3 + 4.1847x^2 – 5.2866x + 24.4081$ (dB),
$R^2 = 0.6200$

In each of these x is the measured V_{10} wind averaged over the same ten minute interval.

The polynomials of degree p = 2 and p = 3 are those that almost certainly would have been accepted as appropriate models on which to base the ETSU assessment., but we cannot resist pointing out that an alternative, equally plausible, model that actually fits the data better than all but the degree p = 5 model is the rather elegant exponential:

$$L_{a90\ 10min} = Y = 22.32e^{0.055x} \text{ (dB)}, R^2 = 0.6124$$

Unless this is to be a scientific hall of mirrors, which of these models should be used in the assessment or will any curve do the job just as well? All suggest that with no wind the background is somewhere between 18.243 and 24.4081 dB, which seems reasonable for a quiet rural location, and all describe the data reasonably well, giving coefficients of determination, R^2, in the range 0.5928 – 0.6200. So which is the 'best fit' that ETSU asks for?

One formal statistical option can be understood by the observation that straight line, degree $p = 1$ polynomial requires estimation of two coefficients whereas the degree $p = 5$ quintic one requires estimation of 6 coefficients for a gain in 'explanation' of just 3.7% (=100 x (0.6200-0.5928)). There is a clear case here for an appeal to Occam's Razor suggesting that the *simplest model that is consistent with the data* is the one that should be fitted. On these grounds alone, and in the absence of any strong theoretical justification to aid the selection of model, we doubt that when presented with this scatter of data points any practising scientist would fit anything other than a simple linear model. As polynomials of progressively higher degree are used they allow the curve to add points of inflexion around which it can twist to accommodate the observed data. It is inevitable that this added flexibility will increase the R^2 and so in some sense be a better fit, but the danger is that of *over-fitting*, introducing features into the curve that are artefacts solely of the degree of function chosen that have nothing to do with nature herself. A 'better fit' is not necessarily the 'best fit' of the two. The polynomial of degree $p = 5$ shown is a good example of this.

Within ETSU the statistical question that should be asked is NOT 'is a model of degree p+1 a better fit to the data than the model of degree p' as commonly presented, BUT '*given that we have to estimate another coefficient*, *does this new model of degree p+1 significantly improve on the fit given by the model of degree p?*' This is a question well known in data analysis in general and specifically to geostatisticians in the context of fitting polynomial regressions, called *trend surfaces*, to the locational coordinates of mapped information [Ref: 23, O'Sullivan and Unwin, pages 279-287] and a simple analysis of variance approach has been adopted to handle it. Applying this approach to this case, what we find is that, even with such a large number of data points, the additio*n* of the extra quadratic term (x^2) is only just significant at the 95% level, (i.e. one chance in twenty of being wrong), but not at 99%. Similarly the very large, *n,* of strongly auto correlated data points made available by courtesy of the recording devices, ensures that the cubic and higher order terms are also just statistically significant, but almost any statistician confronted with these results would counsel caution and warn against over-fitting.

There are alternative ways of fitting curves to plots that look similar to these and there are alternative regression diagnostics to the crude R^2 coefficient of determination. For example, using a simple statistics package there is often the facility to identify *unusual observations* that are either badly fitted or that exercise undue influence called their *leverage,* [Ref: 24, Unwin & Wrigley]. Of interest in the context of model selection is the distribution of the unusual observations, something that is not necessarily apparent from a visual examination of the plotted line and the scatter of data points. For the degree $p = 1$ polynomial (a straight line) in the example used above, the software we have used (MINITAB) identifies 86 such observations of which 32 are badly fitted having a high *standardised residual* (This is simply the value of the difference between the value at the data point and that predicted by the fitted curve divided by its standard deviation) and 54 have undue influence on the fitted line indicated by a high *leverage*. Of the badly fitted points the majority (24 from 32) have negative residuals, implying that the best fit line suggests a higher background than is the case. Note that if you relied on the linear curve there is a possibility of departures at some time or other of up to +/- 10dB which is a doubling or halving of the predicted sound level from the curve. Figures A.2 and A.3 show that these residuals are relatively well-behaved with a roughly normal (bell-shaped) distribution around the fitted line and with no obvious pattern when plotted against the fitted values.

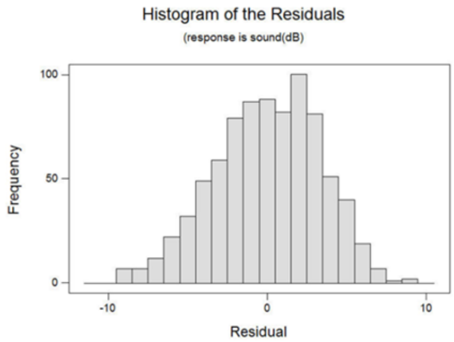
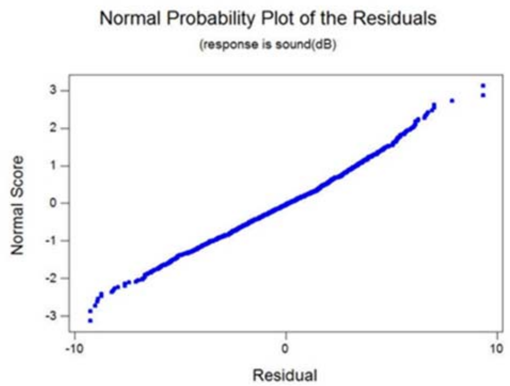
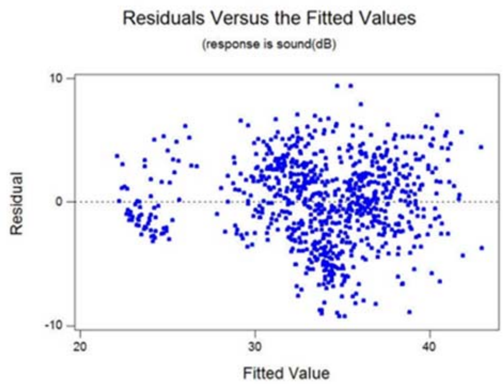


Figure A.2: Residuals over the linear model



a) The distribution is roughly normal



b) … and there is no obvious pattern with respect to the fitted values

Figure A.3: Some simple regression diagnostics

Of rather more significance to our argument are the 54 observations that exert undue leverage on the solution. Leverage is also known by the phrase *distance to the centre of the data* and in the example this is very evident, but with a particular bias towards observations at low winds. In fact 52 of these points are at V_{10} winds less than 2.0m/s which leads directly to a very important point of principle: *although most assessments might choose to ignore the data at low winds, less than 'cut in' for the turbine, these data have* *disproportionate importance in 'fixing' the shape of the model fitted to the entire data set*. In fact, the behaviour of the model close to the V_{10} = 0, no wind, axis is critical. Because the fitted lines are so similar, fitting the quadratic or even cubic models makes very little difference to these results and the same issues emerge.

If, any practising scientist had been presented with these same data without any information on the variables that they represent, we think that they would undoubtedly have concluded there is no reason to fit anything other than a linear curve which has a background value at zero wind of $L_{A90\ 10min}$ = 21.0dB on top of which is a modest increment of 1.77dB for every 1.0 m/s increase in the mean V_{10} wind.

However, this is not the path that the noise assessment in every EIS we have examined follows. Instead, in what we think to be some sort of assumed ETSU compliance and in order to increase the fit they add quadratic, cubic and even quartic and quintic terms to the model. In doing this the risk of over-fitting becomes very evident and can be illustrated by no less than three models offered in response to various objections at the Winwick public inquiry, again for the quiet daytime at an obviously at-risk receptor.

The initial attempt, shown here as Figure A.4, used a simple degree p= 2 quadratic polynomial with a plot showing all of the data down to V_{10}=0 m/s, but did not report the R^2. The equation of the best fit quadratic was:

$$: \ L_{A90\ 10min} = Y = 0.0587x^2 + 0.5167x + 30.548$$

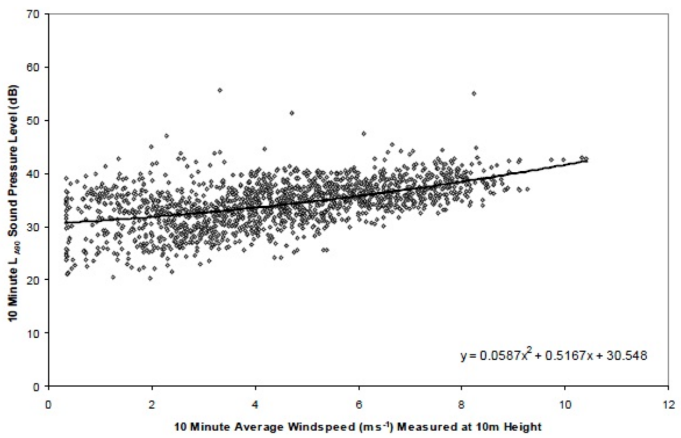


Figure A.4: The quadratic model

Note that this suggests an arguably high background at V_{10}=0 m/s of $L_{A90\ 10min}$ = 30.548 dB. Note further that the coefficient on x is an order of magnitude greater than that on x^2, which may well indicate that the simpler linear model would have been adequate. Without the original data or some measure of the fit we simply cannot take this further, but responding to a query from the local planning authority, the next attempt used a different method of referencing the winds to 10m AGL and some additional survey data to produce the degree p=3 cubic model shown as Figure A.5.

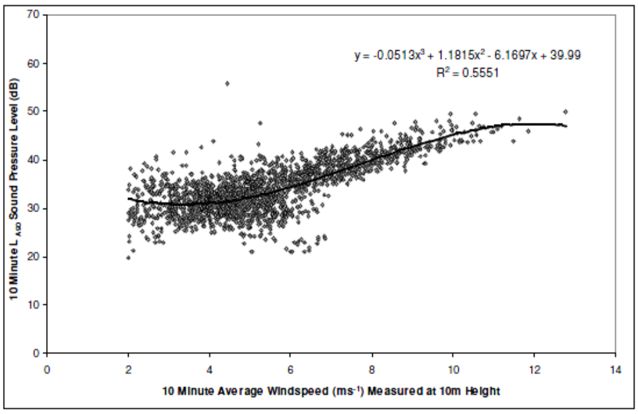


Figure A.5: A cubic model?

Degree p= 3: $L_{A90\ 10min} = Y = -0.0513x^3 + 1.1815x^2 - 6.1697x + 39.99$ (R^2= 0.5551)

No comments were made about the change of function, but at least this reported the rather modest fit that we assume to have been higher than that for the quadratic At what cost in logic do we get this improvement? Notice that the introduction of a cubic term (x^3) into the equation means that we now allow the function to have two points of inflection at which its curvature changes from being concave upward (positive curvature) at low wind speeds to concave downwards (negative curvature) at higher speeds. What matters here isn't whether or not the additional term significantly improves the fit but whether or not it makes sense in simple logic. It does not and for two reasons. First, at V_{10}= 0 m/s it predicts a background in quiet daytime at a site in a very quiet rural area of an extremely unlikely $L_{A90\ 10min}$ = 39.99dB from which we *subtract* background as the wind speed (x) and wind speed cubed (x^3) increases but *add* as the wind speed squared (x^2) increases.

Although we are not acousticians, we doubt that any acoustical theory or characteristics of the actual background at this receptor would sustain this. Second, although the full extent of this feature is hidden by the 'blanking out' on the plot of many of these data, from V_{10} = 0 to around V_{10} = 3 m/s it suggests that as the wind increases so the background noise gets less, which is equally unlikely.

In our opinion both features, the high intercept and the negative gradient, have nothing to do with nature and everything to do with over-fitting a cubic model to data that do not warrant it. Any cubic function will inevitable bend through two points of inflection and that it is inevitable that this extra freedom for bend will increase the goodness of fit as measured by the R^2. Note also that if a cubic function fitted by least squares doesn't show two points of inflection in the range of the data that is of interest, logically it must be the wrong function and an example of over-fitting.

Does it matter that in the range of wind speeds that are of concern that we have different versions of the background curve that the ETSU process requires? For the various models shown in Figure A.1, at V_{10} = 5m/s the background curve value to be used in the ETSU assessment is as is given as in Table A.1:

Model fitted	Background at V_{10}=5m/s $L_{A90\ 10min}$ (dB)
Polynomial, degree 1	29.84
Polynomial , degree 2	29.71
Polynomial, degree 3	30.62
Polynomial, degree 5	31.31
Exponential	29.38

Table A.1: Fitted models, first example

For the second example used in this Appendix the equivalent background values are as in Table A.2:

Model fitted	Background at V_{10}=5m/s ($L_{A90\ 10min}$ dB)
Initial Quadratic	34.60
Polynomial Degree 3, Model (2)	32.27

Table A.2: Fitted models, Winwick example

In both cases at V_{10}=5.0m/s there is a *range* of background values of around 2.0dB in the $L_{A90\ 10min}$, which increases at V_{10} lower than this and decreases as V_{10} increases above it. This range has very little to do with nature and everything to do with the choice of model fitted to the data. The uncertainty is of a similar magnitude to that reported as arising with different corrections for wind shear and although modest it could well be important in any decision made with receptor sites that are marginal in the ETSU guidance.

It should be stressed that *any* of these curves could well have been used in determination of an application to build a wind farm and/or in the determination of critical limits for any agreed conditions. That anyone or other of them increases or decreases the reference values at the receptor sites, and so does or does not favour a developer, is in our opinion irrelevant. Just as by manipulation a developer might be able to raise the background by choice of data and function, so could any competent data analyst find a function that would lower it by the same, or even greater, amount. The difference is that a competent data analyst would be well aware of this fact, report the uncertainty, and allow for it in any decisions based on it. Regrettably, on this uncertainty ETSU is simply silent.

Appendix B: Wind Shear Case Study

In 2003 and following years, van den Berg published a series of academic papers, [Ref: 07 and Ref: 12] which demonstrated that understanding of the problem in the ETSU group was limited, to the extent that even the formula used to estimate hub height wind speeds from V_{10} wind speeds is rarely accurate in the real world. Because it is the wind speed at hub height that dictates the rotational speed of turbines and thus the noise emitted, this has enormous implications for noise generation and hence application of the ETSU process.

ETSU originally assumed that there is a *constant* relationship between wind speeds at 10m and turbine height. This is simply incorrect, the basic point being that in the Planetary Boundary Layer (PBL) there are other forces involved such that one cannot assume a constant relationship (i.e. a constant amount of wind shear). In fact, the difference between low and higher altitude wind speeds varies throughout the day with meteorological conditions. Figures 4 and 5 in the main text are typical plots of the wind shear exponent and this same point can be illustrated using 2010 data made available to the Winwick Parish Meeting from the mast at Winwick. Figure B.1 shows the 2010 annual average ratio of the measured V_{60} wind with a best estimate of the V_{10} wind plotted as it varies with time of day:

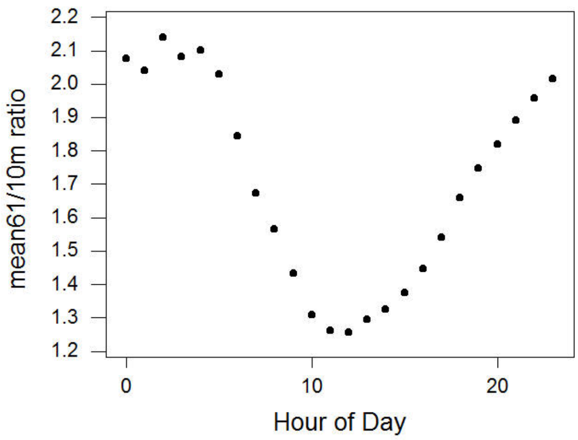


Figure B.1: Diurnal variation of the ratio of the observed V_{60} to V_{10}, Winwick

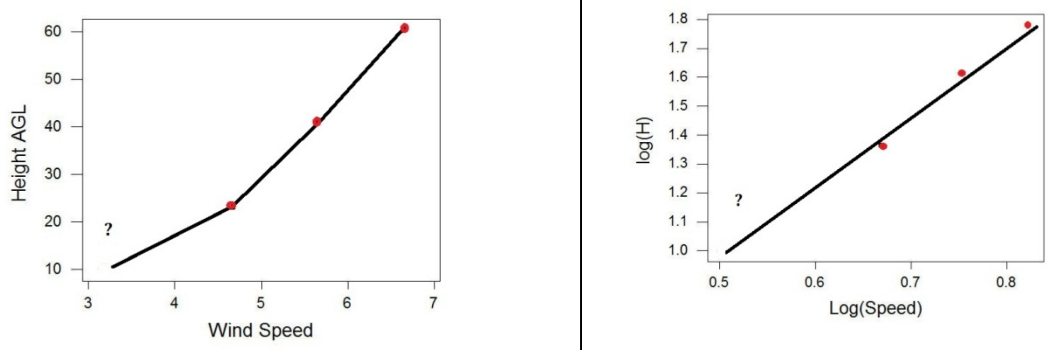
In these averages, the ratio is always greater than 1.0, which implies that *on average* winds increase with height over this height range. If the assumption of constant ratio were correct the plot would show a horizontal line of dots at the same ratio. It can be seen that this ratio, and thus the average wind shear it represents, is emphatically not constant, such that any attempt to predict V_{60} from V_{10}, or *vice versa*, using a constant relationship is doomed to failure. Even in these annual hourly averages there is a range in V_{60} from around 1.25 to over 2.00 times V_{10}.

Meteorologically, this behaviour can be explained by noting that during the daylight hours when the sun is heating the ground considerable vertical mixing of air takes place which has the effect of decreasing the overall wind shear. Meteorologists refer to this as an *unstable* atmosphere which favours vertical motion. At these times, the difference in wind speed between low altitudes and hub height, the wind shear, is small. Consequently, the chance of low levels of wind turbine noise being masked by wind-induced noise near ground level as ETSU allows for is reasonably high. At night the vertical mixing is reduced in what is known as a *stable* atmosphere, the wind shear is high, and the difference between the wind speed at low heights and hub height is large, such that chance of even quite low levels of wind turbine noise being masked is low.

Van den Berg noted that a useful formula, virtually standard in meteorological practice, for describing the variation in wind speed with height for much of the time (but *importantly* not all of the time) is the so-called power law equation:

$$V_1 = V_2 * (h_1/h_2)^{\alpha}$$

Where V_1 = wind speed in m/s at a height of h_1 (m AGL) and V_2 is the value at some other reference height h_2. Note that the ratio of the two heights is raised to some power denoted as the variable α. Strictly, the total shear should be computed for the *velocity*, that is, including any directional change, but in practice studies tend to look solely at the shear as expressed by the change in wind *speed*, using the values of α estimated from the rate of change of wind speed with height. The variable α is the so-called the *shear exponent* and overall the equation describes a wind profile which, when the raw values are plotted, describes a curve.



Wind speeds v height	The *log-linear* profile

Figure B.2: Wind profiles in the Planetary Boundary Layer

The left hand side of Figure B.2 shows a typical plot with data at three heights AGL. This shows that the rate of change of wind speed with height (the slope of the line) isn’t constant but normally decreases as one ascends such that the curve is concave upwards. The three red dots are the data points and the question mark has been drawn to emphasise the fact that predicting the V_{10} wind involves an *extrapolation* outside the range of these data.

The right hand side of the same figure shows that by taking common logarithms of both the heights and the wind speeds the result is to move these data onto a straight line, which describes the so-called *log-linear wind profile*. The line itself is characterised by the intercept at which point the wind is zero and the slope, given by the value of α in Van den Berg's equation. The question mark remains, but, provided the profile is reasonably well-fitted by the linear model, its estimation should be more reliable than any recourse to the untransformed data.

Wind shear exponents can be estimated from just *two* reasonably well-spaced sets of height measures by a straight forward calculation in which we take the logarithms of the two winds speeds, subtract the lower one from the upper and divide by the logarithm of the height difference. This is easily implemented on a spread sheet such as Excel ™ An alternative way used where there are three or more measurement heights (and is in fact standard meteorological practice) is to use all the available heights and fit a line of best fit to them using the standard statistical technique of ordinary least squares regression (OLS).

The best fit line whose gradient is α is that which minimises the sums of squares of deviations of the data values from it. With only three points and well-defined log linear wind profiles it is hardly likely to make much difference except perhaps when we extrapolate well outside of the range of the data. Note that both approaches imply quite a lot of computation since typically the data loggers used record data at every ten minutes and, also typically a years' worth of data are collected giving a potential maximum of 365(days) x 24 (hours) x 6(intervals) = 52,560 profiles.

The ETSU guidance is silent on how the observed wind shear should be incorporated into the analysis.

A simple approach would be to use an average value for the shear, taking the average over some specified time period. At one extreme this could simply be the average of the entire year. For example at Winwick for 2010 the annual average wind speed profile is very well-described by the log-linear model:

$$\log(\textit{Wind speed in m/s}) = 0.389 + 0.230 \log(\textit{Height AGL in m})$$

The value $\alpha = 0.230$ is the annual average wind shear exponent. Although the mean winds at each level are higher, an identical analysis based on data for anemometers at four heights at Harrington around 25km to the east of Winwick for 2009 gives a value of α = 0.249 and for data from three heights at Kelmarsh 20km to the east for 2010 the value was α = 0.288.

This use of an average value for the shear conceals a great deal of variation that significantly impacts on the ETSU process. This was recognised by the planning inspector at the

Shipdham wind farm public inquiry where her Appeal Decision report [Ref: 09] states at Para 29; "*fluctuations in wind shear can be substantial, and averages can hide significant details*".

The most reliable way of assessing this is to use the original 10-minute observations and compute the shear exponent for each and every one. Figure 15 shows the overall frequency and cumulative frequency distributions of 10-minute shear exponents at Winwick in 2010.

The average, at = 0.254, differs slightly from the estimate obtained from the regression on the averaged wind values, but of more importance is the considerable range shown.

The standard deviation of these values, σ_{α}, is 0.158 indicative of considerable spread around this average and it can be seen that there is a slight 'tail' in their statistical frequency distribution towards the higher values. It is this *spread* of values around the average, and also around the averages at each whole number wind speed, that is critical to the argument. Use of any averages such as averages based on wind speeds as applied by wind farm developers can be relied upon to 'average out' those times of the day at which very high shear occurs and, when attempting to isolate any possible noise nuisance.

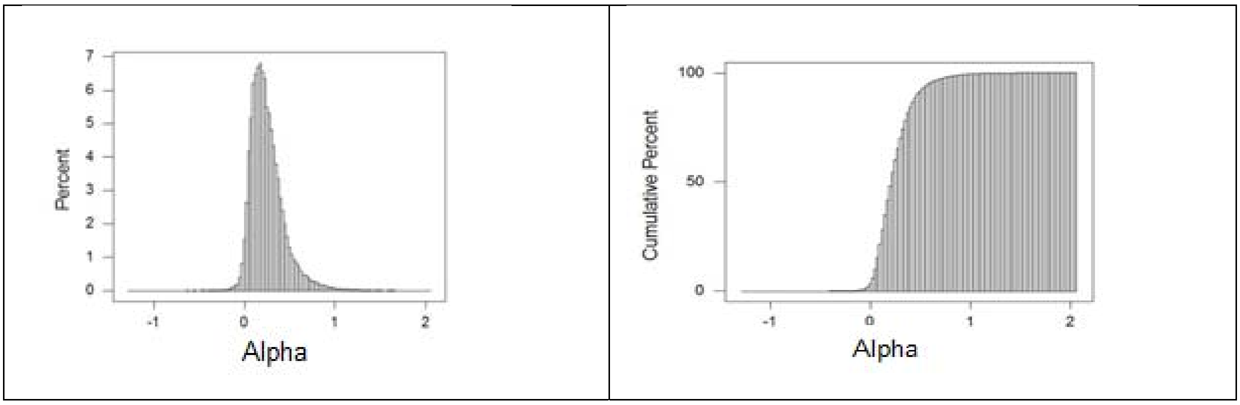


Figure B.3: 10-Minute Shear Exponents, α, Winwick mast 2010, actual and cumulative percentages of the year

The question to be asked should not be 'will this average shear cause the ETSU-R-97 limit to be exceeded?' but 'with this distribution of values of the observed wind shear how often and for how long will the ETSU-R-97 process limits be breached?'

Figure B.4 shows a 'funnel' plot of all the 51,943 data points from the Winwick site. The horizontal axis shows the estimated V_{10} as might have been measured by an anemometer at that height. The vertical axis is the value of the calculated shear exponent.

The plot is virtually identical to Bowdler 2009 [Ref: 05] Figure 6. Bowdler observes: '*This is a typical pattern shown by all analysis of shear data. On flat land and hill land, in principle, the pattern is always the same irrespective of location, time of day or time of year*'.

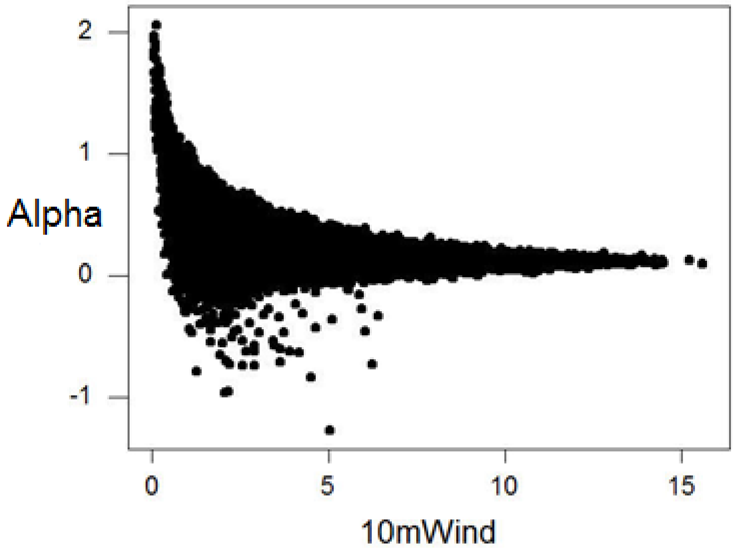


Figure B.4: Funnel plot of wind shear exponents α *vs.* V_{10}, Winwick mast 2010

Some features of the plot should be pointed out:

- For any given wind speed, there is a range of possible shear exponents;
- For any given wind speed, and with the exception of a few outliers, both the lower and upper limits of these ranges are well-defined;
- As wind speeds increase so this range decreases and the actual values of the wind shear become less;
- Although the majority of the shear values are positive, indicating an increase in wind speed with height, incidents when the reverse is the case and we have a negative shear exponent are not unknown.

Value of shear exponent α	%of time
<0.16	34.1
0.16-0.30	33.7
0.30-0.50	23.2
>0.5	8.9

Table B.1: Distribution of the wind shear exponent, α, Winwick mast, 2010 (% of the total time)

High values of wind shear across the turbine rotors have three possible implications for their performance and the ETSU process:

- They are likely to cause excessive noise when evaluated against agreed limits;
- They are held to be implicated in the phenomenon of excess amplitude modulation (EAM);
- Potentially, they may well cause additional loads on the blades that lead to premature, and possibly dangerous, failure [Ref: 08].

What can be seen from these data is the percentage of the time the wind shear exceeded specific values. Table B.1 presents a summary of these data over the complete range of wind speeds.

These data can be compared with equivalent results at Harrington in 2009 when $\alpha = 0.5$ was exceeded for 7.1% of the time and for Kelmarsh in 2010 when $\alpha = 0.5$ was exceeded for 11.1% of the time. The view sometimes expressed that high shear is an issue confined to low lying flat land is simply incorrect.

Appendix C: Malcolm Hayes blog – wind noise at microphones

The text below was taken from a blog dated 7 July 2000 by Malcolm Hayes of HMP at the Google Newsgroup site. The link to the web site for the full blog is:
http://groups.google.com/group/alt.sci.physics.acoustics/browse_thread/thread/1f934b7b36ae36/b006058f299e2198%3Fq%3D%2522Kees%2Bde%2BVisser%2522%23b006058f299e2198&ei=iGwTS6eaOpW8Qpmqic0O&sa=t&ct=res&cd=3&source=groups&usg=AFQjCNGKl0BWN5fRzHJN0TSGK84w3r_GpA

Newsgroups: **alt.sci.physics.acoustics**
From: **Malcolm D Hayes <100547.…@CompuServe.COM>**
Date: **2000/07/07**
Subject: **Re: Wind noise in microphone recordings**

B&K publish data for their wind shields that have been tested in a wind tunnel with the lowest published frequency being 20 Hz. However, in the real world, the wind shield is affected by turbulence in the air. This results in greater self noise for a given wind speed than that published by B&K, especially at low frequency.

I would suggest that unless you undertake noise measurements in still wind conditions, that you need to improve your wind shield(s). 6 – 8 inches (150 – 200 mm) as a diameter is quite small for windy environments. In the wind turbine world we use ground boards with primary and secondary wind shields, half a 90 mm ball as the primary and a secondary of 500 mm diameter, 25 – 50 mm thick with 4 – 10 pores / sq. inch. (mixed units due to the ISO nature of the Standard) Even with this arrangement, we still have problems with very low frequency measurements and wind turbulence.

When undertaking environmental noise measurements around wind farms we use a double wind shield arrangement, with a B&K UA 0570 type foam shield with a secondary shield of between 300 and 500 mm diameter. Appropriate tri-pod arrangement is required due to increased wind loading from large wind shield.

I've also seen wind shields designed for the purpose of recording bird song which had diameters approaching 1 metre.

The Energy Techonolgy Support Unit in the UK have published a report that provides a handy summary of wind shield design and a list of references (ETSU W/13/00386/REP Noise Measurements in Windy Conditions) which was undertaken by ISVR at Southampton. There are also a number of techinical reviews published by B&K which consider wind shield design. You could also check out JASA 92(2) p1180- 1183 Investigation of the mechanisms of low-frequency wind noise generated outdoors.
MalcolmX

Appendix D - Members of Noise Working Groups and Reports

No Groups	Name	Organisation	ETSU Working Group 1997	Noise Working Group Aug 2006	Noise Working Group Oct 2006	Noise Working group Apr 2007	Salford Report 2007	Acoustics Bulletin Apr 09	The Measurement of Low Frequency Noise at Three UK Wind farms 2006	Wind Farm Statutory Nuisance Methodology Apr 2011	Analysis of How Noise Impacts are Considered in the Determination of Wind Farm Planning Applications	IoA wind farm Working Group 2011/12
		Sponsor	ETSU (DECC)	BERR (DECC)	BERR (DECC)	BERR (DECC)	BERR (DECC)	IoA	BERR (DECC)	DEFRA	DECC	IoA
1	Dr. Mags Adams						x					
4	Dr Mike B Anderson	Renewable Energy Systems (RES)	x	x	x	x						
1	Kristian Armstrong	DTI			x							
3	Jeremy Bass	RES		x	x	x						
4	Mr B Berry	National Physical Laboratory then consultant	x	x	x	x						
4	Dick Bowdler	New Acoustics		x	x	x		x				
6	Dr Andrew Bullmore	Hoare Lea Acoustics	x	x	x	x		x			x	
1	Douglas Crockett	DCLG			x							
5	Bob Davis	Robert Davis Associates		x	x	x		x				x
3	Mark Dorrington	AEA Energy & Environment then FES		x	x	x						
2	Sue Ellis	DEFRA			x	x						
1	Duarte Figueira	DTI				x						
2	Dani Fiumicelli	AECOM								x	x	
9	Mr Malcolm Hayes	Hayes McKenzie Partnership	x	x	x	x	x	x	x		x	x
3	Dr. Sabine von Hünerbein	University of Salford				x	x				x	
5	Mr M Jiggins	Carrick District Council then Hoare Lea Acoustics	x	x	x	x		x				
2	Zoë Keeton	RWE Npower then seconded to DTI			x	x						
1	Sarah Kydd	DTI			x							
1	Mr E Leeming	The Natural Power Company Ltd	x									
4	Dr Mark L Legerton	ETSU then nPower	x	x	x	x						
4	Geoff Leventhall	Noise consultant		x	x	x		x				
3	Helen Matthews	DEFRA		x	x	x						
6	Andy McKenzie	Hayes McKenzie Partnership		x	x	x		x	x		x	
1	Mr R Meir	DTI	x									
2	Dr Andy Moorhouse	University of Salford				x	x					
1	Dr P Musgrove	National Wind Power Ltd	x									
3	Jonathan Perks	FES then AEA Energy & Environment		x	x	x						
4	Richard Perkins	Parsons Brinckerhoff Ltd seconded to DEFRA		x	x	x						x
2	Ben Piper	University of Salford				x	x					
3	Alan Purdue	Castle Morpeth LA		x	x	x						
3	Mike Raw	Scottish Borders LA		x	x	x						
1	Mr DJ Spode	North Cornwall District Council	x									
1	Ms E Tomalin	EcoGen Ltd	x									
1	Mr HA Thomas	Isle of Anglesey County Council	x									
4	Mr Marcus Trinick	Bond Pearce Solicitors	x	x	x	x						
1	Alan Smith	RWE Npower then seconded to DTI		x								
3	David Spode	Shrewsbury LA)		x	x	x						
2	Huw Thomas	Anglesey LA			x	x						
2	Chris Tomlinson	BWEA now RenewableUK			x	x						
1	Nigel Triner	AECOM								x		
2	Dr J Warrren	National Wind Power Ltd then nPower	x	x								
1	Anne Wood	CLG				x						
1	Mathew Cand	Hoare Lea Acoustics										x
1	Chris Jordan	Northern Group Systems (Env. Health)										x
	Key	**Frequent Appearance**		**Most Frequent Appearance**								

Appendix E

(1) 'Onshore wind—direct and wider economic impacts' (May 2012) by BiGGAR Economics—see:

http://www.decc.gov.uk/en/content/cms/meeting_energy/wind/onshore/benefits_wind/benefts_wind.asp

The findings of the report are based on 18 case studies of experience on the ground, and set out the gross impacts of commercial onshore wind development.

Chris Heaton-Harris: To ask the Secretary of State for Energy and Climate Change what estimate his Department has made of the number of standard-sized wind turbines that need to be constructed in order to match the level of energy generated by a single standard sized nuclear power station. [111664]

Charles Hendry: The Department does not maintain a 'standard size' definition for either wind turbines or nuclear power stations.

Chris Heaton-Harris: To ask the Secretary of State for Energy and Climate Change whether his Department includes the effects of the *(a)* mining of ores used in the manufacture of electromagnets and *(b)* manufacture of concrete used for turbine bases in its environmental impact assessment for wind farms. [111676]

Charles Hendry: Potential environmental impacts are considered on a project by project basis as part of the planning process through the requirement for wind farm developers to undertake environmental impact assessments (EIAs).

Chris Heaton-Harris: To ask the Secretary of State for Energy and Climate Change what assessment he has made of the level of non-compliance with ETSU97 in respect of wind-induced noise and the use of microphone secondary windscreens for wind farm noise assessments. [111787]

Charles Hendry: No such assessment has been made by DECC. It is for planning authorities to assess compliance with ETSU-R-97 as appropriate.

The use of double/secondary microphone windscreens for wind farm noise measurements is considered current good practice by acousticians. Further technical advice on noise measurement equipment including windscreens will be included in the forthcoming guidance on the implementation of ETSU-R-97, which DECC has asked the Institute of Acoustics to develop. The draft guidance is expected to be issued for consultation in the summer.

Chris Heaton-Harris: To ask the Secretary of State for Energy and Climate Change if he will consider establishing a public inquiry to investigate lobbying by the wind power industry and its effects on Government policy over the last 10 years. [111788]

Charles Hendry: DECC does not have any plans to establish a public inquiry to investigate lobbying by the wind power industry and its effects on Government policy over the last 10 years.

19 Jun 2012 : Column 902W

Mr Hollobone: To ask the Secretary of State for Energy and Climate Change how many grid connection points there are in *(a)* the Borough of Kettering, *(b)* Northamptonshire and *(c)* the UK to which it would be feasible to link an onshore wind turbine. [112286]

Charles Hendry: The electricity grid owned by the National Grid and the distribution network operators consists of many hundreds of substations and interconnecting lines. There are generally no

Her Majesty's Court of Appeal
04 AUG 2008

IN PRIVATE
Appeal No.

C1/2008/0793
C1/2008/0793B
C1/2008/0793C

IN THE COURT OF APPEAL

Order no. 8152

ON APPEAL FROM THE HIGH COURT OF JUSTICE
QUEEN'S BENCH DIVISION
ADMINISTRATIVE COURT

CO24492007

BEFORE LORD JUSTICE RIX

B E T W E E N

MICHAEL WILLIAM HULME

APPELLANT

- and -

(1)THE SECRETARY OF STATE FOR COMMUNITIES & LOCAL GOVERNMENT
(2)WEST DEVON BOROUGH COUNCIL
(3)RES DEVELOPMENTS LIMITED

RESPONDENTS

ON READING the Consent Order dated 22nd July 2008 signed by the Solicitors for the Appellant and signed by the Solicitors for the Respondent

AND UPON READING the Appellant's Notice, the Appellant's Skeleton Argument, the Respondent's Notice, the Skeleton Argument filed on behalf of the Third Respondent, and the evidence filed by the parties.

AND UPON the First and Third Respondents (the Second Respondent having taken no part in the appeal) indicating that they do not contest the appeal

AND UPON the Appellant and the First and Third Respondents agreeing that the appeal should be allowed on the terms set out below for the reasons set out in the Schedule hereto

AND UPON the Court being satisfied that the facts and matters set out in the Schedule hereto constitute good and sufficient reasons for allowing the appeal

AND UPON none of the parties being a child or protected party, and the appeal not being from a decision of the Court of Protection

ST

Appendix F

IT IS ORDERED that

1) the order of Mr Justice Mitting dated 19th March 2008 be set aside;

2) the decision of the First Respondent's Inspector dated 22nd March 2007 be quashed;

3) the First and Third Respondents do pay to the Appellant his costs of the proceedings in this court and in the High Court, to be subject to detailed assessment on the standard basis if not agreed; and

4) the hearing of the appeal, fixed for 25th July 2008, be vacated

ST

By the Court

SCHEDULE

1. The Third Respondent ("the developer") applied to the Second Respondent ("the Council") for planning permission to construct and operate a wind farm, consisting of nine turbines and associated development, at a site known as Den Brook in Devon. The Council refused planning permission and the developer appealed to the Secretary of State who appointed an inspector to determine the appeal ("the Inspector"). A public local inquiry was held from 22 to 24 and 27 to 30 November 2006. On 22 March 2007, the Inspector issued his decision, by which he allowed the appeal and granted planning permission for the wind farm subject to conditions. This is the decision under challenge by the Appellant, who lives in the vicinity of the proposed wind farm.

2. One of the main issues on the appeal was whether the proposed wind farm could operate without creating levels of noise harmful to the amenity of the Appellant and others living in the vicinity.

3. Before the Inspector, the Appellant gave evidence that in conversations with the developer's noise expert, the latter had accepted that there were errors in the background noise measurements on which the developer's noise evidence was predicated. The Appellant considered himself unable directly to take issue with the developer's noise evidence in this respect because the developer had declined to disclose the raw data upon which it was based.

4. In paragraph 47 of his decision, the Inspector accepted that accurate background noise measurements were important not just for the Appellant but also for the wider application of the proposed planning condition relating to noise. The Inspector referred to the dispute between the Appellant and the developer as to background noise measurement, but concluded that he was content that background noise measurements had been properly taken in accordance with the relevant methodology.

5. However, the Inspector, like the Appellant, was not provided with the raw data upon which the developer's noise evidence was based and he too was thereby precluded from determining whether or not there actually were any errors in the background

noise measurements. Despite this, the Inspector did not state the reasons why he resolved the dispute between the Appellant and the developer in the manner that he did. As the Inspector himself accepted, the dispute related to an important matter which was relevant not just to his decision that planning permission should be granted but also to his consequent decision as to the terms of the condition intended to control the level of noise generated by the windfarm. Accordingly, the Inspector's failure to give reasons for his conclusion in this respect amounted to an error of law.

6. The Appellant has been substantially prejudiced by the absence of reasons in this respect. The developer has, since the decision of Mitting J, met a request by the Appellant to provide the raw data upon which its noise evidence was based. Both the Appellant and the developer have now adduced evidence, which was not before the Inspector or Mitting J, to the effect that an analysis of the raw data reveals that there were errors in relation to the background noise measurements upon which the developer's noise evidence was predicated. Whilst there is disagreement between the Appellant and the developer as to the significance of those errors, this Court is not in a position to resolve that disagreement. Accordingly, absent the Inspector's reasons for deciding as he did, it cannot safely be concluded that, had the Inspector had the benefit of having the relevant errors drawn to his attention and hearing the parties' contentions on them, his decision would inevitably have been the same.