WIND TURBINE NOISE – A REVIEW OF PROGRESS TO DATE, AND WHERE TO NEXT?

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1 INTRODUCTION

Wind turbine noise assessment has come a long way in the last five years, and the completion of an IOA sponsored initiative to produce Good Practice Guidance has done much to codify extant practice. In this paper the path to the production of the IOA Good Practice Guide, and the six Supplementary Guidance Notes, along with how the IOA managed the relationship between the technical and the policy elements of the process will be revisited as a blueprint for future IOA ventures into developing guidance documents. The paper will then introduce the current programme of worked aimed at providing a metric and methodology to quantify and assess the amplitude modulation within turbine noise, and that element of it which is considered to give rise to complaints. The paper will also consider ways how the IOA may go forward to influence the ongoing debate about the appropriate limits on overall noise levels from on-shore wind turbines.

2 BACKGROUND

In the UK, noise assessments for wind farm developments are undertaken using the methodology set out in ETSU-R-97 'The Assessment & Rating of Noise from Wind Farms' published in September 1996. The Government Department of Energy and Climate Change (DECC), which has policy responsibility for ETSU-R-97, commissioned a report in 2010 to analyse how noise impacts are considered in the determination of wind farm planning applications, and specifically look at how the ETSU-R-97 methodology was being applied. The Hayes McKenzie Partnership (HMP) undertook the study, and reported back in April 2011. The HMP report highlighted variations and aspects of the methodology that in practice were being misunderstood and incorrectly applied, leading to confusion and uncertainty in the planning process.

The DECC then wrote to the UK Institute of Acoustics (IOA) to invite them to take forward (where possible) the recommendations of the HMP Report, and to produce a 'Good Practice Guide' (GPG). The IOA accepted the invitation, and appointed a noise working group (IOA-NWG) to produce good practice guidance. The IOA agreed only to consider the technical elements within ETSU-R-97, and not to look at the noise limits which remain a matter for Government.

A review of the available literature and initial drafting led to an 80 page consultation document which was peer reviewed before forming the basis of a formal IOA consultation which ran over the summer of 2012. The working group held two workshops in Dublin and London to discuss the issues raised in the consultation document, and to encourage feedback.

Consideration of the consultation responses led to final drafting, another peer review and the publication of the IOA Council approved GPG on the IOA website on 20th May, and launched at a one day meeting in Bristol on 21st May 2013. Government endorsement from England, Wales, Scotland and Northern Ireland followed shortly after, so the document is now well used in the planning system as "current good practice".

The successful integration of the GPG into the planning system was the direct result of close liaison and collaboration with the respective Government departments. Regular meetings with the Government Oversight Group provided an opportunity to inform on progress and ensure the latest issues causing problems in the planning system, such as wind shear, were captured in the GPG,

and swift endorsement was achieved. Whilst some IOA Members felt this endorsement was unnecessary, it would be wrong to ignore the way the planning system works, and the weight given by decision makers to endorsed guidance.

The work of the group did not stop there, as there was still the small matter of the production of six Supplementary Guidance Notes (SGN), and what to do about the unresolved issue of Amplitude Modulation. The IOA NWG continued to draft six SGN's which they consulted on in early 2014, four of which were published in July 2014, and the remaining 2 in September 2014. As with the GPG, the SGN's were subject to peer reviews before consultation and before final publication and the IOA have written again to Government to seek their endorsement.

Two IOA One Day meetings were held in March and May 2014 where the subject of Amplitude Modulation was discussed and debated. The output of those discussions was a recommendation for the IOA NWG to take on the task of refining a metric and methodology with which to quantify AM, which was approved in June 2014. A sub group of the IOA NWG was formed, and it is hoped that the work will be well underway by the time of the 40th Anniversary Conference. More details of the AM work can be found on the IOA website (www.ioa.org.uk).

Last but not least, there is the issue of the ETSU-R-97 noise limits. A sample poll of attendees at the IOA launch day conference revealed that a large majority of attendees feel that the noise limits are too high, particularly the 'lower fixed limit' at night. This feedback has been made to the Oversight Group, who pointed out that the ETSU-R-97 noise limits are guideline maximum levels, and local authorities have the flexibility to set more stringent limits in accordance with their local plans. The next steps are being considered by IOA Council.

The following sections describe the current good practice established in the GPG and the SGN's.

3 GPG INTRODUCTION

3.1 Scope

The scope of the GPG considers all wind turbine developments above 50 kW, reflecting the original principles within ETSU-R-97, and the results of research carried out and experience gained since ETSU-R-97 was published. This does leave smaller developments without formal guidance, for which a number of regional policies appear to be filling the gap, although many of the principles covered in the GPG would still apply.

The presentation of the GPG includes text and graphics, with numbered summary boxes at the end of each section. The GPG notes that it represents good practice as of the date of publication, and does not exempt further advances from being used. It is anticipated that a regular review of this document will be undertaken, and a new version produced when significant changes have occurred. Updates can therefore occur without the need for lengthy legislative procedures.

3.2 The ETSU-R-97 Noise Assessment Procedure

The ETSU-R-97 assessment procedure consists of the following steps:

- Predict noise levels from all turbines (existing and proposed) at the nearest receptors;
- Determine a study area;
- Identify potentially affected properties;
- (If required) Undertake a measurement survey consisting of simultaneous measurement of background noise levels at representative properties with wind speed and direction at the proposed turbine site;
- Analyse the data to remove rain affected and atypical data, and derive the noise limits for the scheme;
- Update noise predictions & assess compliance with the noise limits for a candidate turbine, and provide design advice if compliance with the limits is considered unlikely.

The GPG notes that the main purpose of the procedure is to set out the noise data required, and the subsequent analysis needed to allow a decision maker to make an informed decision to assess compliance with ETSU-R-97.

3.2.1 Engagement

Experience has shown time and time again that engagement of all of the relevant parties (decision makers, developer and local residents) at an early stage of a project and continuation of that engagement throughout the project is desirable. Engagement should be viewed as an ongoing process.

3.3 Background Data Collection

3.3.1 Scoping for Background Noise Surveys

ETSU-R-97 considers turbine noise levels from the proposed, consented and existing wind turbine(s)at any property below 35 dB L_{A90} at up to 10 m/s wind speed (10 metre standardised wind speed) to be acceptable, so 'study areas' for background noise surveys (and noise assessment) tend to use this as a benchmark. However, when establishing the baseline noise climate, there should be no influence from any existing turbines.

The selection of monitoring locations is not a straightforward process, and requires a number of factors to be taken into account, such as the presence of atypical noise sources, access, the use of proxy sites, and capturing the range of different climates around the wind farm site. The GPG concludes that '*the background noise monitoring locations within the study area should be selected on the basis of professional judgment, with the objective of collecting sufficient data to enable the background noise levels at each noise-sensitive receptor within the study area to be characterised*'. Decision makers can help with this process, but as a minimum should be informed of the measurement plans to avoid later debate. A well constructed and documented survey methodology is vital to reduce uncertainties in the assessment process.

3.3.2 Timing of surveys

Whilst it is acknowledged that some sites can be influenced by seasonal effects, the IOA-NWG concluded that '*Background noise surveys may be carried out at any time of the year provided that seasonal effects leading to raised noise levels can be excluded by selection of measurement position or by exclusion of non-typical data during analysis.*'

3.3.3 Noise Measuring Equipment

The noise measurement equipment and calibrators used for a background noise survey require careful consideration, as the nature of the equipment has been the subject of scrutiny at several planning appeals. The GPG recommends that the equipment should comply with Class 1/Type 1 of the relevant standard(s). Type 2 is not recommended due to the need to reduce the level of uncertainty in the measurement chain, and the costs are not prohibitively expensive with the current state of the art. Whilst most other surveys would avoid windy situations, it is necessary to consider measurements in high wind conditions for a wind turbine, and therefore it is vital that an enhanced microphone windscreen be used. The GPG notes that standard windshields of a diameter of less than 100 mm cannot be relied upon to provide sufficient reduction of wind noise in most circumstances.

3.3.4 Siting Noise Measurement Equipment

The placement of the equipment is also a critical part of the methodology. ETSU-R-97 requires measurements be made in amenity areas between 3.5 and 20 metres from a dwelling, and this remains current good practice. The measurement position should permit measurement of

background noise levels judged to be typical/indicative of the area around the associated dwelling and any other dwellings for which the measurement location will serve as a proxy. The influence of noise from local sources should be taken into account when selecting measurement locations.

The GPG also notes that the person selecting background noise monitoring positions and visiting these locations should record subjective impressions of sources contributing to local ambient noise levels, and that residents should be consulted to establish the occurrence of unusual noise events during the monitoring period. Photographs showing the positions of measuring equipment are also required.

3.3.5 Wind Speed & Rain Measurement

The GPG considers that three methods of wind speed measurement may be adopted:

a) Direct measurements at hub height using either:
   i. A met mast carrying one or more anemometer(s) at the proposed turbine hub height.
   ii. A SODAR or LIDAR system (installed in a suitable location) to determine hub height wind speed directly, or at the two nearest heights to allow hub-height wind speed to be derived using an exponential profile.

b) A met mast lower than hub height, but carrying anemometers at two different heights: these are then used to calculate the hub height wind speed, using an exponential profile. A meaningful extrapolation should be undertaken, and this would be achieved with the upper anemometer (2) being at a height not less than 60% of the hub height of the proposed turbine and the lower anemometer (1) at least 15 metres below it. Within those requirements, the two measurement heights closest to the hub height should be used.

c) A met mast carrying anemometer(s) at a height of 10 metres (with wind shear corrections to be determined).

Methods a) and b) are preferred. Method c) is only advised if the other methods are not justifiable in terms of costs. A recording rain gauge should be deployed (or other methods can be used with care) to identify noise data affected by rainfall.

3.3.6 Synchronisation of Noise, Wind and Rainfall Measurements

The GPG notes that measurement intervals for wind speed, noise level and rainfall should be synchronised to within (at most) one minute over the survey period. Logging devices may use different time references and the logging protocol may apply a time marker at either the start or end of a measurement interval. Such differences must be taken into account. The synchronisation of rainfall measurements is less critical.

3.3.7 Durations of Surveys

The survey duration is determined entirely by the requirement to collect sufficient valid data over an adequate range of wind speeds. For pitch-regulated turbines, data should cover the range of wind speeds between cut-in and the speed at which maximum sound power level is achieved. This is an important distinction from the original ETSU-R-97 statement that data was required up to 12 m/s, as most modern machines reach their maximum sound power output at a lower wind speed, and some sites do not exhibit regular wind speeds above 12m/s.

As a guideline, the GPG considered that no fewer than 200 valid data points be recorded in each of the amenity hours and night time periods, with no fewer than 5 valid data points in any 1 m/s wind speed bin. In specific cases where background noise levels are dependent on wind direction and data is to be ‘filtered’ into two or more datasets then a minimum of 100 valid data points and 3 valid data points per 1 m/s bin in each data set may be adequate. Supplementary Guidance Note 1 describes the Data Collection process in more detail.

3.4 Data Analysis and Noise Limit Derivation

3.4.1 Data Filtering

ETSU-R-97 requires that a number of filtering processes are undertaken before the wind speed vs. background noise relationship can be derived. The first is temporal. ETSU-R-97 only considers Amenity Hours (defined as 18:00 – 23:00 hrs Monday – Sunday, 13:00 – 18:00 Saturday and 07.00 to 18.00 Sunday) and Night-time Hours (defined as 23:00 – 07:00 weekday and weekend).

The next filtering step is to identify the presence of noise sources which are not common to the representative measurement locations and neighbouring noise sensitive properties, and remove them from the data, using a review of time histories and scatter plots.

Finally, data directly affected by rainfall, or when rainfall has resulted in atypical levels should be removed, and where appropriate, clear dawn chorus effects should be removed from night-time data. ETSU-R-97 also allows the inclusion of rush hour traffic in the night period where it is a significant feature in the noise environment. If this does not routinely occur, it should be removed.

3.4.2 Derivation of Wind Speed & Background Noise Plots

ETSU-R-97 states that noise levels should be plotted against wind speed to determine the prevailing background noise levels at a measurement position. The order of regression analysis to use (linear to fourth order) will depend upon the nature of the noise environment. Directional analysis of prevailing background noise levels may be necessary in specific circumstances, where a wind farm is located upwind of a receptor but a significant contributor to the background noise environment is downwind of the receptor in the same wind conditions.

3.4.3 Determining the ETSU-R-97 Limit

The complete ETSU-R-97 noise limit for each property is obtained from a combination of the respective fixed limit and the derived relative limit (prevailing background curve + 5 dB). The day amenity noise limits have been set in ETSU-R-97 on the basis of protecting the amenity of residents whilst outside their dwellings in garden areas. The daytime amenity noise limits are formed in two parts: Part 1 is a simple relationship between the prevailing background noise level (with wind speed) with an allowance of +5 dB; Part 2 is a fixed limit during periods of quiet. ETSU-R-97 describes three criteria to consider when determining the fixed part of the limit in the range of 35 dB to 40 dB L_{A90}, all of which should be considered. They are:

1) the number of noise-affected properties;
2) the potential impact on the power output of the wind farm; and
3) the likely duration and level of exposure.

The rationale for a choice of this limit, or factors which would assist the determining authority in this respect should be set out in the assessment. It is beneficial to the decision maker to display both sets of limits to illustrate the range available and/or the noise limit for the development if agreed previously. The GPG does not consider these areas further as the consensus was that this was ultimately a material planning consideration, and therefore outside the terms of reference.

ETSU-R-97 indicates that for the protection of sleep of occupants within buildings an external free-field level of 43 dB L_{A90} is appropriate when background noise levels are low. When background noise levels are sufficiently high, then the noise limits are set to the prevailing background + 5 dB, in the same manner as that used for the Amenity Hours. Supplementary Guidance Note 2 describes the Data Analysis process in more detail.

3.5 Noise Predictions

3.5.1 Predictions

ETSU-R-97 does not describe a method to predict the immission levels at the nearest residential properties resulting from the operation of the wind farm, but clearly, estimates of the likely noise impact at the nearest receptors are required in any planning situation, and this must be reliable and robust. The general study of outdoor noise propagation has received extensive attention in the past, but there has also been additional research undertaken specifically on the subject of wind turbine noise propagation in recent years and since the publication of ETSU-R-97.

Several recent studies focused on the application of engineering methods to the prediction of noise from wind turbines. Wind turbines are elevated large sources, and calculations are often required at distances of 1 km or more, which may fall outside of the stated scope of well-recognised standards such as ISO 9613-2. The range of meteorological conditions which need to be considered are also more varied and significant than for many other applications. Therefore several relatively recent studies have involved detailed measurements using elevated loudspeaker sources or operational wind turbines: see Bullmore et al. 2009, Søndergaard / Plovsing 2009, Evans and Cooper 2011.

The outcome of this research has demonstrated that the ISO 9613-2 standard in particular, which is widely used in the UK, can be applied to obtain realistic predictions of noise from on-shore wind turbines during worst case propagation conditions (i.e. sound speed gradients due to downwind conditions or temperature inversions), but only provided that the appropriate choice of input parameters and correction factors are made. In particular, the use of “soft-ground” factor should be avoided, and the full theoretical effects of terrain screening will usually not be achieved.

The GPG also recognises that the choices which are made in the calculation parameters adopted for the prediction calculation can have a significant bearing on the outcome results, and can lead to unrealistic estimates. In addition, as not all wind turbine sound power level data is defined in the same manner, care needs to be exercised before any calculations can be performed. The choices which are made in the calculation parameters adopted for the prediction calculation should be clearly outlined and detailed in any noise assessment so that they can be reviewed by any assessor.

The GPG notes that whilst some of the source documents for sound power levels may be confidential, numerical values of the source data should be clearly set out in any assessment and it is good practice to reference the data sources used, and that predictions should be based on octave band frequency data whenever available. Supplementary Guidance Note 3 describes Sound Power Data in more detail.

The observation in ETSU-R-97 that L_{A90} levels should be determined from calculated L_{Aeq} levels by subtraction of 2 dB is still considered to be valid. Current good practice is that tonal issues for wind farms are generally best dealt with through a suitable planning condition, since most of the available information derived using IEC 61400-11 does not apply at typical separation distances.

However, whilst the ISO 9613-2 standard is currently regarded as good practice, a number of factors need to be used to ensure a realistic estimate of immission level can be obtained. The GPG notes that:

- Equation 9 of the standard should be used to calculate ground effects; if no representative spectral data can be obtained, A_{gr} = -3 dB should be used and the air absorption rate corresponding to the 250 Hz octave band;
- A ground factor of G=1 should not be used;
- With the exception of propagation over large bodies of water or in urban areas, it is recommended to use a ground factor of G=0.5, in combination with emission levels which include a margin of uncertainty;

- A receiver height of 4.0 m, and atmospheric conditions of 10°C and 70% humidity should be used.
- Topographic screening effects of the terrain (ISO 9613-2, Equation 12) should be limited to a reduction of no more than 2 dB, and then only if there is no direct line of sight between the highest point on the turbine rotor and the receiver location.
- A further correction of +3 dB should be added to the calculated overall A-weighted noise level for propagation across a concave ground profile.

Predictions made using the ISO 9613-2 standard relate to "worst-case" conditions (typically downwind propagation from source to receiver and/or downward refraction under temperature inversions). When considering cumulative noise impacts, the effects of propagation in different wind directions can be considered. Any such direction attenuation factors, if used, should be clearly stated in any assessment. Similarly the effects of wind shear should be taken into account, and stated in the assessment. Supplementary Guidance Note 4 describes Wind Shear in more detail.

3.6 Cumulative Issues

ETSU-R-97 states at page 58, *"…absolute noise limits and margins above background should relate to the cumulative effect of all wind turbines in the area which contribute to the noise received at the properties in question…*" During scoping of a new wind farm development the GPG states that consideration should be given to cumulative noise impacts from any other wind farms in the locality. If the proposed wind farm produces noise levels within 10 dB of any existing wind farm/s at the same receptor location, then a cumulative noise impact assessment is necessary. Equally, in such cases where noise from the proposed wind farm is predicted to be 10 dB greater than that from the existing wind farm (but compliant with ETSU-R-97 in its own right), then a cumulative noise impact assessment would not be necessary.

In the presence of an existing wind farm, the GPG considers that suitable background noise levels can be derived by one of the following methods:

- switching off the existing wind farm during the background noise level survey (with associated significant cost implications);
- accounting for the contribution of the existing wind farm in the measurement data e.g. directional filtering (only including background data when it is not influenced by the existing turbines e.g. upwind of the receptor, but mindful of other extraneous noise sources e.g. motorways) or subtracting a prediction of noise from the existing wind farm from the measured noise levels;
- utilising an agreed proxy location removed from the area acoustically affected by the existing wind farm/s; or
- utilising background noise level data as presented within the Environmental Statement/s for the original wind farm/s (the suitability of the background noise level data should be established).

If previously presented background noise level data is to be used, care should also be taken with respect to any differences in wind speed conditions between the original and proposed site. The underlying principle of ETSU-R-97 requires that the background noise levels at any given location must be correlated with the wind speeds measured on the wind farm site of interest. Where a systematic difference exists between the wind conditions on the two sites, then a correction will need to be applied, meaning that the derived background noise curves for the two sites will be different.

Whenever a cumulative situation is encountered, the noise limits for an individual wind farm should be determined in such a way that no cumulative excess of the total ETSU-R-97 noise limit would occur. The GPG goes on to consider a number of methods to be used when considering cumulative impacts, which include strategic planning, negotiation, and cumulative noise limits.

3.7 Other Aspects

3.7.1 Other Issues in the GPG

The GPG includes a list of reporting requirements for a robust noise assessment report, but stops short of providing prescriptive templates. A sample planning condition is provided in the GPG, but with a caveat that legal advice should be sought when applying it. No good practice on how to deal with excessive amplitude modulation was found, but the AM working group is now actively working on a metric and assessment methodology.

Post Completion Measurements and propagation over water is covered in SGN 5 and 6 respectively.

3.7.2 Recommendations for Future Research

The working group considered a number of issues where future research is needed to further our understanding of wind turbine noise assessment. These could include:

i) More evaluation of wind shields to establish suitable designs to limit wind effects on the microphone;
ii) The effects of wind shear variations on background noise measurements;
iii) An investigation of the proposed planning condition to deal with excess amplitude modulation for the Denbrook site in the UK (May 2013) [The AM working group is now actively pursuing this];
iv) A UK-based dose response study.

3.7.3 Consideration of the Noise Limits

It is considered by many acousticians in the UK that the increased fixed night time limit relative to the daytime one is open to question, and that whilst most sites are constrained by the day time limit, some developers are now designing sites to take advantage of the higher limits allowed at night. Few would argue that this is what the original authors of ETSU-R-97 had intended.

At the GPG launch meeting in Bristol in May 2013, a show of hands revealed that most delegates were in favour of the IOA considering the issue of the ETSU-R-97 noise limits. This mirrored a number of the responses received to the GPG consultation. The IOA will no doubt discuss this matter further before deciding what action (if any) to take, although as this is ultimately a matter for Government, a considered response will be needed.

3.8 Conclusions

The IOA has published a Good Practice Guide and six Supplementary Guidance Notes to supplement the use of ETSU-R-97 in the UK when assessing wind turbine noise. It is a significant step forward for the industry, and will level the playing field. However, it still leaves a number of questions unanswered, particularly on how to predict and assess excessive amplitude modulation that will require further research and assessment. The GPG will need revisiting when significant advancements in good practice have occurred.

A working group has been set up to take forward the metric and methodology for Amplitude Modulation (a terms of reference and Options Paper are on the IOA website) and Government has been lobbied to put together the penalty scheme and the threshold of acceptability that accords with existing Government policy. This work is due to report in early 2015.

4 REFERENCES

1. Hayes McKenzie Partnership Ltd. Report on “Analysis of How Noise Impacts are considered in the Determination of Wind Farm Planning Applications” Ref HM: 2293/R1 dated 6th April 2011
2. Institute of Acoustics - Terms of Reference
3. Institute of Acoustics ‘A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise’ May 2013
4. Institute of Acoustics - The GPG can be found at http://www.ioa.org.uk
5. Bullmore, J. Adcock, M. Jiggins, M. Cand, Wind Farm Noise Predictions and Comparison with Measurements. Proc. Wind Turbine Noise 2009 Conference, Aalborg Denmark, June 2009.
6. Søndergaard, B. Plovsing, Prediction of noise from wind farms with Nord2000, Part 1 and 2, Proc. Wind Turbine Noise 2009 Conference, Aalborg Denmark, June 2009.
7. T. Evans and J. Cooper, Comparison of predicted and measured wind farm noise levels and implications for assessments of new wind farms, Proceedings of ACOUSTICS 2011, 2-4 November 2011.