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Propagation of Noise from Wind Farms According to the Institute of Acoustics' Good Practice Guide - A Sensitivity Analysis

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Summary

A sensitivity analysis has been undertaken to determine the differences that could be obtained when calculating predicted noise levels at locations surrounding wind farms in accordance with the methodology described in the Institute of Acoustics' Good Practice Guide (IoA GPG). Four main sources of discrepancy have been identified:

1. Different independent test reports may be held for the same turbine such that different allowances for measurement uncertainty may be deemed appropriate, leading to potential differences of up to 2 dB in the sound power level data used, resulting in similar differences in the predicted noise levels.

2. The IoA GPG notes that the spectrum provided for the wind speed corresponding to the highest level of noise emissions can be scaled to the overall sound power level at other wind speeds, before going on to say that spectra for specific wind speeds can also be used. The difference between these two options can be in the order of 1 dB.

3. The IoA GPG notes that small changes in the mean propagation height between the source and receiver can trigger the application of the correction for propagation over a concave ground profile. As such, differences in the methodology for calculating mean propagation height, or in the terrain data resolution, can result in differences of up to 3 dB in predicted noise levels.

4. In addition to the above, alternative directional attenuation factors are presented in the IoA GPG, the use of which can produce different results.

Identifying potential sources of discrepancy is important because one of the goals of defining best practice is that two acousticians analysing the same site, with the same input data, should reach identical conclusions. The magnitude of the differences in predicted noise levels due to the sources of discrepancy identified can significantly affect the conclusions of an assessment.

1.0 Introduction

The Institute of Acoustics' Good Practice Guide to the Application of ETSU-R-97 (DTI, 1996) for the Assessment and Rating of Wind Turbine Noise (Institute of Acoustics, 2013), hereafter referred to as the IoA GPG, defines a methodology for predicting the noise levels at nearby properties due to an operational wind farm using the ISO 9613-2 propagation model (ISO, 1996). Whilst this represents progress in efforts at standardisation, updating the guidance provided in an Acoustics Bulletin article (Institute of Acoustics, 2009), there remain some areas

of the process which are open to interpretation or sensitive to the data held on a specific turbine so that two acousticians analysing the same site could potentially produce different results. The purpose of this paper is to highlight some of the main sources of potential discrepancy and to quantify the resulting differences, with a view to suggesting how the IoA GPG might be improved in future.

2.0 Methodology

In order to quantify the impact of each source of potential discrepancy, noise immission levels have been predicted in accordance with the recommendations of the IoA GPG for the same site using the same turbine layout, house layout and warranted sound power level data whilst varying the setting in question so that the results can be compared. In each case the theoretical maximum difference has been highlighted along with the differences that are likely to be experienced in practice, identified by performing the analysis on actual wind farm sites.

The four sources of potential discrepancy that this paper will focus on, identified through experience of undertaking predictions of wind farm noise, are as follows:

- Allowance for measurement uncertainty;
- Effect of frequency spectra;
- Mean propagation height; and
- Directional attenuation factors.

The allowance for measurement uncertainty that is deemed appropriate is subject to the specific selection of test reports held for the turbine under consideration.

Similarly, the frequency content of the acoustic emission is not typically warranted by turbine manufacturers so that the frequency spectra used in an assessment are often also dependent upon the test reports held by the analyst. In addition, the frequency spectra used in an assessment can vary due to the options presented in the IoA GPG.

Likewise, different mean propagation heights can be calculated and different assumptions regarding propagation directivity can be made due to the alternative methods provided in the IoA GPG.

3.0 Results

3.1 Allowance for Measurement Uncertainty

Of the three sources of acoustic emission data described in paragraph 4.3.6 of the IoA GPG: declared, warranted or specified and tested, it is most common, in the case of large wind turbines, for data that has been warranted or specified by the manufacturer to be used for noise propagation purposes. The IoA GPG states that such data can be used provided a margin to account for uncertainty has been included. In order to determine whether this is the case, the data should be compared to the results of one or more representative test reports. A margin of 1.645σ, where σ is the reported test uncertainty, between the tested and warranted or specified values over the majority of wind speeds provides a clear indication that suitable uncertainties have been incorporated. If the manufacturer specifies a value of uncertainty then this should be used unless the above test is satisfied. If no data on uncertainty is provided, or no test reports are held, then 2 dB should be added.

With the allowance for uncertainty dependent upon the information provided in independent test reports, discrepancies can occur where different test reports are held for the same machine by different parties. This is illustrated by Figures 1-3 which show the acoustic emission data warranted by the manufacturer in comparison with the results from three different test reports for the same turbine. In Figure 1 the test data plus 1.645σ is less than the warranted data for the majority of wind speeds, indicating that a suitable allowance for uncertainty has already been incorporated and that no additional uncertainty allowance is necessary.

However, the results of the test reports displayed in Figures 2 and 3 indicate that an allowance of 1 dB and 2 dB, respectively, would be more appropriate.

Figure 1 - Test report indicating no additional allowance for uncertainty required

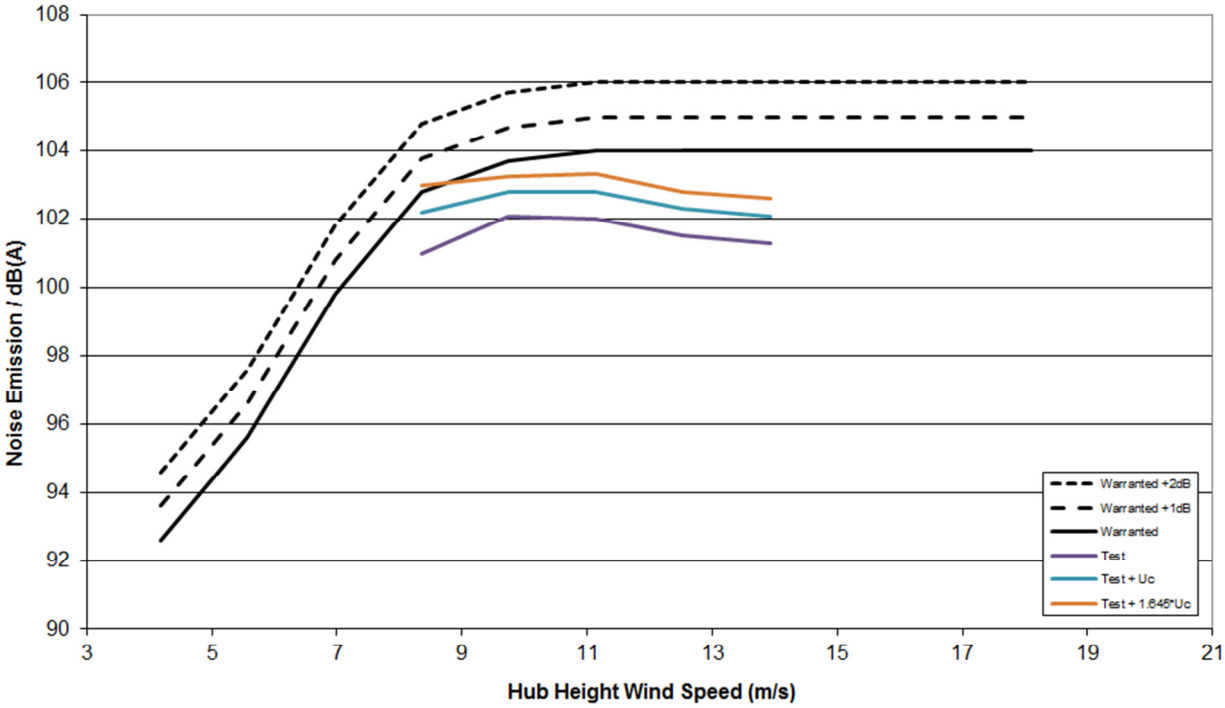


Figure 2 - Test report indicating that a 1 dB allowance for uncertainty is required

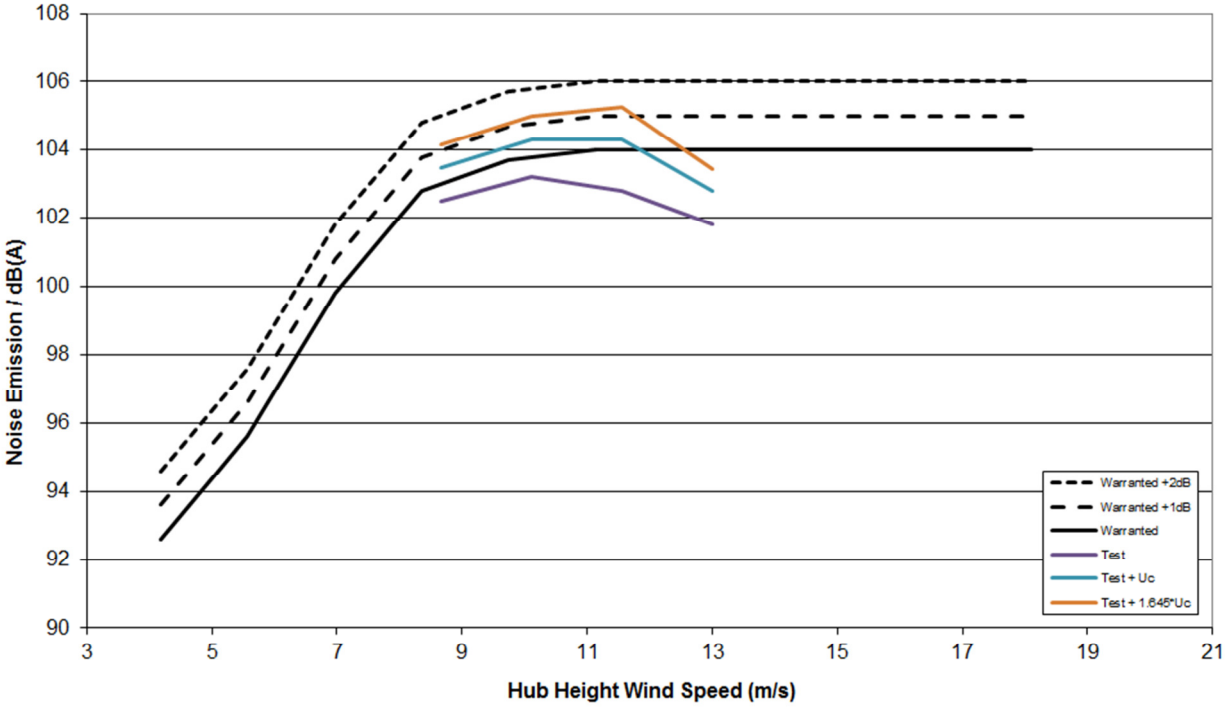
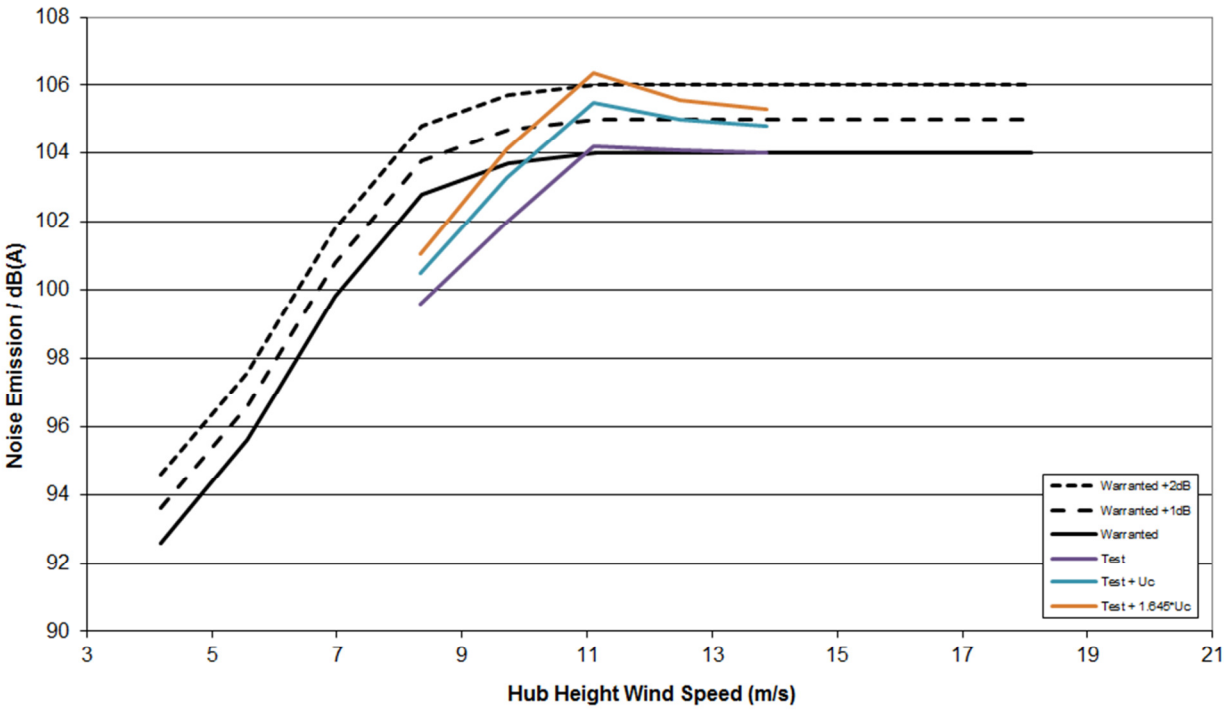


Figure 3 - Test report indicating that a 2 dB allowance for uncertainty is required



In summary, two acousticians using the same warranted data may apply a different allowance for measurement uncertainty depending upon the information contained within any test reports held for a given turbine. This can cause differences of up to 2 dB in the resulting predicted noise levels.

Requesting the latest test report from the turbine manufacturer for the machine for which predictions are being made should reduce the likelihood of such discrepancies occurring and it is recommended that this takes place at regular intervals as test results can become out of date if changes are made to the design or operation of a turbine.

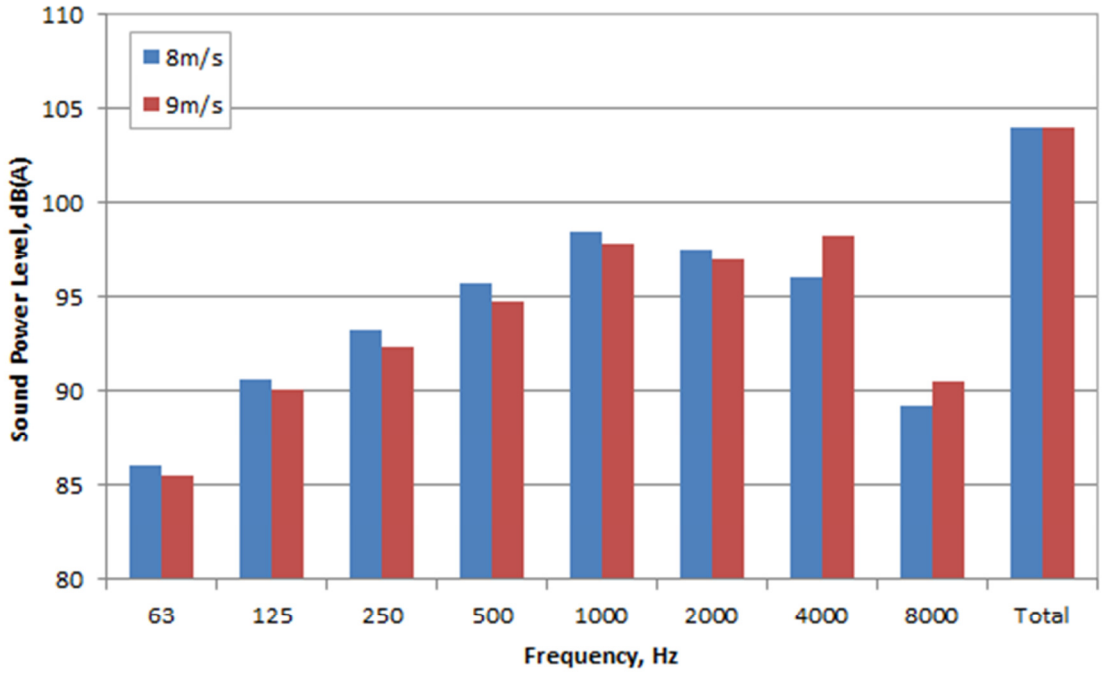
3.2 Effect of Frequency Spectra

Paragraph 4.2.6 of the IoA GPG allows for two options when using noise emission frequency spectra: either use the noise spectrum provided for the wind speed corresponding to the highest level of noise emissions scaled to the overall sound power level at other wind speeds, or use noise spectra for specific wind speeds. The difference in the resulting predicted noise immission levels between these two options can be in the order of 1 dB, with the largest differences occurring at properties furthest from the turbines.

The magnitude of the difference between these options depends upon the relative change in the low frequency content of the acoustic emission with wind speed. The most conservative predictions would be obtained using option one if the spectrum provided for the wind speed corresponding to the highest level of acoustic emission contained relatively more low frequency content than the spectra at other wind speeds. Option two would be more conservative if the spectra at other wind speeds contain relatively more low frequency content than the spectrum at the wind speed corresponding to the highest level of acoustic emission.

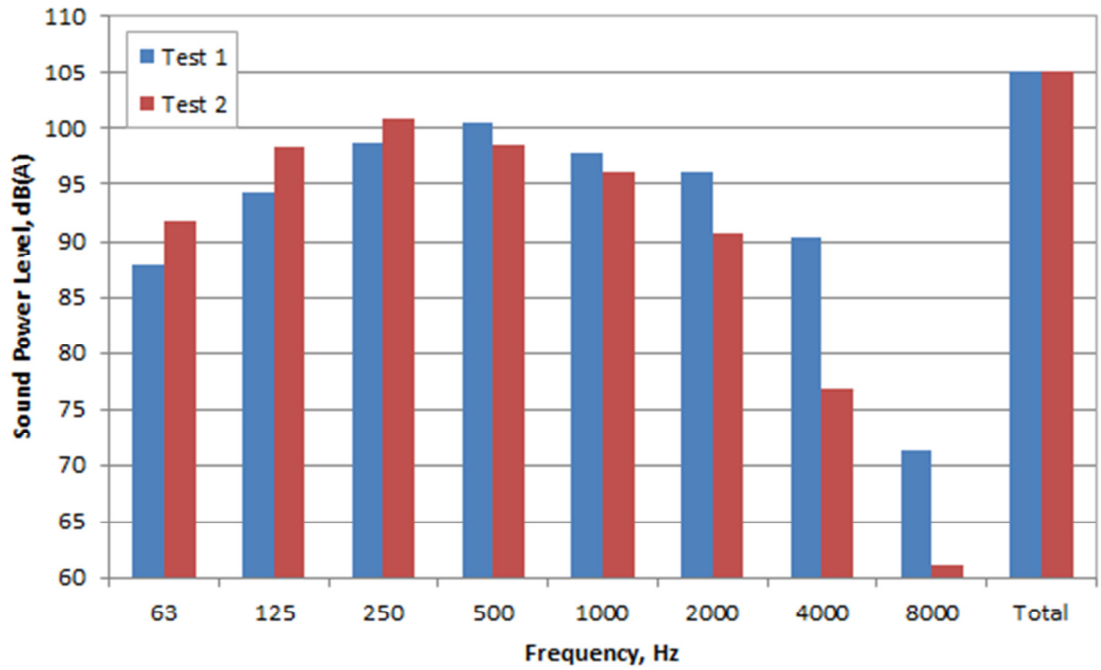
Figure 4 shows an example of how the frequency content of the acoustic emission for a given turbine can vary with wind speed. The data is taken from the same independent test report and scaled to the warranted sound power level which is the same at standardised 10 m wind speeds of 8 and 9 m/s. The spectrum at 8 m/s results in predictions that are 1 dB higher than the 9 m/s spectrum whereas the predicted noise levels would be the same had the same spectrum been used. When predictions are being made the acoustician should be aware of this source of potential discrepancy and consider using the most conservative option.

Figure 4 - Difference between frequency content at different wind speeds



Data on the frequency content of the acoustic emission often comes from an independent test report and can therefore differ depending upon which test reports are held by the acoustician. Using frequency spectra from different sources can have an even greater impact upon the resulting predicted noise levels with differences of up to 3 dB in some cases. Figure 5 details the magnitude of the differences that can occur in the frequency spectrum for the same wind speed when data is taken from different sources. As with the allowance for measurement uncertainty, requesting the latest data from the turbine manufacturer at regular intervals should reduce the likelihood of such discrepancies occurring.

Figure 5 - Difference between frequency content in different test reports

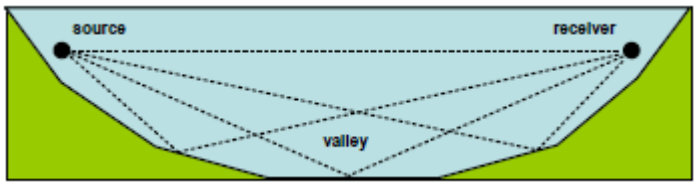


In summary, the predicted noise levels produced by two acousticians using the same warranted data along with frequency data from the same independent test report may differ by up to 1 dB should the frequency content of the acoustic emission vary significantly with wind speed. Differences in the predicted noise levels obtained when the same warranted data but frequency content from a different test report are used can be even greater, e.g. up to 3 dB.

3.3 Mean Propagation Height

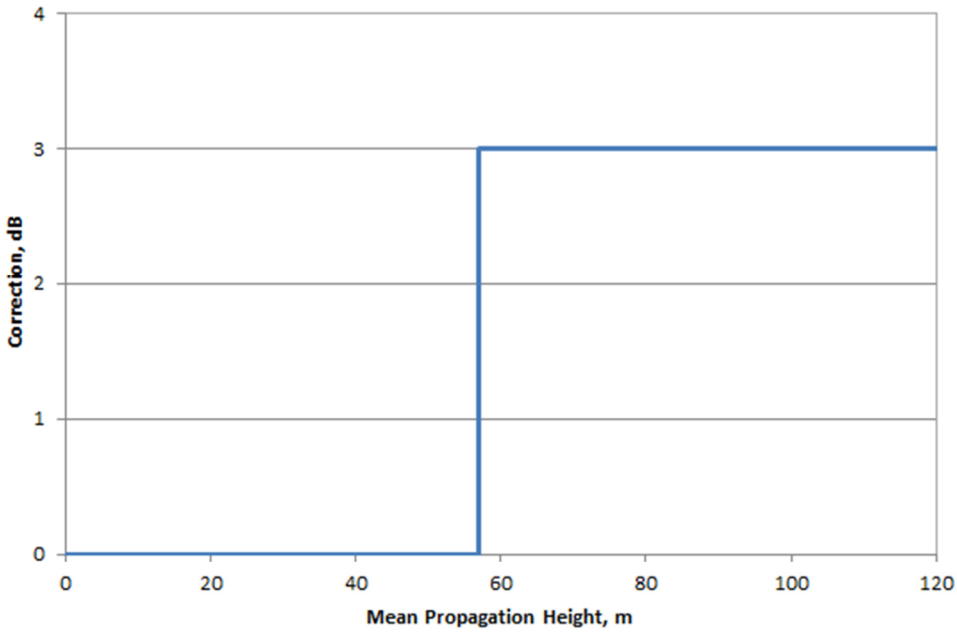
Section 4.3.9 of the IoA GPG states that a correction of 3 dB should be added to the calculated noise immission levels where propagation over a valley occurs, to account for the reduced ground effect and potential for additional reflection paths, as illustrated in Figure 6. The recommendation is to apply the correction when the mean propagation height (h_m) is greater than or equal to 1.5 multiplied by half the difference between the source (h_s) and receiver (h_r) heights, i.e. when $h_m \geq 1.5 \times (\text{abs}(h_s - h_r) / 2)$.

Figure 6 - Additional reflection paths (Institute of Acoustics, 2013)



As detailed in Figure 7, for a hub height of 80 m and a receiver height of 4 m the critical mean propagation height above which the correction is triggered is 57 m. As this is a step-change the correction would not be applied for a mean propagation height of 56.9 m but would be applied for a mean propagation heights ≥ 57 m, demonstrating that small changes in the methodology for calculating mean propagation height, or in the terrain data resolution, can trigger the application of a large correction.

Figure 7 - Step change due to mean propagation height

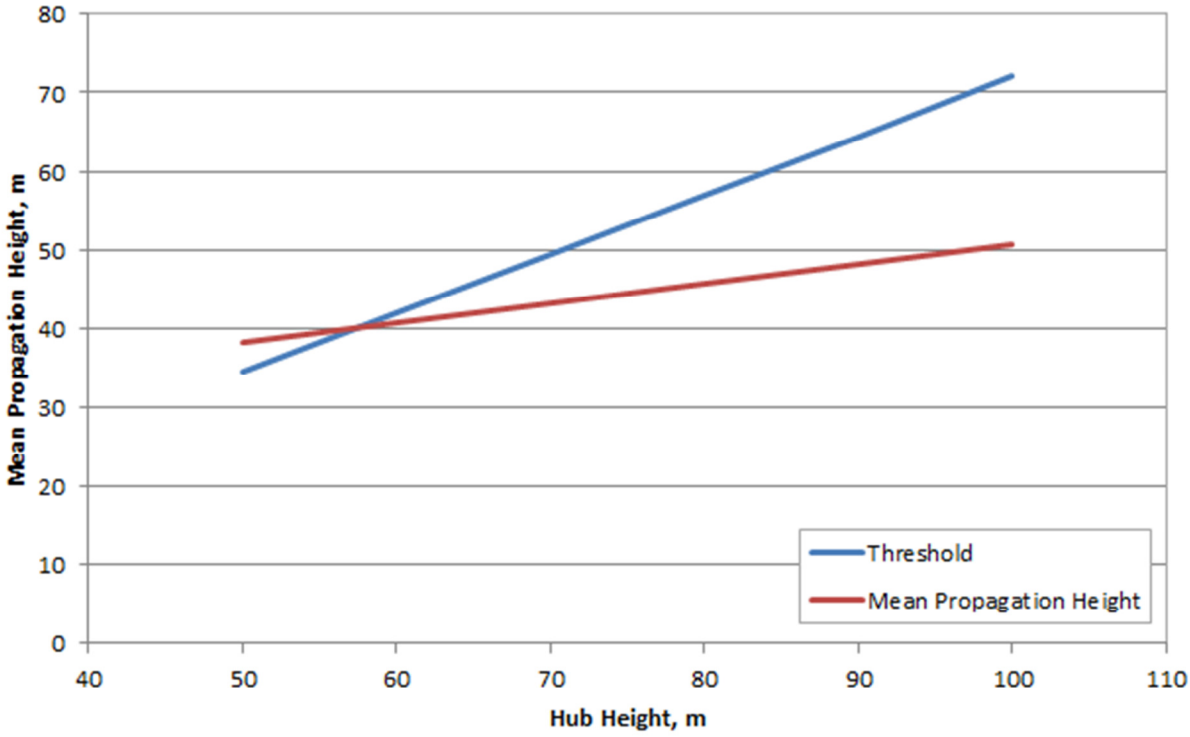


The theoretical maximum difference in the resulting predicted noise levels is equal to the magnitude of the correction. However, such differences are unlikely in practice as they would only occur when the change in mean propagation height between alternative calculation methods is significant enough that the correction is applied for all or none of the source-receiver pairs.

Maximum differences of 1.5 dB have been noted in practice, with the largest differences occurring on complex sites where the likelihood of the correction being required is greater. Larger differences are also more likely for sites with fewer turbines where applying the correction for a certain number of source-receiver pairs would make a greater difference to the total predicted noise level than for a site with a greater number of turbines.

Figure 8 highlights the impact of changing the hub height on the threshold at which the correction is applied. Increasing the hub height by 10 m increases the threshold by 7.5 m. However, the corresponding increase in mean propagation height due to a 10 m change in hub height is less than 7.5 m such that the correction is more likely to be applied for shorter rather than taller hub heights. In the example shown, the correction would be applied for hub heights of around 60 m or less. Increasing the hub height above 60 m would reduce the predicted noise level from this turbine by 3 dB at the property in question.

Figure 8 - Variation of threshold and mean propagation height with hub height



In summary, as noted in the IoA GPG, small changes in the mean propagation height between the source and receiver can trigger the application of a large correction for propagation over a concave ground profile. As such, differences in the methodology for calculating mean propagation height, or in the terrain data resolution, can result in differences of up to 3 dB in the resulting predicted noise immission levels, with such differences increasing in likelihood for sites with fewer turbines and short hub heights in complex terrain.

3.4 Directional Attenuation Factors

On propagation directivity, section 4.4 of the IoA GPG references evidence from the Joule project (Joule, 1998) to justify the application of directional attenuation factors of around 2 dB crosswind and at least 10 dB at a sufficient distance upwind. For intermediate directions a linear or polynomial interpolation can be used. The IoA GPG goes on to note that such reductions will only progressively come into play at distances of between five and ten tip heights.

In addition to the Joule project, the IoA GPG also references work undertaken for NASA (Shepherd & Hubbard, 1990) and the Wyle report (Wyle, 1988) to provide additional propagation directivities for flat and complex landscapes. The presentation of alternative directional attenuation factors provides scope for difference, not just in the choice between the Joule directivities and those detailed in Figure 6 of the IoA GPG, but also in:

- the choice between a linear or polynomial interpolation for intermediate directions when the Joule directivities are being used; and
- the classification of terrain as flat or complex when the directivities presented in Figure 6 of the IoA GPG, hereafter referred to as NASA/Wyle, are being used.

To illustrate both the scope and magnitude of the differences that can be expected, Figures 9-11 show the directional attenuation factors from the Joule project, alongside those from NASA/Wyle, at separation distances of 7.5, 11 and 18 tip heights respectively. Through examination of these figures it can be seen that the most conservative directional attenuation factors depend upon the terrain type, the orientation and separation distance.

Figure 9 - Directional attenuation factors at 7.5 tip heights

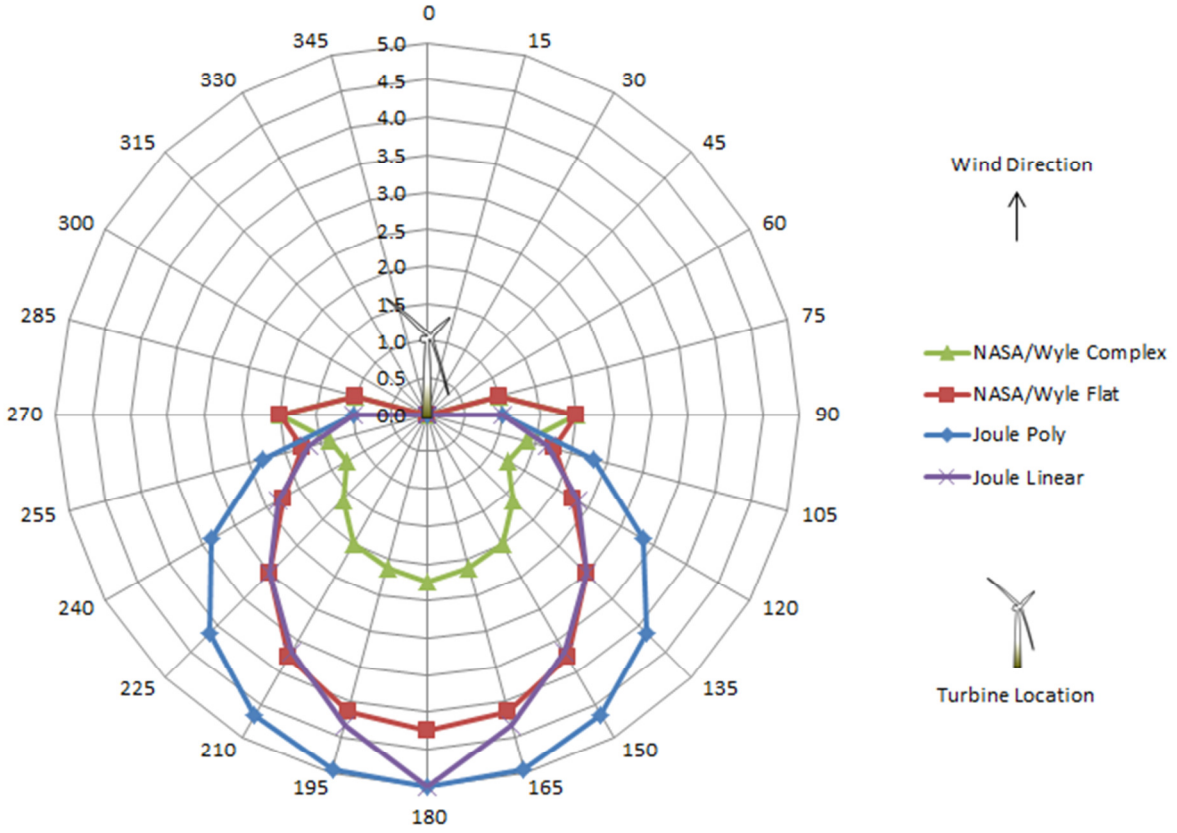


Figure 10 - Directional attenuation factors at 11 tip heights

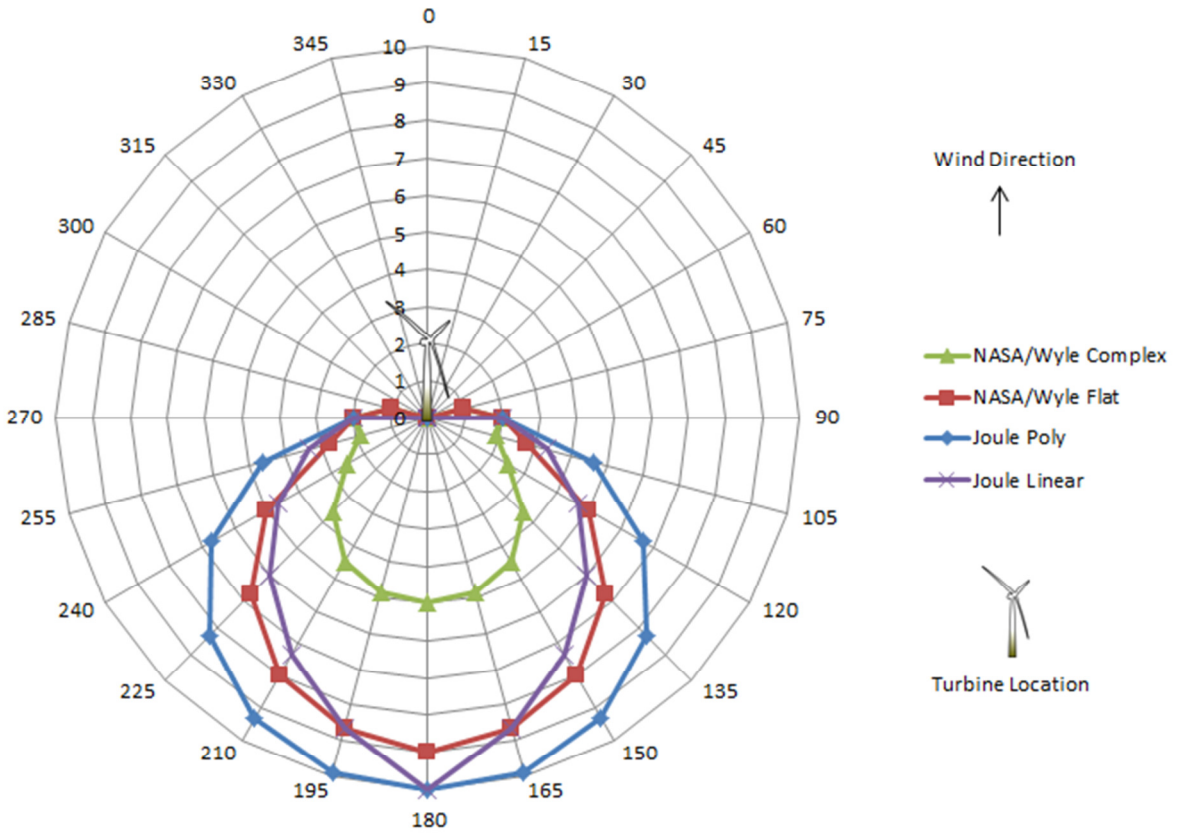
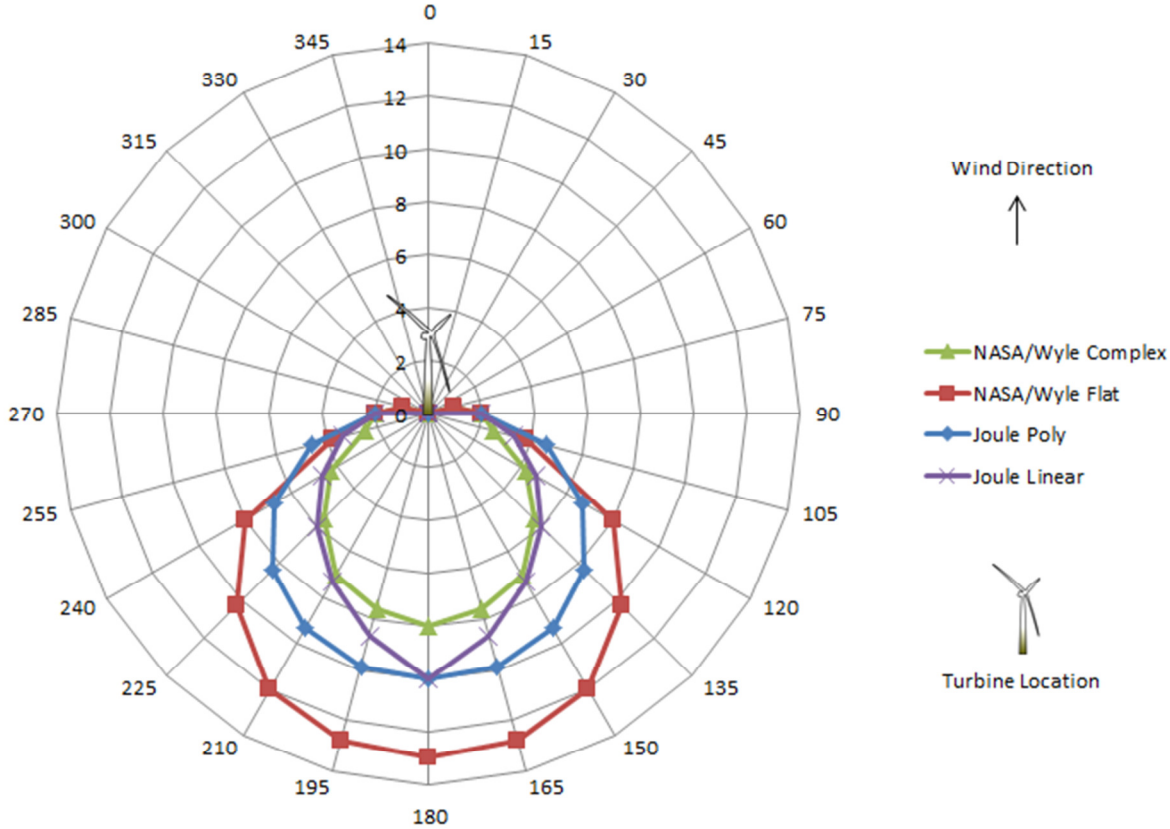
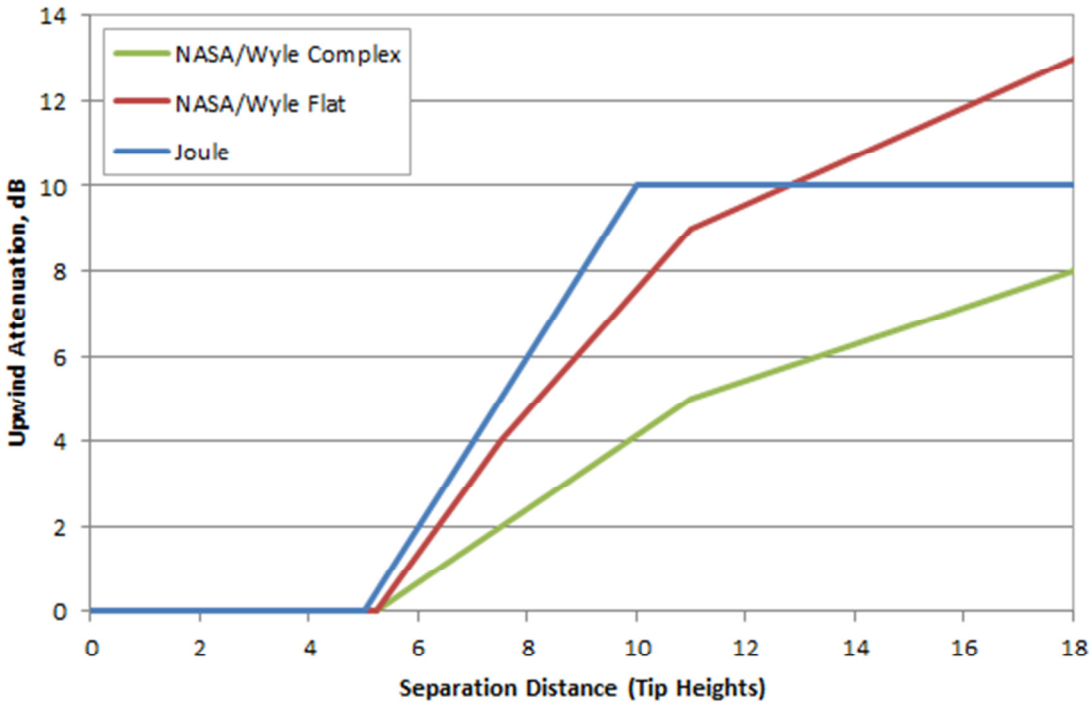


Figure 11 - Directional attenuation factors at 18 tip heights



Regardless of separation distance, the Joule directivities are more conservative than NASA/Wyle in crosswind directions. In the upwind direction the NASA/Wyle attenuation in complex terrain is the most conservative regardless of distance. The NASA/Wyle attenuation factors upwind in flat terrain are more conservative than the Joule attenuation factors at distances of 7.5 and 11 tip heights but less conservative at 18 tip heights. The cross-over point at which the Joule upwind attenuation becomes more conservative is 12.75 tip heights, as can be seen in Figure 12. There is no difference between the alternative sets of propagation directivities in the downwind direction where there is no attenuation.

Figure 12 - Variation of upwind attenuation with separation distance



In intermediate directions at 7.5 tip heights the NASA/Wyle directional attenuation factors in complex terrain are the most conservative, followed by the NASA/Wyle directional attenuation factors in flat terrain and the Joule (linear) directivities which are similar, with the Joule (polynomial) directivities the least conservative.

In intermediate directions at 11 tip heights the NASA/Wyle directional attenuation factors in complex terrain are the most conservative, followed by the Joule (linear) directivities, the NASA/Wyle directional attenuation factors in flat terrain, and finally the Joule (polynomial) directivities.

In intermediate directions at 18 tip heights the NASA/Wyle directional attenuation factors in complex terrain and the Joule (linear) directivities are similarly conservative, followed by the Joule (polynomial) directivities, with the NASA/Wyle directional attenuation factors in flat terrain the least conservative.

The maximum magnitude of the difference in the resulting predicted noise levels is 2.8 dB at 7.5 tip heights, 5.0 dB at 11 tip heights and 5.1 dB at 18 tip heights. When split into flat/complex sites the maximum differences are 1.2/2.8 dB at 7.5 tip heights, 2.3/5.0 dB at 11 tip heights and 4.7/2.7 dB at 18 tip heights. The differences will typically be less in practice where all turbines are rarely the same distance and orientation from a given property.

Testing at two real sites, one flat and one complex, resulted in a maximum difference of 0.8 dB at the closest property and 4.5 dB at the furthest property from the turbines on the flat site and a maximum difference of 0.8 dB at the closest property and 3.4 dB at the furthest property from the turbines on the complex site. The differences at the closest properties are more likely to have an impact upon the results of an assessment and it is notable that these were less than 1 dB at both the flat and complex sites tested.

4.0 Conclusions

A sensitivity analysis has been undertaken to determine the differences that can be obtained when calculating predicted noise immission levels at locations surrounding wind farms in accordance with the methodology described in the IoA GPG. Four main sources of discrepancy have been identified and the resulting differences quantified:

1. In determining an appropriate allowance for measurement uncertainty, two acousticians may reach different conclusions depending upon the test reports held for the turbine that is being considered, resulting in differences of up to 2 dB in the predicted noise levels. It is recommended that the latest test reports are requested from the turbine manufacturer on a regular basis as they can become out of date should changes be made to the design or operation of the machine.

2. When the same test report is held, the choice between using frequency spectra for specific wind speeds and scaling the spectrum provided for the wind speed corresponding to the highest level of noise emission can result in predicted noise levels that differ by up to 1 dB if the frequency content of the acoustic emission varies significantly with wind speed. The differences can be even greater when frequency spectra from an alternative report are used.

3. When applying the correction for propagation over a valley, differences in the methodology for calculating mean propagation height, or in the terrain data resolution, can result in differences of up to 3 dB in the predicted noise immission levels, with such differences increasing in likelihood for sites with fewer turbines and short hub heights in complex terrain.

4. In taking propagation directivity into account it should be noted that the most conservative directional attenuation factors depend upon the terrain type, orientation and separation distance. Maximum differences of up to 5 dB are possible although this reduces as the separation distance between the source and receiver decreases.

Identifying potential sources of discrepancy is important because one of the goals of defining best practice is that two acousticians analysing the same site, with the same input data, should reach identical conclusions. The magnitude of the differences in predicted noise levels due to the sources of discrepancy identified here can profoundly affect the conclusions of an assessment and it is suggested that this needs to be addressed.

5.0 Further Work

Further work can be undertaken to quantify the differences in predicted noise immission levels that could occur due to additional sources of potential discrepancy which include:

- Variation in wind speed between reference location and turbine locations;
- Differences between proposed hub height and height to which acoustic emission data is referenced;
- How the barrier attenuation calculated by ISO 9613-2 is added back on to the predicted noise level when there is line of sight between the source and receiver;
- Whether or not to take into account screening from obstacles such as buildings or trees; and
- The definition of a significant barrier warranting 10 dB of attenuation.

References

DTI, 1996. The Assessment and Rating of Noise from Wind Farms, The Working Group on Noise from Wind Turbines, ETSU Report for the DTI, ETSU-R-97

Institute of Acoustics, 2009. Prediction and Assessment of Wind Turbine Noise, Acoustics Bulletin Vol. 34 No. 2, March/April 2009

Institute of Acoustics, 2013. A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise, Institute of Acoustics, May 2013

ISO, 1996. Acoustics - Attenuation of Sound during Propagation Outdoors, Part 2: General Method of Calculation, International Organisation for Standardisation, ISO 9613-2

Joule, 1998. Development of a Wind farm Noise Propagation Prediction Model, Bass J., Bullmore A. & Sloth E., Final Report for EU Contract JOR3-CT95-0051, 1998

Shepherd, K. & Hubbard, H., 1990. Wind Turbine Acoustics, NASA Technical Paper (TP) 3057, December 1990

Wyle, 1988. Measurement and Evaluation of Environmental Noise from Wind Energy Conversion Systems in Alameda and Riverside Counties, Wyle Research Report WR 99-19, 1988