DEVELOPMENT OF A WIND FARM NOISE PROPAGATION PREDICTION MODEL

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15. CONCLUSIONS

The two dominant factors controlling the far field sound pressure levels due to the opration of wind turbines are the sound power output characteristics of the turbines and propagation effects. The aim of the present study is to identify and quantify the dominant factors controlling the attenuation of sound as it propagates over large distances from wind turbines.

When undertaking a programme of work designed to identify the influence of specific parameters on noise propagation it is important to isolate as fully as possible the effects of the various controlling parameters. The use of operational wind farms as the test noise source would not enable the effects of specific parameters to be investigated in isolation. This is primarily because the sound power output of a wind turbine is by no means constant, and is indeed a function of wind speed which is believed also to be one of the factors controlling noise propagation.

The major part of the project therefore involved the use of a high powered, omnidirectional loudspeaker noise source. This loudspeaker was mounted at heights of between 15m and 30m above ground level to replicate the elevated nature of the sources of noise on wind turbines. Noise levels then synchronously monitored at up to 15 receiver locations around the loudspeaker using source to receiver separation distances of between 30m and 900m. the measurements were repeated at three different green field sites with topographies on the sites being classified as ‘flat’, ‘rolling’ and ‘complex’. Measurements of important meteorological parameters were also undertaken simultaneous with the noise measurements at all the sites. Measurements lasted for continuous periods of approximately four weeks on each site.

The results of the measurement campaign are believed to be unique in that very extensive and successful steps were taken to filter out all potentially corrupt data from the results. As a consequence a large database of high quality noise and meteorological measurements was available which allowed the major parameters controlling long distance noise propagation to be quantified.

The conclusions that now follow have been validated for the case of broad band noise radiation from an elevated source over arable or pasture land of all topographical complexities, from flat to complex. The results have further been validated at distances up to 900m from the source.

As a result of the measurements just described it has been concluded that:

- Noise levels at all distances from the source do vary, even if the source of sound has a constant power level.
- The measured variation in noise levels increases with increasing distance from the source.
- Based on typical wind speed ranges of between 0ms^{-1} and 10ms^{-1} encountered during the experimental measurements, the one standard deviation spread of noise levels either side the mean level was found to

increase at a rate of approximately 0.004dB(A) per meter increase in the source to receiver separation distance.

- The variations in noise levels about the mean just described were found to be strongly correlated with vector wind speed, but not with the other meteorological parameters.
- A positive component of vector wind speed from the source to the receiver tends to increase the received sound pressure level, whilst a negative component of vector wind speed tends to reduce the sound pressure level. The further the source to receiver separation distance, the greater the effect.
- At distances of 700m to 900m from the source, positive components of vector wind speed were found to increase the received noise level by up to 5dB(A) compared with the level measured under neutral propagation conditions.
- In situations where the receiver location is acoustically screened from the source, an excess attenuation of 10dB(A) or more can result under neutral or negative vector wind speed conditions. However, the effect of a positive vector wind speed is always to substantially reduce the excess attenuation.
- Once the systematic effect of vector wind conditions have been isolated, the residual scatter in measured noise levels is greatly reduced – especially under conditions of strong downwind propagation.
- The ground between the source an receiver, and particularly closae to the receiver, has a significant effect on received noise levels. Where the ground falls away between the source and receiver, noise levels 3dB(A) higher than would otherwise be expected can result.

The results of the noise measurement exercise enabled the effects listed above to be quantified. They also allowed an accurate comparison to be made between the output of existing noise propagation prediction models and the measured levels. This comparison resulted in the following conclusions:

- Models that rely on analytical descriptions of sound propagation through the atmosphere are overly sensitive to changes in meteorological parameters. Variations in noise levels of up to 30dB(A) were predicted by these models, whereas measured variations under the same range of meteorological conditions were limited to less than 10dB(A).
- The more advanced empirical model tested was that set out in ISO 9613-2. This method generally provide high levels of accuracy to within 2dB(A) in predicting received noise levels under ‘conditions favourable to noise propagation’, or downwind propagation.
- There are, however, two observed situations in which the ISO 9613-2 model fails to model the effects of the interaction of the ground effect and meteorological factors correctly.
- The first situation occurs for acoustically screened locations under downwind propagation conditions. In these cases the excess attenuation provided by the screening can be reduced to just 2dB(A). This reduction in effectiveness is not always modelled correctly by the ISO method.

- The second situation occurs where the ground falls away significantly between the source and receiver, and particularly in the immediate vicinity of the receiver. In these cases the measured noise levels are approximately 3dB(A) higher than those predicted by the ISO method.
- The simplest calculation procedure tested was the IEA method. This model accounts for losses due to geometric spreading plus a single excess attenuation factor due to atmospheric absorption. This it models as linear octave band attenuation factors which are determined from published tables and are dependant on temperature and relative humidity.
- For unscreened locations the IEA method generally provides levels of accuracy to within 2dB(A) in predicting received noise levels under 'conditions favourable to noise propagation', or downwind propagation. This accuracy is as good as that of the ISO method, despite the greatly increased simplicity of the IEA procedure.
- Because the IEA procedure does not include any facility for modelling ground profiles, it fails to predict the effects of screening or of situations where the ground falls away significantly between the source and receiver. However, these situations are in any case incorrectly modelled by the ISO method.

On the basis of the above findings it is concluded that the adoption of the IEA model as the basis for a simple noise propagation prediction method is the preferred choice. However, in order to account for the specific cases where the model has been shown to be deficient, an additional excess attenuation factor must be included.

The proposed model uses as its starting point the A-weighted sound power level, L_w , of the noise source under consideration. This sound power level is then modified by three attenuation factors to arrive at the received sound pressure level, L_p , at a given line of sight distance 'd' meters from the source due to the operation of that source in isolation:

$$L_p = L_w + 10 * \log\left(\frac{Q}{4 \cdot \pi \cdot d^2}\right) - A_{atm}\left(- A_{ter}\right) \qquad (12.1)$$

The total received sound pressure level at any given location is then calculated by energetically summing the calculated sound pressure levels at that location due to all the individual noise sources.

The first attenuation factor in equation (12.1) accounts for the directivity, Q, of the source in its installed location and the effect of geometrical spreading over the propagation distance, d.

The second attenuation term, A_{atm} , accounts for excess attenuation due to atmospheric absorption. Values for A_{atm} can be found in ISO 9613-1.

The first two attenuation terms of equation (12.1) should be applied separately for each octave frequency band from 63Hz to 4000Hz inclusive, and the octave band results then summed to arrive at the overall A-weighted sound pressure level at the receiver.

The third attenuating term, A_{ter} , is applied to the resulting overall A-weighted level. It accounts for additional effects arising from the presence of certain ground effects between the source and the receiver. This term is zero except for the following two special cases.

Case 1:

$$A_{ter} = -3dB(A) \qquad \text{if} \qquad h_m \geq 1.5 \cdot \left[\frac{abs(h_s - h_m)}{2} \right] \qquad (12.2)$$

where h_m is the mean height above the ground of the direct line of sight from the receiver to the source, and h_s and h_m are the heights above local ground level of the source and receiver respectively. Note that where this condition exists it serves to <u>increase</u> the received sound pressure level, hence A_{ter} in this instance is negative.

Case 2:

$$A_{ter} = +2dB(A) \qquad (12.3)$$

where the direct line of sight between the receiver and the source is just interrupted, or the interruption occurs due to a natural terrain feature that does not provide a distinct and pronounced interuption to the direct path and does not lie within 5m of the receiver.

Case 3:

$$A_{ter} = +10dB(A) \qquad (12.4)$$

where the direct line of sight between the receiver and the source is interrupted by a barrier that lies within around 5m of the receiver and provides a significant interuption to the direct line of sight path (a minimum interruption of 0.5m is suggested). Where any doubt exists it is suggested that the excess attenuation due to barrier effects should be limited to the 2dB(A) given in equation (12.3).

Based on the results of extensive measurements, the use of equations (12.1) to (14.4) have been shown to result in calculated sound pressure levels that lie within 2dB(A) of the level not expected to be exceeded for at least 85% of the time. The calculated levels correspond to conditions favourable to noise propagation over flat, rolling or complex terrain comprising typical arable or pasture land. Conditions ‘favourable to noise propagation’ relate to a $6ms^{-1}$ component of wind speed in the direction from the source to the receiver measured at 10m height on the wind farm site. The increase in noise levels for stronger components of positive vector wind speed have been measured to be negligible.

The proposed calculation procedure has also been validated against measurements undertaken at a 42 turbine wind farm, with predicted levels agreeing with measured levels under favourable propagation conditions to within 2dB(A). However, the results of the wind farm measurements have indicated a greater degree of scatter of the results than for the controlled loudspeaker test measurements. This increased scatter arises from variations in the source sound power level as the wind conditions vary. Sound power output levels of turbines within a wind farm are usually calculated assuming a single wind speed applies across the whole site, whereas in practice each turbine sees a different wind speed depending on the sheltering afforded by the other turbines.

It is therefore recommended that when the recommended calculation procedure is used to predict far field noise environmental levels from wind farms, an uncertainty factor should be included for the expected variation of wind speeds seen by the different turbines.