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AERODYNAMIC NOISE OF WIND TURBINES

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1. Introduction

Noise is a critical factor in the public acceptance of wind turbines in Europe. Noise limitations placed on wind turbines are a key issue in determining the size, and thus cost effectiveness, of many wind farms. Wind turbine noise is also an extremely complicated phenomenon, involving several different kinds of noise source. This paper reviews sources of noise in wind turbines, compares prediction from a theoretical model with experiment and offers some suggestions for noise control.

2. Noise Sources

The noise sources on wind turbines can be divided into two groups Mechanical and Aerodynamic. These will be discussed separately.

Mechanical Noise

Mechanical noise is principally due to the gear box, although there are other sources (e.g. the generator). Mechanical noise sources are also significantly affected by local resonances in the wind turbine structure. Early wind turbines suffered from quite severe mechanical noise. Although the worst of these problems have now been eliminated, all current wind turbines show significant levels of mechanical noise in their lower frequency bands (say below 1000Hz). Mechanical noise can be attacked by essentially conventional approaches and can also be attacked by standard muffler treatments etc. Thus mechanical noise can regarded as an excess noise over that due to the basic nature of the wind turbine.

A recent feature of much noise legislation for environmental purposes has been the imposition of penalties, typically 5dB, for discrete tone components. These are normally due to mechanical noise sources. This additional penalty gives a higher priority to the reduction of mechanical noise sources. It is reasonable to anticipate that future wind turbines will have considerably lower levels

However, nearly all data which is currently available has been taken on wind turbines which have had significant contributions from mechanical noise. This makes interpretation of the data for other sources noise very difficult. It is possible to do this by careful measurement, and identification and rejection of mechanical noise tones. However few measurements have gone to this level of sophistication in the analysis. This is being done in the work which currently being undertaken reported separately at the present conference [1].

Aerodynamic Noise
The aerodynamic noise from wind turbines is directly linked to the same aerodynamic processes in the wind turbine that produce power, and is an inevitable result of the wind turbine operation. Thus proper understanding and prediction of wind turbine aerodynamic noise levels is a key feature of the wind turbine design.

The aerodynamic noise sources can be divided into two parts: the noise due to interaction of the rotor with wind turbulence, and the noise due to the self noise of the blades.

Turbulence Inflow Noise: Turbulence in the natural wind will cause blade noise radiation as it enters the turbine. It has been shown by Lowson (1993) that the turbulence noise principally occurs at lower frequencies, (<1000Hz). Thus it is frequently masked by the mechanical noise. Indeed because of the noise penalties noted above which apply to tones which emerge above the background level, it may be that turbulence noise is actually favourable from the point of view of wind turbine noise rating, since it provides a broad band masking of mechanical noise sources which would otherwise be the cause of noise penalties.

The other sources of noise are all due to the direct action of the wind turbine rotor blade, and are classified as self noise. These include a further four sources:

Trailing Edge Broad Band Noise. This noise source is due to the passage of a turbulent boundary layer past the trailing edge. This noise generation mechanism has been known for some years, and there is a reasonable amount of information about this source in the scientific literature. The most fundamental source of noise is due to the passage of turbulence past the blade trailing edge. The mechanism by which this noise is generated was first demonstrated by Ffowcs Williams and Hall [2]. Their theory has been used to develop a prediction model for the noise process reported by Lowson [3], calibrated by extensive data reported by Brooks et al [4]. A fuller prediction model for wind turbine aerodynamic noise has been reported by Lowson and Fiddes [5].

Tip Noise This source of noise is due to the interaction of the separated vortex flow at the tip with the blade surface. This source has been the subject of some debate in the past, but recent evidence Jakobsen and Andersen [6], is that tip noise can generate high levels. Increases of over 15dB have been observed, typically in frequency bands above 2000Hz. There is some evidence that it is the tips which are responsible for the majority of the modulated noise from wind turbines. Some authorities are considering additional penalties on wind turbines which have high levels of modulated noise. If this issue was found to be related to the tips there would be a higher priority on reduction of this noise source. Virtually all wind turbine designers have taken inadequate (or incorrect) account of this source in their blade design.

Blunt Trailing Edge Noise. This is a discrete frequency noise due to the Karman vortex street leaving a blunt trailing edge of the aerofoil. This noise can produce high (20dB) levels of discrete frequency noise. It can be eliminated by sharpening the trailing edge, cf Hubbard and Shepherd [7].

Laminar Boundary Layer Instability Noise. This is a further discrete frequency whistle, typically around 3000Hz, which has been observed on a number of wind turbines. Laminar boundary layer instability noise can give rise to very large (40dB) frequency peaks. This has been demonstrated, Lowson, Fiddes, and Nash [8], to be related to the existence of laminar separation bubbles on the lower surface of the blade, and may therefore be controlled by removal of the laminar separation bubble. This source can now be predicted and controlled with reasonable confidence.

There are also further possible noise mechanisms, but the above covers the principal cases.

3. Discussion

The last three aerodynamic sources can also be regarded as excess noise which can be eliminated by proper design, and thus in the same category as mechanical noise. Unfortunately since understanding of these noise sources is limited, many current wind turbines still have important contributions from these noise sources in their measured spectra. However it is reasonable to assume that such sources can be eliminated on future turbines.

This means that the fundamental noise sources which require attack are the first two. Of these it is the trailing edge broad band noise which is the most important. This is quite helpful since there is a known mechanism for this, i.e. the passage of the turbulent boundary layer past the trailing edge, which is susceptible to attack by change of the aerofoil section near the trailing edge.

All aerodynamic noise sources have strengths which are a sensitive function of the blade speed, typically varying as tip speed to the fifth power. Until recently reduction of blade tip speed was the only aerodynamic noise control approach available to the designer. Fortunately better prediction tolls are now becoming available.

4. Noise Prediction

An initial model for aerodynamic noise prediction of wind turbines was given by Lowson in [3]. This was based on models of the turbulence induced noise and the broad band trailing edge noise as discussed above. A typical result and comparison with experiment is given in Figure 1. Detailed comparisons of the predicted noise levels with data from wind turbines [9] has shown that reasonable accuracy is achieved, typically around 2dBA for wind turbines which possess no excess mechanical, tip, or instability noise sources.

These measurement were based on the IEA methods. Unfortunately such methods have significant limitations from the point of view of detail comparison with experiment. A comparison with careful recent measurements [1] on a modern Vestas V34 wind turbine is shown in Figure 2. This shows that the original models are underpredicting in the mid range , but overpredicting the self noise at the higher frequencies.

More recently improved models have been developed which relate the noise generation process to the characteristics of the boundary layer passing the trailing edge [10]. In general this more recent model gives results which are lower than the previous predictions. The new models are fairly complex to use, and require considerable detail on the full blade geometry, including planform , section characteristics, twist etc. Thus no full comparison of the result with the more recent theory has yet been undertaken.

Nevertheless the models appear to give reasonable first order predictions for the effects and so could be used for quiet aerofoil design, in conjunction with full aerodynamic codes, so that the noise could be optimised together with wind turbine performance.

5. Conclusions

Noise radiation by wind turbines is an important element in determining overall wind turbine effectiveness. Recent studies demonstrate significant increases in understanding of wind turbine noise, and provide both prediction methods and suggestions for noise control which can be incorporated in future designs to reduce wind turbine noise at source. Useful reductions in aerodynamic noise from wind turbines appear to be possible.

Acknowledgements

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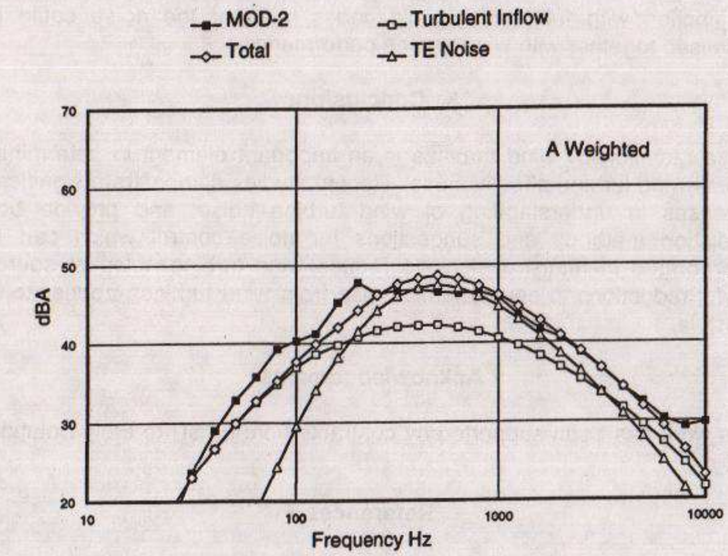

Figure 1 Prediction versus Experiment for MOD-2

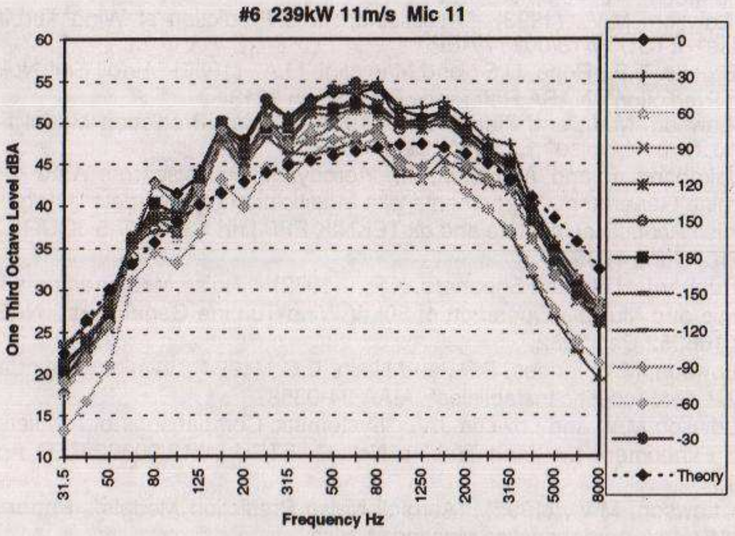

Figure 2 Comparison of Theory with Detail Measurements on V34