Appendix 12

Measurements of Noise Immission from Wind Turbines at Receptor Locations: Use of a Vertical Microphone Board to Improve the Signal-to-Noise Ratio

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MEASUREMENTS OF NOISE IMMISSION FROM WIND TURBINES AT RECEPTOR LOCATIONS: USE OF A VERTICAL MICROPHONE BOARD TO IMPROVE THE SIGNAL-TO-NOISE RATIO

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ABSTRACT

The growing interest in wind energy has increased the need of accuracy in wind turbine noise immission measurements and thus, the need of new measurement techniques. This paper shows that mounting the microphone on a vertical board improves the signal-to-noise ratio over the whole frequency range compared to the free microphone technique. Indeed, the wind turbine is perceived two times noisier by the microphone due to the signal reflection by the board while, in addition, the wind noise is reduced. Furthermore, the board shielding effect allows the measurements to be carried in the presence of reflecting surfaces such as building facades.

1 INTRODUCTION

Acoustical outdoor measurements are often made difficult by the action of the wind on the microphone system, the existence of ambient noise and the presence of scattering obstacles (building facades, etc.) around the measurement position as they contribute to lower the signal-to-noise ratio. Mounting the microphone on the surface of a rectangular vertical board is expected to be an efficient solution to improve it as the reflection by the rigid board adds 6 dB to the signal-to-noise ratio whereas the microphone is sheltered from the background sources located behind the plate. Furthermore, the wind velocity, viz. the pseudo-noise generation, is reduced at the microphone due to the blocking effect of the board on the flow.

Nevertheless, diffraction occurs at the plate boundaries, affecting not only the reflection of the incident noise but also the sheltering effect. This study was designed to evaluate the scattering effect of a board placed vertically above a ground as well as the wind noise generation.

2 DIFFRACTION EFFECTS

The board is oriented so that the microphone is mounted on the side facing the turbine, considered here as a point radiator. For any source located in the semi-infinite space V_1 (Figure 1), the corresponding pressure at the microphone is the sum of the incident, the reflected and the diffracted fields.

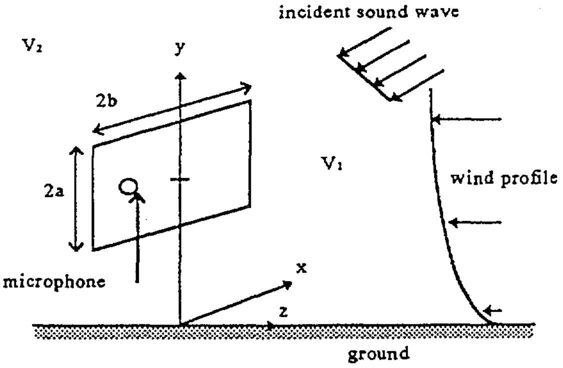

Fig 1. Description of the problem

As the microphone is mounted on the rigid board, the reflected and incident pressure are equal, and this leads to a pressure doubling effect (+ 6 dB) while the diffraction effects are responsible for the deviation from pressure doubling.

2.1 Deviation from pressure doubling

The expression of the pressure at the microphone has been derived by writing the problem in its integral formulation and using the Kirchhoff's assumptions. The diffraction field appears then under the form of a sum of several integrals which might be evaluated asymptotically by the method of stationary phase as described by [1]. Thus, in the simplest case, i.e. at the centre of a square plate of half edge length a, the expression of the total field under normal incidence is given by:

$$\frac{p}{p_i} = 2 - \frac{2\sqrt{2}e^{i\frac{\pi}{4}}}{\sqrt{\pi}}\frac{e^{ika}}{\sqrt{ka}} + \frac{4i}{\pi\sqrt{2}}\frac{e^{ika\sqrt{2}}}{ka} \qquad (1)$$

The first term at the right shows the pressure doubling due to the reflection, the second the diffraction by the edges and the third the one produced by the corners. It appears that diffraction depends only on the Helmholtz's number (*ka*) and the bigger it is, the less the diffraction effects. Eqn.(1) also shows that the edges and the corners generate respectively cylindrical and spherical waves. Due to the simplicity of the solution obtained by the method of stationary phase, it is quite easy to obtain a presentation of the diffraction field over the board surface. Indeed, by computing eqn.(1) over the frequency range (100, 5000 Hz) sampled with a frequency resolution of 10 Hz, the standard deviation of the departure from pressure doubling may be calculated at each frequency and summed over all the frequencies. Figure 2 shows the result of such a simulation repeated for numerous board points. It appears that some positions minimise the diffraction effect and that, under normal incidence, the centre and the board axis of symmetry are maxima of diffraction. The position of the best minimum depends of course on the angle of incidence, the size of the board and the frequency range of interest. For the sake of convenience, this point will be will be denoted M_{opt} in the rest of the article.

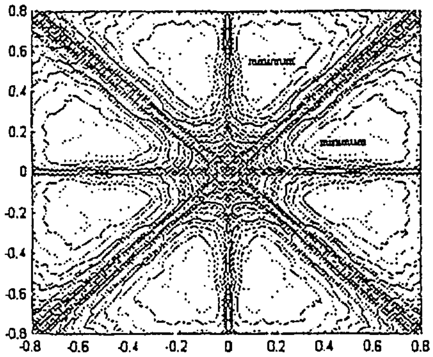

Fig 2. Standard deviation of departure from pressure doubling plotted over the board surface

2.2 Ground reflection

The ground induces reflection for both the acoustical waves launched by the turbine and by the diffracted field. Nevertheless, this latter is neglected due to its poor contribution and the scattering effects of the direct and reflected fields from the turbine may be assessed separately by considering two plane waves impinging on the board with different angles of incidence.

2.3 Sheltering effect

The microphone perceives only the diffracted fields of the sources located in the volume V_2 and, thus, the shielding effect is also maximum at M_{opt} as the diffracted fields are equal on the two board sides. This effect is especially important when the measurement location allows reflections to occur from building facades situated behind the microphone. By considering a plane incident field impinging on one side of the board and its image by the board plane impinging on the other side, the shielding effect is defined as the difference between the sound pressure levels induced by both fields at the microphone. Figure 3 shows the result of a calculation made with an incident field composed of two non-correlated waves of incidences 10° and -10° respectively impinging on a board of dimensions (1.8mx1.5m). It is observed that the sheltering is already 10 dB at about 150 Hz when the microphone is positioned at $M_{opt}(0.45, 0)$ while this effect, assessed at the centre is lower and more irregular.

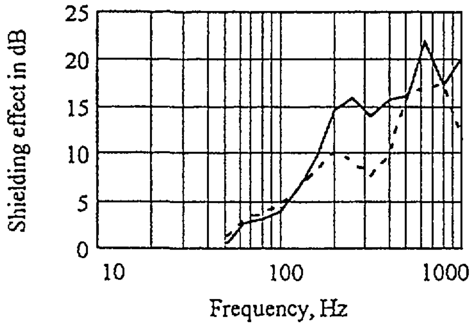

Fig 3. Shielding effect assessed at M_{opt} (—) and at the board centre (---)

3 WIND NOISE GENERATION

The wind noise arises from the action of the wind on the measurement system itself and is composed of a non-radiated aerodynamic noise due to the internal flow velocity fluctuations and of the near field aeroacoustical noise of the measurement system. According to previous studies [2][3][4], the first component is dominant in the wind and the second in a low turbulence rate oncoming flow.

3.1 Flow description

As the flow passes the board, bands of vorticity are generated at the edges of the obstacle and, at some distance behind, they roll up and form the vortex street also called the wake [5]. In the windward, the flow velocity decreases as it approaches the board surface and even vanishes at the stagnation point which characterises a division of the stream. The pseudo-noise is then expected to be lower at this point compared to any other point of the board.

3.2 Measurement description

Outdoor measurements have been carried out to provide an estimation of the attenuation given by the use of a board measurement system instead of a free microphone. They were performed in the neighbourhood of Stockholm in July 1996. The records were made with two board sizes, (1.8m x 1.5m) and (0.9m x 0.75m) during the day and for wind velocities contained in the range (4m/s, 7m/s). The velocity is given at 1.5 m above the ground which is the board centre height. The pressure perceived by a microphone mounted on the board and sheltered by a 9.5 cm hemispherical windscreen is compared with the 'free microphone' value given by a microphone embedded in a 9.5 cm spherical windscreen. On the board, the microphone was located at the centre and at the point M_{opt} (0.45, 0).

3.4 Measurement results

It has been observed that the wind noise generation is strongly dependent on the board size, on the flow velocity and on the frequency of interest. Thus, it was straightforward to express it under the dimensionless form adopted by Strasberg [3]. And it has thus appeared that the measurements satisfy eqn.(2) with a standard deviation of 3 dB.

$$20\lg\left(\frac{p_{13}(f)}{\rho V^2}\right) = A + B\lg(St) \qquad (2)$$

where p_{13} is the pressure in the third octave band f and ρ is the flow density. St, the Strouhal number, is defined by St = fD/V where D is a typical dimension of the board or of the windscreen and V is the flow mean velocity. A and B are two constants which vary with the measurement point. Finally, as expected, it has been observed that the gain is slightly better when the microphone is placed at the stagnation point.

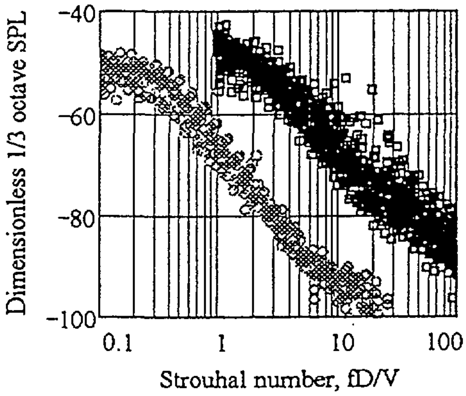

Fig 5. Outdoor dimensionless wind noise
(o) Measurements with the free microphone
(□) Measurements with the boards

Figure 6 shows the gain of signal-to-noise ratio obtained by using the board instead of the free microphone. It is *seen that this gain is greater than 5 dB over the* frequency range [20, 1000 Hz].

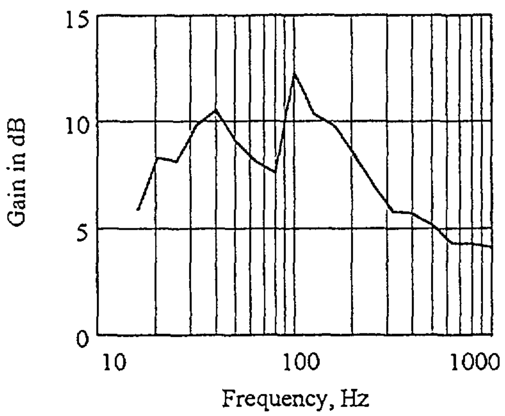

Fig 6. Gain of signal-to-noise ratio

4 DISCUSSION AND CONCLUSIONS

Dimensionless laws giving the wind noise generation for both the board and the free microphone have been derived, allowing the results to be extrapolated to different board sizes or wind velocities. Nevertheless, these laws could have suffered from the influence of the short velocity range [4-7m/s]. It has been shown that the board should be placed normal to the wind direction in order to maximise its blocking effect. Then, a suitable microphone position on the board surface is the stagnation point, which may be located a bit over the board centre (about 10 cm) due to the logarithmic wind velocity profile. Both indoors and outdoors, it has been observed that the board measurement system might lead to a higher background level compared to the free microphone at middle and high frequency. It is difficult to conclude if it arises from the generation of pseudo-noise by the board, i.e. a high sensitivity to the flow turbulence, or if it is the consequence of the reflection of the background noise by the board. Anyway, the addition of 6 dB to the incident signal counteracts largely this negative effect and makes the board measurement system still interesting for improving the signal-to-noise ratio.

Concerning the diffraction effect, it has been seen that it might be reduced at suitable positions on the board *surface. For those points, the sheltering for a board of* (1.8mx1.5m) is greater than 10 dB above 150 Hz. Thus, this study shows that the use of a board is advantageous for outdoor measurements when one is dealing with low signal-to-noise ratios or with reflecting surfaces around the measurement location.

5 ACKNOWLEDGEMENTS

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