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THE EFFECT OF WEATHER CONDITIONS ON THE PROPAGATION OF SOUND

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1 ABSTRACT

An overview will be given of the effects of weather on outdoor noise propagation. A physical interpretation of the propagation of sound will be given in terms of the three principal mechanisms of refraction, atmospheric absorption and scattering. Measurement of environmental noise as described in the Standards will be reviewed. The effects of weather will be illustrated by detailed measurements from experimental research. Comparisons will be presented with environmental noise levels predicted using methods depicted in the Standards. Finally, suggestions are made concerning the measurement and prediction of environmental noise levels in practice.

2 INTRODUCTION

Assessing the influence of weather on a particular measurement depends upon the determination of the prevailing meteorological conditions over the propagation path, and also of an understanding of how the various meteorological factors influence noise propagation. Measured sound pressure levels owe as much to near-surface weather as to ground shape and impedance and factors such as source and receiver heights and locations. Wind and temperature gradients in the atmosphere cause refraction that can increase or decrease sound pressure levels significantly. However, the variability in meteorological parameters over the propagation path and measurement duration creates uncertainties in the measurement of temperature, wind speed and direction in practical situations. It is often recommended that measurements be performed under stable downwind conditions described in terms of the vector wind. However, a physical interpretation of outdoor noise propagation can be appreciated better through the three principal mechanisms of refraction, atmospheric absorption and scattering.

3 REFRACTION, ATMOSPHERIC ABSORPTION AND SCATTERING

Refraction is the term used to describe the change in propagation path from a straight line to a curve due to temperature and/or wind speed gradients. Sound may be refracted upwards creating shadow zones of low noise at the ground, or refracted downwards focusing the sound towards the ground. Atmospheric absorption is the attenuation of principally high-frequency noise due to classical and molecular absorption and is determined by the relative humidity and

temperature. Scattering of sound by atmospheric turbulence allows noise to enter shadow zones, reducing the strength of interference patterns. Due to the variability and interdependence of these meteorological variables, the combined effect of the three mechanisms is often complex.
Generally wind speed increases with altitude. On the downwind side this will cause the path of sound to refract down focusing the sound and increasing the noise level. On the upwind side the path of the sound will bend away from the ground creating a shadow zone and a corresponding decrease in noise level. Similar effects to those of wind gradients can be created by temperature gradients. Effects of temperature gradients differ from those of wind gradients in that they are uniform in all directions from the source. Under normal laps conditions such as may occur on a sunny day with little or no wind, temperature decreases with altitude resulting in a shadow effect. Under a temperature inversion such as may occur on a clear night, temperature will increase with altitude resulting in the focusing of sound back towards the ground.

4 STANDARDS AND GUIDANCE

Noise measurements should be performed under weather conditions representative of the situation under investigation. However practical environmental noise measurement are usually made at times dictated by other factors, such as the planned progressive shutdown of factory plant. In this case it is often recommended that measurements be performed under stable downwind conditions. These are often described in terms of the vector wind, which is the component of wind velocity in the direction from the source to the receiver. PPG 24 (1994) [1] for example suggests a light vector wind <2m/s. BS4142 (1990) [2] on the other hand suggested that noise level measurements should not be made with winds >5m/s or temperatures <3ºC. More comprehensive classifications of weather conditions have been described, for example in CONCAWE [3], and these are useful when determining average weather patterns for long-term measurements. Another method is discussed in the draft revision of ISO1996 [4]. This document also gives an indication of the uncertainties likely to be experienced at source-receiver distances up to 400m. The variation of the LAeq with wind speed and temperature under experimental conditions for source receiver distances up to 1km are discussed below.

5 EXPERIMENTAL RESEARCH

5.1 Experimental Set-up

As part of an investigation into the effects of meteorology on outdoor noise propagation, experiments were performed using an omni-directional point source over flat grassland [5]. These measurements were specifically performed at distances typical to community noise problems. Figure 1 illustrates the experimental layout. Measurements were performed at a disused airfield along flat grassland parallel to the runway. A high-power omni-directional electro-acoustic source with centre height 2m was used to provide a sound power of 130dB. Four reference positions were set up around the source at 5m distances in order to monitor any source power fluctuations. Ten acoustical monitoring units with a microphone height of 1.5m were installed at approximately 112m intervals to the east of the source and an additional four units were set up at selected positions to the west of the source.

Each station was used as a stand-alone data logger and audio recorder logging L_{eq}, L_{fast} and 1/3 octave band spectra each second. The source emitted pink noise in five-minute sections separated by one-minute sections of silence to enable background levels to be monitored. The measured noise data were synchronized with meteorological measurements from an acoustic SODAR system. Automatic weather stations were also set-up on 2m and 10m masts at the source and at the receiver one kilometre east of the source. The measurements detailed here were performed between 1900 and 0500 on the shortest night of the year.

5.2 Categorisation of acoustical and meteorological data

The acoustical data presented in this paper were calculated for source-on times only with allowance made for background noise. Measurements <3dB above background noise were discarded. Acoustical and automatic weather station meteorological data were measured each one second, and these data were averaged over 150s time periods to correlate with the SODAR measurements. The 150s average automatic weather station meteorological data were categorized with each sample identified by category in terms of temperature gradient, wind speed and vector wind. Qualitatively, the negative temperature gradient became a positive as the sun set and the ground cooled. The converse is seen as the sun rose and the ground warmed. The temperature gradient in-between is complex, perhaps due to the effects of winds and a nearby thunderstorm. The wind speed fell during the night and became still between around 0100 and 0300 before picking up around sunrise. The most commonly occurring conditions during this measurement are those of a temperature lapse with some crosswind and with some vector wind. Categorisation of the data in this way allows the effects of turbulence, refraction due to wind gradients only, and refraction due to temperature gradients only to be identified and analysed [6].

5.3 Correlation with vector wind

The correlation of the LAeq with vector wind speed is illustrated by figure 2 for a receiver distance of 112m. With a slight vector wind of 1m/s downwind, enhancement is seen, this enhancement increasing slightly with vector wind speed up to around 7m/s. Upwind however, a sharp fall-off of noise level with vector wind is seen as the shadow zone is formed. The shadow increases sharply for vector winds up to around –4m/s and is then seen to plateau with this data set.

As receiver distance increases through 224m to 1008m shown in figure 3, the downwind enhancement is found to change comparatively little with vector wind speed. Two counteracting mechanisms are in action, so that refraction due to the positive sound speed gradient is offset with absorption by the ground. Conversely, the sharp attenuation with negative vector wind speeds is seen to deteriorate. This is due to the scattering of sound into the shadow region by turbulence and is discussed further below.

5.4 The influence of range-dependent meteorology

Meteorological data is not routinely collected at 10m close to the source during environmental noise surveys. Consequently the correlation between LAeq and vector wind as measured at various distances from the source at 2m is of interest. The correlation of LAeq with 2m vector wind speed measured both at the source and at 1008m east is shown in figure 4 for the receiver 112m east. Since the acoustical data is this same as that shown in figure 2 for the correlation with 10m vector wind speed, the same acoustic enhancement downwind and shadow upwind are seen. However, since wind speed increases with height, the spread of vector winds at 2m in figure 4 is less than that in figure 2 at 10m. This means in practice that the onset of the marked attenuation of the shadow zone occurs at lower vector wind speeds as detected at the ground close to the source, and furthermore that the LAeq can vary greatly with only small changes in wind vector in the 0-2m/s range.
The range of vector wind speeds measured at 1008 metres from the source is seen to be greater than at the source. The correlation with AWS data from 1008 metres from the source is seen to be less tight than with AWS data from by the source. This is due to differences in vector wind over the one kilometre. These descriptions can be applied to the correlation of LAeq for the receiver at 1008m east of the source with vector winds measured at the source and at 1008m. The wider range of vector winds at 1008m broadens the spread of the correlation. In particular, upwind scatter is highly developed due to diffraction into the shadow zone.

5.5 Correlation with temperature gradient

Figure 5 illustrates the correlation between LAeq and temperature gradient for receivers at distances 5, 224 and 896m. These data are selected with no vector wind component to be influenced only by temperature gradient. The correlation is seen to be weaker than the correlation between LAeq and vector wind. For conditions of no vector wind, where the temperature gradient and crosswinds influence propagation, a significant spread of LAeq is seen. This spread is seen to increase markedly with distance. This spread in the data collapse is thought to be due to the variations in the sound speed profile with distance and the influence of turbulence.

6 COMPARISON WITH PREDICTIONS

Figure 6 shows comparison between measured and predicted sound pressure levels. Calculations using ISO9613-2 are shown. Fast Field Program predictions [8] are used to illustrate the effects of temperature gradients. The FFP predictions assume a logarithmic sonic profile based on a linearised temperature gradient between 2 and 10m of -0.05, 0, and +0.05K/m. These are compared with experimental measurements selected to best match these conditions, together with a minimum wind speed and minimum positive wind vector. Both FFP predictions and experimental measurements show the enhancement due to refraction by the positive temperature gradient and the shadow due to refraction by the negative temperature gradient.

The ISO9613-2 method predicts the sound pressure level under meteorological conditions favourable to propagation; such as propagation under a well-developed moderate ground-based temperature inversion as commonly occurs on clear nights. These predictions are consequently seen to agree best with the FFP prediction using the positive temperature gradient. The effects of turbulence on propagation in a refracting sonic gradient are illustrated by the PE predictions [9] of figure 7. The PE predictions show the same positive, neutral and negative refraction as the FFP due to -0.05, 0, and +0.05K/m temperature gradients. The addition of turbulence shows all cases converge to that of a positive refracting atmosphere due to scattering into the shadow zone. The propagation patterns observed in these predictions illustrate the principal mechanisms of refraction and scattering.

7 DISCUSSION

It is usually considered that the influence of meteorology may be regarded as negligible when considering propagation distances less than 100 metres, unless frequencies greater than 2kHz are of particular interest. However, meteorological changes may exert significant influence especially with high-level sources where the effects can be observed over long distances. Depending on wind speed, noise levels may increase downwind by a few dB. However when measuring with an upwind or sidewind level decreases in excess of 20 dB may result. PE predictions were used to illustrate that turbulent scattering allows noise to enter shadow zones, there by reducing the strength of interference patterns. For an analytical description of sound propagation in a moving inhomogeneous atmosphere extensive study is required and the treatise presented by Ostashev [10] is highly recommended.

8 CONCLUSIONS

Good agreement between measurement and ISO 9613-2 predictions was observed under favourable conditions for propagation as described by the Standard. The meteorological corrections given by ISO 9613-2 are in practice limited to the range from 0-5dB with values in excess of 2dB said to be exceptional. Meteorological conditions can change rapidly during measurements, and measurements are occasionally made under unrepresentative conditions for a variety of pragmatic reasons. These are sources of uncertainty in the practical measurement of environmental noise. Unless specific meteorological conditions are required, the results presented here illustrate that measurements should be made under conditions favourable for propagation as described by ISO 9613-2. These and other sources of uncertainty arising in the practical measurement of environmental noise are discussed more fully in the DTI Good Practice Guide [11]. Downwind measurement is normally preferred because the end result is more conservative since the deviation is smaller. As a rule of thumb, for downwind propagation the wind direction will be blowing from the source to the receiver within an angle of ±45 degrees with a wind speed between 1-5m/s measured at height of 3-11m above the ground.

9 ACKNOWLEDGEMENTS

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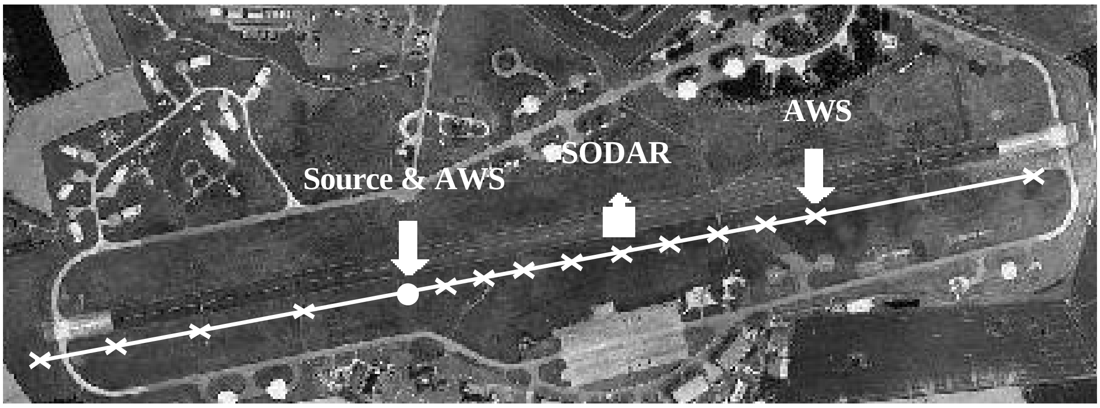

Figure 1: Showing the experimental setup including the line of the receiving array and positions of the automatic weather stations and SODAR

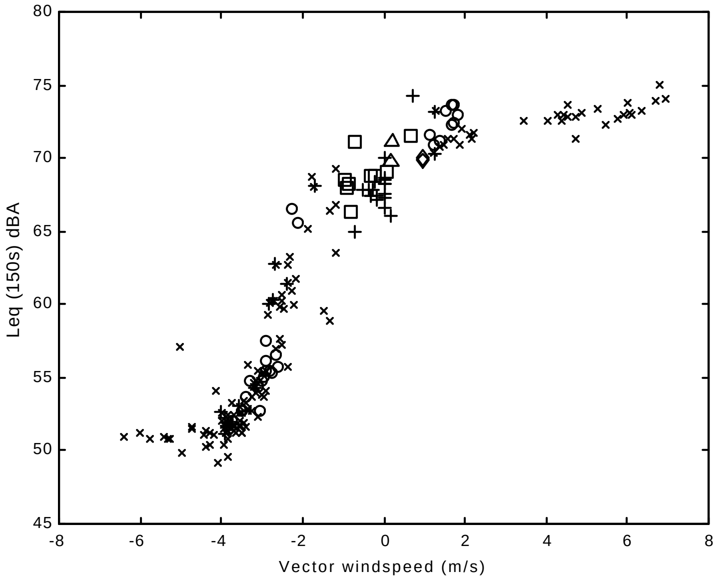

Figure 2: Variation of LAeq (150s) with vector wind speed measured at 10m for receiver 112m East of the source for each meteorological category

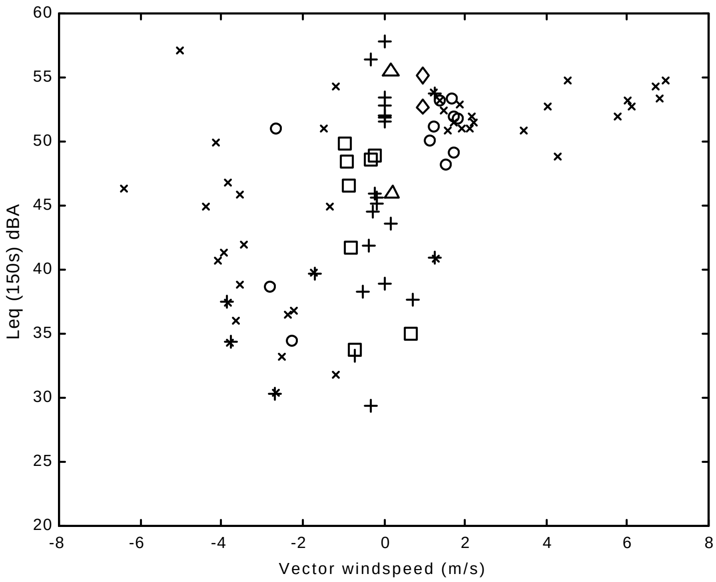

Figure 3: Variation of LAeq (150s) with vector wind speed measured at 10m for receiver 1008m East of the source for each meteorological category

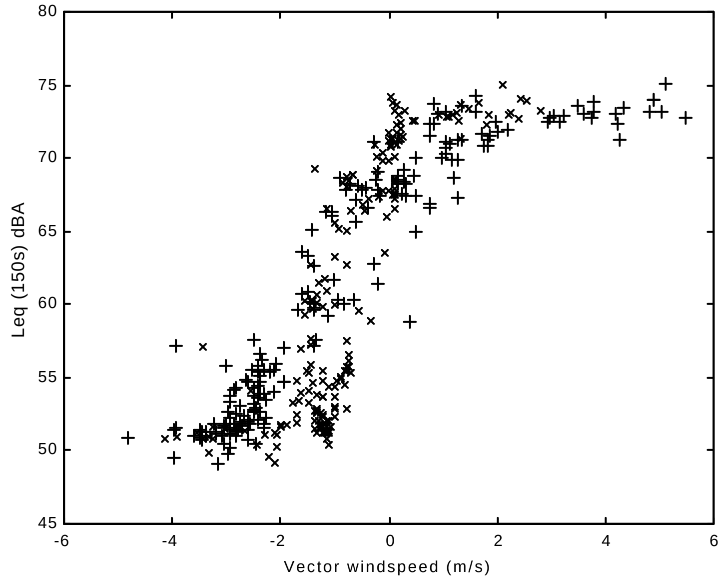

Figure 4: Variation of LAeq (150s) for receiver 112m East of the source with vector wind speed measured at 2m at source (X) and at 2m at 1km from source (+)

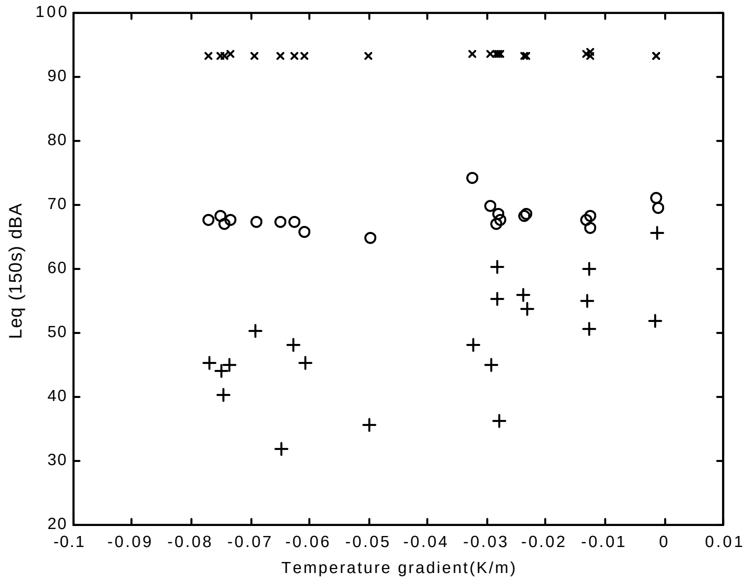

Figure 5: Variation of LAeq (150s) with temperature gradient for receivers East of the source at distances 10m (X), 112m (O) and 672m (+)

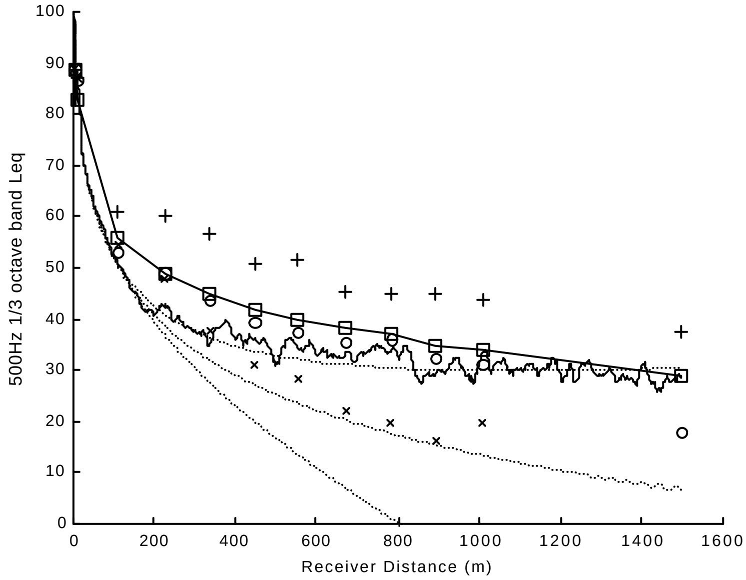

Figure 6: Comparing measurement with predictions at 500Hz. ISO 9613-2 ( ), PE (downwind), measurement and FFP temperature gradients –0.05K/m (x), 0K/m (O), +0.05K/m (+)

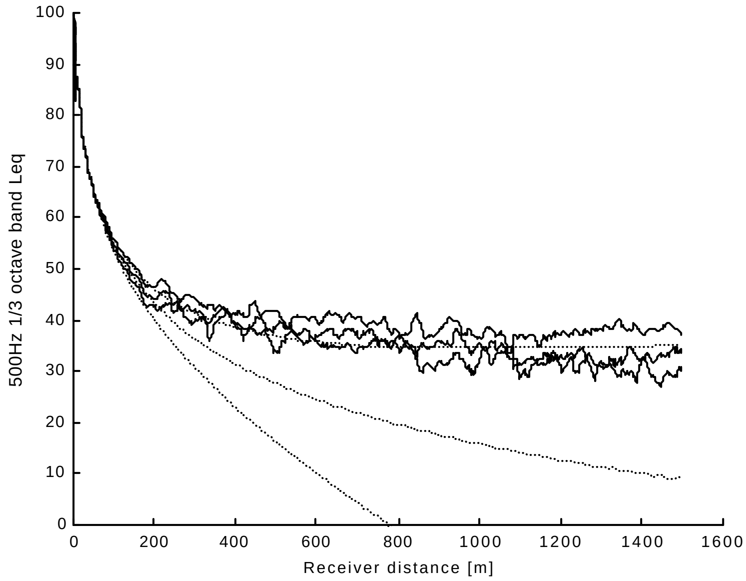

Figure 7: Comparing PE predictions with and without turbulence at 500Hz. Temperature gradients – 0.05K/m, 0K/m and +0.05K/m.