The Influence of Range-Dependent Meteorology on Outdoor Sound Propagation over a Barrier

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ABSTRACT

We report the findings of a field trial programme to investigate barrier sound reduction in a turbulent atmosphere. An experiment is described in which range-dependent meteorological and acoustical data were simultaneously measured. A Doppler LIDAR measured winds in scans across the length of the array. Vertical winds and turbulence were also determined in a column by a SODAR positioned 250m from the barrier. Experimental results are presented investigating the effects of variable meteorology on propagation with distance. Comparisons are made with predictions derived from PE models and limitations in theoretical modelling and experimental techniques discussed.

INTRODUCTION

Accurate prediction of noise reduction from barriers requires methods that must consider the influence of wind, temperature gradient and atmospheric turbulence. Barrier performance may be reduced by an irregular sound speed profile, while the scattering of sound by atmospheric turbulence into the shadow zones formed by the barrier will also reduce transmission loss. Although many possible propagation paths usually exist between a source and the receiving position, for example in an urban area due to multiple reflections between buildings, the scattering of sound by turbulence is stronger for smaller angles. In order to investigate these effects in isolation, a single barrier without reflections from surrounding buildings was selected for investigation.

EXPERIMENTAL METHOD

Figure 1 illustrates the experimental set-up. The investigations were performed on a disused airfield. Experiments were conducted over a large barrier using a powerful omni-directional source fed with a modified MLS sequence. The source was positioned 118 metres from the centre of the barrier and a linear array of omni-directional microphones deployed across 1 kilometre of flat grassland on the quiet side from the barrier. The time-synchronised array was sampled for Leq and $^{1}/_{3}$ octave spectra each second. 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.

Meteorological information was simultaneously measured at various locations along the array. The surface meteorological parameters were determined by automatic weather stations at 2m and 10m close to the source and at the furthest position on the receiving array. Wind profiles were measured using a SODAR positioned 250 metres along the receiving array. The Doppler LIDAR, capable of scanning in three-dimensions to determine radial wind velocities from a single location [1], was positioned at a distance of approximately 900 metres perpendicular to the receiving array. A Radar wind profiler, situated around 28 kilometres southeast of the site, was used to augment the data at the highest altitudes.

RESULTS

The meteorology as measured by the 2m and 10m automatic weather stations at the source was categorised in terms of temperature gradient between 2m and 10m, vector wind and wind velocity at 10m. 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, as discussed more fully in Waddington [2]. A negative temperature gradient predominated with some temperature gradients near to zero in the early hours. A significant crosswind is seen in the earliest and the latest hours of the experiment, and despite the near-zero vector winds between 0000-0500 hours, there is evidence of a significant crosswind.

A comparison of the LIDAR wind profile derived for the position over the barrier with the wind profile measured by the SODAR 250 metres along the receiving array is shown in figure 2. The LIDAR data were obtained using a series of PPI and RHI scans. Profiles of wind velocity and direction with distance were accumulated from several PPI scans with azimuth 48-148 degrees and 20-148 degrees over the time period 2230-0020 hours. The height of the profiles was limited by the elevation angles of the scans. Whilst comparison of the profiles is quite good considering that they are derived from two different sensing systems, it should be noted that these averages are performed over a period of nearly two hours. Consequently it is unclear what differences in the profiles are due to changes in the meteorology over the period. Further, in the case of the LIDAR some variability in the derived direction may results due to dependence of the low-level wind profile on the highly variable near-surface structure over distances of the order of a few kilometres due to the extended volume of the scan.

EFFECTS OF VARIABLE METEOROLOGY

The correlation of LAeq (150s) with vector wind speed is illustrated by figure 3a for the receiver 90m southeast of the source, positioned just before the barrier. With a slight vector wind of 1m/s downwind, enhancement is seen, this enhancement increasing slightly with vector wind speed. Upwind however, a sharp fall-off of noise level with vector wind occurs as the shadow zone is formed. Figure 3b compares the situation 26 metres from the centre line on the quiet side of the barrier. Minimal enhancement is seen with a vector wind and there is little evidence of the formation of a shadow. As receiver distance increases, the downwind level is enhanced slightly with vector wind speed as illustrated by figure 3c. This could be visualised as rays being refracted by the sound speed gradient in addition to those diffracted over the barrier. Conversely, the sharp collapse of data for a zero vector wind speed is seen to deteriorate. This is due to the scattering of sound into the shadow region by turbulence and is discussed further below.

Considered in figure 4 are measurements in the 250Hz 1/3 octave band made under three distinct meteorological conditions:

i. maximum vector wind (vector wind 3.0m/s at 10m, wind speed 5.1m/s at 10m),
ii. closest to acoustically neutral (vector wind 0.2m/s at 10m, wind speed 1.2m/s at 10m),

iii. maximum crosswind (vector wind –0.6m/s at 10m, wind speed 3.4m/s at 10m).

Under neutral conditions, 10 out of 11 measurement positions have valid data. Measured levels are seen to be very low, with the additional measurement discarded due to excessive background noise. Whilst levels under maximum vector wind conditions are slightly higher, only 5 out of 11 measurement positions have valid data with background wind noise causing the remainder of data to be discarded. Crosswind conditions show the highest measured levels and the least influence of background noise, due to penetration of the acoustic shadow by sound scattered from turbulence above the barrier.

COMPARISON WITH PE MODELLING

Figure 5 shows comparisons of GT-PE predictions [3] with measurements in the 250Hz 1/3 octave band averaged over the duration of the LIDAR scan. Similarity-based profiles were generated from averaged 2m and 10m automatic weather station measurements of temperature, wind speed and direction. The temperature profile generated from similarity was combined with the SODAR and LIDAR wind profiles of figure 2 in order to produce sound speed profiles. The barrier was modelled as a Gaussian shape with an assumption of constant ground impedance.

The measured levels show an initial sharp fall-off with distance, perhaps due to complexities in the ground. Whilst the structure of the measured wind profiles is reflected in the GT-PE at distances of 1000 metres, models based upon each of the sound speed profiles are seen to predict significantly higher levels than those measured. These differences could be the result of an overestimate in turbulence strength in the GT-PE modelling. The comparisons of figure 6 however suggest that the differences may be due to the long-term averaging of the meteorology involved in producing a comparison with the LIDAR measurement and the change in propagation conditions during this period. Figure 6 shows a comparison of GT-PE predictions with measurements averaged over the 150s of the selected crosswind case. Measurements and predictions show much better agreement than those seen with the LIDAR comparison above, particularly at larger distances.

CONCLUSIONS

Wind noise on the microphones meant that allowance for background noise was responsible for the disregarding of many data points. Turbulence generated by crosswinds resulted in increased measured levels within the acoustic shadow of the barrier. Under crosswind conditions differences of the order of 15dB were seen between measurements in the 125 and 250Hz 1/3-octave bands at most distances. Moreover, close to the barrier strong variations in the wind profile were measured by the SODAR, and these may contribute to the variations in level. Future experiments will make greater use of sonic anemometers to calibrate the SODAR turbulence measurements to allow more detailed investigations. Limitations in the GT-PE modelling include the assumption of constant ground impedance, the Gaussian geometry modelling of the barrier, and the method of modifying a sound speed profile with distance over the varying terrain.

REFERENCES

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2. Waddington D.C. and Lam Y.W. “Determination of Meteorological Parameters and their Effect in Outdoor Sound Propagation Measurements”, IoA Spring Conference 2002, **24** (2) 2002
3. West M. “The SAL-PE Software Suite”, Acoustical Software, August 2001

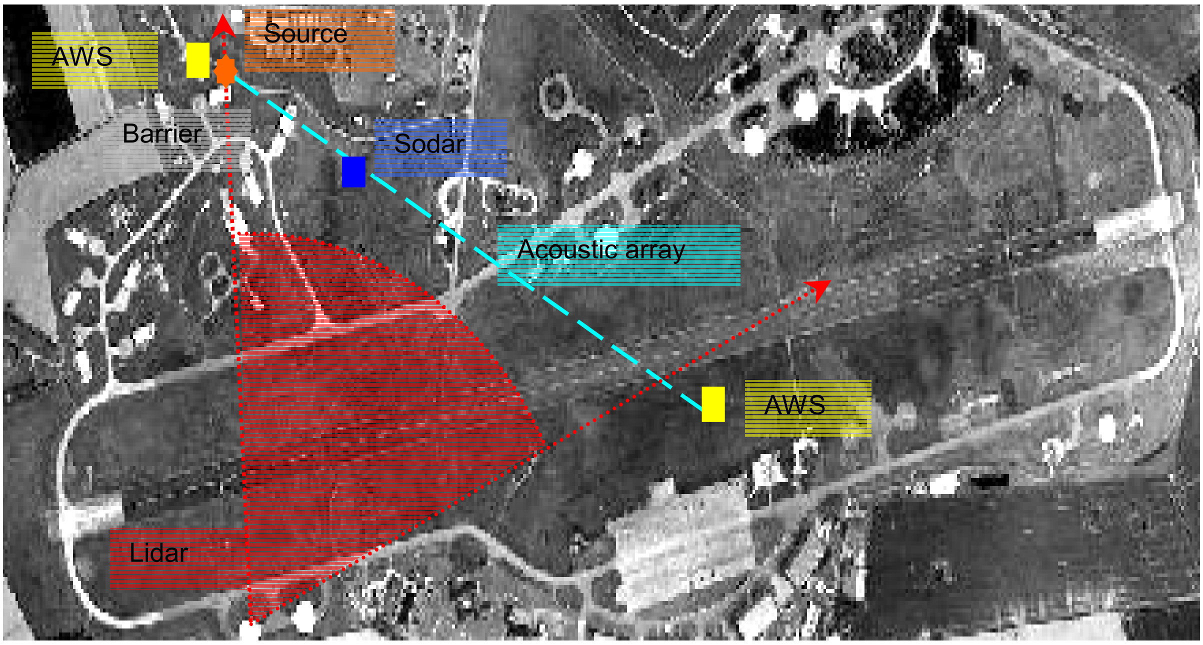

Figure 1: Showing the line of the source, barrier and receiving array, and positions of the automatic weather stations, LIDAR and SODAR

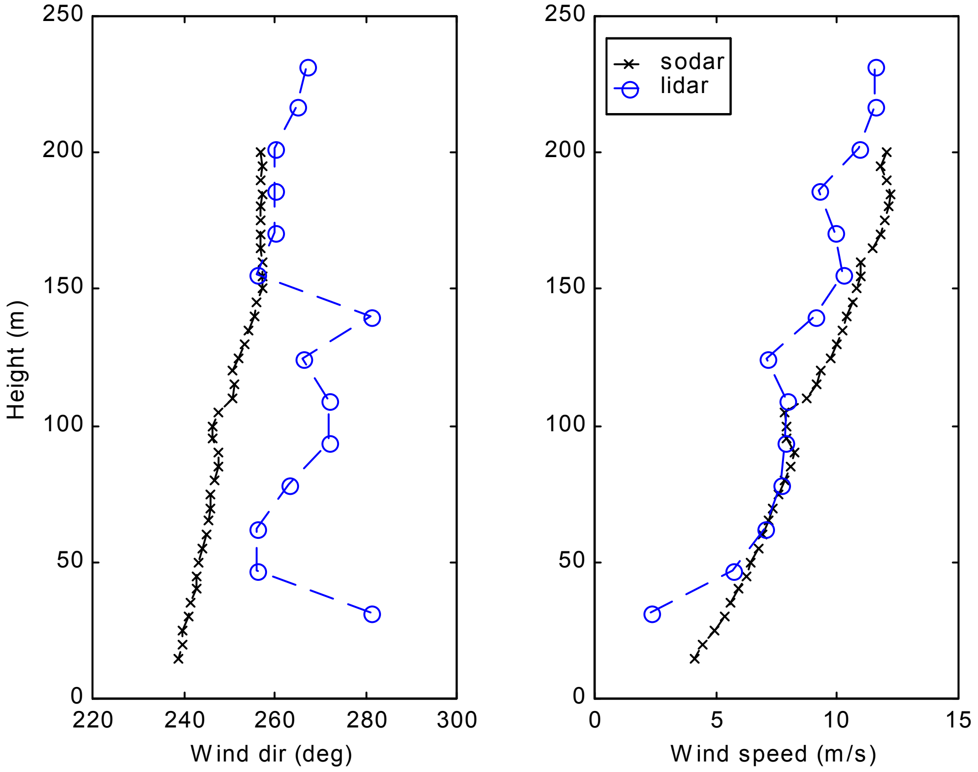

Figure 2: Comparing SODAR (X) and LIDAR (O) average wind profiles from measurements taken from 22:30 27/06/01 to 00:20 28/06/01 during the barrier experiment

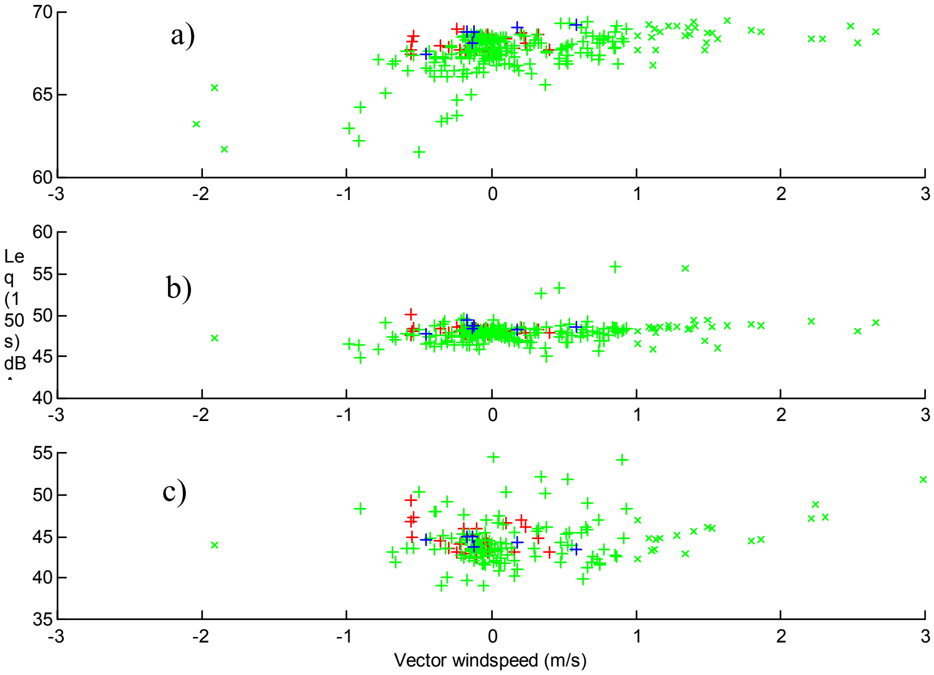

Figure 3: Correlation of measured LAeq level with vector wind speed a) before, b) 26m after and c) 528m after barrier

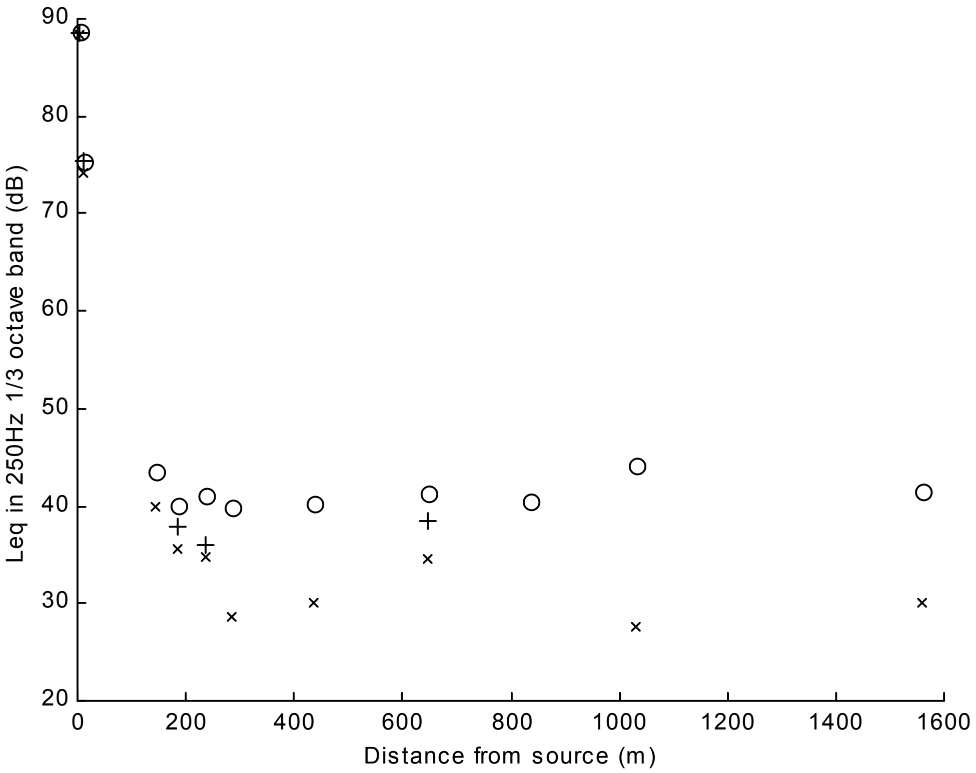

Figure 4: Measured 250Hz 1/3 octave-band levels allowing for background under vector wind (+), neutral (O) and cross wind (X) conditions

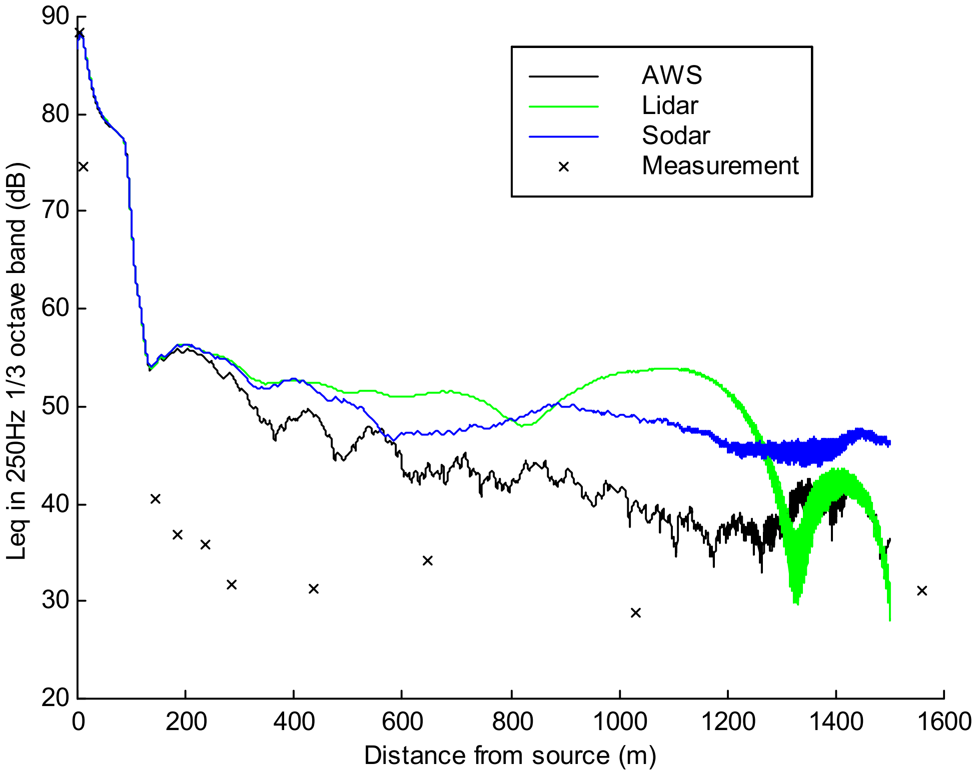

Figure 5: Comparison of GT-PE predictions with measurements over duration of LIDAR scan

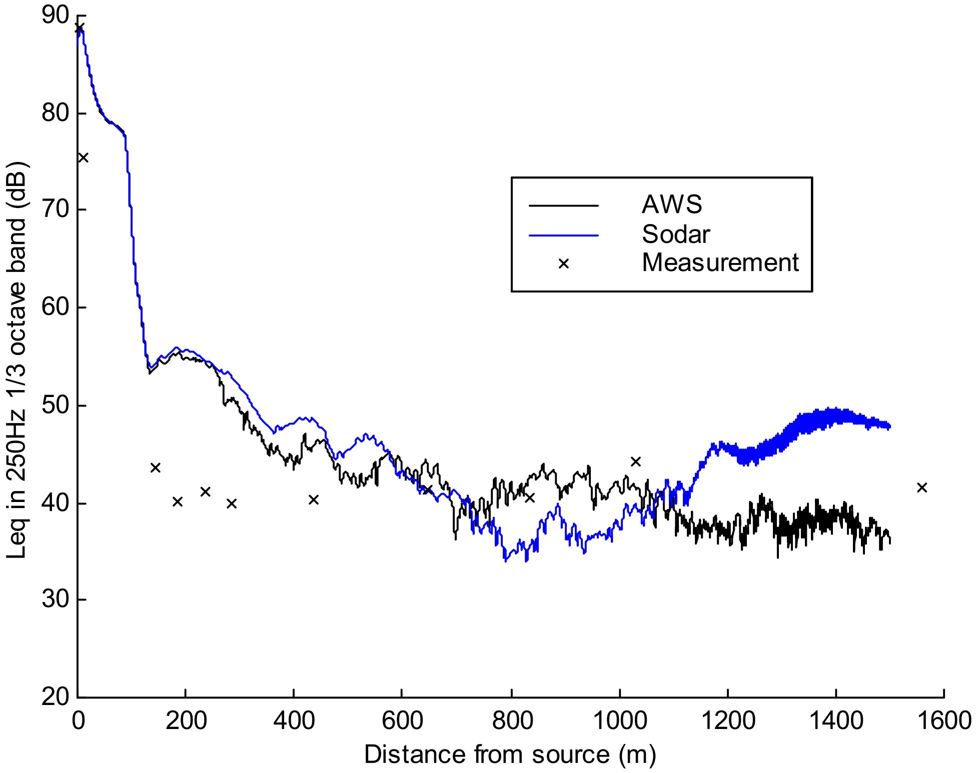

Figure 6: Comparison of GT-PE predictions with measurements for crosswind case