MEASURING THE EFFECTS OF TURBULENCE

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Introduction

Turbulence plays an important role in determining the characteristics of sound propagating through the atmosphere. Only recently have acoustic theory, numeric modelling, and field measurements provided consistent values of SPL in the presence of turbulence. With the recent and rapid development of effective propagation codes, there is an increasing need for reliable and comprehensive field data against which to validate the codes and gain a better understanding of the effects of turbulence.

The effects of turbulence are perhaps most readily observed within an acoustic shadow region. A shadow region is generated near the ground by upward refraction of the propagating sound. It can also occur behind a sound barrier or terrain masking feature. Within an acoustic shadow region, there is no direct propagation path from source to receiver. Near the shadow boundary there is diffracted acoustic energy which decreases rapidly within the shadow region. In the deep shadow region, the meagre diffracted field is dominated by the acoustic energy which is scattered into the shadow region by the insonified turbulence outside of the shadow.

A schematic representation of the three major region is shown in Fig. 1 for a simple upward refracting geometry above a flat ground. Analogous geometries exist for curved ground (terrain masking) or acoustic barriers. The general form of this schematic has been observed repeatedly in outdoor measurements [1,2] and more recently in numeric simulation studies [3].

A large array of microphones was developed to investigate the effects of turbulence on a sound field. A large array is required because simultaneous measurements must be gathered over a large area to characterize the sound field before the parameters of the non-stationary turbulence change.

In this paper, the array is discussed and measurements of spatial coherence within a refractive shadow region are presented as a representative example of the effects of turbulence being measured.

The Microphone Array

The microphone array consists of up to 64 sensors and uses 1/4" electret microphones with matched preamplifiers. The microphone preamplifiers are connected to programmable line amplifiers (PGA) which can handle up to 6 channels. The preamplifier and PGA have a robust circuit design and are housed in a rugged enclosure. The microphones can be located 100 m from the PGA, allowing each PGA to service microphones which cover a large area. The PGA's are controlled remotely for gain settings and a power-saving sleep mode.

With over 70 Km of wire and 5000 connections, the cable set is a significant component of the array. A comprehensive grounding strategy is implemented throughout the cable set and the electronic components to provide good shielding and prevent ground loops. Cable specifications provide abrasion resistance, UV tolerance, water resistance, shielding and ample signal ground return. The main cable trunk lines connect the PGA's to the equipment trailer. They can be configured so that the PGA's are at distances of 100 to 1000 m from the trailer. Up to 96 channels of distinct signal can be carried by the trunk lines.

By using different combinations of cable lengths and clustering microphones at the PGA, tremendous flexibility can be achieved in the configuration of the array. In addition, up to 16 channels can be configured separately from the array using battery power and 4 mm DAT instrumentation recorders to provide satellite array capabilities.

The equipment trailer is equipped with battery and generator power systems and it is possible to switch between power sources without interrupting operation. A patch panel at the equipment trailer allows routing and sequencing of incoming signals and provides a single junction point to earth-ground. Inside the trailer, the signals are filtered using customized, programmable 5-stage analog bandpass filters with 18 poles per channel. The filtered signals are multiplexed using an array of solid state switches. The typical sampling rate is 8000 samples per second per channel and the switches can operate at up to 2 MHz. Data acquisition is performed by a 12-bit DAC hosted by an EISA-PC/486 class computer. Real time recording to disk is performed to the capacity of the disk and the data is subsequently backed up to 8 mm DAT for off-line storage.

The sound source consists of up to four single-driver enclosures tuned for 40-1000 Hz operation. A portable generator and a 2.4 kW amplifier are used to generate about 130 dB ref. 20 μP at 1 meter. A 10 m crank-up tower is used to mount meteorological instruments at heights of 2 and 10 meters. The temperature and wind data arecarried to the equipment trailer by the trunk lines where it is digitized. Most of the field trials have been conducted at a privately owned airport which has 700 m runways and is conveniently located near the laboratories. The flat, hard surface, and the variable weather conditions, have provided numerous interesting data sets.

Sound Field Characteristics

Through repeated tests and analysis we are investigating a number of characteristics of the sound field, particularly within a refractive shadow. The following is a representative list of the measurements and analysis being pursued. **1)** Average sound pressure levels as a function of range, **2)** vertical profiles of the sound pressure level near the shadow boundary, **3)** transverse and longitudinal spatial coherence, **4)** statistics of the fluctuations in the phase and magnitude at various ranges from the source, **5)** coherence between tones of different frequencies (frequency coherence measurements), and **6)** temporal coherence of the sound field.

Collection and processing of the data is ongoing. As an example of the sound field characterization being achieved, some results for spatial coherence will be presented.

Spatial Coherence Within an Acoustic Shadow

The spatial coherence length of the sound field is the separation distance at which the correlation drops from unity by 1/e of the drop at infinite separation. Outside of the shadow region, such as during downward refraction conditions, the transverse coherence length is quite short; it tends to be about 1 m at long ranges. The longitudinal coherence length outside the shadow region, on the other hand, is very long; it can be much greater than 100 meters [4].

Data for the transverse coherence within a shadow region is shown in Fig. 2. The signal frequency is 500 Hz and the range from the source to the receivers is 700 meters. The lower curve corresponds to stronger upward refraction conditions, for which the receivers are within the deep shadow region. The upper curve corresponds to weaker upward refraction and, with the receivers at the same range, they are closer to the shadow boundary yet still within the shadow region. The observed transverse coherence is 1 or 2 meters, which is similar to that expected outside of the shadow region.

The longitudinal correlation data is plotted in a similar format in Fig. 3, except that the sensor separation axis has a different scale. The longitudinal coherence length is greater than the transverse coherence length within the shadow region, yet much less than that expected outside of the shadow.

Summary

A large array of microphones provides a useful tool for investigating the characteristics of sound fields in the presence of atmospheric turbulence. Statistics other than the SPL, such as the spatial coherence, are strongly effected by the atmospheric turbulence. Characterizing these effects will improve our understanding of the relationships between turbulence and the sound field. This research is ongoing and is applicable to propagation modelling and simulation, adaptive beamforming for remote sensing, and acoustic probes for detecting meteorological effects.

Acknowledgements

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References

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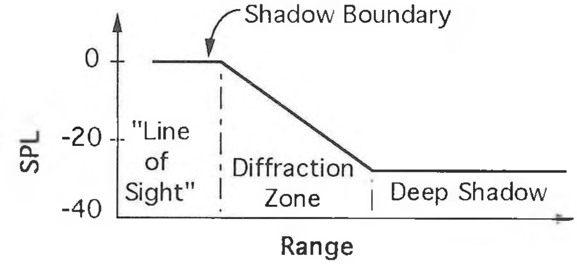

Fig. 1 Upward Refraction

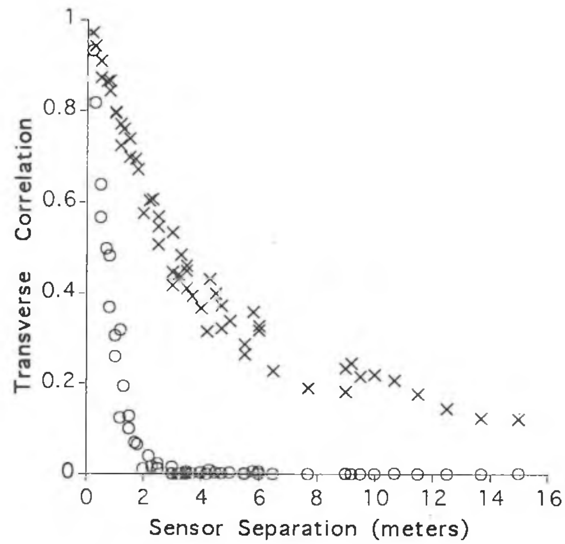

Fig. 2 Transverse Correlation

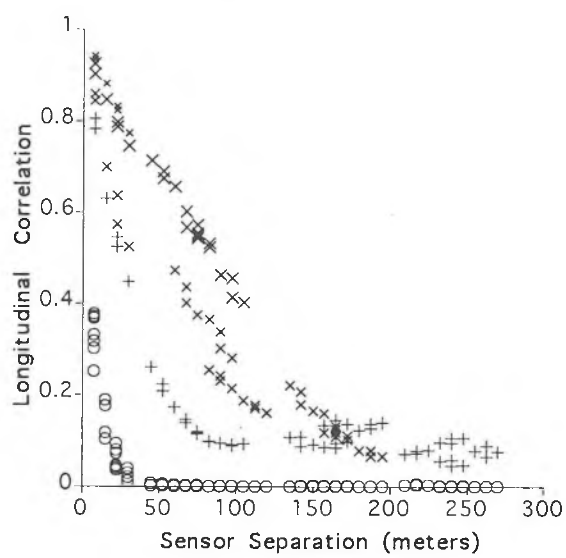

Fig. 3 Longitudinal Correlation