Proceedings of The Institute of Acoustics

THE EFFECT OF WIND TURBULENCE ON SOUND PROPAGATION

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INTRODUCTION

As part of a programme of measurements to investigate the mechanism of turbulent scattering, specifically in relation to its effect on the performance of barriers, measurements have been made in connection with sound propagation over open short-mown grassland in the absence of a barrier. Since the overall purpose has been to acquire information about instantaneous processes rather than dealing with average trends, an experimental arrangement has been developed to allow observations to be made on the propagation of individual noise bursts whilst permitting the concurrent sampling and recording of selected meteorological parameters.

EXPERIMENTAL METHOD

Short bursts of octave-band noise were recorded at two distances from a folded-horn loudspeaker. B&K type 4165 ½" microphones were used in association with conventional measurement amplifiers and automatically selected octave-band filters. The received noise bursts were digitised and stored using a modified dual-channel Kemo type AM4096 analogue memory with a capacity of 4K samples per channel.

The digitised data were returned under programme control to a microcomputer supervising the experiment and the rms value of each signal was evaluated in software. The rms values were compared with a previously taken calibration signal which had been processed in an identical way, and the resulting levels stored for subsequent off-site analysis.

To provide the desired meteorological information a specially designed digital wind-direction meter was used to produce an output signal corresponding to wind direction with an angular resolution of 2°. Additionally a DISA type 55D05 hot wire anemometer and associated circuitry produced a voltage related to instantaneous wind speed; this voltage was also digitised, without linarisation, and stored for subsequent transfer back to the microcomputer using a Datalab type DL901 transient event recorder with a capacity of 1K samples. Air temperature was also recorded.

The acoustical data relating to the passage of each noise burst and the meteorological data for the instant of propagation were stored on floppy disk for later transfer to a DEC20 main-frame computer.

EXPERIMENTAL DETAILS

The folded-horn loudspeaker was found experimentally to have a cut-off frequency of 160Hz. The octave-band centre frequencies selected for measurement were those in the range 250Hz to 4kHz and an equalising network ensured that a level of approximately 85dB was maintained at a range of 5m throughout this frequency range.

The duration of the measured noise burst was effectively set at 28ms; this was the time taken to fill each channel of the analogue memory at a sampling interval of 7µs. In practice a noise burst was initiated immediately following the detection of a satisfactory background noise level. The two channels of the analogue memory were triggered independantly upon detection of their respective received signals; the noise burst was terminated when the memory channel for the further microphone was full.

The anemometer signal was digitised with a sampling interval of 50µs; the wind velocity data captured thus described conditions during an interval of 50ms from the moment of initiation of the sound burst.

RESULTS

The loudspeaker and microphone were all placed at a height of 1.4m above a surface of close-mown grass. One microphone was maintained at a distance of 4.8m from the source whilst the second was placed variously at distances of 9.6m, 19.2m and 28.8m. The microphones were provided with 140mm diameter wind muffs.

The measurement site was free of vertical obstructions at any distance of significance in relation to the measurement method adopted. The weather during the days concerned was fine and dry. Occasional aircraft in the vicinity were the main cause of interruptions to the measurement programme through the generation of unacceptable background levels.

Calculated sound pressure levels for each microphone were stored for each noise burst transmitted.

By way of an attempt at a quantitative measure of turbulent intensity, the arbitrary but computationally convenient ratio of the rms wind velocity to the mean wind velocity (calculated for the interval for which the anemometer voltage was captured) was evaluated. This was designated the turbulence number TN; to provide some distinction from other measurements, not reported here and which were taken with a 500ms total capture time, the parameter was written TN_{50}. In interpreting this quantity it should be noted that the stated bandwidth of the anemometer exceeded 10kHz.

TN_{50} values were calculated using the following relationship based on King's Law.

$$TN_{50} = \frac{4vV}{V^2 - V_o^2} \times 100\% \qquad (1)$$

where V = mean anemometer output voltage

V_o = zero-flow output voltage

and v = standard deviation of the output voltage

ANALYSIS

Evidence was sought of a correlation between acoustic propagation parameters and any one of a number of meteorological parameters evaluated for the instant of propagation. This was done both by the conventional methods of statistical analysis and also be seeking visible evidence from a variety of graphical representations.

One seemingly significant and interesting representation emerged when the measured acoustic level differences between the two microphones were plotted against TN_{50}. The results of this exercise are shown in figures 1 to 5 for the five frequency bands and the three geometries at each frequency. Each point represents the measurement of one noise burst.

It appears from this that the scatter in measured level differences is high and frequency dependant at low values of TN_{50}. The low turbulence limit of scatter is observed to be greatest at 250Hz, falling as frequency rises to 1kHz and rising at frequencies above this.

In attempting to intrpret the information carried in figures 1 to 5 it should be noted that the mean values about which the observed level differences are scattered are broadly in line with the sort of variation to be expected from the measurements of, e.g. Rasmussen [1] if the present use of octave-bands is allowed for. It is clear however, that the effect of any turbulent scattering as far as this effects observed level differences, is a complicated issue. A given degree of turbulent scatter may be expected to produce a relatively large fluctuation in measured level differences when, by virtue of the effect of detailed ground reflection conditions for example, the actual observed value of level difference is particularly small.

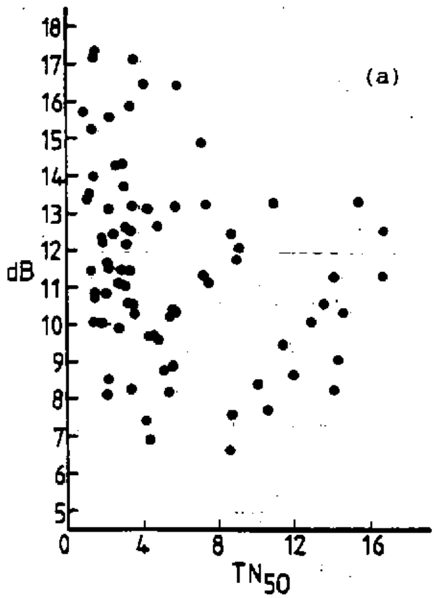
An inspection of the standard deviation of the levels measured at each of the two microphones is also interesting. For close microphone positions and for low frequencies, these levels exhibit a close resemblance to those expected on the basis of $1/2\sqrt{BT}$ alone. This standard deviation rises at frequencies of 1kHz and above.

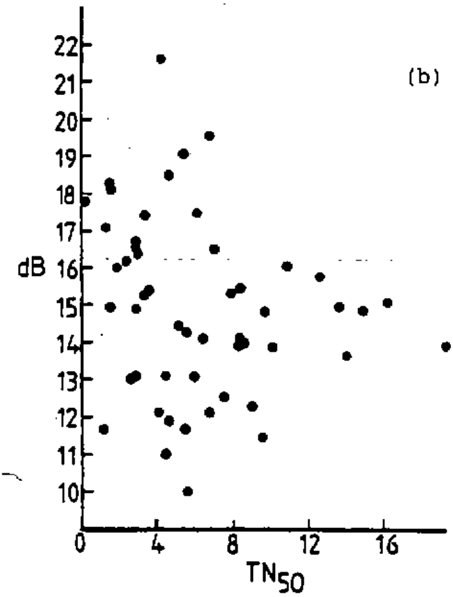
This rise leads to an observed minimum in standard deviation at approximately 2kHz that increases at a rate of .03dB per metre with increasing microphone distance.

Thus at this stage of the analysis it is reasonable to conclude that turbulent scattering enhances the fluctuation in sampled levels which are from $1/2\sqrt{BT}$ considerations to a degree which increases with increasing frequency and acoustic path length. Additionally, and for reasons that are not presently clear, there seems to be some evidence that turbulent scattering reduces with increasing turbulent intensity, at least as measured by an admittedly arbitrary parameter; the medium of propagation, appears to become increasingly homogeneous.

REFERENCE

[1] Rasmussen, K.B., J.Sound Vib., Vol 78, 247-255, 1981





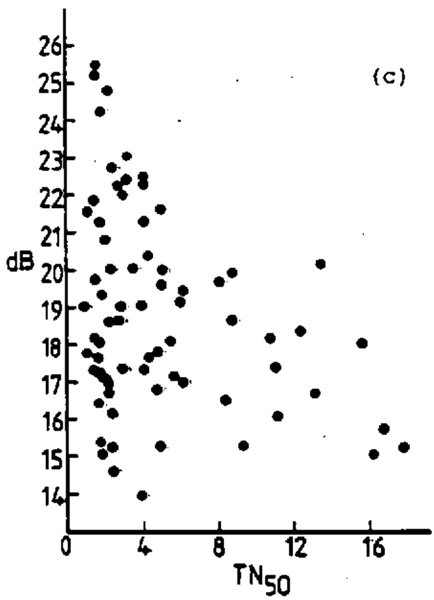


Fig 1. Level Difference vs. TN_{50}

Octave band noise
Centre frequency 250Hz

Near microphone at 4.8m

(a) Far microphone at 9.6m
(b) Far microphone at 19.2m
(c) Far microphone at 28.8m

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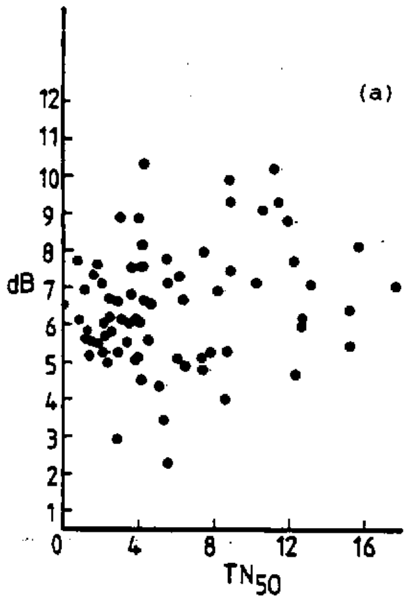
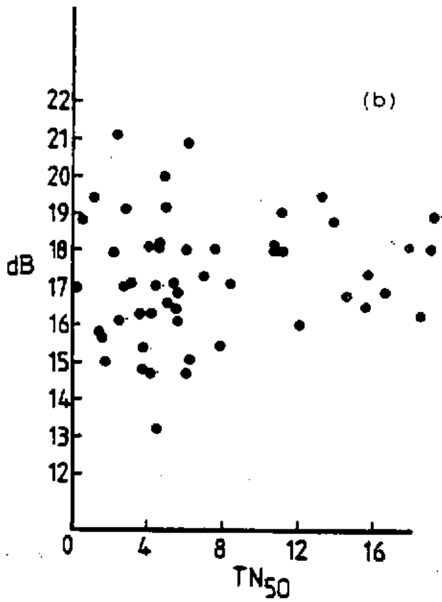




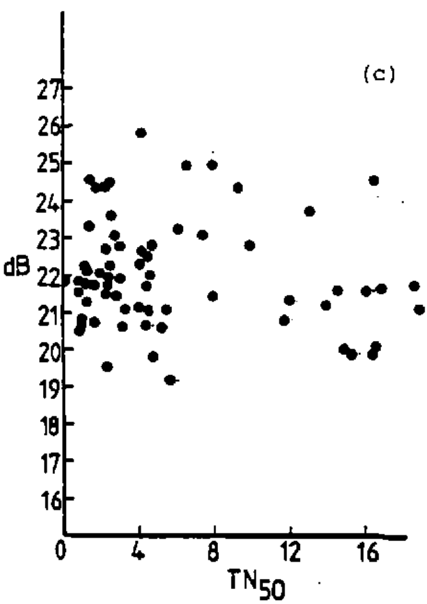
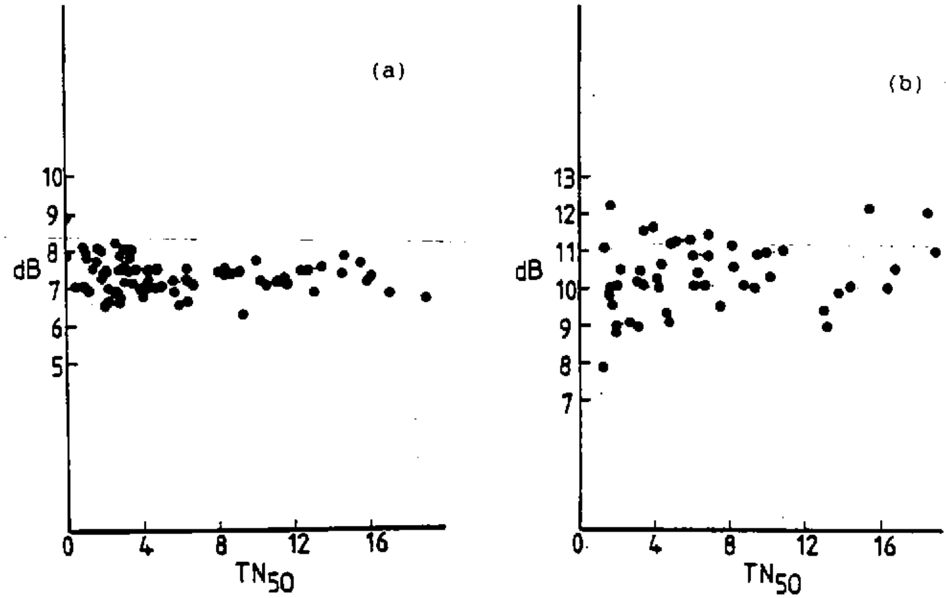


Fig 2. Level Differences vs. TN_{50}

Octave band noise
Centre frequency 500Hz

Near microphone at 4.8m

(a) Far microphone at 9.6m
(b) Far microphone at 19.2m
(c) Far microphone at 28.8m



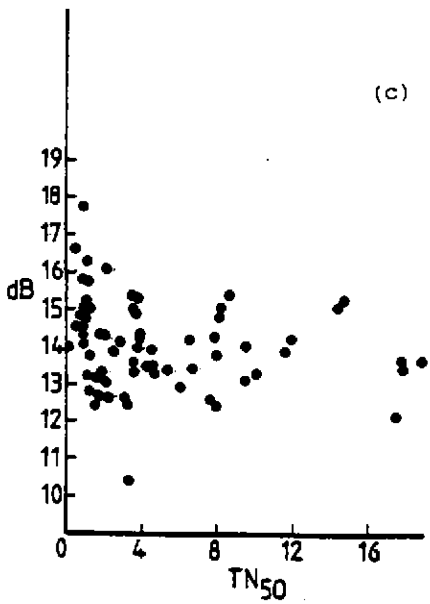


Fig 3. Level Differences vs. TN_{50}

Octave band noise

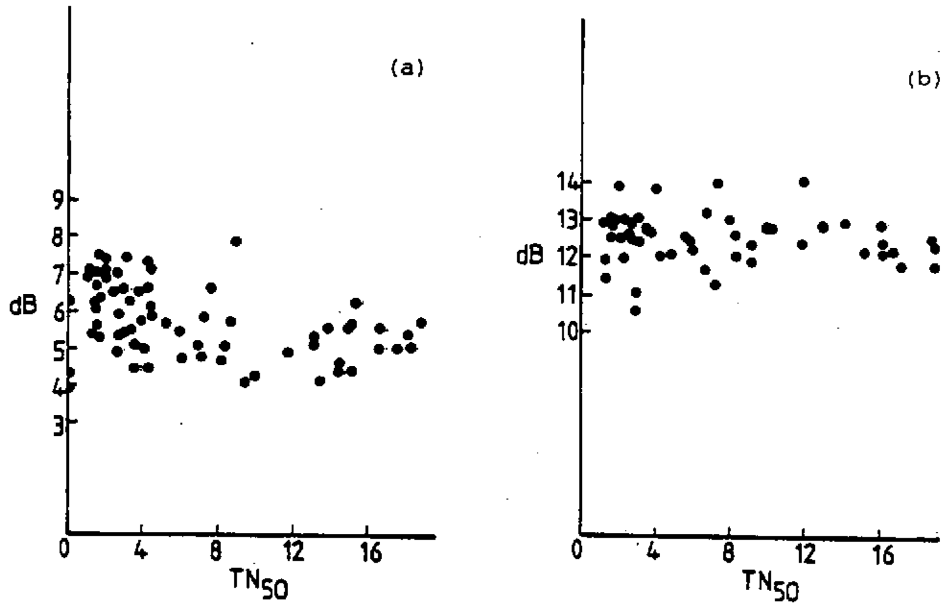
Centre frequency 1kHz

Near microphone at 4.8m

(a) Far microphone at 9.6m

(b) Far microphone at 19.2m

(c) Far microphone at 28.8m



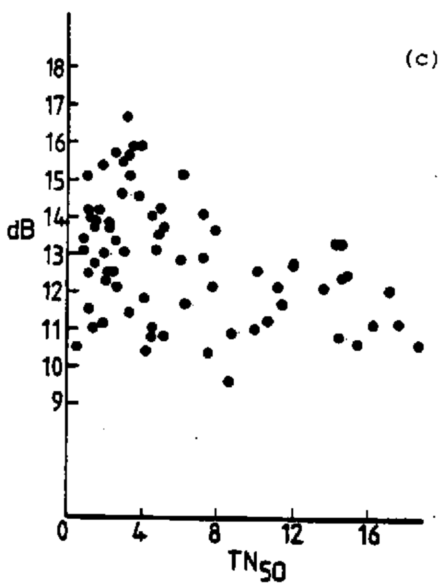


Fig 4. Level Differences vs. TN_{50}

Octave band noise

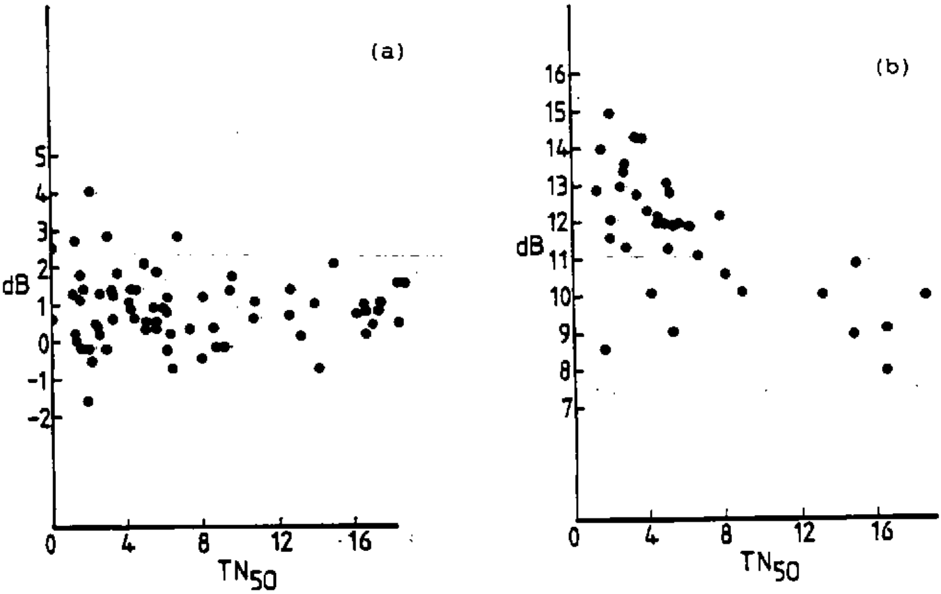
Centre frequency 2kHz

Near microphone at 4.8m

(a) Far microphone at 9.6m

(b) Far microphone at 19.2m

(c) Far microphone at 28.8m



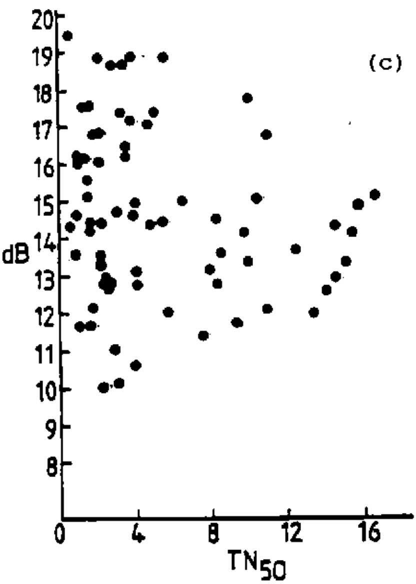


Fig 5. Level Differences vs. TN_{50}

Octave band noise

Centre frequency 4kHz

Near microphone at 4.8m

(a) Far microphone at 9.6m

(b) Far microphone at 19.2m

(c) Far microphone at 28.8m