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DEGRADATION OF VARIOUS TYPES OF SHADOW REGIONS DUE TO TYPICAL ATMOSPHERIC TURBULENCE

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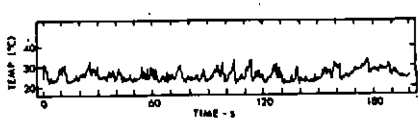
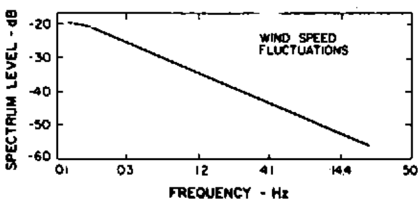
The atmosphere is an unsteady medium with significant random variations of temperature and wind velocity. During the daytime these inhomogeneities are normally much larger than is generally appreciated. Shown in Fig. 1 is a typical record of temperature 1 m above a flat ground surface on a sunny day. Fluctuations in temperature of 5°C which last several seconds are common and 10°C not uncommon. Similarly the standard deviation in wind velocity is commonly 1/3 of the average value. A typical spectrum of the wind velocity fluctuations is shown in Fig. 2. Frequency refers to the Fourier components and is inversely proportional to eddy size. Hence low frequencies correspond to the larger eddies created when the turbulence is formed in the atmosphere. These large eddies then break down into progressively smaller sizes (higher frequencies) until the energy is finally dissipated by viscosity[1].

Fig. 1. Typical chart record of the fluctuating temperature



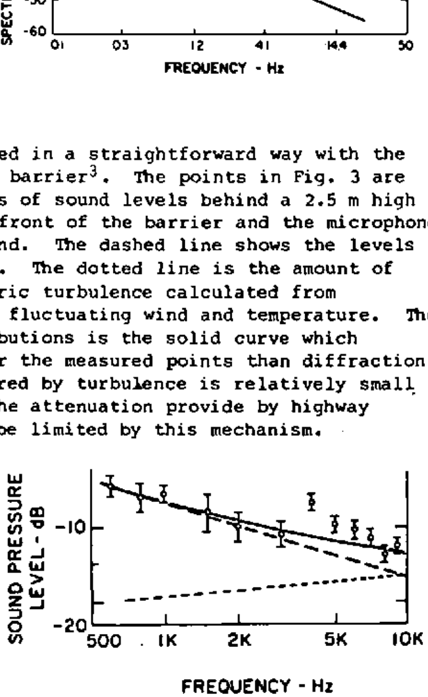
Historically it was speculated that atmospheric turbulence was responsible for sound attenuation in excess of inverse square law. However this was before several other mechanisms such as atmospheric absorption and the ground effect were elucidated[2]. It has now been shown that attenuation by turbulence can usually be neglected in practice except for highly directional fields such as a collimated acoustic beam. Instead work is now starting to show why, and to what extent, turbulence degrades various types of shadow regions producing levels that are higher than would be expected from coherent theory.

Fig. 2. Typical measured spectrum of the wind velocity fluctuations (dB re 0.56°C)



This can first be illustrated in a straightforward way with the acoustical shadow behind a noise barrier[3]. The points in Fig. 3 are carefully controlled measurements of sound levels behind a 2.5 m high barrier. The source is 10 m in front of the barrier and the microphone 30 m behind it, both on the ground. The dashed line shows the levels expected from diffraction theory. The dotted line is the amount of energy scattered by the atmospheric turbulence calculated from simultaneous measurements of the fluctuating wind and temperature. The sum of the two calculated contributions is the solid curve which provides a better explanation for the measured points than diffraction theory alone. The energy scattered by turbulence is relatively small and at higher frequencies, but the attenuation provide by highway barriers barriers will probably be limited by this mechanism.

Fig. 3. Points are measured levels behind a barrier. Dashed curve is diffraction theory, dotted curve is scattering theory and solid curve is the sum of both energies.



Secondly, shown in Fig. 4 are measurements of the propagation of sound between a point source and a microphone 50 m apart, each 1.2 m above a plane asphalt surface[4 5]. The dashed curve shows the interference due to path-length difference between direct and reflected waves. The solid curve is calculated using a theory of propagation in a turbulent atmosphere using simultaneous measurements of the fluctuating wind and temperature. Both theory and measurements clearly show that normal daytime turbulence destroy the interference shadow.

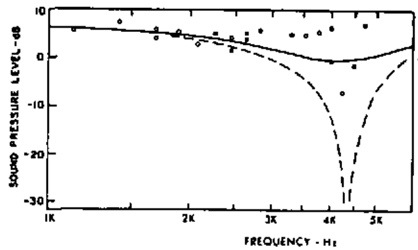


Fig. 4. Points are measured levels above asphalt. Dashed curve is coherent theory and solid curve is theory for propagation in turbulence.

A third situation can be illustrated by the propagation of soun above a finite impedance boundary[6]. The points in Fig. 5 are measurements by Parkin and Scholes of the ground effect for jet noise propagating across a grass covered field to a distance of 600 m. The dashed curve is calculated using coherent acoustical theory and includes the familiar direct, reflected, ground and surface waves. The solid curve is calculated by including the effect of typical daytime turbulence. Turbulence degrades the ground shadow by several decibels at frequencies greater than a few hundred hertz.

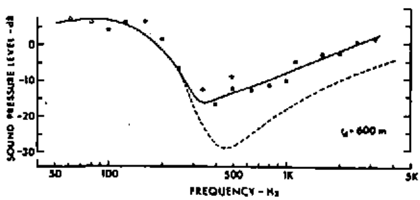


Fig. 5. Points are measured levels above grass. Dashed curve is coherent theory and solid curve is theory for propagation in turbulence.

A fourth shadow which is degraded by turbulence is that resulting from refraction[7]. Close to the ground the temperature and wind velocity vary strongly with height. On a sunny day the air near the ground is warmer than higher up. Similarly because of drag at the surface the wind velocity is lower near the ground. Thus when sound propagates over a warm ground and/or upwind the rays refract upward producing a shadow near the ground into which no sound can penetrate directly. The solid curve in Fig. 6 is an approximate prediction of the diffracted energy below the shadow boundary and shows a strong dependence on height. The points are measured sound levels at a distance of 200 m. A preliminary estimate of the scattered sound energy into the shadow by turbulence is illustrated by the short dashed curve. This situation is, in principal, similar to the barrier case, however it is less well understood.

In summary atmospheric turbulence is responsible for enhancing sound levels but only in regions where the levels have already been reduced according to coherent theory by phase relations.

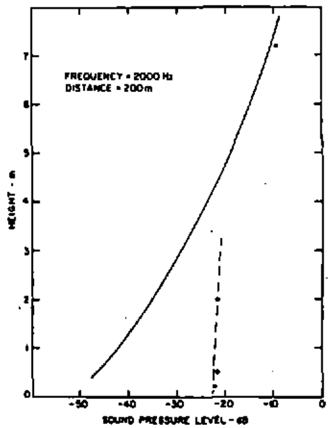


Fig. 6. Points are measured levels in refractive shadow. Solid curve is coherent theory and dashed curve is a preliminary theory for scattering by turbulence.

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