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The calculation of overground sound propagation in the presence of wind and temperature gradients

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THE CALCULATION OF OVERGROUND SOUND PROPAGATION IN THE PRESENCE OF WIND AND TEMPERATURE GRADIENTS

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THE CALCULATION OF OVERGROUND SOUND PROPAGATION IN THE PRESENCE OF WIND AND TEMPERATURE GRADIENTS

1. NOTATION

		SI	*British*
$c(z)$	speed of sound as a function of height, z	m/s	ft/s
D	overground sound propagation distance	m	ft
f	frequency	Hz	Hz
H_r	height of receiver	m	ft
H_s	height of source	m	ft
J_0	Bessel function of zero order		
$k(z)$	wave number as a function of height, z	m^{-1}	ft^{-1}
P	transform of p [see Equation (3.3)]		
P_f	porosity factor		
p	acoustic perturbation pressure	Pa	lbf/ft^2
$T(z)$	absolute temperature as a function of height, z	K	K
$V(z)$	wind speed as a function of height, z	m/s	ft/s
x, y, z	Cartesian co-ordinates		
z_1	height of temperature measuring station	m	ft
z_2	height of wind speed measuring station	m	ft
δ	Dirac delta function		
γ	constant describing sound speed gradient [see Equation (3.7)]	m^{-1}	ft^{-1}
θ	angle between sound propagation direction and wind direction (see Sketch 3.1)	deg	deg
κ	variable of integration in Equation (3.3)		
σ	specific flow resistance per unit thickness	$kN\ s/m^4$	*
ω	circular frequency	rad/s	rad/s

* In the computer program, σ must be entered in SI units.

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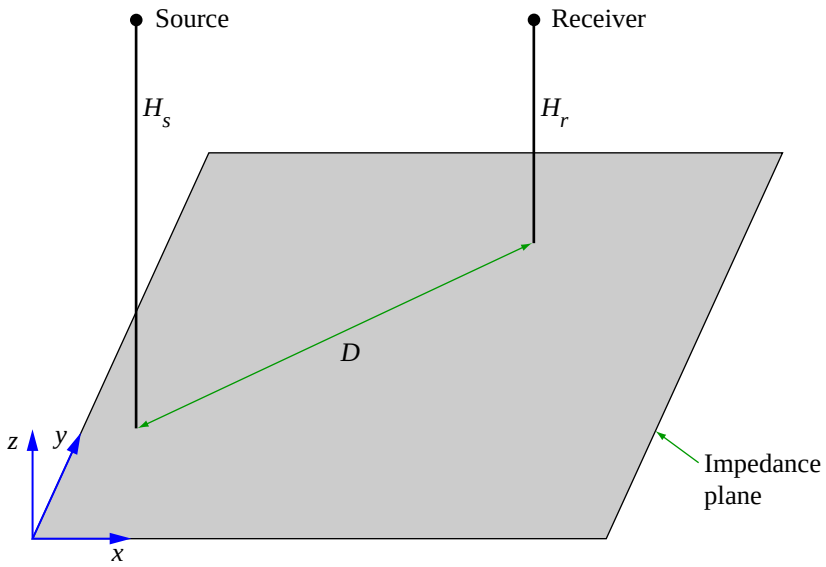
2. INTRODUCTION

Over the years, a number of theoretical models of outdoor sound propagation above an impedance plane in still atmospheric conditions have been developed, and accurate solutions may be obtained for still, homogeneous atmospheric conditions. One such method is given in ESDU 94035 (Reference 5).

This Item provides a means of estimating the effect of wind and temperature gradients on sound propagating between two points located above a flat impedance plane. The method is applicable for overground sound propagation, *i.e.* when source and receiver are relatively close to the ground, and includes the effect of ground reflection. The effect of wind and temperature gradients is estimated in the form of a difference spectrum, in one-third octave bands, which may be subtracted from a measured spectrum to give a free-field spectrum. The geometric representation of the source and receiver is shown in Sketch 2.1.



Sketch 2.1

Atmospheric effects on sound propagation may be broken up into three basic components. These are atmospheric absorption, wind and temperature gradient (*i.e.* variation of wind speed and temperature with height) effects and atmospheric turbulence. Atmospheric absorption is well understood and methods of estimating it are given in ESDU 78002 and ESDU 78003 (References 3 and 4). This component may be considered as an additional attenuating effect to basic spherical spreading. Atmospheric turbulence effects are not yet thoroughly understood although some preliminary investigations have been carried out. This Item considers the effect of wind and temperature gradients on sound propagation and does not take the influence of turbulence into account, the implications of which are discussed in Section 4.

The basic prediction method used in this Item was developed by Rasmussen (Derivation 1) and follows from Pridmore-Brown (Reference 2) and Pierce (Reference 5).

3. BASIC THEORY

In the case of a monopole point source above an impedance plane, the acoustic pressure satisfies the relationship

$$\nabla^2 p + k^2 p = -4\pi\delta(x)\delta(y)\delta(z - H_s)\,. \tag{3.1}$$

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If a vertical temperature or wind speed gradient is present, the effective sound speed (which accounts for both temperature and wind speed) will vary with height. Equation (3.1) may still be applied, but now,

$$k(z) = \omega/c(z)\,. \tag{3.2}$$

Assuming that the field is cylindrically symmetric around the z-axis, the solution for the acoustic pressure may be expressed as a Hankel transform

$$p = -2\int_0^\infty J_0(\kappa D)\ .\ P(z,\kappa)\ .\ \kappa\ .\ \mathrm{d}\kappa\,, \tag{3.3}$$

where $P\ (z,\kappa)$ denotes the transform of p.

In order to find a closed-form solution of Equation (3.3) it is necessary to make the assumption that the sound speed variation with height is linear.

The effects of wind and temperature gradients are considered through the resulting variation of sound speed with height. In SI units, the sound speed $c(z)$ at a height z is given by

$$c(z) = 20.05\sqrt{T(z)} + V(z)\cos\theta\,, \tag{3.4}$$

where $T(z)$ and $V(z)$ are the absolute temperature and wind speed at height z, and θ is the angle between the direction of interest and the wind direction (see Sketch 3.1). The wind speed at the surface is zero.

The method assumes a constant sound speed gradient exists just above the surface, which can be expressed as

$$c(z) = c(0)(1+\gamma z)\,, \tag{3.5}$$

where $c(0)$ is the speed of sound at the surface given by

$$c(0) = 20.05\sqrt{T(0)}\,, \tag{3.6}$$

$T(0)$ is the absolute temperature at the ground and γ is a constant which is given by

$$\gamma = \frac{c(z)-c(0)}{c(0)\ .\ z}\,. \tag{3.7}$$

If the heights at which temperature and wind speed are measured are different, say z_1 and z_2 respectively, then γ is given by

$$\gamma = \frac{c(z_2)-c(0)}{c(0)\ .\ z_2}\,, \tag{3.8}$$

where $c(z_2) = 20.05\sqrt{T(z_2)} + V(z_2)\cos\theta\,,$ (3.9)

and $T(z_2) = T(0) + (z_2/z_1)[T(z_1) - T(0)]\,.$ (3.10)

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