



ESDU 89036

Issued October 1989
With Amendments A and B
July 1992
Re-issued November 2012

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

Associated software: ESDUpac A8936



Endorsed by
The Royal Aeronautical Society

AVA Documents
Document Sharing Hub

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Item was monitored and guided by the following Jet Noise Working Party on behalf of the Aircraft Noise Committee:

Mr W.K. Boyd	— Rolls-Royce plc, Derby
Dr M.J. Fisher	— Institute of Sound and Vibration Research, University of Southampton
Dr D.I. Page	— Energy Technology Support Unit, Harwell
Mr R.C. Payne	— National Physical Laboratory, Teddington
Mr S. Rogers	— British Aerospace (Commercial Aircraft) Ltd, Hatfield
Mr J.D. Turton	— Meteorological Office, Bracknell
Mr C.J. Winfield	— Rolls-Royce plc, Derby.

The Aircraft Noise Committee, first met in 1971 and now has the following membership:

Chairman	
Mr R. Pinker	— Independent
Members	
Mr S. Arrowsmith*	— European Aviation Safety Agency (EASA), Germany
Mr W.D. Bryce	— Bryce Research (Member Emeritus)
Ms C.L. Burley*	— NASA, Langley Research Center, USA
Mr P.J. Hopkins	— Rolls-Royce plc, Derby
Dr I. Imamura*	— Japan Aerospace Exploration Agency, Japan
Prof. P. Joseph	— Institute of Sound and Vibration Research, Southampton
M. P. Lempereur	— Airbus France, Toulouse, France
Mr C.J. Mead	— QinetiQ, Farnborough
Mr D. Patience	— BAE SYSTEMS, Farnborough
Mr W.J. Readman*	— European Aviation Safety Agency (EASA), Germany
Dr D. Rhodes	— Civil Aviation Authority, Environmental Research & Consultancy Department (ERCD), London
Mr D.C. Riordan	— Bombardier Aerospace Short Brothers plc, Northern Ireland

* Corresponding Member

The construction and subsequent development of the Data Item were undertaken by

Dr C.B. Chinoy	— Head of the Aircraft Noise and Structural Dynamics Group.
----------------	---

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

CONTENTS

	Page
1. NOTATION	1
2. INTRODUCTION	2
3. BASIC THEORY	2
4. ACCURACY AND LIMITATIONS	4
5. COMPUTER PROGRAM	7
6. DERIVATION AND REFERENCES	8
6.1 Derivation	8
6.2 References	8
7. EXAMPLE	9
8. INPUT FILE	11
APPENDIX A – THEORY	12
A.1 ADDITIONAL NOTATION	12
A.2 CALCULATION OF SOUND PRESSURE	13
A.3 GROUND IMPEDANCE	14
A.4 DERIVATION AND REFERENCES	15
A.4.1 Derivation	15
A.4.2 References	15

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

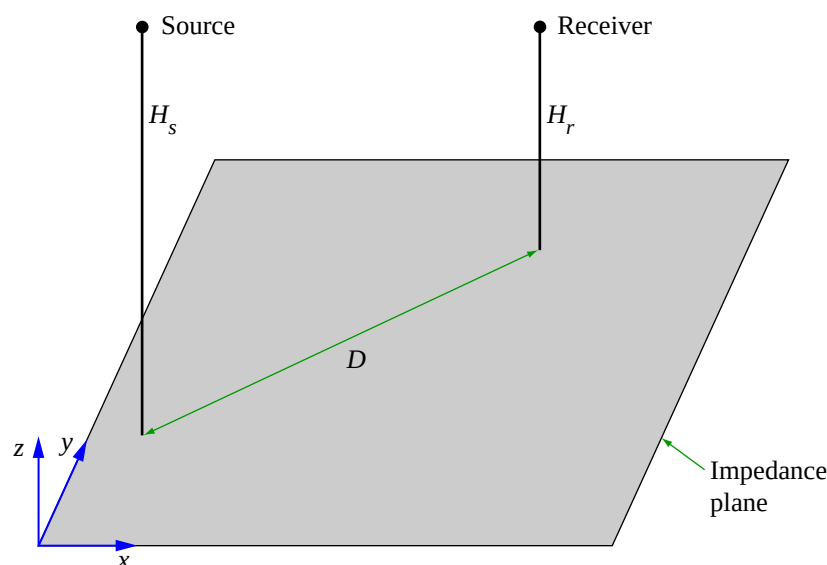
* In the computer program, σ must be entered in SI units.

Issued October 1989
With Amendments A and B, July 1992 – 15 pages
Re-issued November 2012 – 15 pages

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

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

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,

$$k(z) = \omega/c(z). \quad (3.2)$$

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

$$p = -2 \int_0^\infty J_0(\kappa D) \cdot P(z, \kappa) \cdot \kappa \cdot d\kappa, \quad (3.3)$$

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

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

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

$$c(z) = c(0)(1 + \gamma z), \quad (3.5)$$

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

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

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

$$\gamma = \frac{c(z) - c(0)}{c(0) \cdot z}. \quad (3.7)$$

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

$$\gamma = \frac{c(z_2) - c(0)}{c(0) \cdot z_2}, \quad (3.8)$$

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

$$\text{and } T(z_2) = T(0) + (z_2/z_1)[T(z_1) - T(0)]. \quad (3.10)$$