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SOUND ATTENUATION OVER LONG RANGE GROUND-TO-GROUND PROPAGATION PATHS

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ABSTRACT
Rolls-Royce plc, Derby were commissioned by ESDU International plc to perform a series of tests to measure sound attenuation over distances up to 1.5 km. The tests were funded by government departments and industry in the UK. The sound source was a Rolls-Royce Avon single-stream jet engine. Weather data were measured at three stations. A balloon traverse was also carried out to measure atmospheric data profiles. The first stage of the analysis has been completed. A method of predicting the attenuation of sound as it propagates through a homogeneous atmosphere has been issued as a "Data Item" which is available commercially. The second stage of the exercise is the development and validation of a method that will predict sound attenuation in the presence of wind and temperature gradients. This paper describes the progress made so far and the path we intend to follow in the future.

1 - INTRODUCTION
Analysis of the data obtained from the Rolls-Royce tests allowed us to improve the existing ESDU ground-reflection correction procedure and also to incorporate it in a new Data Item (Reference [1]) that provides the user with a computerised method for predicting, in nominally still conditions, the attenuation of sound as it propagates between two fixed locations in the presence of a stationary noise source close to the ground. If the noise spectrum at one location is known, the method allows the user to estimate the noise spectrum at any other location. For example, with reference to Figure 1, the method allows the user to predict the attenuation of sound between any two locations, A and B. If the noise spectrum at location A is known, it is then possible to predict the noise spectrum at location B.
If the spectrum at location B is not known, the program calculates the attenuation in sound propagating from location A to location B.
The method considers the attenuation of sound due to spherical spreading, atmospheric absorption and the effect of ground-reflection and air turbulence. The method does not account for variations in sound velocity caused by wind and temperature gradients. The program calculates the A-weighted sound pressure level, dBA, the overall sound pressure level, OASPL and the perceived noise level, PNL, when appropriate, of the spectra at locations A and B.
The calculation procedure requires the input of the

- source-receiver geometry,
- air temperature, relative humidity and atmospheric pressure,
- impedance of the ground surface and the prevailing level of air turbulence.

2 - METHOD OF CALCULATION
The components of sound attenuation addressed are those due to:

- spherical spreading,
- atmospheric absorption

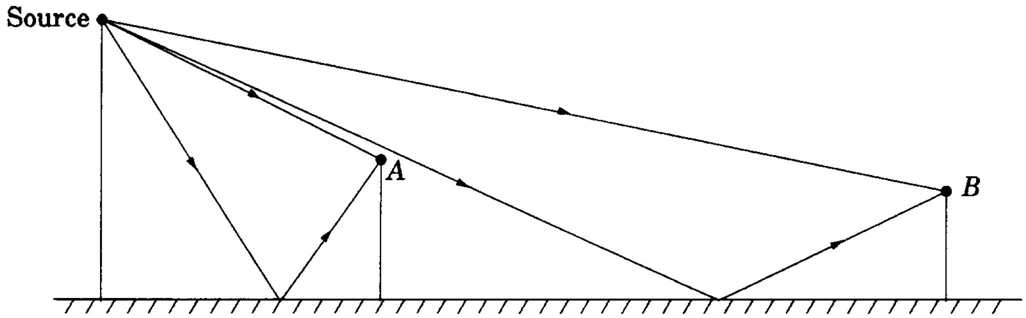

Figure 1: Source – receiver geometry.

- ground reflection with air turbulence effects.

The calculation of the first of these components is straightforward. For every doubling of distance from the noise source, the sound pressure level at the reception point drops by 6 dB.
The two other components are more difficult to calculate, and each of them is considered separately below. First, however, the basic method of calculating the sound attenuation between two points, for example A and B in Figure 1, is described.
By definition, the difference between a measured spectrum at a point located above the ground and the free-field spectrum at that point is caused by ground reflection effects.
If, at location A, the measured spectrum is denoted by MA, the free-field spectrum is denoted by $FB$and the ground reflection correction denoted by CA, then

$$MA = FA + CA$$

and similarly

$$MB = FB + CB$$

Then, the attenuation between points A and B can be expressed as

$$MA - MB = FA - FB + CA - CB$$

$FA-FB$ is the difference in free-field levels at locations A and B that can be attributed to spherical spreading and air absorption. $CA-CB$ can be calculated from separate calculations of the ground reflection correction at locations A and B.
If MA is known, then it is simple to obtain MB once $MA-MB$ has been evaluated.

2.1 - Atmospheric absorption
The atmospheric attenuation of sound over a frequency band is calculated by integrating discrete frequency attenuation values over the frequency range. If the noise spectrum for which attenuation is to be estimated is available, the spectrum slope is used to evaluate the band attenuation. If no spectrum is available then the band attenuation is calculated on the basis of assuming the spectrum to be that of white noise.

2.2 - Air turbulence
Air turbulence has an important effect on long range sound propagation. In this Data Item, the presence of air turbulence is taken into account by considering its effect on the coherence between the direct wave and the reflected wave.

2.3 - Ground reflection effects
Ground reflection effects are due to interference between the direct wave between a noise source and a receiver and the wave that reaches the receiver after being reflected off the ground. The phase relationship between the two waves which causes this interference is determined by the difference in path lengths between the direct and reflected waves, and the impedance of the ground material. In addition, air turbulence affects the coherence between direct and reflected rays and modifies the ground reflection effect.
In the theory used to calculate the ground reflection effect, spherical waves are broken down into a large number of plane waves. The plane wave sound pressure reflection coefficient, which is dependent on the

angle of incidence of the reflected wave and the ground impedance, can then be used. The prediction method also accounts for the effect of air turbulence.

Originally, the Delaney and Bazley single parameter model of ground impedance was used. Subsequently it was found that the Attenborough two-parameter model (Reference [2]) gave more accurate results and that is the one which is currently employed.

The equations used for calculating the ground reflection correction are given in Reference [3]. That Data Item permits the user to convert a free-field spectrum to a ground-reflection spectrum and *vice versa* for a particular source-receiver geometry.

3 - LIMITATIONS, RESULTS AND DISCUSSION

The method is applicable to point sources. If, however, propagation distances are such that the receiver can be considered to be in the geometric far-field of a distributed source, the method may still be used. As a rough guide, locations at distances from a jet nozzle greater than fifty times the nozzle diameter may be considered to lie in the far-field.

When no noise spectrum is available from which the slope required for the calculation of band attenuation may be obtained, a white noise spectrum is assumed.

The theoretical approach to the ground reflection correction assumes that the sound wave propagates through a still, homogeneous atmosphere with a spherically-divergent wave front from a point source. The effects of refraction due to wind and temperature gradients are not considered.

The theory assumes that the ground plane between source and receiver is flat. It also assumes that the sound source radiates equally strongly in the direction of both sets of direct and reflected rays. The propagation paths are assumed to be unobstructed by barriers.

Both source and receiver are assumed to be stationary.

It is obvious that the greater the accuracy with which the input parameters describe the particular situation under consideration, the higher will be the accuracy of prediction. To illustrate the quality of prediction one may reasonably expect, comparisons of sound pressure level differences between predictions and measurements over grassland during nominally still weather conditions are shown in Figures 2, 3, 4 and 5. The tick on the y-axis marked ISL denotes the attenuation due to spherical spreading alone.

Level differences at two reception points located 150 m and 760 m from a noise source for two different microphone heights are shown in Figures 2 and 3.

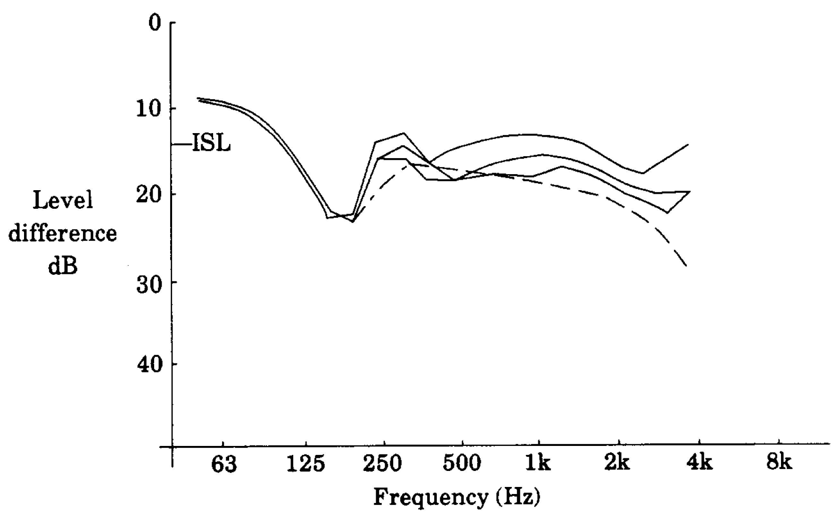

Figure 2: Predicted and measured level differences between 1.2 m high microphones, 610 m apart.

In Figures 4 and 5 the distant microphone is further away from the source at 1160 m. The source height is 2.16 m. The low microphones are at 1.2 m and the high microphones at 6.4 m. The prediction is shown by the dashed line and measured data by solid lines. Data shown were measured within a period of three minutes.

4 - FUTURE WORK

The second stage of the exercise is the development and validation of a method that will predict sound attenuation in the presence of wind and temperature gradients. Wind speed and temperature variations with height cause the speed of sound to vary with height. If it is assumed that the speed of sound is not

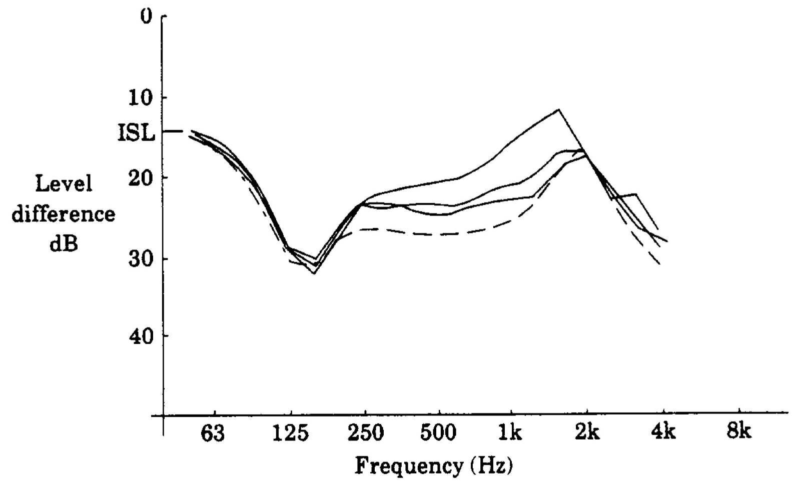

Figure 3: Predicted and measured level differences between 6.4 m high microphones, 610 m apart.

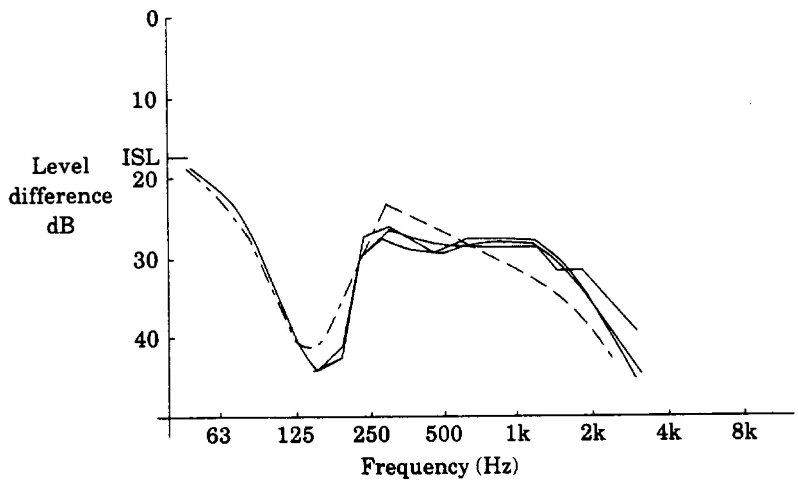

Figure 4: Predicted and measured level differences between 1.2 m high microphones, 1010 m apart.

range dependent, a Fast Field Program is an accurate and efficient method for predicting the propagation of sound above a surface.
Air turbulence is another important factor to consider. In the past its effect has been taken into account by considering its effect on the coherence between the direct and the reflected wave. When turbulence effects are included in the calculations carried out by the Fast Field Program, the basic efficiency of calculation is reduced considerably. However, considering the rate at which the rapidity of calculation is increasing this ought not to be a major cause for concern.
The development of this work was contracted out by ESDU to the Open University, and a Fast Field Program with turbulence effects has been developed by Prof. Attenborough and Dr Taherzadeh. The program has been written with an emphasis on accuracy rather than on computational time. Preliminary results look encouraging. After further validation has been carried out, this work will be issued in the form of a Data Item and associated computer program.

REFERENCES

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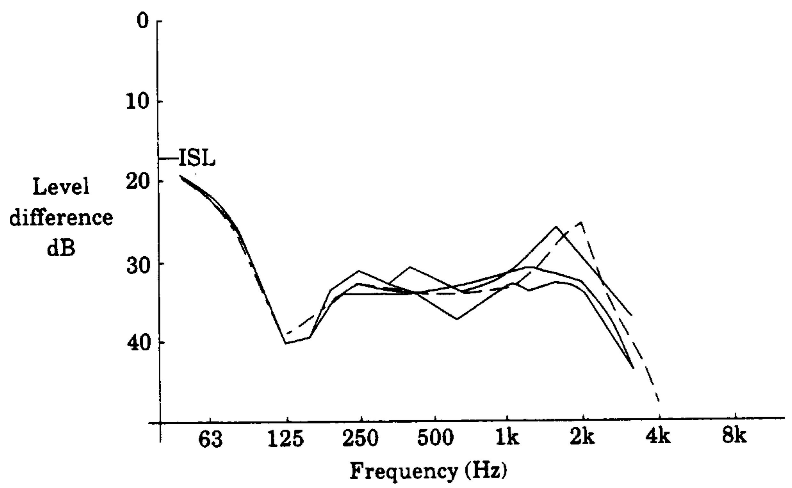

Figure 5: Predicted and measured level differences between 6.4 m high microphones, 1010 m apart.