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CALCULATION OF NOISE BARRIER PERFORMANCE IN A TURBULENT ATMOSPHERE BY USING SUBSTITUTE SOURCES ABOVE THE BARRIER

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ABSTRACT

A model is presented that can be used for calculating the sound reduction by a noise barrier in a turbulent atmosphere. The field due to the acoustic source is substituted by a distribution of sources above the barrier (here called substitute sources). The mean power at the receiver is calculated as line-of-sight propagation through a turbulent atmosphere from all substitute sources using a mutual coherence function. In this study the strengths of the substitute sources are calculated using the Kirchhoff approximation and a two-dimensional geometry. The calculated results show good agreement with those from using a parabolic equation method.

1 - INTRODUCTION

The presentation of the model held here is based on a paper with the same title submitted to Acustica [1], to which the reader is directed for a more complete presentation.

Screens and buildings along the roadside are used as noise barriers for reducing the traffic noise in residential areas. For a good prediction of the performance of noise barriers, the non-homogeneous nature of the outdoor air is needed to be taken into account.

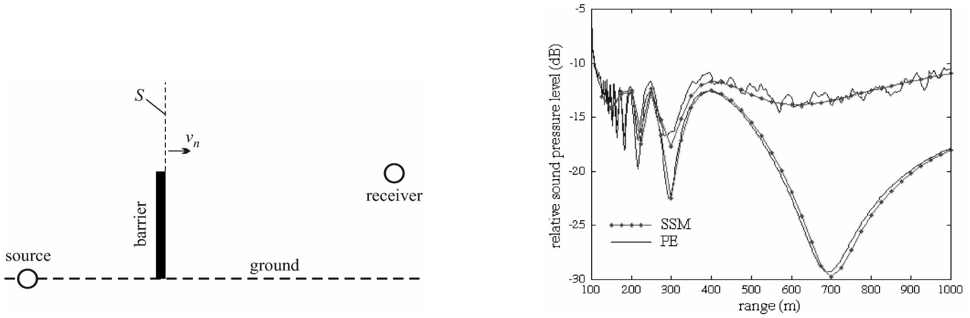
In terms of physical modelling, the problem situation with a noise barrier in an outdoor environment can be seen as consisting of two interacting processes: diffraction (due to the barrier) and sound propagation in an inhomogeneous medium. A direct numerical solution of the whole problem would in general be very expensive computationally (using e.g. a finite element method), and therefore a model is preferable where the two processes can be separated to some extent, without too large approximations. Two previously used models are a parabolic equation (PE) approach and one based on the scattering cross-section for an inhomogeneous atmosphere [2].

In this paper a prediction model is presented that is based on the Rayleigh integral. The model is not limited to low angles, as the PE is. Moreover, it does not demand a step-wise solution over distance, as the PE does, but could directly produce a result for a given geometry and frequency, and also it is numerically faster than the PE. Compared to scattering cross-section calculations it is much slower, but is not limited by the single-scattering approximation.

The approach is that the field at a receiver, due to a source, can be described as a superposition of fields from a distribution of sources on a surface located between the source and the receiver. The surface will here be called the substitute surface, and the sources on it substitute sources. (See Figure 1.) If the substitute surface S is located between the barrier and the receiver, there will be a free path from all substitute sources to the receiver, and the calculation of the sound propagation along the free path is possible for various types of inhomogeneous atmosphere. Here, a mutual coherence function (MCF) for a turbulent atmosphere is applied.

In this model the turbulent atmosphere is assumed to cause an increased noise level behind the barrier due to a decorrelation of the contributions from the substitute sources. This implies that, in the absence of turbulence, the contributions from the substitute sources must be interfering negatively.

The strengths of the substitute sources can, as a first approximation, be calculated as for a barrier in a homogeneous atmosphere. This approximation would be acceptable for weak inhomogeneity (a weak



(a): Geometry. **(b):** Results.

Figure 1: The two upper curves show the sound field behind the barrier for a turbulent atmosphere using SSM and PE; the two lower curves are for a non-turbulent situation.

turbulence) and if the distance from the source to the barrier is short compared to the total source-receiver distance.

2 - RESULTS

The surface of integration S is placed so that it coincides with the barrier's surface toward the receiver, as shown in Figure 1. The source strengths on the substitute surface S above the barrier is the velocity in normal direction. On the barrier surface the velocity is zero. The Kirchhoff approximation is used which means that only the free field contribution to the velocity is considered; the field due to the insertion of the barrier is neglected. The Kirchhoff approximation is in general valid when the distances from source and receiver to the screen are large compared to the height of the screen, i.e. for small diffraction angles. It should be noted that, strictly, this only holds for a semi-infinite screen. In real cases the field diffracted at the screen edge might be reflected in a ground surface and diffracted again at the edge, and thereby influence the field at the receiver. These higher-order diffraction terms increase in strength when the screen height is reduced. Therefore, the error when using the Kirchhoff approximation (or other models) for a screen on ground can be substantial for very low screens in comparison to the acoustic wavelength.
The expected power at the receiver of the sum of the waves propagated through the turbulent atmosphere from all the substitute sources is calculated by using a mutual coherence function (MCF) for a random medium. Here, a turbulent atmosphere is described by an index of refraction with a fluctuating part which follows a Gaussian correlation function with the standard deviation $\mu_0^2 = 3{\cdot}10^{-6}$ and the correlation length l=1.1 m. The MCF can then be written

$$\Gamma\left(L,\rho\right) = \exp\,\left[-\sqrt{\pi}\mu_0^2 k^2 L l\left(1-\frac{\Phi\left(\rho/l\right)}{\rho/l}\right)\right], \tag{1}$$

where k is the wave number, ρ the transversal distance between two sources, L the longitudinal distance, and $\Phi\left(z\right) = \int_0^z \exp\left(-u^2\right) du$.
For N discrete source contributions p the mean square pressure amplitude can be formulated as [3]

$$\left\langle |p|^2 \right\rangle = \sum_{i=1}^{N} |p_i|^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} |p_i p_j| \cos\left[\arg\left(\frac{p_j}{p_i}\right)\right]\Gamma_{ij} \tag{2}$$

Here, the free space Green's function is used. Some other Green's function could be used if it suits the situation better. For instance, a sound speed gradient that causes a curving of the sound paths can be described by an appropriate Green's function, obtained analytically, numerically, or by measurements. Other turbulence models than the Gaussian could be used, and this would then lead to different mutual coherence functions.
For a reflection in a ground surface, the maximum separation distance h between the two paths is used as ρ in Equation 1. For the coherence between the direct wave from one source and the ground reflected wave from another source, the transversal separation between the two sources is added to h to give the value of ρ used in Equation 1.
The results are compared with those from using a PE method [2]. The source is located on the surface of a hard ground 100 m from a thin screen and the receiver is at the height of the screen edge (10 m). The mean acoustic power is calculated for receiver ranges up to 1000 m (horizontal distance from the

source). In the PE calculations, 50 realisations of the turbulent atmosphere were used for the estimation of the mean power.

The maximum height used for the substitute sources was 250 m. Artificial damping was introduced from half that height to decrease the small oscillations in the solution when the receiver distance is varied. The strengths of the substitute sources above that height were multiplied by the factor $\exp\left(-a * (y - 125)\right)$, with a=0.05 m^{-1} and y the height. The vertical discretisation for the substitute sources was constant with five points per acoustic wavelength.

The calculated results are presented in Figure 1 as the sound pressure level relative to the pressure without the screen, i.e. the negative of insertion loss. The calculations using the substitute-sources model (SSM) are made each 25 meters in range, and the results are plotted as solid lines with circular marks. The PE calculations are plotted as solid lines. The results for a turbulent atmosphere have been plotted together with the results for a homogeneous (i.e. non-turbulent) atmosphere, and the two highest curves show the results for the turbulent atmosphere using the two different models.

The model using substitute sources gives results that show a good overall agreement with the PE calculations, and the results show a significant influence of turbulence. Other situations than the one shown here have also been investigated and the agreement between the two methods was good in general. For a situation at the frequency 1000 Hz, however, the two models give results that differ by about 2 dB. The cause for this can be a focusing effect in the PE calculations for situations in a turbulent atmosphere, without a barrier, and a source on a hard ground. For a fuller discussion see [2].

For future work it would be of interest to extend the model to three dimensions, with a point source and a three-dimensional turbulence. Also to take into account the correct diffraction above the barrier would be of interest to try, i.e. to not use the Kirchhoff approximation. Moreover, it could be possible to include in the model a thick barrier of finite length, a finite impedance ground, a sound speed profile, and an anisotropic and inhomogeneous turbulence.

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