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NORD 2000. STATE-OF-THE-ART OVERVIEW OF THE NEW NORDIC PREDICTION METHODS FOR ENVIRONMENTAL NOISE

J. Kragh

DELTA, Building 356, Akademivej, 2800, Lyngby, Denmark

Tel.: +45 45 93 12 11 / Fax: +45 45 93 19 90 / Email: jk@delta.dk

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ABSTRACT
A Nordic project is aiming at a new generation of methods for predicting various types of environmental noise. The project is scheduled for 1996−2000 and is financed by the Nordic Council of Ministers and by the Nordic environment and traffic authorities. The project is carried out by DELTA, by SINTEF Telecom & Informatics, and by SP Swedish National Testing and Research Institute. Sound propagation models based on geometrical ray theory and on diffraction theory were developed for calculating 1/3-octave band attenuation in a homogeneous atmosphere. The combined effect of ground and single or multiple noise barriers were dealt with as well as the effect of rough ground surfaces, non-flat terrain, and terrain consisting of combinations of different types of ground. Also, the effect of reflection from obstacles and scattering by objects such as buildings or vegetation can be calculated. The models have been extended to include the effect of various weather conditions according to the so-called 'heuristic model concept', assuming the sound speed gradient to vary linearly with the height above the ground. Comparison between results of measurement and calculation shows good agreement although further model adjustment is foreseen during 2000. The paper aims at giving an overview. A detailed summary can be found in [1], while special features are presented in these proceedings [2] − [5].

1 - BACKGROUND, GOALS, AND DELIMITATION
A new generation of environmental noise prediction methods shall be built up, utilizing results of research and development that has taken place since the first Nordic prediction methods were published in the 1970s and early 1980s.

The idea is to develop basic sound propagation models and to build up source-related prediction methods for any kind of environmental noise source, e.g. road, rail, and air traffic, all applying the same propagation models.

The ambition is to arrive at models valid for any terrain profile consisting of any combination of ground surface types (acoustic impedance), and to avoid the requirement of having skilled users interpret the terrain and decide how to represent it in the calculation. Instead, the intention is to make a computer program able to do the predictions solely based on digital elevation data and information on the type of surface. Similarly, the ambition is to provide models for predicting noise levels under any 'regular' weather condition.

The range of frequencies has been specified to be 25 Hz − 10,000 Hz. The ambition is to cover distances up to 1000 m with 'good' accuracy, and distances 1000 m to 3000 m with 'acceptable' accuracy. The project does not deal with propagation over larger distances.

2 - BASIC MODELS
Existing theory and prediction methods were looked at in a search for suitable models. Among other 'empirical' models ISO 9613-2 was looked at and found insufficient, e.g. to deal with the effect of ground on the propagation of noise from low sources such as road traffic and high sources such as aircraft and wind turbines. It was decided that in the new propagation models the ground effect should be calculated

by algorithms from geometrical ray theory and the effect of barriers on the ground by algorithms from diffraction theory combined with geometrical ray theory.

The new propagation models will involve direct application of theory algorithms in frequency band calculations. Such direct application of algorithms from theory in the Nordic prediction methods will be a novelty. In the present and past Nordic prediction methods only approximate or empirical solutions have been used because theoretical solutions were too time-consuming or too complicated for 'manual' calculation. With the availability nowadays of personal computers and the rapid growth in their calculation speed, there seems to be no urgent need for avoiding calculation according to theory. Numerical methods like the Parabolic Equations (PE) method, Fast Field Program (FFP), or Boundary Element Method (BEM) are not useful in practical prediction methods due to the excessive calculation times. However, numerical methods are useful and have been used to develop and verify the approximate methods.

Air Absorption

The method described in [6] has been decided upon. The third-octave band attenuation is calculated based on ISO 9613-1 pure-tone attenuation at the center frequency, corrected to obtain the band attenuation. The band attenuation is smaller than the attenuation at the center frequency, and the difference increases with increasing attenuation. The difference is insignificant when the air absorption is less than 10 dB while there is substantial difference at high attenuation.

Ground Effect

Geometrical ray theory deals with the interference between sound waves transmitted directly from source to receiver and sound waves reflected from the ground between source and receiver.

A major improvement of the new models compared with the present Nordic prediction methods is that the ground surface impedance is used in the calculations. In existing methods distinction is made between 'hard' and 'porous' ground. In the new methods a classification has been introduced for typical ground surfaces [7].

Other major improvements are that the new Nordic models can deal with ground surfaces consisting of a mixture of different types of ground, based on Hothersall et al. (JASA 1995), see [8], and with terrain profiles consisting of many plane surface segments.

Screening

A diffraction model by Hadden and Pierce (JASA 1981) has been selected [4]. The effect of multiple screens will be calculated according to Salomons (Act. Acoust. 1997) who combines diffraction coefficients for each individual screen into an overall diffraction coefficient [4].

Comprehensive Model for Non-Flat Terrain

An essential achievement of the new Nordic models is that they give meaningful answers in many situations not covered by existing methods, which mainly deal with flat ground and thin, vertical screens. The real terrain profile shall be approximated by a number of straight-line segments, and the comprehensive model consists of three parts [2]:

Flat terrain includes undulating terrain deviating only insignificantly from flat ground. An equivalent flat terrain shall be determined using the least-squares fit (linear regression) to the actual terrain, and predictions shall be made using the base model for flat terrain.

Valley-shaped terrain is terrain that is non-flat and at the same time does not provide significant screening. A new method has been developed based on predictions made by the flat terrain base model for each ground segment separately. The contributions from each segment are subsequently added according to the Fresnel-zone interpolation principle, see [8].

Hill-shaped terrain includes cases with significant screening. Every terrain profile segment not being part of a screen is a reflecting impedance surface. A calculation is made for every combination of screen and terrain surface segment, and the calculation results are again combined according to the Fresnel-zone interpolation principle, see [8]. For practical reasons calculations are limited to two screens and for each screen to two edges.

Transitions. Discontinuity in prediction results have been avoided wherever possible, and the methods have been designed so that the prediction results become the same no matter which segmentation is chosen to represent a given terrain profile. As an example, if a simple flat terrain is divided into several sub-segments, which together constitute a flat terrain, then the prediction result for the segmented terrain is the same as for the simple terrain. Transition principles have been elaborated to obtain a smooth transition between the flat terrain, valley and hill model. An example is the transition between 'screened' and 'unscreened' case, using a parameter expressing the 'efficiency' of the screen based on a combination of path length difference and screen height relatively to the wavelength and to the effective width of the sound field at the screen.

Comparison with measurement. The model behavior has been studied and found plausible in calculations for a number of cases. A Swiss measurement result was available from an uneven grass-covered terrain where great care had been taken to ensure non-refracting atmospheric conditions [9]. The distance was 200 m, the terrain a two-screen case with low screens, see Fig. 1. The primary screen was 150 m from the source, the secondary screen at 60 m. Calculation results marked with full line in Fig. 2 were determined for a homogeneous atmosphere. To indicate the uncertainty introduced by small changes in weather conditions, calculation results for curved rays are shown corresponding to a wind speed of ±0.2 m/s, respectively, at 10 m above ground (or temperature gradients in the order of ±0.06 °C/m). The agreement between measurement and calculation is fine except at 500 Hz where the calculation did not reproduce the large dip in the measured spectrum.

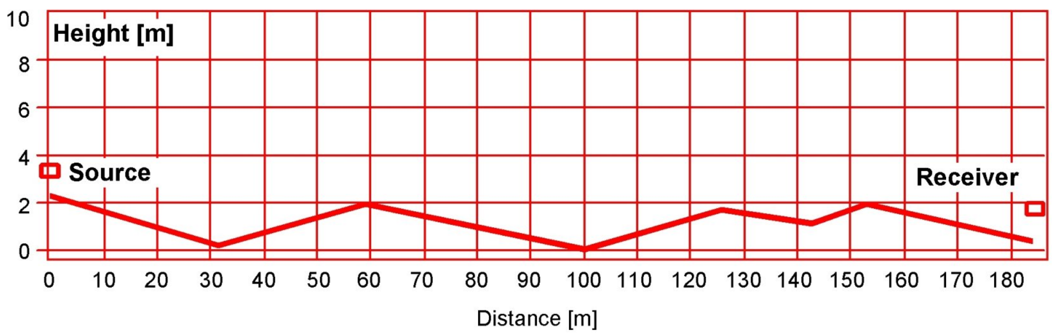

Figure 1: Vertical section through non-flat measurement site; $h_s = 1.0$ m; $h_r = 1.5$ m [9].

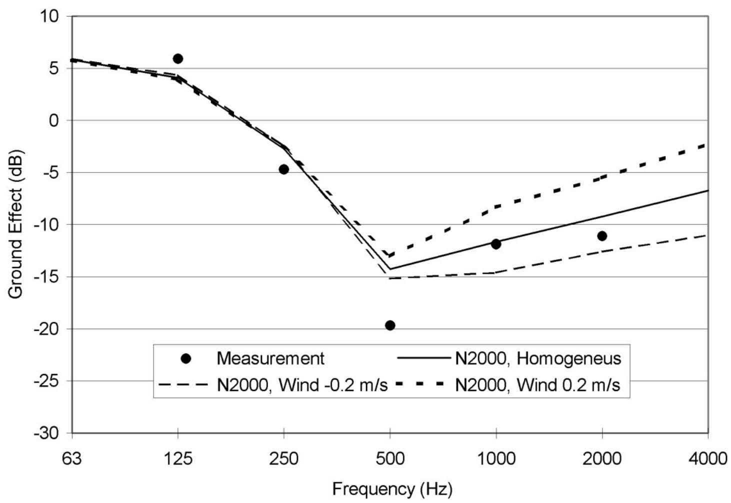

Figure 2: Measurement and calculation results, Swiss site shown in Fig. 1.

3 - REFLECTION FROM OBSTACLES

Sound reflected from an obstacle such as a building facade is dealt with by introducing a new source at the image of the real source, mirrored by a plane containing the reflecting surface, Fig. 3. The reflected sound is considered uncorrelated with the direct sound.

A Fresnel-zone approach illustrated in Fig. 3 is used to ensure continuity when the reflection point moves from inside to outside the reflecting surface. In Fig. 3, no reflection would exist at the receiver according to the present Nordic prediction methods because the ray does not hit the building facade. In the new Nordic methods the effect of the part of the mirror marked 'Active' in Fig. 3 is included, i.e. the part of the building facade inside the Fresnel zone.

4 - SCATTERING

Scattering objects break up the phase-coherent ground effect, and a more or less diffuse (non-coherent) sound field predominates above a certain frequency, and at the same time sound energy is removed. The models distinguish between scattering in housing areas and in forests, because the effects of scattering differ, although the overall principles are the same. The findings and models, based on Leschnik (Acoustica 1980) and Huisman et al. (JASA 1991), have been summarized in [3].

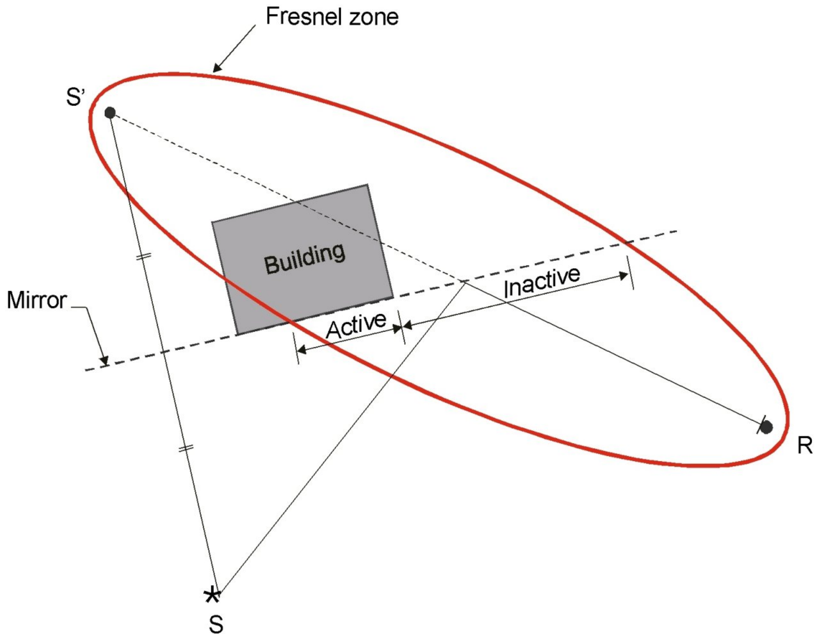

Figure 3: The reflected sound is proportional to the active part of the mirror.

5 - WEATHER INFLUENCE

Geometrical ray theory is valid for a sound field without any atmospheric refraction generated by wind speed or temperature gradients. The theory has been extended in a 'heuristic' model [10] to be valid also in the presence of refraction. Modified interference between direct and reflected sound is taken into account as a consequence of sound ray curvature caused by refraction, and reflection and diffraction angles must be modified to account for the ray curvature.

Linear gradient. The heuristic model presupposes that the sound speed varies linearly with the height above the ground so the sound path is part of a circle. The non-linear sound speed profiles occurring in the real atmosphere must be approximated in a way that ensures good calculation results. Some proposals have been made, but it has not yet been finally decided how to do.

Fluctuating gradient. When contributions from different rays are added coherently, the interference patterns in calculation results are stronger than observed in outdoor measurement results, among other things because of fluctuations in the sound speed gradient. This is taken into account by coherence coefficients applied to other rays than the primary ray [2].

Multiple rays or shadow. In strong downward refraction a larger number of rays may reach the receiver than in the non-refraction case. This has been taken into account by a model adding incoherent sound energy depending on the number of extra rays. In upward refracting shadow zones may occur into which no ray can enter. A model for calculating the sound level in shadow zones has been developed considering the shadow zone screened by a wedge of terrain.

Turbulent scattering. Atmospheric turbulence scatters sound energy into the shadow zone behind a screen. A model has been developed for adding incoherent scattered energy to the sound behind screens.

6 - MODEL VALIDATION

The models have been validated by comparison with existing measurement results, with results of new measurements carried out within the Nordic project, and with results of calculations made using numerical methods like the Parabolic Equations (PE) approach, Fast Field Program (FFP), or Boundary Element Method (BEM). An example is shown in Fig. 4 [11], which could be considered an outdoor scale measurement of the noise from a source behind a screen on an embankment. Space limitation prevents details to be included here. References can be found in [1].

7 - PREDICTION METHODS

In 2000 the propagation models shall be combined with source models [5] and with a first generation of 1/3-octave band source data so that the first version of the new generation of prediction methods are available.

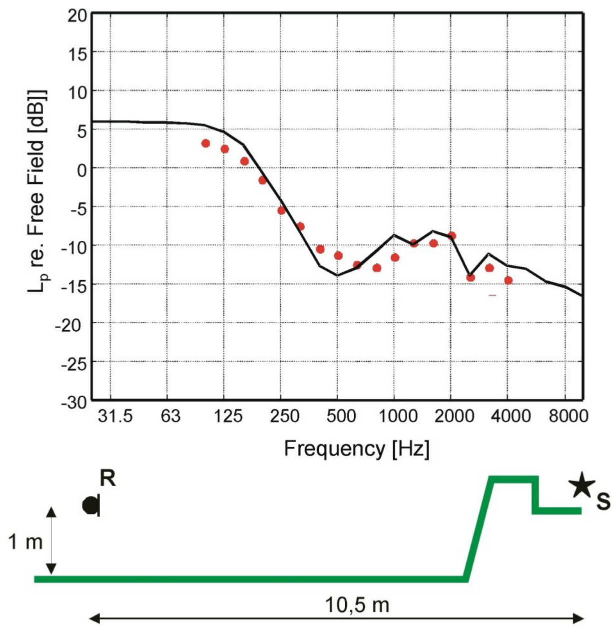

Figure 4: Measured [11] and calculated [12] effect of ground and barrier.

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