inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 2.4

LONG TERM PREDICTION USING A RAY MODEL AND CLIMATOLOGICAL DATA

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Keywords:
NOISE PROPAGATION, RAY MODEL, NOISE MAPPING, SCREENING

ABSTRACT
Outdoor sound propagation is strongly dominated by ground impedance and meteorological parameter, which govern the speed of sound in the atmosphere. To predict a long term immission noise level Leq - as defined in ISO 9613-2 - a model is needed, which allows to take the important meteorological parameter into account on the basis of its long term occurrence. It is shown that a ray model is sufficient, were the rays are limited to quadratic terms in distance using speed of sound profiles derived from air quality propagation models. The latter includes the change of wind speed, temperature as well as the turbulence with height as a function of cloud cover or atmospheric stability. It will be demonstrated that the so-called ground attenuation is different during nighttime compared to daytime, or for situations with or without cloud cover. It will be shown that the meteorological factor Cmet - as defined in ISO 9613-2 - can be calculated as function of propagation direction using available meteorological data frequently used for air quality predictions. Furthermore it is shown that source coherence, vertical observation angle and turbulence govern the ground interference effect.

1 - INTRODUCTION
At present five working groups are active for the European Commission to formulate a basis for a new European policy on noise prevention and protection. Of course rail, road and air traffic noise is a major part on the agenda of these groups including the problems how to get a reasonable prognosis of the ambient noise levels. It is a well known fact, that practically each European country uses its own approach to predict road or rail traffic noise.
It will be examined how an harmonized European model on sound propagation from the above source can be achieved.

2 - TASK
Following the work of the above mentioned working groups of the European Commission it seems at least by now sufficient to be able to predict from source data the following quantities for daytime and night-time separately: Leq, SEL and Lmax on a long term basis for a specific period of time, eg. daytime, night-time etc. to be assessed. Special meteorological situations such as down wind conditions may be of interest, however, all available sociological data which correlate noise levels with annoyance or sleep disturbance refer to long term rating levels and not to data observed under specific meteorological conditions. Therefore, in the context of a harmonized model long term average data have priority, which can be defined by:

$$L\left(longterm\right) = 10\log\sum_{i=1}^{n} w_i \cdot 10^{0.1\cdot\bar{L}_i} \tag{1}$$

where w_i is a weight factor which describes the long term frequency of occurrence of the meteorological situation i, having average level $\bar{L}_i$ and n the number of meteorological situations to be considered.

3 - PROPAGATION MODEL

The questions to be asked now are, how do we define a meteorological situation, what assumptions are to be made on the wind and temperature field and how can we decide which situation is observed? To do this, a model is needed, which describes sound propagation under different meteorological conditions. Ray models allow to calculate the rays and the reflected rays under the assumption that the wave length is small compared to the influencing parameters such as wind speed, temperature and humidity in dependence of the gradients of these quantities.

If these paths have been calculated, spherical waves may be assumed which follow these paths and are added at the reception point taking into account ground reflection and different path length. In this respect ray tracing models are an approximation for the solution of the wave equation as e.g. the parabolic approximation or similar methods to solve numerically the wave equation.

Three different cases should be considered using such models:

1. Source description and sound propagation over small distances.
2. Sound propagation over flat ground and obstacles with no influence on the wind and temperature profile.
3. Sound propagation over ground with changing ground elevation and obstacles influencing the wind and temperature profile.

The distinction between case 1 and the other is, that in case 1 meteorological influences are negligible. In case 2 the speed of sound depends only on height z whereas in case 3 we have to assume that c is also a function of x and y. Basically the ray model should be able to provide all information needed for a specific meteorological situation i to calculate the reception noise level from source data:

$$L_p(i) = L_w + D(\Omega) + A_{div} + A_{air}(i) + A_{gr}(i) \tag{2}$$

where L_w is the sound power level, $D(\Omega)$ describes the directivity, A_{div} the spatial divergence, A_{air} air absorption and $A_{gr}(i)$ all effects resulting from ground reflection, a specific meteorological situation i, barrier effects and shadowing. Air absorption is also a function of meteorological situation i.

3.1 - Case 1: source description and small distances

Up till now all propagation models are based on point or line sources having no vertical size. The point source model implies that the source radiates sound coherently, an assumption which is only true in rare cases for real sources. The line source assumption implies that infinitesimal small point sources on the line are radiating incoherently. The effect can easily be demonstrated, that interference effects are predicted, which are not observed with real sources. To avoid this, an additional parameter for the source description is needed, which might be the vertical height of the source, a parameter which can easily be established by observation and measurements. Using this, the source consists of a sum of incoherent sources in a small volume, which is seen for small distances as incoherent and for larger distances quasi coherent.

3.2 - Case 2: propagation over flat ground with obstacles

In this case we may assume that the flatness of the ground and the elevation of obstacles is such that the meteorological parameters which govern sound propagation are only affected in a minor and negligible extent. The speed of sound is then solely dependent on the height above ground. This means that the rays are translation invariant.

It is widely believed that A_{gr} as described by ISO 9613-2 [1] is caused by interference between the direct wave and the reflected waves from the ground. If the maximum value of the spectrum is at 300 Hz, this effect might be very strong, however, if white noise or pink noise is assumed, this effect disappears for the total level due to the indisputable fact that interference annihilation is always followed by interference amplification.

The main effect that governs A_{gr} can be explained by the fact that the ray tube opens up down wind further as would be expected under a constant wind speed and temperature gradient:

$$A'_{gr} \approx 10\log\frac{\Delta F_1}{\Delta F_0} \tag{3}$$

where ΔF_1 is the opening area of the ray tube in a wind and temperature field and ΔF_0 the opening area in an atmosphere, which is homogenous with respect to the sound speed.

If we assume, as it is done for the calculation of air pollution propagation, that the wind profile can be described by

$$\upsilon(z) = \upsilon_0 \cdot \frac{z^m}{z_0} \text{ where } z_0 = 10\text{m} \tag{4}$$

$$\upsilon(z) = \upsilon_0 \left(\frac{z}{z_0}\right)^m \text{ where } z_0 = 10\text{m} \tag{5}$$

$$T(z) = dth \left(\frac{z}{z_0}\right)^m$$

and υ_0 is the wind speed in 10 m height and m a factor describing the atmospheric stability varying between $m = 0.4$ for stable or inversion condition over 0.25 for indifferent conditions as they might occur in the morning and evening or under cloud cover at day and night-time or 0.15 a less for instable conditions as they can only occur in daytime with the sun shining and a sky which is at least partly open. If we assume further that the temperature follows a similar functionality with height it can be shown that for larger distances A'_{gr} can be given by [2]:

$$A'_{gr} = 10\log\left(\frac{m}{2-m}\right) \tag{6}$$

which means that under inversion conditions A'_{gr} reaches 5 dB for $m = 0.5$ and 12 dB under conditions of an open sky and sunshine.
This means that the governing parameter of sound propagation is besides wind direction and wind speed atmospheric instability as can be seen from Fig. 1, where A'_{gr} is depicted for down wind direction as a function of atmospheric stability.

	0	1	2	3	4	5	6
m	1	0.42	0.37	0.28	0.22	0.20	0.09
dth	0.6	1.07	0.47	0.0	-1.1	-1.45	-2.76

Table 1: Model parameter from air quality models.

3.3 - Propagation over non flat ground

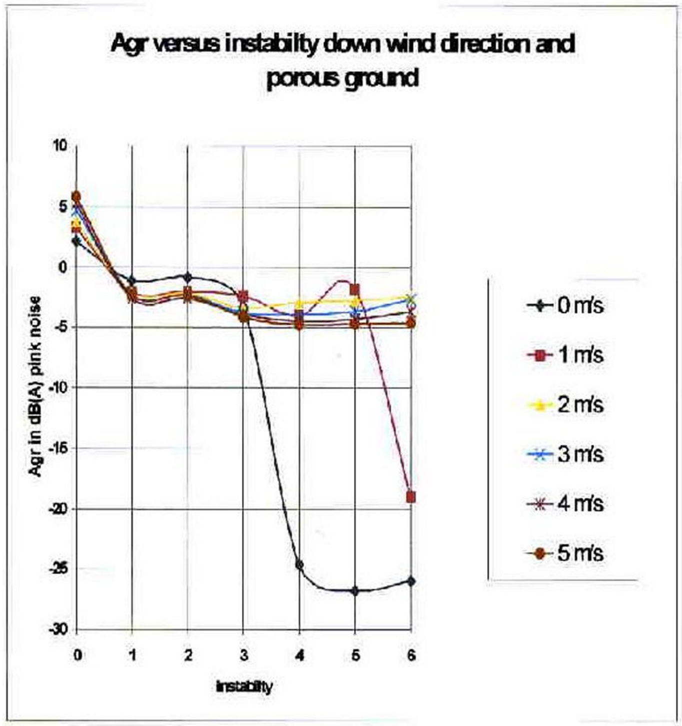
In this case we have to assume that the speed of sound is not independent on the horizontal distance from the source. The most simplest way in dealing with this is to assume that the air flow will be constant through a given cross section limited by a specific height H_0 above ground as e.g. 100 m.
Using above wind speed profile we obtain

$$\upsilon(z, x) = \upsilon_0 \cdot \left(\frac{H_0 - gr\,(source)}{H_0 - gr\,(x)}\right)^{m+1} \cdot \left(\frac{z}{z_0}\right)^m \tag{7}$$

This way ray tracing can take the interaction effects of ground and wind gradients into account. In Figs. 2 and 3 an earth berm is shown 8 m above ground, stability class 4 is assumed with 2 m/s wind speed under down wind conditions. The rays are shown for an opening of 3° until they are reflected at the berm. If the upper height for an constant air flow is 180 m shadowing by the berm is observed up to a distance of 1700 m. If this height H_0 is reduced to 80 m as shown in Fig. 3 shadowing is terminated at 300 m. This simple example shows that interaction between ground elevation, buildings and similar obstacles does have a strong effect which can not be easily separated from diffraction.

4 - CONCLUSION

It has been shown that ray tracing models, which use a description of the atmosphere as it has been done successfully for in air quality modelling, can be used to improve the prediction of noise at larger distances. The advantage of this approach is that the weighting factors for the frequency of occurrence of the different meteorological situations needed for the long term Leq (see Eq(1)) are available to predict the long term equivalent levels. For smaller distances the incoherent nature of the radiation of technical sources must be included.
There are numerous publications in this field which are well summarised by V. Ostashev, Acoustics in moving inhomogeneous media, E&FN Spon, 1997. Stability classes have been introduced by Pasquil,



Source : 1.5 m , Reception 4 m , Distance 1000 m

Figure 1: A_{gr} versus instability downwind direction and porous ground.

Turner and Manier. The respective definition might be found in national regulations on air pollution propagation.

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2. ISO 9613-2, 1996

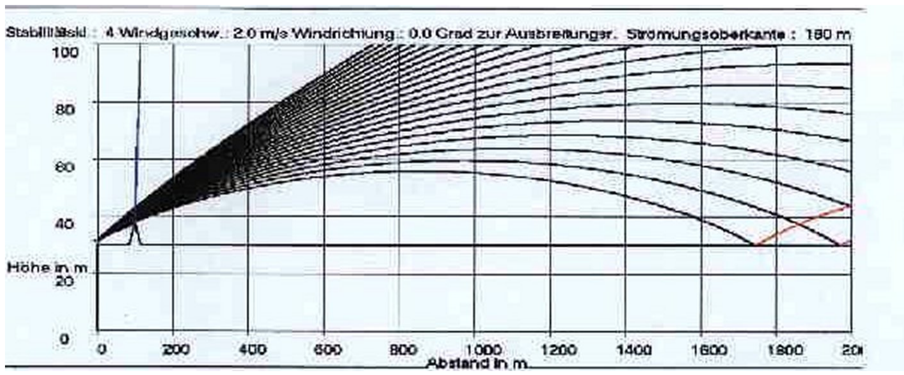

Figure 2: Ray tracing for a berm of 8 m at a distance of 100 m, no berm wind interaction.

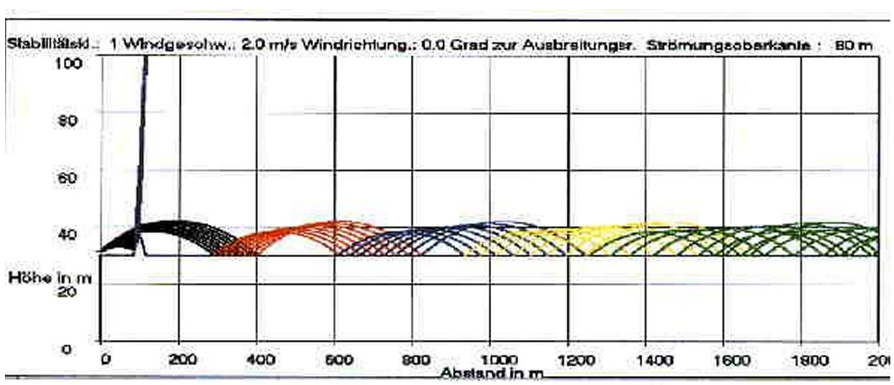

Figure 3: Ray tracing for a berm of 8 m at a distance of 100 m with berm wind interaction.