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[N586] AN ENGINEERING METHOD WHICH CONSIDERS TERRAIN FEATURES IN LONG RANGE SOUND PROPAGATION MODELS

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ABSTRACT

The prediction of shooting noise from large weapons focuses on a range of several kilometres around the source - the typical distance between a military training area and residential areas. Due to the dominant long wavelengths of the blasts and the long propagation distances, noise prediction models normally neglect shielding effects. In hilly terrain however, tests made clear that terrain shielding should be considered to improve the prediction.

Related standards and regulations give formulae to calculate the shielding of near barriers for downwind conditions. Basically, such formulae assume straight ray paths, though they have an empirical factor to correct for all meteorological influences, for instance ISO 9613. For long range propagation however, refraction induced by wind and temperature gradients becomes significant. Therefore, straight ray path formulae are not directly applicable for long range terrain shielding.

The paper presents an engineering method introducing curved rays into the ISO 9613-2 concept of shielding. The method is controlled by the radius of curvature, depending on wind and temperature gradient. The paper also discusses the results of a first validating measuring campaign.

KEYWORDS: Shooting Noise, Sound Propagation, Shielding of Terrain

INTRODUCTION

The German guideline /1/ to predict the shooting noise from large weapons relies on an empirical model. This blast propagation model considers source data (L_{E250} as source strength and L_{Dir} as directivity), geometrical spreading and air absorption (L_{abs}). In order to adjust the propagation attenuation to measured data, the calculation scheme provides three fitting coefficient (K_{log}, K_{lin} and K_{met}).

Eq.(1) evaluates the L_{SEL}, the long term average single event receiver level of the muzzle blast, of a certain weapon/ammunition combination i, at a given source to receiver distance, d and at a given angle α between the sound propagation direction and the line of fire.

$$\begin{aligned} L_{SEL,i}(d,\alpha) = L_{E250,i} + D_i(\alpha - 135°) - 20\lg\left(\frac{d}{250\ m}\right) - L_{abs,i}(d - 250\ m) \\ - K_{\log,i}\lg\left(\frac{d}{250\ m}\right) - K_{lin,i}(d - 250\ m) - K_{met,i}\lg\left(\frac{d}{250\ m}\right)w \end{aligned} \qquad \text{Eq.(1)}$$

In eq.(1) let w denote a sound wind speed gradient in the direction from source to receiver. The coefficient K_{met} then determines the sensitivity of the sound propagation to the long term average wind influence and within this model, plays a similar role as the c_{met} in the ISO 9613, /2/. The sound speed gradient approach in eq.(1) follows from the empirical formula 2 that correlates the effective sound speed gradient to the respective wind speed measured at 10 m height.

$$w = 0.0012\left[\frac{1}{s}\right] + 0.042\left[\frac{1}{m}\right]v \qquad \text{Eq.(2)}$$

Eq.(2) roughly confirms the general observation that wind normally increases with height. For the purpose of the model this is expected to be a sufficient description of the influence of prevailing wind on long term average levels.

The propagation model according to eq.(1) does not take into account any shielding effect - either close to the source, close to the receiver or along the sound path -, because it was expected that due to the dominating low-frequencies (i.e. long wavelengths) of such blasts and due to the long propagation distances under consideration, shielding is negligible. However, measurements in hilly terrain provide evidence that the shielding of the terrain does influence receiver levels: for downwind conditions, the receiver levels behind shielding hills were significantly lower than the model predictions. Therefore a method that considered the shielding effect of terrain was to be added to the calculation scheme of the blast propagation model.

RESTRICTIONS

Firstly, this procedure should be compatible to the model's concepts in /1/. That means that this correction should be additional like all other corrections such that for flat terrain the procedure yields a zero decibel number. The wind gradient correction governed by the source specific K_{met} should still correct for long term average wind influences. As a consequence, this 'propagation weather' should not be in contradiction to the 'shielding weather': The wind speed gradient, w which also determines shielding.

Secondly, the noise prediction model including the additional shielding procedure should still be applicable to daily noise mapping. A typical map relies on around 200,000 point to point calculations of eq.(1), and there is only a tenth of second available. This is a practical premise and a rather strong restriction because it excludes any detailed physical description of the atmosphere but it must take into account the prevailing weather.

The physics of shielding outdoors is complex if any weather effect comes into play. For short-range propagation (< 25 m) weather is not that important though source measurements at 10m distance from muzzle blasts of small arms clearly indicate the influence of wind profiles and, in particular, the wetness of the ground, on one-third spectra.

For mid-range propagation (25 m to 1000 m) wind and temperature profiles strongly influence the sound propagation even over flat terrain. Thinking of sound propagation in terms of rays, these sound rays don't follow straight lines. For, so-called down-wind conditions, which in acoustics is typically meant as a synonym for a condition of increasing sound speed with height above ground, the rays are refracted backwards to the ground. In contrast of course, for upwind conditions the rays curve upwards. As a first consequence, the downwind levels are significantly higher than upwind levels. As a second consequence, downwind refracted rays are able 'to curve' over the top of a barrier; shielding is less effective downwind than upwind. The engineering shielding model in ISO 9613, applicable for this mid-range propagation, does not consider curved rays, but it introduces an empirical correction that takes into account the effects of lower shielding efficiency under downwind conditions. For other outdoor effects however, for instance excess attenuation caused by vegetation, ISO 9613 refers to circular rays (circles), see fig.1.

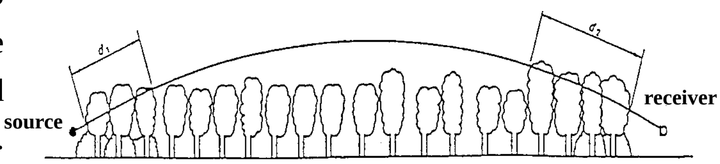

Fig.1 Curved ray in ISO 9613 for excess attenuation through forest (fig. A.1 in /2/: the guideline recommends the radius of curvature to be 5000 m and the angle of radiation and the angle of incidence to be 15°

For long-range propagation the influence of weather is even more complex, in particular in hilly terrain. Sound will be propagating through higher layers of the atmosphere which may have different wind directions and gradients. In addition, the topography will directly influence the wind and temperature profiles over the terrain. For example, the wind will follow valleys, there are particular air flows driven by temperature gradients during night time etc. It is rather a challenge to even discuss these phenomena. In conclusion, the method to be used with the given propagation model in /1/ must be very simple, but at least it has to consider curved ray paths.

SHIELDING MODEL

The basic idea of the simple shielding model for long-range propagation is to use the concept given in ISO 9613 as far as possible but introduce curved ray paths. Formula 14 of ISO 9613 evaluates the shielding correction D_Z. In case of no wind and only one barrier, formula 14 reduces to

$$D_Z = 10 \lg \left[3 + \frac{20}{\lambda} z \right] \qquad \text{Eq.(3)}$$

In eq.(3), let denote λ the wavelength and let z denote the excess path of the sound around the barrier; Eq.(3) defines z as the difference between the path length over the barrier - i.e. the sum of the distance from the source to the edge of the barrier d_{ss} and the distance from the edge to the receiver $d_{sr,}$ - and the direct distance between source and receiver d

$$z = d_{ss} + d_{sr} - d \qquad \text{Eq.(4)}$$

For straight rays it is clear which ray has to be considered. This ray is made up by the distances discussed above. In order to evaluate z with curved ray paths, the length of the respective curved ray replaces each distance in eq.(3). However with curved rays, 1) the radius of curvature and 2) the radiation angle are two more parameters that need to be determined. In addition, 3) it will be necessary to define what happens, if d is greater than the radius of curvature.

1) Radius of curvature

In the context of the present model, the curvature of the rays is assumed to be constant. Hence, in order to use the same weather for the long term wind correction in formula 1 and for the new shielding correction, the radius of curvature can be derived from eq.(2). Then the radius of curvature R is the average sound speed c divided by the average sound speed gradient R = c/w.

2) Radiation angle

For downwind condition, ISO 9613 recommends the 15°-ray is used for calculation, see fig.1.

Also the results of the Norwegian trials support the view that the sound at far distances has typical angles of incidence between 0° and 15°/3/. Hence the present shielding model also introduces the 15°-ray as the significant ray for calculation of shielding under downwind conditions. For upwind conditions, the 15°-ray is obviously not the significant one. The ray that just does not touch the ground before it is refracted upwards is assumed to be the most important ray path for the propagation calculation. For sources close to the ground it is good enough to use the 0°-ray.

3) Distance greater than radius of curvature

If the 15°-ray cannot directly reach the receiver because the distance between source and receiver is too large, then a ground reflection would occur due to the assumption that the radius of curvature is constant. This would require the introduction of ground properties into this simple model which is not compatible with the model in /1/. Therefore, in such casese, the shielding model under discussion inserts a straight line segment between the curved ray at the source and the receiver; fig.2 indicates the rules for downwind conditions. The upper sketch shows the terrain and the ray in the 'normal' view. It is much easier to analyse the geometry in the world 'seen' through the eyes of a ray. Rays always see themselves as straight; in the ray's view, the terrain gets out of shape according to the same, now reversed rules. The lower sketch in Fig.2 indicates the geometry in this world. Now the ground is bent downwards and the ray is a simple straight line between source and receiver. In this world it is very easy to evaluate the distances and the effective height of the terrain in order to apply eq.(3) and (4) for shielding. The defined rules always determine a solution for downwind conditions. For upwind conditions, the geometry is different. Again, it is easier to understand the model looking at the sketch in world of the rays. In this case the terrain is bending up according to the given radius of curvature, see fig.3. Even if the terrain is flat,

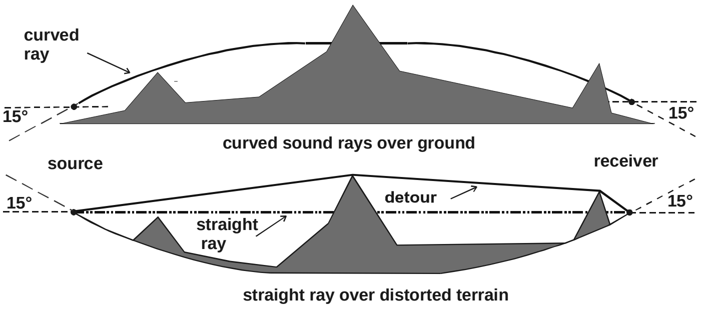

Fig.2 Sketch of geometry for downwind
upper sketch – normal view
lower sketch – 'rays view'

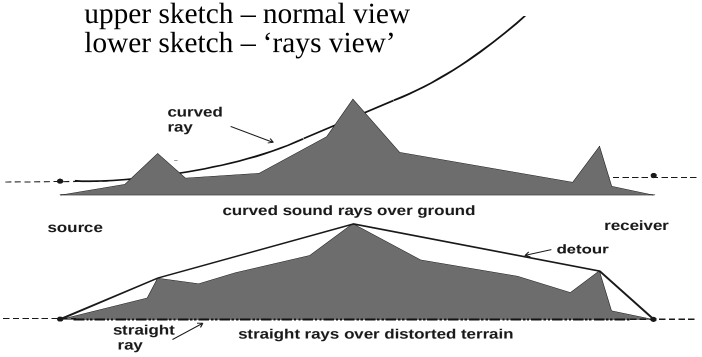

Fig.3 Sketch of geometry for upwind
upper sketch – normal view
lower sketch – 'rays view'

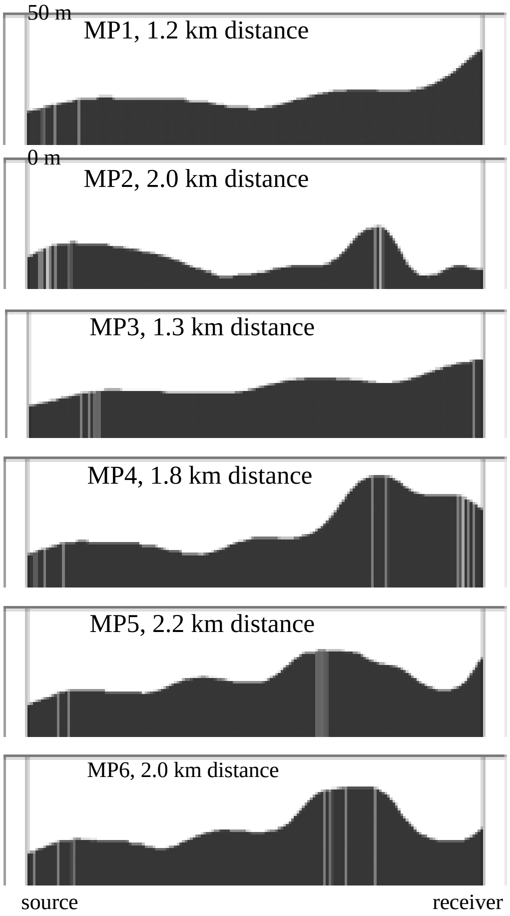

Fig.4 Terrain from source to each receiver

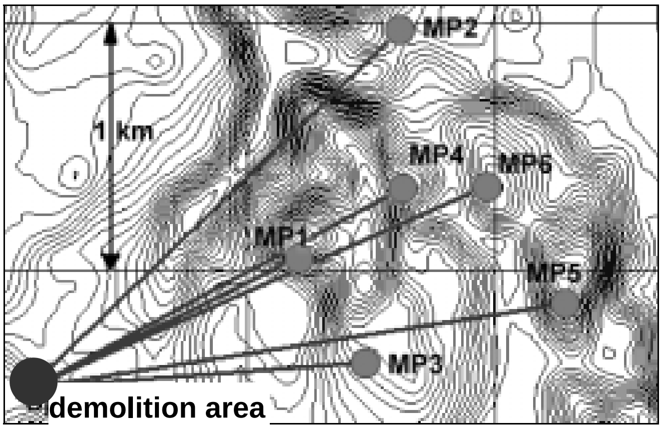

Fig.5 Receiver locations relative to demolition area

upwind conditions will generate a spherical hill and there will be contributions from the shielded rays caused by the continuous shielding of the ground.

It is strange to look at shielding in this way. However neglecting turbulence and scattering, curved rays yield a shadow zone, which also is strange because blasts are heard upwind in a typical outdoor situation.

The blast propagation model /1/ is used for noise contour mapping that - for a single map - requires both downwind and upwind calculations. Therefore, it is necessary to have a procedure for terrain shielding that corrects for both conditions. In addition, though the view is strange, the prediction of this upwind shielding procedure predicts upwind levels over flat terrain that do correlate with first measurements, discussed later. Obviously, it is promising to look at shielding in this way.

VALIDATION

The receiver levels from blasts at larger distances scatter significantly even for a downwind series within a short measuring interval. The change in the atmosphere is the reason for this scattering though wind speed and direction measurements close to the source or receiver indicate constant conditions. For upwind conditions, the level range is even wider. Expecting such uncertainties for flat terrain, it is rather difficult to set up a test plan that is sensitive to terrain shielding in order to validate the present model.

The test plan

Fig.5 shows the chosen set up. The basic idea is to measure the receiver levels from blasts fired at a demolition area at six locations. Three locations (MP1, MP3, and MP5) are expected to generate no shielding effects. At the remaining three locations the shielding effect should be significant (MP2, MP4 and MP6). Fig.4 indicates the shape of the terrain from source to each receiver. At all positions, the microphones lay on the ground enforcing pressure doubling for the low frequency range (< 100 Hz). This position was selected to avoid uncertainties with respect to ground dips generated by pressure release reflections at the soft grassy ground. These ground dips may even at this height influence higher one-third octave levels. Therefore, the analysis relies on the low frequency range. This is not a strong restriction, because shielding is a geometrical effect and the results for the, long wavelength region can be extrapolated to higher frequencies for the purposes of this model.

In general, a large number of single events is a premise to yield acceptable uncertainties. However, more shots last longer and a systematic change of wind conditions cannot be excluded. Nevertheless, the following results include 70 blasts from demolitions fired in 10 series of 7 shots each over a whole day. The charges vary from 3 kg to 25 kg of PETN. It happened that there was a prevailing upwind condition from the demolition area to the measuring locations during the whole time window of the measuring campaign.

Analysis of measurements

All receiver levels were corrected for geometrical spreading using the direct distance between the source and each receiver. In order to minimize the influence of different wind conditions during each single shot and to compare shots with different charges, the analysis focus on the difference between the receiver levels at the measuring points. The results in MP1 are chosen as a reference, because this location should not be shielded even in upwind conditions.

Fig.6a shows the spectral difference A_{Ter} between the one-third octave spectra measured at the locations relative to MP1. For all measuring positions except MP3, fig.6a indicates significant level reductions up to 20 dB at 80 Hz. At 100 Hz, the shielding effect seems to decrease but a detailed signal analysis confirms that ground reflections cause this decrease.

Fig.6b to fig.6d indicate the predictions of the present model for different assumption of the radius of curvature and the source height. The source height, of course, plays an important role. Though the demolitions are fired at the ground the centre of the location of the sound source of the explosion can be expected to be higher. It is obvious that the shielding model under discussion yields the best predictions assuming a radius of R = 10 km (upwards) and a source height of 3 m (fig.6d). Both, the measured and the predicted level difference increase with frequency, a behaviour that would be expected for shielding.

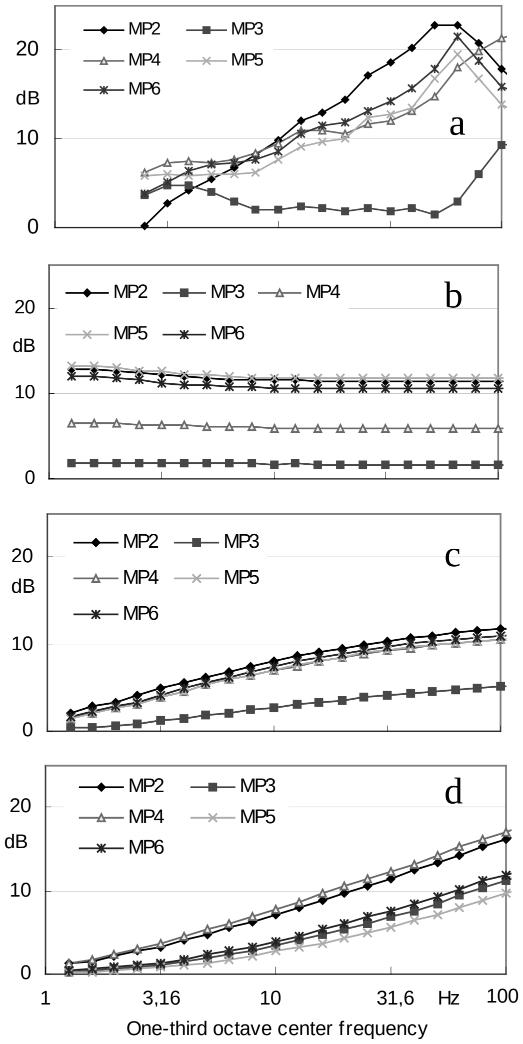

Fig.6 Spectral Shielding correction A_{Ter}
a measurement
b r = 1 km (up), h = 0 m
c r = 10 km (up), h = 0 m
d r = 10 km (up), h = 3 m

Fig.6 also shows that the simple model is rather sensitive to the parameters, confirming that the test plan and the analysis is appropriate.

The results of the first measurement campaign are not a validation of the model but they do provide evidence that the model is significantly correct. The corrections are in the right order and have the right sign. It is necessary to perform more tests to support the model but it is looking rather promising.

CONCLUSION

The proposed method, which considers terrain features is compatible with the prescribed prediction model and is a simple enough to be used for noise contour mapping. The method depends on only one further parameter, the radius of curvature and that depends on ground wind assumptions. First validation measurements indicate that the predictions of the model are not in contradiction to experimental data. It will be necessary to perform additional validation measurements, in particular for downwind conditions. The proposed method is also applicable to other sounds. It is an extension to the concept of shielding given in the ISO 9613 using curved rays to evaluate the long range shielding correction of terrain.

REFERENCES

1. “Schießlärmrichtlinie”, Provisional guideline of the German Ministry of Defense to measure, predict and assess shooting noise from large weapons in Germany
2. ISO 9613-2:1996 “Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation”
3. Hirsch, K.-W.: “On the influence of local ground reflections on sound levels from distant blasts at large distances”, Noise Control Engineering Journal, Vol. 46 No.5 1998 page 215-226