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A new approach to consider forest attenuation in engineering noise prediction schemes

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Summary

In an informative annex, the international standard ISO 9613-2 proposes a basic method to take excess attenuation of forest areas into account. According to ISO 9613-2, forest attenuation can be only considered if one cannot see through the forest over a short range. Hence, the standard relies on the estimation of the penetration length of a circular arc – constant radius 5000 m - through the forest multiplied by forest-independent but frequency-dependent factors to estimate the forest attenuation.

This paper proposes an enhanced scheme. The average height of the canopy, the depth of the forest areas at the direction of sound propagation and the distance of the forest edges to source or receiver are the geometrical parameters of this enhanced scheme. A forest-dependent attenuation coefficient takes into account the forest features. The radius of curvature of sound rays, calculated according to ISO 1996-2, is used to include the influence of different weather conditions on the forest attenuation.

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1. Introduction

Most of the literature on sound attenuation of forest areas focuses on the interaction between sound and forest edges with respect to reflection or backward scattering of the edge, or on the propagation within the forest with respect to scattering and ground absorption. Dedicated studies on the overall mitigation of forest areas and technical approaches to consider the excess attenuation of forest areas for noise prediction schemes are rare. For industrial noise, the ISO 9613-2 [1] describes in its informative annex a rather simple procedure. This approach is frequency dependent but does not consider any forest properties. In addition, a forest can only be taken into account if one cannot see through the forest over a short range. Such unclear pre-conditions are not appropriate for any quality controlled noise mapping.

In [2], the present author discussed the multitude of principle effects of forest areas on the sound propagation and gave references to some key papers. This paper also reports on dedicated long term forest attenuation measurements using the concept of paired path measurements, i.e. simultaneous measurement of the sound propagation along two adjacent paths in the two opposite directions; one path over grassy land, the other path over the forest area under test. The results of these measuring campaigns are the basis of the engineering model proposed here. These results clearly indicate that forest areas have a significant effect on the sound propagation.

Therefore, it is also not appropriate if noise prediction schemes neglect forest attenuation because the level reduction can reach the same order as the corrections for example for ground reflection, for air absorption or for the shielding of terrain. For example, a 280 m-deep, dense, and approximately 30 m-high coniferous forest yields on the average a 4 dB reduction if the source is 50 m and receiver 100 m away from their facing forest edge.

As a conclusion, a forest model is needed to consider the excess attenuation of forest areas in engineering noise prediction schemes.

2. Requirements of an engineering model

A sophisticated sound propagation model needs to consider the scattering from trunks and branches, the absorption by the vegetation itself, the enhanced ground absorption, the changed wind and temperature profiles above and especially beneath the canopy that often let the forest behave like a wave guide.

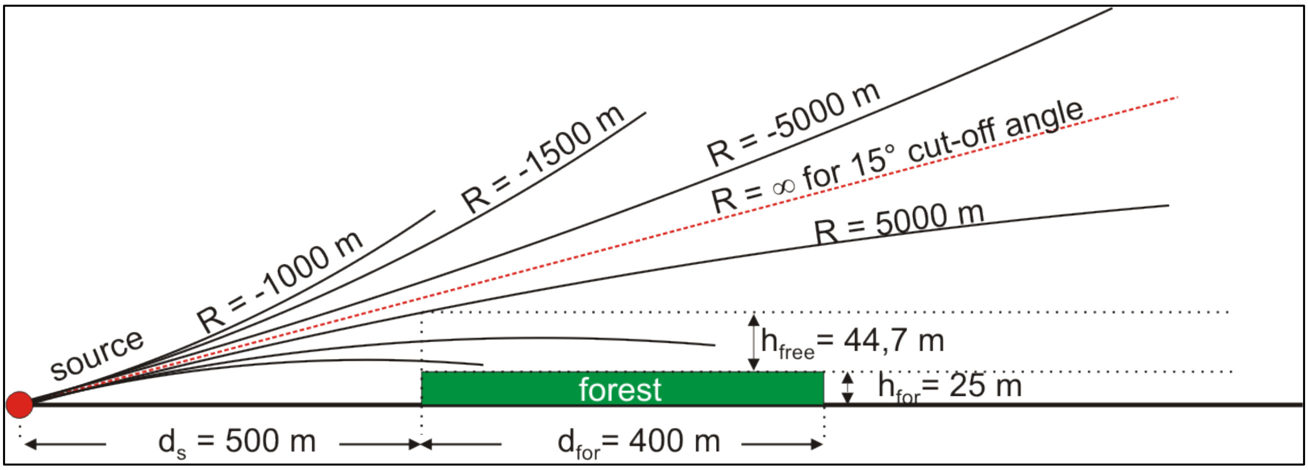

Figure 1 Sample situation for the geometry with respect to up- and downwind radius of curvature

An engineering prediction scheme, in particular if used for noise mapping, sets pre-conditions that strongly constrain the modelling options of the scheme to estimate the overall excess forest attenuation. The scheme needs available or observable input data of the forest areas. This does not look like a constraint, but forest areas can differ in so many properties; naming only a few exceptional features: height and kind of brushwood, ratio between coniferous and deciduous forest within one area, distribution of tree height and trunk diameter. Therefore, the first important step of modelling is to reduce these input data to a reasonable set of parameters appropriate to describe a forest area for noise prediction.

The proposed scheme will rely on the geometry of the forest area taken from a map, a mean height of the forest and a mean length-related, frequency dependent attenuation coefficient of the forest related to a classification of forests. That is a poor data set compared to the needs of a sophisticated model but it is a clear progress compared to the indifferent data in the scheme of the ISO 9613.

There are some general features the model should match: It should take the wind and temperature condition into account. The excess attenuation should tend to zero if the forest height or the forest depth tends to zero. The attenuation should increase for stronger downwind gradients and decrease if the forest is shifted towards the middle of source and receiver. The model should be reciprocal for source and receiver. The model should be capable to handle successive forest areas with different properties along the sound propagation path. And, at the end of the day, the engineering model must yield a fast code appropriate for noise mapping.

3. Concept of the engineering model

Figure 1 indicates the basic idea: The model assumes that sound reaching the receiver originates from the angular range from 0° to the cut-off angle α at the source and makes up the 'total ray'. In Figure 1, α is set to 15°. In the case $R = \infty$ two straight lines border that range. Under downwind conditions the range narrows with decreasing R. Under upwind conditions the range widens, respectively.

At the forest edge the total ray splits into a free ray and a forest ray according to the ratio of the height of the total ray above the forest height to the forest height itself. The free ray indicates the sound that propagates unaffected by the forest. The forest ray indicates the sound that is attenuated by the excess attenuation of the forest proportional to the forest specific attenuation coefficient and its length through the forest area.

As an example, Figure 1 shows the split for a downwind radius of curvature of 5000 m for a source at the ground. For a forest height of 25 m and a distance between source and forest edge of 500 m the ratio between free ray and forest ray is 47,5:25. Both rays are propagated independently and their contributions add up at the receiver. Due to reciprocity, the considerations Figure 1 depicts for the source and its facing forest edge also holds for the receiver and the respective forest edge. The geometry that yields the higher fraction for the forest ray is relevant.

In Figure 1, roughly 2/3 of the sound is unaffected regardless of the depth and absorption coefficient of the forest area. Areas that are far away to both source and receiver are not really efficient.

The efficiency increases if

- the forest edge is nearer to the source or to the receiver,
- the forest height increase,
- the absorption coefficient increase,
- the radius of curvature decreases from up-wind to downwind conditions,
- the source or the receiver height increases.

4. Formulae of the engineering model

This chapter gives the basic formulae of the proposed engineering model. Table I constitutes some important definitions.

Table I. Definitions for the forest model

forest area	forested area with constant properties
free ray	area bordered by the straight line with cut-off angle α at the source and the circular arc with radius R connecting source and receiver and being tangent to the edge of the forest area nearest to the source
h_{free}	relevant height of the free ray [m]
forest ray	area between the free ray and the ground
K_{lin}	length-related forest absorption coefficient of the forest area [dB/km]
h_{for}	average height of the forest area [m]
d_s	distance from source to the forest edge at the receiver direction [m]
d_r	distance from receiver to the forest edge at the source direction [m]
d_{for}	Length of the section through the forest area [m]
h_s	Source height [m]
h_r	Receiver height [m]
α	cut-off angle [°]
R	radius of curvature [m]

To simplify matters, Figure 1 shows a propagation situation with h_s = 0 m. In general, the source height and the receiver height is taken into account through an effective forest height $h_{for,eff}$ that may be different at the source side and at the receiver side of the situation. In order to distinguish between source side and receiver side a superscript left to the symbol s for source and r for receiver is used to indicate the side. Equation 1 and 2 evaluate the effective forest heights.

$$^{s}h_{for,eff} = h_{for} - h_s \quad (1)$$

$$^{r}h_{for,eff} = h_{for} - h_r \quad (2)$$

The height $h_{for,eff}$ is set to 0 m if Equation 1 or 2, respectively, yields a negative value.

The next step is to calculate the height of the free ray h_{free}. This is the altitude of a circular ray above the forest edge minus the effective height of the forest at the forest edge under consideration, $^{s}h_{free}$ for the source side and $^{r}h_{free}$ for the receiver side. The radius R of the circular ray is the radius of curvature that can be calculated from a given temperature and wind profile for example according to ISO 1996-2 [3]. The circular ray is tangent to the straight line with a slope according to the cut-off angle α at the source or receiver, respectively.

The calculation is different for the following cases:

Case 1: $R \geq 0$ m and $d_s \leq R\,sin(\alpha)$ or $d_r \leq R\,sin(\alpha)$

(Downwind, the circular ray reaches the forest edge.)

$$^{s}h_{free} = -R\cos(\alpha) + \sqrt{R^2 - (d_s - R\sin(\alpha))^2} - {}^{s}h_{for,eff} \quad (3)$$

$$^{r}h_{free} = -R\cos(\alpha) + \sqrt{R^2 - (d_r - R\sin(\alpha))^2} - {}^{r}h_{for,eff} \quad (4)$$

Case 2: $R \geq 0$ m and $d_s > R\,sin(\alpha)$ or $d_r > R\,sin(\alpha)$

(Downwind, the circular ray does not reach the forest edge.)

$$^{s}h_{free} = R(1 - \cos(\alpha)) - {}^{s}h_{for,eff} \quad (5)$$

$$^{r}h_{free} = R(1 - \cos(\alpha)) - {}^{r}h_{for,eff} \quad (6)$$

Case 3: R < 0 m and $d_s \leq R\,(1 - sin(\alpha))$ or $d_r \leq R\,(1 - sin(\alpha))$

(Upwind, the circular ray reaches the forest edge.)

$$^{s}h_{free} = -R\cos(\alpha) - \sqrt{R^2 - (d_s - R\sin(\alpha))^2} - {}^{s}h_{for,eff} \quad (7)$$

$$^{r}h_{free} = -R\cos(\alpha) - \sqrt{R^2 - (d_r - R\sin(\alpha))^2} - {}^{r}h_{for,eff} \quad (8)$$

Case 4: $R < 0$ und $d_s > R\,(1 - sin(\alpha))$ or $d_r > R\,(1 - sin(\alpha))$

(Upwind, the circular ray does not reach the forest edge.)

$$ {}^{s}h_{free} = R\cos(\alpha) - {}^{s}h_{for,eff} \quad (9)$$

$$ {}^{r}h_{free} = R\cos(\alpha) - {}^{r}h_{for,eff} \quad (10)$$

The height h_{free} is set to 0 m if the relevant Equation 3 to 9 yields a negative value.

The side with the higher influence of the forest area determines the relevant height of the free ray h_{free} and the relevant forest height $h_{for,eff}$ in the formulae to calculate the excess attenuation of the forest area. Equations 11 and 12 define this rule.

$$h_{free} = \begin{cases} {}^{s}h_{free}, if \; \dfrac{{}^{s}h_{for,eff}}{{}^{s}h_{free} + {}^{s}h_{for,eff}} \geq \dfrac{{}^{r}h_{for,eff}}{{}^{r}h_{free} + {}^{r}h_{for,eff}} \\ {}^{r}h_{free}, if \; \dfrac{{}^{s}h_{for,eff}}{{}^{s}h_{free} + {}^{s}h_{for,eff}} < \dfrac{{}^{r}h_{for,eff}}{{}^{r}h_{free} + {}^{r}h_{for,eff}} \end{cases} \quad (11)$$

$$h_{for,eff} = \begin{cases} {}^{s}h_{for,eff}, if \; \dfrac{{}^{s}h_{for,eff}}{{}^{s}h_{free} + {}^{s}h_{for,eff}} \geq \dfrac{{}^{r}h_{for,eff}}{{}^{r}h_{free} + {}^{r}h_{for,eff}} \\ {}^{r}h_{for,eff}, if \; \dfrac{{}^{s}h_{for,eff}}{{}^{s}h_{free} + {}^{s}h_{for,eff}} < \dfrac{{}^{r}h_{for,eff}}{{}^{r}h_{free} + {}^{r}h_{for,eff}} \end{cases} \quad (12)$$

The excess attenuation A_{for} of the forest area is calculated according to Equation 13.

$$A_{for} = 10\lg\left(\frac{h_{free}}{h_{free} + h_{for,eff}} + \frac{h_{for,eff}}{h_{free} + h_{for,eff}} 10^{-\frac{d_{for}K_{lin}}{10000\,\mathrm{dB}}} \right) \quad (13)$$

If h_{free} = 0 m and $h_{for,eff}$ = 0 m the excess attenuation is zero (A_{for} = 0 dB).

In situations where two or more forest areas intersect the propagation path or in the case where the same forest area intersects more than once the model needs more rules to account for multiple sections w of forest areas with the same or different properties. The following rules may be appropriate if the forest areas border on each other or the gap between them is small compared to their depths and, in addition, they do not differ too much in height:

1. For the evaluation of the height of the free ray h_{free} and the effective forest height $h_{for,eff}$ that forest area is relevant which yields the highest influence. This can be different forest areas for the source and the receiver.
2. In the case of a single forest area, the excess attenuation of the forest ray is proportional to the $K_{lin} \cdot d_{for}$ of that area. In the case of successive areas the attenuations are added as long as the forest areas have the same forest heights. If these are not the same the contributions are weighted with respect to the ratio of $h_{for,eff,w}$ of the forest area w under consideration to the effective forest height $h_{for,eff}$.

The following Equation 14 evaluates the excess attenuation in the case of successive areas:

$$A_{for} = 10\lg\left(\frac{h_{free}}{h_{free} + h_{for,eff}} + \frac{h_{for,eff}}{h_{free} + h_{for,eff}} 10^{-\frac{\sum_{w}\left[h_{for,eff,w} d_{for,w} K_{lin,w}\right]}{h_{for,eff}\,10000\,\mathrm{dB}}} \right) \quad (14)$$

Again, if h_{free} = 0 m and $h_{for,eff}$ = 0 m the excess attenuation is zero (A_{for} = 0 dB).

5. The coefficient K_{lin}

The measurements in [2] suggest a cut-off angle of 20° and a K_{lin} ≅ 12 dB/km for dense coniferous forest and ≅ 6 dB/km for dense deciduous forest. Both values hold for frequency components around 300 Hz. The coefficient may increase for higher frequencies and decrease for lower frequencies.

6. Outlook

Since 2011, the proposed engineering model to consider the excess attenuation of forest areas is part of the noise prediction scheme of the „Guideline for Noise Management on Ranges" issued by the German Ministry of Defense [4]. This guideline controls the shooting noise around the military training facilities in Germany. The approach is under test and will be validated during the regular monitoring measurements. In the case of successive forest areas a general approach applicable for any possible situation in noise mapping, in particular for far range propagation, is still under way.

In addition, the German Federal Office for Real Estate Management, responsible for the state forest, is about to develop a so-called forest formula: a classification scheme to estimate K_{lin} from forest data available in respective databases of the Federal Office.

References

[1] ISO 9613, Acoustics -- Attenuation of sound during propagation outdoors -- Part 2: General method of calculation

[2] K.-W. Hirsch: Noise mitigation through forest areas around shooting ranges, Proceedings Internoise 2010, Lisbon

[3] ISO 1996-2, Acoustics -- Description, measurement and assessment of environmental noise -- Part 2: Determination of environmental noise levels

[4] German Ministry of Defense, „Guideline for Noise Management on Ranges (Noise management guideline – LMR)", Armed Forces Staff IV 3, 2007, ["Richtlinie für das Lärmmanagement auf Schießplätzen (Lärmmanagementrichtlinie - LMR)"