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# The Prediction of Sound Due to a Panel Radiating over an Impedance Plane

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## INTRODUCTION

There are many published calculations of ground effect in outdoor sound propagation for point and line sources [e.g. ref. 1 and 2]. The main motivation of these studies has been road traffic noise reduction, although several studies have referred specifically to industrial noise [3]. Recently the prediction and control of noise in the neighbourhood of large industrial plants has received considerable interest [4-6] both in design and operations of such plant. This is due to stricter government legislation, complaints of neighbouring communities and the awareness of the possibility of causing permanent hearing damage to plant workers.

A common situation involves several sources and buildings within the site perimeter. A simple approach treats each contributory source as a point and incorporates various propagation factors such as ground effect, topography and meteorology. On the other hand, previous consideration of propagation due to finite sources [7, 8] have ignored ground effect, while remarking that it should be considered if the length of propagation is significant [9].

This paper concerns the initial stage of the development of a numerical model for the prediction of ground effect due to radiation from a finite panel. The panel is considered to consist of an infinitely dense array of point source elements. The sound pressure due to each element is computed by using the well-established theory [10] for sound propagation due to a point source above an impedance boundary. The total sound pressure due to the panel is then evaluated by using a numerical integration method to sum the contribution from each element.

## THEORY

### (A) Sound propagation over an impedance boundary due to a finite panel

The field potential due to a point source over a locally reacting boundary at near grazing incidence may be approximated by the Weyl-Van der Pol formula [10] in the form

$$P = A\left\{\frac{e^{ikR_1}}{R_1} + Q\,\frac{e^{ikR_2}}{R_2}\right\} \qquad (1)$$

where

$A$ = source strength

$Q$ = spherical wave reflection coefficient which is a function of the source/receiver geometry and the normalised impedance of the ground surface

$k$ = wave number of the air

$R_1$ and $R_2$ = distance of the source and its image to receiver respectively

There are other more accurate models in calculating the field potential [11] but the use of the Weyl Van der Pol formula has an advantage of its relatively simple and compact form. Moreover, a recent detailed study [12] for the comparison of the sound field calculated by equation (1) and those due to other more accurate models, do not reveal any significant differences for a practical range of geometries and ground conditions.

For a distributed source equivalent to a finite panel, the total field potential can be evaluated by integrating equation (1) to give

$$P_{tot} = \int_S \left\{ \frac{A}{R_1} \exp(ikR_1) + \frac{A\,Q}{R_2} \exp(ikR_2) \right\} ds \qquad (2)$$

where S is the surface of the panel.

The first term of the integrand in equation (2) represents the direct sound field due to a panel source. The excess attenuation (E.A.) due to a panel source is defined by

$$E.A. = 20 \log \left\{ \frac{\text{total field}}{\text{direct field}} \right\} \qquad (3)$$

(B) Total sound field by numerical integration

There is no simple analytical solution for the integral in equation (2) due to the fact that the spherical reflection coefficient Q, is a complex function of the source dimensions. However it is straightforward to evaluate the integral numerically by use of a compound Simpson's Rule [13] in two dimensions.

The panel is divided into 2n x 2m rectangular sub-panels of size h1 x h2. Consequently there are (2n + 1) x (2m + 1) modal points on the mesh formed by the sub-panel boundaries. Each mode is considered to be an independent point source with a weight function determined from the compound Simpson's Rule procedure. Hence,

$$P_{tot} = \frac{h_1 h_2}{9} \sum_{i=1}^{2m+1} \sum_{j=1}^{2m+1} a_i \; b_j \; A_{ij} \; P_{ij} \qquad (4)$$

where Pij is the sound pressure due to a point source of unit strength located at the model point (i,j) and

$$a_{ij} = \begin{cases} 4 & \text{if } i = 2,4,6.....2n \\ 2 & \text{if } i = 3,5,7.....2n-1 \\ 1 & \text{if } i = 1, \text{ or } 2n+1 \end{cases} \qquad (5)$$

$$b_{ij} = \begin{cases} 4 & \text{if } j = 2,4,6.....2m \\ 2 & \text{if } j = 3,5,7.....2m\text{-}1 \\ 1 & \text{if } j = 1, \text{ or } 2m+1 \end{cases} \qquad (6)$$

The rectangular panel is assumed to be simply supported and vibrating with simple harmonic motion in one of its natural modes, say the (p, q)th mode. The source strength Aij can be expressed [14] as

$$A_{ij} = \hat{A} \sin\left[\frac{(i-1)p\pi}{2n}\right] \sin\left[\frac{(j-1)\, q\, \pi}{2m}\right] \qquad (7)$$

where $\hat{A}$ is the amplitude of the source strength.

However, if all elements of the panel is assumed to be vibrating in phase, i.e. piston like motion, then $A_{ij}$ is written simple as

$$A_{ij} = 1 \qquad (8)$$

(C) Ground Impedance Model

The complex normalised impedance, Z of the ground surface may be computed conveniently by using variable porosity model [15] given by

$$Z = 0.218\sqrt{\frac{\sigma_e}{f}} + i\left(0.218\sqrt{\frac{\sigma_e}{f}} + \frac{9.74\ \alpha_e}{f}\right) \qquad (9)$$

where $\sigma_e$ and $\alpha_e$ are respectively the flow resistivity and effective rate of change of porosity with depth of the ground surface and f is the frequency. The real and imaginary parts of the complex impedance are both decreasing functions of frequency.

The use of the variable porosity model will allow tolerable fits to a range of outdoor ground surfaces. For calculation presented in this paper, values of $\sigma_e$ = 200,000 MKS rayls $m^{-1}$ and $\alpha_e$ = 150 $m^{-1}$ have been used which are typical values for grassland.

## PRELIMINARY RESULTS OF NUMERICAL MODEL AND CONCLUSIONS

Calculations have been carried out for several panel/receiver geometries which may be defined in the co-ordinate system shown in figure 1.

Figure 2 shows the excess attenuation spectrum for a 5m x 5m panel in the vertical y-z plane with the observer situated at a range of 50m and 1m height. The contribution from the central vertical line of the elemental source is most important. For a panel of identical size but in x-z plane (figure 3), again the contribution from the central vertical line source serves as the principal component for the ground effect. Indeed the ground effect for the point at the geometric centre of the panel is predicted to provide a good approximation to that for the complete panel. The ground effect calculated for the geometric centre provides an excellent indication of the predicted ground effect at 50m range and 1m height for the whole of a horizontal 5m x 5m panel at 5m above ground (see figure 4).

The irregularities in the predicted curves for the whole panel shown in figures 3 and 4, are the result of numerical difficulties associated with the coarseness of the mesh used in the numerical integration and the strong sensitivities to small changes in phase associated with the path length differences which are most significant in the x-direction. It should be noted also that the predicted tendencies in geometrical domination are independent of mode shapes.

## ACKNOWLEDGEMENTS

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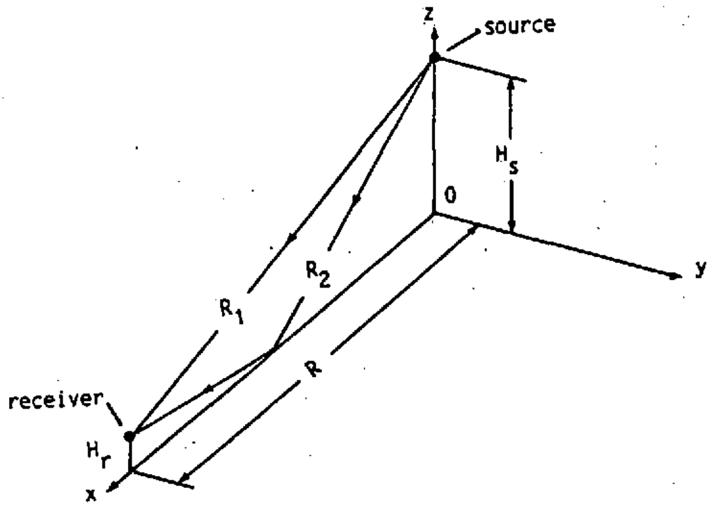


Figure 1 : Geometry of source and receiver.

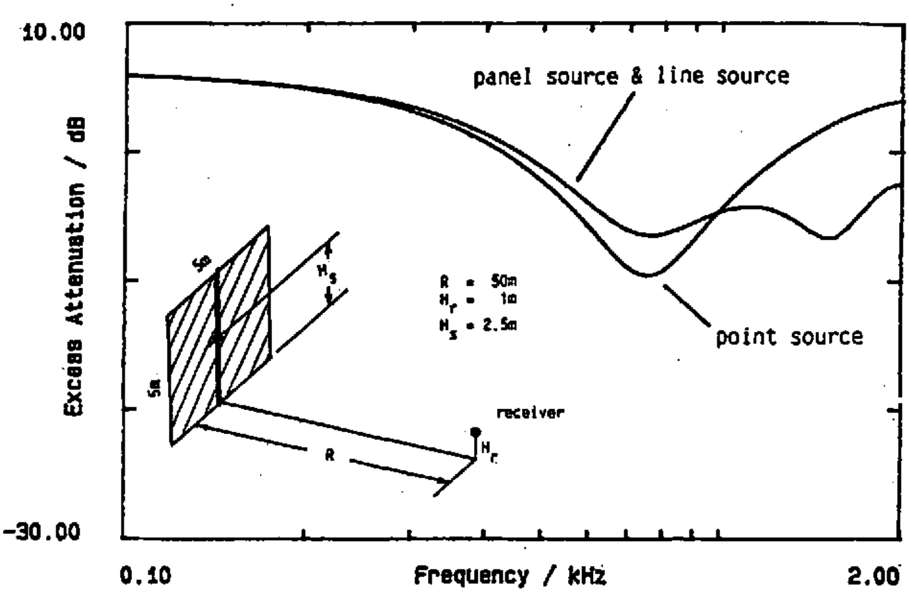


Figure 2 : Predicted excess attenuation at 1m above ground due to a 5mX5m panel in the vertical y-z plane with horizontal separation of 50m. (The predicted excess attenuation due to equivalent point and line sources of similar geometry are also shown for comparison.)

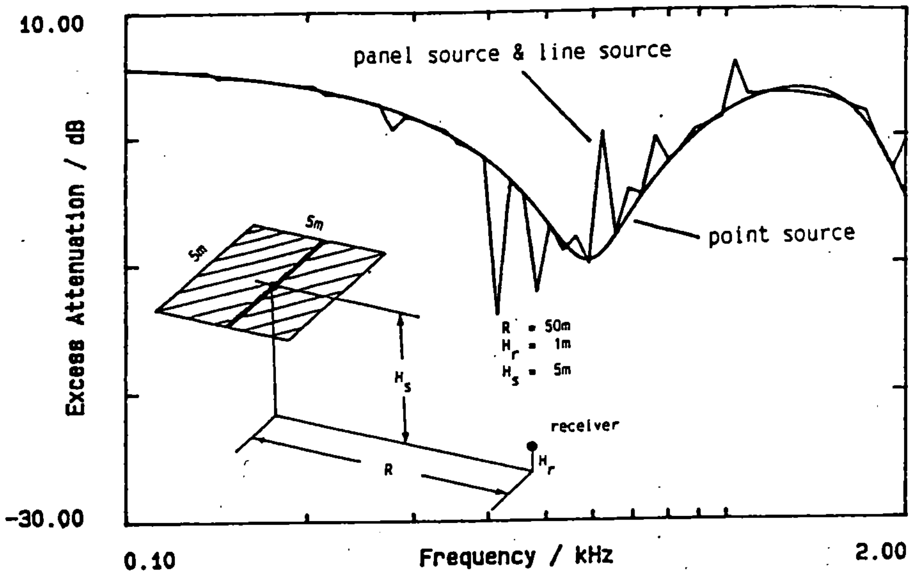


Figure 3 : Predicted excess attenuation at 1m above ground due to a 5mX5m panel in the x-z plane at 5m above ground and 50m separation.(The predicted excess attenuation due to equivalent point and line sources of similar geometry are also shown for comparison.)

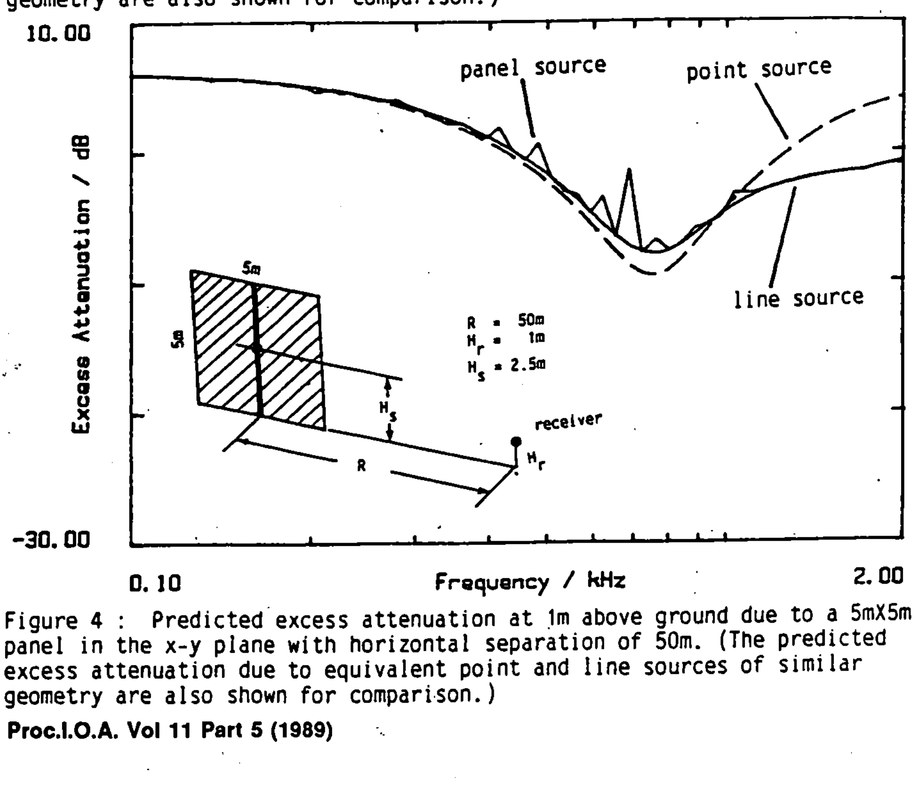


Figure 4 : Predicted excess attenuation at 1m above ground due to a 5mX5m panel in the x-y plane with horizontal separation of 50m. (The predicted excess attenuation due to equivalent point and line sources of similar geometry are also shown for comparison.)

# REVERBERATION AND ATTENUATION BY TREES: MEASURED AND MODELLED

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## SUMMARY

Measurements of vegetation structure, micro-weather and sound transmission were performed in a pine forest. Sound transmission over 100 meters appeared remarkably constant during a full week, whereas a ray tracing model that neglects tree scattering predicts considerable variations as a consequence of sound speed profiles. This leads to the conclusion that within the forest the tree scattering predominates over meteorologic effects.

A stochastic ray tracing model was built that neglects meteorology and ground, but accounts for scattering by the tree trunks and for air absorption. Measured reverberation and attenuation could be explained tolerably well by fitting the effective scattering diameter and reflection coefficient of the trunks. Results at elevated measuring heights however suggest that tree scattering and ground reflection interact so strongly that separate modelling of the two phenomena is not realistic.

## INTRODUCTION

Sound transmission through a forest is the resultant of possibly interacting phenomena like geometrical spreading of sound, reflection at the ground, scattering and absorption by vegetation, atmospheric absorption, and refraction due to sound velocity gradients.

Most models described in literature neglect one or more of these phenomena and consider the effect of the others to be additive. Especially the neglect or misunderstanding of the ground effect has led to considerable confusion concerning the effect of vegetation. It is now generally recognized that any model of outdoor sound transmission near to the ground should include a description of the interference of direct and ground-reflected sound.

Scattering by vegetation has been modelled by considering the forest as a random array of infinitely long parallel cylinders without canopy or ground ([3], [8], [2]). Price et al [9] demonstrated that a combination of a ground effect model and a tree scattering model can fit quite well to level difference measurements in various forests. The assumption in their composite model was that the effects of tree scattering and ground reflection are additive, and that interference effects are not relevant above a frequency of 2000 Hz. Also, isothermal windless conditions were assumed.

Huisman [4] studied the effect of meteorology by using a ray tracing model for a stratified medium. Temperature profiles were input that are typical in and over vegetation. Here, ground absorption, interference, and scattering by vegetation were neglected. It was shown that both the night and day profiles occurring in the canopy of a closed forest lead to a downward refraction of sound rays. However, no empirical data existed to verify this finding.

REVERBERATION AND ATTENUATION BY TREES: MEASURED AND MODELLED

This study combines predictions by models of ground effect, meteorologic effects and tree scattering with measurements of micro-weather, excess attenuation and reverberation. Its aim is to verify the models as well as to consider whether simple addition of their effects is acceptable.

## MATERIAL & METHODS

The measurement site was a 29-year old stand of Pinus nigra on a sandy, completely flat ground covered with a thick layer of needles in various states of decomposition. Vegetation structure was horizontally very homogeneous (Fig. 5). Cut-off dead branches still carrying needles and sparse, low undergrowth covered together about 30% of the ground. Tree height was 11.90 m (SD 0.90m) with trunk diameter of 0.16m (SD 0.04m) at 1.50m height. Trunks were bare up to 2.20m, carried dead bare branches up to 7m and above that a crown with projected cover 79% transmitting 8% of the day light. Trunk density was 0.19 trees/$m^2$, average horizontal visibility at 1.50 m height was 36 m.

Temperature, wind, and irradiation were measured along a mast extending 3m over the tree tops. A single loudspeaker with cone height 1.00 m produced a variety of signals, of which only the pink noise and logarithmic frequency sweeps are treated here. The sound was received by two microphones at 10 m distance and four at 100 m distance. Received signals were both analyzed real-time and stored on AM tape for later analysis. A Norwegian Electronics RTA 830 two-channel 1/3 octave band real time analyzer was used in transient mode. With the appropriate software, the analysis of the frequency sweep yields 40 equivalent sound levels per octave with an inaccuracy of at worst 1/80 of an octave. Rearranging these levels into 1/3 octave bands gives the same result as the 1/3 octave band analysis of the noise, within 1 dB.

Measured spectra are presented as true excess attenuation by subtracting the free field spectra and correcting for air absorption. The high and mid frequency parts of the free field spectra were measured in an anechoic room, whereas the low frequency part was deduced from measurements over asphalt.

## METEOROLOGIC EFFECTS

A striking resemblance occurs in the measurements performed under various weather conditions. At the largest measuring range, 100 m, no systematic difference in the 1/3 octave band 10-minute Leq spectra could be found. Non-averaged sound transmission measurements demonstrate that rapidly varying temperature effects do occur [5], but apparently the effects cancel out in the averaging process.

A ray tracing model [6] was used to study the possible influence of the measured temperature and wind prnfiles (shown in [5]). This yielded the prediction that most of the profiles may at best exert an influence at much larger distances or at higher receiver positions. Only the pronounced air temperature maximum in the canopy at sunny weather may well cause converging of sound rays (and therefore enhanced levels) at distances short as 100m. As described above, in reality there was no such enhancement.

This apparent invalidity is believed to originate from the assumption of a homogeneous stratified medium which is made in this ray tracing model. Possibly, it is invalid in a forest: the effect of trees and branches on sound propagation direction may well be larger than the effect of gradients.

## GROUND EFFECT

Together with the measured excess attenuation, figure 1 shows the excess attenuation $A_e$ for isotherm windless conditions as modelled by the Weyl-van der Pol approximation in combination with the variable porosity impedance model [1]. The two parameter values for the impedance model were chosen to make a best fit to the shape and position of the low frequency flank of the ground dip. The choice of the impedance model and the values of the parameters hardly influence the mid- and high frequency part of the curve.

It appeared to be possible to find parameter values that yield reasonable fits to the low frequency part of all measurements for all geometries. In the mid and high frequencies the ground model is clearly insufficient. At 10 m from the source the predicted interference pattern is disturbed, most probably by an overlaying interference pattern caused by reflection at the tree trunks. For pure tones, this pattern is very well audible [5]. At the 100 m range the ground effect is gradually overshadowed by a vegetation effect from a frequency of 500 Hz upwards.

If ground interference is not to be included in the model predictions, the ground model may still be used with the modification that direct and ground-reflected sound are summed incoherently. The resulting 'incoherent excess attenuation' $A_i$ is also drawn in the figure. In the high frequencies, in this experiment from 3000 Hz, where in the forest the ground interference pattern is disturbed, it is certainly more realistic. In the mid and low frequencies the coherent calculation clearly functions better.

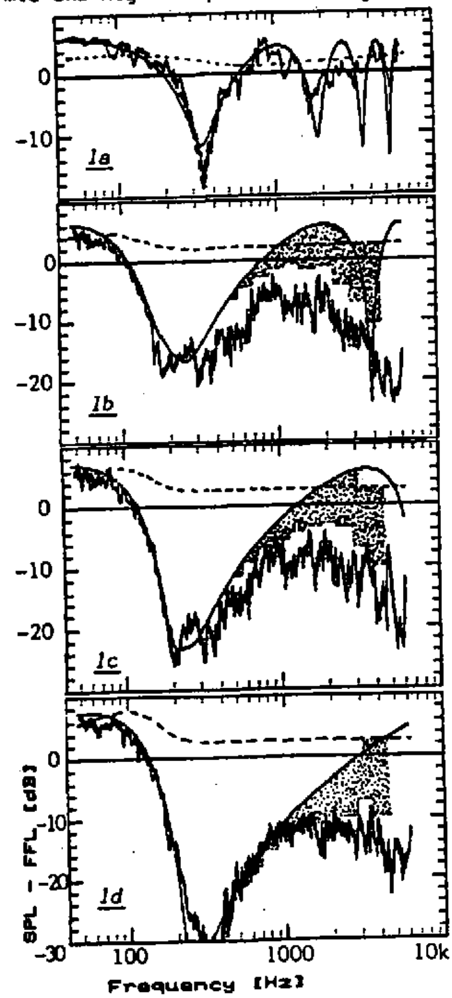



Figure 1 Measured and modelled excess attenuation.

Measurements of a logarithmic pure tone frequency sweep, normalized to free field and corrected for air absorption. Source height 1 m. Clear windless night.
Excess attenuation modelled by ground effect model:
Solid line: coherent ($A_e$); broken line: incoherent ($A_i$).
Parameters: Effective flow resistivity $\sigma_e$ = 30000 $Nsm^{-4}$; effective rate of exponential change of porosity $\alpha_e$ = 50 $m^{-1}$.
Line below dotted area: summed attenuation by stochastic scattering model and ground model (incoherent from 3000 Hz).
a Receiver at $r_r$ = 10 m; height 1 m. Average of 4 sweeps. The thick broken line ($\sigma_e$ = 20000 $Nsm^{-4}$; $\alpha_e$ = 25 $m^{-1}$) fits better at this geometry.
b-d: Receivers at $r_r$ = 100m; heights 4.50m (b); 2.50m (c); 1.00m (d). Four sweeps made within ten minutes.

## A MODEL OF REVERBERATION BY TREE TRUNKS

The well audible reverberation in a forest demonstrates the scattering effect of the trees and branches. Partly following Kuttruff [8] a model was defined where the forest is represented by a random array of infinitely long parallel cylinders scattering sound particles from a point source. However, instead of calculating algebraicly with probabilities, a stochastic ray tracing program was built [7]. This had the advantage that no secondary assumptions had to be made apart from the usual geometrical acoustics approximation. (The assumptions in [8] necessary to derive the decay equation for a forest are so that it is hardly applicable in practical situations, as is shown in figure 2)

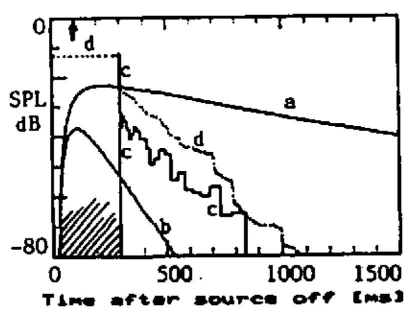
Besides the <u>source-receiver range</u> $x_r$, four parameters are relevant for the pulse response curve (figure 2). These are the <u>air absorption</u>, to be applied in dB/s; the <u>density of the forest</u> n, in trees/m²; then the <u>effective tree diameter</u> $D_e$, which will only equal the actual tree diameter in the high frequency limit; and the <u>effective reflection factor</u> $R_e$, which is the factor of energy loss of a ray after specular reflection on the tree (for ideal hard cylinders, $R_e = 1$).

The pulse response predicted by the stochastic model consists of two parts, the 'direct sound field' and the 'reverberant sound field'. To compute the direct field the numerical technique is not necessary. It is built up by the rays that have not hit any tree before reaching the receiver. These rays all arrive at the same time, which is simply the source-receiver range divided by the sound speed. Therefore, the direct field is a pulse with known energy but undefined intensity since its duration is 0. This energy $E_d$, normalized to the free field (no trees) energy $E_f$ is found analytically by just accounting for the shielding effect of the trees. It can be expressed in decibel as the <u>direct field attenuation</u> $A_d$:

$$A_d = 10 \log ( E_d / E_f ) = 10 \log ( \exp (- n D_e x_r) ) \quad \text{dB}$$

The reverberant field is built up by rays that have one or more times hit a tree. Its energy is the integral of the pulse response minus the direct field energy. The pulse response shape as well as its energy depend on all four parameters mentioned above. However, the range is hardly important for the reverberant part of the pulse response.

<u>Figure 2</u> Modelled reverberation
Parameter values: range $x_r$ = 100m; density n = 0.19 trees/m²; scattering diameter $D_e$ = 0.16 m; air absorption 10 dB/s; sound velocity c = 333 m/s.




<u>a+b</u> Pulse response as modelled by [8]. Level normalization is arbitrary. Arrow indicates $t = 1/nD_ec$. Curves should be valid for $t \gg 1/nD_ec$. The hatched area denotes curve parts that are certainly incorrect (no sound can arrive before $t = x_r/c$). Reflection factor: $R_e = 1$ (<u>a</u>); $R_e = 0.1$ (<u>b</u>).

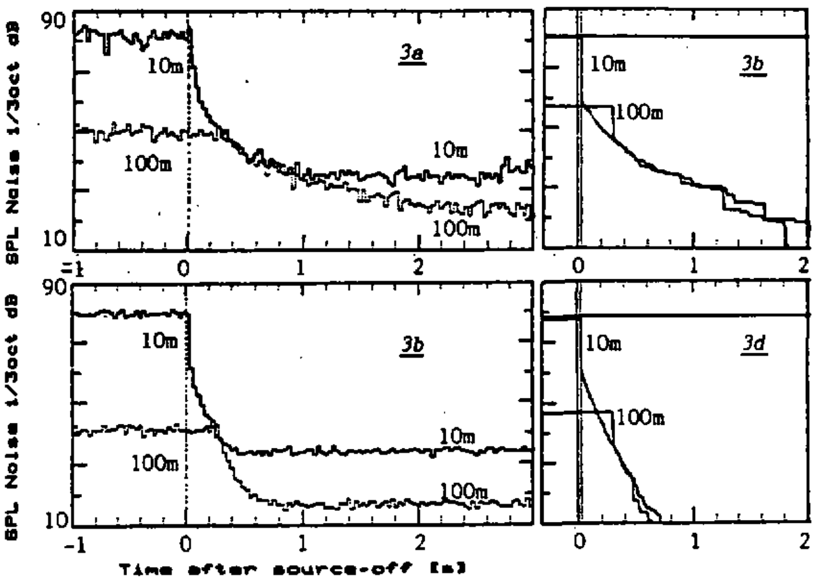
<u>c</u>. Pulse response generated by the stochastic ray tracing model. Intensity level is normalized to a free field intensity of one pulse per 5 ms.
Reflection factor $R_e = 0.1$. 20000 rays are computed.

<u>d</u>. Source-off response computed from line <u>c</u>. Source-on level and decay levels are normalized to the free field source-on level. The decay curve gives a good fit to the 4000 Hz measurement.

The <u>total scattering attenuation</u> $A_s$ (that is, due to the thus modelled scattering phenomenon, i.e. without ground effect) is found from the energy of the pulse response E and the free field energy $E_f$:

$$A_s = 10 \log ( E / E_f ) \quad dB$$

By summating a train of pulse responses in time, the response of a source switch on/off sequence is obtained (Fig. 2). The steady source-on level now equals the total scattering attenuation $A_s$.




<u>Figure 3</u> Measured and modelled reverberation.

<u>a+b</u> Simultaneously measured source-off response at range $x_r$ = 10 m (upper lines) and at $x_r$ = 100 m (lower lines), for 1000 Hz (<u>a</u>) and 4000 Hz (<u>b</u>) 1/3 octave band noise, analysed from tape recordings. In the background is apparatus noise of which the apparent level differs for the two receivers because of different microphone amplifications.

<u>c+d</u> Modelled source-off responses fitting to <u>a</u> and <u>b</u>. The parameter values that yielded the fits were found by overlaying model calculations over the adapted source-on level at $x_r$ = 10 m and over the concatenated decay curves at 10 m and 100 m. The adaptation made to the source-on level was the exclusion of ground interference effects.
Parameter values input: n = 0.17 trees/m²; air absorption 0 dB/s (<u>a</u>) and 10 dB/s (<u>b</u>).
Fitted values: reflection factor $R_s$ = 0.1 (<u>a+b</u>); scattering diameter $D_s$ = 0.04 m (<u>a</u>) and 0.16 m (<u>b</u>).
Also drawn are model predictions for $x_r$ = 100 m with parameter values found for $x_r$ = 10 m.
The difference between measured and modelled source-on levels at $x_r$ = 100m is considered as a ground effect.

## ANALYSIS OF MEASURED REVERBERATION

The measured source-off curves at 10m and 100m appear indeed to coincide shortly after the moment that the source-off event reaches the 100m receiver. (Figure 3)

A number of model predictions for $x_r$ = 10m was made with various values for the parameters $R_e$ and $D_e$, with n equal to the actual forest density. The modelled curves were laid over the measured curves, with the modelled source-on levels at the level of the measurement free field plus 2 dB. In this way the overall sound energy is regarded as the incoherent addition of direct sound and ground-reflected sound; i.e. the interference effect is taken out.

Table 1 summarizes the values for $R_e$ and $D_e$ that fitted best to the 1/3 octave band reverberation measurements. For practical reasons it was not attempted to find fits for all measurements. The decay curves change only slowly and very regularly with frequency, so the missing values may safely be interpolated.

The decrease of $D_e$ with increasing wavelength is quite reasonable (larger wavelengths hardly 'feel' the small trees). However, the value $R_e$ = 0.1 is very low even for the irregular cork-like bark of Pinus nigra. But as pointed out in [2], this parameter also accounts for scattering of sound out of the plane perpendicular to the cylinder axes, that is, for effects caused by the trees not being ideal cylinders.

With the found parameter values new model predictions were made for the range $x_r$ = 100m. The reverberant field fits very well, but the total scattering attenuation $A_s$ underpredicts the measured overall attenuation. This is not surprising, since forests do have a ground which may cause considerable attenuation due to coherent interference of direct and ground-reflected sound, which effect is not included in this essentially incoherent scattering model.

Table 1 Results of stochastic scattering model.

| | | | | | | |
|---|---|---|---|---|---|---|
| Parameters used for prediction of reverberation at $X_r$ = 10 m: | | | | | | |
| Reflection factor $R_e$ | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | |
| Scattering diameter $D_e$ | .01 | .02 | .04 | .08 | .16 | m |
| Air absorption | 0 | 0 | 0 | 3 | 10 | dB/s |
| Fit to measured decay curves of 1/3 oct band: | 500 | 630 | 1000 | 2000 | 4000 | Hz |
| Scattering attenuation predicted for $X_r$ = 100 m | | | | | | |
| Total scattering att. $A_s$ | -0.8 | -1.6 | -3.1 | -6.3 | -12.8 | dB |
| Direct field atten. $A_t$ | -0.8 | -1.7 | -3.3 | -6.6 | -13.2 | dB |

The low value found for the reflection factor of the trees causes the contribution of the reverberant field to the sound field to be minimal. The sound field even at 100 m is mainly due to the direct field. This may also be deduced from the measured decay curves at 100 m: the source-off event is very marked and causes a deep drop in sound pressure level. Therefore, the treating of the sound propagation in forests as a diffusion problem ([8], [2]) is at least at this range not suitable.

## COMBINING THE MODELS

Figure 1 shows the attenuation resulting from addition of the ground model and the scattering model predictions. For the receiver height 1.00 m, the correspondence between predicted and measured is quite good. However, for the highest receiver position, 4.50 m, correspondence in the frequency range 500 Hz to 2000 Hz is disappointing. The results of the other two microphones, 1.50 m (not shown) and 2.50 m, are in between.

In figure 4, results are presented as vegetation effect, either measured directly in an anechoic room, modelled with models neglecting ground effect, or deduced from measurements by subtracting the ground model prediction. From the forest structure, it is very unlikely that such a strong height dependence of the vegetation effect should occur: the pine plantation indeed looks like a random array of equal parallel cylinders (Fig. 5). Foliage effects are to be expected at much higher heights and then mainly in the high frequencies.

Therefore, it is concluded that the ground effect is influenced by the tree scattering to a much greater extent than just loss of coherence in the high frequencies. And since an accurate knowledge of the ground effect is needed to deduce vegetation attenuation from excess attenuation measurements, we cannot empirically verify models of vegetation effect.

A final remark on the old question of using forests to abate traffic noise. Figure 1 shows that the measured attenuations at 100m in the frequency range of interest (around 1000 Hz) are between -6 dB and -12 dB, which values appear to be valid for all meteorological conditions. Currently research is being done on the impact of this observation to traffic noise propagation prediction. This implies at least considering a line source, the traffic noise spectrum, A-weighting, and predicting the open field sound propagation including the there existing meteorologic effects.

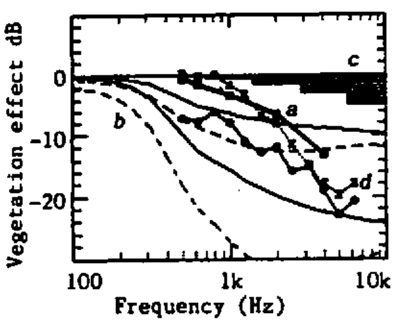



Figure 4. Ground-independent vegetation attenuation.

a Squares: Attenuation $A_e$ predicted by the stochastic ray tracing model (table 1).

b Attenuation predicted by the model by Embleton [3] as implemented by Price et al. [9]. Diameter 0.16 m, density 0.19 trees/m², range 100m.
Solid lines: hard cylinders; broken lines: $\sigma_e$ = 100000 Nsm⁻⁴.
Lower lines: original values; upper lines: reduced to 40% [9].

c Hatched area: Insertion loss by ten 4-year old sawn-off Pinus nigra trees in an anechoic room packed into a 'forest' of 2.00 by 2.80 m, height 1.85m, fresh weight 67 kg, stem diameter at the ground 0.05 m; horizontal transmission of light from source to receiver 0.5 % (= -8.2 dB/m).

d Measured vegetation effect, that is, difference between measured excess attenuation and modelled ground effect $A_g$ (over 3000 Hz: incoherent, $A_i$)
Crosses: receiver at 1.00m; Circles: receiver at 4.50m.

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Figure 5. Vegetation structure.

Left: side view of six soil profiles including covering material. Layers A to C are mineral.
Right: side view of a plot of 2m by 15 m with bare trunk zone, dead branches zone, and canopy.