VALIDATION OF AN OUTDOOR SOUND PROPAGATION MODEL IN PRESENCE OF TREES

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ABSTRACT

Following our research line, where we try to validate an outdoor sound propagation model, *Nord 2000* [2], we include in this paper new experimental results obtained in different woods, with different trees' density and different trunk diameters. This model considers, among other things, the effect of ground, the atmospheric absorption and two different effects associated to the presence of trees: scattering and screening. We have already compared the model to the experimental results obtained for poplar woods [1] and in this work we intend to validate the model for other species. We have performed measurements in five more woods with completely different characteristics. Some are natural oaks and pine woods and the rest correspond to farming woods from our region, the Castilla and León Autonomous Community, in Spain.

INTRODUCTION

With the purpose of validating the model we have made a great number of sound pressure level measurements in different types of forests with different species and different conditions: regular disposition, irregular, with leaves, without leaves, with deciduous leaves, with perennial leaves, with different density of trees and with trees of different trunk diameters. The results that we present in this paper correspond to three regular forests: catalpas, poplars and plane tree, and to two irregular forests: holm oaks and pines. The characteristics of all of them are shown in table 1.

	Catalpa	**2 year old poplar**	**Plane tree**	**Holm Oak**	**Poplar**	**Pine 1**	**Pine 2**
Type of leaves	Deciduous	Deciduous	Deciduous	Perennial	Deciduous	Perennial	Perennial
Density (trees/m^2)	1.33	1.33	1.33	0.2	0.042	0.027	0.0067
Diameter (m)	0.057	0.048	0.045	0.2	0.27	0.15	0.15
Height (m)	4	3	3	4	9	10	10

Table 1: Different woods parameters.

MODEL DESCRIPTION

As it was explained in [1] the model includes several parameters related to the measurement geometry, to the meteorological conditions, to the ground characteristics and to the specific characteristics of the woods. The sound pressure level L(r) in dB at a distance r (m) is given by the equation:

$$L(r) = L_w - 10\log(4\pi r^2) + K(Z) + Ae(r) + A_A \qquad (1)$$

Where L_w is the source sound power, $10\log(4\pi r^2)$ corresponds to the geometrical divergence, K(Z) is the correction factor due to ground impedance Z, Ae(r) is the attenuation due to the scattering effect and A_A the attenuation due to the air. Ground and scattering effects can be added according to the following expression:

$$K_{gr+sc} = 10\log[\,(1-kf\cdot T)\,\left|1+pr\right|^2 + kf\cdot T\,(1+\left|pr\right|^2)\,] + kf\cdot T\cdot kp\cdot Ae(r) \qquad (2)$$

EQUIPMENT AND MEASURMENT PROCEDURE

The measurement equipment was basically the B&K 4224 sound source, the B&K 2260 and the B&K 4230 sound calibrator.

We have followed a similar procedure for all cases. The source and the receiver where placed inside the forest at 0.8 and 1.2 m height respectively. We measured the Leq of one minute for the following source-receiver distances: 2,10,20,40,60 y 80m.

In the regular forests, the imaginary line from the source to the receiver point was parallel to the tree lines, and in the middle of two consecutive tree lines.
The experimental sound pressure level referred to free field is given by equation (3) where Lp_d is the sound pressure level measured at a distance d from the source and L_w is the source sound power.

$$\text{SPL re free field} = Lp_d - Lp_{free}\text{ field} = Lp_d - L_w + 10\log 4\pi d^2 \qquad (3)$$

MEASUREMENT ENVIRONMENT DESCRIPTION AND RESULTS

Results are shown in different graphs where we represent the sound pressure levels re to free field, in dB (experimental and predicted by the model with and without trees), versus frequency and for each of the source-receiver distances.

In order to obtain the results given by the model, we must introduce all the required parameters and, for each source-receiver distance, we have adjusted the ground flow resistivity, σ, in order to obtain the best fit between the theoretical and the experimental results. What we do it to find the σ value that leads a better correspondence in the widest frequency range and keeping in mind that the first interference dip must appear at the same frequency for both curves. We have found a different σ value for each source-receiver distance. This can be due to the fact that depending on the ground extension that is considered, σ may vary a little as shown in table 2.

	FLOW RESISTIVITY RESULTS (KNS/m^4)									
	CATALPA		2 YEAR POPLAR		PLANE	PINE(1)		PINE(2)		OAK
d(m)	Summer	Winter	Summer	Winter	Summer	Summer	Winter	Summer	Winter	Summer
2	30	400	50	500	200	30	-	20	50	20
10	300	600	250	300	300	-	-	-	130	30
20	50	600	200	200	160	100	-	100	100	40
40	60	250	110	250	90	50	50	90	80	40
60	35	250	80	250	110	50	-	60	70	-
80	60	300	-	220	-	40	65	60	60	-

Table 2: σ (kNs/m^4) for different sound-receiver distances d(m) and for different types of woods.

Regular Forests

We include in the group of regular forests those where the trees were artificially planted and thus evenly distributed. All these woods had deciduous leaves. In some of these woods we have performed measurements both in summer and winter in order to obtain some information concerning the effect of leaves. The trees were two and three years old and were planted in rows 1.5 m apart. Within each row the distance between two consecutive ash trees was 0.5 m.

The ground was made just of clean and soft earth, frequently watered and that was easily crushed while walking over it.

Catalpas Forest

This forest was planted in a rectangular field with dimensions 12.8 m by 100 m. The leaves were rather big, around 200 cm^2.

Looking at the results it can be concluded that:

- At short distances (2, 10 y 20 m) the model predicts accurately the frequencies where the maxima and minima appear in the curves. For 20 m distance the model predicts a higher attenuation than the one observed in the experimental values.
- For distances of 40, 60 y 80 m, and from 100 Hz to 1600 Hz the predicted values correspond very well with the experimental values. Above 1600 Hz experimental values are always higher that the predicted values. This means that, in general, the model yields higher attenuation than the experimental results. This can be due to the fact that the sound scattering effects associated to the presence of trees increases with the source-receiver distance and become higher at higher frequencies.
- The σ values found are shown in table 3. Except for the measurement at 10 m distance, the summer σ varies between 30 y 60 KNs/m^4, and in winter between 250 y 600 KNs/m^4. It is clear that impedance is then higher in winter time. The reason for this variation can be due to the hard rigid ground that can be found in a winter day, after a freezing night, whereas in the summer time, the ground is frequently watered and softer.

Two year-old poplar forest

This forest was planted in a square field of 100 m side. In the sunny and windless days it is possible that the temperature gradient creates certain sound shadow areas. This shadow areas can be observed in certain figures when at medium and high frequencies the experimental values follow a parallel curve to the one given by the model starting from the minimum of the curve, but shifted down, (the experimental values are much smaller that the predicted ones). This is what happens for 60 and 80 m in the case of the trees without leaves. See figure 1.

In this forest it is observed again that the σ values turn out to be smaller for the situation where trees have leaves than without them. It is also observed that, except for anomalies, the values tend to diminish with the distance.

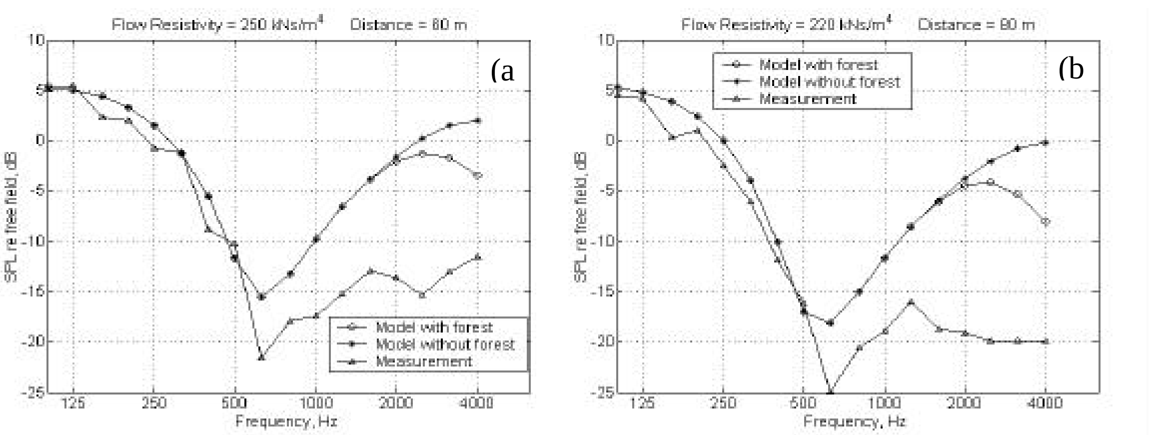

Figure 1: Two year-old Poplar

Plane trees forest

This forest was planted in a rectangular field 100 m long by 20 m wide.

The agreement between the theoretical and the experimental values is better at 40 and 60 m than for short distances, 10 y 20 m. The minimum experimental value is always smaller than the minimum value calculated by the model.

The flow resistivity values for each of the measuring distances are shown in table 2. It can be seen that the trend is to smaller flow resistivity values for longer distances.

Irregular Forests

In the group of irregular forests we include those where the trees are spread randomly in a non homogeneous distribution. These forests have trees of perennial leaves

Pine forest

This was a not too big extension (1000 m^2 approximately) with randomly spaced pine trees, and with different heights and trunk diameters. In this forest there were two clearly different zones according to the tree density, which we will from now on refer to as pine 1 and pine 2 respectively. Measurements were made both in summer and winter time.

From the analysis of all the results it can be deduced that the model predicts the same values with and without the forest, for all source-receiver distances. That is, the attenuation values do not depend on the presence of trees in this case. This is certainly due to the small trees density found in this case.

As it can be seen in figure 2 a, for pine 2 and for 40 m distance, the agreement between the experimental values and the predicted by the model is very good for all the frequencies. This is an evidence of the good fit between the model and the experimental results in this specific case. For 60 and 80 m, according to figures 2 c y d, the model makes a good prediction for low and medium frequencies. However, at high frequencies the experimental data are much smaller than the predicted ones, reaching even 5 dB difference at some frequencies. We believe that the reason for this divergence is that although the trees really attenuate sound propagation, the model does not take this effect into account due to the small tree density value.

The values of the σ are low in all cases and very similar both in summer and winter, as it can be seen in table 2. From 10 m distance, σ values decrease as source-receiver distance increases.

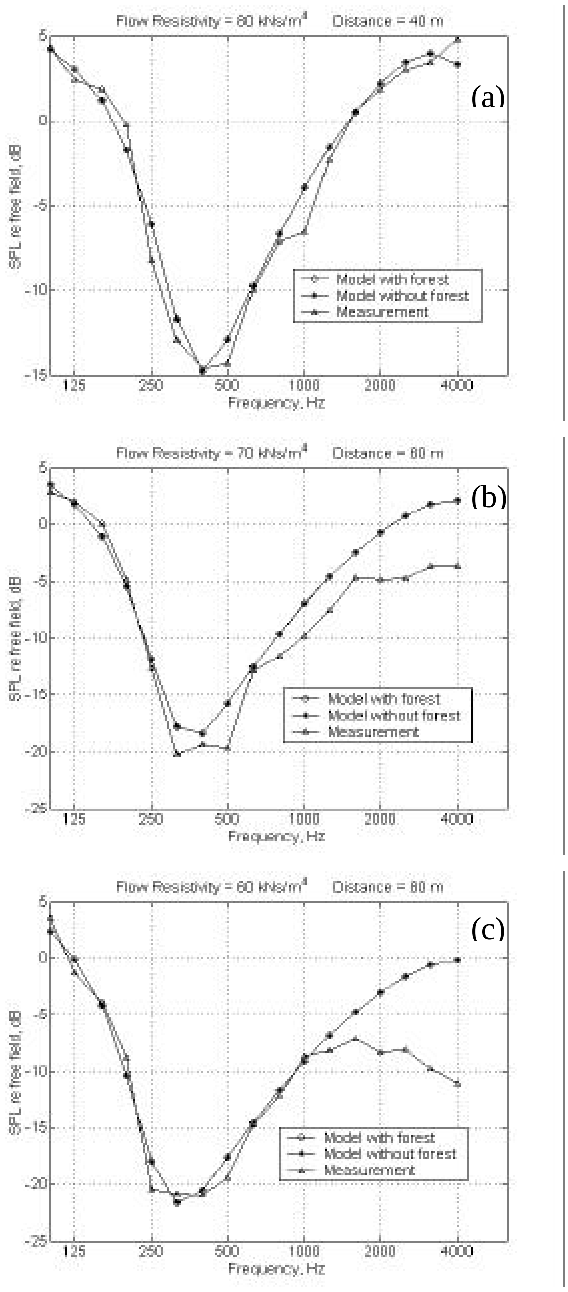

Figure 2: Pine 2

Holm oak forest

This forest can be described as a big extension of holm oaks where the ground was covered by a thick layer of dried grass and oak leaves of about $3cm^2$. The depth of this covering layer was estimated to be of 5 cm. The holm oaks were randomly distributed and were very different among them.

In this forest, the results predicted by the model for 40 m distance show a very good agreement with the experimental values, except at 1000 Hz (See figure 3). It can also be seen that, for high frequencies, there is a considerable difference between the results given by the model considering the presence of trees or not. This difference reaches even 6 dB in some cases. Also, at high frequencies the excess of attenuation due to the forest predicted by the model is in perfect agreement with the experimental data. This result is interesting since it did not occur in the previous cases. A possible explanation is that in this holm oaks forest, both the trees' density and the trunks' diameter had a big value and thus the presence of the trees has a greater effect in the model and in the experimental results, specially at medium distances such as 40 m.

The σ values obtained for each distance are shown in the table 2. The values are very low, between 20 and 40 kNs/m. These results seems to agree with what a priori could be expected since the ground was very porous.

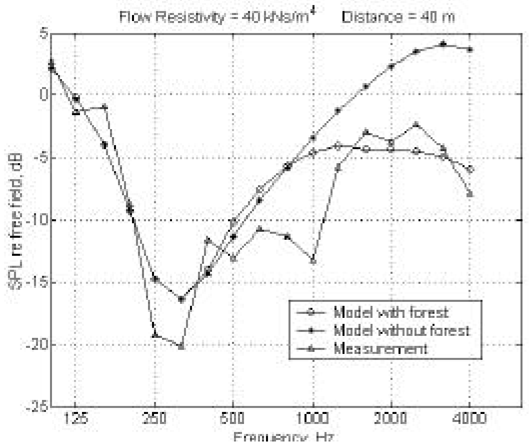

Figure 3: Holm Oaks

DISCUSSION

a) Concerning the minimum values shown in the curves which are associated to the destructive interference between direct and ground reflected sound, we can conclude that:

- The amount of minima shown by the model corresponds with those obtained in the experimental curve. This number decreases as the distance source-receiver is increased. For d= 2 m and d= 10 m there are three minima while for d= 20 m there are only two and for d>20 m there is only one minimum.
- Both the model and the experimental results confirm that the minima become deeper as the distance is increased.
- For a fixed source-receiver distance, if the σ decreases the minima shift to a lower frequency.

b) When the σ values are adjusted so that the first theoretical and experimental minimum coincide, the σ becomes a function of the absorption and it can be seen that:

- σ values decrease as distance increases.
- Forests with trees with perennial leaves yield similar vales for σ both in summer and winter.
- Forests with trees with deciduous leaves have σ values smaller in summer (with leaves) than in winter (without leaves).

This can be due to the fact the effect of the leaves' absorption is "included" in the σ, since is the only parameter that takes into account all the effects simultaneously.

c) If we compare the results given by the model taking the presence of trees into account with the results given by the model without considering the trees, we observe that:

- The divergence between the attenuation values given by the model with and without forest is visible above certain "critical frequency" which seems to depend on the forest characteristics ad the source-receiver distance.

- If the trees' density is rather small (0.027 trees/m^2) there is no significant difference between the attenuation values predicted by the model with and without trees. As trees' density increases (0.042 trees/m^2) and with a trunk diameter of approximately 0.27 m, attenuation difference show up starting at 40 m source-receiver distance. The trees attenuation turns out to be negative at medium frequencies and positive at high frequencies.
- For slightly higher trees' density (0,2 trees/m^2) and trunks' diameters of 0.2 m, the attenuation differences become important starting at 20 m distance, reaching up to 8 dB for 40 m distance and at high frequencies.
- If the trees' density is high (1.33 trees/m^2), even with rather small trunk diameter, 0.05 m, we can observe big differences at high frequencies from 40 m distance.

The final conclusion is that the trees' density is the variable which has greater influence in the values predicted by the model.

d) If we compare the experimental results with the model values, we can conclude that:

- In most cases, the attenuation values predicted by the model fit rather well with the experimental results, especially at low and medium frequencies. At high frequencies there is certain divergence between experimental and theoretical values, and the trend is not clear since in some cases the predicted values are above the experimental values, and in other cases they are below.
- For each kind of forest there is a source-receiver distance (between 40 and 60 m) where the agreement between the experimental and the predicted values is almost perfect in all the frequency range.

d) Looking at the experimental values we can see that:

- The excess of attenuation associated to the presence of trees, which appears only at high frequencies, is observed when the source-receiver distance is above 40 m.
- For the pine forests, the model does not predict the excess of attenuation due to the forest, but the experimental values show this effect for distances above 60 m.
- The agreement between the experimental and the theoretical values is very good for evergreen oak forests, starting even at shorter source-receiver distances than in the other types of forests.

CONCLUSIONS

With this research we have proved that the model predicts accurately the frequencies where the maxima and minima sound pressure levels referred to free field appear. For low and medium frequencies the model agrees very well with the experimental results, although at higher frequencies the agreement is not so accurate.

When the model predicts a different behaviour with and without forest, this divergence appears for distances above 40 m, except for one specific case where the trees had a bigger trunk diameter and this different behaviour appeared already at 20 m distance. The frequency above which the difference appears, decreases as the source-receiver distance increases, for each type of forest.

It has been observed that in forests with rather high trees' density, but with thin trunk diameters, there is no difference between the values predicted by the model with and without forest at short distances. The divergence can only be found for distances above 40 m and frequencies equal or above 2000 Hz.

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