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EXPERIMENTAL STUDY OF ROAD TRAFFIC NOISE CONTROL BY A PINE FOREST

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ABSTRACT
In order to precisely bring to the fore the effect of meteorology on sound propagation through forests, an important measurements campaign has been carried out in the French Landes forest mainly composed of pine trees. The originality of the experiment is that road traffic noise and meteorological conditions have been measured simultaneously for both a forest situation and a plain situation, this for different positions of the receiver. All valid measured data have then been classified according to three propagation conditions: favourable to propagation, unfavourable to propagation and homogeneous conditions. As expected, the results depend on these conditions. In favourable conditions, the gain brought by the forest is between 3 and 5 dB(A) with the receiver at least 100 m away from the road. This meteorological situation occurs very often at night due to a temperature inversion phenomena. Moreover, it is of most interest since it corresponds to the periods when the annoyance due to the road in a plain situation is the highest. In unfavourable conditions, the forest may increase somewhat the received sound level. In homogeneous conditions, the sound propagation through the forest is not appreciably affected by meteorology anymore but only by the scattering by the trunks and foliage. Finally, these results have permitted to validate a new calculation method for the attenuation of road traffic noise by forests based on a fast implementation of the Parabolic Equation.

1 - INTRODUCTION
In order to precisely bring to the fore the effect of meteorology on sound propagation through forests, an important measurements campaign has been carried out in the French Landes forest mainly composed of pine trees [1]. The originality of the experiment is that road traffic noise and meteorological conditions have been measured simultaneously for both a forest situation and a plain situation, this for different positions of the receiver. All valid measured data have then been classified according to three propagation conditions: favourable to propagation, unfavourable to propagation and homogeneous conditions. As expected, the results depend on these conditions. The measurement campaign have also permitted to validate a new calculation method [1-4] for the attenuation of road traffic noise by forests based on a fast implementation of the Parabolic Equation.

2 - PRESENTATION OF THE EXPERIMENT

2.1 - Description of the site
The site is along the national road RN10 (2 lanes) 30 km Southwest from Bordeaux, France. The measurement area is composed of a wooded zone and an adjacent deforested zone (called plain hereafter). The road is straight and oriented NNE/SSW with dominant east-west winds. The wooded part is made of pine trees with an average height of 11.83 m, an average circumference of 53.1 cm and a density of 0.1078 trunks/m^2. First row of trees is about 40 m from the road. Measurements zones are east from the road.

2.2 - Description of the measurements
The period of measurements was 16-29 June 1999. Four microphones were located 2 m high on the plain 150 m from the forest at different distances from the road: 50, 100, 150 and 300 m. On the other hand,

a set of four microphones were positioned 2 m high within the forest, at the same 4 distances. These 4 positions correspond to a forest depth of 10, 60, 110 and 260 m respectively. At these 8 measurement points were recording every second, day and night, the LAeq (1s) as well as the 3rd octave band SPL spectrum.
In order to get wind speed and temperature vertical profiles in simultaneity with acoustic measurements, two meteorological masts, 20 m high, have been installed 150 m inside the forest and inside the plain. The masts were equipped with 3 bi-directional anemometers located 3.7, 9.7 and 20.7 m high, and 4 temperature probes installed 1.5, 3, 9 and 20 m high. The measurement frequency was 1 second but the recording of data was achieved every 2 minutes (mean wind speeds, mean wind directions, standard deviations and mean temperatures).
Road traffic was measured by means of a counting loop on the road. During the measurement period, the mean flow was 2200 vehicles per day, for each of the two lanes, with 5% of heavy trucks. The mean speed of light vehicles was 85 km/h.

3 - RESULTS

3.1 - Meteorological classification

In order to underline the influence of mean meteorological parameters, the meteo-acoustical conditions have been determined from a criterion corresponding to a wind speed of ±1 m/s 10 m high with no temperature gradient. First, from the temperature and wind measured data, a mean logarithmic-type sound celerity profile [5] have been determined every 2 minutes and the calculation of theoretical sound level have been led for each 150 and 300 m away receiver.
The conditions of propagation have then been classified as:

- favourable (to acoustic propagation) if the calculated level was greater than the one calculated with the criterion 1 m/s 10 m high for a fair wind,
- unfavourable (to acoustic propagation) if the calculated level was greater than the one calculated with the criterion 1 m/s 10 m high for an adverse wind,
- homogeneous otherwise.

Globally, at daytime (0600-2200), occurrences were 52.6% for favourable conditions, 8.7% for homogeneous and 38.7% for unfavourable ones. At night (2200-0600), we got 93.3% favourable and 6.7% homogeneous (no unfavourable conditions). These values are close to those given by the NMPB French method [6] where they have been calculated from an average over 10 years of meteorological data (Bordeaux region, direction source-receiver 260°: 41% favourable at daytime and 95% favourable at night). Though this measurements campaign is of short time, it represents quite well a long term situation.

3.2 - Attenuation due to the forest

The efficiency Δ_{dm} of the forest strip compared to the plain situation for a receiver located at $d = 100$, 150 or 300 m from the road is referred to the measurements at 50 m and is given by:

$$\Delta_{dm} = (LAeq_{forest,dm} - LAeq_{forest,50m}) - (LAeq_{plain,dm} - LAeq_{plain,50m}) \quad (1)$$

The first observation is that in favourable conditions, the mean measured forest efficiency is about -2 dB(A) at 100 and 300 m, and -3 dB(A) at 150 m. This phenomenon is mainly due to the decreasing or cancellation of the positive temperature gradient inside the forest, especially at night. As expected, the efficiency seems to increase with the width of the forest strip; however, the value at 300 m is lower than the one at 150 m for two main reasons: first, a distortion due to a too high electronic background noise (cable length > 100 m) and second, a too small acoustic signal-to-noise ratio observed at this large distance from the road. Noise from the forest (as bird songs, foliage noise) have also to be taken into account.
In homogeneous conditions, the mean efficiency is -2 dB(A) at 150 m. However, this meteorological situation being rarely encountered, the data generally correspond to only something like 20 minutes of data making somewhat difficult the interpretation of results.
In unfavourable conditions, the mean efficiency is -1 dB(A) at 150 m. This negative value does not correspond to the expected one; indeed, the GFPE calculation predicted a positive value of the efficiency, that is an increasing of sound level in a forest situation compared to a plain one. Again, a small signal-to-noise ratio made difficult the acoustic analysis.

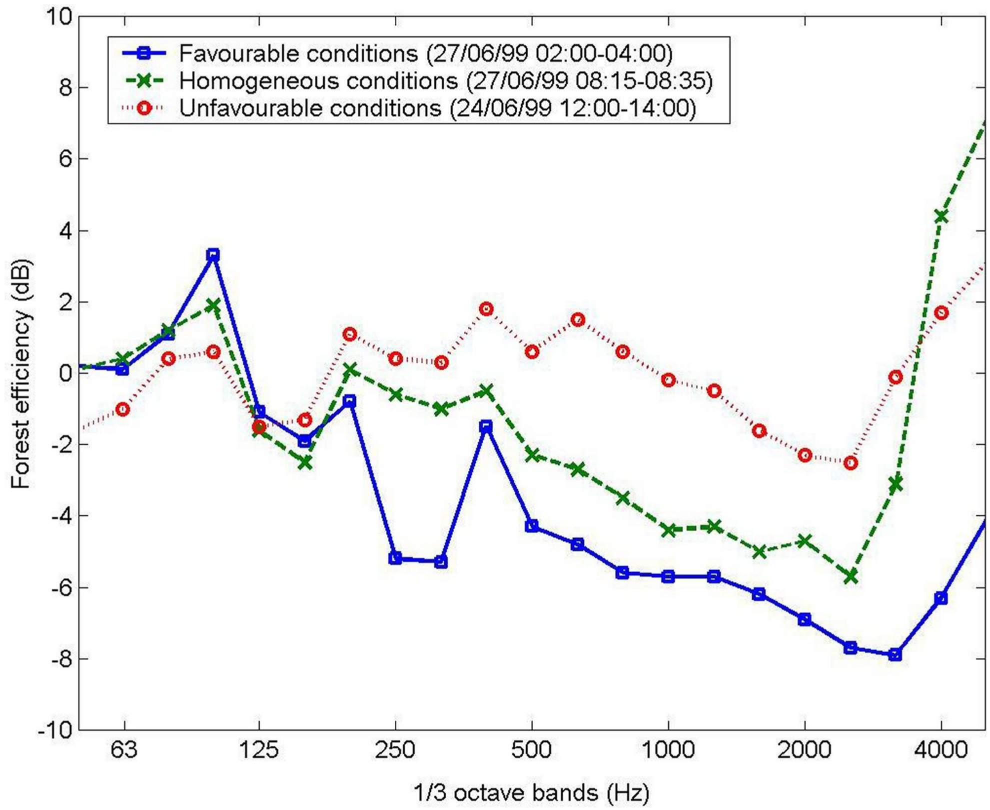

Figure 1: Example of comparison of mean SPL 3^{rd} octave bands spectra for the 3 different meteorological conditions and for the receivers 150 m from the road.

Figure 1 gives an example of results for the receivers located 150 m from the road and for the 3 meteorological conditions (average efficiencies on 120 consecutive minutes for the favourable and unfavourable situations, and on 20 minutes for the homogeneous one).
It is of importance to notice that Δ_{150m} has been calculated in reference with the plain situation where the ground is very absorptive (recent deforested zone). If the comparisons were achieved with a harder plain ground, an increasing of the efficiency might be expected.

4 - VALIDATION OF THE GFPE CALCULATION CODE

A calculation prediction method using a fast implementation of the Parabolic Equation has been developed and presented in recent papers [1-4]. The ground impedance (considered to be identical in both plain and forest situations) has been evaluated from impulse measurements with an iterative method. The two parameter model from Attenborough [7] has been used here with σ_e = 13.6 kPa s m^{-2} and $\alpha_e = 3.8 \times 10^{-5}$ m^{-1}. The road line source is modelled as a series of equivalent point sources of height 0.5 m. GFPE calculations are made for each equivalent source by projecting the wind profile on the source-receiver direction. An example of comparison with measurements in favourable conditions (Fig. 2) shows a good agreement.
Table 1 sums up the measurements/calculations comparisons for the meteorological situations presented in Fig. 1. Agreement is good, except for the unfavourable condition.

	GFPE calculations	Measurements
Favourable	-5.5	-5.8
Homogeneous	-2.2	-3.6
Unfavourable	4.7	-0.2

Table 1: Comparison of forest efficiencies Δ_{150m} in dB(A) for the 3 different meteorological conditions corresponding to the situations presented in Fig. 1.

5 - CONCLUDING REMARKS

A measurement campaign achieved in the French Landes pine forest has been presented and results have

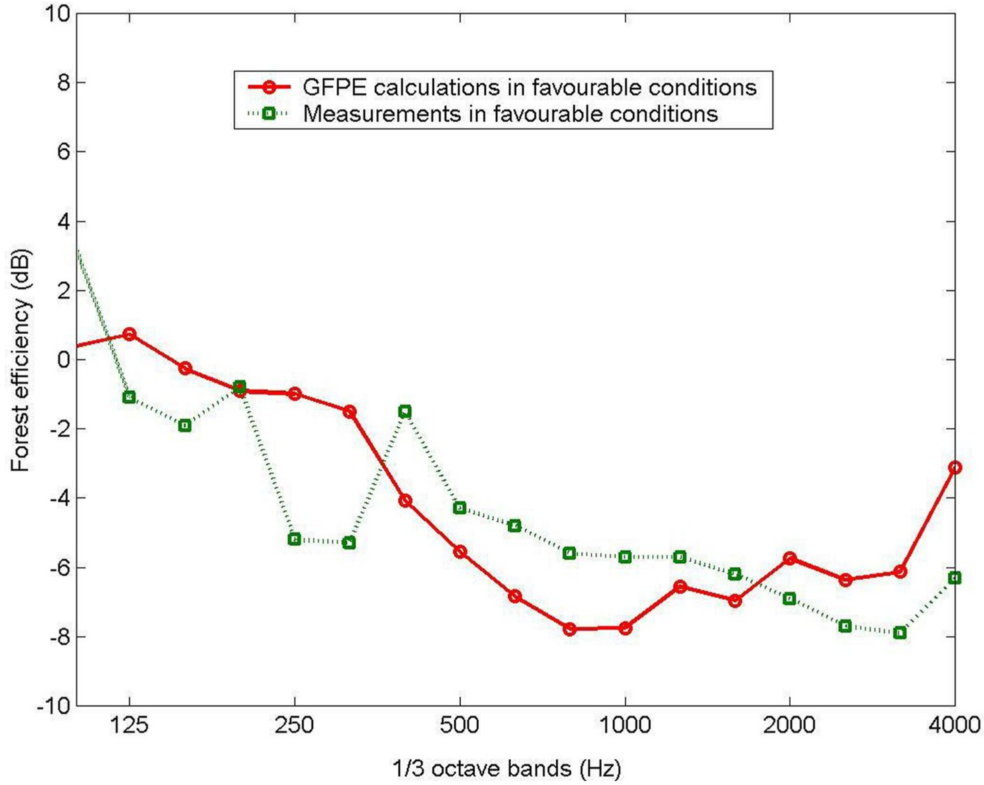

Figure 2: Comparison between measurements and GFPE calculations in favourable conditions (receivers 150 m from the road, 27/06/99 02:00-04:00).

been analysed. In favourable conditions, the gain brought by the forest is between 3 and 5 dB(A) with the receiver at least 100 m away from the road. This meteorological situation occurs very often at night due to a temperature inversion phenomenon. Moreover, it is of most interest since it corresponds to the periods when the annoyance due to the road in a plain situation is the highest. In unfavourable conditions, the forest may increase somewhat the received sound level at large distances but it is of less importance since levels are quite low. In homogeneous conditions, the sound propagation through the forest is not appreciably affected by meteorology anymore but only by the scattering by trunks and foliage. A forest strip of at least 100 m wide appears thus to be an efficient natural acoustic barrier. Lastly, the comparison of these results to those from a new method of forest attenuation prediction based on a fast implementation of the Parabolic Equation has shown a good agreement.

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