Classification of the Relative Influence of Physical Parameters for Long Range Acoustic Propagation

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1 Introduction

In 2003, the French Ministry of Ecology and Sustainable Development has asked many research groups for proposing projects in the framework of “Noise and Sound Annoyance”. The study of long range propagation was in the scope of the proposal.

EDF, LCPC, SNCF and ECL were all involved in a research working group and decided to answer to the proposal. The project called “classification of relative influence of physical parameters for long range acoustic propagation” started in 2004 April 1st. All the partners are familiar to noise propagation for different types of sources (road, railway and industrial). The target of this work is to study the relative influence of a whole set of parameters for different acoustical situations by using both experimentally and numerically results. The numerical sensibility studies have started. They aim at defining the suitable number of values and the range for each specific parameter. The numerical predictions will be done using « laboratory » models such as those developed by the partners. Besides, an important experimental campaign will be carried out involving dozens of microphones and a lot of meteorological sensors around a reference source under the influence of a variety of micrometeorological conditions. The results will provide a basis for a classification method for the main parameters in typical acoustical situations. One of the outcomes is to apply this classification method in standardization works in which most of the partners are involved.

2 Reference case

Among all the situations encountered in outdoor sound propagation, we choose to focus on micrometeorological effects above flat homogeneous ground.

All the cases will be derived from the reference configuration detailed on figure 1.
Where:

$S$ is an omnidirectional source; $R$ is a receiver; $h_S$ the height of the source; $h_R$ is the height of the receiver; $z$ is the elevation; $r$ is the distance between $S$ and $R$; $d$ is the horizontal distance between $S$ and $R$; $\sigma$ is the effective air flow resistivity (kNsm$^{-4}$); the ground effect is calculated by using the Delany and Bazley model for the impedance [1] and considering a spherical reflection coefficient [2]; $c_{eff}$ is the effective sound speed in the $SR$ direction; $\mu$ is the stochastic part of the refraction index of the atmosphere given by:

$$n(r, z) = \frac{c_{eff}(r, z)}{c_0} = \langle n(r, z) \rangle + \mu(r, z)$$  \hspace{1cm} (1)

Where $c_0$ is the reference sound speed (typical value of 344 m/s)

The sound speed profile is given by Eq.(2) and approximated with a log-lin function through Eq.(3):

$$\langle c(z) \rangle = c_0 \sqrt{1 + \left( \frac{T(z)}{273.15} \right)} \cos \theta$$  \hspace{1cm} (2)

and

$$c(z) = c_0 + a \log \left( \frac{z}{z_0} \right) + b z$$  \hspace{1cm} (3)

Where:

$T$ is the temperature (°K);

$u$ is the wind speed (m/s);

$\theta$ is the angle between the wind speed and $SR$;

$a$ and $b$ are respectively the log and lin parameters.

$\mu$ is calculated from the fluctuation $T'$ and $u'$ of respectively the temperature and the wind speed.

8 typical third octave band spectra (50Hz-4kHz) were defined to be able to estimate the influence of each parameter on the dB(A) level (the most popular impact criteria). These spectra are showed on figure 2.

Figure 2: Reference spectra. The spectra are normalized such as the overall level equals 0 dB(A).

BVTP, BVTA and BVAERO come from industrial sources database of EDF (transformers and cooling towers). ES, BBSG and BBDR come from road sources database of LCPC. TGV and CORAIL come from the railway source database of SNCF.

3 General method

The goal is to determine sensitivity of influent parameters in a given realistic situation. Starting with all the parameters varying together is not possible in a rigorous approach. Moreover, the number of situations to be considered is too large. Thus, we have to do preliminary studies which allow us to find a realistic discretization of all the parameters.

This is all achieved according to the error we fixed for the study which is +/- 1 dB(A) for all the types of spectrum we have previously defined above.

In each preliminary study, for each parameter, we define the “a priori” situation in which the variation of the parameter has the strongest influence on the result. The set of data we obtain allows to evaluate number of situations to take into account. It also determines the choice of the most relevant numerical approach and the setting of the experiments.

The working group has got all the numerical tools that allows to predict all the possible set of parameter for the reference configuration. The only obstacle is the required time. This is where experimental results can bring an alternative. Moreover, the experimental results will/could be used to validate some numerical approaches.

The last step, the conclusion of the study, consists in defining the method to group all the results in a data base, which will be useful for both scientific community and engineering end-users.
4 Variations ranges for each parameter

A variation range is fixed for each parameter:
- \( 0.05 \, \text{m} < h_S < 50 \, \text{m} \);
- \( 1 \, \text{m} < h_R < 10 \, \text{m} \);
- \( 10 \, \text{m} < d < 1000 \, \text{m} \);
- \( 100 \, \text{kNsm}^{-4} < \sigma < 3000 \, \text{kNsm}^{-4} \).

The limits are defined to be representative of the propagation of road, railway and industrial noise.

For the micrometeorological parameters, we choose to use Monin-Obukhov similarity theory for the determination of sound speed profiles. Thus, we have fixed the following limits values for \( u \) (wind speed), \( u^* \) (friction velocity) and \( H \) (sensible heat flux):

**Downward refraction**
- Wind: \( u = 0 \, \text{ms}^{-1} \) at \( z = 0 \, \text{m} \); \( u = 10 \, \text{ms}^{-1} \) at \( z = 10 \, \text{m} \); \( \theta = 0^\circ \)
- Temperature: \( u^* = 0.1 \, \text{ms}^{-1} \); \( H_{\text{night}} = 100 \, \text{Wm}^{-2} \)

**Upward refraction**
- Wind: \( u = 0 \, \text{ms}^{-1} \) at \( z = 0 \, \text{m} \); \( u = 10 \, \text{ms}^{-1} \) at \( z = 10 \, \text{m} \); \( \theta = 180^\circ \)
- Temperature: \( u^* = 0.1 \, \text{ms}^{-1} \); \( H_{\text{day}} = 500 \, \text{Wm}^{-2} \)

These limits values allow us to cover about 99% of the situations encountered in outdoor propagation included strong thermal gradients (black surface dry and smooth – strong radiation – no wind) and strong wind gradients (\( u = 10 \, \text{ms}^{-1} \) et \( \cos \theta = \pm 1 \) ) [3].

Figure 2 shows the variation range of sound speed profile derived from the previous assumptions.

Then we have to define:
- The number of frequencies to be calculated in each third-octave band;
- The discretization of the horizontal distance \( d \);
- The discretization of the effective air flow resistivity \( \sigma \);
- The discretization of the height of the source and the receiver respectively;
- The discretization of the effective sound profiles;
- The discretization of the parameter for turbulence effects (intensity \( \mu \)).

The following parts give some results of our first studies.

5 Discretization of the parameters

The discretization aims at defining the number of situations to be studied according to the variation range of each parameter and to the +/- 1 dB(A) error criteria.

5.1 Number of frequency points for each third octave band

We consider the case which leads to the strongest interference effect. This is total reflexion case. A reference result was constructed by using 50 frequencies geometrically distributed in each third octave band.

The number of frequencies which must be taken into account to get a estimation of the dB(A) level with the required precision depends on the nominal frequency and is given in table 1.

<table>
<thead>
<tr>
<th>Third octave band</th>
<th>( N_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 50 Hz to 160 Hz</td>
<td>1</td>
</tr>
<tr>
<td>200 Hz to 250 Hz</td>
<td>2</td>
</tr>
<tr>
<td>315 Hz</td>
<td>3</td>
</tr>
<tr>
<td>From 400 Hz to 630 Hz</td>
<td>4</td>
</tr>
<tr>
<td>From 800 Hz to 1250 Hz</td>
<td>5</td>
</tr>
<tr>
<td>From 1600 Hz to 2500 Hz</td>
<td>6</td>
</tr>
<tr>
<td>From 3150 Hz to 4000 Hz</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 1: \( N_p \) is the number of frequency points per third octave band.

Third octave calculation can then be obtained from monochromatic models with a limited (very acceptable) number of frequency points.

5.2 Discretization of the horizontal distance \( d \)

We consider the case which leads to the strongest decay in far field, i.e. when the effective air flow resistivity is fixed at its lowest value (100 kNsm\(^{-4}\)) and
with no meteorological effect (homogeneous conditions).
The relative sound pressure levels (excess attenuation from the direct field) were calculated in third octave bands (7 frequencies for each third octave band) for a lot of configurations which cover the range of variation of the parameters (1 point per meter for \(d, h_S \in \{0.05, 1, 2, 4, 10, 50\}; h_R \in \{1, 2, 4, 10\}\).

Sound decay curves (in dB(A)) were obtained for each reference spectra in each situation. This is shown on figure 3.

By analyzing the decay curves, we found that the CORAIL spectrum lead to a stronger decay than all the other ones. For the discretization of \(d\), one can distinguish 2 domains: in the first one (below 400m) the maximal sensitivity corresponds to the maximal values \(h_S\) of and \(h_R\); the variation is imposed by the interference pattern. In the second domain, the grazing incidence leads to the strongest decay: this is a range in which the decay is constrained by the ground absorption.

5.3 Discretization of the effective air flow resistivity \(\sigma\).

The case which maximizes the influence of \(\sigma\) is defined by: \(h_S = 0.05\) m, \(h_R = 1\) m, \(d = 1000\) m. (large distance, grazing incidence). The variation of the dB(A) level for each reference spectra is showed on figure 4.

To comply with the error criteria in 100% of the cases we studied, 70 values of \(d\) are to be considered.

5.4 Discretization of the source and receiver heights: \(h_S\) and \(h_R\)

The case which maximizes the influence of the height of the source (receiver) is defined by: \(s = 100\) kNsm\(^{-4}\), \(d = 1000\) m. (large distance, grazing incidence). The variation of the dB(A) level with the height for one reference spectrum is showed on figure 5.

Thus, we have verified – and quantified - that the sensitivity of the ground effect strongly depends on the height of the source (receiver). If the source is located at more than 10 m (industrial sources), the level is more or less independent of the type of ground, if the source is close to the ground (road, railway, ...) one must define the ground parameter with a great precision (24 values of \(\sigma\) are to be taken into account to fulfill the error criteria).
considered for the height regarding the error criteria of the study.

5.5 Discretization for the meteorological parameters

This part of the study is still in process. A ray tracing method could be used to discretize the sound speed profiles and to define shadow zones. The turbulence could be taken into account by using the approach developed by Ostashev [4] for downward refraction and by using numerical simulation [5] for upward refraction.

6 “Lannemezan 2005”: an experimental campaign

The measurement campaign we plan to lead will involve the resources of all the partners, in order to produce a set of data with a high level of sampling both in time and space.

6.1 Goal of the campaign

The aim of the campaign is to characterize the ground and meteorological effects over a flat land at several distances and heights from a reference source.

The resulting data will be used to validate and to complete our numerical approach.

The campaign will take place in two stages:
- “short period” from June 6th to June 24th 2005 of intensive recording (high sampling) with a maximum number of sensors
- “long period” from June 25th to the end of August 2005 with a limited number of sensors.

We will pay special attention to the quality and the accuracy of the installation which only could ensure the confidence in the resulting data.

6.2 Measurement site

The choice of the site was justified by the following considerations:
- Quiet area;
- Flatness of the ground;
- No obstacle between the source and the receivers;
- Grass land terrain: impedance variation can be very sensible to weather (humidity) conditions;
- Variety of wind speeds and directions;
- Presence of a reference weather station (from METEO France) and the scientific environment of the CRA (Univ. Toulouse);
- Practical skills: available power supply, weather conditions, …

The figure 6 shows some pictures of the site.

6.3 Acoustics

The source is placed far enough from the trees to avoid interactions with unwanted turbulent flows. The height of the source can be fixed from 1.5 m to 4 m. The source is omnidirectional (12 loudspeakers) and is fed with a stationary white noise.

A total of about 50 microphones (of which 20 will stay during the “long period”) are settled along 4 measurement directions (MD). The spacing between the microphones is 25 m long from 50 m to 200 m from the source. Some microphones are in double to avoid the lost of data in case of trouble. The height is 2m and 4m for all the microphones located up to 125 m from the source and only 2 m for the others. Reference microphones are placed close to the source to be able to derive the excess attenuation due to propagation effects.
Each third octave band in the range [50Hz;4kHz] will be stored every 1 second in $L_{eq}$.

### 6.4 Ground impedance measurement

The ground impedance parameter will be monitored in one point during the 3 months (2 narrow band spectra each 4 hours).

During the «short period», we will proceed to additional frequent measurements along every measurement directions (spatial variability).

### 6.5 Micrometeorology

The measurement data should allow to derive sound speed profiles. This will be achieved by:

- Fitting a log-lin function with the measured values of wind and temperature at 3 heights (10 m high meteo tower);
- Using ultrasonic anemometers to obtain the fluctuations of temperature and wind in one point and deriving the sound speed profile from the Monin-Obukhov similarity theory [6].

During the “short period”, two 10 m high towers and one ultrasonic anemometer will be placed very close to each propagation direction. One other meteorological 60 m high tower with 3 ultrasonic anemometers, 3 temperature sensors and 3 humidity sensors is located at 200m Northbound from the source. This leads to a total number of 70 micrometeorological sensors during this 3 weeks period.

During the “long period”, we will keep the 10 m high meteo towers and the 60 m high tower (about 60 micrometeorological sensors).

### 6.6 Conclusion

This project will provide useful results for evaluating the relative influence of ground and micrometeorological effects on road, railway and industrial sources. It will also provide an original set of experimental data (about 50 microphones and 50 meteorological sensors) which could be used by the outdoor sound propagation community to improve its knowledge and to support its further works.

### References


[3] Private communication with Y. Brunet (INRA - F)

