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CALCULATE NOISE OF WIND-FARMS

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ABSTRACT
During the conference Windturbinenoise 2005 in berlin, we described [1] a model which had been developed and used for noise mapping adapted for wind-farms. This model takes into account the influence of the meteorological characteristics upon the sound propagation. Moreover It differs from the conventional models of specular reflection in that it is based on the assumption that the sound waves are diffused when reflecting back from it**.** The meteorological characteristics are defined by temperature and wind speed changes at height. This model assumes that this changes are homogeneous on the area which is investigated. This current paper describes the evolution of the model with the view to taking into account the non-homogeneity of the changes of wind and temperature on the area.

INTRODUCTION
In France, the noise impact of wind turbines is measured by what is called the “sound emergence”. This measured value must not be exceeded. Noise impact studies have to make predictions in order to ensure that this limit is not exceeded and if necessary indicate to wind farm developers how their projects can be modified to satisfy this requirement. These modifications often consist in decreasing the number of wind turbines in operation if the weather conditions would cause the legal limits to be exceeded. Therefore these conditions have to be identified as closely as possible.
Weather conditions have an impact on sound propagation and are one of the parameters which influence this “sound emergence”. The noise level may vary considerably upwind and downwind of a noise source. The models used for the impact assessment should take into account the weather conditions which are least propagators of noise emissions so that the operation of the wind turbines can be adjusted to suit these conditions. Thus, models which are defined for airborne noise emissions only (such as ISO 96-13) are not sufficient to cover these particular site characteristics. Moreover, in France, wind turbines are often installed on hilly terrain. The models must therefore take into account the influence of topography on sound propagation.
The model presented at WTN05 had been developed and applied to operational forecasting for with wind farms (short calculation, time, noise map plotting, etc.). We present here the modifications of the model and the new comparisons between the calculations and the measurements.

THE REFRACTION INFLUENCE
In the context of a wind turbine impact study, we seek to calculate the noise levels far from the sources. Any changes in the characteristics of the atmosphere will have an influence on the result. Two phenomena are to be taken into account:

- The change of sound velocity with altitude leading to the refraction of the sound waves
- The absorption of sound by the atmosphere

This latter point is included in our model, as proposed by standard ISO 96-13 Part1. Thus we will not expand on it further here and will examine the refraction phenomenon.
The variation in the temperature and the wind speed with altitude induces a celerity change with altitude which leads to refraction of the sound waves propagated in the atmosphere. This well-known phenomenon leads to curvature of the sound waves. There are complex models for

solving the parabolic approximation of the Helmoltz equation which translates acoustic wave propagation (FFP, PE, GF-PE, Split-step Padé, LE and Lagrangien Model) exist. They are expensive in calculation time and cannot be easily adapted to operational applications such as ours. This is part of the geometrical acoustic approximation. In our case, it consists in determining[1] the trajectory of the "ray" of sound. This results from the integration of the classic following equation:

$$\frac{dz}{dx}=\frac{c(z)\cos i(z)}{c(z)\sin i(z)+U(z)} \qquad \text{(Eq.1)}$$

where, C(z) is sound's celerity et U(z) wind's speed, at the height z.
The trajectory is curved and the curvature is oriented towards the ground or towards the sky. In the latter case, from a certain distance there would no longer be any acoustic energy coming from the source (shadow zone). However, experience has shown the existence of energy in this zone. Several factors explain this acoustic irrigation of the shadow zone (presence of turbulence in the atmosphere which diffuses the sound energy, diffraction of sound waves by the ground, etc.)
At present, our model takes into account this shadow zone irrigation phenomenon by the diffraction of the sound wave on the ground and by diffusion of the sound energy striking the ground.

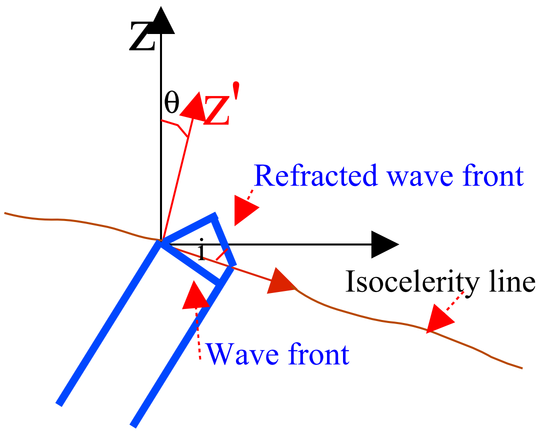

Figure 1 - Refraction

It is to be noted that, in cases of complex topographies and meteorological environments, the equation for the trajectory (figure 1) becomes:

$$\frac{dz}{dx}=\frac{U(z)\sin(\theta+\alpha)+c(z)\cos i(z)}{U(z)\cos(\theta+\alpha)+c(z)\sin i(z)} \qquad \text{(Eq.2)}$$

With

- θ is the angle of the isocelerityline to the horizontal
- α is the angle of inclination of the wind speed to the horizontal

The model presented at WTN05 consists of analytic resolution of eq.1 for each configuration “noise source / receptor”. For this resolution we evalue the celerity for each point (source/ receptor) and we assume that the evaluation of the celerity is linear between the two. This hypothesis allows the analytic resolution and gives one equation for the sound wave trajectory.
This model underestimate the high curvature of the trajectory near the ground. This high curvature is given by the “logarythmic” evolution of the celerity in according with the height, near

[1] And use of this trajectory in the model presented in reference [1]

the ground. This underestimation gives one sound level's estimation a little higher than wished in the “shadow zone”.
To mitigate this disadvantage, we have adapted a numerical resolution of the equation 2 (based on a upwind scheme).The trajectory of sound waves take, like this, in account the variation of celerity's gradient and is more realistic.
This resolution's method allows us to take into account of the spatial variation of the celerity's evolution with height. So, we are currently working at integrating a model of temperature's evolution and wind's speed's evolution that is better adapted at broken relief than our current model.

COMPARISON OF THE CALCULATED RESULTS WITH MEASURED RESULTS
The modification of the method of resolution didn't have any impact on the results presented previously [1], so we present here only results obtained for a new site.
An impact study type of approach has been used to measure the noise level. The purpose of this approach is not to detail its thoroughness. These results are meant to be representative of the noise level generated by the wind turbines alone (i.e. corrected for background noise).

The new site is a rural site with bush vegetation.
There are seven wind turbines on this site (70 m hub height). As with site 2 & 3 [1], they are on a crest and the relief is broken. The level difference between the highest wind turbine and the lowest point of reception is approximately 260m. The measurement points (1 to 4) are between 1000 and 1500m away from the wind turbines. The measurements compared with the computated results correspond to nighttime operation with a north-west wind at an average wind speed of 8m/s, 10 m above the ground. The mean temperature during this period is 17°C. The image below schematises the wind turbines (red points) and the measurement points (green points):

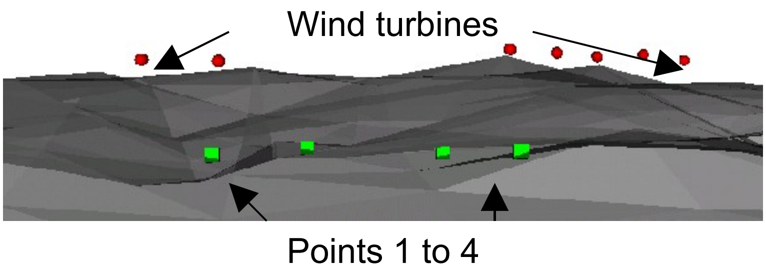

Fig. 3. Site 4

This site is interesting in that it is critical with regard to the combined influence of the topography and refraction. The wind turbine line is not directly visible from these points. However, the noise generated by the wind turbines is audible, and impacts on the noise level in dB(A).
The following table shows the computed results obtained compared with the measured results.

Table 1. Computed results for site 4

	Level dB(A)			
Points	Measu.	Our calcul	Calc. ISO 96-13	Calc. without refr.
1	34	32	--or 12(1)	13.5
2	34	32.5	--or 13(1)	14.5
3	26	28	--or 12.5(1)	14
4	32	34	--or 12.5(1)	14

(1) if ground considering like a screen

The last column shows the results of calculations without taking into account the influence of refraction: the masked effect caused by topography is clearly visible.

CONCLUSION

The model that we have presented in this paper can be used to assess the noise impact of wind turbine farms by accurate calculations which match the accuracy of measurements and take into account the main factors that influence sound propagation over long distances. These factors are atmospheric absorption, refraction, diffusion and diffraction on the ground, and topography.
This model is sufficiently operational to allow dimensioning of scenarii in the context of wind turbine impact studies, and to plot useful sound maps for communication to residents living close to wind turbine farms. Moreover, it is better suited to the calculation of wind farm impact than the one proposed by standard ISO 9613-2.
His recent modification allows us to take into account the inhomogeneity of meteorological data on the site.

Somes references

[1] R. Gamba, S.Garrigues, C.Sénat "Mapping of upwind and downwind airborne noise propagation", First International Meeting on Wind Turbine Noise Control, Berlin 17th and 18th october 2005.

[2] Comprehensive outdoor sound propagation model. Part 2 : propagation in an atmosphere with refraction, DELTA Acoustics&Vibration Report, Birger Plovsing, jorgen Kragh, Nord 2000;

[3] Three-dimensional acoustic ray tracing in an inhomogeneous anisotropic atmosphere using hamilton's equations, Chessel, JASA 53, (1), PP 83-87, 1973