Outdoor sound propagation modelling in complex environments : A new PE code coupled with a micrometeorological code.

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Introduction

In complex environments the modelling of outdoor sound propagation implies to take into account the mixed influence of ground characteristics (topography, obstacles, impedance, etc.) and atmospheric conditions (refraction and turbulence). We have developed a new PE code coupled with a micrometeorological code in order to calculate the sound propagation above a non flat ground for realistic outdoor situations.

Numerical resolution have been developed using the paraxial approximation of the wave equation in bidimensionnal configurations with a split-step Padé marching scheme. Our code can deal with different boundary conditions like the introduction of impedance jumps, thin screens or complex topography. Therefore, predicting long-range sound propagation over a non-urban site with complex propagation media requires the knowledge of micrometeorological fields in the lower part of the atmospheric boundary layer. Thus our modelling is coupled with a dedicated micrometeorological code (SUBMESO) which simulates wind and temperature fields over moderately complex terrain with high resolution. Its output data are used as input data for our PE code through a suited routine.

The SUBMESO atmospheric Code

The SUBMESO atmospheric model is derived from the ARPS model [1]. SUBMESO is a 3D non-hydrostatic compressible model suited to the study of atmospheric flows at sub-mesoscales. The equations are written in the 'terrain-following' coordinate system. An option for stretching the mesh vertically is available. Second-order accurate finite difference schemes are used to evaluate the derivatives. The solution is advanced in time using a time-splitting method [2] according to an explicit scheme. The simulations are performed using Large-Eddy Simulation, which gives access to turbulence statistics. The sub-grid fluxes are evaluated with the model of Smagorinsky [3] modified by Lilly [4]. A simplified version of the grid-nesting module AGRIF [5] was recently coupled with SUBMESO in order to locally increase horizontal resolution at lower cost and introduce the large scale features in the flow prediction at high resolution in a limited-area domain.
Submeso code provides wind velocity in the 3 directions as well as the temperature at each point of the mesh (50*50*50 m).

The Padé (1,1) Acoustic Code

We consider the two-dimensional propagation of a point source located at $x = 0$ and $z = h_s$ where x is the direction of propagation and z is the vertical axis. The acoustic code is based on a parabolic equation (PE) solved through a Padé (1,1) method. The PE used is derived from the exact wave equation in a uniform moving media when in the conventional approach the real moving atmosphere is replaced by a hypothetical motionless medium with a effective sound speed [6]. Introducing the complex amplitude of the sound field $\phi(\mathbf{r})$, so that $p(\mathbf{r}) = \phi(\mathbf{r})e^{ikx}$, the PE takes the general following form:

$$\mathcal{F}[1, \frac{\partial}{\partial z}, \frac{\partial^2}{\partial z^2}]\frac{\partial\phi(\mathbf{r})}{\partial x} = \mathcal{G}[1, \frac{\partial}{\partial z}, \frac{\partial^2}{\partial z^2}, \frac{\partial^3}{\partial z^3}]\phi(\mathbf{r}), \qquad (1)$$

where $\mathcal{F}$ and $\mathcal{G}$ represent operators including first, second and third order z-partial derivatives. This equation is discretized on a uniform mesh $(i\Delta x, j\Delta z)$ using a standard finite difference method. $z-$derivatives are evaluated with centered difference approximations, and Crank-Nicholson scheme is implemented as a marching algorithm. In our computations, the ground is modelled with finite complex impedances calculated using the one parameter formula of Delany-Bazley [7]. Reflexions at the top of the numerical grid are controlled by introducing a thin artificial absorption layer in the upper part of the computation domain. The non flat ground is treated

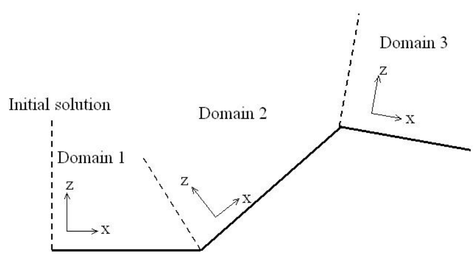

Figure 1: Definition of the computational domains.

as a succession of flat domains [8]. After each flat domain the coordinate system (x, z) is rotated so that the x axis stays parallel to the ground. The calculation above each domain needs an initial solution. The values of the initial solution for the domain $n+1$ are obtained from the interpolated values of the pressure field of the domain n except for the first domain where the source is initialized by a Gaussian starter.

Validation

The numerical predictions are quantitatively compared to numerical, analytical and experimental results already published for gradually more complex situations: homogeneous, heterogeneous and/or screened ground [10, 12], for a homogeneous, stratified and/or turbulent atmosphere [11, 9]. Concerning non flat ground, the model has been validated through a comparison with results obtained from a method using conformal mapping [8]. Comparative results show very good agreement for frequencies from 100 Hz to 5 kHz.
The Padé (1,1) PE predictions are also qualitatively validated through 2D mapping. For example, figure (2) represents sound pressure level relative to a reference microphone localized close to the source. The sound source elevation is 0.1 m, the frequency is 1 kHz. The mean vertical sound speed profiles are logarithmically shaped: $c(z) = c_0 + aln(z/z_0)$ where $z_0 = 0.1m$ is the roughness parameter and $a = 2m/s$ the refraction parameter. The air flow resistivity of the ground turns rapidly from 3×10^5 $kNsm^{-4}$ (sealed concrete for instance) to 3×10^2 $kNsm^{-4}$ (grass) 10 m from the source position. A 2 m high thin screen is placed at middle distance on the top of the embankment. This figure illustrates three kind of diffraction phenomena: one due to the mixed ground (near the source), another due to the slopes of the ground and the last due to the presence of the screen. One can observe an acoustic shadow zone behind the screen. In reality, the sound pressure level is enhanced by the atmospheric turbulence which scatters acoustic energy in this region.

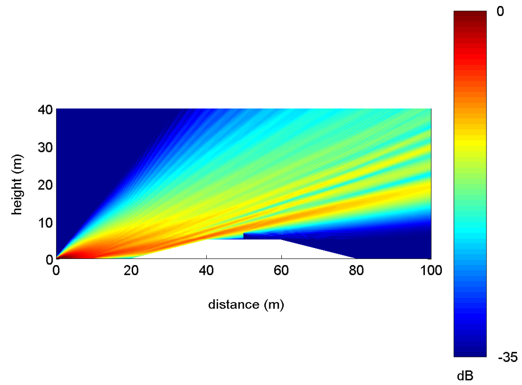

Figure 2: Relative sound pressure above an embankment with a screen in the case of downward refraction condition (parameters values: cf text).

Conclusion

We have developed a new numerical code for sound propagation including all most common complex situations. This acoustic code is coupled with a micrometeorological code in order to have an accurate description of the atmospheric conditions. Our numerical results will be further compared with acoustical and meteorological measurements performed on an outdoor site in a complex environment (mixed ground, non flat terrain, stratified and turbulent atmosphere).

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