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DEVELOPMENT OF A NEW OPERATIONAL URBAN LAGRANGIAN DISPERSION MODEL FOR EMERGENCY RESPONSE

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Abstract: The atmospheric dispersion of RBC-E (Radiological, Biological, Chemical or Explosive) toxic substances, of accidental or intentional origin, on an urban or industrial complex built area, is a subject of major concern for the safety of people and the protection of infrastructures. In order to face these different types of risks and threats, industrial companies and public authorities need operational simulation tools for assessing, in advance or in emergency situations, the health consequences of harmful discharges on the population and on first-responders.

In this context, a new software called BUILD (Building, Urban and Industrial Lagrangian Dispersion model) has been developed to simulate the atmospheric dispersion of gases and particles in a complex built environment. The BUILD model uses a "SIRANE like" parameterization for the flow in the dense part of an urban area (Soulhac et al., 2011, 2012, 2017). However, the SIRANE flow model has been enhanced to take into account the recirculating transverse component of the flow in each street, a mass-consistent velocity field in each intersection and a three-dimensional flow model in the roughness sublayer, to take into account the deviation by buildings and obstacles. For the moderately dense built areas (suburbs), a new model is proposed, based on an analytical building wake parameterization. The dispersion model of BUILD is based on a Lagrangian particles stochastic approach coupled with the simplified flow field defined above.

In order to validate this new model, simulations have been performed on the wind tunnel experimental test case of continuous and instantaneous releases behind a 2D square obstacle (Gamel, 2015) and in a regular network of streets (Cierco et al., 2010, Ben Salem et al., 2015). Results of the operational BUILD model are compared with experimental data and with detailed CFD calculations.

Key words: *Atmospheric dispersion model, street canyon, network of streets, operational and emergency response*

INTRODUCTION

For several years now, the release of NRBC-E substances (Nuclear, Radiological, Biological, Chemical and Explosive) into the atmosphere has become a problem that retains the attention of public authorities and industrialists because it concerns the safety of people and infrastructures. In order to prepare for situations of industrial accidents, malicious or terrorist acts, the public authorities and industrialists are interested by the approach of numerical simulation of the atmospheric dispersion to help the first responders and the decisions makers during the crisis management phase. These software tools must be usable simply, provide a fast answer and a reliable estimate of the hazardous plume.

In the continuity of the development of the SIRANERISK model (Soulhac et al., 2016), CEA and the Fluid Mechanics and Acoustics Laboratory of University of Lyon have initiated the development of a new software called BUILD (Building Urban and Industrial Lagrangian Dispersion). BUILD is a numerical model dedicated to the simulation of atmospheric dispersion at the local scale, making possible a simplified description of the influence of buildings and obstacles particularly for urban or industrial areas. It is developed with the aim of being operational with fast response and to produce maps of the evolution of a cloud of NRBC hazardous materials in contexts of industrial accidents or malicious acts.

This article presents the principles and the first validations of the BUILD software. In the second section, we describe the theoretical principles of the model. In the third section, we present the experimental cases used for software validation. In the fourth section, we discuss some examples of comparisons between the model and the measurements. Finally, in the last section, we detail the next steps in the development and validation of the BUILD model.

BUILD MODEL DESCRIPTION

The BUILD model is based on a coupling between an analytical model to describe the flow and turbulence in the canopy and the atmospheric boundary layer, and a Lagrangian stochastic particles model to describe the turbulent dispersion of pollutants.

The modelling of the flow in the urban canopy is based on the parameterization proposed in Soulhac et al. (2008) and used in the SIRANE model (Soulhac et al., 2011). The geometry of the urban canopy is described using the streets network approach. The longitudinal velocity in each street is modeled analytically from a balance between the entrainment by the external flow and the friction on the street walls. In the BUILD model, the street cross-sectional components of the velocity are modeled, assuming a separation of variables:

$$\begin{cases} \overline{v}(\eta,\zeta) = V_{street}.f(\eta).g(\zeta) \\ \overline{w}(\eta,\zeta) = W_{street}.g(\eta).f(\zeta) \end{cases} \quad \text{with} \quad \begin{cases} \eta = y/W \\ \zeta = z/H - 1/2 \end{cases} \quad \text{and} \quad \frac{V_{street}}{W} = \frac{W_{street}}{H} \tag{1}$$

where y and z are the transverse and vertical coordinates. The constant V_{street} is defined from the projection of the friction velocity u_* perpendicular to the street. The constant W_{street} is set to satisfy the continuity equation. Different models of the functions f and g have been tested, among which the linear model, defined by:

$$\begin{cases} f(x) = 1 - 4x^2 \\ g(x) = 2x \end{cases} \tag{2}$$

In each intersection, the flow is assumed to be horizontal and vertically invariant, consistent with the approach proposed by Soulhac et al. (2009). To describe the velocity distribution in the intersection, we introduced into the BUILD model a potential flow model, using the panel method to describe the street walls. An illustration of the velocity field obtained with this approach is shown in Figure 1.

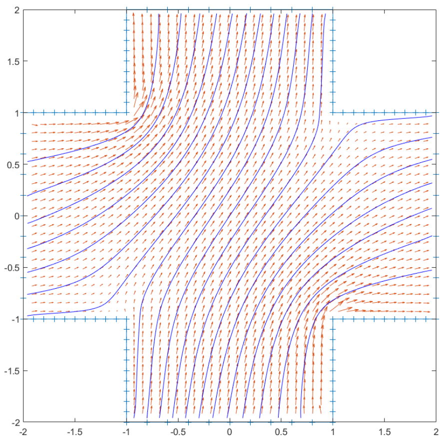


Figure 1. 2D potential flow model within the intersection of streets, based on the panel method.

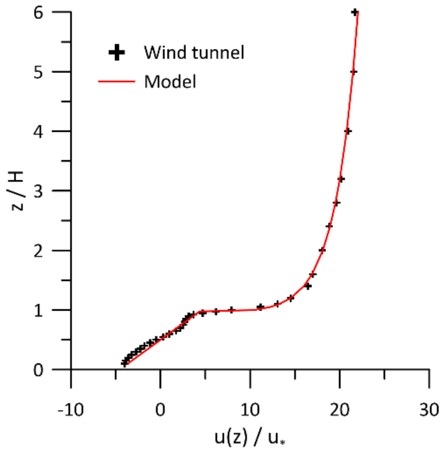


Figure 2. Vertical profile of the horizontal transverse component of the velocity inside and above a square street-canyon. Comparison between the analytical model and the wind tunnel experiments (Soulhac, 2000).

Over the roof level, the flow within the atmospheric surface layer is modelled using the Monin-Obukhov similarity theory, as described by Soulhac et al. (2011). Coupling these different models, the vertical profile of the horizontal velocity, in the street and over the canopy, has been compared on Figure 2 with wind tunnel measurements performed by Soulhac (2000). It confirms that the model of equations 1 and 2 is able to describe the main features of the transverse flow inside the street.

The flow model described above is coupled with a stochastic particle dispersion model, based on the tracking of Lagrangian trajectories of individual particles. This approach is introduced to improve some limitations of the SIRANE/SIRANERISK approach. The temporal evolution of the Lagrangian position of each particle is described by:

$$dX_i = \left(\overline{u}_i + U_i'\right)dt \tag{3}$$

where $\overline{u}_i$ is the mean velocity of the flow (given by the analytical model described above) and U_i' is the Lagrangian fluctuating velocity, for which the temporal evolution is modelled by the stochastic differential equation:

$$dU_i' = a_i dt + b_{ij} d\xi_j \quad \text{with} \quad \begin{cases} a_i = -\dfrac{U_i'}{T_{Li}} + \dfrac{1}{2}\dfrac{\partial \sigma_{ui}^2}{\partial x_i} + \dfrac{U_i'}{2\sigma_{ui}^2}\left(U_j \dfrac{\partial \sigma_{ui}^2}{\partial x_j}\right) \\ b_{ij} = \delta_{ij}\sqrt{C_0 \varepsilon} \\ T_{Li} = \dfrac{2\sigma_{ui}^2}{C_0 \varepsilon} \end{cases} \tag{3}$$

in which the terms a_i and b_{ij} are expressed in terms of standard deviations of velocity fluctuations and of the turbulent kinetic energy dissipation rate ε. Specific parameterizations of these variables are integrated in the BUILD model but not presented in this paper.

EXPERIMENTAL TEST CASES

In order to validate the BUILD model, we are starting a complete and progressive work, in which several types of configurations will be used. In this paper, we present two case studies on two different wind tunnel configurations. The first is an isolated obstacle configuration (Gamel, 2015), the second is an idealized neighborhood configuration (Cierco et al., 2010, Ben Salem et al., 2015).

Isolated obstacle validation case (Gamel, 2015)

Wind tunnel experiments were conducted around a two-dimensional square-section isolated obstacle placed in a rough boundary layer of neutral stratification (see Figure 3). A continuous line source of pollutant is placed downstream of the obstacle. Velocity and concentration measurements were made around the obstacle to characterize the dispersion and the turbulent fluxes of pollutant.

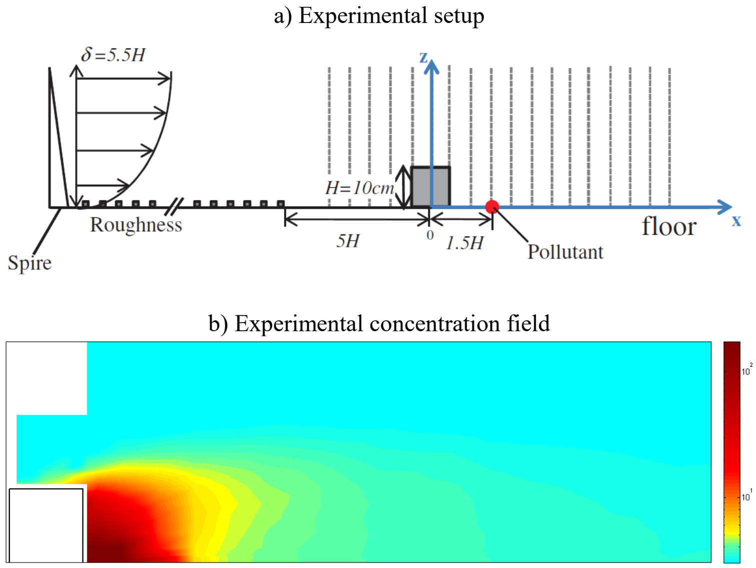


Figure 3. Experimental test case of the dispersion downwind of a two-dimensional square obstacle. The line source is located 1 H from the downwind wall of the obstacle.

Network of streets (Cierco et al., 2010, Ben Salem et al., 2015)

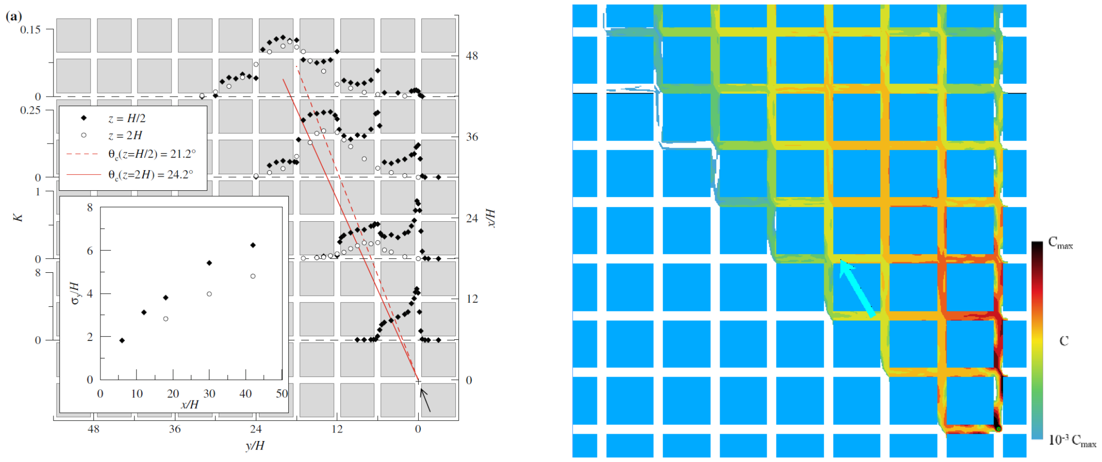
Wind tunnel experiments of the dispersion of pollutants in an urban idealized district have been performed for continuous and instantaneous point sources. The geometry of the canopy, illustrated on Figure 4, is made of a regular network of perpendicular square streets (W / H = 1). The point source is located at the center of an intersection. The concentration field was characterized by horizontal profiles measured within and above the canopy.

VALIDATION RESULTS

Preliminary validation results have been performed between the first version of the BUILD model and the wind tunnel experiments described above. An example of application of the BUILD model on the district test case is shown on Figure 4-b and one can observe a very good qualitative agreement between the model and the measurements. The different preliminary tests provide very encouraging results. An extensive validation exercise and a sensitivity study on model parameters will be performed in the next steps of the project.

CONCLUSION AND PERSPECTIVES

A new Building Urban and Industrial Lagrangian Dispersion model has been developed as an emergency response tool to help first responders and decision makers. This model improves the SIRANE parameterization for the flow inside the urban canopy and includes a Lagrangian stochastic approach to simulate the dispersion more accurately. The first validations against wind tunnel experiments provide encouraging results. The development and the validation of the model will be improved in the next future.



a) Wind tunnel experiments
b) Numerical simulation with the BUILD model

Figure 4. Concentration field in a network of streets for a wind direction $\varphi = 27.5°$: a) wind tunnel measurements and b) Numerical simulation with the BUILD model.

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