TESTING MICRO-SCALE MIXING IN A BENARD VON KARMAN ALLEY USING MONTE CARLO PARTICLES

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RESUME
L'objectif de ce travail est de tester trois modèles de micro-mélange classiques: le modèle de Curl (C), le modèle de Curl modifié (MC) et le modèle d'interaction par échange avec la moyenne. La simulation numérique adoptée est basée sur le modèle Monte Carlo. Le domaine de calcul est similaire au domaine expérimental, qui correspond à l'allée de Bénard Von Karmàn en aval d'un obstacle cylindrique. Les vitesses attribuées aux particules Monte Carlo sont mesurées expérimentalement [1]. Cependant, le champ de températures est simulé par notre code de calcul et ensuite comparé aux températures mesurées expérimentalement. Les résultas montrent que les isothermes dépendent du modèle de micro-mélange utilisé. Il est à souligner que l'accord entre la simulation et l'expérience est obtenu avec le modèle de Curl et surtout avec le modèle de Curl modifié.

ABSTRACT
This work aims to validate three classical micro-scale mixing models: Curl (C), modified Curl (MC) and interaction by exchange with the mean (IEM). The numerical simulation is based on Monte Carlo model. The calculation domain is similar to an experimental one, which corresponds to the Bernard- Von Karmàn alley downstream of a cylindrical obstacle. Velocities attributed to Monte Carlo particles are taken from experimental measurements [1]. However, the temperature field is simulated by our code and then compared to experimental one. Results show that the isotherms behavior depends on mixing models used . One can notice that the accuracy between simulation and experience is obtained with C model and especially with MC model.

1. INTRODUCTION

The phenomenon studied in this work was observed for the first time by Bénard (1908) and was studied few years later by von Karmàn (1911). Also, G.I. Taylor (1921) treated meticulously this problem. So, although the problem was known one hundred years ago, we think that it needs to be studied at the present time, because we ignore some aspects of the eddies. Situation in literature shows that the dynamic approach is much studied than the thermal one. Experimentally the B-V-K alley can be observed downstream of an obstacle with different shapes (for example: a cylinder) and for the small critic Reynolds number. The latter is based on the upstream flow velocity U_∞ and the viscosity of fluid ν_g.

$$Re_c = U_\infty \, d/\nu_g \qquad (1)$$

Experimental results in bi-dimensional configuration [1-3] show That B-V-K alley is characterized by two alternative lines of eddies turning differently in opposite senses and with a frequency *f* linked to the Strouhal number as:

$$S_t = f\ D/U_\infty \qquad (2)$$

Nowadays, the subject takes more and more of consideration so as to solve some ecological and technological problems, especially, in relation with many turbulent inert / reactive flows. Indeed, it is known that one of the most important properties of a turbulent flow is its capacity to make the dispersion of an injected scalar, increasing significantly. This phenomenon associates all scales of eddies and is called turbulent diffusion. Besides, there is another characteristic very important in turbulent flow which is the micro-scale mixing.

The contaminant injected in the turbulent flow and used as a tracer, may be a pollutant, a chemical product or an inhomogeneous temperature created by a heat source like it is the case in our study. In this sense, our work aims to test three classical micro-mixing models, while studying heat transfer in a rectangular domain where a Benard- von Karmàn alley occurs. Experimentally, Godard [1] measured the velocity field using Anemometry Doppler Laser (ADL) technique at different points and for different time steps. At the same time he measured the temperature field using the technique of thermometry cold thread. The source of heat placed behind the main recirculation zone, is a linear thin conductor thread at which a continuous current goes through. To carry out our numerical simulation, we have used the same velocity field measured by [1]. We have adapted our calculation domain, the space steps and the temporal increment to the experimental case.

According to S. B. Pope [4], the fluid particle in the real space has almost, the same trajectory in phases space as the stochastic particle. This observation confirms the validity of using Monte Carlo method in such a problem. So, the problem will be well described by solving the joint PDF transport equation established by Lund green [5]. Such a formulation requires a stochastic treatment: The Poisson's process in this case. The study field is divided into N_c small rectangular cells, in each one, we have put a given number N_i of particles. At each point and for different time increments, we attribute to these particles velocities given by the experimental measurements and then we follow the temperature evolution using different mixing models.

Finally, this study seems to be very interesting to test developed physical models, when studying dispersion, turbulent diffusion, and mixing models. Indeed, with the present study we highlighted the phenomenon of false flows when one uses the (I.E.M) model. And especially, we verify that the MC model is the optimal model for the Monte Carlo simulation in the case of weak turbulence.

2 A BRIEF DESCRIPTION OF THE EXPERIMENTAL DEVICE

The experiment with which we try to valid our calculations was made [1]. Weiss [6] described meticulously the mechanism that blows air vertically. The obstacle is a steel cylinder that has a diameter D = 2mm and a total length L = 335mm, parallel to $\vec{oz}$. It is placed in the longitudinally symmetrical plan of the throw. The source of heat is a thread that has a diameter d = 20µm and a length ℓ_s = 110mm, heated by Joule effect and parallel to the obstacle. During the experiment the temperature gradient between the source and ambient air is 120°C. To localize the measuring points, G. Godard [1] uses axes system illustrated in figure 1. The measure of dynamic field is effectuated by A.D.L (Anemometry Doppler Laser). However, the temperature measurements are carried out thanks to a cold thread thermometry. Figures 2 shows the calculation domain in which we have made our simulation. This domain corresponds to the principal zone of recirculation downstream the obstacle.

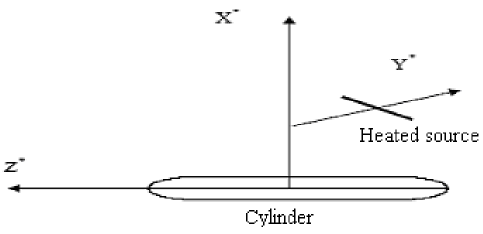

Figure 1

Figure1: Simplified schematic of the experimental device

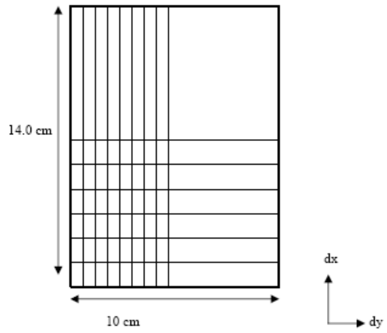

Figure2: The calculation domain

3. RESULTS AND DISCUSSIONS

In order to have an idea on the mean velocity in the direction of the flow, we have studied its variation versus transversal axis (o,y). Results are shown in figure 3 for three values of x^{*}[1]. We can easily note the characteristics of a wake flow; the profile is symmetric per rapport the central line. Yet, we remark the progressive diminution of the deficit of the mean velocity when we go away from the obstacle.

In figure 4, we can see the snake shape of isotherms. Isotherm contours are illustrated for a given $x^{*}$and for two time steps k_t in the case of the Curl model. We remind the reader of the fact that there is a relationship between time steps and phases [1].

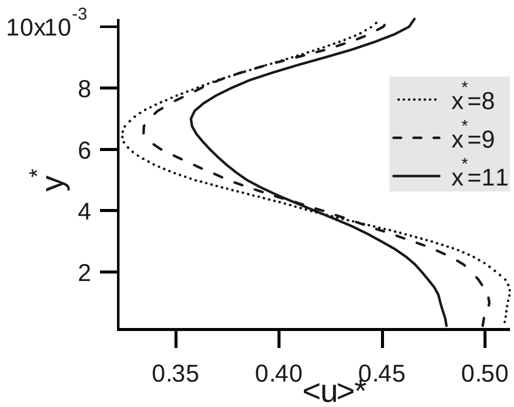

Figure3: $<u>^{*} = f(y^{*})$ for kt = 100 corresponding to phase = π; for x^{*} =8 (dotted line), x^{*}= 9 (dashed line) and x^{*}= 11(solid line)

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[1] * Non-dimensioned variable by D for lengths and by U_∞ for Velocity

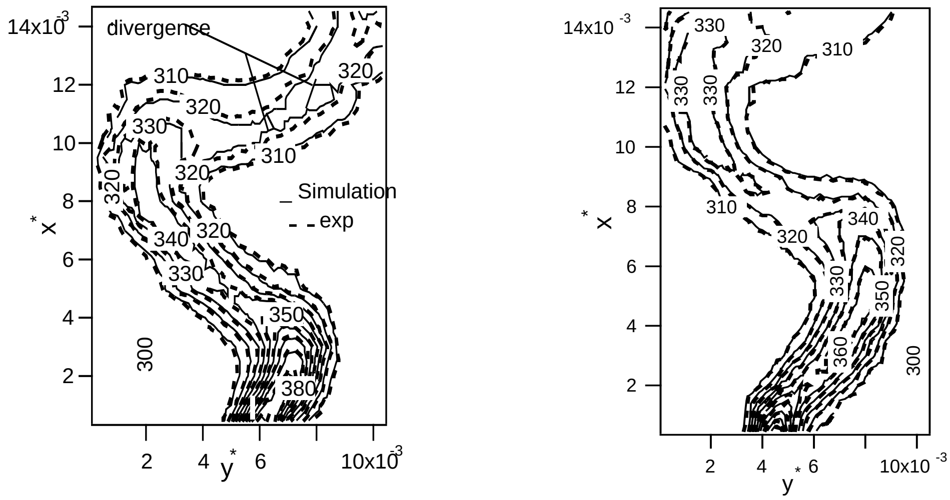

Figure 4: Isotherms contours plot at respectively phase =π/4 on the left and phase = π/2 on the right in the case of Curl model. Dashed line refers to experience and solid line to simulation.

Working under the same conditions above, we change only the C model by MC model. Results illustrated in figure5 show that the accuracy between simulated and experimental isotherms, is better than in figure 4. So, we deduce that MC model describes better the micro-mixing of particles.
In order to check the IEM model, we have made the same work as with the other models. Results of figure 6, show that accuracy between experimental and simulated temperature is less satisfactory than with both C and MC models. Besides, we can detect an oscillating behavior of isotherm contours. This phenomenon appears when we use the IEM model because we can lose precision concerning each particle characteristics. Indeed, this model is designed on the basis that the major action of the mixture is to homogenize the field of concentration. However, although it is simple, fast and largely used in the pdf approach, it presents at least two disadvantages:

- First, the inability for respecting the fact that for an homogeneous scalar field (statistically homogeneous in a homogeneous and isotropic turbulence), the pdf of the scalar must tend towards a distribution normal and centered around the average. Discussions in connection with this subject [7], show that the pdf must tend asymptotically towards a function of Dirak around the average $\delta(\phi - \langle \phi \rangle)$.
- Second, the incapacity of verifying in the case of a high Reynolds number that high scalar fields mustn't be affected by adopted micro-scale mixing.

Consequently, one will expect the creation of false fluxes, which deteriorate the average field of concentration marked by the oscillating tendency as we see it clearly on figure 6. This phenomenon has been carefully described by Pope [8].
An alternative for solving this IEM disadvantage (a thing that we haven't tried yet) is based on another model called IECM (interaction by exchange with the conditional mean) as has been made by Cassiani et al.[9]. This last model is governed by the following equation:

$$\varphi_\alpha = - \frac{\varphi_\alpha^* - \left\langle \varphi_\alpha^* \,\middle|\, x_i^* = x_i,\ u_i^* = v_i \right\rangle}{\tau_{mix}} \qquad (10)$$

φ_α^* is the random modeled composition of specie α and τ_{mix} is the characteristic time of mixing. x_i^* is the modeled position and u_i^* is the modeled velocity fluctuation.
The difference with IEM model is that the relieving of the instantaneous scalar field tends towards a local average in space velocity-compositions. To simplify, one can say that the particles in IECM

model interact with others having similar positions and speeds. Physically; this can be seen as a mixture occurring between particles which belong to the same swirl.
Finally by simple comparison between isotherms corresponding to experimental data and those corresponding to simulation, we can say that accuracy varies from a model to another. The result confirms two facts: first, the legitimacy of application of the Monte Carlo method and second, the just choice of the micro scale mixture of “coalition-redispersion” known as modified Curl model.

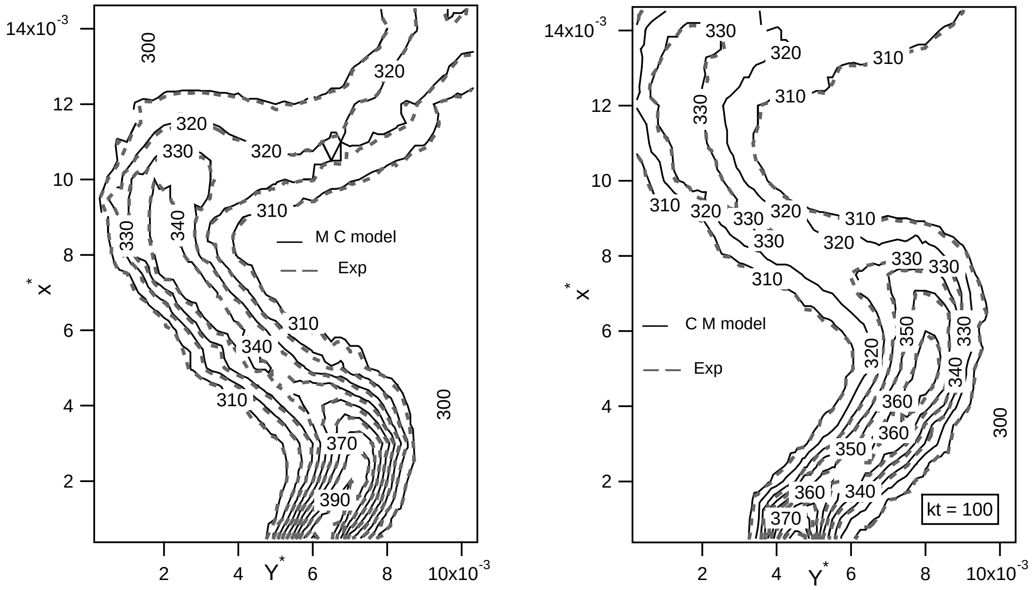

Figure 5: From the left to the right isotherms contours plot at respectively phase =π/4 and phase = π/2 in the case of MC model

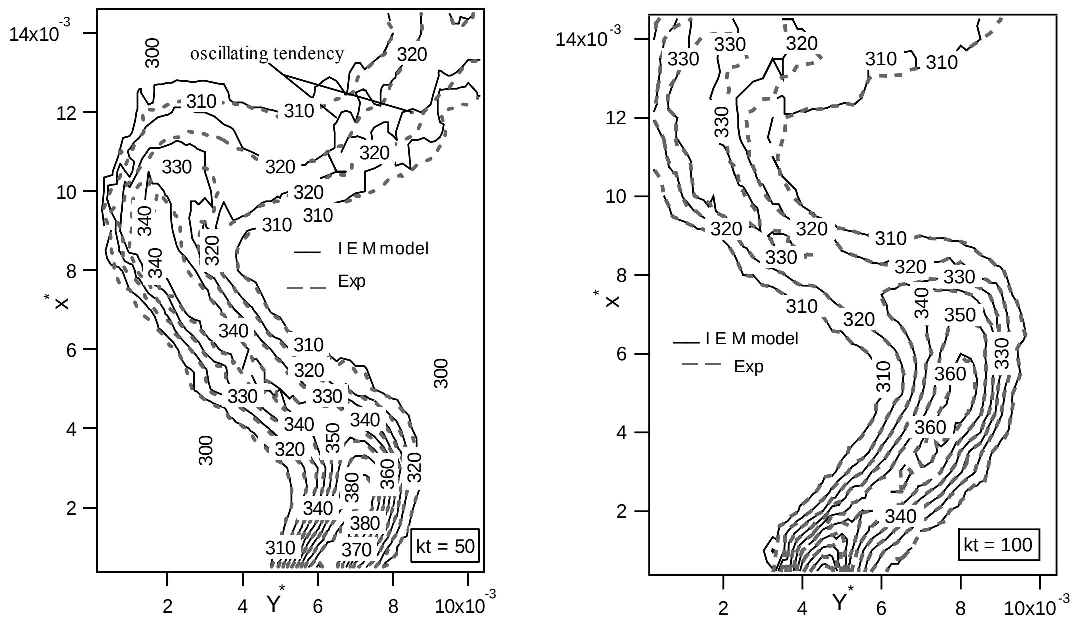

Figure 6: From the left to the right isotherms contours plot at respectively phase =π/4 and phase = π/2 in the case of IEM model.

4. CONCLUSION

We have simulated an old/new phenomenon called Bernard-Von Karmàn alley by using the same dynamic field measured by Godard [1]. The simulation is based on PDF formalism and Monte

Carlo model. Our interest is attached to the principal zone downstream of a cylindrical obstacle, where the turbulent wake is much more important. We place emphasis on the thermal field showing the B-V Karmàn alley. Besides, we have tested particles mixtures using three classical models; respectively C, MC and IEM. The results are encouragements. Indeed, the accuracy concerning isotherm contours between experiment and simulation is satisfactory, especially; with MC mixing. However, with IEM model the concordance between experiment and simulation is less good because of false fluxes that take place.
Does the applicability of MC model, remains the same in moderate and high turbulence with Monte Carlo simulation?
In future work., we try of responding to the latter question and of treating the same problem in reactive case, while studying the flame characteristics such as; the propagation velocity and the flame-brush thickness.

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5. REFERENCES

[1] G. Godard, 2001, Experimental study of the passive scalar field structure in a Benard-Von Kàrmàn alley, PhD thesis,. University of Rouen, France.
[2] E. Giacomazzi, V. Battaglia, C. Bruno, 2004, The coupling of turbulence and chemistry in a premixed bluff body flame as studied by L.E.S, combust. and Flame,Vol., 138, pp: 320-335.
[3] D. Calluaud, L. David, 2002, Backward projection algorithm and stereoscopic particle image velocimetry measurements of the flow around a square section cylinder. 11th International Symposium on Applications of Laser Techniques to Fluid Mechanic, 8-11 July Lisbon.
[4] S.B. Pope, 1991, Transport equation for the joint probability density function of velocity and scalars in turbulent flow, the physics of fluids, Vol., 24, pp: 561-606.
[5] T.S. Lund green, 1967, Distribution functions in the statistical theory of turbulence, the physics of fluids, Vol., 10, pp: 969-975.
[6] F. Weiss, 1999, Experimental study of the heat diffusion upstream of a linear source placed in a Benard-Von Kàrmàn alley, PhD thesis, University of Rouen, France.
[7] P.C. Chatwin, 2004, Singular PDFs of a dispersing scalar in turbulence, Flow Turbul. Combust., Vol., 72, pp: 273-285.
[8] S.B. Pope, 1998, The vanishing effect of molecular diffusivity on turbulent dispersion : implications for turbulent mixing and the scalar flux, J. Fluid Mech. Vol., 359, pp: 299-311.
[9] M. Cassiani, A. Raddichi, J.D. Albertson, U. Giostra, 2007, An efficient algorithm for scalar PDF modeling in incompressible turbulent flow ; numerical analysis with evaluation of IEM and IECM micro-mixing models, J. of computational physics, Vol., 223, pp: 519-550.