Laser Diagnostics Compared to CFD for Gas Dispersion in Urban Environments

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ABSTRACT

Measurements of velocity and concentration fields in street canyons are presented, serving as benchmark data-sets for code-validation using FLUENT with a realizable k-ε turbulence model.

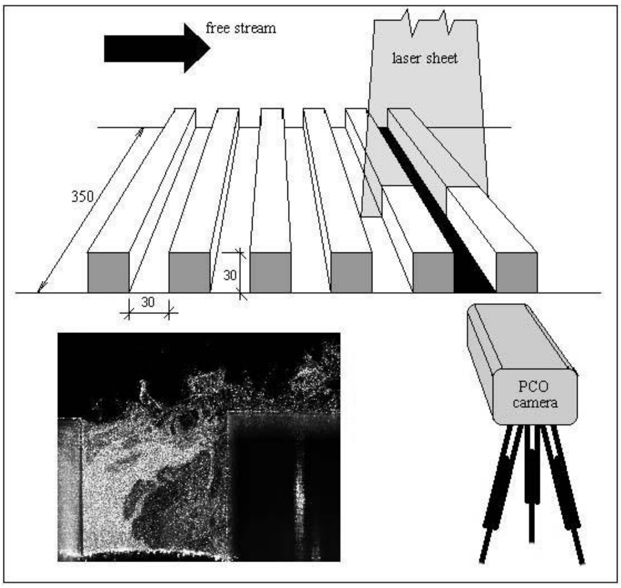

Figure 1 Sketch of 2D street canyon configuration. Pulsed laser sheet freezes the flow, which is recorded by a PCO camera. A typical instantaneous particle image is shown.

SIMULTANEOUS MEASUREMENT OF VELOCITY AND CONCENTRATION

For the velocity measurement PIV is used, providing instantaneous 2D velocity fields, from which mean fields and standard deviations around them are discerned. A pulsed laser is used to generate the still particle images. For the concentration measurement, a laser-sheet concentration assessment technique

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(LSCAT) is employed. It uses PIV-type images; the light intensity in each velocity vector interrogation window is summed to reach a relative concentration. This technique requires prior subtraction of background light and the application of mono-disperse scatterers.

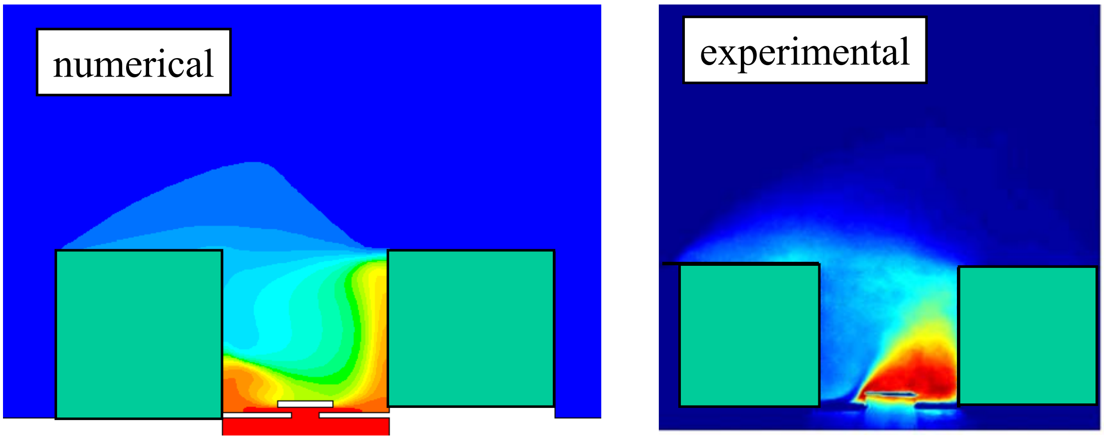

Figure 2:FLUENT Simulation of concentration field in a 2D street canyon compared to experimental results obtained by LSCAT. Wind direction over the street flows from left to right.

A typical test configuration is sketched in Figure 1 for a 2D urban street canyon configuration mounted in the VKI L2-B wind tunnel. A line source of air seeded with mono-disperse oil particles is injected in one of the canyons via slits or a porous ground floor. It is assumed that gas concentration is proportional to particle concentration.

COUNTER-GRADIENT TURBULENT MASS DIFFUSION

Numerical and experimental velocity fields are compared and reveal that flow topology is well captured. Figure 2 shows the comparison between measured and computed concentration field, using the realizable k-ε turbulence model. The agreement is poor and worse than what could be expected by comparing the mean velocity fields [1]. The reason for this large discrepancy could lie in the false computation of turbulent diffusion, which is assumes to be proportional to the gradient in mean concentration. This hypothesis is checked by measuring velocity and concentration at the same time, to construct the turbulent mass flux vector u'c', which represents turbulent mixing in the used turbulence model. This measurement has been done recently at VKI using Particle Tracking Velocimetry (PTV) [2]. A typical result is presented in Figure 3. It shows counter gradient diffusion in two regions. This phenomenon is well-known in scalar diffusion problems where the gradients of velocity and concentration (or temperature) are not aligned (3). It requires a more complex turbulence modeling, such as Reynolds Stress Modelling (RSM) or Large Eddy Simulation (LES) [4]. The latter has the crucial ability to assess concentration exceedence probability.

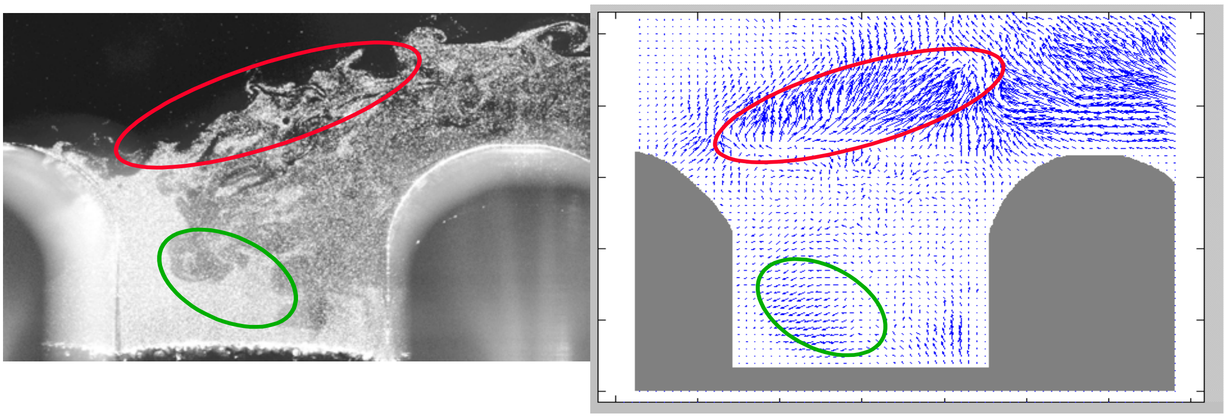

Figure 3: Measured turbulent mass flux revealing gradient diffusion in the red zone and counter gradient diffusion in the green zone.

Figure 4 shows a typical example how complex gas diffusion in urban environments can be. The CFD results are obtained by FLUENT. A top view of the mean concentration at ground level is plotted in a 3D street canyon configuration with a line gas source in one of the streets. Yellow color represents high concentration. Even though the mean wind direction above the urban canopy goes from left to right, a significant amount of gas diffuses upstream! A correct description of this phenomenon is important in order to establish confidence in the various possible scenarios for safety measures. CFD is the design tool for this but needs to be validated by well-chosen benchmark experimental data-sets, for which appropriate experimental techniques are to be developed.

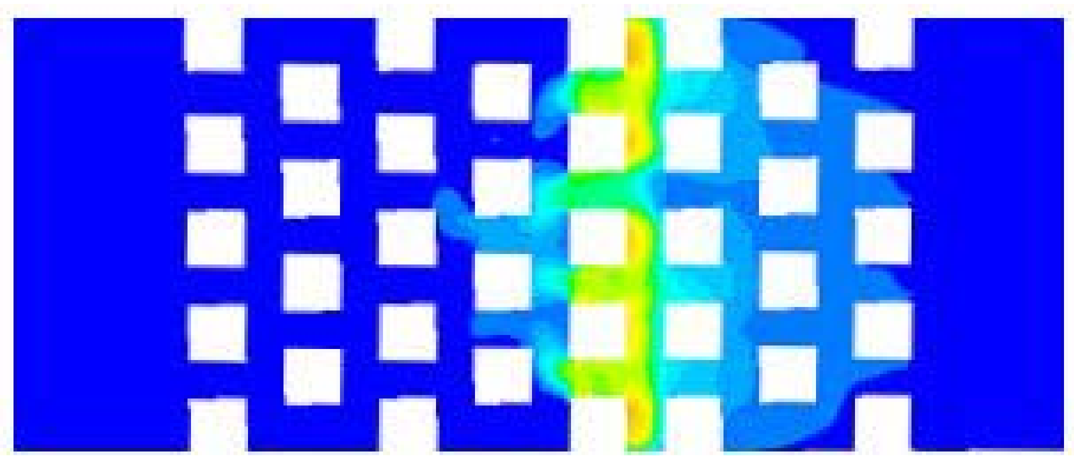

Figure 4: Mean concentration field in a 3D street canyon numerical model with FLUENT, showing pollutant dispersion upstream of the main flow direction over the urban environment.

REFERENCES

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