II-455 Large Eddy Simulation of the Dispersion of a scalar in a Street Canyon

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1. Introduction. Recently, with the rapid development of cities, the urban environmental problems cause serious concerns. Among other factors, toxic gases released from the combusted fuel or factories located inside cities to the streets are very harmful for health. Thus understanding the dispersion of a scalar in a street canyon is important for solving these problems. This paper intends to give an inside view to the dispersion of a scalar quantity release to a street canyon by an unknown source. The Navier-Stokes equations and transport equation of the scalar were solved using spatial average technique (Mason and Callen, 1986; Mason and Thomson, 1992, Armfield and Asaeda, 1993). The grid eddy viscosity was evaluated using Smagorinski (1963) model. A non-uniform and non-staggered grid (Armfield, 1991; Armfield and Debler, 1992) was used to give fine solutions in the near wall region and speed up the computation.

2. Governing Equations. In real situation, the street canyon can be of a very complicated shape and the problem of computing the dispersion of a scalar in a street canyon must be considered as a three dimensional problem. However, due to the restriction of the computational time, at this state the problem has been solved two dimensionally by assuming the wind blow perpendicular to a long straight street canyon. The non-dimensional Navier-Stokes equations, continuity equation and equation of transport of the scalar written in tensor form are as follows:

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} + = -\frac{\partial P}{\partial x_i} + \frac{1}{Re}\frac{\partial^2 u_i}{\partial x_j^2} + \frac{\partial \tau_{ij}}{\partial x_j} \quad (1)$$

$$\frac{\partial u_j}{\partial x_j} = 0 \quad (2)$$

$$\frac{\partial S}{\partial t} + u_j \frac{\partial S}{\partial x_j} = \frac{\partial H_j}{\partial x_j} \quad (3)$$

where x_i and u_i are the Cartesian coordinates and corresponding velocity components respectively; t is the time, P the pressure, R_e the Reynolds number, S the concentration of the scalar, τ_{ij} and H_j the subgrid scale Reynolds stress and flux of the scalar. In the system of equations (1)-(3), the density effect has been neglected by assuming the scalar density the same as the density of ambient air and constant temperature throughout the flow domain.

3. Numerical Solution. The Smagorinski model (Smagorinski, 1963, Armfield and Asaeda, 1993 and Mason and Thomson, 1992), was used to compute the subgrid scale Reynolds stress and flux of the scalar as follows

$$\tau_{i,j} = \nu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \frac{2}{3}\delta_{ij} k \quad (4)$$

$$H_i = -\frac{\nu}{P_r}\frac{\partial S}{\partial x_i} \tag{5}$$

where k is the subgrid scale kinetic energy, δ_{ij} the kronecker delta and P_r the Prandtl number, taken to be 0.7 (Mason and Thomson, 1992). The subgrid scale eddy viscosity ν is evaluated as follows (Mason and Thomson, 1992)

$$\nu = (C\Delta)^2 \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)^2 \tag{6}$$

where $C = 0.2$ and Δ is a characteristic length scale (Mason and Thomson, 1992).
A numerical scheme was developed to integrate equations (1-3) to get the velocity and scalar field. A non-uniform and non-staggered grid was used (Armfield, 1991, Armfield and Debler, 1992) to get fine resolution in the near wall region and speed up the solution. Such scheme has been proved of satisfying the regular ellipticity and integrability requirement and much more economic than the staggered one (Armfield, 1991).

4. Initial and Boundary Conditions.

At the upwind boundary a log-law velocity distribution was assumed while zero downwind velocity variation was assumed at the downwind boundary. Zero shear was assumed at the upper boundary and the bottom is nonslip. For the scalar, a constant flux is specified at the bottom of the street canyon and zero normal gradient was assumed for all other boundaries. Beginning of the computation, the street was assumed filled with the scalar of constant density and nowind. Suddenly the wind started and the solution begin until the steady state was reached.

5. Results and Discussions.

The velocity field and density contour lines after the steady state has been reached are shown in Fig. 1 and Fig. 2, respectively. A large vortex was shed from the upper corner in the street canyon and pull the scalar to form a large splash of the scalar. The scalar density is largest in the bottom of the street and near the two vertical walls. The computations (not shown) showed that with increasing wind velocity, the vortex and the splash of the scalar extend further in the vertical and downstream directions.

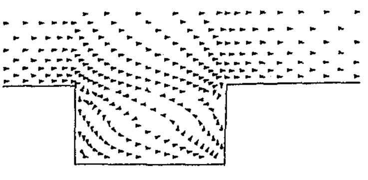

Figure 1. Instantaneous velocity field

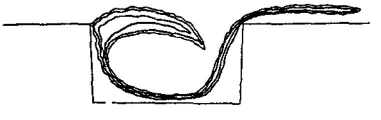

Figure 2. Density contour lines of the scalar

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