The Modelling of Turbulence from Traffic in Urban Dispersion Models – Part I: Theoretical Considerations

S. DI SABATINO\textsuperscript{a,b,c,*}, P. KASTNER-KLEIN\textsuperscript{d,e}, R. BERKOWICZ\textsuperscript{f}, R.E. BRITTER\textsuperscript{a} and E. FEDOROVICH\textsuperscript{d,g}

\textsuperscript{a}Department of Engineering, University of Cambridge, Trumpington Street, Cambridge, CB2 1PZ, U.K.; \textsuperscript{b}Cambridge Environmental Research Consultants Ltd, Cambridge, U.K.; \textsuperscript{c}Dipartimento di Scienza dei Materiali, University of Lecce, Lecce, Italy; \textsuperscript{d}School of Meteorology, University of Oklahoma, Norman, U.S.A.; \textsuperscript{e}Institute for Climate Research ETH Swiss Federal Institute of Technology, Zurich, Switzerland; \textsuperscript{f}National Environmental Research Institute, Department of Atmospheric Environment, Roskilde, Denmark; \textsuperscript{g}Institute for Hydromechanics, University of Karlsruhe, Karlsruhe, Germany

Received 8 April 2002; accepted in revised form 19 September 2002

Abstract. The modelling of pollutant dispersion at the street scale in an urban environment requires the knowledge of turbulence generated by the traffic motion in streets. In this paper, a theoretical framework to estimate mechanical turbulence induced by traffic in street canyons at low wind speed conditions is established. The standard deviation of the velocity fluctuations is adopted as a measure of traffic-produced turbulence (TPT). Based on the balance between turbulent kinetic energy production and dissipation, three different parameterisations for TPT suitable for different traffic flow conditions are derived and discussed. These formulae rely on the calculations of constants that need to be estimated on the basis of experimental data. One such estimate has been made with the help of a wind tunnel data set corresponding to intermediate traffic densities, which is the most common regime, with interacting vehicle wakes.

Key words: dispersion modelling, low wind conditions, pollutant dispersion, street canyon, traffic-produced turbulence, urban areas

1. Introduction

Low wind speed conditions are typically associated with the worst air pollution episodes in cities. Urban dispersion models poorly reproduce these episodes, with the pollutant concentration generally overestimated. In these cases the turbulence, mechanically generated by traffic motion, becomes responsible for much of the dilution of pollutants in streets. Especially for low wind speed conditions, any improvement in the estimation of the traffic-produced turbulence (TPT) will impact significantly on model predictions of concentration values.

Field measurements of TPT are not readily available. It is difficult, in a field experiment, to separate TPT from other forms of turbulence such as wind-generated,

\*Corresponding author, E-mail: sd282@eng.cam.ac.uk
or thermally generated turbulence. Rotach [1] and Louka [2] provide field measurements for flow and turbulence in street canyons but do not explicitly address TPT. However, the recent Nantes99 experiment [3,4] had among its aim the determination of turbulent kinetic energy ($TKE_1$) production due to vehicle's motion. Although the data analysis is still under process, important insights have been delivered on TPT components in an urban street canyon. They will be further discussed in connection with wind tunnel data and the theoretical framework developed in the present study.

In wind tunnel studies, the investigation of flow and dispersion characteristics in street canyons has been of great importance during the last years (see, e.g., Brown et al. [5], Schatzmann et al. [6], Kastner-Klein [7]). Regarding the flow field parameters, mainly vertical profiles of mean and turbulent velocity components have been measured and analysed.

Some major questions arising from these studies are: (i) How strong is the influence of the particular experimental arrangement on the observed flow characteristics in a street canyon and (ii) in what way can these characteristics be parameterised. These questions were first addressed by Kastner-Klein et al. [8] through an inter-comparison of three wind tunnel studies [5, 7, 9]. Furthermore, wind tunnel results have been compared with data from related field experiments [10]. In both studies the analysis focused on vertical profiles of mean velocity and turbulent kinetic energy inside the street canyon and above roof level. It was shown that qualitative similarity exists between the flow characteristics in the wind tunnel model and its atmospheric counterpart. A good agreement was ascertained between the flow characteristics obtained in different wind tunnel studies inside and above idealised street canyons of similar geometries. A vortex-type motion and associated reverse flow in the lower part of the canyon was observed in isolated as well as in urban-type idealised canyons. As an example, velocity vectors and streamlines determined in the central plane of an idealised street canyon are plotted in Figure 1 [7]. The in-canyon re-circulation is clearly indicated by the inversely directed flow at street level and nearly zero velocity values in its centre. Amplification of turbulent kinetic energy typically occurred in the flow region just above the roof levels, in particular for situations with changes of surface roughness.

The effect of traffic on mean flow, turbulence and concentration patterns in street canyons has also been subject of wind tunnel studies by Kastner-Klein et al. [10–13]. Different traffic configurations were simulated by small metal plates moving on two belts along the street in the wind tunnel model (see Kastner-Klein [7] for technical details). The wind flow was directed perpendicular to the street. In order to ensure Reynolds number independence, the wind velocity was varied in the range from 5 m/s up to 12 m/s. Thus, the results resemble the interaction of traffic- and wind-induced flow components in the street canyon. While the longitudinal (cross-canyon) mean flow component was only slightly affected by whether the traffic was one-way or two-way, the lateral (along-the-canyon) mean flow component was strongly affected (see [10]). For both traffic arrangements the turbulence