PROPER INLET CONDITIONS FOR MODELING ATMOSPHERIC BOUNDARY LAYER FLOWS USING STANDARD K-ε MODEL

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Introduction

On October 9th 2018, Mayor of London, Sadiq Khan,, tweeted the following message on twitter:" Our filthy toxic air is a national health crisis, contributing to tens of thousands of premature deaths in the UK every year - but working together with London's councils, we can turn it around & improve our neighborhoods for the benefit of all Londoners", https://www.london.gov.uk/what-we-do/environment/pollution-and-air-quality. Air quality modeling is an important topic among many research groups around the globe and CFD has become the standard tool to investigate air quality in any city, see Chang and Meroney (2003).

As a first requirement for an accurate CFD simulation, we need to provide correct boundary conditions for the computational domain for variables such as stream wise velocity and turbulence quantities. In this paper, we plan to solve the averaged-Navier_stokes equations (RANS) using the popular k-εmodel. As a first step towards achieving this goal, the computational model should be able to predict equilibrium Atmospheric Boundary Layers (ABL). For equilibrium ABLs, the stream wise gradients for all variables must be zero. However, this is not true for boundary layers. In boundary layers with zero pressure gradient in the stream wise direction, the cross-stream shear stress is balanced by the change in momentum in the stream wise direction. In addition, there is a net outflow through the top boundary of the computational domain. The non- homogeneity of the inlet profiles in the horizontal direction is widely discussed in literature, see Franke et al., 2007; Blocken et al 2007.

Horizontal homogeneity cannot be achieved in boundary layer flows with zero pressure gradient. The profiles of velocity, turbulent kinetic energy and dissipation rate are self- similar, but not homogeneous. Hence, a channel flow is selected to study the inlet profiles that would be homogeneous in the x-direction. For RANS simulations with the standard k-εmodel, following boundary conditions are often prescribed for atmospheric boundary layer, see Richards and Hoxey (1993);

- The velocity profile at inlet is specified as a logarithmic function of height;
- Turbulent kinetic energy (k) is specified as a constant at inlet;
- And Turbulent dissipation rate (ε) is specified as inversely proportional to the height.

However, these prescribed profiles for velocity, k and ε do not match the fully-developed profiles for channel flow and it will take some distance before these profiles become fully developed.

Gorle et al (2009) allowed the turbulent Prandtl number, σe, to vary with the height so that the governing equation for ε is satisfied at the inlet. However, the momentum equation for U was not satisfied at the inlet. In the present paper, we set out to investigate fully- developed profiles for U, k and ε which would not require special distance for the profiles to become fully-developed. The goal of this study is to obtain the velocity and turbulence kinetic energy profiles for Atmospheric Boundary Layer by solving the fully-developed flow in a large channel using RANS simulations with the standard k-ɛ turbulence model.

2 Governing equations for fully developed channel Flow

The partial differential equations governing the velocity component turbulent kinetic energy and energy dissipations, ε for fully developed channel flow are given below:

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial y}\left\{[\nu + \nu_t]\frac{du}{dy}\right\} + \frac{u_\tau^2}{h} \qquad (1)$$

$$\frac{\partial k}{\partial t} = \frac{\partial}{\partial y}\left\{[\nu + \nu_t]\frac{dk}{dy}\right\} + \nu_t\left[\frac{\partial u}{\partial y}\right]^2 - \varepsilon \qquad (2)$$

$$\frac{\partial \varepsilon}{\partial t} = \frac{\partial}{\partial y}\left\{[\nu + \nu_t]\frac{d\varepsilon}{dy}\right\} + C_1\nu_t\left[\frac{\partial u}{\partial y}\right]^2\frac{\varepsilon}{k} - C_2\frac{\varepsilon^2}{k} \qquad (3)$$

With the following boundary conditions:

$$at\ \ y = y_P, \qquad k_P = \frac{u_\tau^2}{\sqrt{C_\mu}}, \qquad \varepsilon_P = \frac{u_\tau^3}{\kappa y_P}, \qquad U_P = \frac{u_\tau}{\kappa}\, ln\left(\frac{y_P + y_0}{y_0}\right)$$

$$with, \qquad y_0 = 0.00075\ m, \qquad u_\tau = 0.374\frac{m}{s}\ \ and\ \ \kappa = 0.4187$$

Where,
P is the first grid point in the y-direction.

The equations are written in unsteady form so that one could march in time to get the steady-state, fully-developed profiles for velocity and turbulence quantities.

2. *Comparing fully-developed profiles with available computational data*

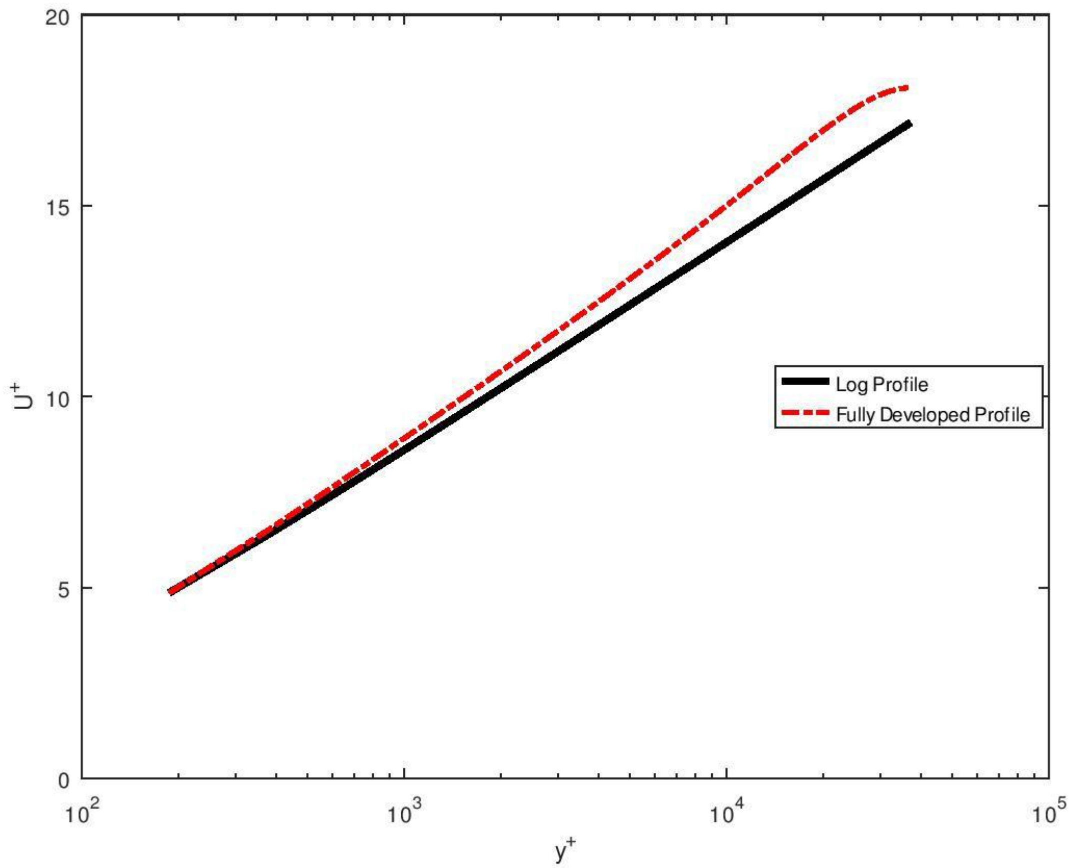

Fig. 1: Plots of computed velocity profile compared with the logarithmic profile given by $U^+ = 1/k\ln[1+y/y_O]$

In Fig. 1 , computed fully-developed velocity profile is compared with the logarithmic velocity profile given by:

$$U^+ = 1/k * \ln(1+y/y_O)$$

The plots started to deviate from each other around $y^+ = 1000$. Same trend was observed in the experimental data of Zagarola and Smits (1997).

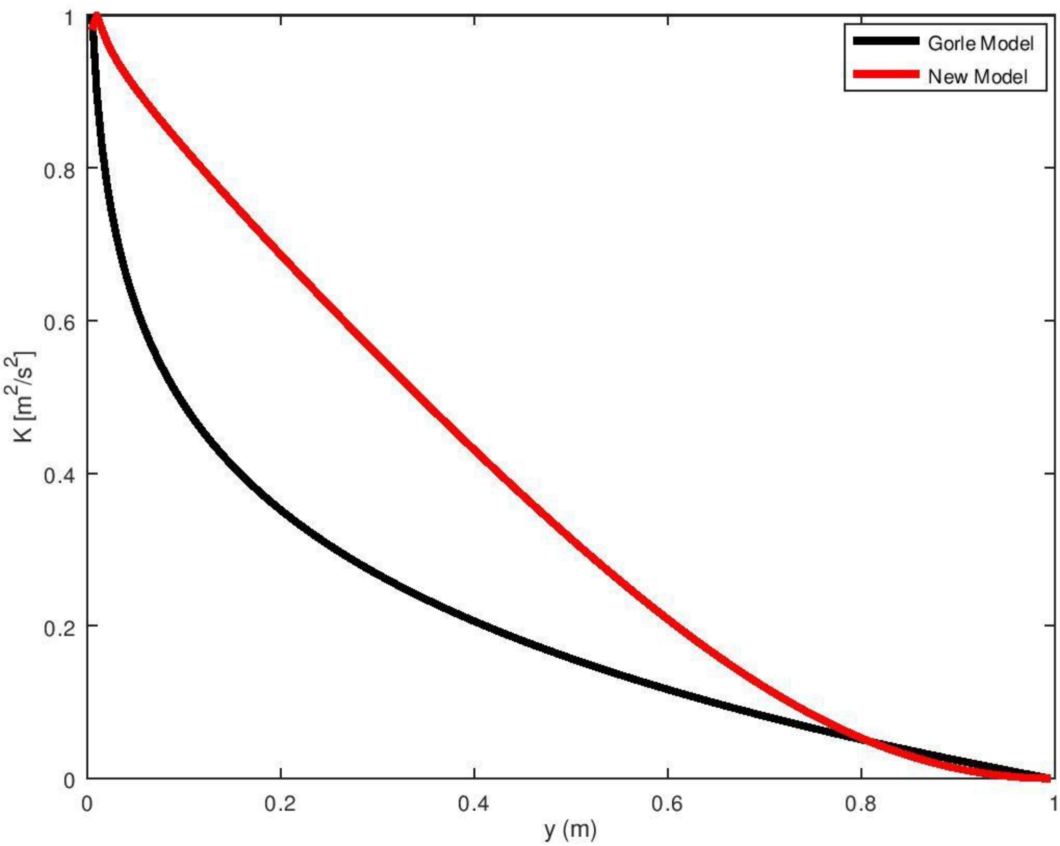

Fig.2: Plots of (k-kmin)/(kmax -kmin) against y/H

In Fig.2 , Gorle's log-k profile is compared with the fully-developed k-profile of a channel. Gorle's log-k profile is unusually steep at the wall and in addition the gradient of k is not zero at the center line. The fully-developed k-profile obtained in this study looks much more reasonable and the gradient of k-profile at the center is zero.

3. Discussion

It is proposed to use a fully-developed velocity, k and εprofiles at the inlet to study the particle dispersion process in built-up environment.

4. References

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