7.4 Improved Velocity Deficit Parameterizations for a Fast Response Urban Wind Model

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1. INTRODUCTION

The QUIC (Quick Urban & Industrial Complex) dispersion modeling system has been developed to provide high-resolution wind and concentration fields in cities. The fast response 3D urban wind model QUIC-URB explicitly solves for the flow field around buildings using a suite of empirical parameterizations and mass conservation. The technique is based on the work of Röckle (1990, 1998) and Kaplan & Dinar (1996).

Previous evaluations of the model against single and multiple building wind tunnel data sets have shown weaknesses in several of the standard parameterizations (Kastner-Klein, 2003; Pardyjak and Brown, 2002; Pardyjak and Brown, 2001). One such weakness is the empirical parameterization for the far wake velocity deficit region behind a single building. Since conservation of mass does not provide a mechanism to produce diffusion, the far wake parameterization must include such physics. The standard QUIC-URB parameterization contains an ellipsoidal envelope for the velocity deficit region that is confined to the width of the building. As a result, mean velocity gradients associated with turbulent production are excessively strong and confined to a narrow region. For this work, the Taylor and Salmon (1993) shelter model has been implemented and compared against the wind tunnel data of Snyder and Lawson (1994, hereafter SL94). This shelter model employs a Gaussian shaped envelope that extends beyond the width of the building in the far wake region. The shelter model significantly improves the prediction of velocity distributions in the far wake.

2. SHELTER MODEL DESCRIPTION

The wake model investigated here is based on the wake deficit or shelter model for three-dimensional obstacles developed by Taylor and Salmon (1993). This model produces a Gaussian velocity deficit profile of the form,

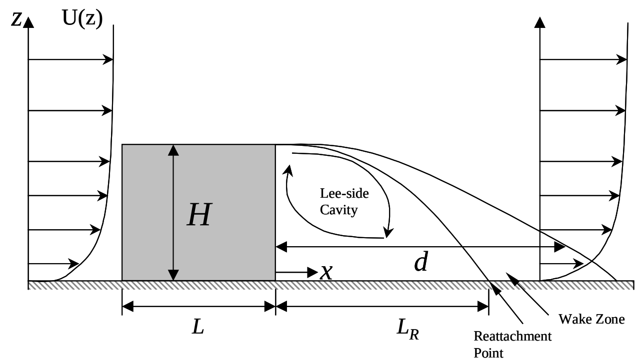

Figure 1: Schematic of flow in the wake of a building.

$$\frac{u_d(x,y,z)}{U(H)} = \Gamma C_D \left(\frac{W}{H}\right)\left(\frac{x}{H}\right)^{-1.5} F(\eta)G(\zeta)$$

$$F(\eta) = \frac{1}{(2\pi)^{1/2} a_f} \exp\left(\frac{-\eta^2}{2a_f^2}\right)$$

$$G(\zeta) = c_a \zeta \exp\left(-a_g \zeta^{1.5}\right)$$

In the above equations, x is the streamwise coordinate, W and H are the width and height of the building, u_d is the velocity deficit in the wake of the building, $U(H)$ is the mean velocity at building height based on the upstream power law profile, $\Gamma = 0.6c_a^2$ and C_d is the drag coefficient. The function $F(\eta)$ represents the lateral velocity deficit variation and $G(\zeta)$ represents the vertical variation based on the similarity coordinates:

$$\zeta = \left(\frac{z}{H}\right)\left(\frac{x}{H}\right)^{-1/2} \quad \text{and} \quad \eta = \left(\frac{y}{H}\right)\left(\frac{x}{H}\right)^{-1/2}$$

The coefficient a_f is the lateral wake spread parameter. The vertical coefficients c_a and a_g are defined as:

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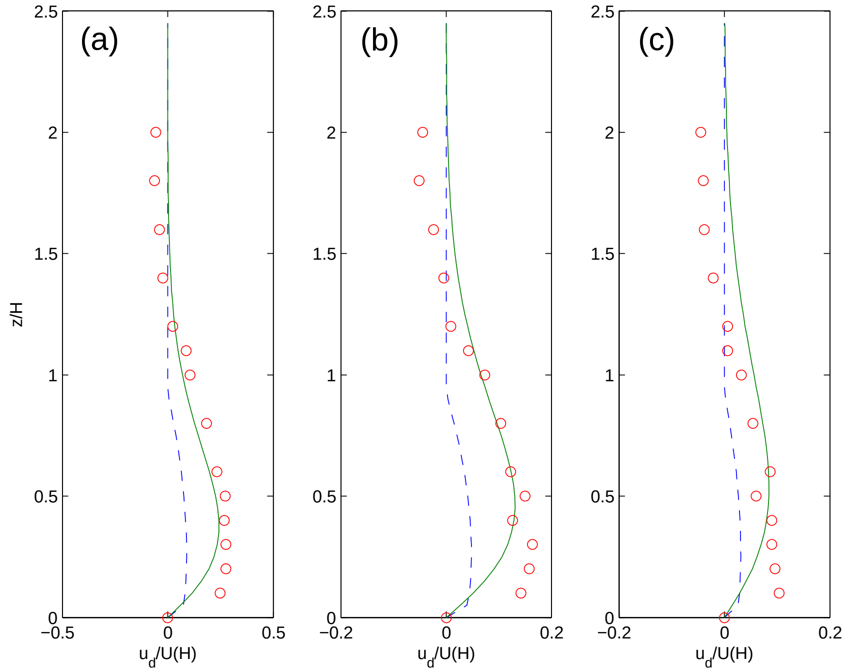

Figure 1: Plot of the streamwise velocity deficit as a function of the wall normal distance (*z*) as calculated using the original Röckle (1990) model (– – –), the shelter model (——), and the SL94 data (o) at three streamwise locations far downstream of the cube: (a) x/H = 4, (b) x/H=6, (c) x/H = 8.

$$c_a = \sqrt{\frac{\ln\left[(H + z_o)/z_o\right]}{2\kappa^2}}$$

$$a_g = 0.8c_a^{1.5}$$

where z_o is aerodynamic roughness and κ is th von Kármán constant (taken as 0.4). For brevity, we skip the details of the theory and development of this model (see for example, Taylor and Salmon, 1992; Perera, 1981; Counihan et al., 1974)

3. ROCKLE MODEL DESCRIPTION

The far wake velocity deficit description used in the original Röckle (1990) model is applied in an ellipsoidal volume (Wake Zone in Figure 1) after the recirculating cavity in the building wake and is assumed to be approximately 3 cavity lengths deep (i.e., $3L_r$). The recirculating cavity length, L_r is defined as:

$$\frac{L_r}{H} = \frac{1.8\frac{W}{H}}{\left(\frac{L}{H}\right)^{0.3}\left(1 + 0.24\frac{W}{H}\right)}$$

Within this region ($L_r < x < 3L_r$), the following velocity parameterization is specified:

$$\frac{u(x,y,z)}{U(H)} = \left(1 - \left(\frac{d}{x}\right)^{1.5}\right)$$

The cavity length, d in the streamwise direction is defined by an ellipsoid shape (See Figure 1) and calculated as:

$$d = L_R\sqrt{\left(1 - \left(\frac{z}{H}\right)^2\right)\left(1 - \left(\frac{y}{H}\right)^2\right)} - \frac{L}{2}$$

where L is the length of the building in the streamwise direction. This cavity is confined vertically to the height and laterally to the width of the building.

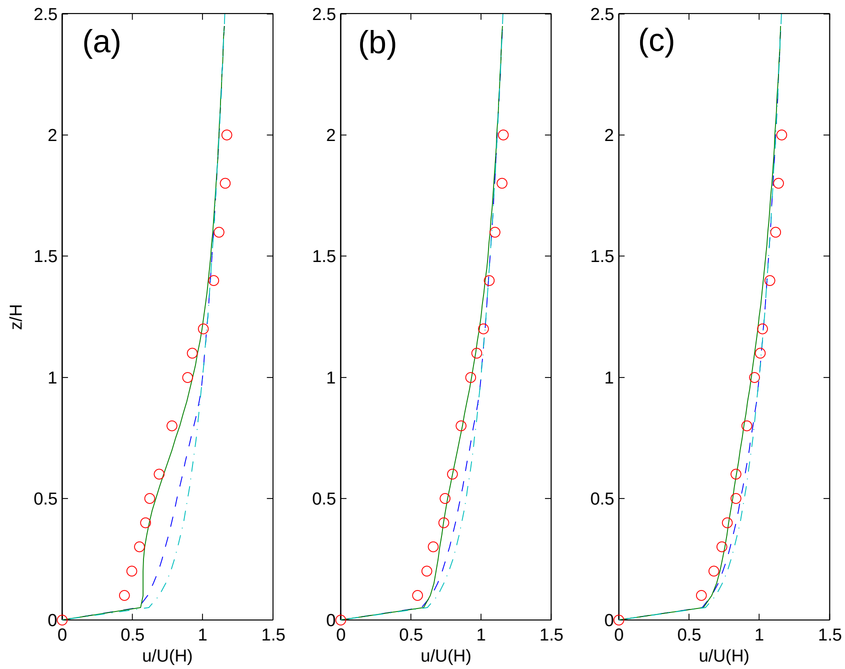

Figure 2: Plot of the streamwise velocity component as calculated using the original Röckle (1990) model (– – –), the shelter model (——), and the SL94 data (o) at three streamwise locations far downstream of the cube: (a) x/H = 4, (b) x/H=6, (c) x/H = 8. Also shown is the upstream boundary layer profile (— · —).

4. DESCRIPTION OF THE TEST CASE

The test case chosen to evaluate the two velocity deficit models was flow over a cube in deep boundary layer described by a power law of the form:

$$\frac{u(z)}{U(H)} = \left(\frac{z}{H}\right)^{p}$$

where p was taken to be 0.16 to match the data of SL94. The upstream wind was normal to the upstream face of the cube.

For the shelter model calculations, the aerodynamic roughness was taken as 0.01H in accordance with the experimental data of SL94. The rest of the coefficients were chosen based on the range of recommendations of Taylor and Salmon (1993). In particular, the drag coefficient was taken as C_d = 0.4 and $a_f = 0.5$.

5. RESULTS AND DISCUSSION

The original Röckle (1990) model and the Taylor and Salmon (1993) shelter model were run and compared to the SL94 data. Figure 1 is a plot of the velocity deficit as function of height away from the wall at three different streamwise locations: x/H = 4, x/H=6 and x/H = 8. The streamwise velocity deficits computed using the shelter model are much closer to the experimental data than the original Röckle. Both the “shape” and the magnitude more closely match the SL94 data. The improved shape is important as it indicates that momentum has diffused above the building height. A feature not included in the Röckle model where the velocity gradient at the edge of the ellipsoidal volume is very strong. Figure 2 shows the streamwise velocity profiles at the same down stream locations as they approach the upstream boundary layer profile. Based on the data shown in Figure 2, the Taylor and Salmon model has a decrease in error of 51% over the original model.

Figure 3 shows the streamwise velocities in the crosswind direction very close to the ground (x/H=0.1). Both models significantly overpredict the velocities near the ground. As seen in Figure 2, the lowest data points always have the largest error when compared with the SL94 data. However, the shelter model does provide a mechanism for diffusion well outside of

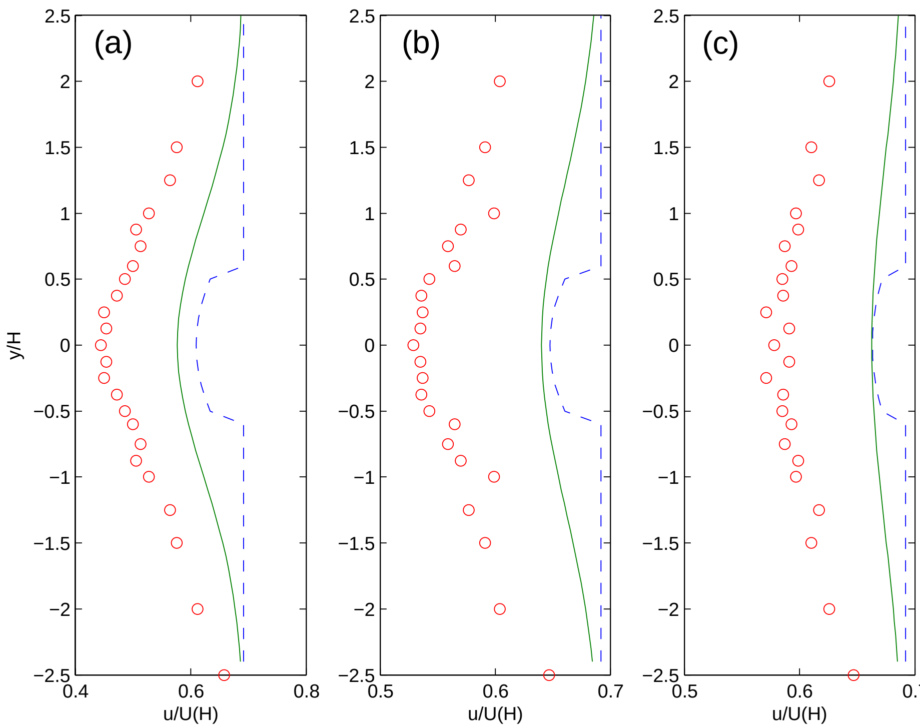

Figure 3: Plot of the streamwise velocity component as a function of the crosswind direction (y) near the ground ($z/H=0.1$) as calculated using the original Röckle (1990) model (– – –), the shelter model (——), and the SL94 data (o) at three streamwise locations far downstream of the cube: (a) x/H = 4, (b) x/H=6, (c) x/H = 8.

the width of the building where the original model suggests very strong velocity gradients.

6. SUMMARY

QUIC-URB is a high resolution 3D fast response urban diagnostic wind model that relies on empirical parameterizations. The standard wake deficit model currently used in the code is based on the original Röckle (1990) model. Since QUIC-URB only solves the continuity equation (i.e., no momentum equation is solved), the model is reliant on these types of parameterizations to provide a mechanism for diffusion. The results shown here indicate that the Taylor and Salmon (1993) shelter model provides a reasonable means (requires similar computational effort as the Röckle model) to add momentum diffusion beyond the width and height of the building that is in good agreement with the experimental data.

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