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IMPROVED UPWIND CAVITY PARAMETERIZATION FOR A FAST RESPONSE URBAN WIND MODEL

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1. INTRODUCTION

The QUIC (Quick Urban & Industrial Complex) fast response dispersion modeling system has been developed to provide high-resolution wind and concentration fields in cities. It consists of an urban wind model QUIC-URB, a Lagrangian dispersion model QUIC-PLUME, and a graphical user interface QUIC-GUI. The 3D wind model, QUIC-URB, explicitly solves for the flow field around buildings using a suite of empirical parameterizations and mass conservation. This procedure is based on the work of Röckle (1990).

Previous evaluation of the QUIC-URB model against single and multiple building wind tunnel data has shown weaknesses in several of the standard parameterizations. In particular, the upwind cavity associated with the horseshoe vortex does not compare well with the experimental results (Pardyjak and Brown, 2001). The cavity size is over predicted and the velocities within the cavity are quite poorly reproduced.

In this work, the upwind cavity parameterization has been modified and evaluated against wind tunnel data for several rectangular building geometries. The upwind cavity has been divided into two regions: a “displacement zone” where a modified power law profile is implemented and “front eddy” region where a simple vortex parameterization is specified. The model provides significant improvement over the previous standard parameterization.

2. MODIFIED UPWIND CAVITY LENGTH PARAMETER

For flow around a single building of rectangular geometry, the original Röckle (1990) model does not predict the velocities within the upwind cavity well. In this work, additional physics have modeled in an attempt to improve the velocity predictions upwind of a single building.

The basic physics of flow around a single building have been reviewed by Hosker (1984). For flow approaching a building, the main flow separates from the ground plane some distance ahead of the building, it then passes above the standing front eddy and then reattaches at the stagnation point (see Figure 1). Castro and Robins (1977) found that separation and lateral deflection of the main flow occurs at some distance before the maximum upwind extent of the horizontally standing vortex. The perturbations that are observed ahead of the eddy represent a “displacement zone”.

In the original Röckle (1990) model, the displacement zone and the standing front eddy were combined. This upstream zone is defined as an ellipsoid with an upstream extent of *Lfx* where the velocities are specified to be zero (see for example Kaplan and Dinar, 1996). The original Röckle (1990) model used the following parameterization for the upwind cavity length:

$$L_{fx,R} = \frac{2\frac{W}{H}}{1+0.8\frac{W}{H}} \qquad (1)$$

where W is the width of the building in the crosswind direction and H the height.

After comparing this length with the experimental data of Snyder and Lawson (1994) for various W/H ratios, it was determined that the original model captured the shape of the curve well but seemed to be offset. As a result, a new parameter for the length of the “displacement

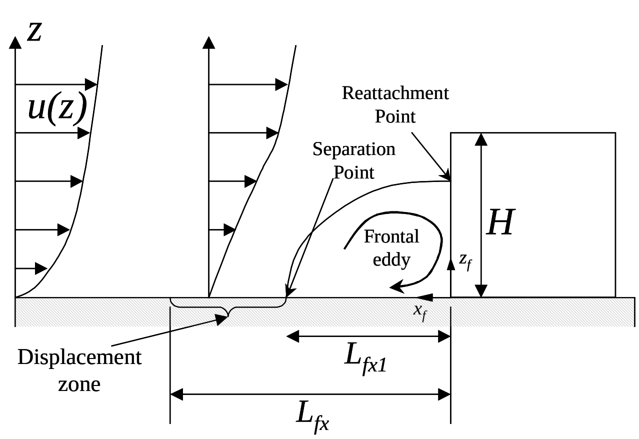

Fig. 1: Schematic of the interaction of the upwind boundary layer flow and a rectangular obstacle.

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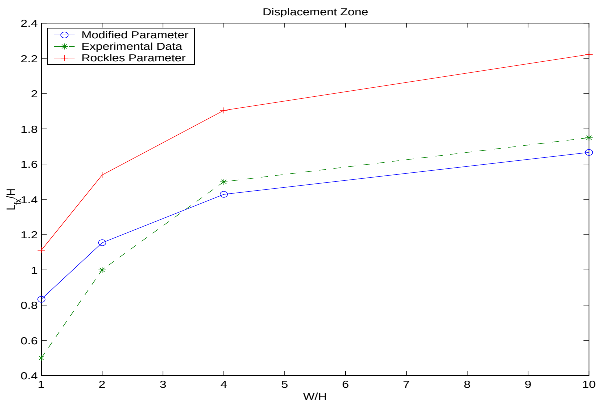

Fig. 2: Comparison of the upwind displacement zone length (L_{fx}) as calculated by the Rockle (1990) model and the proposed model (Eq. 2) against the data of Snyder and Lawson (1994) for various W/H ratios.

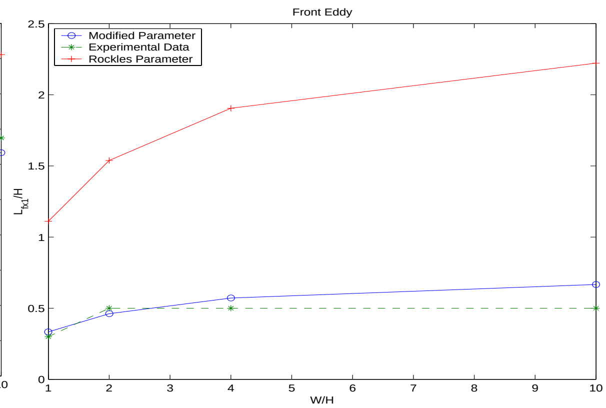

Fig. 3: Comparison of the frontal eddy length (L_{fx1}) as calculated by the Röckle (1990) model and the proposed model (Eq. 3) against the data of Snyder and Lawson (1994) for various *W/H* ratios.

zone" has been proposed as follows:

$$L_{fx} = \frac{1.5\frac{W}{H}}{1 + 0.8\frac{W}{H}} \quad (2)$$

Figure 2 is a comparison of the modified parameter L_{fx} for the displacement zone with that of the original parameter of Röckle (1990) and the experimental data of Snyder and Lawson (1994) for various building geometries.

An adverse pressure gradient causes the flow to separate from the ground surface upwind of the building. As a result, a standing vortex is formed near the upwind face of the building. The length of this "front eddy" (see Figure 1) was visually fit to the data of Snyder and Lawson (1994) and found to be reasonably approximated by:

$$L_{fx1} = \frac{0.6\frac{W}{H}}{1 + 0.8\frac{W}{H}} \quad (3)$$

Figure 3 shows the front eddy length as calculated from Eq. (3) as a function of *W/H* with the original parameterization of Röckle (1990) and the experimental data of Snyder and Lawson (1994).

3. UPWIND CAVITY PARAMETERIZATION FOR DISPLACEMENT ZONE WINDS

In the original QUIC-URB model the initial wind speeds (u_o, v_o and w_o) within the upwind cavity are set equal to zero. The final velocity field is obtained by forcing the initial velocity field to be mass consistent. In the new parameterization, an *ad hoc* modified power law velocity profile is implemented in the displacement region. The new parameterization for the velocity field in the displacement region is obtained by multiplying the power law profile by a factor (C_{dz} = 0.4)

$$\frac{u_o(z)}{u_o(H)} = C_{dz}\left(\frac{z}{H}\right)^p \quad (4)$$

where $u_o(H)$ is the prescribe velocity at the building height H and p is a power law exponent taken to be 0.16. Physically, this should force more lateral and vertical flow upon the application of conservation of mass

4. UPWIND CAVITY PARAMETERIZATION FOR FRONT EDDY WINDS

QUIC-URB solves only the equation of conservation of mass. Hence, pressure gradients and vorticity generation are not considered. The impact of these terms has been accounted for through a simple vortex parameterization applied to the front eddy region. The experimental data of Snyder and Lawson (1994) was fit to a simple trigonometric relation for the streamwise and spanwise velocities. The parameterization shown in Eqns. (5) and (6) generate the u_o and w_o velocities in the front eddy region as a function of varying length (x_f) and height (z_f) of the vortex region (see Figure 1).

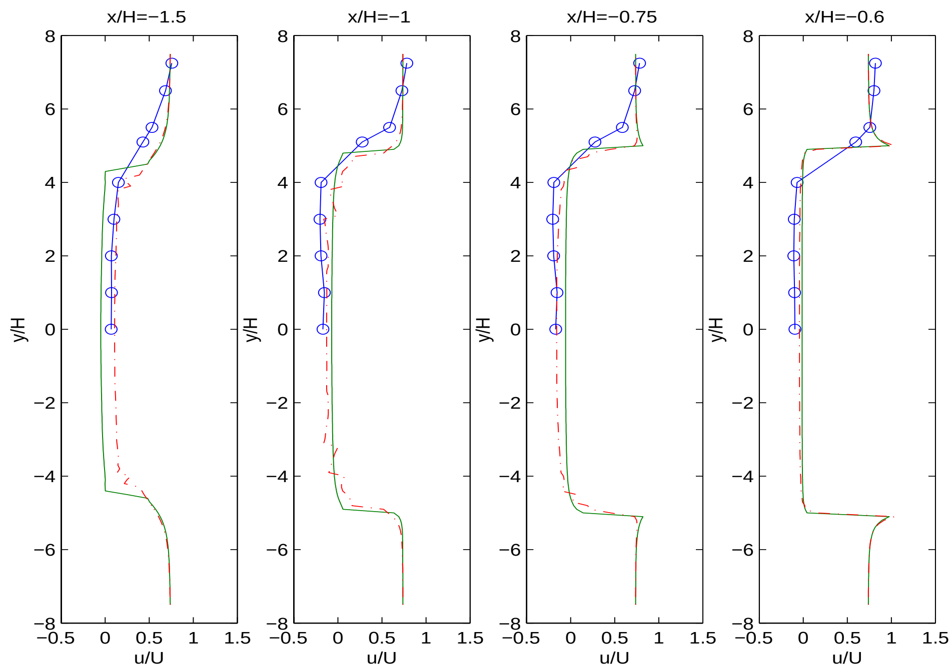

Fig. 4: Comparison of normalized streamwise velocities in the spanwise direction for the modified QUIC-URB model (red dot-dash), the original Röckle (1990) model (green solid line), and the experimental data (blue circles) of Snyder and Lawson (1994) for a building with W/H = 10.

$$\frac{u_o}{u_o(H)} = \left(0.6\cos\left(\frac{\pi z_f}{0.5H}\right) + 0.05\right) * \left(-0.6\sin\left(\frac{\pi x_f}{L_{fx1}}\right)\right) \quad (5)$$

$$\frac{w_O}{u_o(H)} = \left(-0.1\cos\left(\frac{\pi x_f}{L_{fx1}}\right) - 0.05\right) \quad (6)$$

5. MODEL DATA COMPARISON

QUIC-URB was run using both the Röckle upwind parameterization and the new modified parameterization and results were compared to wind-tunnel experimental data for a relatively wide building ($W = 10H$). Figures 4 and 5 show the computed normalized velocities $u/U(H)$ in both the spanwise and vertical directions for the modified QUIC-URB, the original QUIC-URB, and the experimental values. The computed velocities of the modified model follow the experimental data better than the original parameterization in the upwind cavity region. The vertical profiles of mean velocity show the most improvement when using the new upwind cavity parameterization (Fig. 5). There is a 35% reduction in the error between the computed velocity field and the experimental data when comparing the new parameterization to the original QUIC-URB model.

6. SUMMARY

In this work, an attempt was made to incorporate more physics associated with the flow in the upwind region of an isolated rectangular prism into the 3D fast response urban wind model QUIC-URB. To this end, the upwind cavity was separated into two regimes: a displacement zone and a frontal eddy. Simple parameterizations obtained from data fitting were then implemented. The results for a wide building show that the new parameterization is significantly better than the original parameterization. Additional, work is planned to investigate how well the model performs for buildings with smaller aspect ratios. In addition, the effect of the upwind boundary layer profile on the upwind length scales will be investigated.

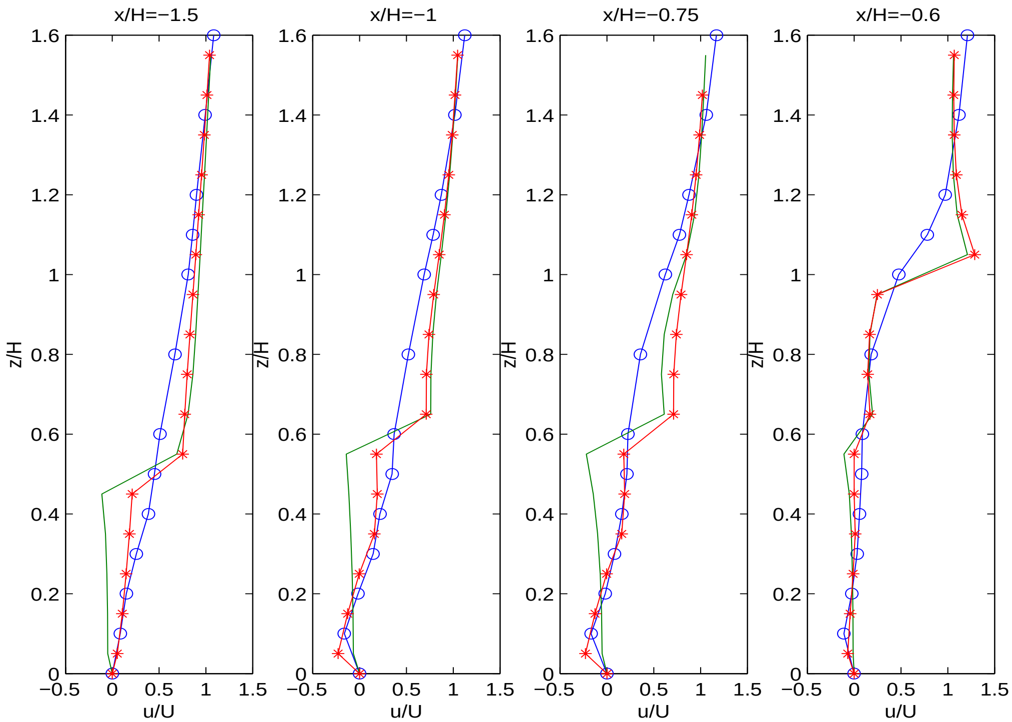

Fig. 5: Comparison of vertical profiles of normalized streamwise velocities for the modified QUIC-URB model (red stars), the QUIC-URB model with the original Röckle (1990) parameterization (green line), and the experimental data (blue circles) of Snyder and Lawson (1994) for a building with W/H = 10.

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