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Velocity field measurements above the roof of a low-rise building during peak suctions

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ABSTRACT

The flow over a low rise building has been investigated through synchronized pressure and velocity measurements. Peak suctions on the upper surface were investigated utilizing ensemble averages, conditioned on the peaks. Near the leading edge, it was found that the reattachment length scales with the size of the roof surface area over which the pressures are integrated, with small areas being associated with reattachment lengths that are significantly smaller than the mean. However, within the separation bubble, but further downstream, the dependence of the reattachment length with the size of the surface area is not significant. Peak suctions are associated with locally accelerated flow near the leading edge of the building, which scale with the size and location of the roof surface area over which the pressures are integrated. Quasi-steady theory under-predicts the peak suctions that would result from these locally accelerated flows. The scale of these accelerated flows is consistent with Melbourne's (1979) small scale turbulence parameter. As the instant of the peak suction on a small area near the leading edge is approached, the position of the separation bubble decreases in both length and height as suctions near the lead edge increase. Higher speed flow also emerges along the separated shear layer above the leading edge. After the peak suction the separation bubble grows and large suctions both decrease in magnitude and span a larger area, while high speed flows decrease in magnitude and become dispersed.

1. Introduction

The flow over and around low-rise buildings results in a series of vortical structures which are associated with the peak aerodynamic loads. When the wind direction is normal to one of the walls, the largest suctions on the roof occur under the separating-reattaching shear layer generated at the leading edge (Saathoff and Melbourne, 1989). While the structure of the mean flow and pressure fields in the separated region are generally well understood, see for example, Castro and Robins (1977), Martinuzzi and Tropea (1992), Tieleman et al. (2003) and Kim et al. (2003), the aerodynamic mechanisms that result in peak events are not as clear. Melbourne (1979) and Saathoff and Melbourne (1989, 1997) provided interesting investigations into the mechanisms that result in peak suctions for the flow over a blunt flat plate in a turbulent flow. Large peak suctions were found to be associated with the growth, convection (from the leading edge, in the downstream direction), and eventual shedding of a strong vortex within the separation bubble. Interestingly, the mechanisms causing the peak suctions in both smooth and turbulent flows are believed to be the same. The present work aims to expand this to a low-rise building in a typical atmospheric boundary layer. The present work also investigates the peaks for integral areas ranging from a single tap to areas approaching this size of the mean separation bubble.

2. Experimental setup

To investigate the aerodynamic mechanisms associated with peak suctions, a series of experiments were conducted using synchronized time-resolved particle image velocimetry (TR-PIV) and pressure measurements. While there have been several studies which have collected pressure and/or velocity data separately (e.g., Castro and Robins, 1977; Martinuzzi, Tropea (1992); Kim et al., 2003; Tieleman et al., 2003; Ho et al., 2005), synchronized measurements allow one to identify peak events in the pressure time history and then examine the flow field associated with these events. The focus of this study will be on the flow field along the building's centerline that develops during wall-normal

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winds. Experiments were conducted in Boundary Layer Wind Tunnel (BLWT) II at the University of Western Ontario's Boundary Layer Wind Tunnel Laboratory (BLWTL). A full description of the wind tunnel facility can be found in Ho et al. (2005).

2.1. Model details

The model used in the present experiments had a height of 243 mm, and plan dimensions of $530 \times 750\ \text{mm}^2$. This geometry was selected so as to balance the constraints of accurately simulating the boundary layer while maintaining a large enough size to provide good resolution of the flow field with the PIV data. Furthermore, the entire separation bubble can be captured simultaneously utilizing two cameras.

Experiments were conducted at a wind tunnel reference speed of approximately 15 m/s. The reference speed was measured above the boundary layer at a height of 1.5 m above the test section floor. Utilizing velocity profiles obtained without the model in place, a mean velocity at roof height can be determined for each run from the reference velocity. The Reynolds number, based on the roof height and roof height mean velocity was 1.9×10^5. The blockage ratio of the model was less than 3%.

The coordinate system used herein, described in Fig. 1, is referenced to the leading edge and centerline of the model. Thus, the origin lies at the center of the leading edge, the x-axis runs along the roof parallel to the mean wind direction, the z-axis is in the vertical direction, and the y-axis runs laterally across the roof.

2.2. Terrain simulation

The upstream terrain utilized for the present experiments was a simulated open country terrain. To achieve the desired boundary layer profile a combination of roughness elements arranged along the tunnel's 39 m upstream fetch, trips and spires were employed. The terrain simulation was achieved by matching the wind tunnel profiles to the ESDU (Engineering Sciences Data Unit, 1982) mean profiles, Engineering Sciences Data Unit (1983) turbulence intensities and Engineering Sciences Data Unit (1974) velocity spectra. Details pertaining to the profiles can be found in Kopp et al. (2012) who measured streamwise and vertical velocity profiles using an X-wire probe, compared these to the target profiles, and found there was an excellent agreement between experimental and target mean and intensity profiles within the range of the building's height. The agreement between the measured and target spectra were felt to be acceptable. The profiles and spectra are not repeated here for brevity.

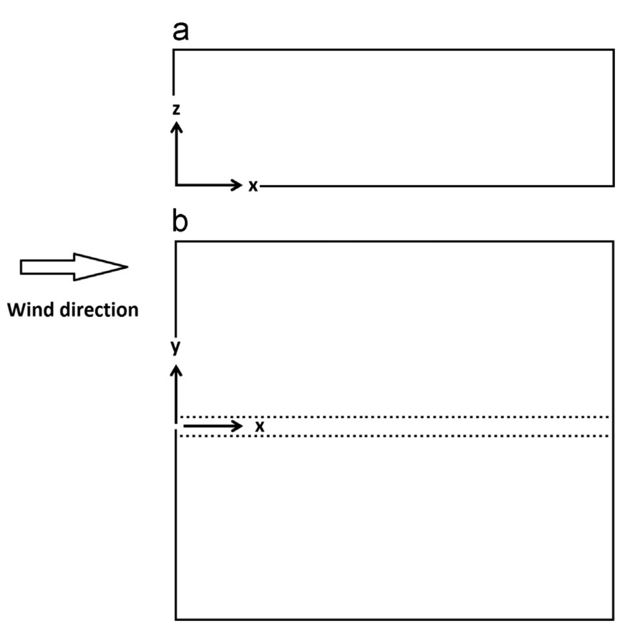

Fig. 1. Coordinate system definition: (a) section view through center of model; (b) plan view of the model. Location of the two lines of pressure taps shown by the dashed line.

2.3. Measurement system

2.3.1. Surface pressure measurements

The bare roof building was instrumented with two rows of 96 pressure taps each, located at $y = \pm 0.078H$, as shown in Fig. 1. In general, pressures from only a single row of taps, corresponding to the position of the plane of the PIV data will be reported. Since the columns of taps are located at approximately the centerline of the roof, this single set of pressure results will be referred to as the centerline pressures. Pressure measurements were made at a rate of 1110 samples/sec and low-pass filtered at 200 Hz. Full details of the pressure measurement system can be found in Ho et al. (2005).

The measured pressures were referenced to the dynamic pressures at the upper level of the wind tunnel where the flow is uniform with low turbulence levels. The pressure coefficients were then re-referenced to the dynamic pressure at roof height using the mean velocity profile; doing so has been shown to produce the least variability in aerodynamic data (Ho et al., 2005).

2.3.2. Particle image velocimetry measurements

Flow field measurements were obtained utilizing the TR-PIV system developed at UWO's BLWTL by Taylor et al. (2010). This system provides velocity data with good spatial resolution while streaming data at the same frequencies and durations typical of wind engineering wind tunnel pressure experiments. The light source is a double-head diode-pumped Q-switched, Nd:YLF laser operating at 1000 Hz. The seeding particles used in this study were created by atomizing olive oil. Images were captured using two Photron FASTCAM-1024PCI CMOS cameras operating in tandem. The cameras have a spatial resolution of 1024×1024 pixels and the system is able to stream individual images to a digital computer at 1000 Hz, giving a sampling rate of 500 Hz for velocity data. Full details of the TR-PIV system can be found in Taylor et al. (2010). The experimental set-up, showing the position of the cameras and the laser sheet illuminating the field of view, is depicted in Fig. 2.

The velocity data were computed from PIV image pairs using the FFT cross-correlation method with a 32×32 pixel interrogation windows and 50% overlap. Typical particle displacements outside of the separated shear layer were 5–6 pixels. The raw

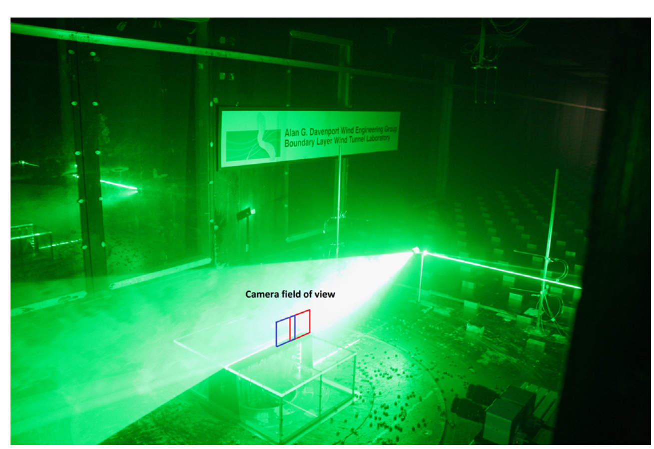

Fig. 2. Photograph of experimental setup showing positioning of the two cameras and the laser sheet.