UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF ENGINEERING, SCIENCE & MATHEMATICS

SCHOOL OF ENGINEERING SCIENCES

Doctor of Philosophy

MEASUREMENTS OF THE STRUCTURE OF URBAN-TYPE BOUNDARY LAYERS

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In order to gain a better understanding of the fundamental structure associated with turbulent flows over very rough, urban-type surfaces, laboratory experiments were undertaken in a subsonic wind tunnel facility at the University of Southampton. It was anticipated that undertaking this work would provide better insight into fundamental differences in the flow structure compared to smooth-wall surfaces. After modification of an existing facility to accommodate a longer working section length, testing proceeded over a regular array of cube roughness elements with a 25% area density. Measurements were conducted with hot-wire anemometry, Laser Doppler anemometry, and particle image velocimetry. Development of the particle image velocimetry technique to obtain accurate turbulence statistics over and among the roughness elements was successfully undertaken providing significant new analysis opportunities and results.

Initial testing characterised a large-scale spanwise variation discovered within the boundary layer developing over the cube surface. It was found that mean velocity variation in the span at a height of 50% of the boundary layer thickness could exceed ±5%. Further testing was conducted at locations far enough downstream to minimise the amplitude of the variation. Time-averaged mean velocity and turbulence statistics were collected revealing the averaged flow features. The peak Reynolds shear stress near the cube surface was found to be a strong function of the relative boundary layer thickness compared to the roughness size. Quadrant analysis showed the instantaneous sweep motions found near the rough surface intermittently producing large percentages of the local shear stress. Spatial correlation analysis of the instantaneous field data collected with particle image velocimetry revealed long, streamwise-stretched regions of streamwise mean velocity cross correlation. Correlation analysis also allowed calculation of the structure angle of the streamwise velocity cross correlation and the associated integral length scales of the turbulence structure. Two integral length scales were found in certain locations near the cube surface highlighting the complex nature of the flow and inherent difference compared to smooth wall flows. Comparisons were made with existing direct numerical simulation studies over identical geometries showing many general similarities but also indicating differences associated with the assumptions governing each approach. Together, the experiments and analysis establish a broad picture of the distinct flow structure found in urban-type flows.