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An experimental study on aerodynamic interaction between a boundary layer generated by a smooth and rough wall and a wake behind a spire

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A wind tunnel experiment to assess the flow characteristics of the wake behind a spire mounted normal to the wind tunnel floor was conducted to clarify the interaction between the wake flow and the wall shear boundary layer. To reproduce the contrasting boundary layer depth, two types of walls—a smooth wall and a regular cube array—were adopted; for each wall, the spanwise distribution of the streamwise velocity was measured at two downwind positions and seven heights within and above the wall boundary layer with and without a spire. The spanwise distribution of the wake generated by the spire far above the wall boundary layer with low turbulence agreed with the well-known function for two-dimensional (2D) wake flow, derived theoretically from the gradient-diffusion model, despite the weak asymmetry of the inflow. In contrast, the spanwise distribution of the wake within or near the outer edge of the wall boundary layer showed different trends from that of the 2D wake flow. In the former, the expansion of the wake width is compressed in the lateral direction by the turbulence of the wall boundary layer and the velocity deficit of the wake is sustained far from the spire.

Key words: *Wind tunnel, spire, wake flow, wall shear boundary layer*

1. Introduction

The flow field around a building has been an important research target in the wind engineering field over the last half-century for robust structural design and the safety of pedestrians (e.g. Hunt[1)]). In particular, flow around a slender tall building or long structures such as cables can be categorized as widely observed typical flow around a two-dimensional bluff body in a free turbulent flow, which has been one of the primary research areas of fluid dynamics for a century (e.g. Townsend[2)], Taneda[3)], and Hunt[4)]).

In contrast, for the past few decades, intensive studies on the aerodynamic nature of the urban boundary layer have been also conducted for better prediction of the urban climate. From a climatological viewpoint, the urban atmosphere has been considered as a boundary layer over a fully rough wall[5)] which consists of several layers, including a roughness sublayer and an inertial sublayer (e.g. Rotach et al.[6)]). Within the inertial sublayer, vertical profiles of environmental variables such as velocity have been known to satisfy the similarity theory characterized by several aerodynamic parameters including the roughness length and displacement height, which depend on urban geometry[7)]. A series of our recent experimental work (e.g. Hagishima et al.[8)]) has been motivated by the interest in the relation between urban geometry and these aerodynamic parameters. In the course of these experiments, the authors encountered an interesting phenomenon related to the aerodynamic interaction between the previously mentioned two types of flow, namely, wakes behind a row of spires installed at the upwind of a wind tunnel and a rough wall boundary layer developing over a block array. The original reason for installing spires was to produce large-scale turbulence similar to natural atmospheric boundary layer having sufficient depth even with the limitation of short streamwise length of wind tunnels[9)].

Meanwhile, several previous studies have investigated the characteristics of flows that simultaneously involve both boundary layers and wakes behind spires. Counihan[10)] measured the distribution of the velocity defect behind a 2D surface obstacle whose height is assumed to be smaller than the boundary layer height (BLH, or alternatively, δ). On the contrary, Castro[11)] studied the

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