PIV analysis of gas-solid multiphase flow relevant to wind-blown sand: Simultaneous measurement of near-wall turbulent motions and instantaneous relative velocity

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Introduction

The wind-blown sand is one of factors in desertification, a serious environmental problem. To clarify the mechanism of the wind-blown sand and to predict the sand movements, a quantitative understanding of the interaction between gas (air) and solid phases (sand grains) in the multiphase flow, although various studies were conducted to control the wind-blown sand, e.g., Tsukahara et al. (2012). We measured simultaneously the spatial distributions of the air-flow velocity ($U_g$) and the sand-grains velocity ($U_p$) in the turbulent boundary layer, using the particle image velocimetry (PIV). We investigated the relationship between the instantaneous streamwise relative velocity and the turbulent characteristics motion, with emphasis on the hairpin vortex and large-scale structures.

Experimental setup

We used a wind tunnel with the test section of 3.0 m long under zero-pressure-gradient condition. The test particle for the multiphase flow is sand grains with the nominal mean diameter of 50.4 mm and the density of 2590 kg/m$^3$. The sand particles were supplied from the upstream of the measurement area by the piston-type sand feeding device, which was installed on the bottom surface of the wind tunnel. Pictures obtained by the PIV measurement were processed after the experiment: we deconstructed each photo into two separated pictures of either of sand particles or oil-mist tracers, based on their brightness of reflection from particles in a shot image. We measured at the main streamwise velocity of $U_0 = 8.7$ m/s and the boundary thickness of $\delta = 76.3$ mm (single-phase flow) or 130 mm (multiphase).

Results and discussion

Figure 1 shows an instantaneous field of the relative streamwise velocity, $U_p - U_g$, in an x-y plane (x, the streamwise; y, the wall-normal direction), while (b) and (c) indicate the Galilean-decomposed velocity field of $U_g - 0.8U_0$ and the swirling-strength ($\lambda_{ci}$) distribution at the same location and instant in the gas-solid multiphase flow. Note that $U_p$ and $U_g$ are the velocities of particle and gas phases, respectively. Although the statistical relative streamwise velocity should be negative in the present measurement area, the relative velocity is found to be positive locally and instantaneously, as shown in Fig. 1(a). The broken line in the figure represents a demarcation between clusters of either relatively high- or low-speed suspending particles. Moreover, a uniform momentum zone of low-speed fluids can be seen in Fig. 1(b). The Galilean decomposition is a technique to visualize uniform momentum zones in instantaneous velocity fields, suggested by Adrian et al. (2000). In their study, a group of hairpin vortices with the same streamwise velocity was referred as the “hairpin vortex packet”. They reported that each packet propagated at different velocities and called the demarcation between this velocity differences as the “shear layer”. As a proof of this, the spanwise vortices which correspond to heads of the hairpin vortices can be seen on the shear layer: see Fig. 1(c). Here, these vortex heads are denoted with circles of A, B and C. Comparison between Fig. 1(a) and 1(b) reveals that the region, in which the positive values of the relative velocity occurs, coincides well with that of the low momentum fluids. According to Adrian’s model on the wall-turbulent structures, a large-scale low-momentum fluid region is induced by the hairpin packet. It can be conjectured that the local relative velocity should be positive instantaneously by the characteristic turbulent structures such as the hairpin packet, while the sand particles are injected into the large-scale low-momentum zone (in the range of $x/d$ from 0.4 to 0.7, $y/d$ from 0 to 0.1) from high-momentum zone (in the range of $x/d$ from 0.4 to 0.7 at $y/d = 0.2$). On the other hand, we also found the modulated head of hairpin vortex with reduced swirling motion and the turbulence anisotropy by the anisotropy invariant map.

References
