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Acceleration Statistics in Turbulent Channel Flow

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Abstract

To study the properties of accelerations is a key element to understand the dispersion and mixing in turbulent flows. Particularly, it is related to the generation of Reynolds stress, behaviors of particles in turbulence, process of collision-coalescence of cloud droplets, and pollutant transport. Accelerations in turbulent flow are found to be highly intermittent and related with the small scales. Also it has been discussed that accelerations seemed to be associated with the coherent structures. However most studies were performed in isotropic turbulence, in which the coherent structures are not obviously observed. In turbulent channel flow, the presence of the wall makes the turbulent field inhomogeneous. And it is expected that accelerations suffer large inhomogeneity near the wall and are associated with the vortical structures. In the present study we use direct numerical simulation to study the properties of accelerations in turbulent channel flow. The probability density functions (PDF) at different wall coordinates and the higher-order statistics of the acceleration components are studied to investigate the behaviors of the acceleration components and the relation between accelerations and the vortical structures.

The acceleration can be decomposed into two components. One is originated from the pressure gradient ($-1/\rho \cdot \nabla p$) and the other is viscous force ($\nu\nabla^2 u$). Due to their inherent characteristics, the former is called irrotational acceleration and the latter is solenoidal acceleration. In isotropic turbulence, accelerations are dominated by the irrotational acceleration. In turbulent channel flow, however, the spanwise and wall-normal components of the solenoidal acceleration are comparable to the irrotational acceleration and the streamwise component is not negligible near the wall. Especially the streamwise component of the total acceleration is influenced by the solenoidal acceleration to relatively large distance from the wall. An interesting feature is that the skewness of the normal acceleration becomes zero at $y^+ \approx 20$. Observing the instantaneous acceleration field, it can be found that the accelerations are converged to center on the vortex core, and it is well known that the center of the streamwise vortex is located at $y^+ \approx 20$. Thus the skewness of the normal component is positive below the center of the streamwise vortex and vise versa. The flatness represents the intermittent property of the acceleration well and it is found that the irrotational acceleration is the main source of the intermittent character of the acceleration. The normal component turns out to be the most intermittent and it reaches maximum value around $y^+ \approx 5$. The skewness and the flatness of normal acceleration reveal that the irrotational acceleration dominates the total acceleration even in the viscous region unlike the streamwise component. The PDFs at three different wall distances ($y^+ = 7.8$, 30.3, 180) are investigated. As expected, the PDFs show very long tail relative to the Gaussian distribution and the spanwise acceleration appears almost symmetric, whereas the streamwise and normal accelerations show strongly skewed shapes especially in the viscous region. Corresponding to the higher-order statistics, the negatively skewed property of streamwise acceleration in viscous region is mainly due to the solenoidal acceleration, whereas the long right tail of the normal acceleration comes from the irrotational acceleration. For the normal acceleration, an extreme event in which the fluctuation is about 50 times larger than the r.m.s. of acceleration occurs and it exceeds the result obtained in isotropic turbulence.

Keyword: *Acceleration, Turbulent channel flow, Skewness, Intermittency*

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