Scaling of turbulence statistics for three velocity components and turbulence kinetic energy in pipe flow

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In the long history of research for wall−bounded turbulent flow, many scaling laws for statistics have been proposed to discuss their universality. The discussion of scaling laws so far has been mainly focused on streamwise velocity component, however, three velocity components are important for a further comprehensive discussion of turbulence structure. The statistical characteristics of each component have been considered in many aspects based on DNS results, but the experimental data at higher Reynolds numbers are also important to study the universality of scaling law. Due to the difficulty of measurement, there are a few measurements of three velocity components under the same flow condition and device at high Reynolds numbers above Re_τ=10000 in pipe flow, and an example is the data by Zimmerman[1]. In this study, we report the measurement of turbulence intensity of three velocity components from Re_τ=990 to Re_τ=20750 and turbulence kinetic energy (TKE). The measurement was conducted using laser Doppler velocimetry at Hi-Reff[2]. Present results show that not only the inner peaks of turbulence intensity of streamwise component, but also TKE peaks grow asymptotically to the maximum value expected from limit of production and dissipation with increasing Reynolds number (Figure 1(a)). Furthermore, the TKE profile has an outer peak at Re_τ=20750. The outer peak is located at closer to the wall than the conventional outer peak of streamwise component. Present results also show that TKE profile has logarithmic behaviour for Re_τ>11200 (Figure 1(b)) at y/R=0.05-0.22. The logarithmic region of TKE is almost consistent with one of streamwise, spanwise components and the constant region of wall-normal component.

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[1] Zimmerman et al., *J. Fluid Mech.* **869**, (2019).
[2] Furuichi et al., *Phys. of Fluids* **27**, 095108, (2015).

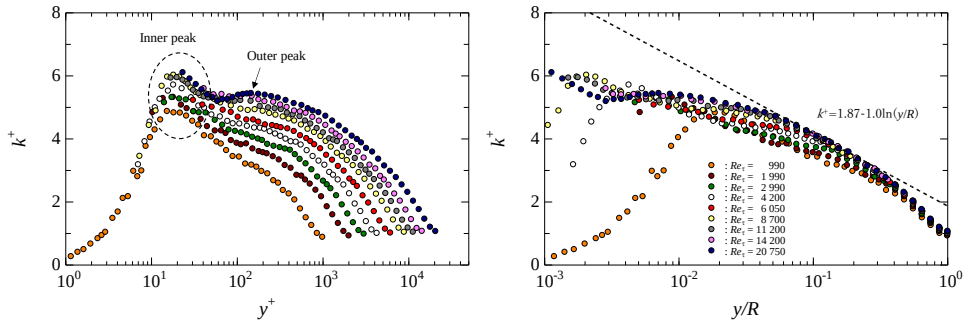

Figure 1: TKE ($k^+=(u'^{+2}+ v'^{+2}+ w'^{+2})/2$) profiles scaled by (a) inner variables, (b) outer variables from Re_τ=990 to Re_τ=20750.