A universal turbulence dissipation inhomogeneity law in the wake of two side-by-side square cylinders

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The topic of this seminar is the scaling of the turbulent kinetic energy dissipation rate. The non-equilibrium energy dissipation rate scaling has been observed in various turbulent flows (e.g. see review by Vassilicos in ARFM 2015). However, all previous studies on the non-equilibrium energy dissipation phenomenon have focused on non-stationarity, i.e. dissipation evolution in time and in streamwise direction (closely related by mean flow convection). The present study focuses on non-homogeneity and examines the scaling of the energy dissipation rate in the lateral direction in the wake of two side-by-side square cylinders, aiming to provide insight into the non-equilibrium dissipation phenomenon in space rather than time. The gap ratio of the cylinders are 1.25, 2.4 and 3.5, and the Reynolds number based on the inlet velocity and the square cylinder thickness (H) varies from 1.0×10^4 to 1.5×10^4. The measurements were taken by using a multi-camera particle image velocimetry (PIV) system in several locations between 2.5-20H downstream of the cylinders.

Fairly well-defined turbulent energy dissipation scalings are observed in the lateral direction, but because of the variety of coherent motions in different flows, the scaling of C_ϵ ($\equiv \epsilon L/k^{3/2}$ where ϵ is the energy dissipation rate, L is the integral length scale and k is the turbulent kinetic energy.) is not unique, but depends on the gap ratios of the cylinders as well as the position in the wake. To remove the effect of the coherent structures, a proper orthogonal decomposition (POD) is employed. Without the influence of the coherent motions, C_ϵ tends to show a universal scaling $C_\epsilon \sim Re_\lambda^{-3/2}$($Re_\lambda$ is the Taylor microscale Reynolds number), regardless of streamwise position in the wake, gap ratio of the cylinders, and inlet Reynolds number. Finally, it is also shown that C_ϵ can be uniquely determined when the integral scale Reynolds number Re_L ($\equiv \langle k' \rangle^{1/2} \langle L \rangle / \nu$, where $\langle \cdot \rangle$ denotes the space average over the measurement field of view, and k' is the kinetic energy without the contribution of the coherent motions) is taken into account: $C_\epsilon = C \left(\frac{\sqrt{Re_L}}{Re_\lambda} \right)^{3/2}$ (where C is a dimensional constant) collapses all measured cases with different gap ratios, inlet Reynolds numbers and streamwise positions in the flow. This universal scaling occurs in the presence of various mean flow and turbulence inhomogeneity profiles and various large-scale coherent structures. It seems to characterise a universal non-equilibrium in space rather than time which we will try to discuss at the end of the seminar as it may suggest the existence of laws of turbulence inhomogeneity.