§35. Extraction of Hierarchical Energy Spectrum in Turbulence and its Correlation with Organized Structure

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We have investigated on the properties of the energy spectrum in turbulent flow which is in a statistically stationary state. In the previous studies (Yoshizawa 1994; Woodruff & Rubinstein 2006), it was shown that the correction to the Kolmogorov -5/3 energy spectrum which constitutes a base state in the inertial subrange is derived as the -7/3 power, and it is induced by the fluctuation of the dissipation rate ε and represents a nonequilibrium state. We applied the averaging conditioned on the temporal variations of ε to the ensemble of the energy spectra.

Assessment is carried out using the DNS data for forced homogeneous isotropic and homogeneous shear turbulence which are in statistically steady state. It is shown in both flows that the base steady state fits the -5/3 power, but the deviatoric part exhibits a fitting with the -7/3 power as shown in figure 1. The role of the $k^{-7/3}$ spectrum in generation of energy cascade is elucidated by studying the temporal variations of the energy spectra and the energy transfer function in the Fourier space. It is shown that the entire cascade process is divided into the two phases, Phases 1 and 2. In Phase 1, the deviations from the -5/3 spectrum, i.e., the -7/3 power component, are positive and negative in the low-wavenumber range and high-wavenumber range, respectively (figure 2). The energy contained in the low-wavenumber range in Phase 1 is transferred to the high-wavenumber range in Phase 2 with the occurrence of the switchover of the sign in the -7/3 power component. Although the $k^{-7/3}$ spectrum appears only transiently, it acts as a sort of catalysis to initiate the generation of the cascade. In Phase 1, a very large gain in the energy occurs at the scale corresponding to the integral length and the wavenumber at which the largest gain occurs shifts to the higher wavenumbers in Phase 2. The flow visualization shows that the vortex sheet whose lateral length is comparable to the scale of this energy input is created. With the interaction of these large scale vortex sheets, many stretched spiral vortices (LSV, Lundgren 1982) in Mode 3 are created in Phase 1. These Mode 3 LSVs are converted to Mode 1 configuration in Phase 2 (Horiuti & Fujisawa 2008). This transformation of the configuration in Phases 1 and 2 is consistent with the temporal development of the spectrum.

The statistics are compared in Phases1 and 2. The turbulent energy is larger in Phase 1 than in Phase 2. The moderately large dissipation rate dominates in Phase 2, but the dissipation field is more intermittent in Phase 1 than in Phase 2. Averaging conditioned on the dissipation and enstrophy indicates that intense dissipation is often accompanied by intense enstrophy, but intense enstrophy is less often accompanied by intense dissipation (Donzis, Yeung & Sreenivasan 2008). The extreme events of high enstrophy, however, is accompanied by extreme dissipation in Phase 1. The events with extreme dissipation and enstrophy occurs along the vortex sheet similar to Burgers' vortex layer in which the regions of dissipation and enstrophy possess a significant degree of overlap.

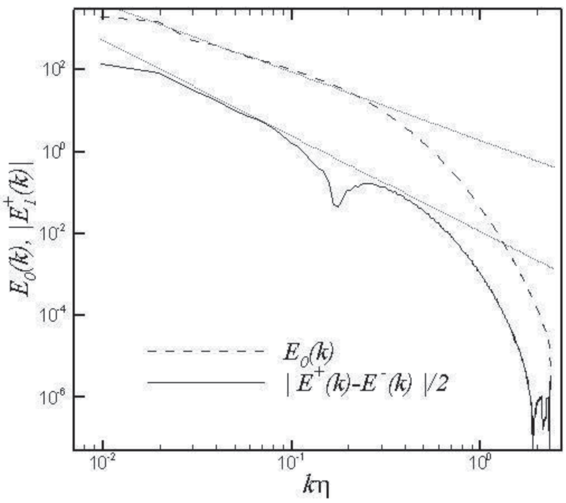

Fig. 1 Normalised energy spectra obtained from homogeneous isotropic turbulence. The average spectrum is plotted versus $k\eta$ using the dashed line. Deviation from the average is plotted using the solid line. The dotted lines indicate scaling with $k^{-5/3}$ and $k^{-7/3}$.

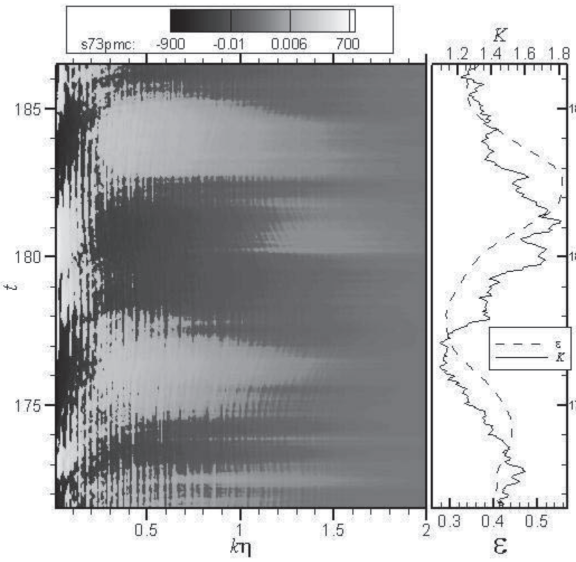

Fig. 2 Isocontours of deviatric spectrum as functions of $k\eta$ and t. The small frame shows the temporal variations of the turbulent energy K and ε.

1) Lundgren, T.S., Phys. Fluids **25** (1982) 2193
2) Horiuti, K. and Fujisawa, T., J. Fluid Mech. **595** (2008) 341-366