Life, Structure, and Dynamical Role of Vortical Motion in Turbulence

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Turbulence is full of vortical motions of various types. Among others, the tubular swirling vortices with strong vorticity are commonly observed in many kinds of turbulent flows to play central roles in turbulence dynamics, such as the enhancement of mixing, diffusion, resistance, and so on. We study here the dynamical properties of vortical motions in isotropic turbulence as well as in a wall-bounded turbulence by analyzing and visualizing the direct numerical simulation data in terms of the low-pressure vortices which we have recently introduced [1-3]. One of the most interesting findings by this method is the existence of double spiral vortex layers wrapped around tubular vortex cores. The energy dissipation is taking place more actively in the layers than in the central cores [1, 3, 4]. The name of spiral vortex is reminiscent of the Lundgren spirals. But these two spirals are completely different. Vorticity in the Lundgren spirals is parallel to the core vortex, whereas that in our spirals is orthogonal.

Although the fluctuations of physical quantities are statistically invariant as a whole in stationary turbulence, the individual vortices, if identified, might have their own finite lives. It is anticipated that they are born through a kind of Kelvin-Helmholtz instability, interact with other vortices, with the background shear flow and also with the boundaries, then they break down into scattered vorticity, which will be sources of new vortices $\cdots$. This interesting scenario is likely to occur, but it is hard to be confirmed primarily because lots of other vortices are moving around and tend to hide a particular one behind them. Fortunately, our low-pressure vortex method enables us to pick up and trace arbitrarily chosen vortices. We are currently developing a numerical code to follow particular vortices and investigate the lives of individual vortices.

The dynamical role of vortices in turbulence mixing and diffusion is another subject in our study. It is well-known that passive lines in turbulence are stretched exponentially in time [5, 6]. Very recently [7], we have performed a passive line simulation in turbulence with a special care for the numerical accuracy to find that indeed they are stretched exponentially in time but the growth rate is considerably different from the previously established ones which were obtained by the passive-vector-element simulation. The true growth rate is $0.17/\tau_\eta$, where τ_η is the Kolmogorov time. The exponential growth of the total length of lines is rather smooth but the stretching rate of each part of the lines is quite non-uniform, which is the main reason why the previous estimation of the growth rate was inaccurate [7]. We are currently simulating passive lines as well as passive sheets in forced turbulence. Our preliminary results show that they are often trapped by tubular vortices and suffered from strong stretching there.

In the symposium I am planning to present these numerical results with a special emphasis on the life cycles, the structures, and the dynamical roles of individual vortices.

References

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