§34. Simulation Study of Scale Hierarchy in Plasma Turbulence

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A variety of phenomena in plasmas with shear flow has attracted much attention in plasma physics research. Such phenomena have been intensively studied: for example, it is known that turbulence in magnetically confined fusion plasmas generates shear flow, which suppresses the turbulence itself. The motivation of our study is especially on clarifying fundamental factors determining the characters of turbulence in steady shear flow, rather than examining such characters via computer simulation. Since the dynamics of plasmas is governed by coupled velocity and magnetic fields and is complex, we focused on neutral fluids firstly and studied energy spectra of turbulence and so on in neutral fluids with shear flow.

The Kolmogorov's -5/3 power law of energy spectra in homogeneous and isotropic turbulence in neutral fluids is well known. However, the energy spectra in the presence of shear flow have not been fully studied. If we only need to know the index of power law, we must rely on experiments or large-scale direct numerical simulation of the Navier-Stokes equation. However, we try to clarify what kind of mathematical structures in the Navier-Stokes equation is essential in determining the index of the power law. This may lead to our understanding of the fundamental factors which determine various characters of turbulence in steady shear flow. In order to study such an essential structure, we have extended the so-called shell model[1)] to incorporate with the shear flow effect. The conventional shell model is a dynamical system, which discretizes the wave-number space in the logarithmic scale and approximates the nonlinear term in the Navier-Stokes equation by mode couplings among nearby wave-number shells. Then, the shell model reproduces the Kolmogorov's -5/3 power law of energy spectrum. Therefore, the essential factor in determining such a power law is found to be the couplings among waves with close wave numbers. This is also an assumption adopted by Kolmogorov in deriving the famous power law.

In our study, we assumed that a steady fluid flow $u_0(x)$ in the z direction, and that the flow velocity $u_0(x)$ is a linear function of x. The nonlinear term in the Navier-tokes equation then can be divided into two terms: the ordinary nonlinear coupling terms and the linear terms which arise because of the shear flow $u_0(x)$. If we rewrite the Navier-Stokes equation in the wave-number space, one of the linear terms is found to be proportional to $du_1(k)/dk$ where $u_1(k)$ describes the velocity field of turbulence, and the other be proportional to $u_1(k)$ itself. The former one seems to transfer energy in the wave-number space, and the latter one to growth or decay of the wave; like linear stability. We have developed several models which approximates the linear terms, and have studied the turbulence especially with focus on the energy spectra, energy transfer function and eddy turn over time.[2)]

In either model, the energy spectrum has -5/3 law when the total energy in the turbulence is large. The energy transfer dominantly occurs via the nonlinear term since the velocity field of the turbulence has large amplitude. Then, the conventional picture of turbulence can be applied and we obtain the -5/3 power law. On the other hand, the total energy in the turbulence is small, the nonlinear term becomes smaller and does not play a dominant role. The linear term plays a role in transferring energy instead. The index of the power law was not unique among the models developed. These results need to be compared with experiments and/or direct numerical simulations.

1) Yamada, M. and Ohkitani, K.: J. Phys. Soc. Jpn. **56** (1987) 4210; Ohkitani, K. and Yamada, M.: Prog. Theor. Phys. **81** (1989) 329.
2) Kin, T., "Development of shell model and simulation study of energy spectra in turbulence with steady shear flow" (Bachelor thesis, Faculty Eng., Univ. Tokyo 2008).