§18. Development of Magnetohydrodynamic and Hydrodynamic Turbulent Modeling

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We examined small-scale statistics of magnetohydrodynamic (MHD) turbulence and hydrodynamic (HD) turbulence. The understanding of the statistics is important for developing proper models of turbulence, such as those in large eddy simulations (LESs) and wavelet-based simulation method. We analyzed direct numerical simulation (DNS) data of 3D homogeneous MHD turbulence without mean magnetic field, and also performed DNS of spatially-developing turbulent boundary layer (TBL) and 2D compressible turbulence with chemical reaction.

3D homogeneous MHD turbulence

Statistics on energy transfer

Statistics on the total energy transfer T from grid scale (GS) to sub-grid scale (SGS) are examined by the analysis of the MHD DNS database at different grid points from 256^3 to 1024^3. To define the GS and SGS fields, we use the spectral cut filter. The filter has a cut-off wavenumber k_c characterizing the smallest scale of GS. The transfer T depends on the position and the scale.

The average over the physical space is almost constant for k_c in the inertial subrange. Figure 1 shows that the spatial variance V_T grows approximately as $V_T \propto k_c^{3/4}$. The variance increases more in the inertial subrange than the variance V_H of the kinetic energy transfer from GS to SGS in HD homogeneous isotropic turbulence where $V_H \propto k_c^{1/3}$ in the inertial subrange[1].

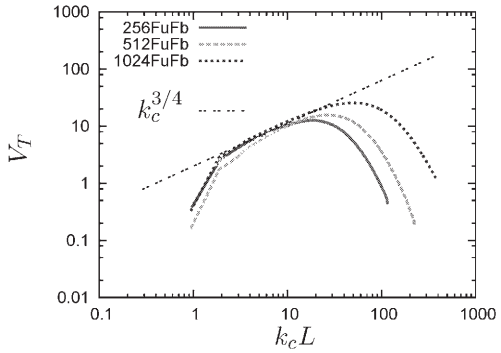

Fig. 1: Variance of T, V_T, vs. k_c at 256^3, 512^3 and 1024^3. Here, L is an integral length scale.

Scale dependent intermittency

In order to examine scale-dependent intermittency of MHD turbulence quantities, we applied orthonormal wavelet analysis to the DNS database. The intermittency plays key roles in development of wavelet-based simulation method of MHD turbulence, e.g. coherent vorticity sheet and current density sheet simulation proposed by Yoshimatsu *et al.*[2]. It is shown that the scale-dependent velocity and magnetic field flatness quantifies the spatial variability of the kinetic and magnetic energy spectra, respectively. The Eulerian acceleration becomes more intermittent as scales decreases than the Lagrangian acceleration in MHD turbulence. In contrast, HD turbulence exhibits extreme intermittency of the latter, where the flatness of the Lagrangian acceleration is one order of magnitude larger than the flatness of the Eulerian acceleration[3].

Spatially-developing turbulent boundary layer

We performed spectral DNSs of zero-pressure-gradient TBL along a flat plate using the so-called fringe method proposed by Spalart *et al.*[4]. In order to assess the applicability of the method to a large-scale DNS, we examined the fringe method by several preliminary DNSs in which the DNS results at the same Reynolds number under different flow conditions are compared. The results show that various statistics such as the shape factor, the friction coefficients, and the root-mean-square of velocity fluctuations in a region approximately $300\theta_0$ downstream from the fringe region are insensitive to the conditions in the fringe region, and are consistent with the experimental results so far reported at the similar Reynolds numbers, where θ_0 is the momentum thickness at the exit of the fringe region. They also show that grid spacing in the streamwise direction should be less than 10 wall units in order to appropriately resolve the fluctuations of the gradients of pressure in the TBL.

Compressible turbulence with chemical reaction

The influence of intermediate species diffusion on autoignition process at high pressure was investigated with 2D DNS applied a reduced chemical kinetic mechanism of n-heptane/air. 2D numerical analysis results which were conducted by giving the temperature distribution under turbulence and non-turbulence conditions were compared with 0D results of ignition delay and chemical reaction process. In conclusions, the ignition delay strongly was affected by the diffusion of intermediate species. It was shown that the outflow of OH radical decreases reaction rate and the reaction rate was enhanced by OH radical influx.

1) Aoyama, T. *et al.*: J. Phys. Soc. Jpn. **74** (2005) 3202.

2) Yoshimatsu, K. *et al.*: Phys. Plasmas **16** (2009) 082306.

3) Yoshimatsu, K. *et al.*: Phys. Rev. E **79** (2009) 026303.

4) Spalart, P.R. and Watmuff, L.H.: J. Fluid Mech. **249** (1993) 337.