Large Eddy Simulation of Compressible Magnetohydrodynamic Turbulence. Model Development and Validation

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Numerical simulation of compressible turbulent magnetohydrodynamic (MHD) flows is an effective tool for study of flows of charged fluid of astrophysical, helio and geophysical plasma (for instance, solar corona expansion, solar wind, flows in the solar convection zone, turbulence in interstellar matter), that is beyond the reach of direct experimental study. Complete information about turbulent fuid flow can be obtained by means of direct umerical simulation (DNS) that lies in numerical solution of full nonstationary system of equations. That approach allows resolving all scales of charged fluid flows and does not require special closures for magnetohydrodynamic equations. However, direct numerical computation of MHD-turbulence faces fundamental difficulties concerned with large hydrodynamic and magnetic Reynolds numbers typical for studied processes, because in that case the number of degrees of freedom of turbulent flow is large and minimal number of mesh points must be so large that application of direct numerical simulation for study of turbulent flows with real Reynolds numbers is limited by available computational resources. Large eddy simulation (LES) approach describes approximate turbulence dynamics, where the large-scale part of turbulent fowl is computed directly, while the small-scale one is simulated. Possibility of using filtration operation in LES for decomposition of turbulent flow characteristics into large-scale and small-scale parts is due to sufficient isotropy, homogeneity and universality of small scales of turbulent flow In present work. Large Eddy Simulation (LES) technique for study of compressible magnetohydrodynamic turbulence is developed. The filtered equations of magnetohydrodynamics of compressible fluid are obtained with use of mass-weighted filtering procedure (Favre filtering). Favre filtered equations for large-scale component of turbulence include subgrid scale terms describing subgrid phenomena. For the case of polytrophic fluid these terms represent combination of subgrid stresses already known from studying incompressible magnetohydrodynamic turbulence and compressible turbulence of neutral fluid. Different models of closures for subgrid terms appearing after filtration of initial equations of magnetohydrodynamics of compressible fluid are developed. The results of numerical direct numerical simulation (DNS) computations and various subgrid closures for LES approach are demonstrated; analysis and comparison of obtained results are carried out. It is shown that subgrid scale closure models suggested in this work provide sufficient dissipation of kinetic and magnetic energy and reduce computational efforts at simulation of compressible magnetohydrodynamic turbulence. In this work LES method for modeling of compressible decaying MHD turbulence is applied for various similarity parameters, namely, magnetic Reynolds numbers, hydrodynamic Reynolds numbers and Mach numbers. Numerical study is performed for five subgrid-scale closures for MHD case: the Smagorinsky model, the Kolmogorov model, the cross-helicity model, the scale-similarity model and mixed model. The comparison between LES and DNS results is carried out regarding the time evolution of kinetic and magnetic energy, cross felicity, sub grid-scale and molecular dissipations for kinetic and magnetic energy, turbulent intensities and quantities that describe anisotropy of flow, that is, skewness and kurtosis of velocity and magnetic field. It is shown that some subgrid-scale models proposed in the work provide sufficient dissipation of kinetic and magnetic energy, reduce computational efforts and produce adequate results of magnetohydrodynamic turbulent modeling for various values of similarity parameters of flows. In the whole, the best results are demonstrated by the Smagorinsky model for MHD case and the model based on cross-helicity. The scale-similarity model do not provide sufficient dissipation of both kinetic and magnetic energy, and it is necessary to use this subgrid-scale closure only together with eddy viscosity model (for example, with the Smagorinsky model), that provided a basis idea for mixed model. Thus, LES method has good future trends for research of compressible magnetohydrodynamic turbulence.