

Large Eddy Simulation of MHD Turbulence in Space Plasma

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Numerical simulation of 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 fluid flow can be obtained by means of direct numerical 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 flow 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. Under these conditions small-scale flow is eliminated from the initial system of flow equations with use of filtration procedure and then their influence is taken into account by means of subgrid scale (SGS) models, parameterizing all the magnetohydrodynamic values of small-scale turbulent flow through the filtered ones. LES is a method for simulation of flows with large Reynolds numbers, since large eddy simulation assumes that the energy is transferred within the inertial subrange that results in reduction of number of degrees of freedom and significant increase of computation efficiency as compared with DNS. In present paper large eddy simulation 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 polytropic 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 DNS computations and various subgrid closures for LES 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. The three subgrid closures are compared: Smagorinsky model, Kolmogorov model and cross-helicity model. Smagorinsky model and cross-helicity model represent more accurate results than Kolmogorov model. Results presented in the paper allow drawing conclusion that LES is a convenient tool for simulation of compressible magnetohydrodynamic turbulence in space plasma.