Three-dimensional development of the Kelvin-Helmholtz instability: dependence of the turbulent structure on the plasma parameters

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The low latitude boundary of the magnetosphere is the attractive region for the energy transport from the solar wind. Particularly, in the case of northward IMF, recent in-situ observations often show the mixing of the solar wind and magnetospheric plasmas in the low latitude boundary layer (LLBL), in which the Kelvin-Helmholtz instability is considered unstable. These observations suggest that the plasma transport through LLBL is an important candidate of the plasma supply process into the plasma sheet and the K-H instability plays an crucial role in a new transport mechanism. In addition to the mass transport into the magnetosphere, the K-H instability may owe the energy transport to the ionosphere via closed magnetic field lines. Aurora, which is a reflection of dynamical motions in space, often shows the vortex pattern in association with appearances of auroral arcs. This kind of signature is thought to be a visual evidence of the K-H instability at the magnetospheric boundary. The satellite observations have also shown the localized regions of auroral intensity enhancements. Lui et al. [1989] reported the periodic bright spot intensifications observed in the post-noon sector. They suggested that those bright spots were related to the small scale FACs resulting from the dynamic change of vorticity associated with the K-H instability growing at the low latitude boundary of the magnetosphere. However, the detailed physical process that explains the observations still require the theoretical support. This motivates the authors to explore the energy transport in the three-dimensional nonlinear development of the K-H instability. The main objective is to elucidate the solar wind energy transport to the magnetosphere (plasma sheet) and to the ionosphere along the magnetic field lines across the velocity shear layer, which eventually develops to turbulent structure through the three-dimensional nonlinear evolution.

We have developed three-dimensional ideal MHD code to explore the nonlinear development of the K-H instability. The velocity shear is provided with a functional form of Vz = -V0/2*tanh(y/l). We fixed the shear strength with V0/Vf = 1, where Vf denotes the magnetosonic speed. The magnetic field is transverse to the velocity field (i.e., B=(B0,0,0)) which corresponds to a closed magnetospheric configuration. The pressure and the density is set uniformly. We changed plasma beta in order to explore the effect of the transverse magnetic field on the growth of the three-dimensional secondary instability, which is known to lead to three-dimensional turbulence in hydrodynamics case. The results show that in the early nonlinear stage (~T=150 l/V0), the three-dimensional secondary instability starts growing at the hyperbolic point and inside the vortex core even for the strong magnetic field case (beta=0.1). The By and Bz components of the magnetic field, whose strength becomes comparable to the background field, lead the two-dimensional vortex motions to the turbulent one in the three dimensions. The spatial scale of the secondary instability is shorter for a higher beta case. In particular, the result for beta=0.1 shows that the secondary instability, whose wave length is about four times as long as the K-H mode, can collapse the two-dimensional vortex structure against the strong transverse magnetic field. These results suggest that the simple two-dimensional K-H evolution cannot be applied to the magnetospheric boundary and the three-dimensional evolution may owe the energy transport along the closed magnetic field lines. The generation mechanism of the secondary instability and further speculations on the interaction with the ionosphere will be also presented.