Current and Vortex Singularities : Drivers of Impulsive Reconnection Dynamics

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Reconnection in nature is rarely quasi-steady. Most often, it is impulsive or bursty, characterized not only by a fast growth rate but a rapid change in the time-derivative of the growth rate. Current and vortex singularities play a crucial role in impulsive magnetic reconnection in plasmas and the analogous phenomenon of vortex reconnection in fluids. We will present new results, obtained by asymptotic analyses and high-resolution numerical simulations [using Adaptive Mesh Refinement (AMR) techniques] of Hall MHD and Navier-Stokes equations.

Within the framework of Hall MHD, we consider fast reconnection models, with broad applications to sawtooth oscillations in tokamaks, magnetospheric substorms, and solar flares, in which electron inertia and resistivity provide the mechanism for breaking field lines. When the resistivity is zero, we demonstrate that current singularities tend to form in finite time and drive fast and impulsive reconnection. In the presence of resistivity, the tendency for current singularity formation tends to slow down, but the reconnection rate accelerates to produce large magnetic islands. The characteristic timescale of the process does depend on the mechanism that breaks field lines, unlike results reported in recent quasisteady collisionless reconnection studies. We will also present new results on the analogous problem of finite-time vortex singularity in a high-symmetry 3D Euler flow containing null points of the flow. The implementation of AMR enables us to pursue the time-development of this vortex singularity to unprecedented levels of resolution. It is found that while the initial condition tends towards a self-similar finite-time singularity near a null in the early nonlinear stage, in the late nonlinear stage the self-similarity is broken and the singularity becomes exponential. Eventually viscosity intervenes, producing fast vortex reconnection.