Fluid simulation of instabilities in partially magnetized plasmas

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Fluid simulations are widely used in research on low-temperature plasma applications. They can be very valuable tools to obtain a qualitative picture of the plasma device operation and to predict trends, but they sometimes fail to capture essential physics. A particularly problematic case is that of magnetized plasma devices such as Hall thrusters or magnetrons, featuring magnetized electrons and non-magnetized ions. These plasmas are sensitive to turbulent instabilities, often involving kinetic effects and enhancing the transport of electrons across the magnetic field lines. Fluid models usually take this into account by ad hoc "anomalous" transport coefficients, which strongly reduces their predictive capabilities. Yet, when solved properly in the 2D plane perpendicular to the magnetic field lines, or in 3D, even very basic fluid models of these plasmas turn out to predict certain types of instabilities and anomalous transport in a self-consistent manner. This poses the following questions. Do these fluid instabilities represent any physical reality, to what extent are they affected by the fluid approximations, and how does this depend on the plasma conditions and configuration? Can the fluid model closures be improved to make these instabilities more realistic and consistent with kinetic theory? How to keep control of numerical discretization errors in the presence of these instabilities and make sure they are not in fact numerical artefacts?

In this presentation, we discuss the above questions on the basis of simulation results from a fluid code developed at the LAPLACE laboratory in Toulouse in the context of different magnetized plasma applications. This code solves standard fluid equations for continuity, momentum and energy of (magnetized) electrons and (non-magnetized) ions, coupled by quasineutrality, with boundary conditions derived from classical sheath theory. We show and discuss magnetized plasma instabilities arising in fluid simulations of different ion source configurations, and make links with particle in cell simulations and linear stability analysis.