LARGE SCALE FORCING OF A TURBULENT PLASMA DYNAMO

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Abstract This investigation focuses on the forcing of a large scale velocity field in a plasma. The ultimate goal of the project is to develop efficient stirring mechanisms in order to generate a large-scale driven turbulent flow in a plasma vessel and to generate, and better understand, a large scale dynamo. Numerical simulations are carried out using recently developed numerical methods for plasma flows. It is shown how the vessel can be stirred by locally imposing an electric field, and what the resulting three dimensional flow-field looks like.

The generation of planetary magnetic fields through the turbulent movement of liquid metals in the core is an intriguing phenomenon. It is not only an important issue in geophysics, but also explains the self-organization in Reversed Field Pinch plasma devices. This so called dynamo effect is now reproduced in several experimental set-ups such as the VKS experiment in Cadarache [1], but the detailed physics are still poorly understood. One drawback in the liquid metal experiments is the very low value of the magnetic Prandtl number (the ratio of the kinematic viscosity to the magnetic diffusivity, and also the ratio of the magnetic Reynolds number to the kinetic Reynolds number). Liquid metal experiments require therefore huge kinetic Reynolds number to obtain only a moderate magnetic Reynolds number. For this reason the construction of a plasma dynamo has been undertaken at the laboratoire de Physique of the Ecole Normale Supérieure de Lyon. The use of a plasma instead of a liquid metal allows the experiment to attain larger magnetic Reynolds numbers at moderate kinetic Reynolds numbers. The measurement of the dynamics in a plasma experiment, and the forcing of the large scale flow field, is however highly nontrivial. Therefore, in parallel with the experiment, we investigate the plasma dynamics by direct numerical simulations using a recently developed method for confined magnetohydrodynamics [2]. This numerical part of the investigation is presented in the present paper.

In this work we model the plasma vessel by imposing solid, no-slip boundary conditions at the walls of a cylinder, periodic in the axial direction. An imposed magnetic field B_0 is pointing in the axial direction. An electric field is created in the radial direction as illustrated in Figure 1. The hereby generated current induces a Lorentz force in the azimuthal direction. It is this Lorentz force which is supposed to induce a large scale motion.

The magnetohydrodynamic equations are used to describe the dynamics of the velocity field $\boldsymbol{u}$ and magnetic field $\boldsymbol{B}$. To model the electrodes a constant current density $\boldsymbol{j}_0$ is introduced in the velocity equation and a constant electric field $\boldsymbol{E}_0$ in the induction equation. These two quantities are localized in the upper half of the cylinder of radius 1 and height 2π (see Fig. 1 (left)). The system of equations solved is the following:

$$\frac{\partial \boldsymbol{u}}{\partial t} - M^{-1}\nabla^2\boldsymbol{u} = -\nabla\left(P + \frac{1}{2}\boldsymbol{u}^2\right) + \boldsymbol{u}\times\boldsymbol{\omega} + (\boldsymbol{j}+\boldsymbol{j}_0)\times(\boldsymbol{B}+\boldsymbol{B}_0), \tag{1}$$

$$\frac{\partial \boldsymbol{B}}{\partial t} = -\nabla\times(\boldsymbol{E}+\boldsymbol{E}_0), \qquad \boldsymbol{E} = S^{-1}\,\boldsymbol{j} - \boldsymbol{u}\times(\boldsymbol{B}+\boldsymbol{B}_0), \tag{2}$$

$$\nabla\cdot\boldsymbol{u} = 0, \qquad \nabla\cdot\boldsymbol{B} = 0, \tag{3}$$

with $\boldsymbol{j}_0 = \sigma\boldsymbol{E}_0$ and M, S the viscous and resistive Lundquist numbers, respectively. The Lundquist numbers are chosen $M = S = 10$, corresponding to unity magnetic Prandtl number. The imposed electric field, magnetic field and current density are given the value $E_0 = 5$ and $B_0 = 0.5$ and $j_0 = 50$, respectively.

Preliminary results are shown in Figure 1, right, in which it is shown how the plasma is set into movement in the horizontal plane containing the electrodes. Three-dimensional flow visualizations are shown in Figure 2, where it is observed that a dipolar velocity structure is created in the plasma. The full paper will describe how the flow depends on the physical parameters and we will present results on the magnetic field generation by the plasma movement.

References

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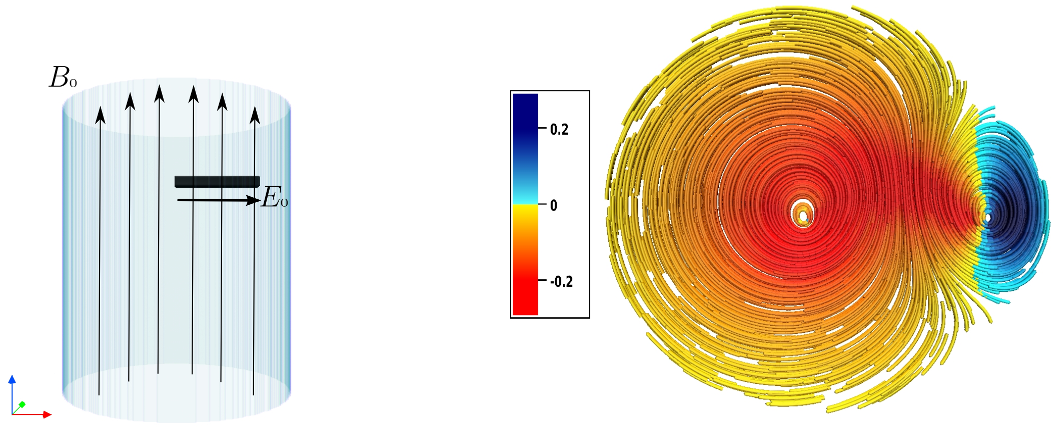

Figure 1. Studied geometry and imposed fields (left). Two dimensional velocity streamlines colored with the azimuthal velocity in a horizontal plane at the axial coordinate where the electric field is introduced (right).

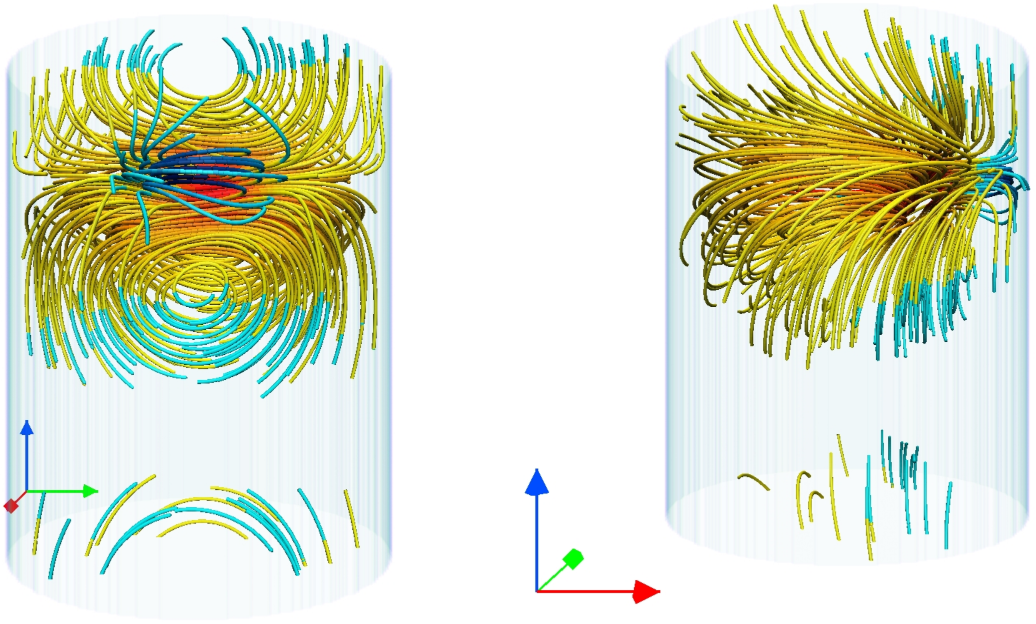

Figure 2. Three dimensional velocity streamlines colored with the azimuthal velocity for early time simulations at low magnetic and kinetic Reynolds numbers. Two views: from a direction orthogonal to the imposed radial electric field (left), and along the imposed radial electric field (right).