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TRANSITION OF MHD FLOWS IN CONFINED GEOMETRIES WITH HELICAL BOUNDARY CONDITIONS

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1 Introduction

The present work reports on a study of flows of conducting fluids in confined geometries, driven by magnetic boundary conditions. The visco-resistive magnetohydrodynamic equations are solved using a pseudo-spectral parallel DNS solver combined with a volume penalization method. The volume penalization technique, which is an immersed boundary method, allows in the present case to use other than periodic boundary conditions in a pseudo-spectral approach. In particular, this type of methods is characterized by a high flexibility in changing the geometry of the considered flow. The use of the volume penalization method was only recently validated in MHD flows [1], and in the present communication we will present results in three-dimensions. As a validation, section 2 contains results of three-dimensional Taylor-Couette flow. Section 3 reports on the flow induced in a conducting liquid by the presence of an imposed helical magnetic field.

2 Validation: simulations of three-dimensional Taylor-Couette flow

Three-dimensional simulations of Taylor-Couette flow are performed at different resolutions for different Reynolds numbers. For the geometry studied the critical Reynolds number, above which Taylor-vortices appear, is known to be around 68 [2]. We observe this bifurcation at $Re = 87$ for our simulation at a resolution of 128^3 grid-points. In Figure 1 we show the vorticity field which clearly illustrates the presence of counter-rotating vortices and their associated boundary layers. The results improve with resolution. For example, a critical Reynolds number is found to be around 72 for a 256^3 grid-point simulation. The bifurcation diagram is shown in Figure 2. Clearly, the method approaches rapidly the analytical value and any precision can be obtained if sufficient computational resources are available.

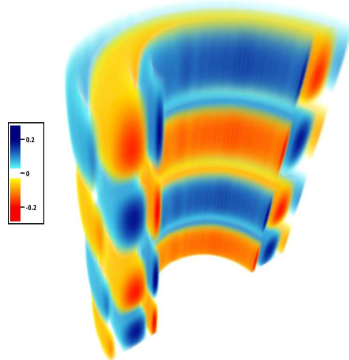


Figure 1: Taylor counter-rotating vortices, azimuthal vorticity colormap

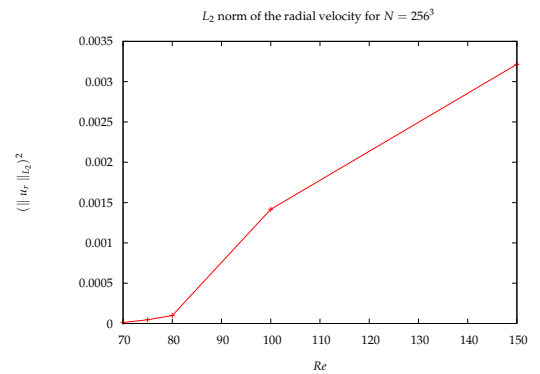


Figure 2: Bifurcation diagram for Taylor-Couette flow

3 MHD dynamics in cylindrical geometry

The main goal of our investigation is the understanding of the velocity fields which are induced in plasmas or conducting fluids by the magnetic field boundary conditions. The present approach is thereby an extension of existing studies by Montgomery and coworkers [3]. Using the penalization method we impose no-slip boundary conditions on the velocity field, and the magnetic field at the wall is imposed to be helical. The pinch ratio Θ , defined as the ratio between the imposed poloidal magnetic field and the imposed axial field ($\Theta = B_\theta/B_z$) is varied and its influence on the flow is monitored. At very low values of the pinch ratio, the velocity field tends to its static limit. At intermediate pinch ratios, a laminar helical velocity field is observed in Figure 4. The



flow is essentially axial and it is composed of two pairs of helical structures, moving in the positive and negative axial direction. We also present the kinetic energy evolution which shows that at long times the kinetic energy tends to a finite and constant value (Figure 3).

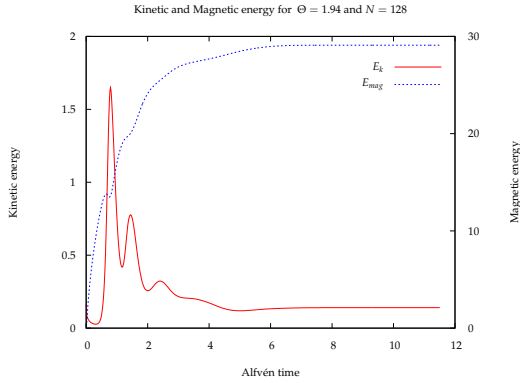


Figure 3: Energies for $\Theta = 1.94$

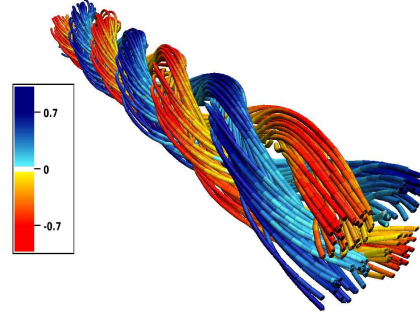


Figure 4: Velocity streamlines and colormap of u_z for $\Theta = 1.94$ and $N = 128^3$

Increasing the pinch-ratio, the laminar flow bifurcates and a multi-mode turbulent flow is observed. A calculation was performed for a pinch ratio $\Theta = 19.4$ ($Re_{rms} = Rm_{rms} \approx 114$). The turbulent behavior is illustrated by showing in Figure 5 the energy evolution which shows a nonstationary, fluctuating behavior. Figure 6 displays less organized streamlines than the laminar flow. Helical modes are still present but many other modes are excited as well.

Further work will consider the influence of breaking the symmetry of the geometry on the flow patterns which are generated, both in cylindrical and toroidal geometry.

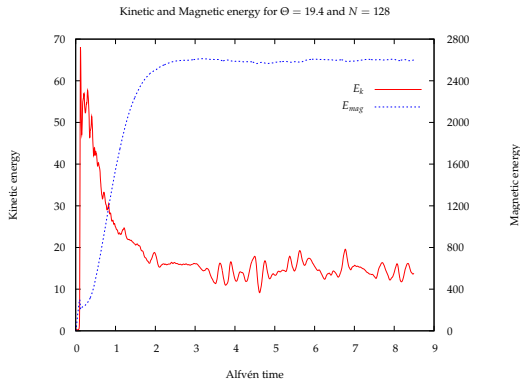


Figure 5: Energies for $\Theta = 19.4$

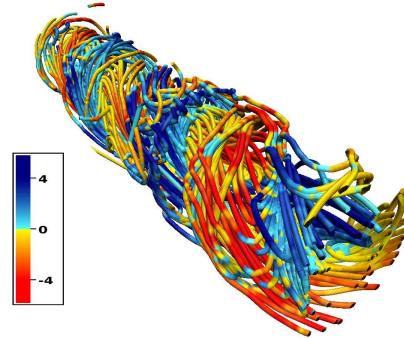


Figure 6: Velocity streamlines and colormap of u_z for $\Theta = 19.4$ and $N = 128^3$

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