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INVESTIGATION OF MHD TURBULENCE IN A PIPE FLOW

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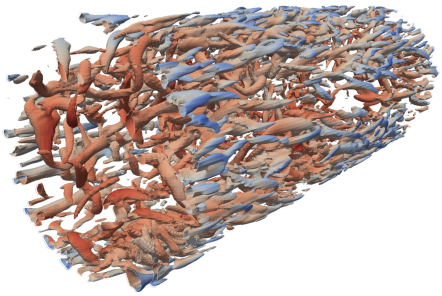
One of the most challenging situations in scientific simulation is the case of magnetohydrodynamic (MHD) flows. Indeed, the nature of the equations describing such flows is dependent on the flow itself and induces lots of interactions between the parameters. The combination of the external magnetic field and the electrical conductivity of the fluid leads to an additional Lorentz force that tends to inhibit turbulence and strongly sharpen the boundary layers.

We are here concerned with the development of a mixed spectral / finite element solver for incompressible MHD flows. The spectral method characterizes the flow in the direction of periodicity whereas the finite element (FE) method is used in the plane orthogonal to this direction of periodicity. The quasi-static assumption is made to characterize liquid metal properties. We therefore assume that the induced magnetic field is weak in amplitude compared to the external one. The electric potential formulation is used to describe the interaction between the flow and the external magnetic field. Stabilized finite elements are used to circumvent the oscillating patterns linked to the incompressibility of the flow.

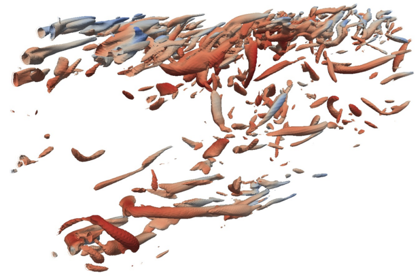
The numerical study of MHD turbulent pipe flows inside a uniform magnetic field has been little studied up to now (with the only known reference being [1]). In opposition, the case of a fringing magnetic field has been extensively studied (see for example [2]) because of its direct application in dual-coolant blankets for fusion energy.

The purpose of this work aims at completing the knowledge of MHD turbulence inside circular pipes subject to an external transverse uniform magnetic field. A second motivation is to further demonstrate that the finite element method developed for MHD flows has a comparable level of precision as other traditional numerical methods (such as the finite volume and difference methods)

We consider here the MHD flow in a circular pipe with no-slip electrically insulated wall,



(a) $Ha = 0$



(b) $Ha = 10$

Figure 1: $Re_b = 8000$ - Instantaneous isosurfaces of Q-criterion for (a) $Ha = 0$ and (b) $Ha = 10$. These isosurfaces are coloured by the norm of velocity (both representations have the same contour level ranging from 0 (blue) to 5.03 (red)).

a transverse external uniform and constant magnetic field and periodic condition in the streamwise and azimuthal directions. Up to now, preliminary DNS results were obtained for the considered flow for a bulk Reynolds number $Re_b = 8000$ with a Hartmann number Ha ranging between 0 and 100 and for $Re_b = 5300$ with Ha ranging between 0 and 20. This range of Ha number covers both turbulent and laminar regimes. Figure 1 shows the laminarization process that occurs first in the core of the flow and in the Hartmann layers (parallel to the magnetic field).

It is found that, at these marginal Reynolds numbers and for this range of Hartmann number, the flow is either fully turbulent or completely laminar. Results of interest are the average velocity profiles and fluctuations, the skin friction coefficients, three-dimensional visualizations of the turbulent structures, the reciprocal von Karman coefficient and the physical dissipations. The damping of turbulence through the magnetic field is observed and is found to be more efficient in the direction of the magnetic field than in the direction perpendicular to it.

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