MHD TURBULENCE AT HIGH INTERACTION PARAMETER

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Abstract Saturation mechanisms in solar and planetary dynamos are due to the feedback of the Lorentz force on conducting fluid flows. The way a magnetic field modify a laminar flow have been explored both analytically and experimentally. But the detailed scale by scale of the modification of a fully turbulent flow is still an open question. We study here both magnetic and velocity fields in a turbulent Von Karman gallium flow with a large external applied magnetic field. First we will show that turbulent induction processes are strongly affected by the presence of a large magnetic field, then we will focus on hydrodynamics measurement (torques and velocity profiles by ultrasound Doppler velocimetry) which highlight the damping of large scale of the flow whereas the statistics of turbulent fluctuations remain unmodified.

INDUCTION AT HIGH INTERACTION PARAMETER

The experimental setup is sketched in fig 1 (a) where a volume of liquid gallium is driven in a cylindrical vessel by two coaxial and counter rotating impellers. The typical rotation rate is about 10 Hz therefore the integral Reynolds number is above 10^6. One pair of coils perpendicular to the axis of symmetry of the cylinder produces an applied homogeneous magnetic field up to 1500 G.
In the frame of MHD where the control parameter for the magnetic phenomenon is the integral magnetic Reynolds number $Rm = \mu_0 \sigma L u$, the influence of the magnetic field on the flow is characterized by the interaction parameter:

$$N = \frac{|Lorentz|}{|inertia|} = \frac{|j \times B|}{|\rho(u \cdot \nabla)u|} = \frac{B^2}{\mu_0 \rho u^2}.$$

where u, B, ρ and $j = 1/\mu_0 \nabla \times B$ are respectively the typical velocity of the flow, the amplitude of the total magnetic field, the density of the fluid and the current density.
In the case where the applied field B^A is transverse, the dominant induced magnetic field B^i is in the axial direction and is linear with Rm for small interaction parameter ($N \ll 1$) see fig 1 (b) and [1].

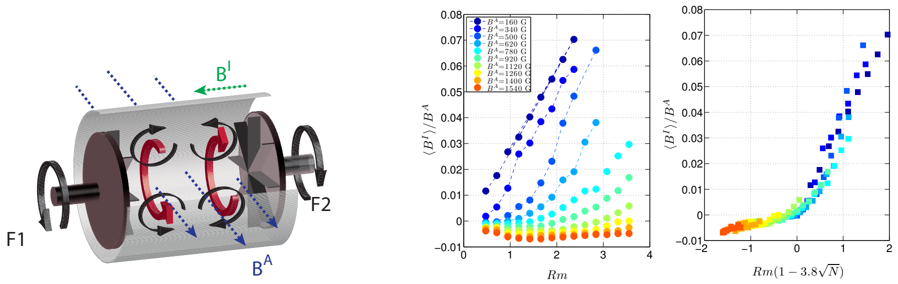

Figure 1. (a) Experimental setup of Von Karman Gallium flow. Mean velocity field is represented with full red and black arrows for $N = 0$. The directions of applied and induced magnetic field are in dotted blue and green arrows. (b) Evolution of normalized induction with the rotation rate. Each curve is for a different B^A. (c) Evolution of normalized induction with the non linear correction.

As described in details [2], the increase of the interaction parameter strongly modify the evolution of the induced magnetic field with Rm (fig 1 (b)). When the Lorentz force is not any more negligible ($N \sim 0.1$), effects of non linearities have to be taken into account and a correction proportional to $Rm\sqrt{N}$ correctly describes this effect. The induced magnetic field follow the law:

$$B^i = f(Rm(1 - \alpha\sqrt{N}))B^A$$

with α a geometrical parameter and f a function. Note that the linearity with Rm for $N \ll 1$ is recovered.
Radial profiles of normalized induced magnetic field for 3 values of the interaction parameter, shown on fig 2, reveal that the profiles of induced magnetic field are strongly modified by the Lorentz force therefore current density in the fluid is

also modified. We can distinguish 3 regimes: a hydrodynamic regime for $N \ll 1$, a transition regime and a MHD regime for $N \sim 0.1$. These features are corroborated by global hydrodynamics measurements.

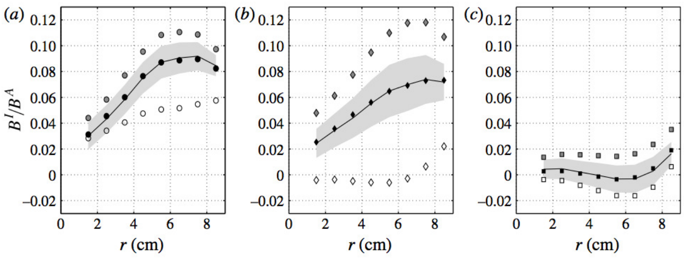

Figure 2. Evolution of magnetic profile with N. (a) Hydrodynamic regime $N \ll 1$. (b) Transition regime $N \sim 0.1$. (c) MHD regime $N \sim 1$. Blacks curves represents mean profiles and other curves represents the furthest profile from the mean. Grey area shows the rms of the profiles.

TURBULENCE AT HIGH INTERACTION PARAMETER

For details on the properties of turbulence and precise power budget estimation at large interaction parameter, velocity measurements are about to be realized. Several difficulties arise for velocity measurements in liquid metals. Their opacity and chemical aggressiveness forbid any optical techniques. Other methods relying on local magnetic measurement are affected by large scale applied magnetic field. Ultrasound Doppler Velocimetry (UDV) had been chosen to determine the modification of velocity profile as the interaction parameter increases. This technique is based on the calculation of the time of flight of wave packets emitted by a piezzo ceramic vibrating at 2 MHz (see [3] for details). For moderate rotation rate of the impeller, velocity profile obtained with UDV technique show the damping of turbulence for large interaction parameter.

Global hydrodynamic features are analyzed by the measurement of the torque of each impeller. We note an increase of the mean torque for increasing magnetic field. For a given velocity, the mean torque evolves linearly with N, a feature consistent with the $\sqrt{N}$ correction factor presented above for the magnetic induction (see fig 3 (b)). We can understand this information by the laminarization of the shear layer in the mid-plane under the action of strong transverse magnetic field.

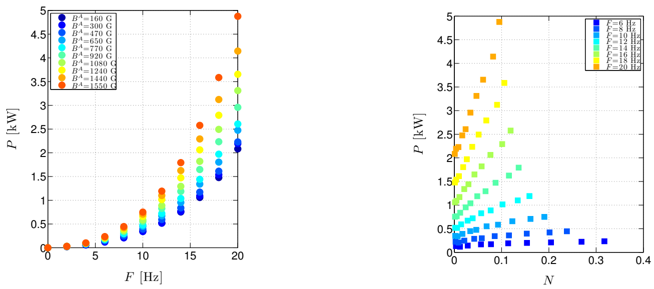

Figure 3. (a) Evolution of global injected power with rotation rate. (b) Evolution of global injected power with the interaction parameter. Each color is for a different amplitude of B^A.

References

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