THE 2D/3D DYNAMICS OF WALL-BOUNDED LOW-RM MAGNETOHYDRODYNAMIC (MHD) TURBULENCE

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Abstract With this experimental study, we give evidence that the dynamics of low-Rm MHD turbulence depends on the diffusion length l_z, which corresponds to the distance over which the Lorentz force is able to diffuse momentum before it is balanced by inertia.

INTRODUCTION

Turbulence displays radically opposite dynamics whether it is three-dimensional (3D) or two-dimensionnal (2D).The former is characterized by a direct energy cascade where energy transits from the injection scale down to the small dissipative scales, while the latter features an inverse energy cascade characterized by energy moving up from the injection scale to the larger scales. The goal of this project is to study the dynamics of a turbulent flow, which features at the same time scales that are "topologically" 2D and 3D, and see how its dynamics is impacted by no-slip boundaries.

This problem is tackled experimentally within the framework of low-Rm magnetohydrodynamics (MHD), which is particularly suited in this case. Indeed, one of the main features of MHD is the diffusion of momentum by the Lorentz force along the magnetic field. In a turbulent flow, this diffusion process is mainly balanced by inertia, whose effect is to break down structures, hence restoring isotropy. As predicted by [1] and recently confirmed by [2], the aspect ratio of a vortical structure of width $l_\perp$, height l_z and velocity u, results from the balance between the two aforementioned effects according to $l_z = l_\perp N^{1/2}$, where $N = \sigma B_0^2 l_\perp/\rho u$ is the interaction parameter, ρ the density of the fluid considered, and σ its electrical conductivity. B_0 is the uniformly imposed magnetic field. Assuming this structure evolves in a bounded domain of height h, a minimum size l^c exists for the structure to span across the whole channel i.e. to be 2D: $l^c > hN^{-1/3}$.

The experimental rig used in this work consists of a $(10\ \mathrm{cm})^3$ box filled with liquid metal (conductivity $\sigma = 3.4 \times 10^6\ \mathrm{S/m}$, density $\rho = 6400\ \mathrm{kg/m^3}$, viscosity $\nu = 4 \times 10^{-7}\ \mathrm{m/s^2}$), immersed in a vertical and uniform magnetic field B_0. A total electric current I is injected through the bottom wall via an array of 10×10 injection electrodes, alternately connected to the positive and negative poles of a DC current generator. The overall state of the system is defined by two independent non-dimensional parameters: the Hartmann number $Ha = B_0 h\sqrt{\sigma/\rho\nu}$, and the interaction parameter N as defined previously, which are experimentally imposed through B_0 and I. The flow is diagnosed using electro-potential velocimetry on the top and bottom Hartmann walls, as well as ultrasound Doppler velocimetry in the bulk of the flow.

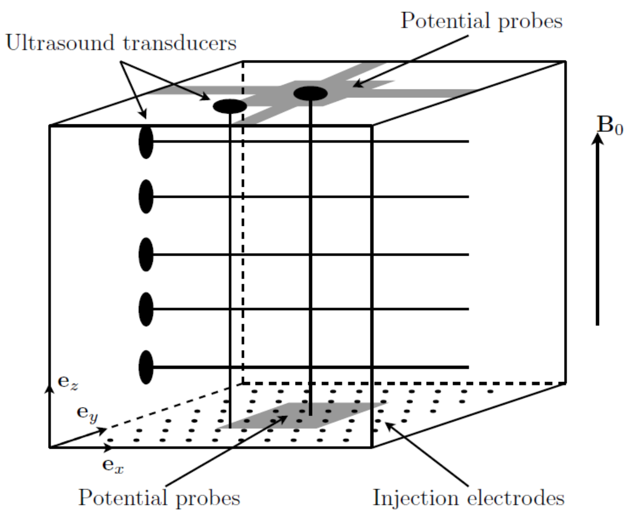

Figure 1. Sketch of the experimental setup showing the different measuring probes.

RESULTS

Figure 2 shows how the flow becomes correlated over a longer horizontal distance as it is considered further away from where the electrical forcing takes place: turbulent structures are statistically larger at the top of the box than at its bottom.

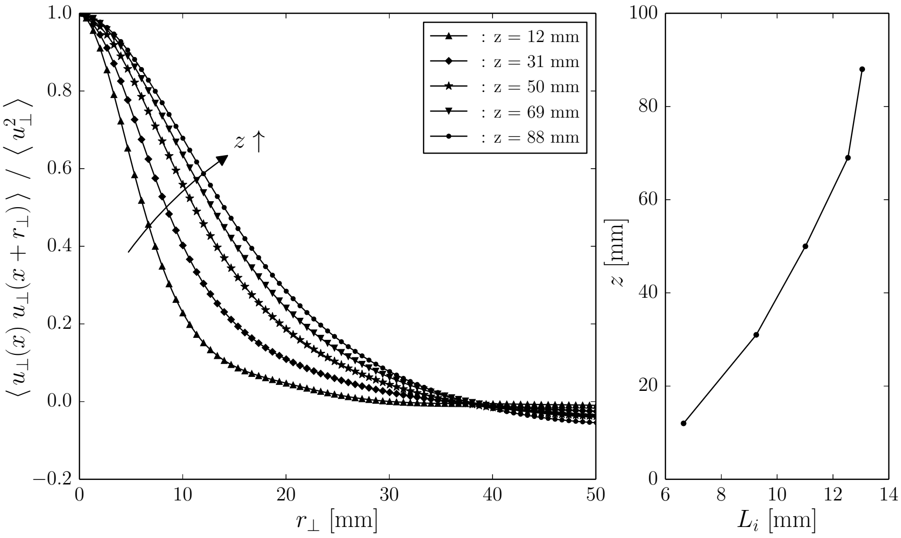

Figure 2. Left: horizontal correlation function measured by the 5 vertically stacked ultrasound transducers. Right: horizontal integral length scale against height.

According to figure 3, the PDF's corresponding to the large scales ($r_\perp > 10$mm) follow a Gaussian distribution, both at the bottom and top of the box, while the PDF's of the smaller scales ($r_\perp < 5$mm) depart from this Gaussian behavior. In other words, the scales following a Gaussian behavior are those that are - according to [1] - more likely to be quasi-2D. Although still difficult to quantify at this stage, our results suggest a scale dependant correlation between topological dimensionality of the flow and intermittency.

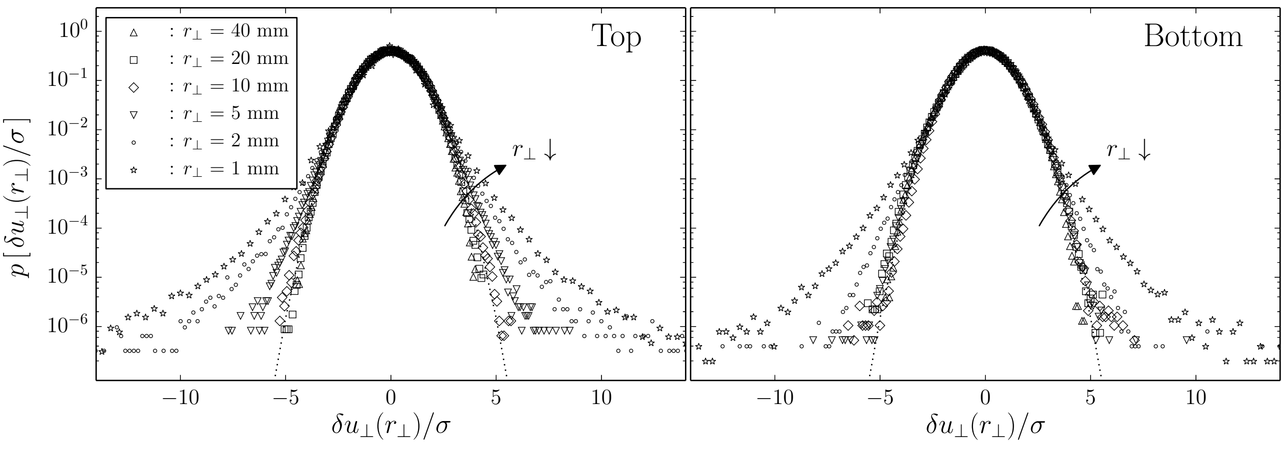

Figure 3. probability density function of several horizontal velocity increments $\delta u_\perp(r_\perp) = u_\perp(x + r_\perp) - u_\perp(x)$ measured using the top and bottom ultrasound transducers. The Pdf's are normalized by their standard deviation σ.

References

[1] J. Sommeria, R. Moreau. Why, how and when mhd turbulence becomes two-dimensional. *J. Fluid Mech.* **118**: 507–518, 1982.

[2] A. Pothérat, R. Klein. Why, how and when MHD turbulence at low Rm becomes three-dimensional. *J. Fluid Mech.* **761**: 168–205, 2014.