INFLUENCE OF VISCOSITY ANISOTROPY ON TURBULENCE LARGE SCALE STATISTICS

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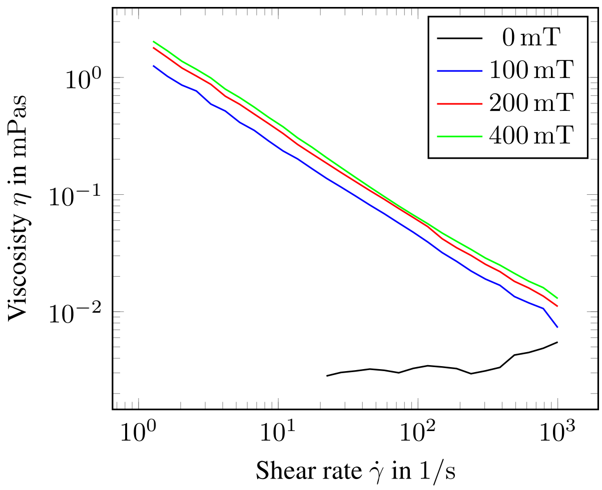
Abstract We report experiments on a turbulent flow of a fluid with anisotropic viscosity. The fluid is an aqueous suspension of paramagnetic nanoparticles which can be aligned by an external magnetic field. We explore the flow at various Reynolds numbers and magnetic field strengths and see pronounced changes in turbulence statistics even at the largest scales.

INTRODUCTION

The description of fluid turbulence is closely linked to the understanding of energy transfer across multiple length and time scales. The present study approaches this phenomenon from a new direction. By changing the isotropy of the viscous dissipation, the turbulence cascade is modified in a controlled manner at the smallest possible length scale. In order to achieve this a ferrofluid, i.e. a colloid of paramagnetic particles, is exposed to a uniform magnetic field. As there are no field gradients present, no additional forces are exerted on the fluid and the only effect is an anisotropy in the fluid's viscosity. Thus changes of the turbulence properties at small, intermediate or even large scales may only be caused by the modification of the dissipation process.

Here we present results from experiments of a turbulent flow with varying levels of anisotropy. We measure Lagrangian autocorrelation functions from which we derive different time scales.

EXPERIMENTS



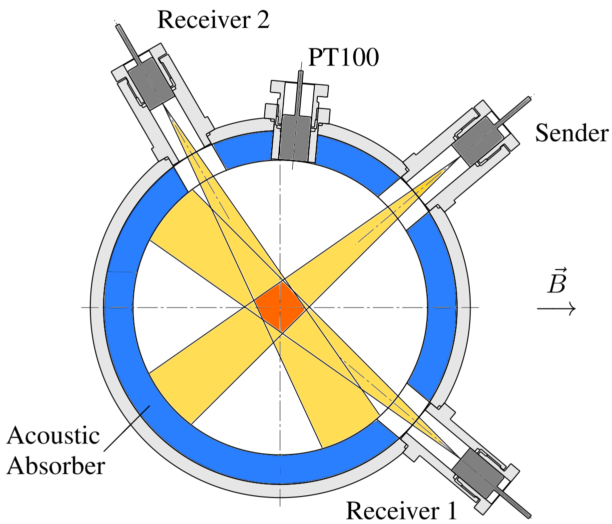


Figure 1. (left) Viscosity of sicastar-M 350 as a function of shear rate at different magnetic field strengths and (right) top view of the central plane incorporating the sending and two receiving ultrasound transducers. The measurement volume is indicated as shaded area.

The turbulent flow is generated in a von Kármán swirling flow apparatus. The flow is driven by two counter-rotating disks (radius $R = 45\,\mathrm{mm}$, separation $H = 100\,\mathrm{mm}$), each fitted with 8 straight, $5\,\mathrm{mm}$ high blades to increase the flow agitation. The temperature is measured with a PT100 resistance thermometer and regulated by an external cooling loop. As the flow is axisymmetric, the magnetic field is applied perpendicular to the apparatus symmetry axis. The magnetic fluid used in the study is an aqueous suspension of paramagnetic nanoparticles (Sicastar-M 350, micromod Partikeltechnologie GmbH, Germany). The particles have an average diameter of $350\,\mathrm{nm}$ and were chosen for their comparatively high saturation magnetisation. Under zero magnetic field the fluid behaves purely Newtonian with density $\rho = 1.0144\,\mathrm{g/cm^3}$ and viscosity $\eta = 3\,\mathrm{mPas}$ close to the values of water. When applying an external magnetic field the particles in the fluid form small linear chains which are preferentially aligned in the direction of the field. An anisotropic response to shearing motions results and its effect can be modelled by a direction dependent viscosity.

As the fluid is opaque we use an ultrasound technique for measuring the velocity fluctuations in the flow. The technique is based on continuous wave ultrasound and gives Lagrangian particle trajectories with high resolution in space and time. An ultrasound transducer continuously insonifies the cell centre (Fig. 1 right). A tracer particle crossing the sound beam scatters the sound, producing a frequency-shifted echo with a frequency proportional to its projected velocity. This echo is then received by three receiving ultrasound transducers.

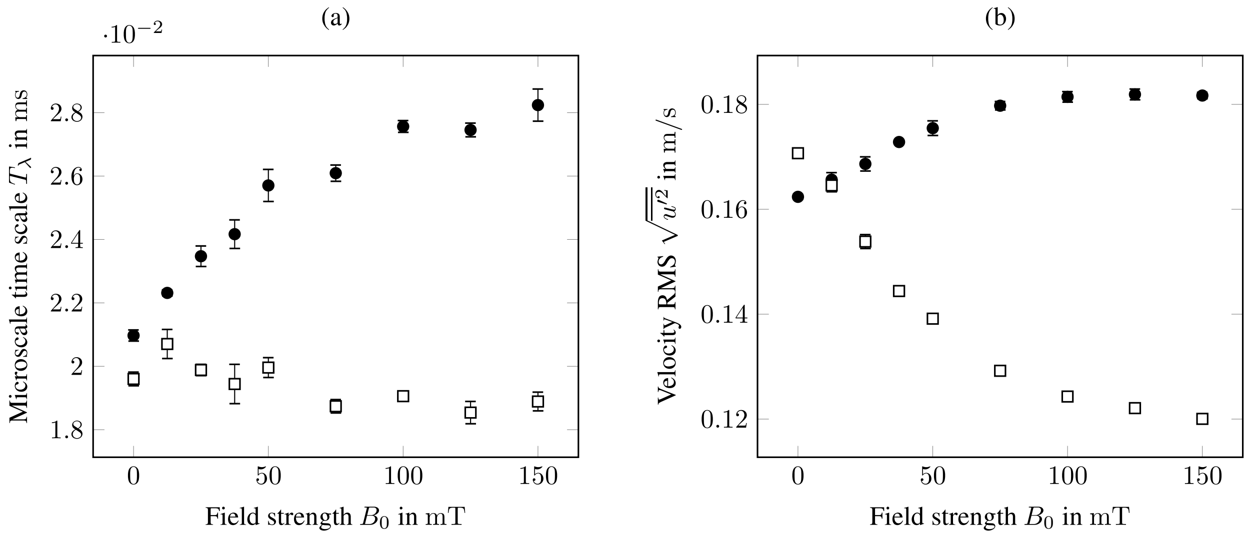


Figure 2. (a) Microscale and (b) velocity RMS as a function of external magnetic field strength (circles parallel and squares perpendicular to magnetic field direction).

RESULTS

Microscale time scale and RMS velocity vary with magnetic field (Fig. 2). With increasing external magnetic field we observe an significant anisotropy on all scales. The RMS velocities are almost isotropic at zero magnetic field. The small residual anisotropy arises most likely from a small misalignment of the transducers which may not sample at the exact stagnation point of the flow. With increasing magnetic field the fluctuations in field direction increase slightly while they are reduced in the perpendicular direction.

As far as we know these are the first measurements in a turbulent flow with controlled small scale anisotropy. Further research in this direction may help to gain better understanding of the energy cascade.