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CONFINEMENT OF TURBULENT FLOWS WITH ROTATION EFFECTS WITH A PENALIZATION METHOD

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We want to analyse the structuration and dynamics of homogeneous turbulence in a cylindrical container with open periodic ends, placed in a rotating frame. To that extent, we performed pseudo-spectral Direct Numerical Simulations at different Rossby and Reynolds numbers using a penalization technique to take into account the radial confinement.

A first part of the presentation is dedicated to the validation of this numerical method by considering the impact of a vortex ring on a flat “penalized” wall and compare the results obtained with the existing experimental data. A second part will then describe the dynamics of the cylindrical flow as well as its anisotropic structure and its main Lagrangian statistics.

1 Context and motivation

Homogeneous turbulence is obviously an idealized picture of actual or experimental flows, as boundaries are always present in nature. Moreover, actual flows in nature or in industry are also subjected, to a certain extent, to body forces such as the Coriolis force when considering rotation effects in geophysical flows, buoyancy in the case of stratified flows or the Lorentz force in the case of an electrically conducting fluid submitted to a magnetic field.

In the present work, we propose to explain some basic features of turbulent flows in a cylindrical enclosure, a geometry which bears some similarities with current experimental settings for studying high Reynolds number turbulence (von Karman flows). This geometry is also chosen because it retains homogeneity in two directions (the azimuthal and the vertical ones). We also propose to add to this confined flow the effect of the Coriolis force that appears when considering background rotation. We will take advantage of the axis of symmetry of the confinement and align the axis of rotation with it. This configuration will allow to evaluate the effect of confinement onto rotating turbulence, and contrast its properties with the well-described dynamics of homogeneous rotating flows [2].

2 Presented work

We use a tri-periodic pseudo-spectral code with an immersed boundary method, namely the volume penalization method. This class of methods has been introduced in 1972 by Peskin (see [5]) and allows the computation of bounded flows on Cartesian grids (meaning that no refinement close to the boundary is needed). The method consists in adding an external force field in the Navier-Stokes equations, where a mask function splits the computational mesh between fluid and solid/porous regions. A penalization parameter allows to describe an impermeable domain in the asymptotic zero limit. A mathematical demonstration of the convergence of the penalized equations to the Navier-Stokes ones with no-slip boundary conditions has been achieved by Angot *et al.* [1]. However, when computing the set of penalized equations with an explicit scheme for evaluating the penalized term, a stability issue appears which hardly constrains the time-step. An original way to avoid this restriction has been developed and is formulated in [3]. In the latter work, we also highlight the fact that the penalization term is compressible and explicitly acts on the pressure term.

First, we propose to test the numerical method by considering the impact of a vortex ring on a wall introduced thanks to the penalization method. Walker *et al.* [6] showed that, in a defined range of Reynolds number, a secondary ring is created and the interaction of those two vortex rings leads to a third one. The comparison of our simulations with this experimental work (see figure 1) is very interesting and reveals that the penalization method is able to reproduce the features described in [6].

We then perform Direct Numerical Simulations (DNS) of confined freely decaying turbulence with and without the addition of the Coriolis force to observe and compare the decay of such flows. A qualitative viewpoint is given by figure 2 at the beginning of the computation. Some trajectories of tracer particles are used to obtain a Lagrangian viewpoint of the global effect of confinement.



Figure 1: Impact of a vortex ring on a flat wall – $Re=1250$. Creation of secondary and tertiary vortex rings. Left : Experimental observation by Walker *et al.*. Right : Present penalized simulation with $\eta = 10^{-6}$, visualization of the enstrophy field.

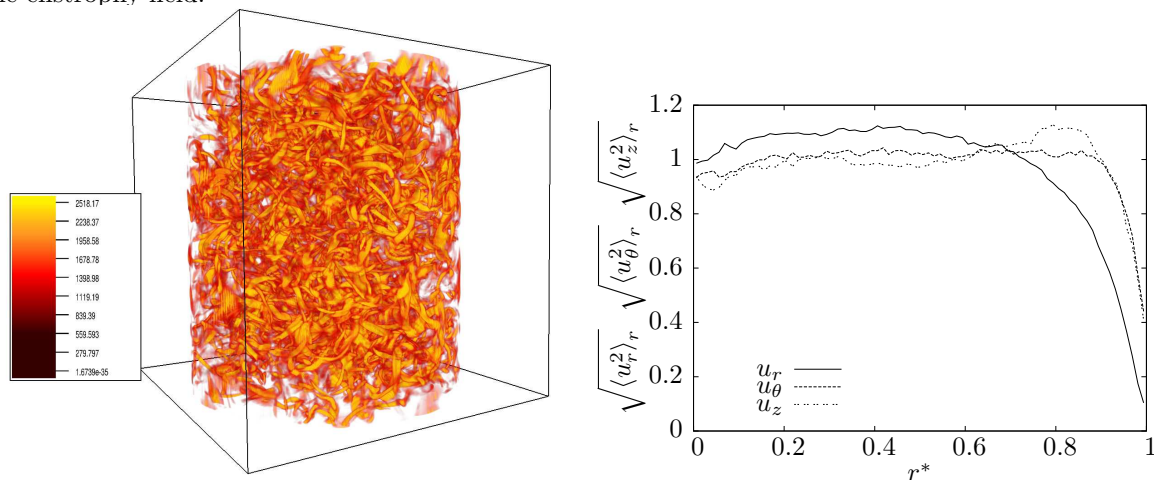


Figure 2: Left: Eulerian qualitative aspect of confined turbulence (no rotation). Visualization of the enstrophy $W = \frac{1}{2}\omega_i\omega_i$. Right: Radial evolution of the *rms* velocities obtained for the non-rotating case.

The principal goal of this work is to present the variation of different statistics in the flow depending on the distance to the wall. Such statistics are the orientation of the velocity vectors, the *pdf* of the different components of the velocity, the radial evolution of the normalized *rms* velocities, the directional length scales, etc. Figure 2 shows the radial distribution of the three *rms* velocities in the cylindrical coordinates.

Our presentation during Euromech Colloquium 525 will include Eulerian statistics from an extended database with high resolution DNS, as well as Lagrangian dispersion statistics.

References

- [1] ANGOT, P., BRUNEAU, C.-H., FABRIE, P. 1999 A penalization method to take into account obstacles in incompressible viscous flows, *Numer. Math.* **81** 497–520
- [2] CAMBON, C., MANSOUR, N.N. & GODEFERD, F.S. 1997 Energy transfer in rotating turbulence *J. Fluid Mech.* **337**, 303–332
- [3] JAUSE-LABERT, C., GODEFERD, F.S. & FAVIER, B. 2011 Numerical validation of the volume penalization method in three-dimensionnal pseudo-spectral simulations. *In preparation.*
- [4] KOLOMENSKIY, D. & SCHNEIDER, K. 2009 A Fourier spectral method for the Navier-Stokes equations with volume penalization for moving solid obstacles. *J. of Comp. Phys.* **228** (16), 5687–5709
- [5] PESKIN, C.S. 1972 Flow patterns around heart valves: A numerical method., *J. of Comp. Phys.* **10** (2), 252–271
- [6] WALKER, J.D.A., SMITH, C.R., CERRA, A.W. & DOLIGALSKI, T.L. 1987 The impact of a vortex ring on a wall *J. Fluid Mech.* **181**, 99–140