DYNAMIC OF LARGE PARTICLES EMBEDDED IN SHEAR FLOWS

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Abstract Large particles ($D \gg \eta$) immersed in a closed turbulent flow tend to explore in a non-uniformly way the cavity in which they are placed[2]. Here we study the slow dynamics of large particles (with various size) advected in closed turbulent flows at different Reynolds numbers. We investigate the spatial sampling experienced by large particles in two fully turbulent closed flows generated between counter-rotating disks (so called von Karman flow), focusing in the slow frequency's ($f_{slow} < \Omega$, where Ω is the rotation rate of the driving impellers) and characterize the power spectrum of the slow fluctuations of particles position. Both considered flows share a common feature : the presence of a shear region dividing two mean re-circulation regions ; however the spatial symmetries and the temporal behaviors of both setups are very different. The principal result in this research is that despite these differences both flows exhibit a well defined slow dynamical behavior that can be identified in Fourier space. We report on the universal characteristics of such slow motion.

EXPERIMENTAL SET-UP'S

We present two different von Karman systems, one operating at the University of Navarra, in Pamplona (VKP) the other at Ecole Normale Superieure of Lyon (VKL) : VKP consists in a cylindrical cavity with a diameter $D = 20$ cm positioned horizontally within a square tank, the cylinder ends were sealed with two plexiglas caps with the objective of enclosing the flow. The fluid is driven by two impellers whose blades have a curvature radius of 4.85 cm and separated by a distance $H = 20$ cm. These impellers are powered via independent motors with a range of rotation frequency between $\Omega = 1 - 12Hz$. For the image acquisition we have used a CMOS Fire-wire monochrome camera (752×428 px), with a maximum frame rate of 60 fps. The location of this camera gave us only the perspective of the y,z plane and the particles used for this study were celluloid spheres filled with water($\langle \rho_p \rangle \approx 1$ g/cm^3), with the purpose of generate almost isodense tracers in where the chosen diameters were $D_p = 10, 20, 30$ and 40mm. VKL consists of a closed square cavity in order to improve the optical access for image acquisition. The flow is driven with two impellers fitted with 8 straight blades (1 cm high), where the discs radius is $R = 9.5$cm and the distance between the impellers is $H = 2R \sim 20$ cm. The driving motors are capable to rotate at frequencies in the range of 1-12 Hz. The square section has a width of $20cm$ and a length of $20cm$. To grab the three components displacement of the particles two high-speed cameras (725×780 px) capable to record up to 10kHz were used. We consider the motion of different classes of particles with diameter $D_p = 6, 10, 18$ and 24 mm and with a density slightly larger than that of water($\rho_{PA} \approx 1.14$ kg/m^3).

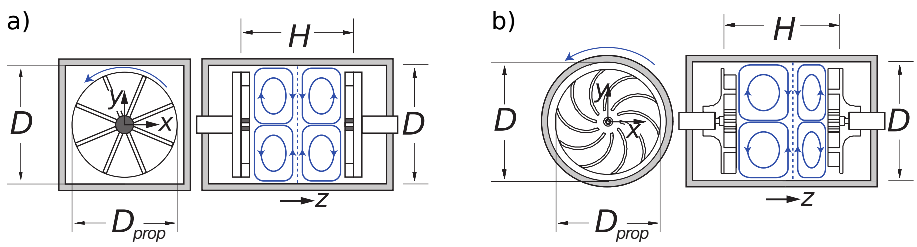

Figure 1: a) Side view of the VKL setup where in blue is represented the mean flow re-circulation with the shear layer placed at the mid plane. b) Side view of the VKP setup where in blue is represented the mean flow re-circulation with the shear layer displaced to the right side of the cavity.

In both experiments we consider the case of counter-rotation, with the two disks rotating in opposite direction, hence producing a strong shear layer in between, which separated two mean recirculation loops. An important distinction of the 2 setup, is that while in VKL the shear layer is stable and located at equal distance of the two impellers[2], the specific symetry of the vessel and the impellers of VKP is known to produce an unstable shear layer[1] , with an equilibrium position closer to one of the impellers (see figs. 1a&b), switching randomly from one side to the other of the vessel (we shall refer to these switchs as “reversals” of the flow topology).

EXPERIMENTAL RESULTS

Such closed turbulent flows have large fluctuations which are responsible of the chaotic motion of particles immersed in the flow and in order to study this motion we have investigate temporal dynamics. In Fig.2 we show the variation of the particle position along the z axis for both devices. We can see that in VKL (Fig.2.a) the preferential sampling of the particle is symmetric, with equal probability for the particle to be on either side of the setup. On the contrary, in VKP (Fig.2.b) due the reversals (solutions represented in green and red, see Fig.2.b) of the flow the particle preferentially samples the larger recirculation region.

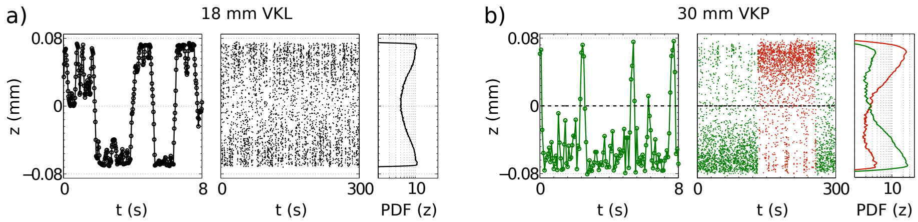

Figure 2: Axial position of a particle on short time (first column) and long time (second column) with the probability density function (noted PDF) of the whole signal (third column). a)Data from the VKL experiment. b)Data from the VKP experiment.

To have a deeper insight into this dynamics we have computed the position power spectra of the z component and the results are shown in the Fig.3. In Fig.3.a-b we observe four slopes in the position power spectra and only two are similar on both devices. For values of $f_{slow} < f_{imp} = \Omega$ there is a power law with slope close to -1.7 which is related to the coming and going of the particle while for lower frequency's the spectra flattens towards a plateau, corresponding to the large scale uncorrelated motion. For VKL we also observe the fast dynamics (accessible due the high camera sampling rate) with a clear -4 slope appear. For the case in VKP due the lack of high frame rate acquisition this region is inaccessible, nonetheless here the very slow dynamics presents a peculiar -2 slope (see Fig.3b) which is the signature of the long term flow reversals.

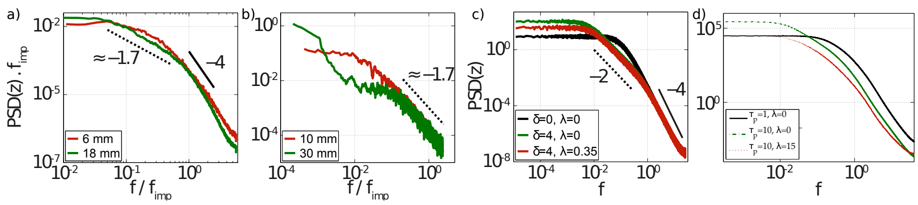

Figure 3: a) Position power spectra for 6 and 18 mm particles in VKL. b) Position power spectra for 10 and 30 mm particles in VKP. c) Postion power spectra via the double well model. d) Position power spectra via the single potential model.

Finally, the objective of this report is describe the behavior of the particle using a model that reproduce the axial motion of the particle taking into account the role of turbulent fluctuations. To this aim, we consider the simple stochastic model $\frac{dz}{dt} = -\frac{dV}{dz} + v(z,t)$, where V is a potential and v represents the turbulent fluctuations. For the turbulent fluctuations term we impose that the temporal and the spatial dynamics are independent, therefore the term can be write as $v(z,t) = B_0\, s(z)\, \eta(t)$. Here the temporal fluctuating part have some characteristics of a turbulent Lagrangian velocity and these characteristics are well captured by a Langevin equation[3], in the spirit of Sawford problem.

To reproduce this dynamics we have tested two different models one based in a double well potential $V(z) = \delta(\frac{z^4}{4} - \frac{z^2}{2}) + \lambda z$ (accounting for the inhomogeneity of the mean flow) with homogeneous fluctuations ($s(z) = 1$) and another one based on a single potential $V(z) = z^n/n + \lambda z$ (simply accounting for the confinement of the flow) but with non-homogeneous fluctuations $s(z)$. Fig.3c presents the results for the double well model while Fig.3d shows the results for the single potential. In conclusion we found that each model taken independently reproduces only partially the observations features but that both the effects of mean flow and fluctuations inhomogeneity are necessary to draw a correct global picture of the slow particle dynamics.

References

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