EXPERIMENTAL STUDY OF CLUSTERING OF FLOATERS ON THE FREE SURFACE OF A TURBULENT FLOW

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Abstract We present an experimental study of the statistical properties of particles floating at the surface of a turbulent flow. Two random flows with different properties are generated in a layer of liquid metal by an electromagnetic forcing. The forcing is strong enough to generate a 3D flow deforming the surface. The motion of hundreds of milimetrical particles floating at the interface between the liquid metal and diluted acid solution is followed by means of a particle tracking technique. Surface level is recorded independently along a line. A statistical procedure is proposed to evidence the clustering of floaters. Some dynamical properties of the cluster are exposed.

INTRODUCTION

For objects floating on a free surface, inertia can play a significant role. Moreover, when the underlaying flow is turbulent, one can expect preferential concentration effects as it is observed for classical turbulence (see for instance [1, 2]). Nevertheless, objects on a free surface can be also subjected to waves and vertical velocity gradients, implying a non-vanishing two-dimensional divergence [3]. Also, objects smaller than the capillary length can experience capillary interactions, as described for instance in [4, 5].
Then, even if there are several arguments to expect preferential concentration effects, the problem lack of a complete description, and experiment are still scarce [3, 6, 7]. We performed complementary experiments with particles floating in turbulent flow in quasi bidimensional configuration, and we propose an statistical procedure that evidence the formation of clusters [8].

EXPERIMENTAL TECHNIQUES AND BASIC RESULTS

We excite turbulence in a quasi-bidimensional configuration, with the help of the Lorentz force $\vec{F}_L = \vec{J} \times \vec{B}$: In a layer of liquid metal (Galinstan, an alloy of 68.5% of Gallium, 21.5% of indium, 10% of Tin, liquid at room temperature), we impose a controlled horizontal homogeneous electrical current between two electrodes. We also impose an inhomogeneous vertical magnetic field generated by permanent magnets. The distribution of the magnets fixes the forcing geometry (we used two kinds: one regular and other random). The configuration is quasi-bidimensional in the sense that the layer thickness (1cm) is very small compared to horizontal dimensions (40cm and 50cm), and also because the most important part of the forcing is in the horizontal direction $\hat{y}$, considering that essentially we have $\vec{J} = J\,\hat{x}$ and $\vec{B} = B\,\hat{z}$. In order to prevent oxidation of the surface, we cover it with acid in low concentration.
We carry out two independent type of measurements: Velocity field is measured by tracking particles that are floating on the galinstan-acid interface. Interface deformation, on the other hand, is measured along a line by using an optical method.
We analyze the standard deviations of the interface deformation, together with a coarse graining of the velocity measurements, allowing us to compare temporal fluctuations and the time averaged flow. In this way we found a clear difference between the two arrays of magnets used to drive the fluid. Regular forcing appears to generate strongly fluctuating fluid motion. Random forcing on the other hand generate a more coherent flow. In both cases, the time averaged part of the flow is highly correlated to the imposed forcing.

CLUSTERING OF PARTICLES

Apart from giving information about the velocity field, floating particles have their own dynamics: They have the tendency to distribute in a heterogeneous way [3, 5, 6, 7]. To take into account those effects, following the ideas developed for classical turbulence [1], we studied the area $\mathcal{A}$ defined by positions of three neighboring particles, or Delaunay areas. We observed that the areas follow a Gamma distribution:

$$p(\mathcal{A}) = \frac{b^a}{\Gamma(a)} \mathcal{A}^{a-1} \exp(-b\mathcal{A}), \quad (1)$$

were Γ is the standard gamma function, and the coefficients a and b come from the distribution itself depending on its variance and mean value. Representative examples of distributions are given in the figure 1(left): Blue crosses correspond

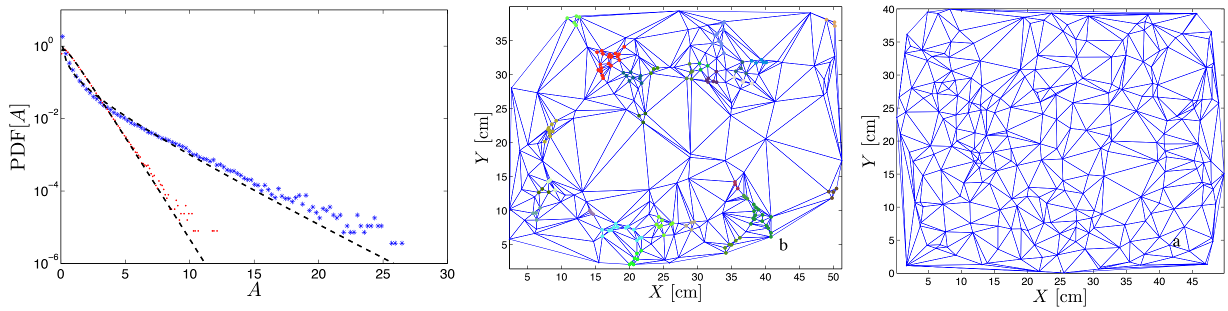

Figure 1. Gamma distributions and clusters. Left: PDF of the normalized Delaunay triangle area obtained experimentally (blue crosses) and constructed from an uniform distribution of points (red points). Dashed lines correspond to the Gamma distribution of same average and standard deviation. Middle: Snapshot of the position of 254 particles and the corresponding Delaunay tessellation for an instantaneous measurement in the experiment with the random array for I = 300 A. Left: Equivalent snapshot for uniformly distributed particles.

to the experimental data, from which figure 1(middle) is an example snapshot. The reference distribution in red, corresponds to areas obtained from an uniformly distributed set of points, as the one shown in figure 1(right). Dashed lines correspond to the Gamma distribution of same average and variance.

From the distribution (1) one can obtain a measure of the degree of clustering, given by the coefficient $a < 1$. It should be noticed that the uniformly distributed set of points gives the marginal case $a \approx 1$ (the exponential distribution). This means that the experimental distribution of Delaunay areas is sharper than one obtained from an uniformly distributed set of points, reflecting the tendency of particles to form clusters in the experiment. This can be seen on the two snapshots in figure 1.

From the first crossing of distributions (see figure 1 left), one can obtain a criterion defining clusters. It was used to define the clusters shown in figure 1 middle (with $A_c = 1.4$). The statistics of the number of particles per cluster show a power law with an exponent close to 2. Finally, we considered the statistics of dynamical properties of particles (velocity's magnitude and orientation): We observe a strong difference between the whole set of particles and the set of particles belonging to clusters. For example, in the former case one has a roughly gaussian distribution of velocities, whereas a sharper distribution is observed in the later case.

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