Detection of vortical structures in inertial and dissipation ranges

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The condensation of vorticity into filamentary structures in turbulent flows has received much attention in the last two decades. So far the detected filaments have been found with diameters of the order of the Kolmogorov scale, η, lengths of the order of the integral scale, ℓ_ε, and velocity difference across their cores of the order of the large-scale velocity, see e.g. Jiménez & Wray [1].

We use two-component cross-wire velocity signals from several turbulent shear flows in the range $250 \leq Re_\lambda \leq 4600$ (cylinder wake, plane and round jet, atmospheric surface layer), to detect the presence of coherent vortices. The detection algorithm assumes the vortices to be rectilinear and infinitely long, with a vorticity distribution which is axisymmetric and Gaussian, and to be advected with a constant advection velocity which is determined locally. It also assumes them to be strong enough for any additional local strain to be negligible, but allows for their orientation to be arbitrary. The particular hypothesis of a Gaussian distribution of vorticity allows us to access quantities of physical interest, and to control the quality of our measurements by comparing the (u, v)-experimental trace with the one produced by the ideal vortex which best approximates the data. The same detection algorithm is applied to raw experimental signals and to low-pass filtered ones, thus making it possible to probe the issue of truly inertial coherent vortices in the case of our highest Reynolds number data. As usual the Taylor hypothesis is used to convert time into space.

For unfiltered signals, the detected vortices have radii of the order of the Kolmogorov scale while, for the low-pass filtered signals, we detect coherent vortices at all the scales. We show in figure 1a the probability density function (PDF) of the radius, σ, obtained from the whole population of detected vortices. We stress that no threshold on the magnitude of the signals is used to identify the vortices in our method, contrary to most of the previous studies. This results in distributions of vortex properties which are broader than those restricted to strong vortices (see the comparison in figure 1a).

To address the issue of intermittency, we examine the transverse gradient of the low-pass filtered velocity, $\partial_x v^<_{\Delta x_f}$, while varying the scale of the filter, Δx_f, within the inertial range. We compute the time fraction, $\mu(s_0, \Delta x_f)$, associated with transverse gradients above a given threshold, $|\partial_x v^<_{\Delta x_f}| \geq s_0 \times \langle(\partial_x v^<_{\Delta x_f})^2\rangle^{1/2}$, and we compare $\mu(s_0, \Delta x_f)$ with the time fraction, $\mu_{vortices}(s_0, \Delta x_f)$, associated with the simultaneous conditions of the realization of the previous threshold and of the identification of the passage of a vortex near to the probe (thus $\mu_{vortices}(s_0, \Delta x_f) \leq \mu(s_0, \Delta x_f)$).

Despite the identification of the vortices, and hence the value of $\mu_{vortices}(s_0, \Delta x_f)$, depend obviously on the severity of the tests used in our algorithm, the evolution of $\mu_{vortices}(s_0, \Delta x_f)$ through the inertial range has a physical meaning. The increase of $\mu(s_0, \Delta x_f)$ as Δx_f decreases in the inertial range is a signature of intermittency, and remarkably we find that $\mu_{vortices}(s_0, \Delta x_f)$ has the same behaviour, see figure 1b.

Therefore our study supports the idea that inertial coherent vortices do exist and contribute to part of the inertial-range intermittency.

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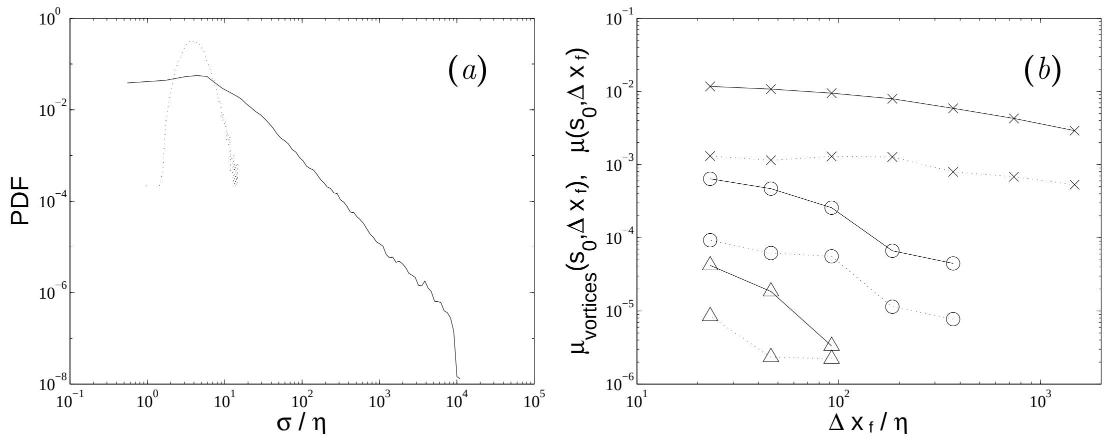

Figure 1: Plane jet with $Re_\lambda \approx 1600$ and $\ell_\varepsilon/\eta \approx 8700$. ($a$) PDF of σ/η: —— , from our detected vortices; ········ , from Ref. [1], DNS of isotropic turbulence at $Re_\lambda \approx 170$. (b) Time fractions: —— , $\mu(s_0, \Delta x_f)$; ········ , $\mu_{vortices}(s_0, \Delta x_f)$; $\times$, $s_0 = 3$; $\circ$, $s_0 = 5$; $\triangle$, $s_0 = 7$.

References

[1] Jiménez. J. & Wray A. A. (1998). On the characteristics of vortex filaments in isotropic turbulence. *J. Fluid Mech.* **373**, 255–285.