MACHINE-AIDED DISCOVERY OF SIGNIFICANT REGIONS IN ISOTROPIC TURBULENCE

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Even if statistics of turbulent flow fields may be homogeneous, instantaneous snapshots of the flow are inhomogeneous at many scales. They exhibit regions where one or more observables of the flow, e.g. kinetic energy or enstrophy, are particularly intense, and stay so for a period of time. Turbulence researchers refer to these regions as coherent structures [7], and they have been a staple in turbulence analysis since their early observations [1]. Typically the relevance of some measurable quantity to the flow dynamics is inferred from the equations of motion (e.g. vorticity appears in the kinetic energy equation) and they are characterised by observing their distribution (following the example, intense vorticity is found to be organised in intense vortices that tend to cluster together [2]).

In this work, we attempt to study regions of the flow relevant to its dynamics, reversing the classical procedure sketched above. We take an approach similar to the one recently proposed by Jiménez [3, 4, 5], which seeks to discover features of the flow staying as free from human bias as possible. First, an initial condition is seeded with localised perturbations, and simulations are performed for each perturbed flow field, tracking the perturbation growth as a function of time. The perturbations used here zero either the local velocity fluctuations or the local vorticity within a region of a given size Δ. Some perturbations are found to grow up to 10^3 times more than others after one turnover, in terms of the global kinetic energy or enstrophy of the perturbation field. Because perturbations are local in space, the procedure classifies regions of the flow according to how much they grow when perturbed. The most 'reactive' regions are studied, showing that they tend to contain strong events, either strong vortices, strong velocity perturbations, or both. We study the top 5% of the structures that grow the most or the least, referring to them as significant or insignificant, respectively.

Large velocity perturbations ($\Delta > 60\eta$) grow or not based on the contribution of the region to the turbulent kinetic energy, whereas smaller ones ($\Delta < 60\eta$) do so based on the vorticity the local flow induces in the rest of the flow field. For the limiting size, $\Delta \approx 60\eta$, both features are equally important for perturbation growth and thus significant regions have more energy and enstrophy than insignificant ones. Figures (1b) and (1c) show the typical configuration of significant and insignificant regions of the flow at size 60η, hinting that the flow in significant regions is more 'complex'. The complexity of the flow is characterised using a box-counting algorithm [6], which allows us to estimate the fractal dimension of the three-dimensional distribution of enstrophy. Figure (1a) shows the estimated fractal dimension for the significant and insignificant sets, with fractal dimensions $D \approx 1.4$ and $D \approx 2.3$ respectively. This suggests that intense regions of vortex clusters are more sensitive to perturbations than the weaker vorticity layers found in insignificant regions.

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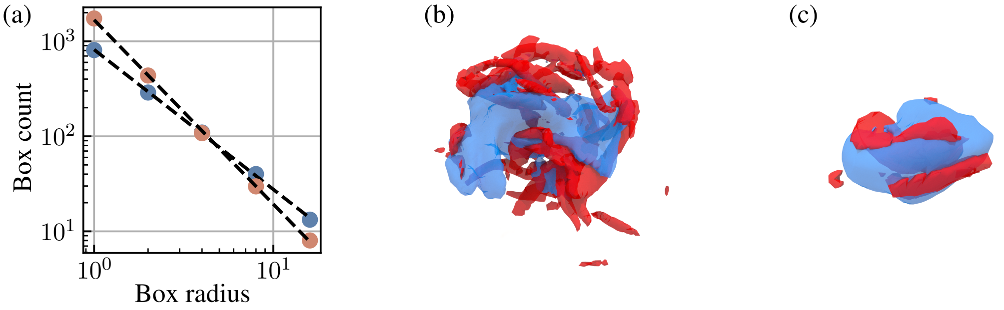

Figure 1. (a) Average box-counting for the significant (blue) and insignificant (orange) regions. The slopes are fitted to $D = 2.3$ (insignificant) and $D = 1.4$ (significant). (b,c) Example of the flow in one significant (a) and one insignificant (b) region. The red iso-surface denotes intense enstrophy and the blue surface, intense kinetic energy. Thresholds are chosen from a percolation analysis.

References

[1] G. L. Brown and A. Roshko. On density effects and large structure in turbulent mixing layers. *J. Fluid Mech.*, **64**:775–816, 7 1974.
[2] J. Jiménez, *et al.* The structure of intense vorticity in isotropic turbulence. *J. Fluid Mech.*, **255**:65–90, 10 1993.
[3] J Jiménez. Machine-aided turbulence theory. *Journal of Fluid Mechanics*, **854**:R1, 2018.
[4] J. Jiménez. Dipoles and streams in two-dimensional turbulence. *Journal of Fluid Mechanics*, **904**:A39, 2020.
[5] J. Jiménez. Monte carlo science. *J. Turbul.*, **21**(9-10):544–566, 2020.
[6] F. Moisy and J. Jiménez. Geometry and clustering of intense structures in isotropic turbulence. *J. Fluid Mech.*, **513**:111–122, 2004.
[7] S. K. Robinson. Coherent motions in the turbulent boundary layer. *Ann. Rev. Fluid Mech.*, **23**:601–639, 1991.