Evaluation of the topological characteristics of the turbulence flow in a ‘box of turbulence’ through 2D Particle Image Velocimetry

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In order to conceptually visualize coherent flow structures in turbulent flows, Perry and Chong (1987) described and classified the turbulent topological flow patterns using the critical points concept, where the slopes of the flow streamlines are indeterminate. These topological flow patterns are defined by invariants of velocity gradients that can be measured experimentally. Previous work, discussing the effect of spatial resolution on the fine scale turbulence, indicates that coarsely resolved velocity vector fields result in underestimation of the magnitude of velocity gradients and errors in the estimate of turbulent quantities (Antonia et al., 1994; Worth et al., 2010). Thus, to provide accurate experimental measurements of turbulent topological patterns, the effect of noise on the velocity invariants needs to be recognized and appropriate digital filtering techniques to eliminate the noise need to be developed. The goal of this paper is to quantify the effect of image noise and establish appropriate filtering approaches for the processing of experimental 2DPIV images of the flow in the ‘box of turbulence’ to eliminate the experimental noise at a satisfactory level in order to identify the two-dimensional topological turbulent flow patterns.

In the current work, the effect of image noise is evaluated by adding random noise on the DNS data from Johns Hopkins University (JHU) open resource turbulence database (Perlman et al., 2007; Li et al., 2008) of forced homogeneous and isotropic turbulence in a 10243 periodic cube. Three filtering approaches to eliminate the added image noise and spurious vectors are considered, namely (a) Median Filter (Westerweel, 1994), (b) Wiener Filter (Press et al., 1988, Souloupolos et al., 2014) and (c) Linear coupling of Median Filter and Wiener Filter. The above methods are applied to measured 2DPIV images of the flow velocity of homogeneous and isotropic turbulence, obtained from the ‘box of turbulence’ facility described in detail by Lian et al. (2013), Lian (2014).

The main conclusions of this paper are summarized as follows.
1. A noise model is established by adding Gaussian noise and Salt & Pepper noise to the velocity vector fields of the DNS velocity data from JHU database. The Salt & Pepper noise is found to be the main noise source in the evaluation of topological characteristics of turbulent flows.
2. A digital Filtering technique has been developed to eliminate the noise. Median and Wiener Filters have been applied and their effectiveness in removing noise examined. Median Filter with 5 x 5 window size is found to be the efficient and effective filtering approach to eliminate the experimental noise at a satisfactory level, so that the joint p.d.f.s of filtered velocity invariants fit closely enough to the noise free p.d.f.s. of DNS data in order to evaluate the topological characteristics of the flow.
3. The clustering of the turbulent zero velocity points is quantified by Radial Distribution Function (Sundaram and Collins 1999) and Voronoi analysis (Monchaux et al., 2010). The RDF measurements of the clustering of the turbulent velocity saddle points are not affected much by the median filtering applied, while the median filter de-noising process results in noticeable difference in the normalized Voronoi cell area p.d.f.s. The statistics of Voronoi analysis depend on two dimensional space tessellation of non-rigid Voronoi cells, while the statistics of RDF are based on pseudo rings and circles that divide the space and result in lower sensitivity to the applied filtering process.

References

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