PAIR DISPERSION STATISTICS AND COHERENT STRUCTURES

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Abstract Pair dispersion is studied to model scalar transport in many natural and industrial applications. The link between the particle pair dispersion and coherent flow structures is explored in this work. This was done by kinematically simulating tracer particles in an ideal flow structure [4] extracted from an isotropic turbulent flow. It was found that the variation of the mean and the mean square separation lengths with time were qualitative similar to the results in actual turbulent flows. It was also observed that the quantitative results matched till 4-5 Kolmogrov time units. Ideal structure with two vortices and a shear layer was able to emulate the qualitative results. Is the combination of shear layer and one/two vortices is sufficient or necessary to emulate pair dispersion statistics needs to be studied in the future.

INTRODUCTION

The motion of particles in fluid is important in many natural (formation of clouds) and industrial applications (chemical reactions, air pollution) and is modeled by scalar transport. The understanding of two point statistics plays an important role in modeling scalar transport. Eddy diffusion coefficient in scalar transport equations depends upon the relative dispersion between particles [8], which is studied in terms of mean and mean square separation lengths mainly for isotropic turbulent flows. If $l(t)$ is the displacement between two particles given by $\mathbf{r}_2(t) - \mathbf{r}_1(t)$ where $\mathbf{r}_2(t)$ and $\mathbf{r}_1(t)$ are position of particles at time t, then $\langle|\mathbf{l}(t)|\rangle$ represents mean separation length. $\langle\Delta\mathbf{l}\Delta\mathbf{l}\rangle$ represents mean square separation length where $\Delta\mathbf{l}(t) = \mathbf{l}(t) - \mathbf{l}(0)$. The variation of the mean and the mean square separation with time for isotropic turbulence flows at different Reynolds number have been extensively reported in literature [2], [3], [9], [10] and many others. Main subject of discussion [8] in all of these studies has been the association of different regimes in pair dispersion with different length scales in the flow and the calculation of the Batchelor or Richardson's constant for the inertial sub-range regime. However not much has been explored on the relation between pair dispersion statistics and the coherent flow structures. It is suggested in [1] that at around 2-5 Kolmogorov time units particles enter vortices. In our study we explore the link between the structures and pair dispersion. We are of the opinion that understanding the dispersion around ideal flow structures may help in finding the link.

PAIR DISPERSION AROUND IDEAL STRUCTURES

The idealized flow structure considered in the paper is an universal small scale structure [4] extracted from actual isotropic turbulent flow (see fig 1). This structure was considered as it describes the average flow field around a point in the flow when aligned with the local principal straining directions, which appears universal across different turbulent flows [4]. From figure 1a, it can observed that this structure consists of a shear layer and two vortices around the origin $(0, 0, 0)$. Tracer particles were uniformly distributed around the origin of the structure and simulated kinematically. The Taylor Reynolds number of the isotropic turbulent flow in this study was $Re_\lambda = 170$. Two point statistics, i.e relative dispersion, was studied in terms of the mean ($\langle|\mathbf{l}(t)|\rangle$) and the mean square separation length ($\langle\Delta\mathbf{l}\Delta\mathbf{l}\rangle$). One particle was fixed at origin (where velocity $= 0$) hence $\mathbf{l}(t) = \mathbf{r}_2(t)$ as $\mathbf{r}_1(t) = 0$. The mean and mean square separation for different initial separations $|\mathbf{l}(0)|$ are shown in figure 2a and 2b. It was found that the statistics (Fig 2a & 2b) around the ideal structure was qualitative very similar to the statistics of actual isotropic turbulence [10] at $Re_\lambda = 230$. However quantitatively both mean and mean square separation did not match the actual statistics for time scales above 4-5 Kolmogorov time units. This may be because of the definition of mean and mean square separation statistics. We are in progress of considering two moving particles instead of fixing a particle at the origin. Also the ideal structures are extracted at higher Reynolds number [7][6][5] to check the differences in the quantitative values.

It was observed that ideal structure with two vortices and a shear layer extracted from actual turbulence flow emulated the pair dispersion statistics qualitatively. And the question is, if combination of one/two vortices and a shear layer is necessary or sufficient to get the pair dispersion statistics needs to be explored.

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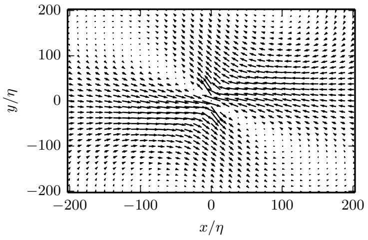
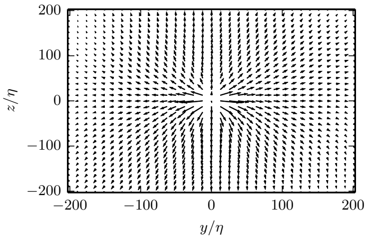
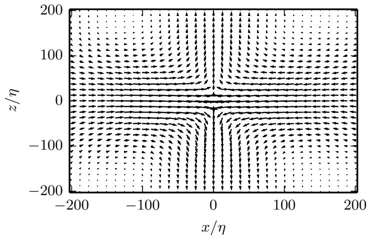


(a) Flow compression and stretching in x and y directions. Two vortices and a shear layer.

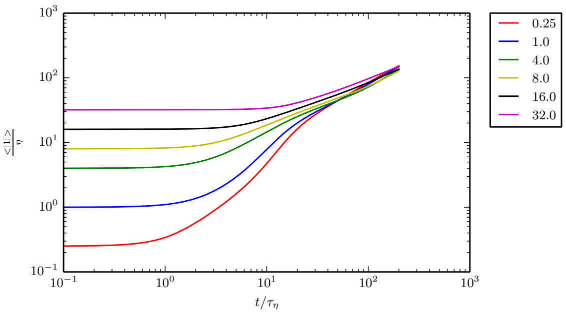


(b) Flow stretching in y direction. Flow pattern represents a node.

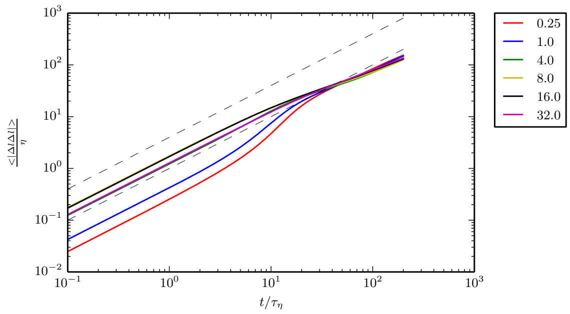


(c) Flow compression in x direction. Flow pattern represents a saddle.

Figure 1. The average perturbation velocity vector plots in three cross planes of the extracted ideal structure [4] from isotropic turbulent flow at $Re_\lambda = 170$.



(a) Growth of mean separation distance. Different color lines indicate the initial separation length scaled with Kolmogorov scale.



(b) Growth of mean square separation distance. Different color lines indicate the initial separation length scaled with Kolmogorov scale.

Figure 2. Pair dispersion statistics around average flow structure [4] extracted from actual isotropic flow at $Re_\lambda = 170$.

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