§34. Development of Direct Numerical Simulation Code for Particles Convected by Turbulence

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Prediction and control of transport of particles, droplets and polymers by NS and MHD turbulence are very important and essential in geophysical context, engineering application and designing of the nuclear fusion reactor. We have developed a new code which tracks the particles and computes their interaction with the surrounding turbulent field. The code consists of two parts, the fluid part and Lagrangian part. For the fluid part the hybrid code was developed by using the spectral method for the incompressible fluid and the combined compact finite difference method for the scalar field [1]. For the Lagrangian part it was used the TS13 scheme for the second order interpolation of the Eulerian field at the particle position and the PIC to feedback the particle attributes to the continuum field.

We have compared the full spectral code which uses the spectral method for all the Eulerian field with the hybrid code at different grid resolution N^3. It was found that when $N^3 = 128^3$ the hybrid method was slower than the spectral code, but when $N^3 = 512^3$ it became faster than the full spectral code by about 30% while keeping the same spatial accuracy as the spectral code.

We have applied the hybrid code to the problem of small water droplets dispersion in the NS turbulence of air flow. It is well known that when the Stokes number $St = \tau_p/\tau_K$ of the droplet is small, where τ_p is the characteristic time of the droplet and τ_K is the Kolmogorov time, the droplet well follows the fluid particle, while for large Stokes number it tends to be behind the fluid particle. Figure 1 shows the droplet distribution within a thin layer of the flow field for $St = 0.01$ and 6 at $R_\lambda = 138$ for decaying turbulence. It can clearly be seen that when the Stokes number is small the droplets distribute quite uniformly over the entire domain while they distribute inhomogeneously and there exist void regions when $St = 6$.

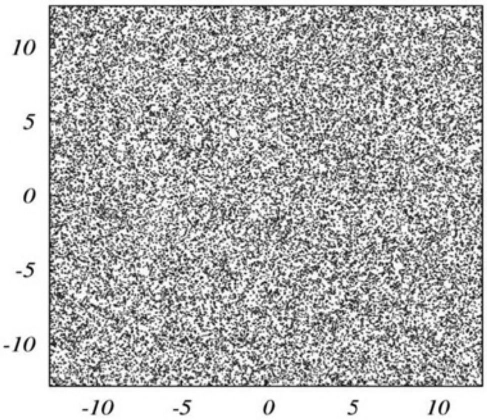
When the Stokes number is small, the particle number density $n(\boldsymbol{x}, t)$ obeys the equation

$$Dn/Dt \equiv \partial n/\partial t + \boldsymbol{V} \cdot \nabla n = -n\nabla \cdot \boldsymbol{V},$$

where $\boldsymbol{V}$ is the particle velocity. This equations means that the rate of increase in n in the Lagrangian frame moving with the velocity $\boldsymbol{V}$ is determined by $Q \equiv \nabla \cdot \boldsymbol{V}$. For positive Q, for example, the number density decreases. When the Stokes number is small, Q is approximately related to the Laplacian of the pressure of the fluid as $Q = (\tau_p/\rho_0)\nabla^2 p$. The change of n depends on how long Q keeps its coherency in the Lagrangian frame. The coherency may be measured by the Lagrangian autocorrelation function

$$\phi(t-s) = \left\langle Q^L(t)Q^L(s)\right\rangle \Big/ \left\langle Q^L(s)Q^L(s)\right\rangle.$$

Figure 2 shows $\phi(t-s)$ of the water droplet with radii $10, 50, 100\mu$m against the time difference normalized by the Kolomogorov time. The Stokes number is 0.06, 1.5, and 6.0 for each case, respectively. It is found that although the characteristic time of the autocorrelation is the Kolmogorov time the larger droplets tend to decorrelate faster, suggesting the fact that the larger droplet's trajectory tend to be less affected by the strong vorticity and/or strain.



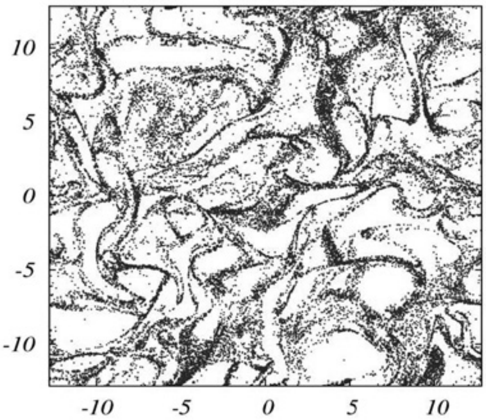


Fig. 1: Distribution of water droplets at $St = 0.06$ (top) and $St = 6$ (bottom). $R_\lambda = 138$.

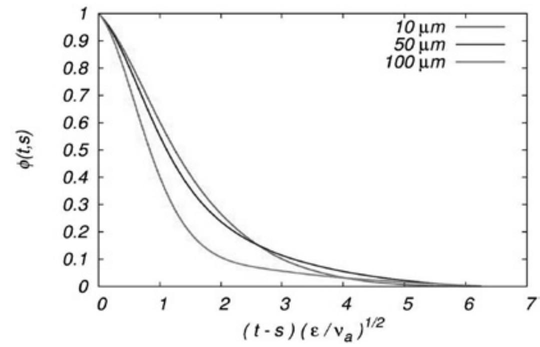


Fig. 2: Lagrangian autocorrelation $Q = \nabla \cdot \boldsymbol{V}$ of the micro water droplets in the air for various St. $R_\lambda = 138$.

1) Gotoh, T. Hatanaka, S., and Miura, H. J. Comp. Phys. (2012) **231**, 7398–7414.