# VπLES- Vortex Particle Intensified Large Eddy Simulation

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**ABSTRACT**

We propose the method to directly resolve the subgrid motion [1]. The method is based on the combination of grid based and grid free Lagrangian Vortex Particle (VPM) methods. Use of the decomposition of the velocity and vorticity fields into the large scale and small scale components $\mathbf{u} = \mathbf{u}^g + \mathbf{u}^v$ and $\omega = \omega^g + \omega^v$, and their substitution into the Navier Stokes equation results in two coupled transport equations:

$$\frac{\partial \mathbf{u}^g}{\partial t} + (\mathbf{u}^g \cdot \nabla)\mathbf{u}^g = -\nabla P^g + \nu\Delta\mathbf{u}^g + \underline{\widetilde{\mathbf{u}^v \times \omega^g}} \quad (1)$$

$$\frac{\partial \omega^v}{\partial t} + ((\mathbf{u}^v + \underline{\mathbf{u}^g}) \cdot \nabla)\omega^v = (\omega^v \cdot \nabla)(\mathbf{u}^v + \underline{\mathbf{u}^g}) + \nu\Delta\omega^v + \nabla \times \underline{[\mathbf{u}^v \times \omega^g - \widetilde{\mathbf{u}^v \times \omega^g}]}, \quad (2)$$

where $\widetilde{\mathbf{u}^v \times \omega^g}$ is the spatially filtered vector. The underlined terms take the coupling between two components into account. The first equation is solved on the grid using the finite volume method whereas the VPM method is utilized for the second one. The separation into $\mathbf{u}^g$ and $\mathbf{u}^v$ components is performed at each time instant using the LES filtration procedure. First, the pulsation field is calculated $\mathbf{u}' = \mathbf{u}^g - \widetilde{\mathbf{u}}^g$ which is approximated by a set of $M$ axisymmetric vortex particles which induce the velocity $\mathbf{u}^v$. The velocity $\mathbf{u}^v$ is then subtracted from $\mathbf{u}^g$. The particles move in the Lagrangian way and change their strengths $\alpha = \omega^v \sigma^3$ according to Eq. (2) as well as their size $\sigma$. The resolution of the $\mathbf{u}^g$ field is equal to the grid size $\Delta$ whereas the $\mathbf{u}^v$ field has sizes ranging from zero to $\Delta$. When the vortex particles become larger $\sigma \sim \Delta$ they are mapped back to the grid $\mathbf{u}^v \to \mathbf{u}^g$. The a-priori analysis of the turbulent fields [2] shows that $\mathbf{u}'$ field possesses the following properties: $\mathbf{u}' \ll \mathbf{u}^g$ and correlation length of $\mathbf{u}'$ is proportional to $\Delta$. This allows one to use only the first neighboring cell layer for $\mathbf{u}^v$ computations using direct Bio-Savart method. Moreover, the assumption $\mathbf{u}^v \approx 0$ in Eq. (2) is proved to be relevant, at least for the cases studied so far. Through selection of the most energetic particles, the total number of particles at each cell is restricted. These simplifications result in a very fast algorithm applicable for big unstructured grids. The method was implemented into OpenFoam.

A thorough validation of the method for 2D problems and some algorithm aspects are described in [1]. Validation and verification studies for the 3D decaying turbulence and the free jet cases are presented in [2] and [3]. Summary of these works is discussed in the final paper. The experience shows that the vortex particles serve just as triggers of turbulence. Hence the name of the method is Vortex Particle Intensified LES or VπLES. VπLES goes into DNS when $\Delta \to 0$ and is automatically switched off at $Re \to 0$.

**REFERENCES**

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