Vortex particle intensified Large Eddy Simulation - VπLES

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ABSTRACT

This paper presents a novel Large Eddy Simulation approach with a direct resolution of the subgrid motion of fine concentrated vortices. The method, proposed first by [1], is based on combination of a grid based and the grid free computational vortex particle (VPM) methods. The large scale flow structures are simulated on the grid whereas the concentrated structures are modeled using VPM. Due to this combination the advantages of both methods are strengthened whereas the disadvantages are diminished. The procedure of the separation of small concentrated vortices from the large scale ones is based on LES filtering idea. Due to the flow instability, which is an inherent property of turbulent flows, small scales are generated inside the velocity field represented on the grid. Small vortices can experience stretching and reduce their size. As soon as a typical size of any fine vortex structure becomes comparable with the grid size or less than it the structure disappears due to artificial or numerical viscosity. The purpose of the new method is to protect such vortices from the artificial viscosity damping inherent to grid based techniques. For that, the vortices are detected in small scale velocity field and converted to vortex particles which keep their identity and are transported according to viscous flow equations written for vorticity- velocity variables. Use of decomposition of the velocity and vorticity fields into the grid based and grid free components $\mathbf{u} = \mathbf{u^g} + \mathbf{u^v}$ and $\boldsymbol{\omega} = \boldsymbol{\omega}^g + \boldsymbol{\omega}^v$ and their substitution into the Navier Stokes equation results in two coupled transport equation (eq.(1) & (2)). The flow dynamics is governed by these two coupled transport equations taking two-way interaction between large and fine structures into account.

$$\frac{\partial \mathbf{u}^g}{\partial t} + (\mathbf{u}^g \cdot \nabla)\mathbf{u}^g = -\frac{1}{\rho}\nabla p^g + \nu\Delta\mathbf{u}^g + \overline{\mathbf{u}^v \times \boldsymbol{\omega}^g} \tag{1}$$

$$\frac{\partial \boldsymbol{\omega}^v}{\partial t} + ((\mathbf{u}^v + \mathbf{u}^g)\cdot\nabla)\boldsymbol{\omega}^v = (\boldsymbol{\omega}^v \cdot \nabla)(\mathbf{u}^v + \mathbf{u}^g) + \nu\Delta\boldsymbol{\omega}^v + \nabla \times [\mathbf{u}^v \times \boldsymbol{\omega}^g - \overline{\mathbf{u}^v \times \boldsymbol{\omega}^g}] \tag{2}$$

Validation and verification was performed for a well tried benchmark test of the decaying homogeneous isotropic turbulence and free turbulent jet flow. Results revealed that the effect of the term $\overline{\mathbf{u}^v \times \boldsymbol{\omega}^g}$ in eq(1) is similar to that of a LES subgrid model and behaves as an energy drain transferring the energy of the grid based motion in to the fine scale energy . This additional term is automatically switched off when the resolution increases and the present method is consistent and converges to the Direct Numerical Simulation [2]. The energy back scattering and anisotropy of small scale motions are observed using this method. High accuracy result at the resolution much less than the pure grid technique is also achieved.

REFERENCES

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