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MIXED MODEL FOR HEAVY PARTICLES IN LARGE EDDY SIMULATION OF TURBULENT FLOW

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Turbulent flows with small particles are of great interest for both physicists and engineers. Dispersed phase is involved into a range of physical phenomena like clustering, aggregation, deposition at the walls and fractal patterns of preferential concentration, being vital for industrial applications, e.g. dynamics of droplets in combustion chamber. Since experiments are costly and usually limited to simple geometries, there is a need for a physics-capturing model that would simulate behaviour of the dispersed phase. In the present contribution, we propose a mixed subgrid-scale (SGS) model for dispersed phase in two-phase Eulerian-Lagrangian Large Eddy Simulation (LES); moreover, the cross-corelation of SGS velocity components is accounted for.

The carrier phase is described by the Navier-Stokes equations for incompressible fluid. Point, heavy particles (drag only) move in the flow according to equations:

$$\frac{d\boldsymbol{x}_p}{dt} = \boldsymbol{V}_p; \quad \frac{d\boldsymbol{V}_p}{dt} = f_D\frac{\boldsymbol{U}_f - \boldsymbol{V}_p}{\tau_p}$$

where τ_p is the particle momentum relaxation time and f_D is a semi-empirical drag correction factor. We assume the one-way momentum coupling.

For small particles ($St = 1, 5, 25;\ St = \tau_p/\tau_f$) non-resolved scales of fluid velocity have an impact on deposition velocity, fluctuation of particle velocity and preferential concentration profiles, which, if neglected, leads to unphysical behaviour. So, the effect of SGS velocity fluctuations should be considered. The fluid velocity is decomposed in the resolved part and the SGS component $\boldsymbol{U}_f = \overline{\boldsymbol{U}_f} + \boldsymbol{u}^{SGS}$. Here, $\overline{\boldsymbol{U}_f}$ is the fluid velocity obtained in LES computations with unknown filter shape. The drawback is that the resolved and subfilter flow scales are usually correlated, $Cov(\bar{u}_i, u_i^{SGS}) \neq 0$, and we cannot separate scales of the flow. A partial solution to that problem is offered by the Approximate Deconvolution Method (ADM) which provides an estimation of exact fluid velocity $\boldsymbol{U}_f$. Performed on a coarser grid, ADM behaves as a low-pass filter, cutting off velocity fluctuations with higher wavenumbers. Then, assuming separation of scales, we add an SGS stochastic part of the model, independent of larger scales

$$\boldsymbol{U}_f = \widetilde{\boldsymbol{U}_f} + \boldsymbol{u}^*$$

where $\widetilde{\boldsymbol{U}_f} = g^{-1} * \overline{\boldsymbol{U}_f}$ and g^{-1} is an approximate inverse of the filtering operator.

To model the effect of SGS flow velocity on particles, we use the Langevin equation:

$$d\boldsymbol{u}^* = -\frac{\boldsymbol{u}^*}{\tau_l}dt + \boldsymbol{\sigma}\cdot d\boldsymbol{W}_t,$$

where $d\boldsymbol{W}_t$ is a vector of independent increments of the Wiener process, and the correlation matrix $\boldsymbol{\sigma}$ (based on SGS velocity components) is defined as: $\sigma_{ii} = \sqrt{2Var(u_i^*)/\tau_l}$ (no sum over i), $\sigma_{ik} = \sqrt{2(Var(u_i^*)Var(u_k^*) - Cov(u_i^*, u_k^*)^2)/(\tau_l Var(u_k^*))}$; τ_l is SGS time scale.

The channel geometry is used to test the model. The Reynolds number based on friction velocity equals $Re_\tau = 150$. Numerical code used (courtesy of prof. J.G.M. Kuerten) is spectral in periodic flow directions and Chebyshev in the wall-normal direction. Fluid velocity at particle position is interpolated with 2nd order Hermite-Lagrange scheme.

Following the literature and our earlier results, in channel flow, the correlation between streamwise and wall-normal velocity is the order of magnitude greater than the two remaining. On this basis we assume $\sigma_{ik} = 0$ for other combinations of directions. Elements of $\boldsymbol{\sigma}$ are computed at every time step with the dynamic procedure, analogous to the Yoshizawa estimation of kinetic energy in non-resolved scales. Results are compared to a priori LES predictions (cf. Fig.1 for the covariance of streamwise and wall-normal SGS velocity components) and then the model is evaluated and compared to DNS results.

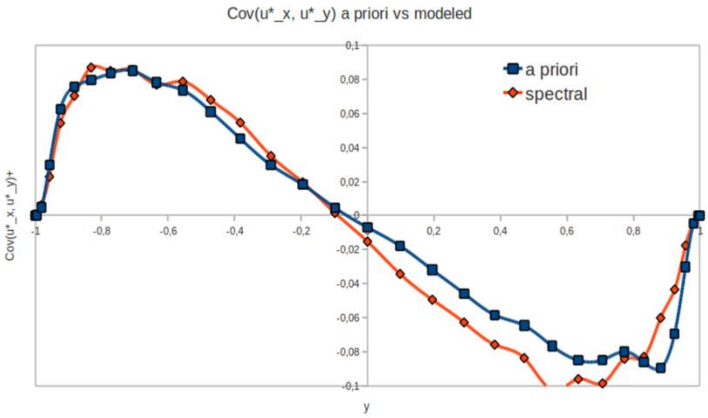

Fig.1 Large-eddy simulation of turbulent channel flow: the SGS fluid velocity covariance estimated *a priori* (from the DNS) and computed with the dynamic procedure.

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