A Dynamic Subgrid-scale Model with a Global Model Coefficient

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ABSTRACT

The well-known drawback of the Smagorinsky model [1] is that the model coefficient should be predetermined as a constant in space and time. The key of dynamic Smagorinsky model (DSM; Germano et al. [2]) is to determine the model coefficient dynamically using the Germano identity based on the concept of the scale-invariance. The dynamic model coefficient is, in principle, local in space and time and vanishes where the flow is locally laminar or fully resolved. However, it turned out that negative Smagorinsky constants often cause numerical instability because the duration of negative eddy viscosity is quite long (Ghosal et al. [3]) unlike real backscatter which is highly stochastic (Langford & Moser [4]). Therefore, DSM actually requires averaging over homogeneous direction(s) and/or ad hoc clipping to avoid numerical instability. This fact hinders the application of DSM to complex flows in which there is no homogeneous direction. A few methodologies have been proposed in the framework of DSM to overcome this problem. The representative ones are the dynamic localization model (Ghosal et al. [3]) and the Lagrangian dynamic model (Meneveau et al. [5]). Although their performances have been proven by successful LES of complex flows, additional efforts for the implementation of these models are non-trivial overheads.

A recently proposed eddy-viscosity model by Vreman [6] has an inherent property that the SGS eddy viscosity vanishes for flows in which the SGS dissipation is expected to be zero theoretically. He showed that the model with a fixed coefficient predicts accurate statistics for turbulent channel flow without introducing any wall-damping function. However, it is unclear whether the model constant used is universal for all turbulent flows and filter sizes.

Therefore, in this study, we propose a dynamic subgrid-scale model for large eddy simulation of turbulent flows in complex geometry, based on the eddy viscosity model by Vreman [6]. A priori tests with the original Vreman model show that it predicts the correct profile of subgrid-scale dissipation in turbulent channel flow but the optimal model coefficient is far from universal. Dynamic procedures of determining the model coefficient are proposed based on the global equilibrium between the subgrid-scale dissipation and viscous dissipation. An important feature of the proposed procedures is that the model coefficient determined is globally constant in space but varies only in time.

Large eddy simulations with the present dynamic model (DVM) are conducted for forced isotropic turbulence, turbulent channel flow and flow over a sphere, showing excellent agreements with previous results.

Figure 1 shows the instantaneous flow fields in the near wake from LES at $Re_d = 10^4$ and the experiment at $Re_d = 1.5\times10^4$. As expected from the characteristics of sub-critical flow, the starting location of shear layer transition is determined by the SGS model adopted. With the Smagorinsky model with a constant coefficient (SM) (Fig. 1(b)), the transition is delayed far downstream and no vortex ring is observed, which is obviously due to large eddy viscosity in

the shear layer that annihilates the Kelvin-Helmholtz instability. On the other hand, LES with DSM and DVM (Figs. 1(c) and (d)) show the formation of vortex ring as in the experiment (Fig. 1(a)). Overall, the result obtained from DVM is quite similar to that from DSM, and they are qualitatively very similar to that from experiment.

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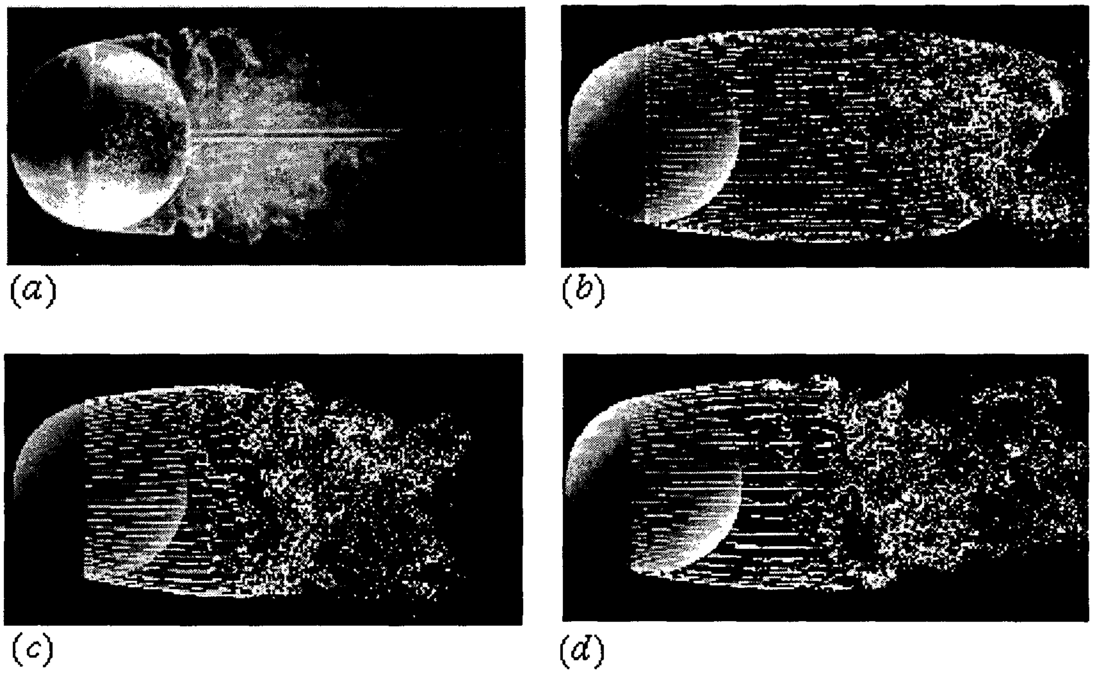

FIG. 1 Instantaneous flow fields in the near-wake region of flow past a sphere from (a) experiment (Werle [7]) and LES with (b) SM (Cs=0.17), (c) DSM and (d) DVM.