LARGE-EDDY SIMULATION OF TURBULENT FLOWS ON COMPOSITE MULTI-RESOLUTION GRIDS BY THE LATTICE BOLTZMANN METHOD

Hatem Touil[1], Denis Ricot[2], Jérôme Boudet[3] & Emmanuel Lévêque[1]
[1]*Laboratoire de physique de l'École normale supérieure de Lyon, CNRS, Université de Lyon, France*
[2]*Renault, Technocentre, 1 av. du Golf, F-78280 Guyancourt, France*
[3]*Laboratoire de Mécanique des Fluides et d'Acoustique, Ecole centrale de Lyon, CNRS, Université de Lyon, France*

Abstract In order to properly address the large-eddy simulation (LES) of complex (weakly compressible) turbulent flows, the lattice Boltzmann method, originally designed for simple structured grids, needs to be extended to composite multi-domain/multi-resolution grids. Therefore, specific conditions need to be specified to determine the mapping of statistical information (about the populations of moving particles) at the interface between two domains. These conditions should in particular account for the subgrid-scale turbulent dynamics. Original mapping conditions based on physical arguments are introduced and tested in the simulation of turbulent channel flows at high Reynolds numbers. The comparison with both reference DNS and LES (based on finite-volume discretization) data show the high capability of the Lattice Boltzmann method to handle large-eddy simulation of turbulent flows.

POSITION OF THE PROBLEM

It is characteristic of fluid flows to develop finer and finer dynamical structures, *e.g.* shear layers or elongated vortices, as the Reynolds number increases. Adapting the whole resolution of the simulation to the size of these finest structures implies considerable computational efforts. So in practice, it is desirable to refine the grid only in regions where more resolution is needed, and use a coarser grid in the rest of the domain. This requirement becomes mandatory for the LES of complex turbulent flows, in which grid refinement is generally required in the vicinity of solid boundaries whereas a coarser resolution can be used in the bulk of the flow, on the condition to account for subgrid-scale turbulent dynamics.

The Lattice Boltzmann method considers the fluid at a mesoscale level, which is intermediate between the microscopic and the macroscopic descriptions [1]. The fluid is viewed as populations of particles that collide, redistribute and propagate along the different links of a discrete lattice, so that the desired macroscopic "collective dynamics" is recovered in the continuous limit. The method expresses the evolution of the probability distributions of these populations on the lattice, or grid. Originally, it was designed for simple structured grid with a constant spacing in the three directions. However, multi-resolution can be fulfilled by embedding domains with different spatial resolutions (see Fig. 1). In that situation, specific conditions are required to determine the mapping of the probability distributions at the interface between two domains. For the LES of turbulent flows, this mapping becomes essential since it should account for the discontinuity of the rate of strain and encompass effects related to the (unresolved) subgrid-scale turbulent dynamics. The development of such mapping conditions is an open problem that requires to examine the physics of the mesoscopic description of fluid dynamics.

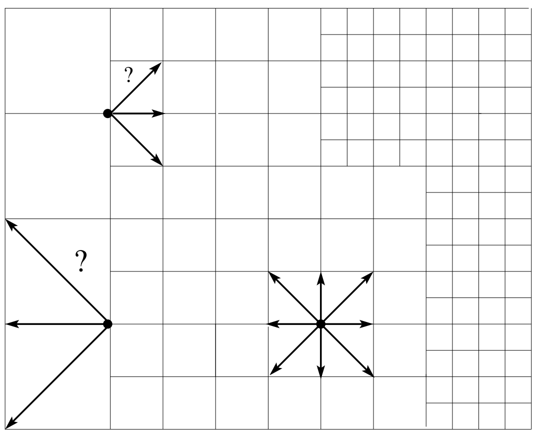

Figure 1. Sketch of a composite multi-domain/multi-resolution grid. Inside each domain, particles can move towards neighboring nodes according to a discrete set of velocities. However, some specific conditions are required to suitably transmit the statistics of moving particles at the interface between two domains with different resolutions.

APPROACH AND RESULTS

In brief, we argue that the mapping conditions can express quite simply in terms of the probability distributions of the underlying discrete-velocity Boltzmann equation. Namely, the continuity of the mass density and fluid momentum is realized by imposing the continuity of the equilibrium part of these distributions at the interface, whereas the discontinuity of the rate-of-strain tensor is ensured by applying a "spatial transformation" to the collision term of the discrete-velocity Boltzmann equation. This latter condition allows us to explicitly account for the subgrid-scale modeling in the treatment of resolution changes.

Test computations of a turbulent plane-channel flow have been considered. The Lattice Boltzmann scheme is based on the standard D3Q19 lattice in a cell-vertex representation and relies on the BGK approximation for the collision term. A shear-improved Smagorinsky viscosity [2] is used for the subgrid-scale modeling.

In a large-eddy simulation at $\mathrm{Re}_\tau = 395$ (with three levels of resolution) the results compare very well with high-resolution DNS data [3] (Fig. 2). The accuracy is improved in comparison with a large-eddy simulation based on finite-volume discretization with the same subgrid-scale viscosity model and comparable grid resolution [4] (Fig. 2).

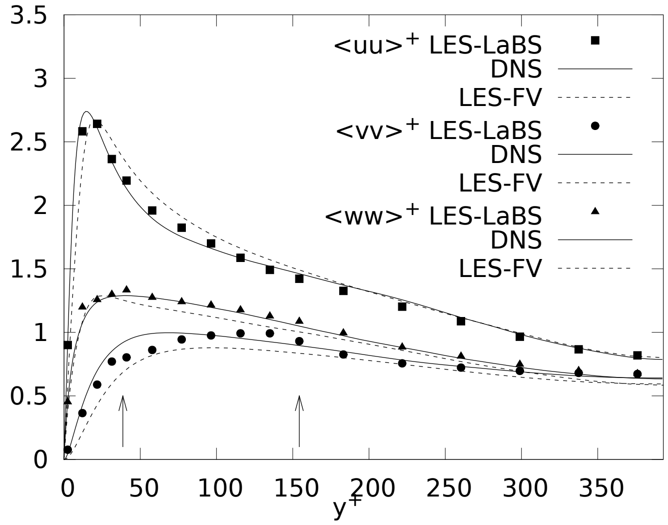

Figure 2. Turbulent channel flow simulation at $Re_\tau = 395$. Mean-squared velocity fluctuations as a function of the distance from the wall (in wall units). Our results (LES-LaBS) compare very well with high-resolution pseudo-spectral data (DNS) and results obtained from a LES based on finite-volume discretization with the same subgrid-scale viscosity (LES-FV). The arrows indicate the changes of resolution.

During this ETC14 conference, we would like to present a poster that introduces the physical content of our modeling and discusses the results of our test simulations.

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