337e Turbulent Internal Flow Simulation Via the Lattice Boltzmann Method

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The internal incompressible flows are important in a variety of engineering applications including gas turbine combustors, microcircuit cooling, thrust vectoring nozzles, and ventilation system. Mixing of three dimensional bounded jets with adjacent jets or with their surroundings plays a critical role in the effectiveness of the injected flow in these applications. To examine the physics of these devices, we are developing the lattice Boltzmann Bhatnagar-Gross-Krook (LBGK) methodology which can accurately simulate the turbulent flow.

The lattice Boltzmann method (LBM) is a versatile numerical tool for simulating fluid flows containing complex physical phenomena. Although LBM is a young methodology, it is already playing a dominant role in computational fluid dynamics (CFD) community. Unlike the conventional numerical methods, LBM is based on mesoscopic kinetic equations, i.e., by constructing simple kinetic models, the essential physics of microscopic processes is incorporated and the averaged properties obey the desired macroscopic behaviors. LBM provides numerous advantages, including clear physical pictures, an inherently transient nature, and novel treatment of multiphase physics & turbulence. LBM provides fully parallel algorithms because physically observable quantities can be written in terms of simple sums that, at most, depend on the nearest neighbor information. Furthermore, LBM has less numerical diffusion/dissipation than conventional CFD methodologies due to the linear advection.

To incorporate the effect of turbulence in LBM, we adopted the standard large eddy simulation (LES) model which models the small eddies instead of modeling all eddies. Among the subgrid models, Smagorinsky model is used to model the subgrid stress. To combine the Smagorinsky model with the LBM, we adopted a simple approach to extend the LBM to include small scale for high Reynolds number (Re) flows. To apply the subgrid scale idea in the framework of the LBM, a filtered particle distribution is introduced which satisfies the modified lattice Boltzmann (LB) equation. For the collision term, we introduce the closure techniques and assumed that the filtered particle distribution approaches a local filtered equilibrium distribution, which can be chosen to depend exclusively on local filtered mean quantities. It is further assumed that the subgrid introduces an eddy viscosity only locally and allows the value of the relaxation time to be adjusted locally so that the total viscosity is equal to the sum of the molecular and the eddy viscosities. In filtered Navier-Stokes equations which can be obtained via the Chapman-Enskog expansion, the total viscosity is related to the space-dependent relaxation time with the same functional form obtained from the original LBM. The eddy viscosity is obtained using the Smagorinsky model and the local strain-rate tensor used in the model was calculated via a finite difference scheme.

We have verified our formulation using several benchmark flow problems, including drag-induced rotating flow (DIRF) as well as Poiseuille and Couette flows. Our preliminary results show excellent agreement with our previous numerical results obtained using a commercial CFD software, a pressure-implicit vorticity method, and smoothed particle hydrodynamics. We tested our LB code for a broad range of high Res in the DIRF calculations. The comparison of Re=2000 and 10,000 flow simulations showed the role of turbulent eddy viscosity in comparison to the molecular viscosity. We also studied the effects of Smagorinsky constant on the overall flow field as it has a great influence on the high Re flows. Our LB based code will enable the analysis of the physics in various turbulent flows via a systematic verification using the experimental measurement data of mean flow and Reynolds stress.