26th International Conference on Parallel Computational Fluid Dynamics
Parallel CFD2014
T. Kvamsdal (Ed)
May 20-22, 2014, Trondheim, Norway

GPU-ACCELERATED LATTICE BOLTZMANN METHOD FOR DIRECT NUMERICAL SIMULATION OF DECAYING ISOTROPIC TURBULENCE WITH AND WITHOUT ROTATION

HUIDAN (WHITNEY) YU[*a], ROU CHEN[*] AND LUODING ZHU[†]

[*] Department of Mechanical Engineering
[†]Department of Mathematical Sciences
Indiana University-Purdue University Indianapolis (IUPUI)
Indianapolis, IN 46202, USA
[a]e-mail: whyu@iupui.edu

Key words: Lattice Boltzmann method, GPU parallel computing, Decaying isotropic turbulence, Rotational turbulence

Abstract. The lattice Boltzmann method (LBM) [1, 2] has been developed as a reliable alternative to solve fluid dynamics especially for complex flows [3, 4] in the last few decades. One of the most attractive advantages of the LBM is that it fits the GPU architecture thus could gain significant benefits from the computational capability. This is promising for LBM to solve complex flow which is both computationally expensive and memory demanding such as turbulence. We have develop a GPU-LBM code [5] on compute unified device architecture (CUDA) for decaying isotropic turbulence (DIT) in a periodic cube in the presence of rotation. Both shared memory [6] and misaligned read [7] schemes are implemented in the streaming process. The CUDA implementation was on two Intel Xeon E5645 2.40 GHz Quad-Core CPUs and 64 GB memory with a Tesla M2090 GPU card with ECC enabled by default. Our evaluation [5] shows the highest performance of 460 MLUPS using misaligned read and 445 MLUPS using sheared memory scheme. The average performance of the former is around 455 MLUPS, and the latter around 430 MLUPS. The preliminary test of computation speed shows outstanding acceleration of the developed GPU-LBM over the original serial CPU LBM. For the resolutions 128^3 and 256^3 which we use to study turbulence fundamentals, more than 250 times speed-up are achieved, which greatly increases our research efficiency and makes us possible to study 256^3 DIT on our group workstation with fairly short computation duration.

The present study is a part of our continuous effort to investigate the underlying physics of decay exponents and low wave-number spectra in canonical turbulence with and without turbulence to examine the effect of reference rotation on the decay of turbulence [5, 8] through direct numerical simulation of DIT [8, 9]. Through the accelerated GPU-LBM simulation, we numerically study DIT in 256^3 periodic cubes with frame rotation. We systematically study the features of energy decay in both irrotational and rotational turbulence varying Reynolds number Re from 50 to 105 and Rossby number from ∞ to 0.8. Major results are on two. First, rotation slows down the decay of kinetic energy and dissipation rate. Without rotation, the decay of the kinetic energy and dissipation

rate follow $-10/7$ and $-17/7$ scaling respectively whereas in the presence of rotation with relatively small Rossby number (large rotation intensity), the former slows down to -5/7 scaling whereas the latter to -12/7. Second, at the early stage of energy cascade, backscatter of kinetic energy from small scale to large scale is observed. Without rotation, the scaling of backscatter spectrum $E(k) \sim k^n$ depends on the initial spectrum scaling $E(k) \sim k^m$: if $m < 4$, $n = m$ while if $m \geq 4$, $n = 4$. It is found that rotation doesn'tt alter this scaling feature when $Re \leq 100$ and $Ro \geq 0.8$.

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