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A Fully Implicit Finite Volume Lattice Boltzmann Method for Turbulent Flows

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Abstract. Almost all schemes existed in the literature to solve the Lattice Boltzmann Equation like *stream & collide, finite difference, finite element, finite volume* schemes are explicit. However, it is known fact that implicit methods utilizes better stability and faster convergence compared to the explicit methods. In this paper, a method named herein as Implicit Finite Volume Lattice Boltzmann Method (IFVLBM) for incompressible laminar and turbulent flows is proposed and it is applied to some 2D benchmark test cases given in the literature. *Alternating Direction Implicit*, an approximate factorization method is used to solve the obtained algebraic system. The proposed method presents a very good agreement for all the validation cases with the literature data. The proposed method shows good stability characteristics, the CFL number is eased. IFVLBM has about 2 times faster convergence rate compared with Implicit-Explicit Runge Kutta method even though it possesses a computational burden from the solution of algebraic systems of equations.

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Key words: Implicit finite volume, lattice Boltzmann method, turbulent flow.

1 Introduction

There are number of methods to approach an engineering problem that associates with fluid flow. These methods can utilize analytic solutions, empirical formulations, panel methods or computational fluid dynamics (CFD) methods. For the CFD methods, engineers want fast and accurate solutions by solving the discretized governing equations

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of the fluid flows. The CFD methods can be realized by using different types of mathematical solution techniques to solve the Navier Stokes equations and continuity equation which represents the conservation of momentum and mass respectively for isentropic flows. For the last 25 years, scientists and engineers are developing and improving an alternative CFD method that is used to solve the discrete Lattice Boltzmann Equation (LBE) to obtain the macroscopic quantities of the flow field.

The Lattice Boltzmann Method (LBM) has originated from the Lattice Gas Automata method (LGA) [13]. The original implementation of Lattice Boltzmann method has some drawbacks, however it is a powerful alternative to the Navier Stokes equations. The number of researches and published papers on the LBM is increasing year by year, in the CFD community.

Standard Lattice Boltzmann Method has the idea of dealing with particle distributions over a discrete lattice mesh. The LBM can be considered as a simple molecular dynamics model and fills the gap between the microscopic fluid simulations to macroscopic fluid simulations [28]. By simple stream and collide algorithm, particle distributions are calculated for each time advancement. The macroscopic flow quantities are then calculated by using the particle distributions. Since the equations are solved locally, the LBM has a high potential for parallel implementations and has an advantage over other CFD methods. However, the cell size limitations, which is coming from the need of setting Courant Fredrich Lewy number to 1 (CFL=1), exposes an adverse influence on solution time and computational memory requirements. Its simplicity allows a small amount of coding effort while the computational and memory cost for large scale problems are significant. Moreover, the pressure and velocity solutions are not coupled in Lattice Boltzmann Method, which saves computational time compared to NS methods that requires the solution of Poisson's equation for pressure and velocity coupling.

The standard LBM is limited to regular meshes. When bodies with complex boundaries are in focus, the resolution of the mesh is increased to have accurate solutions and that yields increase in computational time and memory requirements. Some alternative techniques are developed to overcome this significant disadvantage of the LBM. The techniques [15, p. 78] can be listed as follows:

- Grid Refinement and Multi-block Methods
- Interpolation Methods
- Finite Difference Lattice Boltzmann Method (FD-LBM)
- Finite Element Lattice Boltzmann Method (FE-LBM)
- Taylor Series Expansion Least Square Based Lattice Boltzmann Method (TS-LBM)
- Finite Volume Lattice Boltzmann Method (FV-LBM)

The first technique is to increase the grid density where large gradients exist. The information exchange takes place according to the set of rules defined by different algorithms.