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Entropy Generation Analysis around Airfoil using Multi-Block Lattice Boltzmann Method

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Abstract. This present paper proposes aerodynamic forces and entropy generation characteristics on the flow past two-dimensional airfoil at low Reynolds number by multiple-relaxation-time lattice Boltzmann method to clarify the flow loss mechanism. The block mesh refinement was adopted in which a higher accuracy was needed in parts of the domain characterized by complex flow. The interpolated bounce-back method was used to treat the irregular curve. This numerical method can effectively solve the complex flow field simulation problems with reasonable accuracy and reliability by simulating flow around plate and airfoil. Based on second law of thermodynamics, an expression of entropy generation rate for arbitrary control volume was derived theoretically which could accurately quantify the local irreversible loss of the flow field at any position. After that, a comprehensive numerical study was conducted to analyze relationship of entropy generation and drag force by taking NACA0012 airfoil as the research object. For unsteady condition, entropy generation rate and the drag force are not linearly related any more. Losses due to steady effects mainly consider the irreversibility in the boundary layer and wake while the unsteady effects come from the interaction between the main separation vortex and the trailing shedding vortex.

AMS subject classifications: 76-10, 76D17, 80M22

Key words: Loss mechanism, entropy generation, flow past airfoil, lattice Boltzmann method, multiple-relaxation-time, block mesh refinement.

1 Introduction

Recently, entropy generation analysis which provides complementary information on the quality of energy along with the quantity becomes more superior to traditional energy

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analysis especially in different types fluid flow related problem. According to the second law of thermodynamics, entropy is the property that performs the function of disorder within a system [1]. Viscous dissipation and heat transfer are the exclusively sources of entropy generation in any thermal system. In order to evaluate the energy loss in a fluid flow process, it is important to focus on the causes of entropy generation within the fluid volume. Moore and Moore [2] presented a methodology for calculating entropy generation in viscous flows. Furthermore, Kock and Herwig [3, 4] investigated entropy generation terms in a high-Reynolds number turbulent shear flow and its significance in CFD. Mahmud and Fraser [5] analyzed the mechanism of entropy generation through fluid flows in basic channel configurations and derived analytically general expressions for the number of entropy generation. Li et al. [6] analyzed the flow loss mechanism of a linear compressor cascade at the corner stall condition by entropy generation theory. Bahrami et al. [7], Eiyad Abu-Nada [8] and Haddad et al. [9] investigated entropy generation characteristic within steady flow over a backward facing step (BFS) and a parabolic cylinder. Mortazavi et al. [10] introduced entropy generation theory into aerodynamic optimization design, which is concluded that entropy generation theory has certain engineering application prospects. From the aerodynamic and efficiency perspectives, the information enables the designer to detect the key areas that require a modification in order to obtain an optimized design.

The flow over airfoil at low Reynolds numbers involves highly nonlinear and complicated viscous phenomena. Several researchers have studied the performance and flow structures around airfoils to look deeper into the mechanics of unsteadiness and separation by numerical and experimental methods. Mueller and Batill [11] used smoke visualization method and experimentally investigated the separation on airfoil. Lin et al. [12] and Almutairi et al. [13] numerically studied the unsteady boundary layer separation from airfoil at low Reynolds number. Lee et al. [14] classified airfoils according to the type of pattern shown by its corresponding lift coefficient curve. Different from the classical numerical methods of continuum mechanics, the lattice Boltzmann method is a numerical method on the basis of microscopic model and molecular dynamics. In the application of the standard LBM, another limitation to the numerical efficiency is that it is constrained by a special uniform lattice. To overcome this limitation, a block mesh refinement (BMR) strategy [15, 16] was adopted. In this method, the computational domain is divided into a number of grid blocks such that within each block, uniform lattice spacing can be used. For the grid block near a solid body, the lattice spacing is small, while near the outer boundary, the lattice spacing could be large. Mass and momentum continuities are achieved by maintaining the consistency between the equilibrium distribution functions of the finer and coarse grids, while the non-equilibrium part is scaled for the continuity of the stress tensor.

From the above analysis, an objective of the current work of the present work aims to develop an efficient numerical model for low Reynolds numbers using the lattice Boltzmann method. In order to validate the accuracy of this method, flows past plate and airfoil are simulated firstly. The second objective is to present a critical analysis of the