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ScienceDirect

Energy Procedia 139 (2017) 481–486

Energy Procedia

www.elsevier.com/locate/procedia

International Conference On Materials And Energy 2015, ICOME 15, 19-22 May 2015, Tetouan, Morocco, and the International Conference On Materials And Energy 2016, ICOME 16, 17-20 May 2016, La Rochelle, France

A new approach using lattice Boltzmann method to simulate fluid structure interaction

M. BENAMOUR[a,b]*, E. LIBERGE[a], C. BEGHEIN[a]

[a]*LaSIE, La Rochelle University, Avenue Michel Crépeau, 17000 La Rochelle, FRANCE*
[b]*LINEACT, CESI Brest,* 2 avenue de Provence*, 29200* Brest, FRANCE

Abstract

A numerical approach based on the Lattice Boltzmann method (LBM) and volume penalization technique is proposed to tackle the problem of the interaction of a moving rigid cylinder with an incompressible fluid flow. The present methodology was applied to an oscillating rigid cylinder in a fluid flow. Two cases were considered: flow around a cylinder undergoing forced harmonic oscillations, and flow around a cylinder in free oscillations due to the fluid forces at Reynolds number 20. Our results were validated and compared with those obtained from Code_Saturne. To compare the results of the LBM and Code_Saturne, and to ensure that the resolution of the structure would be the same in both simulations, we used the Shiels et al. [12] structure adimensionalisation. The simulations of LBM were implemented for two level refined grid around the cylinder, where the grid refinement technique proposed by Lagrava et al. [11] based on multi-domain approach was chosen. The flow characteristics, the oscillation frequency, the lift and drag coefficients values associated were investigated. A good agreement was found between the compared results.

Peer-review under responsibility of the scientific committee of ICOME 2015 and ICOME 2016.

Keywords: Lattice Boltzmann method, Volume Penalization technique, Fluid Structure Interaction, CFD.

* Corresponding author. Tel.: +3-322-900-6065; fax: +3-329-800-3902.
E-mail address: mbenamour@cesi.fr

1876-6102
Peer-review under responsibility of the scientific committee of ICOME 2015 and ICOME 2016
10.1016/j.egypro.2017.11.241

1. Introduction

The fluid structure interaction (FSI) problems have a lot of important applications in many different branches of engineering such as, aerodynamics, hydrodynamics, sedimentation, turbulence, biomechanics, etc. The moving fluid structure interface is a critical problem. Various techniques have been developed in the past to model bodies moving in fluids, using the lattice Boltzmann method. In the work of Ladd [1], the non-slip boundary condition is implemented by the bounce-back rule to simulate solid-fluid suspensions. This technique requires the use of a large number of solid nodes in order to represent correctly the physical boundaries of the solid structure. Based on the work of Ladd, many efforts have been made to simulate flows around complex geometries and moving objects. Filippova and Hänel [2] were the first to present a model that treats a curved boundary with lattice Boltzmann method by introducing a fictitious equilibrium distribution function. Noble and Torczynski [3] presented a model to simlate complex moving geometries. A source term that depends on the percentage of the cell saturated with fluid is introduced into the lattice Boltzmann equation, with this term, the conventional lattice Boltzmann equation was recovered for fluid regions and the boundary condition bounce back Zou and He [4] was applied when the lattice node is occupied only by the solid. This method is relatively simple to implement for two-dimensional case, but it is not easy with three-dimensional case.

Nomenclature

f_α	Density distribution function		
f_α^{eq}	Equilibrium distribution function	C_{lmax}	Maximum of the lift coefficient
c_s	Speed of sound	C_d	Drag coefficient
$\boldsymbol{u}$	Fluid velocity	τ	Single relaxation time
F_α	Forcing term	α	Direction
Re	Reynolds number	ρ	Fluid density
k	Stiffness of the spring	ξ	Particle velocity
y_{eq}	Position at equilibrium	ω	Weighting coefficients
f	Oscillation frequency	χ	Mask function
F_y	Lift force	η	Permeability coefficient
C_l	Lift coefficient	Ω_f	Fluid domain
C_{lrms}	Mean square of the lift coefficient	Ω_s	Solid domain

The popular method used for simulate fluid structure interaction is the immersed boundary method (IBM), it was originally introduced by Peskin [5] to model blood flow in the heart. The basic idea is to use a regular Eulerian grid for the flow domain, and a Lagrangian points to represent the moving boundary immersed in the fluid which is not conform to the regular lattice nodes. The interaction between the fluid and the solid boundary is modeled using a Dirac delta function. In parallel with the immersed boundary method, the Lgrange multipliers method has been implemented with the LBM by Shi and Phan-Thien [6] to model flows around moving obstacles. The idea of this method is that the distributed Lagrange multiplier is introduced via a forcing term to enforce the velocity constraints in the solid domain. Recently the Arbitrary Lagrangian-Eulerian (ALE) approach was applied to the Lattice Boltzmann method by Meldi et al. [7]. This method uses a moving grid to describe the flow around obstacle, and an Eulerian fixed grid to resolve the physical domain. The purpose of the present work is to present a new approach that combine the Lattice Boltzmann method and volume penalization technique to treat the problem of the interaction between moving rigid cylinder and an incompressible fluid flow. The paper is structured as follows: after the introduction, section 2 describes the governing equations and the proposed method. We present in section 3 the numerical results of flow around a cylinder undergoing forced harmonic oscillations, and flow around a cylinder in free oscillations due to the fluid forces at Reynolds number 20. Finally, the conclusions are drawn in Section 4.