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Grid Deformation-Multigrid Fictitious Boundary Method for Cylinder Undergoing Vortex-Induced Motions

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ABSTRACT

In this paper, multigrid fictitious boundary method (MFBM) coupled with arbitrary Lagrangian-Eulerian (ALE) and grid deformation techniques (or moving mesh method) is presented to direct numerical simulation of cylinder oscillating transversely to the incoming flow. Both flow-induced and forced oscillations are considered. The flow is computed by a special ALE formulation of Navier-Stokes equations with a multigrid finite element solver. The solid cylinder is allowed to move freely through the computational mesh which is adaptively aligned by a special mesh deformation method (*r*-type moving grid method). The main advantage of this methodology is that they allow the numerical treatment on a fixed structured mesh on a simple shape auxiliary domain, allowing therefore the use of fast solvers. Numerical examples of forced and induced motion of a 2D circular cylinder in a channel viscous flows are presented to illustrate the efficiency of the presented method for numerical solution of cylinder undergoing vortex-induced motions.

KEY WORDS: Multigrid fictitious boundary method; ALE; FEM; Grid deformation method; Vortex-induced motion; Fluid-structure interaction.

INTRODUCTION

Many cylinder structures subjected to wind or water currents may experience vortex-induced vibration (VIV) or vortex-induced motion (VIM), for example, common posts, chimneys, suspended cables for bridges, power transmission lines in air, and pipes, risers, towing cables, mooring lines in water. In some cases, this has to be taken into account in their design as a potential cause of fatigue damage, such as for offshore structures. The problems of vortex-induced motion of marine risers have driven more and more attentions since exploration drilling and production in greater deep water areas around the world are being increasingly performed. One of the challenges is posed by significant current hazard which is the main contribution to the fatigue damage of the marine risers. The most important issue for the fatigue life prediction of the marine risers is to model the lift force and damping on the cylinders as a function of the local fluid velocity and the cylinder own motion. This is a nonlinear interaction that is sensitive to Reynolds number, roughness, velocity, turbulence and interaction between the amplitude and frequency content of the cylinder motion. Experimental work has been unable to capture all of the characteristics of vortex-induced motion. Nominal 2D vortex shedding and consecutive VIV or VIM have been simplified as a wake oscillator. The near wake dynamics was described by a single flow variable modeling the fluctuating nature of the vortex shedding. This variable was assumed to satisfy a van der Pol or Rayleigh equation which models a self-sustained, stable and nearly harmonic oscillation of finite amplitude (Facchinetti, et al, 2004, Shaum A. Johnson, et al, 2004). This elementary wake oscillator was naturally coupled with the motion equation of a one degree-of-freedom elastically supported rigid structure, namely a structure oscillator. Some major features of the near wake vortex shedding and VIV or VIM have been thus qualitatively and quantitatively described, using analytical and numerical methods. Increasing computational resources have made possible the direct numerical simulation of incompressible viscous flows around a fixed, forced or free structure profile. This has provided more detailed flow field analysis to compare with experimental observations and previous simplified method (Blackburn, et al, 1999, Vikhansky, 2003).

In this paper, multigrid fictitious boundary method (MFBM) (Wan, et al, 2006, 2007) coupled with arbitrary Lagrangian-Eulerian (ALE) and grid deformation techniques (Cai, et al, 2004, Huang, et al, 2001) is presented to direct numerical simulation of cylinder oscillating transversely to the incoming flow. Both flow-induced and forced oscillations are considered. The flow is computed by a special ALE formulation of Navier-Stokes equations with a multigrid finite element solver. The interaction between the fluid and the cylinder is taken into account by the MFBM in which an explicit volume based calculation for the forces is integrated. The solid cylinder is allowed to move freely through the computational mesh which is adaptively aligned by a special mesh deformation method (*r*-type moving grid method) such that the accuracy for dealing with the interaction between the fluid and the cylinder is highly improved. The deformed grid is created from an equidistant cartesian mesh in which the topology is preserved and only the grid spacing is changed such that the grid points are concentrated near the surfaces of the solid cylinder. Only the solution of additional linear Poisson problems in every time step is required for generating