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Control of Vortex Shedding Around a Pipe Section Using a Porous Sheath

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Passive control of the flow around a fixed circular cylinder is achieved using a porous layer between the obstacle and the fluid. The various media are easily handled by means of the penalization method. The computational domain is reduced to a close neighbourhood of the body thanks to efficient nonreflective boundary conditions. The porous layer changes the vortex shedding and induces a strong reduction of the vorticity magnitude and of the root mean-square lift coefficient.

INTRODUCTION

In the vicinity of bluff bodies, the shedding of vortices can induce unsteady forces of small amplitude with excitation close to a structural resonant frequency that provoke structural failures (Williamson and Govardhan, 2004). Therefore, the study and the control of vortex shedding have a crucial importance in engineering applications such as the offshore oil industry. In this case, the vortex-induced vibrations (VIV) can affect the risers. As the environmental conditions are a given and cannot be changed, the only way to reduce the VIV is to use an efficient control technique adapted to the riser framework. Several control methods are already proposed to reduce the drag and lift forces, or to regularize the vortex shedding around the 2-dimensional and 3-dimensional circular cylinders (Wong, 1979; Williamson and Govardhan, 2004). Most of them use active control strategies (Gatulli and Ghanem, 2000; Gillies, 1998; Zhijinn, 2003) that are very difficult to implement in riser geometry. In fact, such a geometry needs passive devices which don't need additional energy supply in the system.

Some fruitful research has been already performed in such a case. For example, some authors have added dimples (Bearman and Harvey, 1993) or splitter plates (Kwon and Choi, 1996) to control and regularize the flow around a circular cylinder. In some other cases, the control technique is performed using a secondary small cylinder (Mittal and Raghuvanshi, 2001), or an appropriately distributed electromagnetic field (Posdziech and Grundmann, 2001).

In this paper, passive control is achieved by introducing a porous interface between the solid body and the flow in order to reduce the vorticity production of the boundary layer (Bruneau and Mortazavi, 2001). In fact, the porous medium changes the no-slip boundary condition into a kind of intermediate Fourier boundary condition. Consequently, the whole vortex-shedding mechanism is smoothed, and the flow instabilities, lift and drag forces, and the enstrophy are decreased. Mathematically, it was shown that the change of boundary condition has a significant influence on the boundary layer (Luchini, 1995; Achdou et al., 1998). Thus, we have to solve a problem involving 3 different media: the solid body, the porous interface and the incompressible fluid. This can be very easily handled using the double penalization method. The original penalization method (Angot et al., 1999) is a way to take into account a body immersed in a fluid with 2 permeability coefficients. The method has already been successfully used to simulate transitional and turbulent flows by an array of cylinders (Bruneau et al., 1999; Kevlahan and Ghidaglia, 2001). In the double penalization (Bruneau and Mortazavi, 2001; Carbou, DATE?), 3 values of the permeability coefficient will represent the bluff body, the porous medium and the fluid. The method has been alaready analysed and tested numerically by Bruneau and Mortazavi (2004).

In the present work, we consider a 2-D, unsteady and incompressible flow around a fixed circular cylinder. This cylinder corresponds to a section of a 3-D riser pipe. Such a study, with an appropriate choice of the Reynolds number, can give significant data on the real flow behaviour even if a responding body should be closer to reality. Here we focus on the effect of the proposed control strategy on a given geometry. Numerical simulations are performed for transitional and turbulent flows to better understand the effects of control with respect to the flow regime. In this paper, after a description of the computational method, a parametric study is performed to choose an optimal porous layer with the best control properties. Then we analyse the reduction effects of this control approach on different global flow quantities such as the enstrophy (Z), the lift coefficient root mean square ($CLrms$) and the drag coefficient (Cd). We shall see that the present method induces a drastic reduction of the $CLrms$ and consequently of the VIV. Further, instantaneous pressure, velocity and vorticity fields (with and without control) are plotted to show the effect of control on the flow pattern.

OUTLINE OF METHOD

Let $\Omega = (0, 5) \times (0, 2)$ be the 2-D computational domain around the circular cylinder of diam 0.16 whose center is located at $(1.1, 1)$; we add a porous ring of thickness 0.02 (Fig. 1). This ring can be seen as a sheath around the pipe, and the thickness is chosen so as to have significant results on medium meshes. Previous studies have shown that efficient results can be obtained for a wide range of layer thicknesses (Bruneau and Mortazavi, 2004). To simulate the global flow both in the porous and fluid media, it is necessary to solve simultaneously the Darcy equations in the porous medium and the Navier-Stokes equations in the fluid. This is generally quite difficult to handle. Here, it is easily achieved by the penalization technique that consists of adding a term U/K in the nondimensional incompressible Navier-Stokes equation where K represents the nondimensional permeability coefficient of the medium. This parameter $K = (\rho k \Phi \bar{U})/(\mu D)$ is

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