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Geometrical parameter analysis on stabilizing the flow regime over a circular cylinder using two small rotating controllers

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ABSTRACT

Vortex shedding behind a cylindrical structure decreases its lifetime. Different active and passive methods have been proposed for suppressing the shed vortices. Two small rotating cylinders installing near to the main cylindrical structure can be actively used for this purpose. In the present research work, the impacts of the geometrical parameters on the effectiveness of the two rotating controllers, which were symmetrically installed neighbor to the main circular cylinder, have been numerically studied at a particular laminar flow regime. A finite volume approach has been used to simulate the unsteady flow around cylinders. Numerical computations illustrated that, both the main cylinder and its adjacent rotating controllers might be subjected to oscillatory forces. Also, numerical results showed that if rotating controllers were installed at an appropriate position, oscillatory exerted forces on the system of cylinders might be completely suppressed and flow regime became stable. Besides, the exerted drag forces on the main cylinder and also rotating controllers decreased when rotating controllers were installed at this particular position. Meanwhile, extensive analyses on the details of the flow field have been presented to discuss the mechanism of re-stabilizing the flow regime.

1. Introduction

Many researchers paid their attention on studying the flow over cylindrical structures, because this particular flow field have several industrial and engineering applications. Besides, there are many different flow regimes ranging from both steady and/or oscillatory laminar and/or turbulent flows, which encourage researchers to investigate them. Despite the numerous studies on the subject, it seems that there are many unresolved problem concerning the flow control over these particular structures.

Zdravkovich [42,43], Sumer and Fredsoe [36], and Tropa et al. [37] reviewed many previous researches on the flow over a cylinder to illustrate different flow regimes and their mechanisms of instabilities. In addition to fixed cylinders, rotating cylinders have particular applications. Childs [10] explained many industrial applications of rotating cylinders. Ingham [15] performed a numerical study on the flow characteristics over a rotating circular cylinder. He studied the sensitivity of vortices at different boundary conditions.

Some researchers have studied the interference of two or more adjacent cylinders at different arrangements. Upstream cylinder substantially changes the flow structure over the downstream ones. Yoon et al. [41], Burattini and Agrawal [7], Yang et al. [40] and Zheng et al. [44] are some researchers who studied the flow structure over the system of cylindrical structures.

Morton and Yarusevych [27] experimentally studied the flow over dual step cylinders. They studied the vortex formation in different ratio of length to diameter of cylinder. Drazin [12] and Newman [29] focused on details of stability and instability mechanisms and classified different types of instabilities. Gianneti and Luchini [14] analyzed the perturbations behind the cylinder in separation bubble and far downstream. They studied the instability modes using structural stability analysis. Pralits et al. [34] studied the instability mechanisms for the flow past a rotating cylinder. They used two and three dimensional models and compared their results.

Flow over a long cylinder, i.e. the ratio of the height to diameter of the cylinder is greater than 10, was more studied, because of different inherently instabilities within this particular flow structure. This flow concerns with oscillatory lift and drag forces, which are generated by vortex shedding in the wide range of Reynolds number. Williamson [38] studied different modes of vortex shedding within the wake region behind a circular cylinder at low Reynolds numbers. This region is usually called Karman Vortex Street. Badr et al. [2] also experimentally studied the unsteady laminar flow over a cylinder. They reported a steady periodic vortex shedding structure after enough time intervals. Maurel and

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Nomenclature

A	Amplitude of the drag/lift coefficient
C	Drag/Lift coefficient
d (m)	Controller diameter
d_D	Dimensionless controller diameter
D (m)	Cylinder diameter
f (Hz)	Frequency
F (N)	Force
I	Reduction index
L(m)	Length
p (N/m^2)	Pressure
r (m)	Radial coordinate
r_D	Dimensionless radial coordinate
Re	Reynolds number
t (s)	time
u_∞ (m/s)	Free-stream velocity
$\vec{V}$ (m/s)	Velocity vector

Greek symbols

A	Dimensionless angular velocity
θ (degree)	Angular coordinate
μ (kg/m.s)	Molecular viscosity
ρ (kg/m^3)	Density
ω (rad/s)	Angular velocity
$\vec{\nabla}$	Derivative operator

Subscripts

C	Controller
D	Drag
L	Lift
sys	System

Petitjeans [22] and Brocchini and Trivellato [6] performed a complete investigation on the dynamic of the vortex shedding.

Since instable flow over a cylindrical structure has some hydro-kinetic energy, it induces some lateral vibrations in the cylindrical structure, which may at last destroy it. A complete review on FSI (fluid structure interactions) was performed by Blevins [5], Paidoussis [30,31], and Kaneko et al. [17]. Recently, some devices were invented to capture the hydro-kinetic energy of the shed vortices behind the cylindrical structures. Lee and Bernitsas [19] invented a particular device to control horizontal hydrokinetic energy of water flows. Malla et al. [21] and Dung-An et al. [13] applied new devices for capturing the energy of induced vibrations.

Flow controllers are small objects, which are used to decrease the instabilities in the flow over cylinders in order to increase the life time of the structure. They inject momentum to the wake region for retarding the generation of large separating bubble. Many types of flow controllers such as strips, blades, surfaces, cylinders and etc., have been already investigated. Modi et al. [26] used some objects around the bluff bodies for extending the attached boundary-layer toward the downstream in order to reduce the drag force. Abu-Hijeh [1] showed that a rotating cylinder decreased the separating bubble at the downstream of a 2D backward facing step. He showed that the rotating cylinder even could reattach the shear layer to the backward facing step. Rao et al. [35] studied the vortex shedding behind a circular cylinder at the presence of a wall. They illustrated that rotation of the cylinder could completely suppress the vortex shedding. Wu et al. [39] investigated the flow control by the interaction between a circular cylinder and a flexible plate. They studied the effect of the gap between the cylinder and plate on the rate of flow control.

Maiti and Bhatt [20] presented the results of the flow passed a main square cylinder allocated near a wall at the presence of a rectangular upstream flow controller. They showed that the upstream cylinder reduced both the frequency and the amplitude of oscillatory eddy-shedding on the downstream cylinder. Chen and Chuan [9] experimentally studied the effect of a fix smaller object behind the rectangular cylinder with different geometries. Bergmann et al. [4] numerically studied the flow controllability of a rotating cylinder with a time dependent controller. They found that the drag force could be reduced to 25% when using a harmonic control function. Carini et al. [8] studied the optimal control and stabilization of the cylinder wake at different low Reynolds numbers.

Mittal and Raghuvanshi [24] explained how a rotating cylinder controlled the vortex shedding within the wake region. Dipankar et al. [11] showed that a very smaller circular cylinder behind the main cylinder made the wake region narrow compared to the uncontrolled case. Pralits et al. [33] investigated the instability, sensitivity and different modes of vortex shedding for flow passed a circular cylinder at the presence of a rotating cylinder. Mittal [23] showed that two rotating controllers could significantly decrease the overall drag coefficient and unsteady exerted aerodynamic forces on the main cylinder.

Korkischko and Meneghini [18] investigated the mechanism of moving surface boundary-layer control at the presence of a rotating controller. They showed that rotating controller could reduce the fluctuations of the stream-wise and transversal velocity components within the wake region of the cylinder. Jian Sheng et al. [16] preformed the numerical study on an active control method for flow over a circular cylinder by using two small rotating cylinders. They studied the effects of this particular controlling method on the exerted drag and lift forces on the cylinder as well as the heat transfer effectiveness. Zhu et al. [45] studied the rate of suppression on the vortex-induced vibration at the presence of two rotating controllers, when they rotated unfavorably. They showed that the vortex-induced vibration was not completely suppressed. Muddada and Patnaik [28] experimentally studied the role of two rotating cylinders on the vortex shedding suppression. They examined the influence of rotation rate on the periodic vortex shedding, fluid flow control, and the forces exerted on the cylinder.

Surely, there are many parameters affecting the rate of suppression of the shed vortices within the wake region of the main cylinder. At a particular flow regime with a fixed rotation speed of the rotating controller, and also fixed diameter of the rotating controller, radial and angular position of the rotating controller should affect the rate of vortex shedding suppression. These geometrical parameters have not been already considered in the literature. Therefore, present study concerns with analyzing the impacts of these geometrical parameters on the effectiveness of rotating controllers.

2. Problem description

Many engineering applications of the flow over a cylindrical structure is so that the ratio of the height to diameter of the cylinder is greater than 10. In fact, the cylinder is enough long to neglect the side effects. In these case a two-dimensional model is appropriate for analyzing the details of the flow field.

Fig. 1 shows a schematic description of the present 2D problem. An incompressible laminar flow of a Newtonian fluid passes over the system containing a main cylinder and two small rotating controllers. Two small rotating controllers inject the momentum into the wake region behind the main cylinder. The lower controller rotates counter clock-wise while the upper one rotates clock-wise. Positions of rotating cylinders are defined by dimensionless radial distance, (r_D=r/D), between the centers of the rotating and main cylinders, and also angular distance, θ, which is measured from the