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Complete vortex shedding suppression allocating twin rotating controllers at a suitable position

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ABSTRACT

Vortex shedding decreases the lifetime of a cylinder exposed to a cross flow. Vortex shedding deficiencies may decrease when using rotating controllers near the cylinder. Vortex shedding suppression depends on the flow regime, geometrical and kinematic characteristics of the rotating controller. A numerical simulation based on the finite volume approach has been used to study the impact of the position of the twin rotating controllers on the rate of vortex shedding suppression at a particular laminar flow regime when the angular velocity of the control system is fixed. Obtained results illustrate that there is a most suppressible position for installing the rotating controller. The most suppressible controller position suppresses vortex shedding completely. It decreases the drag coefficient and vanishes the fluctuation of the torque coefficient.

1. Introduction

Unstable two-dimensional flow over a circular cylinder is a popular and basic hydrodynamic problem. It usually concerns with the periodic separating flow behind the cylinder, which is known as vortex shedding (Fox et al., 2011; White, 2010). Vortex shedding may happen behind a cylindrical structure and makes it oscillate transversely. Unstable flow regime exerts oscillatory lift and drag forces on the cylindrical structure. This oscillation may be unfavorable because it decreases the lifetime of the structure or even may damage it. There is no instability at flow regime with low Reynolds number. When the Reynolds number increases, flow inertia increases and viscous effect cannot damp flow instabilities. Thus, instabilities remain in the flow field and exert oscillatory lift and drag forces on the cylindrical structure.

Many studies have been devoted to find the parameters that may cause and/or control this instability. Williamson (1989) studied different modes of vortex shedding within the wake of a circular cylinder. Maurel and Petitjeans (1999) and Brocchini and Trivellato (2006) performed complete reviews on the dynamic of the vortex generation. Blevins (2001), Paidoussis, (1999, 2004), and Kaneko et al. (2008) explained the impact of the vortex shedding on the stability and lifetime of cylindrical structures. Zdravkovich (1997, 2003), Sumer and Fredsoe (2006), and Tropea et al. (2007) reported complete reviews on the experimental and theoretical investigations on the flow over a cylinder. In many industrial applications two or more cylinders are installed near each other. Different arrangements affect the pattern of the vortex shedding. Moshkin and Sompong (2009), Fallah et al. (2011), Nemati et al. (2012), and Dipankar and Gautam (2015) studied the vortex shedding under interaction of two cylinders with different arrangements.

Badr et al. (1989) experimentally studied the characteristic of the flow over a rotating cylinder. Mittal and Kumar (2003) numerically investigated two dimensional flow over a rotating cylinder. They showed that the cylinder rotation affects the vortex shedding. After these studies, Childs (2011) investigated many industrial applications of rotating cylinders.

Vortex shedding makes the cylindrical structure oscillate. If oscillation damages the structure, this instability should be suppressed. The vortex shedding instabilities can be captured for generating the tidal electrical power. Lee and Bernitsas (2011), Malla et al. (2011), and Dung-An et al. (2012) used special devices for capturing the induced energy within the Karman Vortex Street.

Different passive and active methods have been proposed and studied for suppressing the vortex shedding. Rashidi et al. (2016) presented a review on the vortex shedding suppression and wake control methods. Chen et al. (2013) showed that suction flow could suppress the vortex shedding. The presence of another object near the cylinder can suppress the vortex shedding. Chen et al. (2014) performed an experimental study for vortex shedding suppression for a circular cylinder. They used a traveling wave wall for narrowing the wake width and reducing the mean drag coefficient. Bimbato et al. (2013) considered two dimensional unsteady viscous flow over a circular cylinder, which was allocated near a plane. They showed that

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Nomenclature

A	Dimensionless amplitude of the drag/lift coefficient
C	Drag, lift, or torque coefficient
d (m)	Controller diameter
dD	The dimensionless diameter of the controller
D (m)	Cylinder diameter
F (N)	Force
I	Reduction index
M	Torque
p (N/m2)	Pressure
r (m)	Radial coordinate
rD	Dimensionless radial coordinate
Re	Reynolds number
t (s)	time
u∞(m/s)	Free-stream velocity
$\vec{V}$	Velocity vector

Greek symbols

α	Angular dimensionless 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 in space

Subscripts

c	Refers to the controller
D	Refers to drag parameters
L	Refers to lift parameters
M	Refers to torque

the plane movement could decrease vorticity generation behind the cylinder.

The most useful and applicable method is to use small objects near the cylinder as flow controllers. Mittal and Raghuvanshi (2001) used a cylindrical controller in the near wake of the main cylinder at low Reynolds numbers for suppressing the vortex shedding. Dipankar et al. (2006) indicated that a small circular cylinder behind the main cylinder narrowed the Karman Vortex Street. Chen and Chuan (2013) studied the impacts of the presence of a fix flow controller behind a rectangular cylinder with different geometries. Maiti and Bhatt (2014) investigated the flow over a square cylinder, which was allocated near a wall in the presence of a rectangular upstream flow controller. They showed that the aspect ratio and the distance between the controller and the main cylinder changed the wake pattern.

Mittal (2001) showed that rotating controllers could significantly decrease the overall drag coefficient and the unsteady aerodynamic forces on the main cylinder. Pralits et al. (2010) investigated the instability, sensitivity and different modes of vortex shedding for flow passing a circular cylinder in the presence of a rotating cylinder. Jian Sheng et al. (2013) preformed a numerical study on an active control method for flow over a circular cylinder using two small rotating cylinders. They studied the effects of this method on the exerted drag and lift forces on the cylinder. Muddada and Patnaik (2010a) experimentally showed that two rotating cylinders suppressed vortex shedding in a laminar flow over a circular cylinder. Muddada and Patnaik (2010b) also numerically studied the turbulent flow over a circular cylinder in the presence of two rotating cylinders. Two rotating controllers were symmetrically allocated at the fixed positions. They illustrated that rotating controllers injected momentum into the wake of the main cylinder and delayed the boundary layer separation for narrowing the Karman Vortex Street.

The literature shows that the most suppressing rate in vortex shedding may be achieved by using two rotating small cylinders at low Reynolds numbers. There are a few studies that investigate the effects of the geometrical parameters on the rate of suppressing the vortex shedding. All previous studies attempted to report the benefits of the presence of rotating controllers without investigating the impact of the controller position. The present work is devoted to investigate the impact of the controller position at a particular laminar flow regime with a constant rotation speed of the rotating controllers on the rate of the vortex shedding suppression. The main aim of the study is to illustrate if there is a complete suppression of the vortex shedding by installing the controller at the suitable position. Numerical results show that there is.

2. Mathematical modeling and boundary conditions

Incompressible, two-dimensional, and unsteady laminar flow with constant properties over a circular cylinder is investigated through the numerical solution of the Navier-Stokes equations. Two small rotating cylinders inject momentum into the separating flow, which is generated behind the main cylinder. Therefore, upper and lower controllers rotate clockwise and counter-clockwise, respectively. The positions of the rotating cylinders are defined by a dimensionless radial distance, (r_D=r/D), measuring between the centers of the rotating and main cylinders, and also an angular distance, θ, measuring from the wake centerline. Rotating cylinders are symmetrically placed around the wake centerline. Fig. 1 schematically shows the prescribed problem, including geometrical parameters.

Reynolds number (Re) is defined on the basis of the main cylinder diameter and upstream flow characteristics

$$\mathrm{Re} = \frac{\rho u_\infty D}{\mu} \tag{1}$$

where u_∞, ρ, and μ are far field velocity, fluid density, and fluid viscosity, respectively. Controller diameter ratio is the ratio of the controller diameter to the main cylinder diameter

$$d_D = \frac{d}{D} \tag{2}$$

Dimensionless rotation speed characterizes the angular velocity of the rotating controller

$$\alpha = \frac{\omega D}{2u_\infty} \tag{3}$$

where ω is the angular velocity of the rotating controller.

In the absence of gravity or any volumetric force, continuity and momentum equations are the governing equations for this flow field.

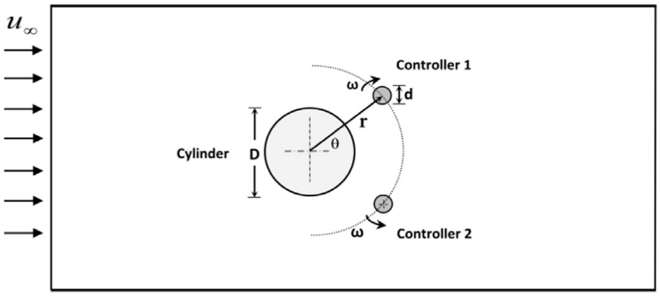

Fig. 1. Schematic of the flow over a 2D circular cylinder at the presence of two rotating cylinders.