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Characteristics of aerodynamic forces exerted on a twisted cylinder at a low Reynolds number of 100

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ABSTRACT

Laminar flow over a twisted cylinder is numerically simulated at a Reynolds number of 100. The flow past a smooth cylinder is calculated for comparison. Jung and Yoon (J. Fluid Mech., 759, 2014) showed the considerable suppression of force coefficients at the subcritical Reynolds number of 3000. The present results verify that the twisted shape of the cylinder can be used to reduce the force coefficients at a low Reynolds number containing the laminar flow. This suppression of the force coefficients is supported by a longer vortex formation length produced by the twisted cylinder. We investigated the characteristics of the local force coefficients for a twisted cylinder. The simple periodic oscillation of the time histories of total and local lift coefficients for the twisted cylinder exhibits the same pattern as that of a smooth cylinder. However, the time history of drag for the twisted cylinder reveals the presence of multi-frequency oscillations, resulting in harmonic behavior of the power spectra. This is confirmed by a time sequence of the instantaneous flow fields during the half-period of the time histories of force coefficients. The nature of the three-dimensional (3-D) twisted shape forms the 3-D vortical structures along the spanwise direction, which leads to the harmonic behavior of the drag time trace power spectra.

1. Introduction

Flow over bluff bodies has been investigated extensively due to its interesting and complex features. In particular, the flow separation and wakes from a bluff body have received much attention for many years, since they are strongly linked to the phenomenon of vortex shedding. When vortex shedding occurs near a bluff body, it can cause an increase in drag and flow-induced vibration with noise problems. Williamson [23] conducted comprehensive reviews on the vortex shedding phenomenon, and reported that vortex shedding strongly affects drag and lift forces with respect to the Reynolds number. Thus, controlling vortex shedding is the main consideration in many engineering applications, and flow control methods have been proposed to reduce the mean drag and suppress lift fluctuations. In general, flow control methods can be classified as passive control or active control.

Choi et al. [3] systematically classified control methods for bluff body flows as boundary-layer controls and direct-wake modifications, which are considered to be active control. Kleissl [11] reviewed existing passive control methods such as surface protrusion, surface indentations, shrouds, and overall shape changes.

Roussopoulos [21] carried out a feedback control experiment at low Reynolds numbers and showed that the feedback control delays the onset of wake instability. However, feedback control cannot stabilize the wake at high Reynolds numbers. Kim and Choi [9] achieved suppression of vortex shedding by using an active open-loop control method (called distributed forcing) at a Reynolds number of 100. Dong et al. [6] showed that windward suction combined with leeward blowing around a circular cylinder can attenuate vortex shedding, resulting in the suppression of vortex-induced vibration (VIV). However, these control methods, when used as the active control, need additional energy expenditure to keep the feedback and the flow control system operating, leading to high cost. In this regard, we focused on passive control for a simplified approach without energy expenditure. One representative passive control method uses a wavy cylinder whose diameter varies along the spanwise direction with sinusoidal waviness. Lam and Lin [15] investigated the flow around a wavy cylinder and identified the effect of the spanwise wavelength and wave amplitudes on forces and flow characteristics of the cylinder at *Re* of 100 and 150. In a continuation of the study by Lam and Lin, [15], Lam and Lin [17] carried out three-dimensional (3-D) numerical simulations of laminar flow around wavy cylinders in the range of $60 \leq R \leq 150$ with variations of the wavelength and wave amplitude. They found that a wavelength in the range of

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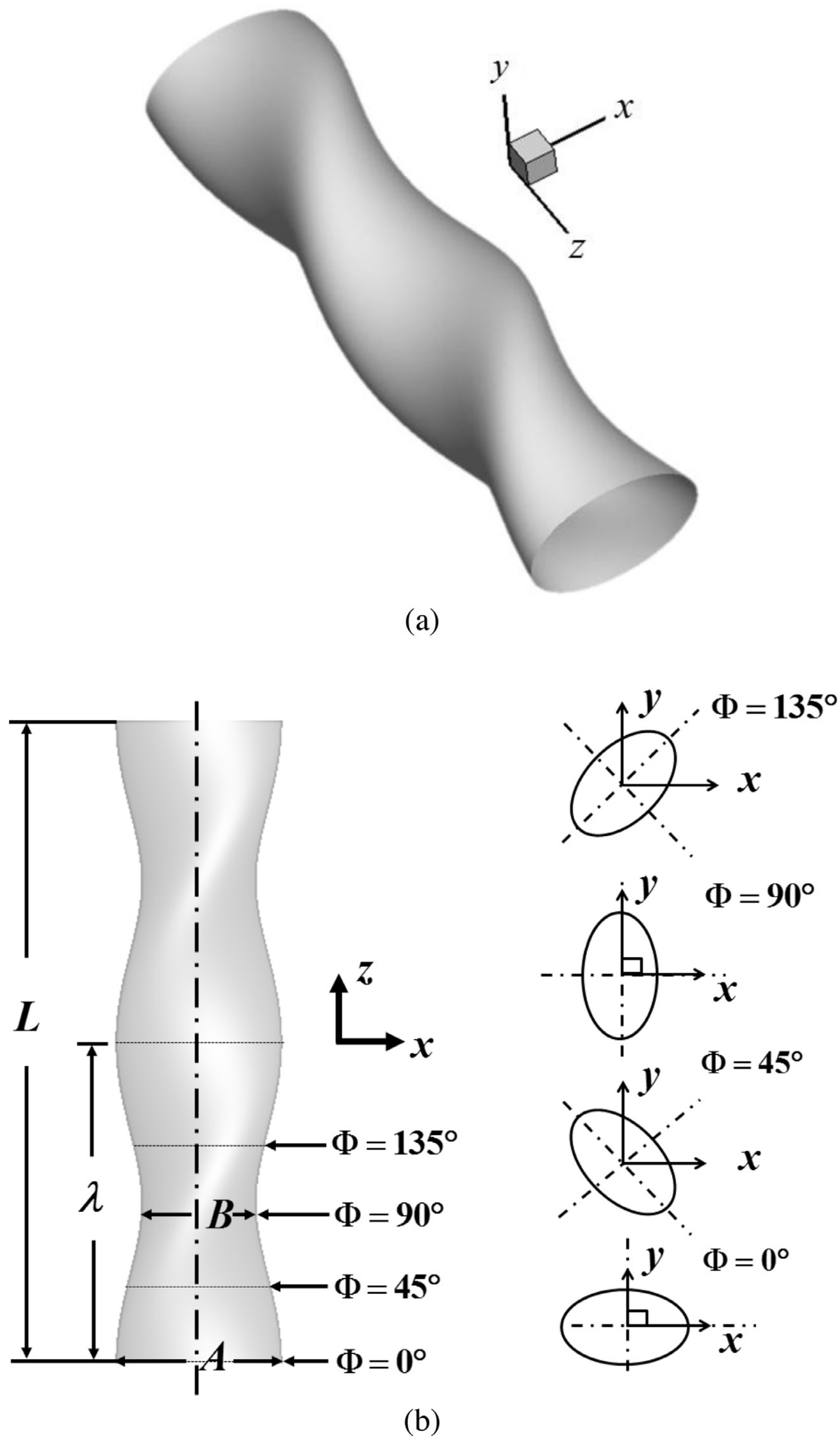

Fig. 1. (a) Geometry and (b) definition of the twisted cylinder.

$1 \le \lambda/D_m \le 10$ can be divided into three groups according to wake structures, where λ is the wavelength and D_m is the mean diameter of the wavy cylinder. In addition, the flow separation line varies along the spanwise direction of the wavy cylinder, leading to the development of a 3-D free shear layer with a periodic structure.

Darekar and Sherwin [5] performed numerical investigations to study the flow past square-section cylinders with a spanwise geometric deformation leading to a stagnation face with sinusoidal waviness in the range of $10 \le Re \le 100$. They demonstrated that a bluff body with a wavy stagnation face achieved a reduction in total drag of approximately 16% at a Reynolds number of 100 in comparison with that of a straight non-wavy cylinder. The reduction rate of the drag reaches about 34% as the Reynolds number increases to 500. Many researchers have also studied turbulent flow over wavy cylinders, as well as laminar flow, due to the practical importance of these cases. [1, 2, 13, 14, 16]

Smooth cylinders with helical surface perturbations are well known as an effective flow control method, and have been investigated extensively. Early research was conducted by Zdravkovich [25], who demonstrated that helical strakes are an effective passive control method to attenuate the vortex shedding from a smooth