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The effect of a wake-mounted splitter plate on the flow around a surface-mounted finite-height circular cylinder

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ABSTRACT

The influence of a wake-mounted splitter plate on the flow around a surface-mounted circular cylinder of finite height was investigated experimentally using a low-speed wind tunnel. The experiments were conducted at a Reynolds number of $\mathrm{Re}=7.4\times10^4$ for cylinder aspect ratios of AR=9, 7, 5 and 3. The thickness of the boundary layer on the ground plane relative to the cylinder diameter was $\delta/D=1.5$. The splitter plates were mounted on the wake centreline with negligible gap between the base of the cylinder and the leading edge of the plate. The lengths of the splitter plates, relative to the cylinder diameter, ranged from $L/D=1$ to 7, and the plate height was always equal to the cylinder height. Measurements of the mean drag force coefficient were obtained with a force balance, and measurements of the vortex shedding frequency were obtained with a single-component hot-wire probe situated in the wake of the cylinder–plate combination. Compared to the well-studied case involving an infinite circular cylinder, the splitter plate was found to be a less effective drag-reduction device for finite circular cylinders. Significant reduction in the mean drag coefficient was realized only for the finite circular cylinder of AR=9 with intermediate-length splitter plates of $L/D=1$–3. The mean drag coefficients of the other cylinders were almost unchanged. In terms of its effect on vortex shedding, a splitter plate of sufficient length was able to suppress Kármán vortex shedding for all of the finite circular cylinders tested. For AR=9, vortex shedding suppression occurred for $L/D\geq5$, which is similar to the case of the infinite circular cylinder. For the smaller-aspect-ratio cylinders, however, the splitter plate was more effective than what occurs for the infinite circular cylinder: for AR=3, vortex shedding suppression occurred for all of the splitter plates tested ($L/D\geq1$); for AR=5 and 7, vortex shedding suppression occurred for $L/D\geq1.5$.

1. Introduction

Bluff bodies are objects with non-streamlined shapes that significantly resist the motion of a moving fluid. This resistance leads to bluff bodies experiencing very high drag forces. Flow around a bluff body is complex, and for a wide range of Reynolds number the flow field is characterized by a large region of separated flow, periodic vortex shedding, and a wide wake downstream of the body that is often unsteady and turbulent. Under certain conditions, vortex shedding may cause unwanted structural motion known as flow-induced vibration.

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The undesirable vortex shedding and high drag forces experienced by bluff bodies have motivated many researchers to consider active (requiring external energy input) and passive (no external energy input required) means of flow control in an attempt to weaken or suppress vortex shedding, thereby alleviating the tendency for flow-induced vibration, and to change the characteristics of the wake, and thereby reduce the drag force. An overview of various active and passive flow control strategies is given in the monograph by Gad-el-Hak (2000). Reviews of flow control devices and strategies specifically for bluff bodies have been published by Zdravkovich (1981) and Choi et al. (2008).

One of the simplest passive flow control devices is the "splitter plate", a thin, flat, two-dimensional plate typically mounted behind the bluff body parallel to the flow on the wake centreline. For two-dimensional or "infinite" bluff bodies, in particular the circular cylinder, the splitter plate may be effective at weakening or suppressing vortex shedding and reducing drag. For undersea cables and oscillating cylinders, splitter plates may be effective at reducing vortex-induced transverse oscillations (Hu and Koterayama, 1994). Splitter plates also have been found to influence the galloping behaviour of infinite square prisms and circular cylinders (Païdoussis et al., 2011) and the wake-induced vibrations of tandem cylinders (Assi et al., 2010). In nature, the tail feathers of a starling behave similarly to a splitter plate to help control aerodynamic drag, the wake properties, and vortex shedding (Maybury and Rayner, 2001). Zdravkovich (1981) refers to the splitter plate as a "near wake stabilizer" while Choi et al. (2008) classify the splitter plate as a "direct wake control" device which introduces a two-dimensional disturbance to the base flow field. The effectiveness of the splitter plate depends on various flow parameters, such as the Reynolds number, and geometrical parameters, such as the plate′s length, thickness, and location relative to the body.

The use of a splitter plate has been examined primarily for two-dimensional or infinite bluff bodies. Many engineering applications, however, involve the flow around surface-mounted finite-height bluff bodies, such as buildings, chimney stacks, offshore oil drilling platforms, and bridge pylons. For such surface-mounted finite-height bluff bodies the effectiveness of a wake-mounted splitter plate has not been extensively studied and this is the motivation for the present study. Here, an experimental investigation is undertaken of the flow (of freestream velocity, U_∞) around a surface-mounted finite-height circular cylinder (of diameter, D, and height, H), partially immersed in a flat-plate boundary layer (with velocity profile, $U(z)$, and thickness, δ), with a splitter plate (of length, L, thickness, T, and height, H_{sp}) mounted on the wake centreline (Fig. 1). Of interest in the present study are the combined effects of plate length (varying L/D) and cylinder aspect (slenderness) ratio ($\mathrm{AR}=H/D$) on the vortex shedding and mean drag force coefficient.

2. Literature review

The issue of manipulating the vortex shedding and the base pressure of two-dimensional bluff bodies led Roshko (1953, 1954, 1955) to study the effects of placing an impediment in the wake of a bluff body, specifically a "splitter plate". Since then, the use of splitter plates in relation to controlling flow fields around two-dimensional bluff bodies, with special consideration given to the circular cylinder, has been extensively studied both experimentally (e.g., Akilli et al., 2005, 2008; Anderson and Szewczyk, 1997; Apelt and West, 1975; Apelt et al., 1973; Gerrard, 1966, 1978; Nakamura, 1996; Unal and Rockwell, 1987) and numerically (e.g., Dehkordi and Jafari, 2010; Hwang et al., 2003; Kwon and Choi, 1996; Lin and Wu, 1994; Mittal, 2003; Tiwari et al., 2005). Splitter plates have also been used with other two-dimensional bluff-body

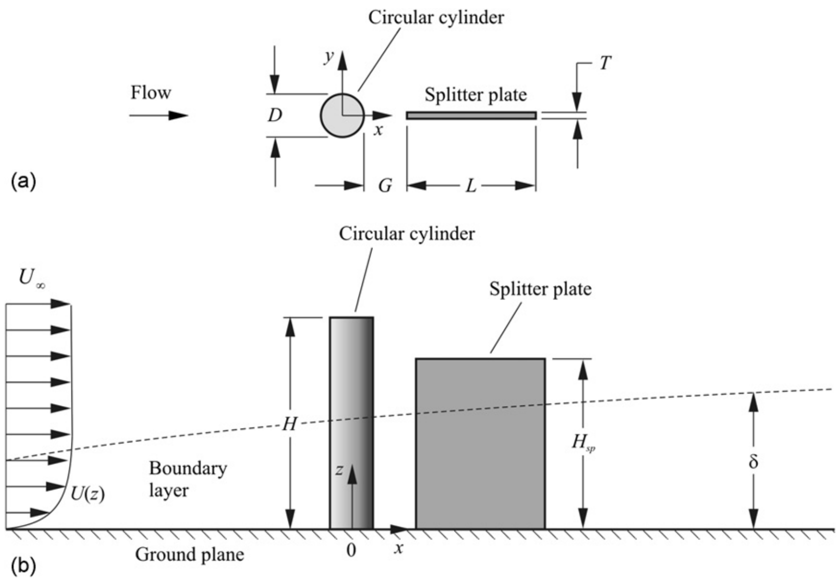

Fig. 1. Flow around a surface-mounted, finite-height circular cylinder (of diameter, D, and height, H) with a splitter plate (of length, L, height, H_{sp}, thickness, T, and gap distance, G) located vertically on the wake centreline: (a) top view; (b) side view.