

Modulation of aerodynamic force on a 2D elliptic body via passive splitter pitching under high turbulence



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ABSTRACT

The mean and fluctuating aerodynamic force on an elliptic body of infinite aspect ratio with hinged splitters were experimentally studied under high incoming turbulence for various angle of attack AoA of the body, Reynolds numbers and splitter length. High-resolution load cell was used to measure the mean and unsteady lift and drag forces of the body; whereas a hotwire anemometry was employed to characterize the incoming turbulence and get insight on the wake flow. Results show that the attached splitters reduce the lift and drag coefficients for AoA well beyond stall. Interestingly, the splitter length did not play a noticeable role on the mean aerodynamic force; this parameter just induced minor effects on the fluctuation counterpart. Such phenomenon appear to be inherently related to the background turbulence levels. Compared to the bare body, the force coefficients exhibit stronger dependence on Reynolds number due to the dynamics induced by the splitter pitching. In general, the force fluctuations are dominated by the natural frequency of the setup under the high turbulence. The joint distribution of the instantaneous lift and drag forces reveals that under sufficiently high AoA , the vortex shedding dominates the force fluctuations along the major axis of the body; whereas the splitters can efficiently dampen the vortex shedding and mitigate the overall force fluctuations.

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1. Introduction

Quantitative characterization of the aerodynamic force on rigid or flexible bodies is undoubtedly of paramount importance in many engineering applications. A canonic, well-documented example is the flow around circular cylinders; there, unsteady lift and drag are modulated by periodic vortex shedding known as von Kármán. Such forcing usually results in vibrations and fatigue of structures (Sarpkaya, 2004; Williamson and Govardhan, 2004; Wu et al., 2012), which lead to shorter life span. Consequently, damping of the vortex shedding is conceptually a good strategy to reduce the fluctuations of the lift and stress on structures.

Fixed splitter placed in the near wake of cylinders has been studied as a passive strategy to reduce vortex shedding. Early experimental investigation by Roshko (1955) showed that a splitter with a length (c) of 5 times the diameter of a cylinder (d) is effective to significantly suppress the periodic vortices. Apelt and West (1975) reported that the Strouhal number St is sensitive to structures with splitters of $c/d \leq 2$. Numerical studies by Hwang and Yang (2007) showed drag reduction and decrease of the stagnation pressure with dual splitter configuration; one located upstream and the other

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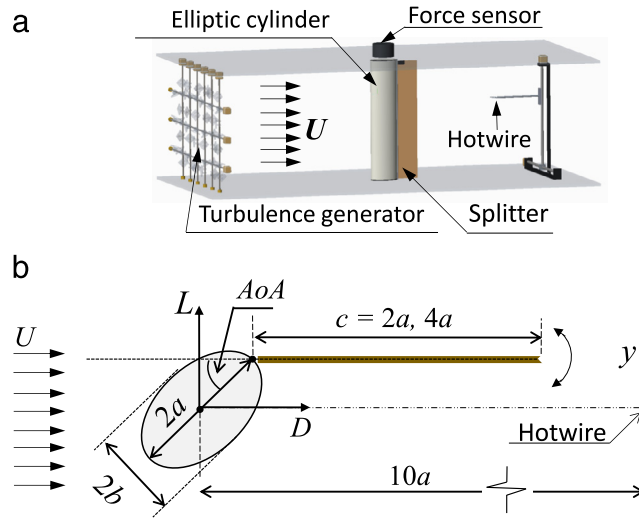


Fig. 1. (a) Schematic of the 2D elliptic body and splitter system in the wind tunnel with the active turbulence generator. Force sensor is located outside the test section. (b) Plain view with basic variables and location of the hotwire probe.

placed downstream of a circular cylinder. In addition to damping the unsteady force on cylinders, attached splitters modify the wake flow. [Mat Ali et al. \(2011\)](#) explored the effect of splitters near square cylinders at low Reynolds numbers Re . They showed that short splitters (say $c/h < 1$, where h is the side length of the square cylinder) delay the formation of vortex street, while relatively long splitters ($1.25 < c/h < 4.75$) may induce secondary vortices near the splitter tip. [Ogunremi and Sumner \(2013\)](#) investigated the wake recovery of a cylinder–splitter system, and found an increase of the velocity deficit with longer splitters at $x/d > 4$, where x is the downstream distance from the cylinder. Recent experiments by [Liu et al. \(2016\)](#) showed that splitter can reduce the turbulence kinetic energy along the wake axis.

Elliptic cylinders can be thought as intermediate geometries between flat plates and circular cylinders with aspect ratios $AR = b/a \in (0, 1)$, where b and a are the semi-minor and semi-major axes. The flow-induced force on these structures and associated wake characteristics are functions of AR and angle of attack (AoA). Here, the vortex shedding from both leading and trailing edges can result in additional unsteadiness in the drag (D) and lift (L) forces ([Nair and Sengupta, 1997](#); [Thompson et al., 2014](#)). [Modi et al. \(1992\)](#) reported that for Reynolds numbers $Re \in O(10^4)$, the drag and lift coefficients, C_d and C_L , remain nearly constant. The understanding of fluid–structure feedback mechanism of flow past elliptical bodies with splitters may provide insight on locomotion, control of dynamic loading in structures, pipeline design and flow mixing, among others. In spite of these applications, the modulation of splitters on the forces and wake of elliptic bodies are not well understood; the main goal of this work is to fill such gap. In most of natural environments and engineering applications, the background flow is turbulent. Indeed, several investigations have shown the significant effect of the turbulence intensity I_u on the aerodynamic force on a body ([Tamura and Miyagi, 1999](#); [Irwin, 2008](#); [Pastò, 2008](#)). Motivated by this, we experimentally inspected the force on an elliptic body with hinged splitters and wake flow under high I_u for various AoA of the cylinder, mean flow and splitter length; results also include the cases without splitter and selected setup with low turbulence to aid comparison. The setup is described in Section 2, the results and discussion are provided in Section 3, and the main remarks are presented in Section 4.

2. Experimental setup

A two-dimensional elliptic body with and without splitters was placed in the freestream section of the Talbot laboratory wind tunnel of the University of Illinois at Urbana-Champaign. The Eiffel-type wind tunnel has a test section of 0.914 m wide, 0.61 m long and 0.45 m. Details of the facility are provided in [Adrian et al. \(2000\)](#).

A smooth elliptic body made with acrylic of semi-axes $2a = 100$ mm and $2b = 60$ mm was placed vertically in the wind tunnel; its cross section spanned from the bottom to the top walls, resembling a 2D body. Two low-weight flat plates made of balsa material with thickness $s = 6$ mm and chord $c = 2a$ and $4a$ were vertically hinged along the trailing edge of the cylinder and supported by two low-friction bearings ([Fig. 1](#)). A minor gap of ~ 2 mm was left between the rotational axis of the splitter and the trailing edge of the elliptic body to avoid collisions during the splitter pitching. The unsteady aerodynamic force and wake were characterized under various mean flow velocities ranging from $U = 2.8$ m s^{−1} to 8.6 m s^{−1}, which correspond to Reynolds numbers $Re = U2a/\nu \in [1.9, 5.7] \times 10^4$; here, ν is the kinetic viscosity of the air. The background turbulence intensity was set at $I_u = \sigma_u/U \approx 10.5\%$, where σ_u represents the standard deviation of the streamwise velocity fluctuations. This was achieved via an active turbulence generator (TG) located at the entrance of the wind tunnel ([Jin et al.,](#)

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