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Near wake field of circular cylinder with a forward splitter plate

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ABSTRACT

Investigation of flow past a circular cylinder has been carried out using experimental tools at subcritical Reynolds number of 5.1×10^4. Pressure, hot wire and particle image velocimetry measurements have been used to understand the flow past forward splitter plate - cylinder combination. The forward splitter plate modifies the flow conditions upstream of the cylinder. Further, the wake characteristics downstream of the cylinder are also substantially altered. At subcritical Reynolds number, the flow separation is delayed and the shedding frequency is increased in the forward splitter plate cylinder case as compared to the plain cylinder case. It has been shown that the forward splitter plate reduces drag by 13% as compared to the plain cylinder configuration. The streamwise and transverse velocity fluctuations in the cylinder wake are reduced by 22% and 27% respectively in the presence of forward splitter plate. The phase averaged PIV measurements reveal that the vortices shed in the forward splitter plate cylinder case are weaker in strength as compared to the plain cylinder case.

1. Introduction

The flow past a circular cylinder is one of the oldest problems in fluid mechanics. It still remains a relevant problem even today because of its wide practical applicability eg., bridge piers, chimneys, towers, heat exchangers, etc. From an engineering point of view, the interest has been towards reducing the drag and unsteady forces on a cylinder using flow control devices. In the past, a variety of active and passive flow control techniques have been used to control the wake shedding. Active control techniques such as plasma actuation (Bhattacharya and Gregory, 2015), acoustic excitation (Roussopoulos, 1993), suction or blowing (Li et al., 2003), etc. require supply of external energy. On the other hand, passive techniques require simple geometric modifications and are easier to implement (Lee et al., 2004). A few examples of the passive methods are splitter plates, rough elements like helical wires or strakes, slit cut across cylinder, control rods along cylinder axis, etc. A comprehensive review on a wide variety of passive control techniques can be found in the article by Zdravkovich (1981).

Passive devices such as the installation of small rods upstream of the cylinder by Lee et al. (2004) and small flat plates placed upstream perpendicular to the freestream flow by Prasad and Williamson (1997) modify the flow around the cylinder. By placing these devices at an optimal location they report a considerable decrease in the drag of the cylinder. Strykowski and Sreenivasan (1990) have used a small control cylinder in the near wake of the main cylinder. They find that the control cylinder can suppress the vortex shedding over a limited range of Reynolds numbers. Qiu et al. (2017) have performed LES simulations using a small control cylinder for four different spacing between main and control cylinder. The spacing ratio (normalised with main cylinder diameter) of 1.5 was found to be optimum with regard to reduction in vortex induced unsteady loads on the main cylinder. Park et al. (2006) have shown the efficacy of small tabs with respect to bluff body drag reduction. Ahmed and Bays-Muchmore (1992) and Tombazis and Bearman (1997) have introduced three-dimensional perturbations along the span of a cylinder with the help of wavy surfaces. They have shown that these perturbations disrupt the vortex shedding in the span wise direction and reduce the drag of the cylinder.

Among the passive devices, the splitter plate placed in the wake of a cylinder has been widely studied (Akilli et al., 2005). Roshko in 1954 has shown that an attached backward splitter plate (BSP) reduces the interaction between the shear layers on either side of the cylinder and also the drag (Roshko, 1954). He has shown that a BSP length of approximately five times the cylinder diameter can reduce the drag coefficient by 37%. He has also presented the results for a detached BSP of length 1.14 times the cylinder diameter and has shown that the base pressure coefficient increases as the distance between the splitter plate and the cylinder increases. Beyond a critical distance, the efficacy of the splitter plate is nullified and the base pressure coefficient drops discontinuously to the plain cylinder value. Akilli et al. (2005) have investigated the effect of a detached splitter plate for varying gap ratios. They report that a splitter

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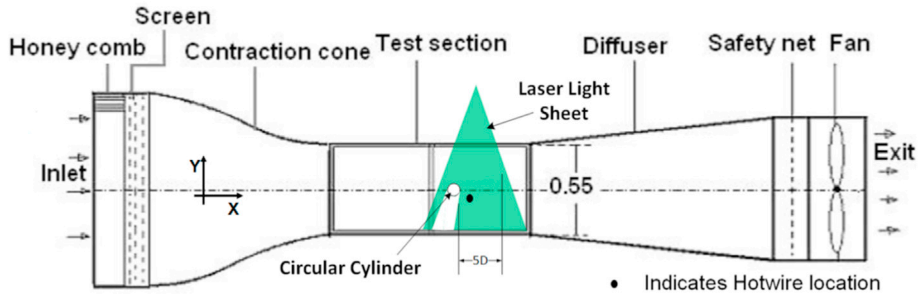
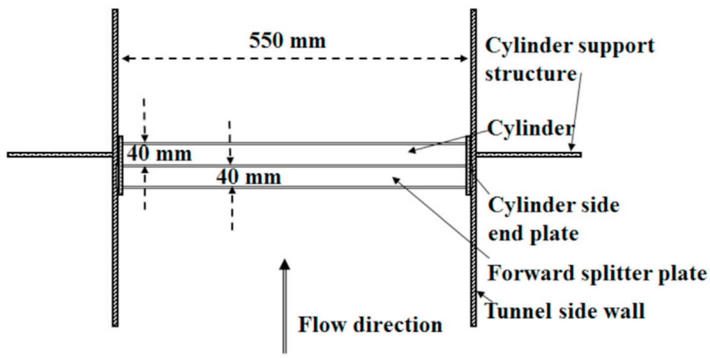


(a) Side view of the tunnel with the cylinder model



(b) Top view of the cylinder model mounted in tunnel

Fig. 1. Schematic of the experimental setup.

plate located more than 2D downstream does not have an effect on wake. Bearman (1965) carried out experiments on blunt trailing edge model with an attached BSP. He reports an increase in the base pressure coefficient for a BSP length less than the base height of the model. Apelt et al. (1973) conducted experiments with backward splitter plate of different lengths and has reported the base pressure and wake envelope for these cases. Igarashi (1982) has carried out experiments on detached BSP and proposed a classification of the flow based on the length of the BSP and its distance from the cylinder. Akilli et al. (2008) have investigated the effect of thickness of BSP using PIV technique. They report that splitter plate thickness hardly influences the wake characteristics. Teksin and Yayla (2016) have studied the effect of flexible BSP and report a reduction in the turbulent fluctuations in the wake. Ozkan et al. (2017) have studied the effect of permeable BSP plate on the wake characteristics and have shown that the vortex shedding is suppressed. The plate porosity ratio of 0.4 and 0.5 is found to be effective in attenuating the shedding frequency. Bao and Tao (2013) have investigated the effect of dual parallel plates attached to the rear surface of the cylinder as a wake control device. They mention that dual plates cause increased drag reduction at relatively shorter plate lengths as compared to conventional BSP. Most of the above results have been performed at subcritical Reynolds number regime wherein the flow transition occurs in the wake of the cylinder. The purpose of flow control devices on the cylinder flow is to reduce the unsteady loads and base drag on the cylinder body; a crucial aspect considering hydrodynamic and aerodynamic applications.

The splitter plate placed upstream at the stagnation end of the cylinder has been referred to as forward splitter plate (FSP) in the paper. In literature, very few attempts have been made to understand the flow past FSP - cylinder configuration. First study on this geometry was by Viswanath et al. (1991). They have conducted experiments on FSP of different lengths and found that the optimum FSP length to be equal to the cylinder diameter. Their results show that the separation is delayed and the base pressure coefficient and shedding frequency increase with the use of FSP. Based on the surface pressure measurements, they have concluded that FSP has a nose streamlining effect on the cylinder. Qiu et al. (2014) have conducted pressure measurements on a FSP - cylinder configuration over a range of Reynolds numbers at near critical regime. They report a considerable reduction in drag coefficient at subcritical Reynolds number and a stable shedding frequency at near critical Reynolds number.

The results discussed above from the literature indicate that the optimum length of a FSP is about one-fifth of the BSP. Furthermore, FSP is an efficient base drag reduction device as compared to a BSP at subcritical Reynolds number. These results clearly indicate a need to further investigate the wake flow of FSP cylinder configuration at subcritical Reynolds number. In this regard, time and phase averaged PIV investigations have been carried out highlighting the near wake characteristics of both the FSP and plain cylinder configurations. To authors knowledge, a detailed investigation of the FSP cylinder near wake flow has not been carried out before in literature.

2. Experimental details

Experiments were carried out in the low-speed wind tunnel at CSIR - NAL, Bangalore. A schematic of the tunnel with the model installed is shown in Fig. 1. The side view of the tunnel with the cylinder model is shown in Fig. 1a. The top view of the cylinder model with forward splitter plate is shown in Fig. 1b. The tunnel consists of an inlet with a honeycomb and screens, a contraction section with an area ratio of 16, a test section, a diffuser section and a fan. The test section has a square cross section with a width of 0.55 m and length of 1.2 m. The freestream velocity within the tunnel can be varied from 1 to 40 m/s. The flow velocity profile within the test section is uniform and the turbulence intensity is less than 0.15%. More details regarding the tunnel can be found in reference (Madhavan et al., 2008).

The circular cylinder model along with the splitter plate was mounted horizontally in the test section. The glass windows on the top and side of the test section provide the access for directing the laser sheet and for viewing the flow field respectively. Measurements were performed at a free-stream velocity (U_∞) of 20 ± 0.3 m/s; corresponding to Mach number of 0.057. The Reynolds number Re_D (based on the cylinder diameter) is 5.1×10^4, which falls under subcritical Reynolds number