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Flow over a cylinder with a hinged-splitter plate

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Abstract

Previous work on rigid splitter plates in the wake of a bluff body has shown that the primary vortex shedding can be suppressed for sufficiently long splitter plates. In the present work, we study the problem of a hinged-splitter plate in the wake of a circular cylinder. The splitter plate can rotate about the hinge at the base of the cylinder due to the unsteady fluid forces acting on it, and hence the communication between the two sides of the wake is not totally disrupted as in the rigid splitter plate case. In our study, we investigate this problem in the limit where the stiffness and internal damping associated with the hinge are negligible, and the mass ratio of the splitter plate is small. The experiments show that the splitter plate oscillations increase with Reynolds numbers at low values of Re, and are found to reach a saturation amplitude level at higher Re, Re > 4000. This type of saturation amplitude level that appears to continue indefinitely with Re, appears to be related to the fact that there is no structural restoring force, and has been observed previously for transversely oscillating cylinders with no restoring force. In the present case, the saturation tip amplitude level can be up to $0.45D$, where D is the cylinder diameter. For this hinged-rigid splitter plate case, it is found that the splitter plate length to cylinder diameter ratio (L/D) is crucial in determining the character and magnitude of the oscillations. For small splitter plate lengths ($L/D \leqslant 3.0$), the oscillations appear to be nearly periodic with tip amplitudes of about $0.45D$ nearly independent of L/D. The nondimensional oscillation frequencies (fD/U) on the other hand are found to continuously vary with L/D from $fD/U \approx 0.2$ at $L/D = 1$ to $fD/U \approx 0.1$ at $L/D = 3$. As the splitter plate length is further increased beyond $L/D \geqslant 4.0$, the character of the splitter plate oscillations suddenly changes. The oscillations become aperiodic with much smaller amplitudes. In this long splitter plate regime, the spectra of the oscillations become broadband, and are reminiscent of the change in character of the wake oscillations seen in the earlier fixed-rigid splitter plate case for $L/D \geqslant 5.0$. In the present case of the hinged-splitter plate, the sudden transition seen as the splitter plate length (L/D) is increased from 3 to 4 may be attributed to the fact that the wake vortices are no longer able to synchronize with the plate motions for larger splitter plate lengths. Hence, as observed in other vortex-induced vibration problems, the oscillations become aperiodic and the amplitude reduces dramatically.

Keywords: Splitter plate; Cylinder wake; Vortex-induced vibrations

1. Introduction

Prior studies have shown that the wake downstream of a cylinder can be greatly influenced by placing a splitter plate along the wake centre-line. These studies in fact show that the vortex formation in the wake can be nearly suppressed by

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the presence of a sufficiently long splitter plate. In these investigations, for example by Roshko (1954) and Apelt and West (1975), a rigid splitter plate is placed behind the cylinder, effectively inhibiting any communication between the two shear layers on either side of the body. In the present work, we investigate the problem of flow over a cylinder with a hinged-rigid (flexibly mounted) splitter plate, as shown in Fig. 1. The splitter plate is allowed to rotate about the hinge point at the base of the cylinder, and hence the communication between the two sides of the wake is not completely inhibited as in the case of a rigid (fixed-) splitter plate. Apart from being an interesting extension to the rigid splitter plate problem and the more recent study of a permeable splitter plate (Cardell, 1993), this problem could also have practical applications in energy extraction (Allen and Smits, 2001) and in suppression of vortex-induced vibrations (VIV) (Assi and Bearman, 2007). This problem is also related to the extensively studied flag flutter problem [e.g. Argentina and Mahadevan (2005), Connell and Yue (2007)], for the case when the flag pole diameter is not negligible compared to the flag/membrane thickness.

A rigid splitter plate can stabilize the near wake and suppress vortex shedding, as has been shown clearly by Roshko (1954). His experiments at Re of about 1.45×10^4 showed that vortex shedding behind a cylinder can be suppressed by a splitter plate $5D$ long, which also resulted in an increased base pressure and a consequent reduction in the drag on the cylinder (D is the cylinder diameter). Apelt et al. (1973) and Apelt and West (1975) continuously varied the length of the splitter plate (L) in their extensive investigations of the effects of a wake splitter plate placed behind a circular cylinder. They report that for short splitter plates ($L/D<5$), the drag coefficient and Strouhal number vary as the splitter plate length is varied due to modifications in the near-wake flow patterns. However, for longer splitter plates ($L/D>5$), vortex shedding is eliminated and the drag coefficient does not vary with the splitter plate length. They suggest this is due to the fact that for longer splitter plates ($L/D>5$), the reattachment point is on the plate surface, and hence any further increase in splitter plate length does not significantly affect the flow pattern. The effects of placing a splitter plate in the wake of other types of bluff bodies have also been studied, for example by Bearman (1965), for a model with a blunt trailing edge, and by Apelt and West (1975) for a flat plate placed normal to the flow. The broad feature of a sufficiently long splitter plate suppressing vortex shedding is also reported in these investigations.

It is clear from the results of rigid splitter plate studies that the near-wake structure can be varied by changing the length of the splitter plate. It should be noted that in these rigid splitter plate cases, no communication is possible across these plates. The work on the effect of a long permeable splitter plate (Cardell, 1993) is an extension of the solid splitter plate investigations discussed above, where some communication is possible between the two shear layers on either side through the permeable plate. Cardell (1993) showed that the near wake can be continuously changed by varying the permeability (or solidity) of the plate. He reported that when the permeability is high, the basic near-wake structure and vortex formation is similar to that when there is no splitter plate present. On the other hand, when the permeability is low, he reported that the near wake is almost disconnected from the vortex formation that occurs further downstream.

In the present work, we are using flexible interfering elements, and one could expect the flexible element to oscillate due to the unsteady pressure forces acting on it. One related study is the work of Allen and Smits (2001), where they placed a piezoelectric membrane or ''eel'' in the wake of a normal plate, and described the oscillations of the membrane. In their work, the membrane was placed downstream of the base of the bluff body. The purpose of their study was to obtain optimal conditions to achieve the largest possible energy extraction from the flow, to possibly generate power for some autonomous systems. The above problem, in the absence of a bluff body reduces to the extensively studied problem of flag flutter. As mentioned by Connell and Yue (2007), the flag flutter problem involves the study of a thin membrane (flag) that is pinned at the leading edge and is otherwise free. As the fluid travels over the flag surface and into the wake, an instability can occur that results in flapping of the flag. This type of natural flapping behaviour also has applications in understanding the efficient locomotion of swimming fish and other aquatic creatures like eels (Shen et al., 2003).

In the present study, we investigate the problem of flow over a cylinder with a hinged-rigid splitter plate, as shown in Fig. 1. As stated earlier, in this configuration, the communication between the two shear layers on either side is not

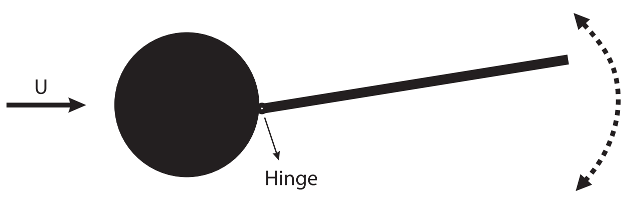

Fig. 1. Schematic of cylinder with a hinged-rigid splitter plate. The rigid splitter plate is free to rotate about the hinge at the base of the cylinder.