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Horseshoe vortex control using low-drag vortex generators

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Abstract. Control of horseshoe vortex in the circular cylinder-plate juncture using vortex generator (VG) was studied at Re_D (where D is the diameter of the cylinder) = 2.05×10^5. Impact of a number of parameters e.g. the shape of the VG's, number of VG pairs (n), spacing between the VG and the cylinder leading edge (L), lateral gap between the trailing edges of a VG pair (g), streamwise gap between two VG pairs (S_{VG}) and the spacing between the two VG's in parallel arrangement (Z_{VG}) etc. were investigated on the horseshoe vortex control. The study is conducted using surface oil flow visualization and surface pressure measurements in low speed wind tunnel. It is observed that all the parameters studied have significant control effect, either by reduction in separation region or by lowering the adverse pressure along the symmetric axis upstream of the juncture.

Keywords: horseshoe vortex; low drag vortex generators; streamwise vortex; series arrangement of vortex generators; parallel arrangement of vortex generators

1. Introduction

When hindrances and obstacles come across the flowing fluid, some very complex flow structures form all around the obstacles (upstream, downstream and sidewise). The complex flow structures exert a number of adverse effects on the obstacle around which they are formed. The results of such flow structures on the obstacle appear in the form of vibration, noise, erosion etc. Some of the common flow structures around an obstacle when it is placed in a fluid stream are the

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wake flow (Karman Vortex), tip flow/vortex and the Horseshoe Vortex (Munson et al. 2009). All of the above flow structures are caused due to the separation of the boundary layer from some parts of the obstacle which results in such vortical flow structures. Horseshoe vortices are spawned due to the adverse pressure gradient offered by obstacles and encountered by the incoming boundary layer on its way. This vortical flow is then, convected downstream along the two sides of obstacles. (Younis et al. 2014)

Controlling the separated flows in various fluid mechanics applications have always remained a great challenge. The horseshoe vortex in junction is also an undesirable flow phenomenon in many situations which needs to be controlled in order to avoid the structural damage. This may be achieved by either using passive or active methods of flow control (Mohamed 2006).

A number of passive control methods have been developed. Some for specific applications concerning Juncture flows like fillets (Kubendran and Harvey 1985, Devenport et al. 1990, Zess and Thole 2002) (for aircrafts wings or for turbine blades junctures) or general purpose e.g. collars (Bijan 1990) etc. are studied. Fillets use the principle of reducing the adverse pressure gradients by making the juncture region more streamline according to the local flow conditions at that region. Studies suggest that the leading edge fillets (Kubendran and Harvey 1985, Devenport et al. 1990, Zess and Thole 2002) are more suitable for leading edge separation control than the fillet along the whole of the juncture (Devenport et al. 1990). The leading edge fillet greatly improves the stability of the flow close to juncture and uniformity of the wake. Leading edge fairing (Oudheusden et al. 2004) has also been successfully utilized to eliminate the horseshoe vortex with similar flow control mechanism to that of the fillets. Gupta (1987) used a delta wing like device in the base of the juncture region, and illustrated that the device acts as a barrier to vortex buildup and generates counter rotating pair of vortices with opposite sense of rotation to that of horseshoe vortex. Except Gupta, who used qualitative flow visualization technique for his analysis, no further detailed studies with this method are observed in available literature.

Variation in the shape of leading edge (Wei et al. 2008, Olcmen and Simpson 1994) of the obstacle plays an important role in horseshoe vortex modifications. Varying the airfoils (Olcmen and Simpson 1994) and the shapes of the cylinders (Wei et al. 2008) revealed that the sharp leading edge produces a weaker horseshoe vortex than a blunt one. This is due to the fact that sharp leading edges produce less adverse pressure gradients compared to the blunt counterparts.

Ribbed surfaces (Kairouz and Rahai 2005) upstream of the juncture also significantly reduce the horseshoe vortex strength and displace the separation point more close to the juncture. Ribbed surfaces adds momentum to the near wall region with the introduction of force mixing of the free stream fluid into the boundary layer region which results in delayed separation compared to the baseline case.

Fencing is another important passive control method which is used to reduce the horseshoe vortex structure in the juncture region. Various ways of fencing (Liu et al., 2010 and Kumar and Govardhan 2011) are used to reduce the strength of the horseshoe vortex system. Fences change the mechanism of flow near the juncture region thus the strength of the near wall vortical flow is reduced. Liu et al. (2014) also used vortex baffle to control the horseshoe vortex. Theberge and Ekmecki (2017) used triangular plate to control the horseshoe vortex.

An inclined thin rod (Wang et al. 2009) attached with the horseshoe vortex system also mitigates the vortex structure. Inclined rod separates the incoming boundary layer before it reaches the juncture, so as due to smaller adverse pressure gradient than that of the main juncture, the horseshoe vortex system in this case mitigates greatly. Two dimensional cavity (Kang et al. 2009) and a small cylinder placed in front of juncture (Younis et al. 2010) are some other passive control