INTERACTION OF A WALL JET WITH A WAKE FLOW- VORTEX STATISTICS

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Summary The interaction between a wall-jet with the wake of a bluff body in an open channel flow is investigated with the help of vortex statistics. Initially, the wake was generated by immersing a sharp-edged bluff body in an open channel flow, and then the body was lifted off from the floor to let the wall- jet interact with the wake of the bluff body. Velocity measurement was carried out downstream of the body with two-dimensional particle image velocimetry (PIV) technique. A swirling strength based vortex identification algorithm has been used to identify and extract the size and strength of vortices downstream of the body. The result indicates that the jet lead to an increase in population, size and strength of counter-clockwise vortices, but weakly affects the characteristics of the clockwise vortices.

INTRODUCTION

Flow around a bluff body is frequently encountered in practical situations, and had been extensively investigated in past so that now it became a well-defined baseline case. Although in most investigations, the body was exposed to a uniform approaching flow without any confinement effects from boundaries, studies are abundant where the body is mounted in a bed. In this particular case, the approaching flow carries a longitudinal vorticity, which manifests as a fluid structure downstream of the body better known as the horseshoe vortex system, in additional to the large scale eddies which emanate due to the boundary layer separation around the side edges of the body. This system of vortices (horseshoe vortex, wake vortex and the trailing vortex) is fairly well documented in the literature [1, 2]. The possible dynamics of this horseshoe vortex is recently a topic of widespread discussions [3]. With this perspective in background, the present study aims to investigate the nature of interaction between a typical horseshoe vortex-system with a wall jet. The horseshoe vortex was generated by placing a body in a typical open channel flow, and the body was lifted slightly to let a small wall jet pass which interacts with the horseshoe vortex. The motivation of the present study was to examine the effect of this jet on the horseshoe vortex by performing a statistical analysis of vortices in the flow with and without the presence of the wall jet.

EXPERIMENT

Experiments are performed in an open channel recirculating flume, with a freestream velocity of 0.45 m/s, and the flow depth was maintained constant at H = 100 mm. A sharp-edged bluff-body of width D = 30 mm has been used to generate the wake. Two dimensional particle image velocimetry has been used to measure the instantaneous velocity field downstream of the body, along the central vertical plane. Immediately downstream of the body, because of the bubble formation and associated reflection, the height of field-of-view is restricted to 70 mm. In the streamwise direction, the field of view extends till 70 mm. The experiment is repeated for three different cases: a) when the bluff body is mounted in the bed, and the gap size is zero, $h_g/H = 0.0$; b) gap size of 5 mm, $h_g/H = 0.05$ and c) gap size 10 mm, $h_g/H = 0.10$. More detail of the experiment setup is discussed elsewhere and is not repeated here [2].

Following the measurement, a swirling strength based vortex identification algorithm has been applied which detects the presence of vortices in the flow field, and extract the information of size and strength of the same. Details of the identification methodology has been reported elsewhere [4] and is not reported here.

RESULTS AND DISCUSSIONS

Table 1 tabulates the population, mean size and strength of the vortices found for three different cases. The vortices were divided into two groups based on the sense of rotation – counter-clockwise (CCW) and clockwise (CW). It can be seen that the total number of vortices increases for $h_g/H = 0.05$, compared to the case $h_g/H = 0.00$. However, the ratio of CCW to CW vortices does not change significantly. But for $h_g/H = 0.10$, the total number of vortices decreases significantly, and the fraction of CCW vortices increases, compared to CW vortices. The size and strength of the CW vortices is found not to be affected by the presence of the jet. However, the size and strength of the CCW vortices increases monotonically with increase in the gap size.

Figure 1 depicts the contour of the probability of occurrence of vortices for three different cases. The signature of the jet can be clearly visualized in the contour plot. For $h_g/H = 0.05$, the jet is found to rapidly expand in the cross-stream direction through mixing, and consequently contributes to the generation of vortices close to the bed and free surface.

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But for h_g/H = 0.10, the jet is significantly stronger and does not expand in the in the cross stream direction till x ~ 0.07 m. This could be because of the increased streamwise momentum carried by the jet, and this leads to the decrease in vortex population for h_g/H = 0.10. However, it would be possible that the jet would start expanding further downstream and thus increase the vortex population further downstream. But that analysis is not presented here due to space constraint.

Table 1: Characteristics of vortex population downstream of the body

h_g/H	Population	Population		Size [mm]		Strength [m^2/s]	
		CCW	CW	CCW	CW	CCW	CW
0.00	43,417	60.3	39.7	2.39±0.71	2.38±0.63	0.12±0.29	0.12±0.25
0.05	57,996	57.1	42.9	2.46±0.75	2.36±0.61	0.15±0.29	0.12±0.22
0.10	41,616	76.9	23.1	2.61±0.92	2.34±0.61	0.28±0.61	0.11±0.28

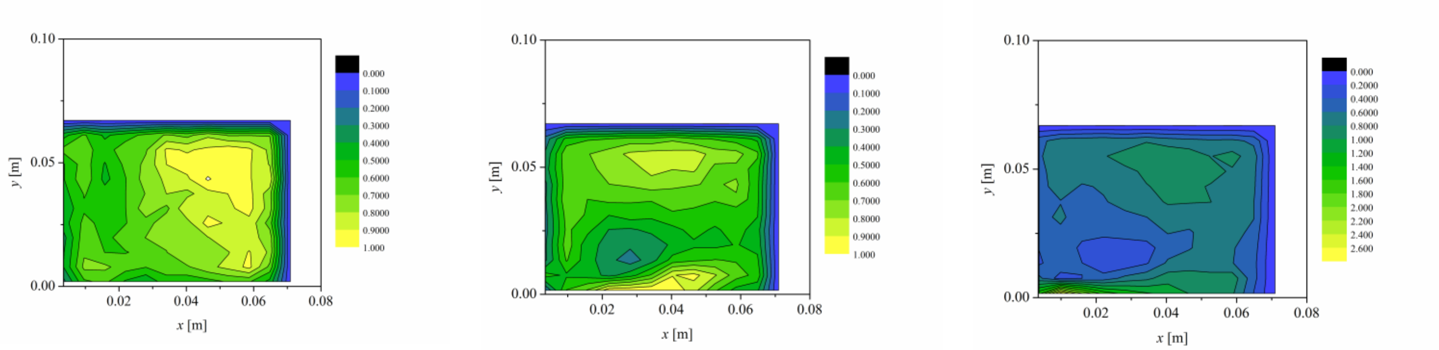

Figure 1: Contour plot of the probability of detection of vortices for h_g/H = 0.00 (left), 0.05 (middle) and 0.10 (right) downstream of the bluff-body.

CONCLUSIONS

The interaction of a wall jet with wake of a bluff body is studied in terms of vortex statistics. A sharp-edged bluff body has been used to produce a wake flow in an open channel, and then the body is lifted off to generate a wall-jet to interact with the flow. A swirling strength based vortex identification scheme has been used to extract the characteristics of vortices. The result indicate that for a normalized gap size of 0.05, the jet starts mixing at $x \leq 0.07$ *m*, and produces more counter-clockwise and clockwise vortices immediately downstream of the body. The size and strength of the counter-clockwise vortices were also increased. For a normalized gap size of 0.10, due to high streamwise momentum, the wall jet shows less amount of mixing and thus does not contribute to the generation of vortices at $x \leq 0.07$ *m*. However, the size and strength of counter-clockwise vortices increases for both cases of gap ratios, whereas the size and strength of clockwise vortices remains almost same.

References

[1] Wolansky E., Imberger J., Heron, M. L.: Island wakes in shallow coastal waters, J Geophysical Res., 89: 10553-10569, 1984.

[2] Singha A., Balachandar, R.: Coherent structure statistics in the wake of a sharp-edged bluff body placed vertically in a shallow channel, *Fluid. Dyn. Res.*, 43:05504-05527, 2010.

[3] Sahin B., Akilli H., Karakus C.., Akar M. A., Ozkul E.:Qualititive and quantitive measurements of horseshoe vortex formation in the junction of horizontal and vertical plates, Measurement, 43:245-254, 2010.

[4] Singha A., Faruque M. A. A., Balachandar R.:Vortices and large-scale structures in a rough open channel flow subjected to bed suction and injection, posted ahead of print, *J. Engg. Mech, 2011*.