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ANALYSIS OF THE NON-STATIONARY FLOW AROUND A RECTANGULAR CYLINDER

Stefano Malavasi*, **Marco Negri**†

* Dept. of I.I.A.R.
Politecnico di Milano, piazza Leonardo da Vinci 32, 20133 Milano, Italy
e-mail: Stefano.Malavasi@polimi.it,

† Dept. of I.I.A.R.
Politecnico di Milano, piazza Leonardo da Vinci 32, 20133 Milano, Italy
e-mail: Marco3.Negri@mail.polimi.it,

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In this work the non-stationary flow around a rectangular cylinder immersed in a steady water flow is investigated through the topological analysis of time resolved PIV velocity fields. The phenomenon considered is characterized by the presence of large scale eddies, which are the main responsible of the hydrodynamic loading on the cylinder. In order to investigate the correlation between the hydrodynamic loading and the flow structures, we have identified and measured the motion of the large scale eddies. The leading and trailing vortices have been characterized by calculating their convection velocities and shedding frequencies.

The velocity fields are obtained by means of a particular time resolved PIV system (Malavasi *et al.* [4]); they are characterized by a 50 Hz time resolution and a spatial resolution of 0.75 cm. The duration of each acquisition is 32 s which correspond to an amount of 1600 velocity fields.

The flow field around a rectangular cylinder of chord L=0.18 m and thickness s=0.06 m (aspect ratio L/s=3) has been analyzed separately in three regions: the intrados region, the extrados region and the rear wake region.

Upgrading the velocity inversion points (VIP) analysis proposed by Blois and Malavasi [1] for the characterization of the mean flow structures, in this work we have investigated the evolution of the large scale structures involved in the same phenomenon. The interpolation of inversion points leads to trace a series of characteristic lines which depict the architectural state of flow and moreover the intersection of these lines allows detecting critical point like vortex centres and saddle points. Fig. (1) shows the mean flow of the cases analyzed in this work, in which the cylinder has different elevations from the floor; critical points have been detected by VIP technique. Case a) is characterized by h_b/s=2.33 (where h_b is the intrados elevation from the floor) and it represents a condition similar to the unbounded flow (Malavasi and Guadagnini [5] found $C_L \approx 0$ for a similar configuration). In case b) the cylinder is closer to the floor (h_b/s=1) and the flow structure in the lateral regions is more asymmetric. As discussed by Blois and Malavasi [1], the gap between the mean dimensions of the side vortices is closely related to the mean lift coefficient, C_L= 0.62 in this condition (Malavasi and Guadagnini [5]).

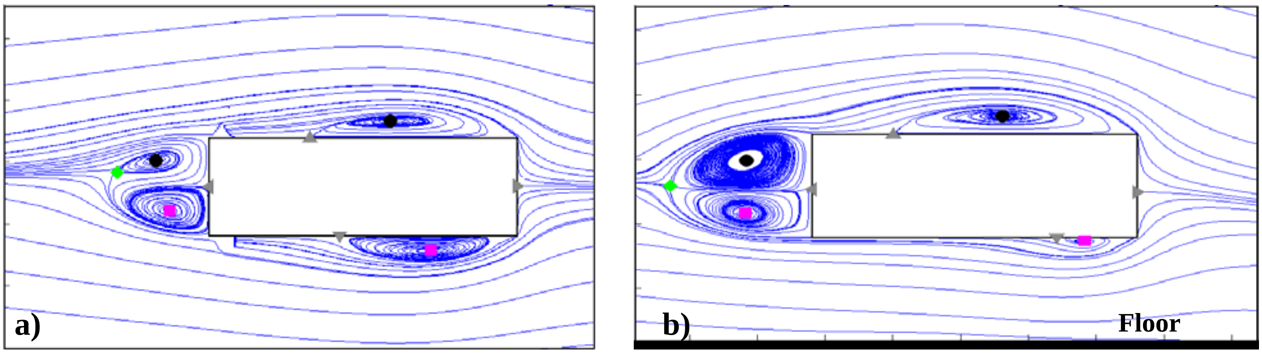

Fig. 1: Mean flow structures and critical points for the two cases considered: a) h_b/s=2.33, b) h_b/s=1. ●, anticlockwise vortex; ■, clockwise vortex; ▲, saddle on the obstacle surface; ♦, wake saddle.

After the description of the mean flow, we analyzed the temporal evolution of the flow around the obstacle. In order to obtain quite regular velocity fields, the original instantaneous velocity fields have been temporally averaged within a non-overlapping window of 0.2 s.

By applying VIP procedure on sequential velocity fields and developing a procedure for solving the correspondence problem (*i.e.* recognizing the same vortex structure at different instants of time) we tracked the path of the vortex centres. Then we calculated the convection velocity and shedding frequency from the trajectories of the vortex centres.

Fig. (2a) shows the evolution of flow in the extrados region (Δt=0.2 s). The dimensionless displacements *x/L* of the marked vortex is evidenced in Fig. (2b), where, the movements of the centre of vortices shedding along the extrados of the cylinder are reported. Every line represents the horizontal trail of a vortex from the leading edge toward the trailing edge.

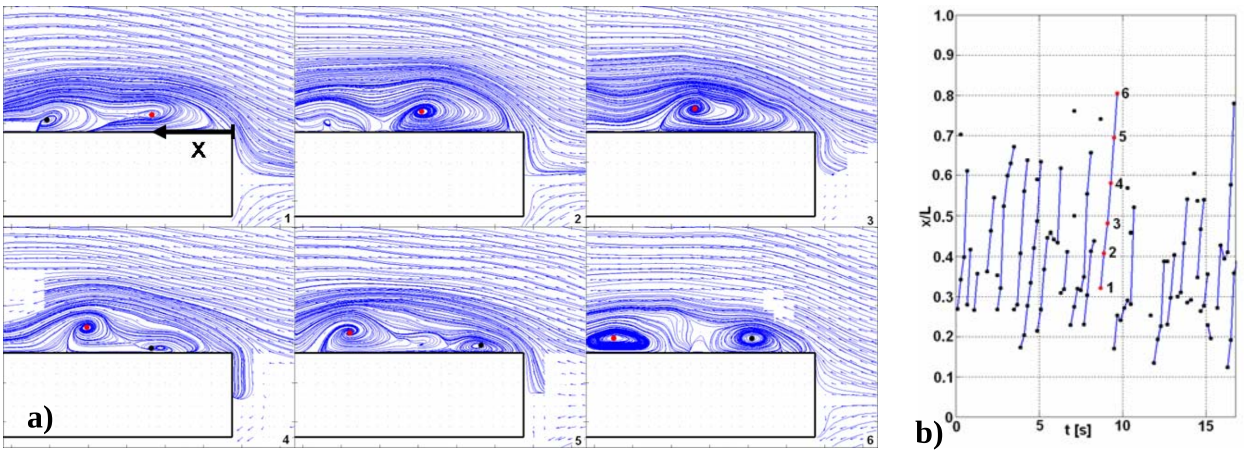

Fig. 2: a)Sequence of images of the extrados flow. b) Horizontal movements of vortex centres versus time

The same analysis has been carried for the intrados region and for the base region. Fig. (3a) shows a complete cycle of TEVS mechanism (shedding of two contra rotating vortices), while Fig. (3b) reports the horizontal movements of the vortex centres *x/s* versus time. In this region, we found a good agreement between dynamics of the flow evolution and the local trend of velocity components. Indeed, Fig. (4) shows that during a velocity period, two contra-rotating vortices are shed. Moreover, frequency spectra of local velocity confirm the frequency calculated with this technique.

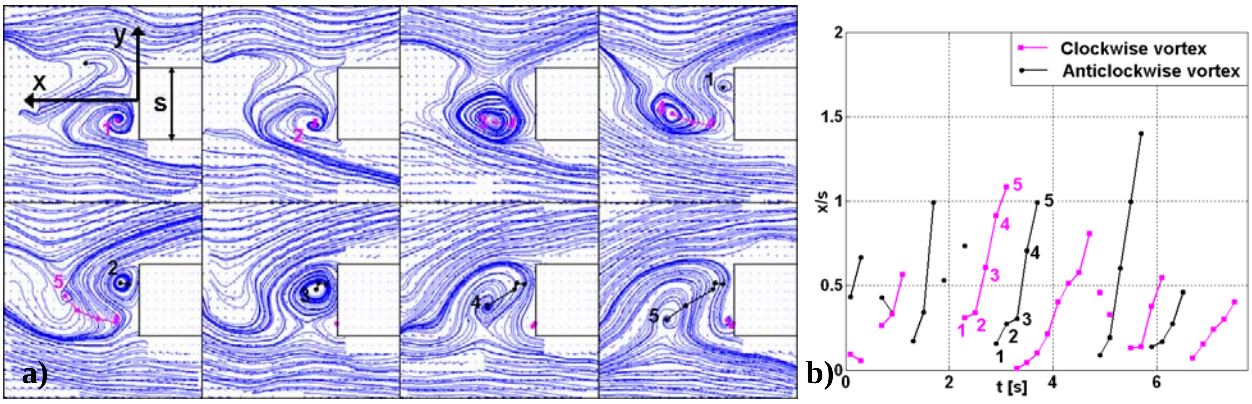

Fig. 3: a) Sequence of images of the base region flow. b) Horizontal movements of vortex centres versus time.

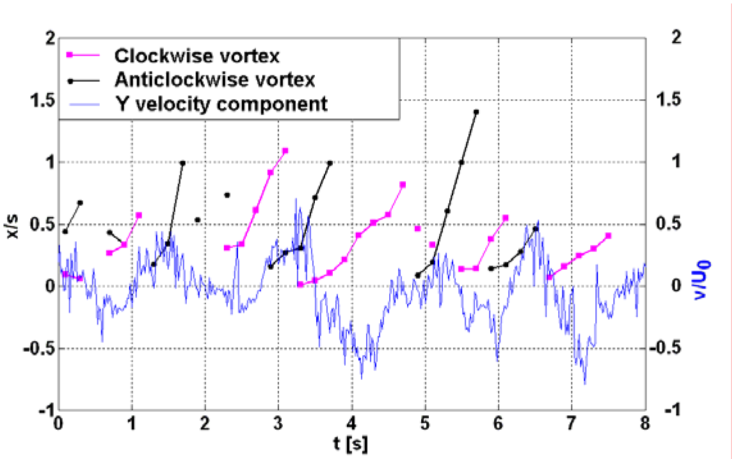

Fig. 4: Developing of the vortex structures and trend of the vertical component of velocity in point x/s=0.5, y/s=0. Where v/U_0 is the ratio between the vertical velocity component and the undisturbed mean velocity of flow upstream the obstacle.

The convection velocities and shedding frequencies of the main vortex structures shedding from the leading and trailing edge of the cylinder have been compared with values of literature, usually calculated by correlation and frequency analysis of local velocity time history (*e.g.* Cherry *et al.* [2]; Saathoff and Melbourne [8], Tafti and Vanka [9], Nakagawa *et al.* [6]). Moreover, the shedding frequency of the base region has been compared with the one obtained by frequency analysis of the hydrodynamic loading on a very similar test case used in a previous work (Malavasi and Guadagnini [5]). Tab. 1 summarizes the values of convection velocity and shedding frequency calculated with our procedure for the two cases analyzed, and the literature values. The results of the present study agree with the literature ones; we note that literature studies usually refer to low blockage configurations (γ=0~5 %), while in this and previous works (*e.g.* Malavasi and Guadagnini [5]) we dealt with a higher blockage (γ=14 % for the case h_b/s=2.33, γ=17 % for the case h_b/s=1). Empty fields of Tab. 1 correspond to values we could not calculate with our technique or we did not find in literature studies. Our results evidence that case with h_b/s=1 is characterized by higher frequencies; this result is in good agreement with the study of Okajima *et al.* [7] and Davis *et al.* [3]. Values of convection velocity don't show relevant difference in the two cases.

	Shedding frequency f			**Convection velocity u_C**		
	Present study		Literature value	Present study		Literature value
	$h_b/s=2.33$	$h_b/s=1$		$h_b/s=2.33$	$h_b/s=1$	
Extrados	$0.73\ U_0/x_R$	$1.01\ U_0/x_R$	$0.5 \div 0.7\ U_0/x_R$	$0.41\ U_0$	$0.43\ U_0$	$0.4 \div 0.5\ U_0$
Intrados	$0.71\ U_0/x_R$	-		$0.43\ U_0$	-	
Base region	$0.20\ U_0/s$	$0.21\ U_0/s$	$0.20\ U_0/s$	$\sim 0.25\ U_0$	$\sim 0.25\ U_0$	-

Tab. 1: Calculated and literature values of convection velocity and shedding frequency. x_R is the time average reattachment length.

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