THE NEAR WAKE OF A SQUARE CYLINDER UNDER THE EFFECT OF CORIOLIS FORCES

Ignacio Mayo[1], Filippo Coletti[2] & Tony Arts[1]
[1]*Turbomachinery & Propulsion Department, von Karman Institute for Fluid Mechanics, Rhode-Saint-Genèse, Belgium*
[2]*Mechanical Engineering Department, Stanford University, Stanford (CA), USA*

Rotational effects are important in a broad spectrum of natural and industrial problems, from turbomachinery to atmospheric flows. Even when there are no density variations in the field (and the effect of the centrifugal force is therefore not dynamically significant), Coriolis force alters the stability of the shear layers, affecting differently regions of cyclonic and anti-cyclonic vorticity. While theoretical and numerical investigations are abundant in the literature, there is still a lack of accurate experimental data due to practical difficulties in measuring velocity in the rotating frame of reference. In most past experimental studies, point-wise velocimetry techniques are used (e.g. [1]), which cannot identify instantaneous flow structures or velocity gradients. Few studies in literature present full field data in rotating channels using PIV, but typically the imaging system is attached to the fixed frame [2]. The relative velocity is obtained by subtracting the peripheral velocity from the measured absolute velocity, resulting in low temporal resolution and large uncertainties, especially at high rotation rates.

The focus of the present study is the effect of system rotation on the turbulent wake of a square cylinder. The axis of rotation is parallel to the cylinder axis. Previous investigators have either inserted a cylinder in a developed crossflow [3], or used a rotating towing tank [4]. In the former case, the wake is affected by the effect of Coriolis on the crossflow, which produces a sheared velocity profile and secondary flows [5]. On the other hand, the towing of the cylinder as an analogue for the crossflow is not fully justified, as the rotating frame is not Galilean. Moreover, the limited measurement time allowed in a towing prevents the acquisition of converged statistics.

We have performed PIV measurements in a rotating wind tunnel with a square cylinder is inserted in the test section. The rig is mounted on a rotating table together with the illumination and imaging hardware. The wind tunnel is sketched in Fig. 1. The blockage ratio imposed by the cylinder to the channel flow is 0.25, whereas the aspect ratio of the cylinder is 12. The Reynolds number based on the cylinder width and the channel bulk velocity is 930. The working fluid is air. No density variations are present in the flow, so the only effect induced by rotation is the Coriolis force. Velocity fields are acquired along the symmetry plane of the channel, perpendicular to the cylinder axis. The PIV system consists of a continuous laser diode and a CMOS high-speed camera with internal memory. The rotating disk is 2.5 m in diameter and is set in rotation at 80 rpm in counter and clockwise senses by a DC motor. The Reynolds number based on the cylinder diameter and channel bulk velocity is 930. The Rotation number (inverse of the Rossby number) is 0.48 for both senses of rotation. The present facility, which is shown in Fig. 2, is derived from the one described in [6], but has an improved flow conditioning: a system of honeycomb and screens placed just upstream of the cylinder provide a uniform incoming flow, without the shear or the secondary motions of a developed rotating channel flow.

Ensemble-averaged results (from 1000 uncorrelated realizations) show how the system rotation breaks the symmetry of the wake. This is clearly illustrated in Fig. 3, where the mean streamlines are superimposed to rms of streamwise velocity fluctuations. The characteristic two-foci pattern of the cylinder wake is substituted by a focus-saddle configuration. Such pattern is a consequence of the increased entrainment into the anti-cyclonic side of the separation produced by Coriolis force. The increased entrainment in turbulent shear layers destabilized by rotation was reported by several authors (e.g. [7]). The result is a net mass flux from the cyclonic to the anti-cyclonic side, which is reflected in the ensemble-averaged streamlines. It is remarkable that the extent of the wake is greatly shortened by rotation. This likely implies a reduction in drag, which would be in disagreement with previous measurements in a rotating towing tank [8]. Direct drag measurements are needed to clarify this point.

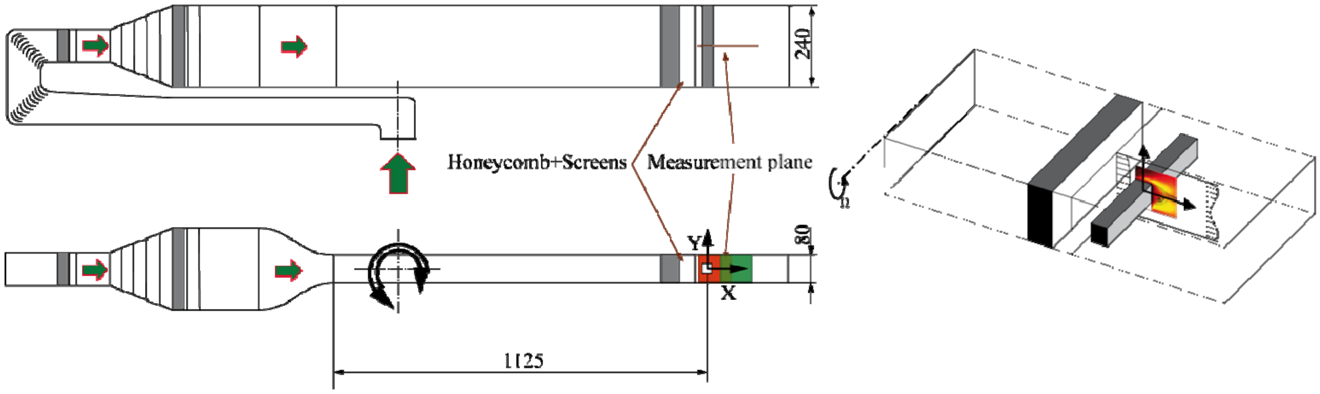

Figure 1. Schematic of the wind tunnel (left) and of the measurement section (right).

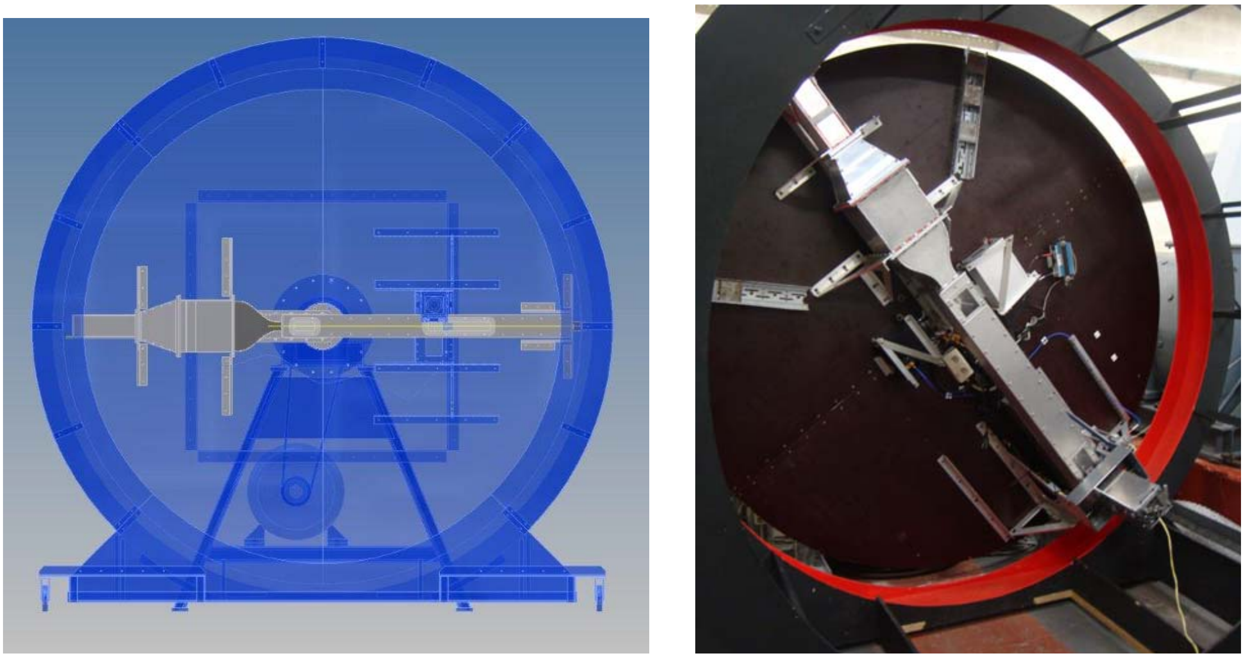

Figure 2. Technical drawing (left) and photograph (right) of the rotating facility.

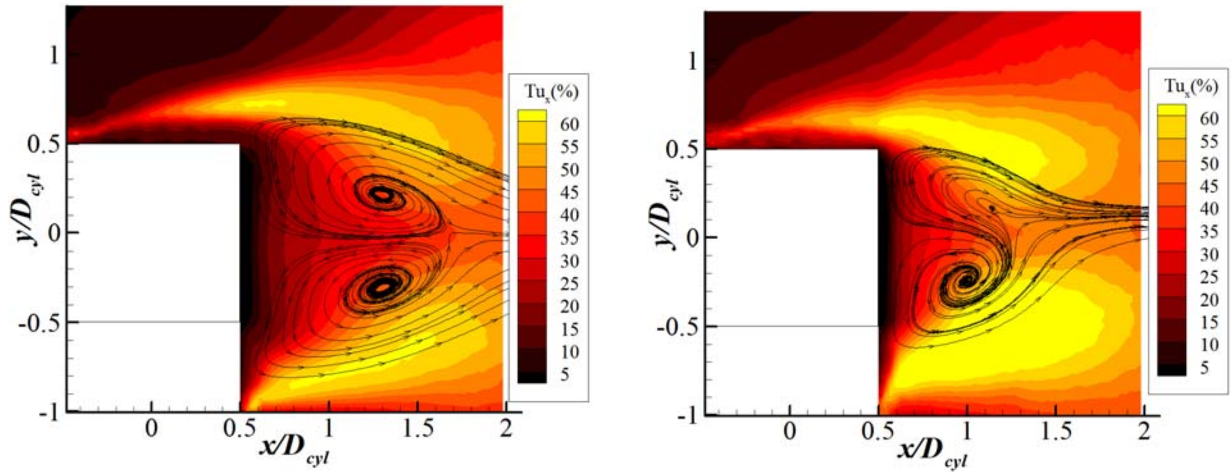

Figure 3. Mean streamlines and color contours of rms of streamwise velocity fluctuation. Left: non-rotating case. Right: counterclockwise rotation.

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