DRAG REDUCTION OF A SQUARE CYLINDER USING COMPLIANT FLAPS

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INTRODUCTION

Turbulent wakes induced by massive separations are often encountered in transport applications. Due to its industrial and societal impact, drag reduction is one of the key issue of flow control. For that purpose, passive to active control strategies have been applied to canonical turbulent wakes [see e.g. 2, 3, 6, 5, 8, 9]. In this work, we investigate the control of a turbulent wake using compliant flaps set on both sides of a square cylinder [7]. Their design is based on a bio-inspired approach in order to mimic bird's feathers [4]. Furthermore, these flaps are hinged so as they can freely rotate around their leading edge in order to self-adapt to the flow dynamics. Depending of the flap properties, e.g. porosity, drag reduction up to 25% can be achieved. The aim of this study is to get a better understanding of the mechanisms responsible for this drag reduction.

EXPERIMENTAL SET-UP

The experiments are performed in a wind-tunnel into which a square cylinder of width $H = 60$ mm is set. More details about the experimental facility can be found in [7]. The Reynolds number defined as $Re = U_\infty H/\nu$ with U_∞ the freestream velocity and ν the kinematic viscosity ranges within 2×10^4 to 6×10^4. The model is equipped with static pressure taps and the flow field is investigated via hot-wire anemometry and Particle Image Velocimetry (PIV, hereafter). The flap dynamics is captured via high-speed imaging.

RESULTS

The mean streamwise velocity U computed from the PIV measurements is shown in dimensionless form in Figs. 1 and 2 for the baseline and the controlled configurations, respectively. The recirculation length L_f is much larger for the controlled wake meaning that the vortex cores featuring the recirculation region are pushed downstream. This results in an increase of the base pressure and accordingly in drag reduction.

In 2D configurations, an integral formulation based on the momentum equation yields [1]:

$$C_d = 2\int \frac{U}{U_\infty}\left(\frac{U_\infty - U}{U_\infty}\right) d\left(\frac{Y}{H}\right) + 2\int \left(\frac{v'^2 - u'^2}{U_\infty^2}\right) d\left(\frac{Y}{H}\right),$$

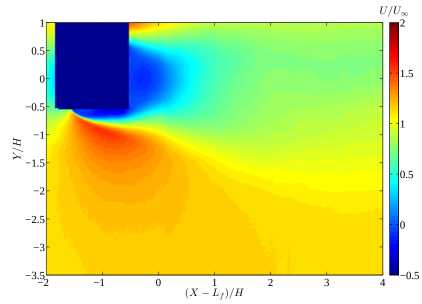

Figure 1: Mean streamwise velocity of the baseline flow.

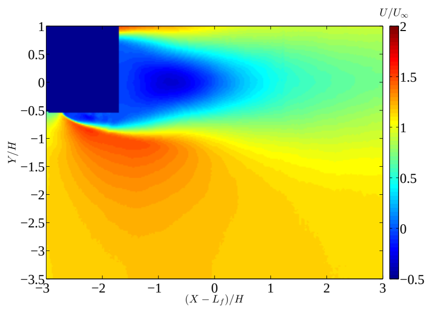

Figure 2: Mean streamwise velocity of the controlled flow.

where C_d is the drag coefficient and u'^2 and v'^2 are the normal Reynolds stresses along the streamwise (X) and the transverse (Y) directions, respectively. This expression emphasizes the contribution of the mean velocity deficit and the turbulence (more especially its anisotropy) to the drag. The terms involved in the hereinbefore expression can be easily inferred from the PIV data.

The dimensionless mean velocity deficit and the dimensionless turbulence anisotropy are plotted in Figs. 3 and 4, respectively. Notice that to be meaningful, the comparison between the baseline and the controlled flows is done at the same location respective to the end of the recirculation region, i.e. at the same $(X - L_f)/H$. It appears clearly that the mean deficit is roughly unchanged by the control device, whereas the turbulent anisotropy is significantly reduced. In fact, the use

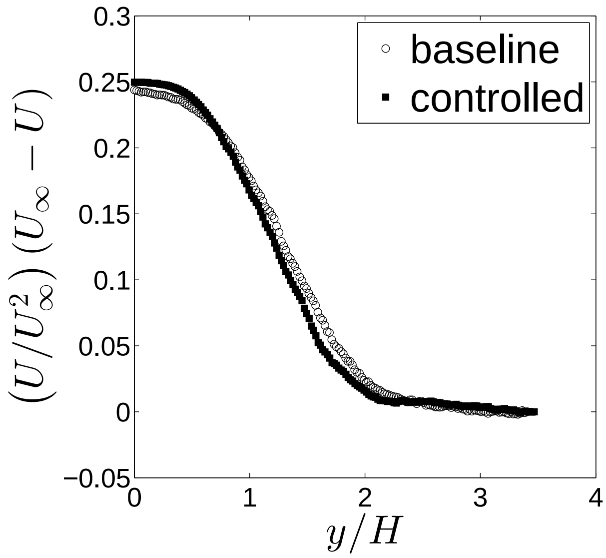

Figure 3: Mean velocity deficit at $(X - L_f)/H \approx 1.67$.

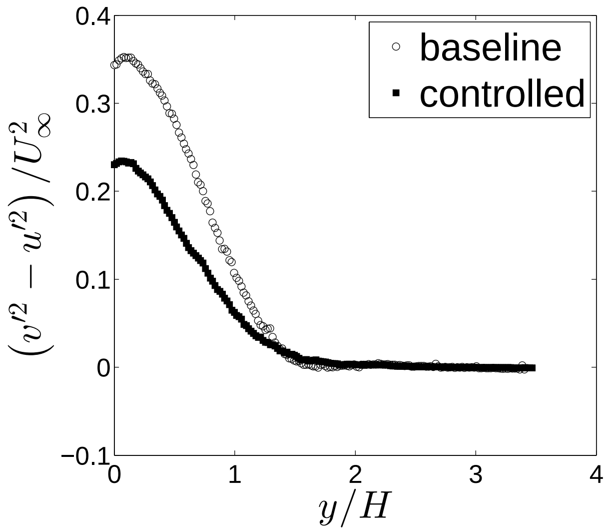

Figure 4: Turbulence anisotropy at $(X - L_f)/H \approx 1.67$.

of the compliant flaps mainly reduces the transverse normal Reynolds stress v'^2 meaning that the mean flow entrainment is also reduced.

CONCLUSIONS

The turbulent wake of square cylinder has been controlled by means of compliant flaps which can adjust themselves to the flow dynamics. The comparison between the baseline and the controlled configurations is performed an experimental investigation. The main results presented here are twofolds: *i.* the recirculation region is longer when control is applied and *ii.* the turbulence anisotropy is strongly reduced in the wake. Altogether these changes lead to drag reduction up to 25%. During the conference presentation, a deep analysis of the spreading rate of the wake and the Reynolds stresses scaling will be provided. Furthermore, the relationship between the flapping frequency of the control devices and the vortex shedding will be investigated.

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