FUZZY COATING INTERACTION ON VON KÁRMÁN VORTEX STREET

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Summary We experimentally study the fluid/solid interaction of a fuzzy coating on the dynamic and topology of the flow past a cylinder at low Reynolds number. The instantaneous velocity field is investigated for various configurations and compared to a reference cylinder: all configurations increase the recirculation area (by up to +128%) and decrease the energy of fluctuations (by up to -43%). Then, the dynamic of the wake is analyzed with the help of High Frequency Particle Image Velocimetry. The fuzzy coatings are able to modify the vortex shedding frequency up to a state of an erratic wake. Finally, the length of the fuzz is increased until they start behaving like a porous coating or that the fuzzes become flexible enough in order to actively interact with the flow.

Introduction

Flow modification by mimicking our natural environment has been an uprising research field for some time now. Over the past decade, some researcher have focus on the particular effect of fuzzy coating. The numerical simulations by Favier et al [1] and more recently the experimental investigation by Niu et al [2] have demonstrated the ability of a self-adaptive hairy coating to significantly reduce the lift fluctuations by -44% and the drag by -15% through naturally adapting to counteract the near-wall separated flow. Gosselin et al [3] studied experimentally and theoretically the ability of poroelastic system to reduce drag. In some cases, solitary filament can even be sufficient to produce nonlinear phenomenon impacting the vortex shedding (Shelleyet al [4]).

Results

We have decided to study the effect of different coating on the wake past a cylinder at various Reynolds number (280 to 1500). For that purpose, multiple fuzz length, stiffness and packing density materials have been applied to cylinders of diameter D. The apparent diameter D_a, including the fuzzy coating, varies from $1.13D$ to $3D$ depending on the configuration. Three materials, called $F1, F2, F3$ with a varying packing density from ϕ_1 = 0.005 to 0.025 are being investigated experimentally in a free surface water channel with the following test-section dimension: $10D$ (width) x $14D$ (height) x $70D$ (length)(figure 1). We made the approximation that the side effects due to the walls were negligible. The wake behind the cylinder is measured by high frequency Particle Image Velocimetry. Glassbeads ($\rho \approx 1.05kg/m^3$, $d \approx 10\mu m$) are used as tracer particles and the middle plane is illuminated by a 1.8 Watt continuous-wave semiconductor laser (532nm). A high-speed CMOS camera is used to acquire the images at a frequency of 83 Hz or 376 Hz for a resolution of 1280 x 1024 pixels. Series of 20000 consequential frames are recorded.

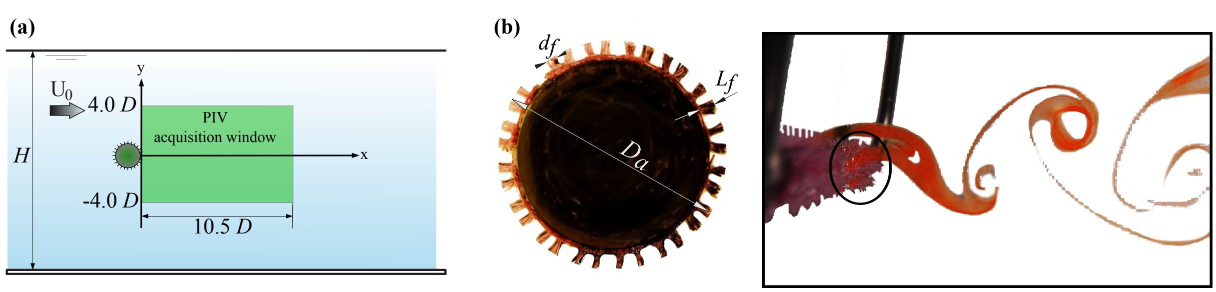

Figure 1. (left) (a) schematic of the experimental setup: $D = 15mm$, $H = 14D$; (b) cross section of one of the fuzzy cylinder (F1). **(right)** Visualization of the flow past a cylinder with fuzz length of $1D$; coloring coming upstream is perspiring through the fuzz layer.

The analysis of the time averaged flow displays significant differences in the average topology. Looking at the recirculation area behind some of the cylinders, defined by $U_x = 0$, we can clearly see that its size is related to the length and the type of the fuzz (figure 2 (left)). The recirculation area length for the reference cylinder is $1.58D$ and increases to $2.10D$ and $3.60D$ as the length of the fuzzes of material $F1$ are increased from $0.1D$ to $0.2D$. In comparison to the reference cylinder, it represents a length increases of respectively +33% and +128%. An increase of the recirculation area means that the vorticity attached to the cylinder will move further downstream before to roll into an independent vortex. As a consequence, the fluctuating forces acting on the cylinders due to the forces exercised by the rotating vortices have to be reduced as the oscillations in the wake have more difficulties to go upstream.

The material $F2$ extends the length of the recirculation area by +114% with a coating thickness of only a third of the "$F1$ long" material (figure 2(left(d))). However, by increasing the fuzz length of material $F2$, we do not achieve to increase

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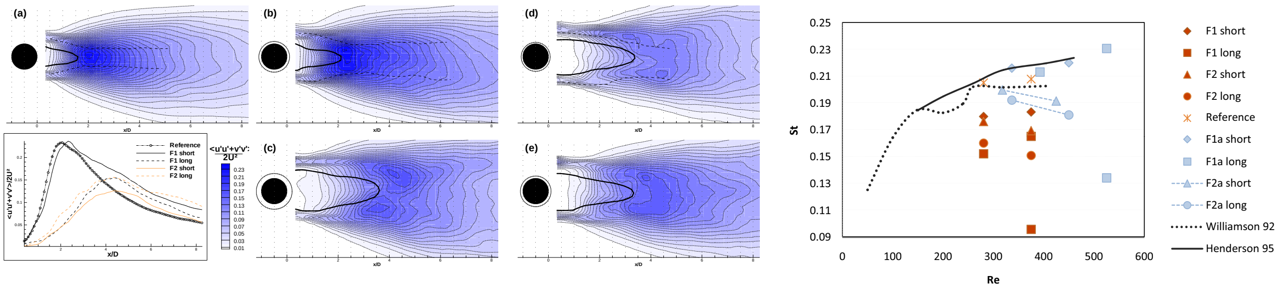

Figure 2. **(left)** Superposition of the energy intensity of the fluctuations, $< u'u' + v'v' > /2D^2$ (flood) and the recirculation area defined by $U_x = 0$ (bold black line); (a) reference, (b) F1 short, (c) F1 long, (d) F2 short, (e) F2 long. Dashed lines on (a), (b) and (d) define the trajectories of the vortex core (Jeong et al [5]). The cylinders of diameter D are in bold black, black dotted circle around them defines the apparent cylinder. The graph displays the energy of fluctuations along the axis centered in the wake of the cylinder. Re = 375 D. **(right)** Strouhal number vs Reynolds number. The F1 short/long and F2 short/long data are calculated using the solid diameter D of the cylinders; The F1a short/long and F2a short/long data are calculated using the apparent diameter D_a. The data "Williamson 92" and "Henderson 95" are taken from the review by Williamson [6].

the recirculation area any further.
Looking at the energy intensity of the fluctuations, we observe a significant reduction in the maximum intensity for the configurations with fuzzes $L_f \geq 0.2D$. The "$F2$ short" material reduces the intensity by -43% (graph 2 (left)). The averaged topology is also noticeably changed. The area of highest intensity, located just downstream of the recirculation bubble in the case of the reference cylinder, is being divided in two as the recirculation bubble increases in length. The material $F2$, due to a fuzz orientation differing from top and bottom generates a slightly asymmetric wake. This asymmetry is less important in the case of the longer fuzzes as it is more likely to adapt to the flow due to its lower stiffness.
The use of high frequency PIV gives access to the vortex shedding frequency and the associated Strouhal number which can be compared to the results summarized by Williamson [6] (figure 2 (right)). If we use D as the reference length for the definition of the Reynolds number and the Strouhal number, we can see that the add of a fuzzy coating on the cylinder drastically reduces the vortex shedding frequency. Yet, if we use the apparent diameter we get a more complex picture. At Re $\sim$ 320, the material $F2$ only slightly decreases the associate Strouhal number. But as the Reynolds number increases, the associate Strouhal number decreases even more, going against the results of Henderson [7] for a smooth cylinder. This tendency is emphasized with the longer fuzz configuration of this material.

The material $F1$, with short fuzzes, seems to have no influence on the St vs Re curve. With longer fuzzes, the tendency could be considered the same if it wasn't for a double frequency at the highest Reynolds number. Looking more closely at this configuration using a modal decomposition of the flow, we found out that the "$F2$ long fuzz" configuration had a considerable effect of the vortex shedding. The correlation matrice lacks of subsidiary diagonal, proving the lost of the periodicity of the vortex shedding. This shows that a fuzzy coating can interact with the flow significantly enough to destabilize the von Kármán vortex street.

Conclusions

In conclusion, we are investigating the effect of a fuzzy coating on the vortex shedding of a cylinder. We are observing that fuzzes have an effect on the size of the recirculation area and the intensity of the energy of fluctuations: yet the tendency seems to depend on the material. $F1$ increases the recirculation area with the increase of the fuzz length (from +33% to +128%); $F2$ has a recirculation are approximately invariant between the short and the long fuzz configuration, however the shorter fuzz generate less energy of fluctuation (-43% compare to the reference). The differences between the various configurations are furthermore emphasized by the analysis of the flow dynamic and the St vs Re graph. The material $F2$ more significantly reduces the vortex shedding frequency as the Reynolds number increases. Nevertheless, the material $F1$ with fuzz long enough is able to almost cancel the periodicity of the vortex shedding.

References

[1] J. Favier and A. Dauptain and D. Basso and A. Bottaro: Passive separation control using a self-adaptative hairy coating. *J. Fluid Mech* **627**:451–483, 2009.
[2] J. Niu and D.L. Hu: Drag reduction of a hairy disk. *Phys. Fluids* **23**:101701, 2011.
[3] F.P. Gosselin and E. de Langre: Drag reduction by reconfiguration of a poroelastic system. *J. Fluid Struct*, in press, 2011.
[4] J.S. Shelley and J. Zhang: Flapping and Bending Bodies Interacting with Fluid Flows. *Annu Rev Fluid Mech* **43**:449, 2011.
[5] J. Jeong and F. Hussain: On the identification of a vortex. *J. Fluid Mech* **285**:69–94, 1995.
[6] C.H.K. Williamson: Vortex dynamics in the cylinder wake. *Annu. Rev. Fluid Mech.* **28**:477–539, 1996.
[7] R.D. Henderson: Details on the drag curve near the onset of vortex shedding. *Phys. Fluids* **7**:2102, 1995.