SYMMETRIES IN THE TURBULENT WAKE OF A SPHERE

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Abstract The axisymmetry of the turbulent wake past a sphere is studied experimentally at $\mathrm{Re} = 1.9\,10^4$. The set-up preserves the axisymmetry of the sphere so that the shedding has no preferred direction. The structure of the wake is analyzed from stereo-PIV measurements in the cross-flow directions and the effect of azimuthal disturbances are considered.

The sphere wake undergoes several transitions as the Reynolds number increases [2, 1]. At very low Reynolds numbers, the flow is steady and axisymmetric. A first bifurcation is reported ($\mathrm{Re} \approx 210$): a steady azimuthal mode $m = 1$ appears (m being the azimuthal periodicity). A lift force is generated and a pair of counter-rotating vortices develops downstream moving the wake off the streamwise axis. A second bifurcation occurs at a higher Reynolds number ($\mathrm{Re} \approx 277$): the wake starts oscillating but preserves the same planar symmetry. Becoming turbulent, the preference toward this azimuthal plane of symmetry vanishes and the flow becomes statistically axisymmetric. At moderate Reynolds numbers, large scale vortex loops developing from the end of the recirculation bubble are reported.
Experimentally, the study of the axisymmetry of a sphere wake is a challenge: for example, wire supports in the cross-flow direction breaks the axisymmetry and a support from behind the sphere controls the wake. The present work aims at generating a perfect axisymmetry wake in order to study the effect of azimuthal disturbances.
The experimental set-up is presented in Fig. 1. The sphere is held using a rod from the front and mounted on a rigid

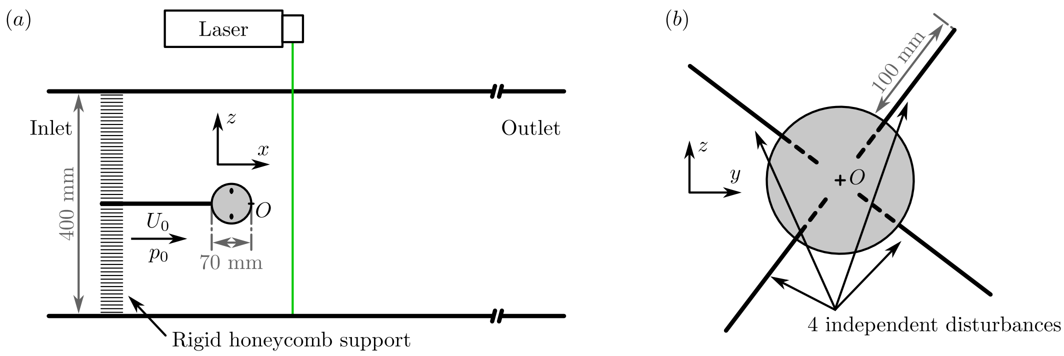

Figure 1. (a) Experimental set-up of the model in the wind tunnel; O sets the origin of the coordinate system. (b) Scheme of the sphere with four independent (removable) disturbances.

honeycomb support to preserve the axisymmetry (see Fig. 1a). The diameter of the sphere is 70 mm and the Reynolds number is $1.9\,10^4$. Besides, rods of 2 mm diameter can be placed in the cross flow direction to generate $m = 1$, 2 or 4 disturbances. The analyses are made from stereo-PIV measurement in the cross-flow plane $x = D$; Each acquisition records 2000 image pairs.
The mean and fluctuating streamwise velocities in the cross-flow plane $x = D$ are presented in Fig. 2. The results is perfectly axisymmetric and the fluctuations of streamwise velocity are distributed in the shear layers: the shedding of the vortex loops has no preferred direction.

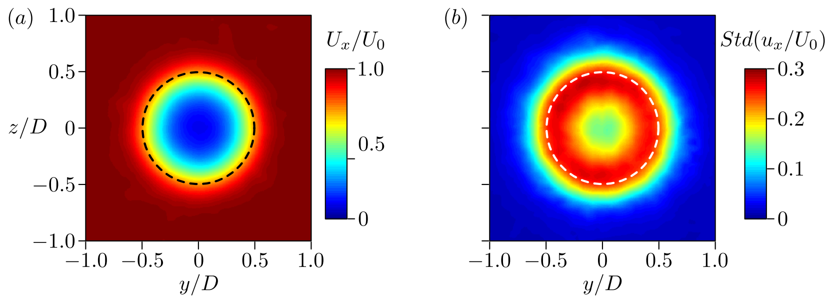

Figure 2. Mean (a) and fluctuating (b) streawise velocity in the plane $x = D$.

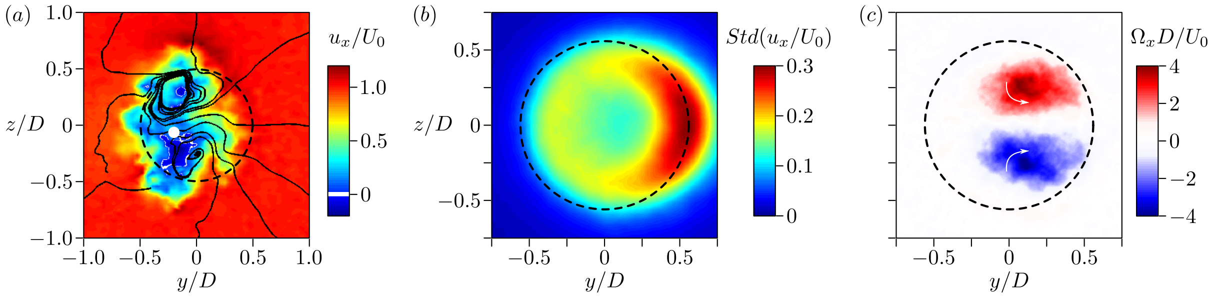

Figure 3. (a) Instantaneous velocity in the plane $x = D$; the white dot presents the barycentrum of momentum deficiency in the wake defined in (1): $r_w = 0.21D$ and $\theta_w = 197°$.(b) Fluctuations of streamwise velocity of the averaged wake for $\theta_w = 0$. (c) Streamwise vorticity of the the averaged wake for $\theta_w = 0$.

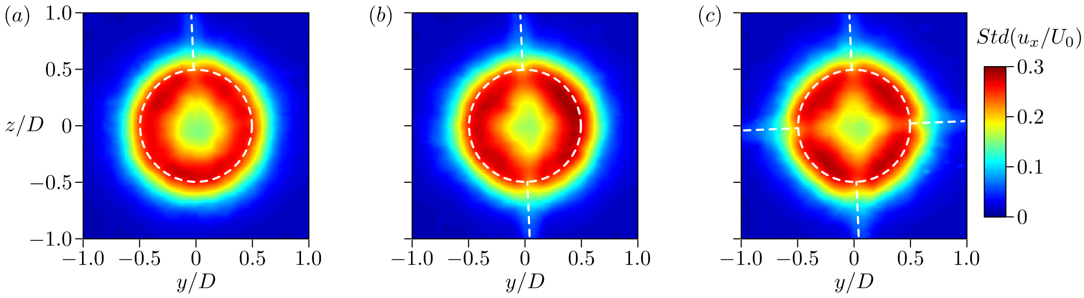

Figure 4. Fluctuating streamwise velocity in the plane $x = D$ for different disturbance periodicity (2 mm rods): $m = 1$ (a), $m = 2$ (b), $m = 4$ (c).

The statistics of this wake are considered from the instantaneous velocity measurements. One snapshot is given is Fig. 3(a). In this velocity field, one can observed that the wake is off-centered and a pair of counter-rotating vortices is distinguished. To quantify the asymmetry of the wake, the barycentrum of momentum deficiency is calculated as:

$$y_w = \frac{\int_{u_x<0.5U_0} y(1-u_x)}{\int_{u_x<0.5U_0} (1-u_x)}, z_w = \frac{\int_{u_x<0.5U_0} z(1-u_x)}{\int_{u_x<0.5U_0} (1-u_x)}. \tag{1}$$

For each snapshot, the orientation of the wake θ_w is obtained as the azimuth of the point of coordinates (y_w, z_w); in the example presented in Fig. 3(a), $y_w = -0.20D$ and $z_w = -0.06D$ so that $\theta_w = 197°$. A conditional averaging can then be computed to obtain the statistics of the wake for $\theta_w = 0$. The distributions of the associated streamwise velocity fluctuations and vorticity are presented in Figs. 3(b)–(c). The distributions are consistent with parallel vortex loops shed in the direction $\theta = 0$ at the end of the recirculation bubble.

As soon as the axisymmetry of the set-up is lost by adding one or several small rods, the wake presents preferred orientations related to the positions of the disturbance: the azimuthal periodicity ($m = 1$, 2 or 4) of the disturbance is recovered in the wake (see Fig. 4). These preliminary results show the critical effect of the cross-flow supports on the wake; the associated asymmetry of the shedding will be studied in the upcoming weeks.

References

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