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Very-low frequency wake dynamics of an axisymmetric body

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1. Introduction

The so-called *very-low-frequency* (VLF) azimuthal meandering of the reversed-flow region has been shown to contribute significantly to the unsteadiness of the turbulent wake flow past a bluff body of revolution (Rigas et al. 2014; Grandemange et al. 2014). Such an erratic behavior causes a continuous change in the wake topology and, particularly due to its slow nature, has been linked with the pronounced sensitivity that turbulent wake flows typically display with respect to the boundary conditions (Klei 2012; Wolf et al. 2013; Grandemange et al. 2012). Currently, the existence of such an instability is attributed to the persistence at high Reynolds numbers of the *reflectional symmetry breaking mode* (RSB) at laminar regime (Fabre et al. 2008; Bury and Jardin 2012). Despite the numerous investigations, some even attempting its theoretical modeling (Rigas et al. 2015), the relation of such an instability with the main vortex shedding process has not been characterized yet. Moreover, the backflow meandering reflects a condition of indifferent equilibrium in the azimuthal-radial plane, which is ultimately dictated by the axial symmetry of the flow. Such a very-low frequency dynamics however, still needs to be examined under the influence of off-nominal (i.e. asymmetric) inflow conditions.

Scope of the present work is to examine how the backflow unsteadiness evolves moving away from separation and additionally, to assess how it is affected by asymmetric inflow conditions. For this purpose time-resolved stereoscopic Particle Image Velocimetry (PIV) measurements are carried in the turbulent near-wake of an ogive-cylinder at different stations downstream of the base and for varying pitch angles, whereas the velocity fluctuations are examined using a snapshot POD approach.

2. Experimental apparatus and techniques

The experiments were conducted in a low-speed open-jet facility (W-Tunnel) operated at the TU Delft aerodynamics laboratories. The model was an ogive-cylinder with a total length-to-diameter ratio $L/D = 5$ (Fig. 1a).

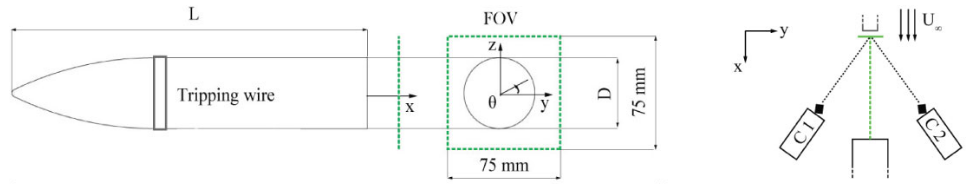

FIG. 1 Wind-tunnel model schematics with measurement FOV and annotation (a). Top view of PIV imaging configuration (b).

A roughness distribution was placed at the junction between the nose and the cylindrical main body in order to force turbulent transition of the boundary layer. Stereoscopic PIV measurements were carried at a freestream velocity of 20 m/s between 0.2 and 1.125 D downstream of the base trailing edge for pitch angles between 0 and 1°. For each test cases sets of 2500 to 5000 double-frame images were acquired such to account for observation-times between 50 and 100 s (i.e. 20,000 to 40,000 D/U_∞ in convective time units). Details on the experiments can be found in Gentile et al. (2016).

3. Very-low-frequency wake dynamics

The long time-averaged velocity field (Fig. 2) renders a toroidal wake topology featuring a circular shear layer bounding an inner region of reversed-flow. The color contours show the development of the wake shear layer, which thickens while moving away from separation (i.e.

increasing *x/D*), and the concurrent contraction of the wake cross-section. The in-plane velocity vectors define a typical zero net-vorticity in-plane axisymmetric pattern as a result of the long-term exploration of all azimuthal wake orientations.

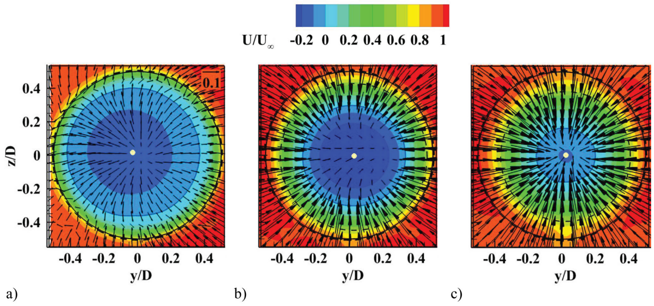

FIG. 2 Time-averaged velocity field. *x/D* = 0.3 (a), 0.75 (b) e 1.125 (c). Color coded out-of-plane velocity component. Vectors plotted every 5th grid point indicate in-plane velocity components. Model base edge in solid black. Mean shear layer axis in dashed black. Mean backflow centroid in yellow.

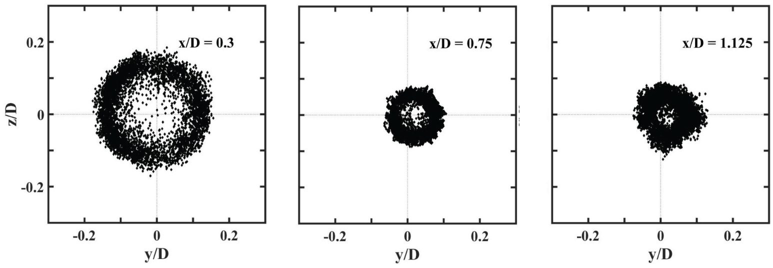

FIG. 3 Scatter-plots of the backflow centroid in-plane position.

The annular distributions defined by the scatterplots in Fig. 3, give evidence of a consistent precession motion of the backflow region about the model symmetry axis, whose amplitude decreases in the streamwise direction.

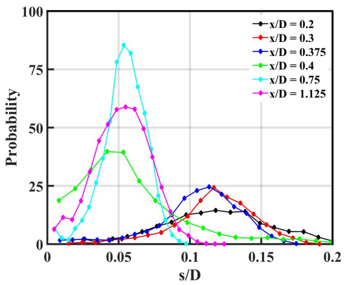

FIG. 4 Probability distribution of the backflow centroid relative radial displacement for increasing *x/D*.

As a result the backflow centroid radial displacement relative to the mean position s tends to reduce from approximately 0.13 D to 0.05 D, when moving away from separation (Fig. 4).

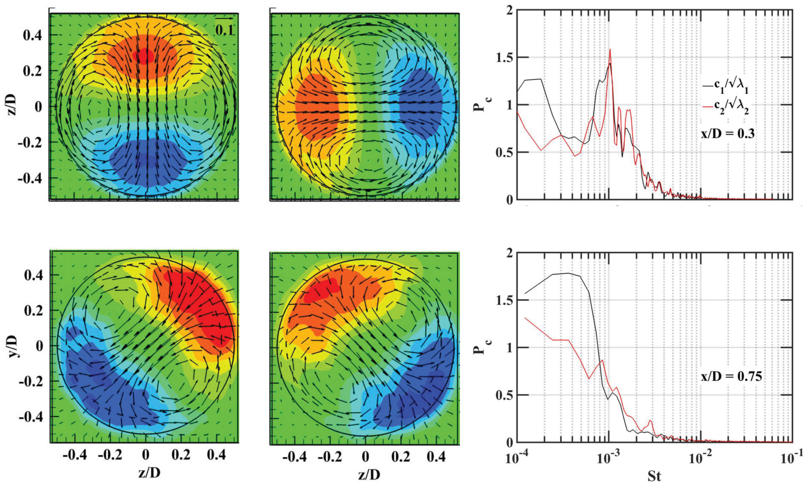

FIG. 5 POD modes $k = 1$ and $k = 2$ for increasing *x/D*. Spatial eigenfunctions (left) and PSD of the temporal coefficients (right). Color on the left coded out-of-plane component of the modes. In-plane vectors plotted every 5th grid point represent in-plane components. Model base edge in solid black. Mean shear layer axis in dashed black.

The spatial distributions of the POD modes (Fig. 5 left) indicate that the large-scale anti-symmetric fluctuating mode $m = 1$ can be linked with a very-low frequency backflow meandering only within 0.3 *D*, while reflecting a displacement of the entire wake region more downstream. Correspondingly the frequency spectra (Fig. 5 right) reflect the weakening of the very-low frequency contribution of the mode with increasing distance from the base.

4. Pitch effect on the backflow instability

Increasing misalignments of the model with respect to the freestream flow are found to progressively confine the erratic motion of the backflow region about the model axis and to introduce a preferred azimuthal orientation of the wake topology (Fig. 6). Consistently, the anti-symmetric mode $m = 1$ loses its spatial coherence, which fact is further highlighted by the vanishing of the corresponding very-low frequency peak (Fig. 7).

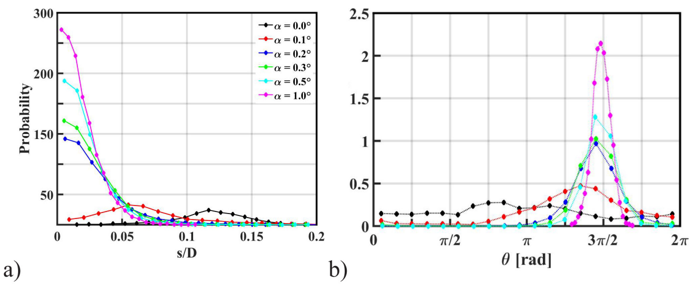

FIG. 6 Probability distribution of the backflow centroid positions for increasing pitch angles α. Relative radial displacement (a). Azimuthal coordinate (b).

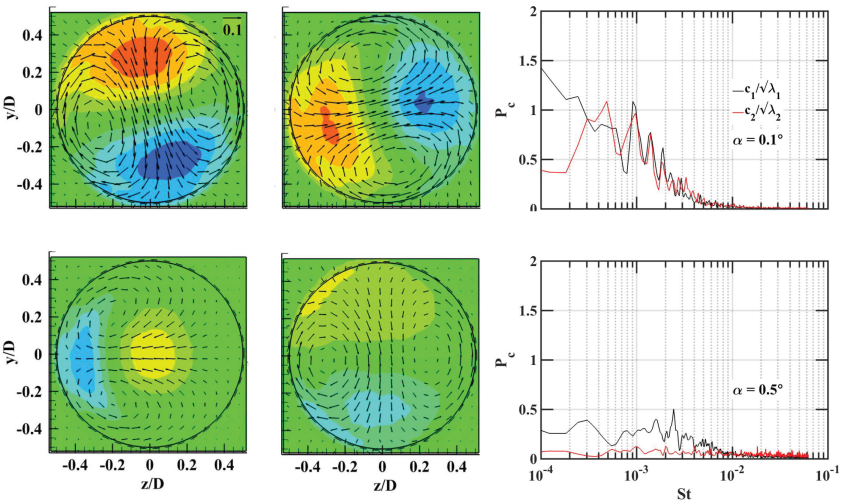

FIG. 7 POD modes $k = 1$ and $k = 2$ for small pitch angles α. Spatial eigenfunctions (left) and PSD of the temporal coefficients (right). Color on the left coded out-of-plane component of the modes. In-plane vectors plotted every 5th grid point represent in-plane components. Model base edge in solid black. Mean shear layer axis in dashed black.

5. Conclusions

Time-resolved stereoscopic PIV measurements were performed in the near-wake of an ogive-cylinder geometry at a Reynolds number $Re = 67{,}000$, based on the model diameter. The long-time averaged velocity field gave evidence of an axisymmetric wake topology in the azimuthal-radial plane featuring a circular shear layer and an inner region of reversed flow. The time-history of the backflow centroid position indicated a progressive that the amplitude of the backflow meandering fluctuations reduces moving away from the base. Moving closer to the rear-stagnation point the large-scale velocity fluctuations identified by POD could be attributed to the shear layer development. Increasing misalignments of the body with respect to the freestream flow were found to progressively inhibit te erratic character of the backflow region.

References

Bury, Y., and Jardin, T. "Transitions to chaos in the wake of an axisymmetric bluff body", *Ph. Rev. Lett.,* **376**, 3219-3222 (2012).

Gentile, V., Schrijer, F.F.J., van Oudheusden, B.W., and Scarano, F., "Low-frequency behavior of the turbulent axisymmetric near-wake", *Ph. Fluids,* **28**, 065102 (2016).

Grandemange, M., Gohlke, M., and Cadot, O., "On experimental sensitivity analysis of the turbulent wake from an axi-symmetric blunt trailing edge", *Phys. Fluids* **24**, 1-16 (2012).

Grandemange, M., Gohlke, M., and Cadot, O., "Statistical axisymmetry of the turbulent sphere wake", *Exp. Fluids* **55**, 11 (2014).

Klei, C. E., "Investigation of the Recirculation Region of a Generic Rocket Configuration Using Stereoscopic PIV", Proceedings of the 8th Pegasus-AIAA Student Conference, Poitiers, France (2012).

Rigas, G., Oxlade, A.R., Morgans, A. S., and Morrison, J. F., "Low-dimensional dynamics of a turbulent axisymmetric wake", *J. Fluid Mech*. **755**, 185-207 (2014).

Rigas, G., Oxlade, A.R., Morgans, A. S., Brackston, R.D., and Morrison, J. F., "Diffusive dynamics and stochastic models of turbulent axisymmetric wakes, *J. Fluid Mech.* **778** (2015).

Vanierschot, M., and Van Den Bulck, E., "Experimental study of low precessing frequencies in the wake of a turbulent annular jet", *Exp. Fluids,* **50**(1), 189-200 (2011).

Wolf, C.C., You, Y., Hörnschemeyer, R, Lüdeke, H., and Hannemann, V., "Base-flow sensitivity of a generic rocket forebody towards small freestream angles," EUCASS Proceedings Series – Advances in Aerospace Sciences, **5**, 169-190 (2013).