BI-STABILITY OF THE TURBULENT WAKE PAST PARALLELEPIPED BODIES WITH VARIOUS ASPECT RATIOS AND GROUND EFFECT

Grandemange Mathieu[1], 2, Gohlke Marc [1] & Cadot [2]
[1]*PSA Peugeot Citroën, Research and innovation department, Vélizy-Villacoublay, France*
[2]*ENSTA ParisTech, Unité de Mécanique, Palaiseau, France*

Abstract Recently, bi-stable properties of the turbulent wake past the Ahmed reference body has been observed [3]. A parametric study is performed to detail the conditions of existence of such bi-stable flow by changing the ground clearance and the aspect ratio of the base (height/width). The preliminary measurements show that the underbody flow is not a necessary condition and the presence of the floor does not necessarily prevent a bi-stable behavior in the vertical direction.

Global bi-stability of turbulent flows have been observed in closed-cell geometries [6]. The recent experiments of Grandemange *et al.* [3] show that at long timescales $T_l \sim 10^3 \, W/U_0$, the turbulent wake of an Ahmed geometry shifts between two preferred reflectional symmetry breaking positions which leads to a statistical symmetric wake. The origins of this phenomenon are found in the laminar wake: at $\mathrm{Re} = 340 \pm 10$, the wake undergoes a pitchfork bifurcation from a trivial steady symmetric state to a steady reflectional symmetry breaking regime. Such a phenomenon is reminiscent of the loss of axisymmetry after the first steady bifurcation in the wakes of spheres and disks [5, 2].
The present work aims at clarifying the ingredients leading to bi-stable behaviors observed in the wakes of three-dimensional blunt geometries. A parametric study exploring the effects of the aspect ratio of the base (height/width) and of the ground clearance is performed.

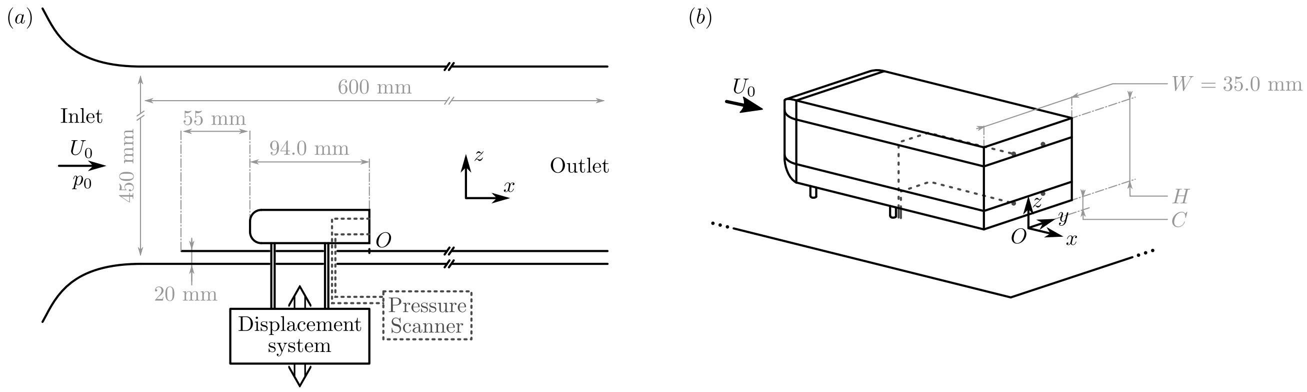

Figure 1. (a) Experimental set-up of the model in the wind tunnel; O sets the origin of the coordinate system. (b) Scheme of the body; grey dots on the base are pressure taps; for clarity, only the pressure tubings from the two taps in the field $y < 0$ are displayed.

The studied bluff bodies are designed from the square-back model used in the experiments of Ahmed *et al.* [1] at scale 9/100 (see Fig. 1). The body is made of several blocs: one for the lower part, one for the upper part and intermediate blocs of variable height so that the total height H of the body can be adjusted between 18 mm and 50 mm by steps of 1 mm. The ground clearance C of the geometry is precisely set between 0 mm and 50 mm with a precision better than 0.1 mm. The Reynolds number based on the width W of the base ($\mathrm{Re} = U_0 W/\nu$) is $4.5 \; 10^4$.
The pressure measurements are performed at 5 Hz, each sample is the average pressure on the associated 0.2 s window. The "instantaneous" pressure gradients in the y and z directions (averaged over 0.2 s), denoted $\mathrm{d}c_p/\mathrm{d}k$ with $k \in \{y; z\}$, are estimated from the four pressure taps located on the base (see Fig. 1). These pressure gradients are used to evaluate the instantaneous asymmetry of the wake [4].

The pressure data obtained for $H/W = 0.74$ (aspect ratio of the reference Ahmed geometry) are presented in figure 2. The results in figure 2(a) clearly evidence one centered state of the wake for $C/W = 0.03$ but two preferred states for $C/W = 0.10$ at $\mathrm{d}c_p/\mathrm{d}y \sim \pm 0.2$. The probability density function then presents one or two maxima (see $C^* = 0.03$ and $C^* = 0.10$ in Fig. 2b). The dependence of the probability density function toward the ground clearance show that the bi-stability of the wake is observed only for $C^* > 0.06$ and persist far from the ground.
The instantaneous pressure gradients of two other configurations are presented in figure 3. The case $H/W = 0.63$ and $C/W = 0$ (see Fig 3a) presents a bi-stable behavior in the y direction. Besides, the case $H/W = 1.34$ and $C/W = 0.1$ (see Fig 3b) evidences two preferred wake position in the z direction despite the presence of the ground. Thus, the under-

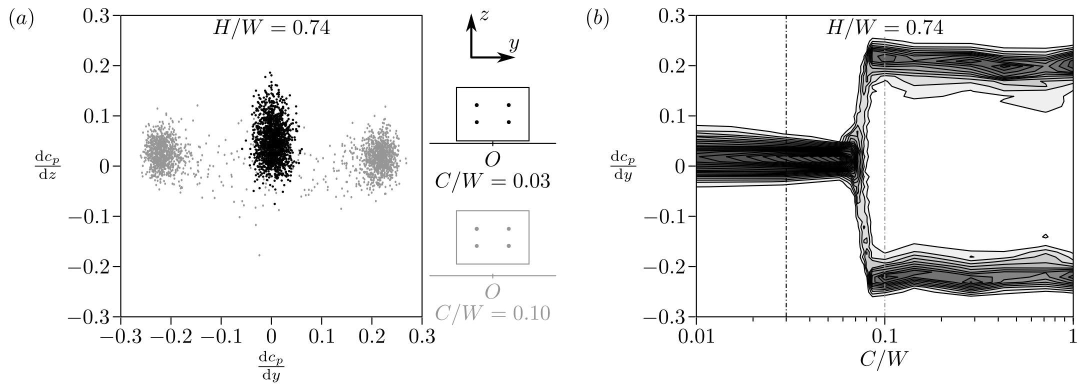

Figure 2. (a) Instantaneous pressure gradients in the y and z directions for $H/W = 0.74$: $C/W = 0.03$ (black dots) and $C/W = 0.10$ (gray dots). (b) Probability density function of the base pressure gradient in the y direction as a function of the ground clearance for $H/W = 0.74$; contour intervals are 1.

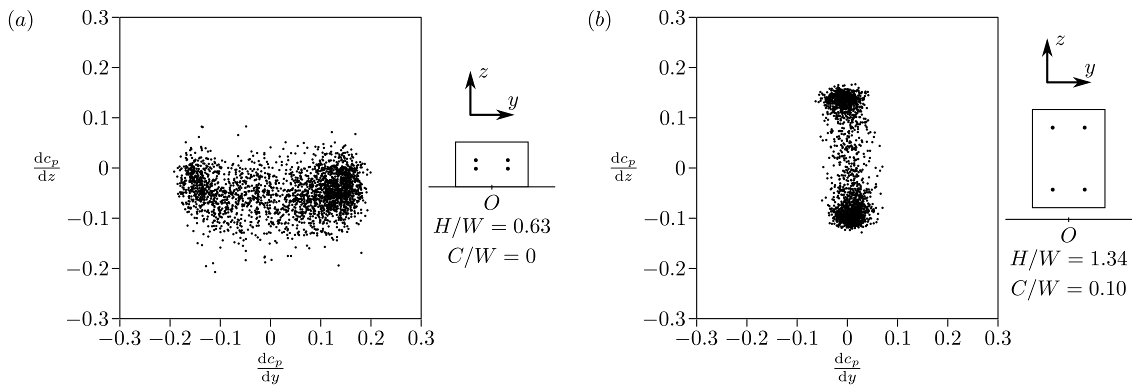

Figure 3. Instantaneous pressure gradients in the y and z directions: (a), $H/W = 0.63$ and $C/W = 0$; (b), $H/W = 1.34$ and $C/W = 0.10$.

body flow is not a necessary condition for bi-stability and the presence of the floor does not prevent bi-stable behavior in the vertical direction.

These preliminary results show that the symmetry breaking observed in the wake of the reference Ahmed geometry is not a singular case and relies on both the ground clearance and the aspect ratio of the base. The detailed conditions of existence of such bi-stable behavior will be studied in the upcoming weeks; there are of fundamental interest since such dynamics affect the understanding of the recirculation region and the associated asymmetries induce cross-flow forces generating additional drag.

References

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