



HAL
open science

Analysis and control of the symmetry breaking wakes behind an Ahmed body by Large Eddy Simulation

Stéphanie Pellerin, Bérengère Podvin

► **To cite this version:**

Stéphanie Pellerin, Bérengère Podvin. Analysis and control of the symmetry breaking wakes behind an Ahmed body by Large Eddy Simulation. Third international conference in numerical and experimental aerodynamics of, road vehicles and trains (Aerovehicles 3), Jun 2018, Milano, Italy. hal-04408855

HAL Id: hal-04408855

<https://hal.science/hal-04408855>

Submitted on 22 Jan 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Analysis and control of the symmetry breaking wakes behind an Ahmed body by Large Eddy Simulation

S.Pellerin^{*,**} and B. Podvin^{*}

Corresponding author: stephanie.pellerin@limsi.fr

* LIMSI-CNRS, Campus universitaire d'Orsay, bât 508, Rue John von Neumann, 91405 Orsay cedex, France

** Universités Paris Sud et Paris Saclay, Faculté des Sciences, Campus universitaire d'Orsay, 91405 Orsay cedex, France

Abstract: The wake behind an Ahmed body is calculated by LES and different types of control are applied, in order to act on the symmetry of the flow and to reduce the drag. POD is used to compare the numerical results with experiment and to analyze the spatial organization of the flow.

Keywords: Ahmed body, numerical simulation, POD, wake control.

1 Introduction

In the current energetic and environmental context, important topics in the automobile industry are drag reduction and control of separation around bluff bodies. For trucks and SUVs most of the drag is due to the recirculation region at the rear of the vehicle, which makes studies of the wake behind square-back bodies of particular interest. In this study, we use Large Eddy Simulation to solve the 3D turbulent flow around a square-back Ahmed body.

Experiments performed by Grandemange *et al.* [1] have shown the presence of symmetry-breaking (RSB) modes, which break the reflexion symmetry of the wake over very long time scales. It was shown that the occurrence of these quasi-steady RSB modes requires the ground clearance C to be large enough, *i.e.* larger than 10% H , where H is the height of the body.

To understand the effect of the ground clearance, the 3D unsteady turbulent flow in the near wake was analyzed, for two cases: (i) a large ground clearance of 30% H , and (ii) a nearly ground-free setting, modelled with a slip condition. A special effort is made to modelize a configuration similar to the reference experiment. POD was then applied to LES data to extract information about the most energetic structures of the flow in the full volume as well as on a plane corresponding to experimental observations [1,2]. This study permits a comparison to the reference experiment and an analysis of the 3D shapes of the modes. Different modified configurations are then implemented with the goal to reduce the deviation and recover the wake symmetry, in a control strategy objective.

2 Numerical method

The simulations are performed using Large Eddy Simulation approach for turbulent modelization of the incompressible Navier-Stokes equations. The subgrid scale model chosen is the mixed scale model, developed in LIMSI [3], $\gamma_{sgs} = [(C_S \Delta)^2 \|\bar{\omega}\|]^\alpha [C_B \Delta \sqrt{|k'|}]^{1-\alpha}$, where k' , which corresponds to the subgrid kinetic energy, and C_B are linked to the TKE model and C_S is linked to the Smagorinsky model. Δ is a

characteristically length of the local cell. This model has the advantage to damp smoothly the eddy viscosity in the regions where all the scaled are well solved. A pseudo-penalization method is used to model the solids, the Ahmed body and the ground. In this approach the calculation is penalized inside the solids through a penalization matrix and a special treatment is made for the frontiers. An infinite upstream velocity U_∞ is imposed at the inlet of the domain. In the vertical direction, slip conditions are imposed at the lower and upper surfaces. A periodicity condition is used for the transverse direction.

3 Results

The modeled Ahmed body has the same dimensions as the reference experimental body. LES use various grids, depending on the cases, from 10 to 20 million points. The grid is regular in the propagation direction x , and is inhomogeneous in the vertical direction y and the spanwise direction z , in order to correctly describe the boundary and mixing layers.

Simulations are performed for two Reynolds numbers $Re = U_\infty H / \nu_{\text{air}} = 4.8 \times 10^4$ and 3.9×10^5 , where ν_{air} is the viscosity of the fluid. Two reference geometries are studied (experiments [1,2]). Without control, the case considered corresponds to a large ground clearance and is equivalent to the experimental one [4,5,6]. With control, the shape of the body can be modified by the addition of flaps. Both passive and active control are investigated: the influence of flaps, aligned or not with the body, as well as the effect of blowing/suction are characterized.

Without control

The figure 1.left represents the vertical component of the vorticity ω_y , for a bottom slip condition. This top-view shows an apparent rather symmetric flow, for this unsteady field. The flow presents structures over a large range of spatial scales and it is fully turbulent. The mixing zone is well visible. The 3D structures are complex. For instance, the shedding phenomenon here mixes the influences of the two kind of vortex shedding rolls, for infinite bodies.

The time-averaged flow is computed and the corresponding top-view is represented on the figure 1.right. In our case, for a body with a width larger than its height, we obtain a left/right deviation of the wake [4,5]. The recirculation zones in the near wake are not symmetric. This result is in agreement with experimental observations, since the ground clearance is sufficiently large.

In addition, the unsteady velocities are recorded in the wake and the characteristic scales identified through Fourier transform. The figure 2 presents the temporal spectra of the longitudinal and vertical velocities in the near wake, in a plane at mid-height immediately downstream of the body. The vortex shedding frequency is recovered.

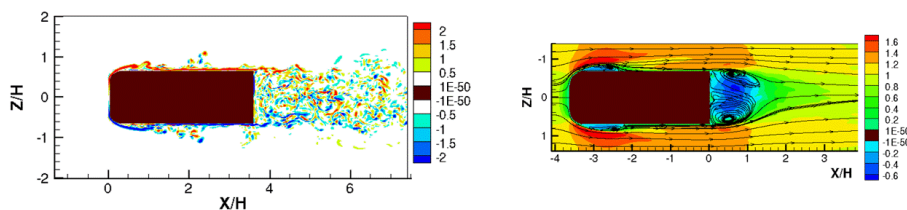


Figure 1: (left) Vertical component of the vorticity ω_y and (right) mean longitudinal velocity $\langle v_x \rangle$ and stream function, in a horizontal plane (zx) at mid-height of the body (top-view).

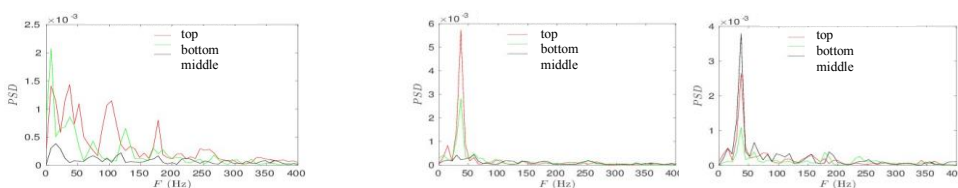


Figure 2: Without control. Spectra of the velocities in the near wake: (left) longitudinal velocity v_x for $x=H/2$, (middle) v_x for $x=2H$ and (right) vertical velocity v_y for $x=2H$.

With control

In a first approach to control the wake, new simulations are performed using flaps located at the end of the profile. Figure 3 presents instantaneous vertical components of the vorticity for two different kind of flaps: (i) aligned with the profile, creating a cavity at the end (left), or (ii) set at an angle of 10° (right). The wake is deviated in the second case. Experimentally, the two cases lead to a drag reduction. The drag reduction will be studied and the control on the wake analyzed. In a second approach, suction or blowing is applied on the roof of the body and an equivalent analysis performed.

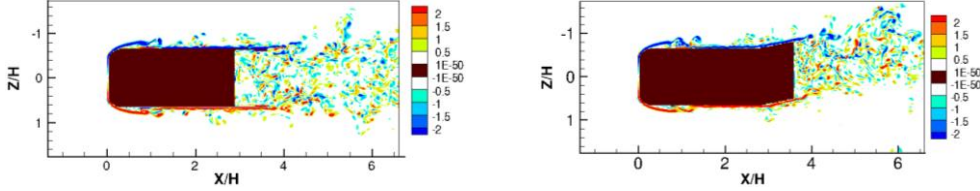


Figure 3: Top-view of vertical component of the vorticity ω_y with control by flaps: (left) aligned flaps and (right) flaps with an angle of 10° .

4 Identification of modes using POD

Proper Orthogonal Decomposition provides a way to extract the dynamics of energetically significant patterns in the flow. The POD is based here on the velocity field. The method of snapshots is implemented. Two domains are defined: (i) full 3-D POD and (ii) 2-D POD in the mid-height plane downstream of the body. 3D-POD permits to identify numerically the most energetic modes of the flow over the full domain. In addition, a 2D-POD allows a direct comparison between LES and experiments. Experimental data are obtained by PIV [2] in the horizontal plane at mid-height.

The first mode corresponds to the time-averaged flow [6]. The second mode captures the wake deviation. The third mode is associated with vortex shedding. Figure 4 shows a very good agreement between the POD modes identified in the LES and the experiment. We note that the second mode is antisymmetric with respect to the horizontal vertical plane (figure 4, mode 2), while the following mode is symmetric (figure 4, mode 3).

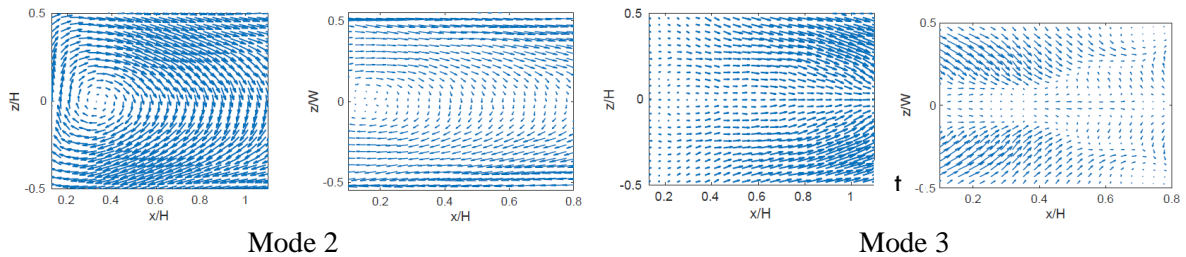


Figure 4: 2D-POD from 3D LES data and PIV experiment: (left) experiment and (right) simulation.

Using 3D-POD, we can now try to understand the organization of the full 3-D modes. The figure 5 presents the mean mode (mode 1), consisting essentially of a regular torus of velocity streamlines, and the deviation mode (mode 2). Note that the restriction of the second 3-D mode to the mid-height horizontal plane corresponds to the second 2-D POD mode. Over the entire domain, the 3D second POD mode corresponds to a horseshoe vortex aligned predominantly in the horizontal direction, with the head of the vortex located in the recirculation bubble. The next pair of modes correspond to vortex shedding modes (figure 6). Both modes 3 and 4 are symmetric with respect to the vertical plane. The vortex is primarily oriented in the spanwise direction, but deformations can be observed. Figure 6 right shows that the temporal amplitudes of the vortex shedding modes are coupled with each other and are characterized by a frequency of about 0.2 (in nondimensional units).

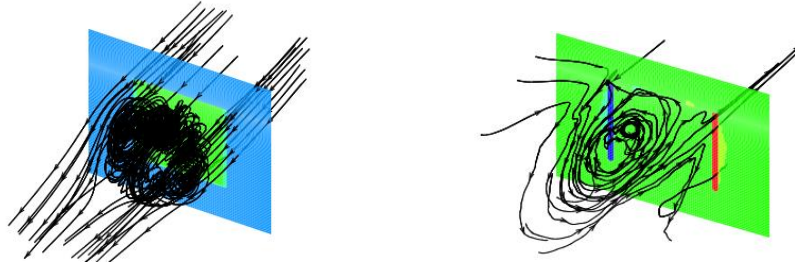


Figure 5: 3D-POD from 3D LES data: (left) mean mode and (right) mode 2 (breaking mode).

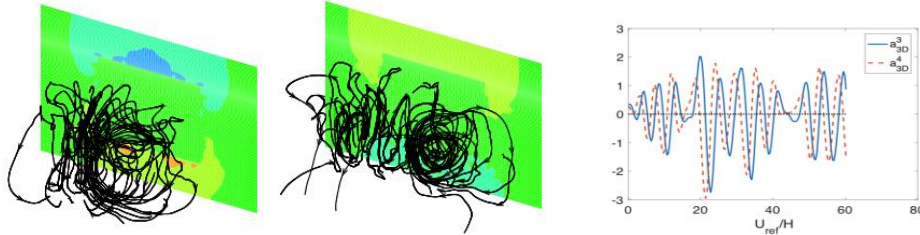


Figure 6: 3D-POD from 3D LES data: (left) 3rd and 4th modes and (right) amplitudes (shedding).

5 Conclusion

The flow around an Ahmed body profile has been calculated using LES. The wake of an Ahmed body can be controlled by a shape modification or an active control like suction on roof. It is important to characterize the physical instability mechanisms of the wake in order to determine the effect of control. POD can be used to identify the different modes and to determine the energy budget of the flow. Two different types of POD were implemented. A 2D-POD showed a good agreement between the simulation and the equivalent experimental configuration. A 3D-POD was also applied in order to extract the spatial organization of the flow. We showed that the main deviation mode is characterized by a horseshoe vortex aligned in the direction of the flow, with a head extending in the recirculation bubble behind the body.

References

- [1] M. Grandemange, M. Gohlke and O. Cadot. Turbulent wake past a three-dimensional blunt body. Part 1. Global modes and bi-stability, *J. Fluid Mech.*, 722:51-84, 2013.
- [2] A. Evrard, O. Cadot, V Herbert, D Ricot, R Vigneron, *et al.*. Fluid force and symmetry breaking modes of a 3D bluff body with a base cavity. *J. Fluids and Struct.*, 61:99-114, 2016.
- [3] C. Tenaud, S. Pellerin, A. Dulieu and L. Ta Phuoc. *Comput. Fluids*, 34:67-96, 2005.
- [4] S. Pellerin and B. Podvin. A study of the ground influence on the wake of an Ahmed body profile. 50th 3AF International Conference on Applied Aerodynamics, Toulouse, France, 30-31 March - 1 April 2015.
- [5] S. Pellerin, B. Podvin and L. Pastur. Characterization of the Near-Wake of an Ahmed Body Profile. ICAAA 2016: 18th Int. Conf. on Applied Aerodynamics and Aeromechanics, Waset Conferences, Amsterdam, the Netherlands, May 11-13 2016.
- [6] S. Pellerin, B. Podvin and O. Cadot. Numerical study of the RSB wakes of an Ahmed body. *Aerovehicles 2*, Chalmers University, Göteborg, Sweden, June 21-23 2016.