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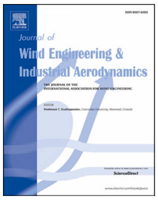

Identification of flow classes in the wake of a simplified truck model depending on the underbody velocity

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ABSTRACT

An experimental study of the near wake of a simplified truck model with an aspect ratio between the height and the width greater than one is presented. The influence of the underbody velocity at a constant ground clearance height is considered. The evolution of the model base pressure and of the near wake as a function of the underbody velocity permits to identify four classes of flow. For large values of underbody velocity, typically above 60% of the free stream velocity, the near-wake structure is similar to what obtained in bluff-body characterizations where the underbody flow momentum is sufficient to prevent its detachment from the ground. For smaller values of underbody velocity, of particular interest when considering real truck applications, base pressure mean value and near wake characteristics strongly depend on the underbody velocity; three different classes are defined through the values of time-averaged rear pressure as well as a qualitative analysis of the near-wake structure. Quantitatively, a momentum budget in the near-wake together with the characterization of the curvature of the underbody flow near the model end provide ad-hoc indicators for discriminating between the different flow classes.

1. Introduction

Medium and heavy duty vehicles can be considered as square-back bluff-bodies with an aspect ratio between their height H and width W above one. Depending on the practical use of the vehicle, the ground clearance height of the cab and the free space under the trailer can vary. This leads to various flow blockages in the underbody area and results in different wake topologies. The possible energy gains linked with a better understanding of the physical phenomena related to drag forces motivated studies at industrial scales. For instance, results on van-type vehicles (Bonnavion et al., 2017) confirmed the occurence of multistability on such a configuration, as previously obtained on a Ahmed body at industrial-scale (Grandemange et al., 2015). At smaller scale or for academic studies, simplified models of medium and heavy duty vehicles are used, among which simplified reduced-scale models of a real heavy duty vehicle, preserving the main aerodynamically significant details (simplified cooling system, indicators and vehicle registration holder plate for instance) (Hwang et al., 2016; Salati et al., 2017), or more simplified models such as the Ground Transportation System (GTS) or the Generalized European Transport System (GETS) (Croll et al., 1996; Gutierrez et al., 1996; McArthur et al., 2016; Storms et al., 2001; Van Raemdonck and Van Tooren, 2008). For these models, consisting of a rounded nose coupled with an elongated parallelepiped shape of aspect ratio $H/W > 1.3$, the ground clearance G is also a parameter of the experimental set-up, and governs the balance between the free stream and the underbody flow. When $G^{\star} = G/H \geq 0.14$, the bulk underbody flow velocity is very close to the free stream velocity (Croll et al., 1996; Gutierrez et al., 1996; Islam et al., 2017; Storms et al., 2001; Van Raemdonck and Van Tooren, 2008); the mean near wake is then composed of a closed recirculation bubble detached from the ground. From a qualitative point of view in this case, the wake structure is reminiscent of that obtained in passenger vehicles studies based on the Ahmed body (Ahmed et al., 1984), Windsor (Littlewood and Passmore, 2012) or ASMO models (Nakashima et al., 2008). Nevertheless, for full-scale trucks, the underbody bulk velocity ranges from 10% to 40% of the free stream velocity. As a consequence, the wake develops closer to the ground because of the limited momentum flux from the underbody flow. Previous studies already tackled the issue of handling the underbody velocity value, or proposed systems that could serve this purpose. A slanted underbody rear geometry was added by Kowata et al. (2008) to a

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Nomenclature

$\overline{\bullet}$	Time-average value of $\bullet$
$\langle\bullet\rangle$	Spatial-average value of $\bullet$
$\bullet'$	Fluctuating part of $\bullet$
$\sigma_\bullet$	Standard deviation of $\bullet$
$\bullet^\star$	Length $\bullet$ normalized by H, or velocity component $\bullet$ normalized by U_∞
U_∞	Free stream velocity
u, v, w	Velocity components in the reference frame
U	Velocity magnitude in the longitudinal plane
U_s	Bulk underbody velocity
λ	Ratio between U_s and U_∞
$k^\star$	Turbulent kinetic energy normalized by U_∞^2
H, W, L	Model Height, Width, Length
ν	Air kinematic viscosity
Re_H	Reynolds number based on U_∞ and H
ϕ	Porosity of pressure loss system

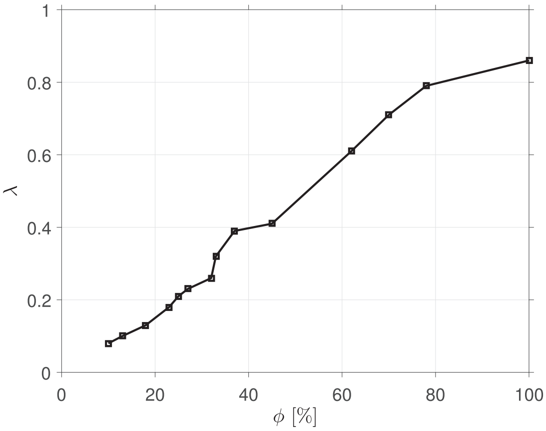
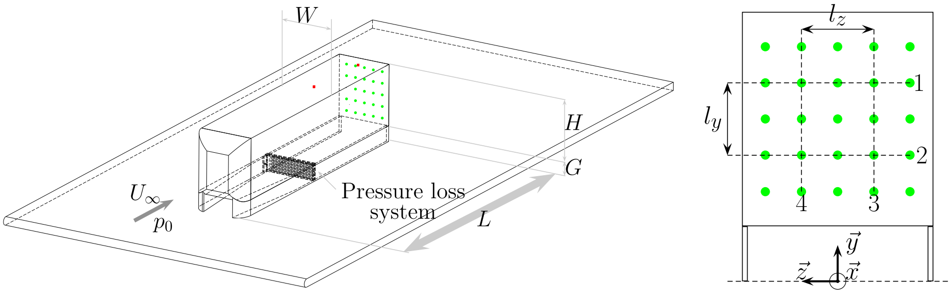
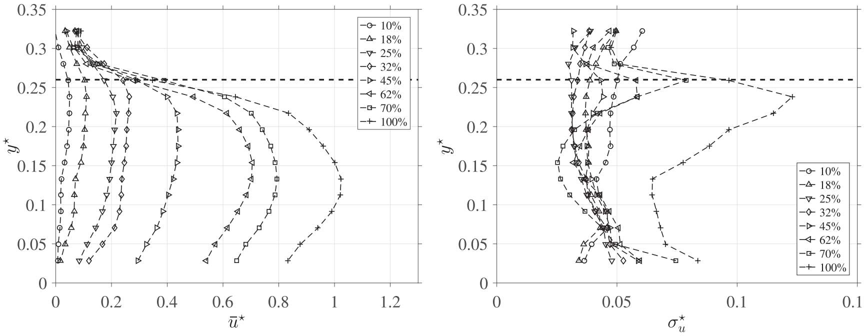


Fig. 3. Evolution of the ratio $\lambda = U_s/U_\infty$ with the porosity.



(a) (b)

Fig. 1. Experimental set-up: (a) perspective view, (b) rear view. Locations of base pressure taps are given by •; those on the roof by ■. The pressure loss system is not represented in (b).



(a) (b)

Fig. 2. Profiles at $x^\star = 0.02$ of (a) normalized mean longitudinal velocity and (b) standard deviation of the underbody flow for several pressure losses. Each symbol in the legend corresponds to a value of porosity ϕ; the black dashed line represents the ground clearance top.

square-back Ahmed body for drag reduction. Varying the angle of the slanted part would result in changing the underbody velocity at the model exit, but would consequently modify the height of the model rear. Perry and Passmore (2013) introduced roughness in the underbody area of a square-back Windsor model, which led to an underbody velocity change due to the induced pressure losses. To some extent, whether the ground displacement is reproduced or not can also influence the underbody bulk velocity, as a consequence of changes in the flow boundary condition on the ground; Garry (1996) for instance measured the base pressure of simplified bluff bodies with $H/W > 1$ for various ground plane velocities ranging from 0 to U_∞, and Krajnovic et al. (Krajnovic and Davidson, 2015) showed that the influence of the floor motion on the wake structure of a slanted surface body is qualitatively limited to the region near the floor and near the slanted surface. Finally, the ground clearance can be decreased to reduce the underbody velocity, because of the enhancement of pressure losses in the underbody area.

Barros et al. (2016) showed that, for a body of simplified geometry and with flow control, a strong connection exists between the change in base pressure and the drag evolution as a function of the actuation parameters. Grandemange et al. (2013a) studied the effect of ground