Aerodynamics of two square back vehicles in platooning configuration

Juan José Cerutti, Gioacchino Cafiero*, Gaetano Iuso
[1]Department of Mechanical and Aerospace Engineering, Polytechnic of Turin, Turin, Italy
*corresponding author: gioacchino.cafiero@polito.it

Abstract We report on the results of an experimental campaign devoted at quantifying the drag variation of a pack of vehicles when traveling in line. We show the existence of an optimal distance between two vehicles at which they both benefit of a significant drag reduction. This benefit is quickly lost for the leading vehicle, but still persists for the rear one, even at values of the non-dimensional distance between the vehicles (d/L) as large as 3. Flow field analysis carried out at d/L =0.5 and 3 reveal that the structure of the wake behind the rear vehicle is significantly perturbed with respect to the case of isolated model, featuring a reduced extent and lower entrainment.
Keywords: drag reduction, road vehicle aerodynamics, PIV

It has been demonstrated [1][2][3] that the aerodynamic drag of a pack of vehicles is reduced when traveling one behind the other; such configuration is referred to as platooning. Very little attempts were devoted at developing a thorough assessment of the wake manipulation which causes the drag reduction phenomena for this configuration, though.

We performed experiments in an open circuit blowing wind tunnel having a test section characterized by height 1.2m, width 0.9m and length 6.5m. A wooden replica of the model (i.e. with same geometry) was alternatively positioned ahead or behind the instrumented one. Details about the model geometry are reported in figure 1a. For the given length of the wind tunnel test section, the distance between the models was varied in the range of d/L from 0.5 to 3.
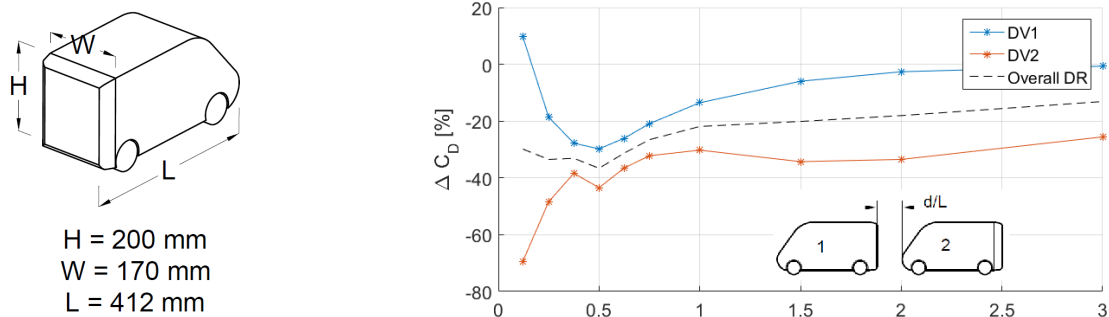

Fig. 1 (left) Schematic representation of the model; (right) Front and rear vehicle drag variation as a function of d/L.

One model is instrumented with a load cell for the drag measurement and with an array of pressure taps distributed around its top, and rear surfaces. Capacitive pressure sensors were mounted on the rear base for pressure fluctuations measurements. Furthermore, we perform PIV in the near wake of the rear vehicle for different values of d/L.

In Fig. 1b the variation of the drag coefficient for front (1, blue line) and rear (2, red line) vehicle are reported as a function of the non-dimensional distance d/L.

The overall drag variation that can be attributed to the whole convoy was calculated averaging the drag variations of each component at the different distances. A maximum overall drag reduction of about 35% is obtained for a distance between models of 0.5L. In particular, 30% of drag reduction was observed for the front vehicle while the rear model evidenced 43% of drag reduction. At larger distances, the beneficial effect progressively reduces for the leading vehicle, whereas the rear one still exhibits significant drag reductions (about 25%) [4].

The pressure coefficient (C_p) distributions on the rear base of both models, front 1 and rear 2, are reported in Fig. 2 for the model alone (Natural) and for two characteristic positions of the other vehicle, namely d/L = 0.5 and 3. The plots show the changes on the pressure coefficient distribution when the models are approaching each other. For the natural case, a downward pressure gradient suggests the existence of a vertical symmetry breaking mode (VSB), as documented in [5]. As d/L reduces, a progressive switch in the pressure gradient direction can be detected. In a recent investigation a similar feature was found in the case of controlled wake, with a progressive approach to a symmetric configuration of the wake.
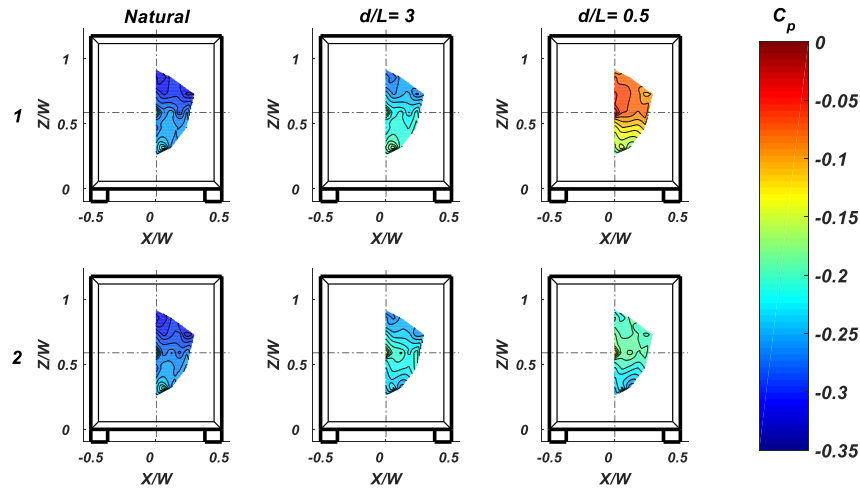
Fig. 2 Pressure coefficient distribution on the rear base of the front (top row, 1) and rear (bottom row, 2) model.

The mean streamwise velocity measured by means of Particle Image Velocimetry in the wake of the rear vehicle is reported in Fig.3. The investigated region extends from the rear base of the model for about $1.6W$. The same three cases are considered: $d/L = 0.5$, $d/L = 3$ and the natural case. A stark difference can be detected when the distance d/L reduces. The wake of the rear model in the isolated case (Fig. 3c) shows two recirculation regions that correspond to the cross section of a toroidal structure, which is stretched in the bottom part because of the high momentum fluid convected through the bottom part of the vehicle. At smaller distances, $d/L = 0.5$, the flow seems to approach a more symmetric configuration. This is in good agreement with the pressure measurements reported in Fig.2. A dramatic change occurs at the smallest investigated distance: the preceding vehicle generates a blockage to the fluid that undergoes the expansion through the bottom part of the vehicle. As a result, the recirculation bubble is strongly distorted, with a local separation near the bottom edge and a significantly lower entrainment from the surrounding flow on the bottom part. This justifies the smaller values of drag evidenced in this case (Fig.1b).
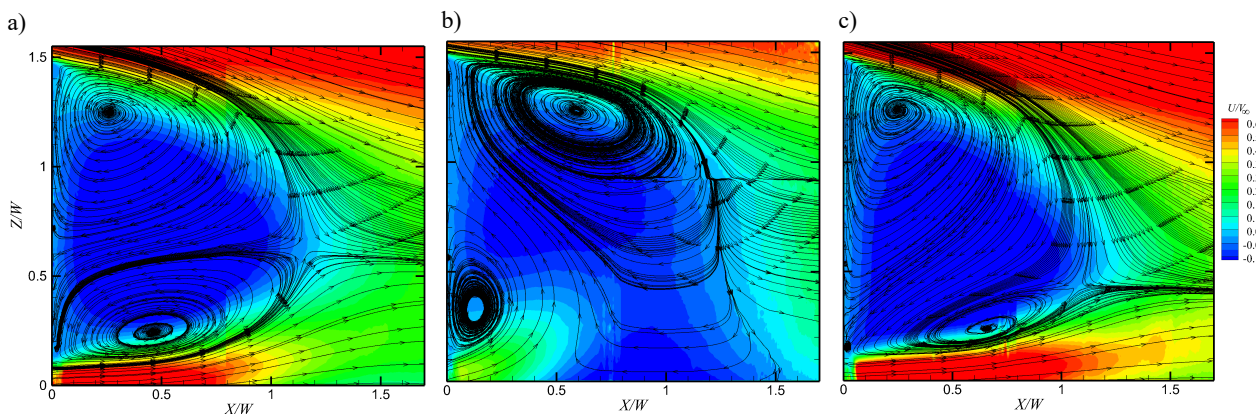

Fig. 3 Streamwise velocity U/V_∞ in the near wake of the rear vehicle at $d/L = 3$ (a) $d/L = 0.5$ (b) and in isolated vehicle case (c).

References

[1]   Romberg G F (1971) Aerodynamic of race cars in drafting and passing situations. SAE technical paper 710231. doi: https://doi.org/10.4271/710213.

[2]   Watkings S, Vino G (2008) The effect of vehicle spacing on the aerodynamics of a representative car shape. *Journal of Wind Engineering and Industrial Aerodynamics,* vol. 96, pp 1232–1239. doi: 10.1016/j.jweia.2007.06.042.

[3]   Davila A, Aramburu E, Freixas A (2013) Making the Best Out of Aerodynamics: Platoons. *International Journal of Heat and Mass Transfer*, vol. 73, pp 776-788. doi: 10.1016/j.ijheatmasstransfer.2014.02.030.

[4]   Zabat M, Frascaroli S, Browand F K (1994) Drag measurements on 2, 3 and 4 car platoons. *SAE technical paper 940421*. doi: https://doi.org/10.4271/940421.

[5]   Grandemange M, Gohlke M, and Cadot O (2013) Bi-Stability in the Turbulent Wake Past Parallelepiped Bodies with Various Aspect Ratios and Wall Effects. *Physics of Fluids*. doi: https://doi.org/10.1063/1.4820372.