Experimental passive control of the Ahmed body without ground effect using deflectors at a low Reynolds number

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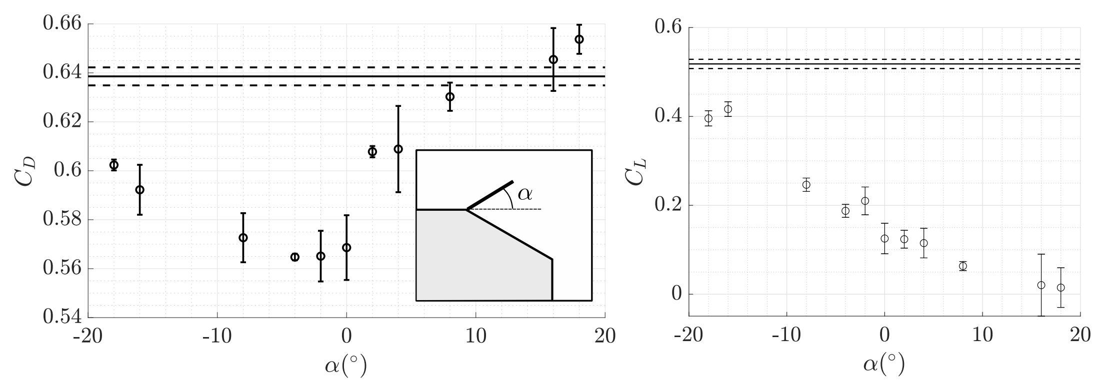
Abstract We have conducted an experimental investigation on the effect of different deflector angles on the drag and lift coefficients of an Ahmed body without ground effect. Our findings show that the minimum drag corresponds to a deflector angle between -4 and 0°.
Keywords: aerodynamics, passive control, bluff body.

Improving the reduction of aerodynamic drag is one of the main tasks in engineering to reduce fuel consumption in ground or air vehicles. Although the geometry of the vehicles is already highly optimized, this is not the case for heavy vehicles such as trucks or buses. Researchers apply different passive and active flow control techniques to reduce aerodynamic drag [1]. Most of these techniques deal with the massive flow separation at the rear of vehicles, where two main flow structures are the origin of drag sources: one recirculation bubble and one pair of longitudinal counter-rotating vortices (C-vortices) [2]. The former causes pressure to drop at the rear, and the latter is a source of (aerodynamic) induced drag [3].

We measured the hydrodynamic forces and the wake velocity fields generated by an Ahmed body model (rear slant angle of 25°, length L=221 mm) with no ground effect using different deflector angles (α) to reduce the drag. We obtained velocity measurements from 2D-PIV in a plane perpendicular to the free-stream direction. We conducted the experiments in a towing water tank at a constant height-based Reynolds number, $Re_H = 20 \times 10^3$. We present the average results over a set of three experiments.

Drag force measurements, see figure 1 (a), show that the maximum drag reduction occurs for α values between -4° and 0°, diminishing the drag up to approximately 12% respect to the base case. This reduction is maintained of the same order of magnitude up to $\alpha \approx -8°$. However, for very low angles, the drag increases approaching the base case value, $\alpha \to -25°$. For positive values of α, despite the bigger projected area, the drag does not overcome the configuration without deflector until $\alpha = 16°$. Additionally, the deflector always reduces the lift respect to the base case, as shown in figure 1 (b). We also observe that lift decreases as α increases, and at the minimum drag configuration, it drops to less than half of the base case. This reduction is a desirable effect since lift reduces the traction of the tyres on ground vehicles and results in an increased risk of skidding.



(a) (b)

Figure 1: Drag (a) and lift (b) coefficients and its standard deviation versus α. Continuous and dashed lines represent the base case. The inset in (a) shows a scheme of the rear of the model with the deflector.

The drag measurements can be related to the wake vorticity. We focus on analyzing three relevant cases: the

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model with no deflectors, the minimum drag configuration ($\alpha = -4°$), and a high drag configuration ($\alpha = 16°$). The streamwise component of the vorticity (ω) is mainly generated by the longitudinal (streamwise) vortices. The integral of ω over the measurement plane results in almost zero net circulation since the vorticity alters signs for counter-rotating vortices. Therefore, we integrate the absolute value of ω to estimate the C-vortices strength (see figure 2). The case with $\alpha = -4°$ displays lower values, suggesting a drop in the induced drag as a cause of the total drag reduction.

Furthermore, the weakening of the C-vortices is also evident when looking at the vorticity and velocity in a (X, Y)-plane, as shown in figure 3. The structure of the counter-rotating vortices is easily identifiable for the base case (a) but not for $\alpha = -4°$ (b), which has a less coherent wake structure. Furthermore, the degeneration of the C-vortices seems to cause a reduction of the downwash, which may be associated with a reduction of the lift.

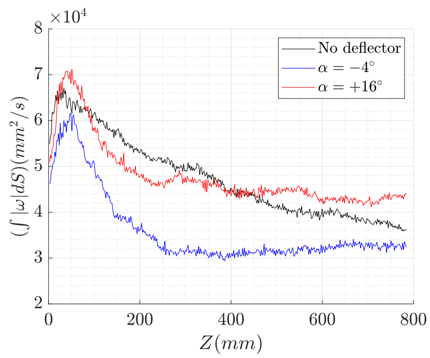

Figure 2: The absolute value of the streamwise component of the vorticity integrated over the measurement plane as a function of the streamwise direction Z from the model vertical origin at the trailing edge.

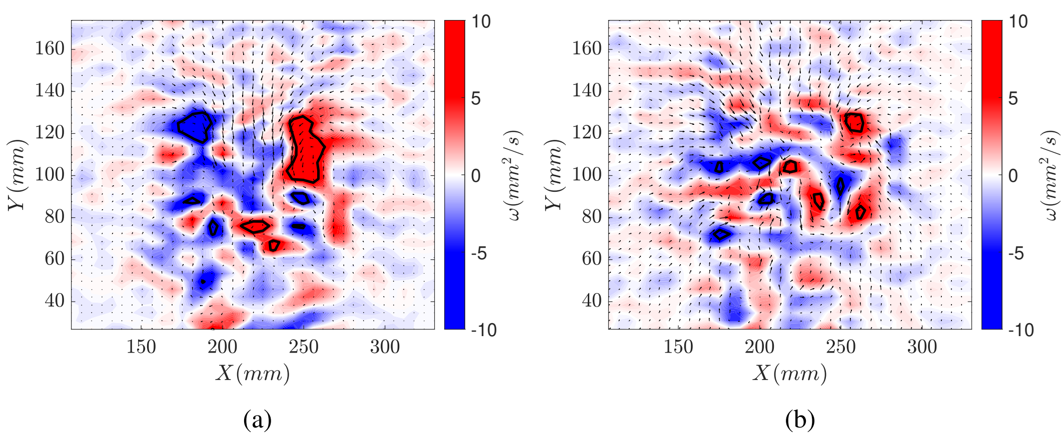

Figure 3: Velocity field (arrows) and vorticity fields (heatmap) at a distance z=10mm to the vertical base for (a) no deflector and (b) $\alpha = -4°$. ω=7mm^2/s level marked in black lines.

References

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