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Influence of a nearby car on the aerodynamic drag of a cyclist

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SUMMARY:
Cycling races contain a multitude of cars including team cars. During parts of the race, the cyclists can ride in close proximity of these cars. An earlier study indicated the drag reduction for a cyclist by a following car. However, to the best of our knowledge, there is no information in the scientific literature about the impact of a car on cyclist drag when the cyclist is positioned either in-line behind the car or in staggered position with the car. This paper presents wind tunnel measurements and CFD simulations of cyclist drag for 29 different cyclist-car arrangements. It is shown that drafting in-line behind a car at a distance of 10 m and 40 m leads to substantial drag reductions of about 20% and 7%, respectively. The staggered positions can lead to either a large drag increase up to almost 9% or a moderate drag decrease up to 1.4%.

Keywords: Cycling, drag, CFD

1. GENERAL INSTRUCTIONS

Cycling races contain a multitude of in-race vehicles including motorcycles and cars. Previous studies investigated the impact of a nearby motorcycle on the aerodynamic drag of a cyclist or the impact of a car behind the cyclist on its drag (Blocken and Toparlar 2015; Blocken et al. 2016; 2020; 2021). However, to the best knowledge of the authors, studies on the aerodynamic impact of a car in front, in parallel to or in staggered position with respect to a cyclist have not yet been published. Outside the scope of the present paper, only Blocken and Toparlar (2015) and Gromke and Ruck (2021) analyzed the aerodynamic interaction between a cyclist and a car. The latter authors performed interesting field tests to assess the lateral loads on cyclist dummies by an overtaking station wagon. In the present paper however, only the longitudinal air resistance (i.e. in the riding direction) is studied.

2. SET-UP OF WIND TUNNEL TESTS AND CFD SIMULATIONS

The wind tunnel (WT) tests were performed at quarter scale. The maximum blockage ratio of the set-up was below the recommended maximum of 5% for WT tests (ASCE 1999). The cyclist model was placed on the force sensor. The force sensor was designed and manufactured in house specifically for high-accuracy quarter-scale cyclist WT tests (Blocken et al. 2018) with an accuracy of 0.001 N. Tests were performed at wind speeds of 15, 20, 25 and 30 m/s in order to detect Reynolds number independence, which was noted above 20 m/s. The Reynolds number independent results were retained and are reported in the remainder of this paper. To assess the repeatability of the experimentally obtained drag values, the drag of the isolated cyclist was measured five times by detaching and remounting the model on the force sensor. The resulting repeatability of the obtained drag values was found to be 0.7-0.9%, which corresponded to drag differences of about 0.3 N for the isolated cyclist. All drag measurements were corrected to match the following reference values: 101325 Pa (standard atmosphere), 15°C, 15 m/s (a top time trial speed) and full geometrical scale.

The CFD simulations were performed at full scale. The maximum blockage ratio was about 0.5%, which is below the recommended maximum of 3% for CFD simulations (Franke et al. 2007; Tominaga et al. 2008; Blocken 2015). The computational domains were discretized with hybrid hexahedral-tetrahedral grids based on both general grid generation guidelines (Franke et al. 2004; 2007; Tominaga et al. 2008; Blocken 2015; Casey and Wintergerste 2000; Tucker and Mosquera 2001) and grid generation guidelines developed specifically for cyclist aerodynamics simulations (Malizia and Blocken 2020). To accurately resolve the thin boundary layer including the laminar sublayer, the wall-adjacent cell size was 20 micrometer (= 0.02 mm) and 40 layers of prismatic cells were applied near the cyclist and car surfaces. Scale Adaptive Simulations (SAS) (Menter and Egorov 2010) were performed involving the Shear Stress Transport (SST) k-ω model with curvature correction. Pressure-velocity coupling was performed by the PISO algorithm. Pressure interpolation was second order, gradient interpolation was conducted with the Green-Gauss node based scheme. Bounded central differencing was used for the momentum equations and second-order discretization for the turbulence model equations. Time discretization was bounded second order implicit. The simulations were performed with the commercial CFD code Ansys Fluent 16.1 (2015). The time step of 0.002 s was selected such that the CFL number was equal to or below unity.

3. RESULTS

Figure 1 presents the results of the WT measurements and SAS CFD simulations for the cyclist drafting in-line behind the car in terms of drag reduction compared to a cyclist riding alone. The comparison of the WT and CFD results shows a fairly good agreement. The maximum drag reduction for the cyclist was almost 80% for the very short – and unrealistic – distance of 0.06 m, but also for 0.96 m the reduction was still very large and equal to about 75%. At about 10 m distance, the drag reduction was about 20% while it decreased to about 7% for a distance of 40 m. The latter number illustrates that the far wake behind a team car is a persistent phenomenon that even at very large distances can still provide a substantial benefit.

Figure 2 holds the results for the cyclist in staggered position with respect to the car, with lateral distance $\Delta y = 1.5$ m. Here, the CFD simulations were only made to provide the typical CFD whole-flow field data of velocity and static pressure to aid in explaining the reason behind the drag changes, which will be provided in the full paper. The agreement between the WT and CFD results is moderate. The deviation is rather large for the situation with the cyclist at 3.84 m downstream of the nose of the car, while the agreement for the other two positions is fair. It is not clear what has contributed to these differences, although the presence of the vertical reinforcement bars in the wheels of the cyclist model and the bottom plate might have had an influence here as the flow near the cyclist will have had a more pronounced lateral component.

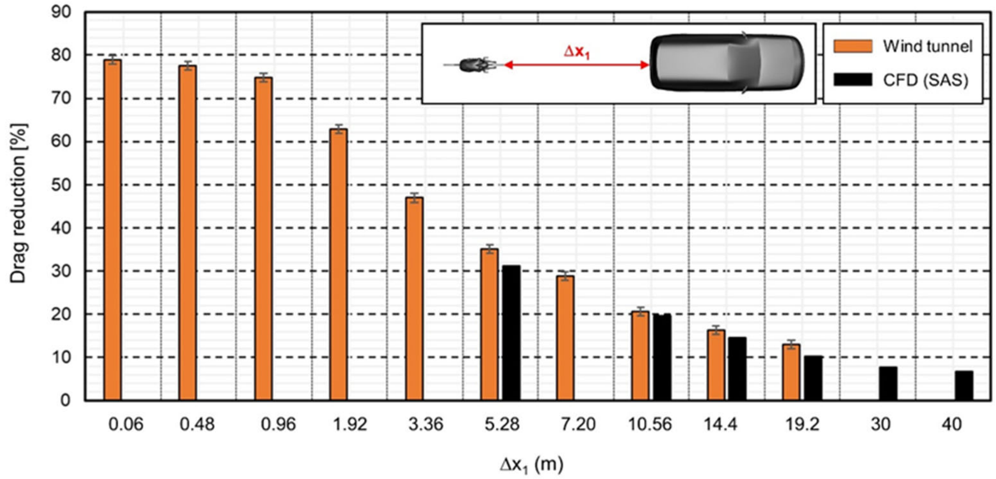

Figure 1. Results of wind tunnel tests and CFD simulations: drag reduction for cyclist by drafting behind a car for different separation distances Δx_1.

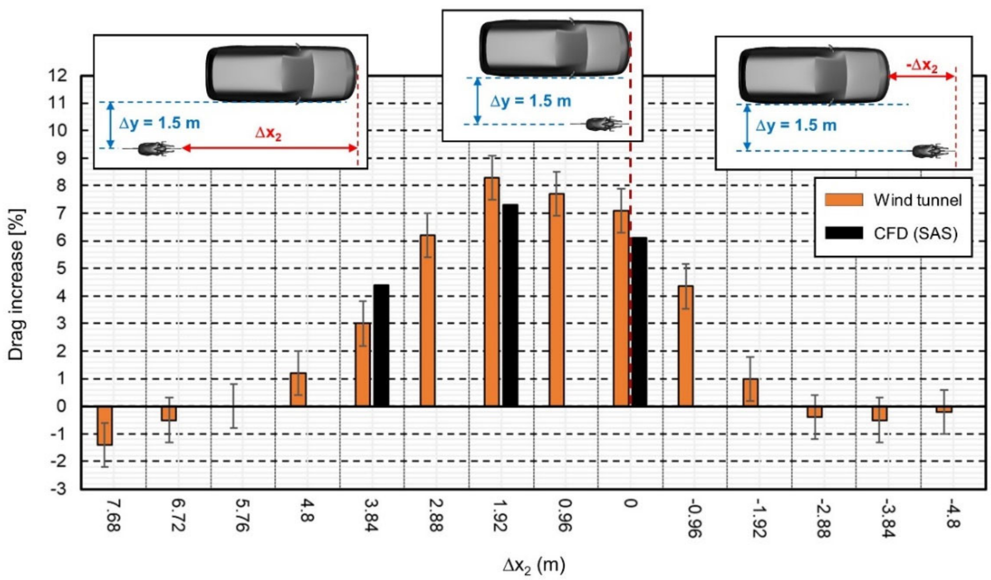

Figure 2. Results of wind tunnel tests and CFD simulations: drag change for cyclist riding nearby a car in staggered position for different streamwise separation distances Δx_2 and lateral distance $\Delta y = 1.5$ m.

4. CONCLUSIONS

Cycling races contain a multitude of cars including team cars. During parts of the race, the cyclists can ride in close proximity of these cars. An earlier study indicated the drag reduction for a cyclist by a following car. However, to the best of our knowledge, there was no information in the scientific literature about the impact of a car on cyclist drag when the cyclist is positioned either in-line behind the car or in staggered position with the car. This paper presented wind tunnel measurements and CFD simulations of cyclist drag for 29 different cyclist-car arrangements. It was shown that drafting in-line behind a car at a distance of 10 m and 40 m leads to substantial drag reductions of about 20% and 7%, respectively. The staggered positions can lead to either a large drag increase up to almost 9% or a moderate drag decrease up to 1.4%. These drag changes can induce time gains or losses that go up to several seconds per kilometer, which is large enough to influence the outcome of cycling races, as will be shown in the full paper.

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