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Aerodynamic drag in cycling pelotons: New insights by CFD simulation and wind tunnel testing

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ABSTRACT

A cycling peloton is the main group of cyclists riding closely together to reduce aerodynamic drag and energy expenditure. Previous studies on small groups of in-line drafting cyclists showed reductions down to 70 to 50% the drag of an isolated rider at same speed and these values have also been used for pelotons. However, inside a tightly packed peloton with multiple rows of riders providing shelter, larger drag reductions can be expected. This paper systematically investigates the drag reductions in two pelotons of 121 cyclists. High-resolution CFD simulations are performed with the RANS equations and the Transition SST-k-ω model. The cyclist wall-adjacent cell size is 20 μm and the total cell count per peloton is nearly 3 billion. The simulations are validated by four wind-tunnel tests, including one with a peloton of 121 models. The results show that the drag of all cyclists in the peloton decreases compared to that of an isolated rider. In the mid rear of the peloton it reduces down to 5%–10% that of an isolated rider. This corresponds to an "equivalent cycling speed" that is 4.5 to 3.2 times less than the peloton speed. These results can be used to improve cycling strategies.

1. Introduction

A cycling peloton is the main group of cyclists riding closely together to reduce aerodynamic drag and energy expenditure (Fig. 1). It is well known that the riders in front experience the largest drag. Therefore, after riding some time at the front, these riders will move farther back in the peloton to recover and others will take over. Generally, the leaders and/or sprinters of each team will not ride in front, but stay embedded somewhere inside the peloton to save as much energy as possible until the most critical part of the race. This critical part can be a long climb or another event that can break the peloton into pieces. It can also be the moment near the end of the race where the peloton will rapidly change shape to prepare for the sprint towards the finish line. For long multi-stage races like the Tour de France, the Giro d'Italia or the Vuelta d'Espaňa, endurance and a low level of fatigue during the third week of the race is critical to win. Therefore, athletes are continuously focused on preserving energy for the critical days like mountain stages or time trials. Hence, the peloton is used to obtain shelter from the wind and limit energy consumption. While it is well known that the aerodynamic drag inside the peloton is significantly less than that at the front, it is not known how much this drag inside the peloton actually decreases and which positions are most beneficial in terms of drag reduction. It is also not known how much the drag is for the riders at the front of the peloton.

The greatest potential for improvement in cycling speed is situated in the aerodynamics (Wilson, 2004). At racing speeds (about 54 km/h or 15 m/s in a competitive cycling event), the aerodynamic resistance or drag is about 90% of the total resistance (Kyle and Burke, 1984; Grappe et al., 1997; Lukes et al., 2005). Aerodynamic drag can be assessed by field tests, by wind tunnel measurements or by numerical simulation with Computational Fluid Dynamics (CFD). The use of CFD in wind engineering, also referred to as Computational Wind Engineering, has seen a rapid growth in the past 50 years (see review papers of e.g. Murakami, 1997, Stathopoulos, 1997, Baker, 2007, Solari, 2007, Meroney and Derickson, 2014, Blocken, 2014, 2015). As part of wind engineering, also

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Fig. 1. Cycling pelotons. Sources: (a,b) Sporza.be; (c) http://johnericgoff.blogspot.com; (d) Sporza.be; (e) Sergii Rudiuk / Shutterstock.com, reproduced with permission; (f) www.danpontefract.com; (g) (c) Cor Vos, reproduced with permission; (h) Getty Images, reproduced with permission.

the field of cycling aerodynamics has adopted the use of CFD (Blocken, 2014; Crouch et al., 2017).

Most studies on cycling aerodynamics focused on the drag of a single (isolated) cyclist (e.g. Kyle and Burke, 1984; Dal Monte et al., 1987, Grappe et al., 1997; Padilla et al., 2000; Jeukendrup and Martin, 2001; Defraeye et al., 2010a, 2010b; Crouch et al., 2014; Fintelman et al., 2014, 2015). Less attention has been given to analyzing the effects of drafting. In drafting, two or more cyclists ride close behind each other to reduce aerodynamic drag. This way, the trailing cyclist can benefit from the low pressure area behind the leading cyclist. Early drafting studies, mostly coast-down tests and wind tunnel experiments, were reported by Kyle (1979), McCole et al. (1990), Hagberg and McCole (1990), Kyle (1991), Broker and Kyle (1995), Zdravkovich et al. (1996), Olds (1998), Martin et al. (1998), Broker et al. (1999), Edwards and Byrnes (2007) and Garcia-Lopez et al. (2008). Broker and Kyle (1995) and Garcia-Lopez et al. (2008) studied the drag of 5 cyclists in time-trial (TT) position while Martin et al. (1998) studied 6 cyclists in TT position. More recently, Blocken et al. (2013) investigated the aerodynamic benefit for a leading cyclist due to the presence of a trailing cyclist based on CFD simulations and wind tunnel measurements. It was found that the trailing cyclist can provide a drag reduction of almost 3% to the leading cyclist due to the upstream effect exerted by the trailing rider on the flow. This effect was later confirmed by Defraeye et al. (2014) and Barry et al. (2015) who studied the aerodynamic drag of four in-line cyclists for a team pursuit. As a special case of drafting, Blocken and Toparlar (2015) assessed the aerodynamic benefit for a cyclist by a following car and Blocken et al. (2016) assessed the aerodynamic benefit for a cyclist followed by one, two or three motorcycles. Mannion et al., 2018a; b also analyzed a special case of drafting, i.e. the interaction between the pilot and the stoker in paralympic tandem cycling, where both athletes are in much closer proximity as in drafting in regular cycling.

However, to the best of our knowledge, studies of aerodynamic drag in large groups of drafting cyclists have not yet been performed. The results of previous investigations of the drag in small in-line groups of