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On the cyclist's drag crisis

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Reduction of the aerodynamic drag in time-trial cycling may be achieved streamlining the rider's skinsuit through zones of smooth and rough textiles (Crouch et al. 2018). This concept is based on the transitions of the boundary layer on the model's surface resulting in postponed flow separation and, hence, a reduction of the aerodynamic drag (e.g. Achenbach 1971), and is typically referred to as the drag crisis. The point of minimum drag coefficient is typically considered the critical condition and, obviously, is preferred in cycling so to achieve minimum aerodynamic drag.

The drag crisis is expected only on the parts of a cyclist that resemble bluff bodies; when considering an athlete in typical time-trial condition, these are the upper arms and the legs. Conventionally, the design of low drag skinsuits is based upon determination of the critical flow condition by experiments on isolated cylinders so to model the flow around the arms and legs (e.g. Brownlie et al. 2009). This approach likely precludes drag minimization, as the flow around the arms and legs is more intricate, among others, due to the proximity of other body parts and the complex geometry of the rider and his or her bike (e.g. Crouch et al. 2014, Griffith et al. 2014). Instead of experiments on isolated models, in this work it is proposed to determine the critical flow condition from measurements on the rider itself. This approach has already been adopted in speed skating aerodynamic research (D'Auteuil et al. 2012), although results on the critical condition have not been presented.

In aerodynamic research, the critical condition is typically characterized by the critical Reynolds number, where the Reynolds number is a flow similarity parameter depending on the size of the object, the flow velocity and the viscosity of the fluid. For a cyclist, the body size and the viscosity of the air are largely fixed and, hence, in this work the critical velocity, V_C is considered a more practical parameter to indicate the condition that minimizes the cyclist's drag area. If the critical velocity exceeds the race speed of the rider ($V_C > V_R$), surface roughness application can reduce the aerodynamic drag. Instead, when $V_C < V_R$ the suit is better designed with a smooth fabric.

The present work uses particle image velocimetry (PIV) to measure the flow around a cyclist mannequin to evaluate the distribution of the rider's critical velocity and to explain the reduction of the overall cyclist drag coefficient with increasing speed (Figure 1). The PIV system employed in this work consists of a set of four cameras imaging sub-millimeter tracer particles, injected in the flow by a seeding system, illuminated by a pulsed laser, to evaluate the flow velocity from the particle displacement. This system is integrated into a so called 'PIV probe' which is installed on a robotic arm to allow scanning the flow in a time-efficient manner (Jux et al. 2018). Cross-sections of the measured flow along the arms and legs are used to determine the wake width locally. By repeated experiments in a large range of freestream velocities, U_∞ = [5 10 15 20 25] m/s, the variation in wake width is obtained, which corresponds to the variation of the drag coefficient (Rodriguez et al. 2015), and, hence, allows to determine the local critical velocity and its distribution.

Preliminary results are obtained in the near-wake of the stretched leg, depicting a clear reverse flow region bounded by zero streamwise velocity (dark blue iso-surface in Figure 2). It is also observed that the wake narrows towards the ankle. This narrowing is also depicted in Figure 3-left, showing the variation of d_w with freestream velocity at three sections along the leg as depicted in Figure 2. The critical velocities at the different sections, corresponding to the values of U_∞ that yield the minimum wake width, are indicated as well (red arrow). Finally, the critical velocity is obtained along the stretched leg (Figure 3-right). Considering a time-trial speed V_R = 14 m/s, it is concluded that rough fabrics should be applied on the leg from the knee to the ankle and, a rougher fabric is required at the lower leg, to obtain minimum drag. Conversely, a smooth fabric should be applied on the upper part of the leg (from the hip to the knee). During the presentation, also the drag crises of the cyclist's hips and arms will be discussed.

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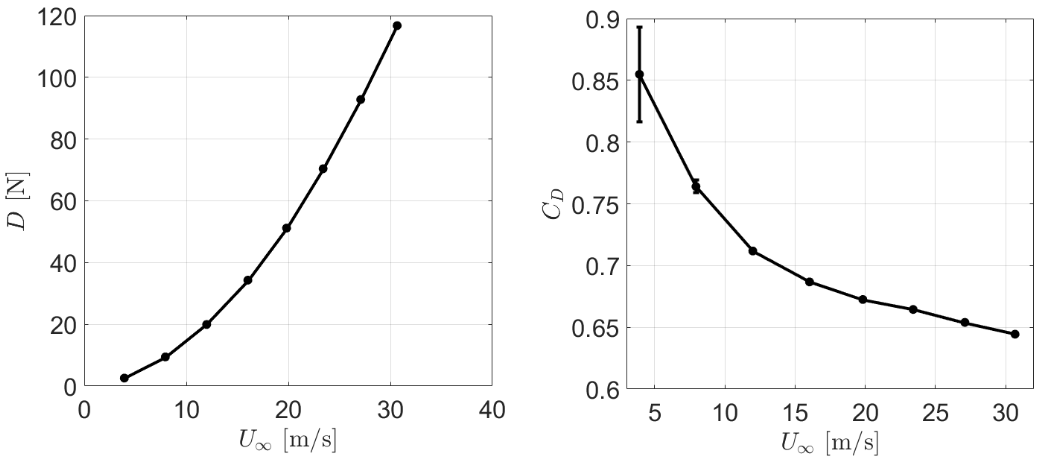

Figure 1: Aerodynamic drag (left) and drag coefficient (right) of the total wind tunnel model.

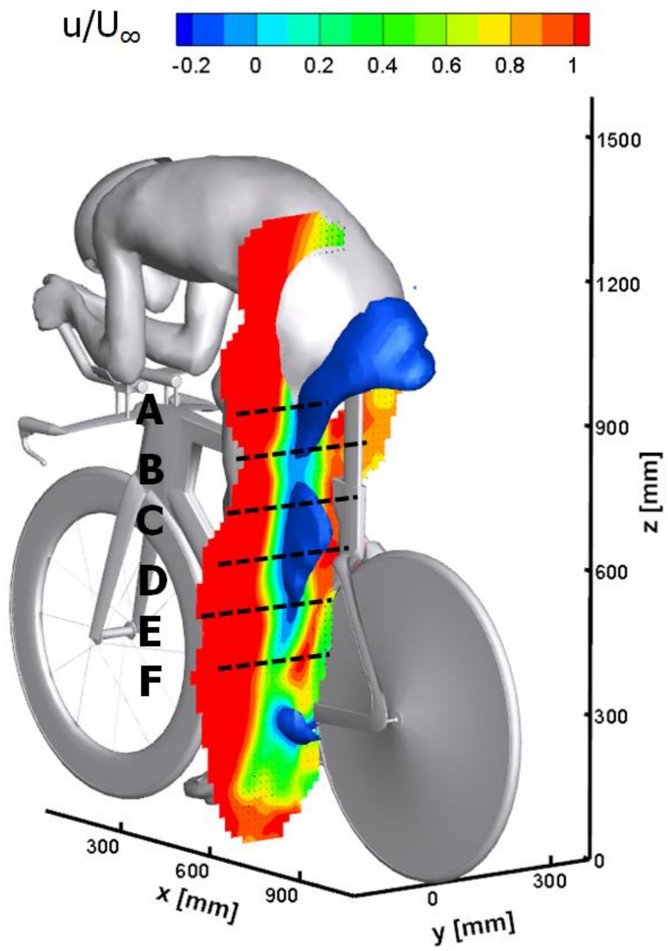

Figure 2: Cross-section of mean non-dimensional streamwise velocity in the near-wake of the stretched leg obtained at U_∞ = 5 m/s. The dark blue iso-surface depicts a zero level of streamwise velocity.

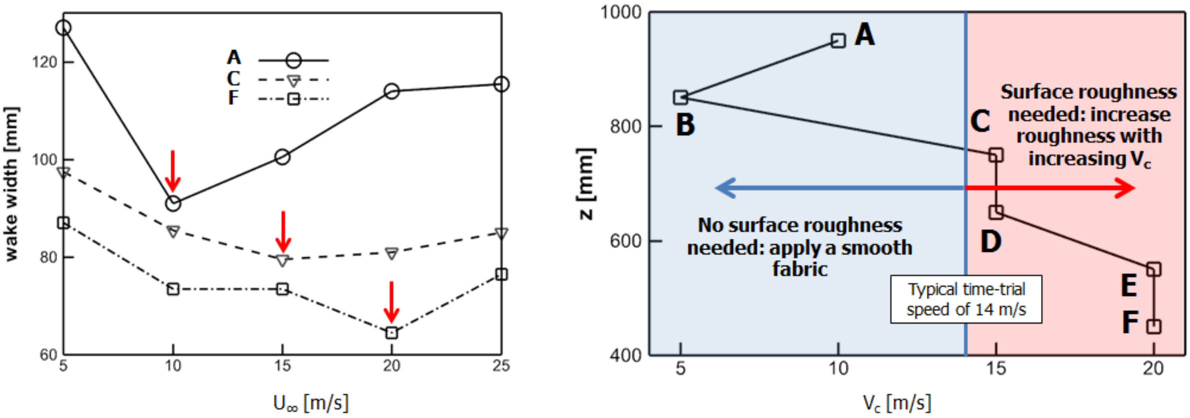

Figure 3: Wake width (left; the red arrows indicate the critical velocities at the different sections) and critical velocity (right) along the leg