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Accuracy assessment of the Ring of Fire system for on-site aerodynamic drag measurements

Abstract

Background: Nowadays, professional and ambitious amateur athletes are seeking small aerodynamic improvements relying on wind tunnel balance measurements, velodrome tests, and outdoor field tests. Many new companies have specialized in offering such testing days, which underlines the growing importance and demand on improving the aerodynamic efficiency. However, one of the big drawbacks of these traditional testing methods is that they act as a black box, as only overall drag data can be extracted, without visualizing the flow structures around the cyclist, which could be used to identify the region that offers the greatest potential. In order to gain further insight into the flow around the cyclist, other approaches need to be employed. One of the methods is CFD (Computational Fluid Dynamics) which allows simulating the airflow around the cyclist numerically. Even though this method shows the capability of simulating complex flows in sports, as shown in Gardan et al. (2017), it is often limited to an idealized environment without modelling the transiting behaviour occurring in most sports, like the pedalling motion of a cyclist.

Recently a new testing method has been developed that quantifies the on-road aerodynamic drag of athletes in motion and visualizes the flow field in its wake (Spoelstra et al., 2019). The measurement system is based on large-scale stereoscopic particle image velocimetry (PIV) measurements over a plane crossed by the cyclist. The measurement concept is referred with the name Ring of Fire (RoF) as the vehicle crosses a region of intense light.

Purpose: In recent years, the Ring of Fire measurement technique has emerged as a feasible option to visualise and analyse flow structures of moving cyclists, as well as determining their aerodynamic resistance (Spoelstra et al., 2019). Despite the differences between RoF experiments and experiments found in literature (e.g. in the measurement method, the cyclist geometry, bike model and the cycling speed), the flow fields and drag measurements compare well with each other. The accuracy of this on-site measurement technique, however, has not yet been validated under equal test conditions. Therefore the aim of the current study is to compare drag area values of a cyclist from Ring of Fire measurements to simultaneous acquired power meter data (the current state-of-the-art for on-site aerodynamic measurements).

Methods: A cyclist was continuously riding laps (±200m) in a spacious indoor facility (Fig. 1) at constant speed of 30 km/h; his drag was evaluated through power meter (SRM) and PIV techniques. Three different configurations were tested, the cyclist in upright position wearing an aerodynamic helmet, the cyclist in time trial position wearing the same aerodynamic helmet and finally the cyclist in time trial position wearing a normal road helmet. These tests were performed to assess the correlation between the two measurement techniques in multiple drag area regimes.

The power meter gives information about the total drag force opposing the cyclist's motion. In order to compare the aerodynamic drag value to the results of the Ring of Fire technique, the aerodynamic drag has to be extracted from the total power output (P_{total}) by (Martin et al., 1998):

$$D = \eta_{drivetrain} \frac{P_{total}}{V} - C_{rr} mg - (91 + 8.7V) \cdot 10^{-3} \quad (1)$$

where $\eta_{drivetrain} = 0.97$ is the drivetrain efficiency, V = 30 km/h is the cyclist's velocity, $C_{rr} = 0.0055$ is the rolling friction coefficient, m = 79 kg is the cyclist's mass and g is the gravitational acceleration.

Drag evaluation with the Ring of Fire is done through a control volume approach. The momentum before and after the passage of the cyclist poses the basis for for this analysis in the cyclist's frame of reference. When the control surfaces S_1 and S_2 are sufficiently far from the object surface (Fig. 2), the drag force can be expressed as follows:

$$D = \underbrace{\rho \iint_{S_1} (u_{env} - u_C)^2 dS + \iint_{S_1} (p_\infty - p_1) dS}_{1} - \underbrace{\rho \iint_{S_2} (u_{wake} - u_C)^2 dS - \iint_{S_2} (p_\infty - p_2) dS}_{2} \quad (2)$$

where ρ is the air density, u_C is the cyclist's velocity, u_{env} and u_{wake} are respectively the flow field before and after passage of the cyclist through the Ring of Fire.

Results & Discussion: A comparison between power meter and Ring of Fire derived drag area coefficient for each of the three configurations is presented in Fig. 3. For the power meter approach a value of C_{rr} = 0.0055 was utilized to derive the drag. The histogram can be studied in two different ways, namely by assessing the relative difference of the measurement techniques between each test condition, or by evaluating the absolute values of the predicted C_dA. The present study will only discuss the relative differences because the absolute drag values obtained from the power meter are strongly dependent on the values of the model constants. Considering the relative performance for the individual cases, the trends of the power meter and the Ring of Fire show good agreement, as a large-scale drag area increase from time-trial to upright position is obtained. While the Ring of Fire predicts an increase in C_dA of 0.039m^2, the power meter results increase by 0.054m^2. Barry et al. (2014) reported a drag area reduction of 17.5% when comparing both postures. This is in accordance with the reduction obtained from the power meter (20 %) and the Ring of Fire (15 %) in the current experiment. Between the two helmet types a small-scale increase of 0.009m^2 (4%) can be extracted from the Ring of Fire measurements, compared to a delta of 0.004m^2 (2%) for the power meter approach. This follows the general reported trend in literature that time-trial helmets are aerodynamically more efficient than road helmets, as reported in Alam et al. (2010), Blair and Sidelko (2009) and Chowdhury et al. (2014). However, since the accuracy of the Ring of Fire system is estimated to be just below 5%, the variations in C_dA from the helmets fall within the uncertainty of the system.

Conclusions: The Ring of Fire method shows great potential, as the measurements are conducted under simulated racing conditions and wake visualisation allows the operator to locate origins of drag. Validation of the drag area results have proven the Ring of Fire's viability as an optimisation tool in the upcoming years.

References

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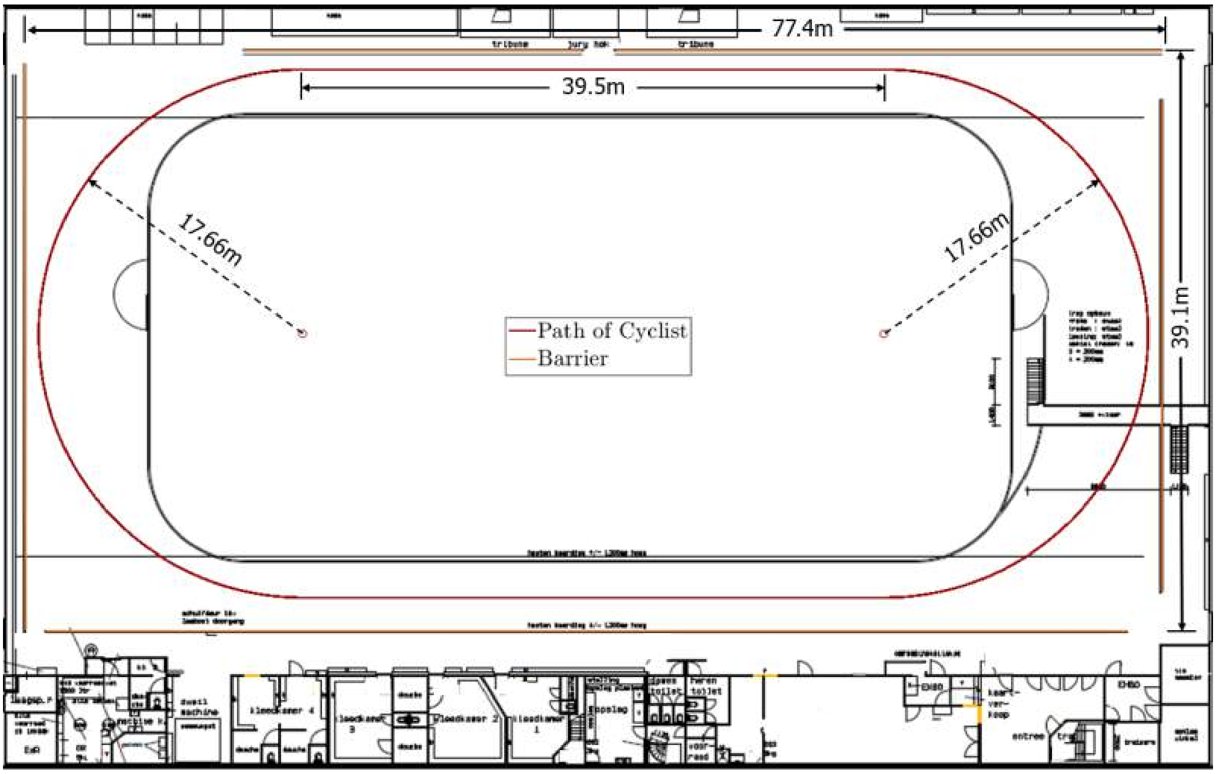

Fig. 1 Top view of the testing facility

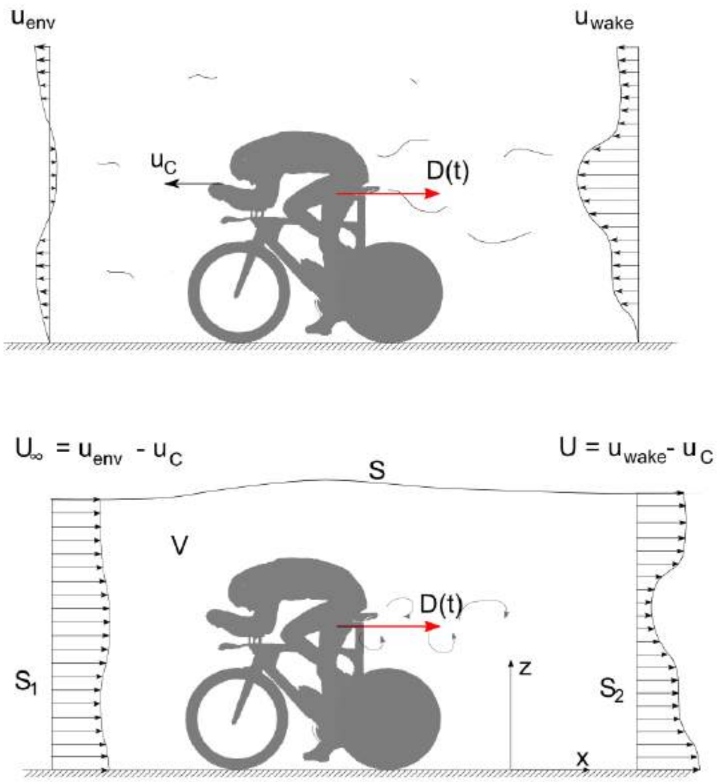

Fig. 2 Schematic view of the velocity distribution before and after the passage of the cyclist (top). Same view after Galilean transformation in the cyclist frame of reference (bottom).

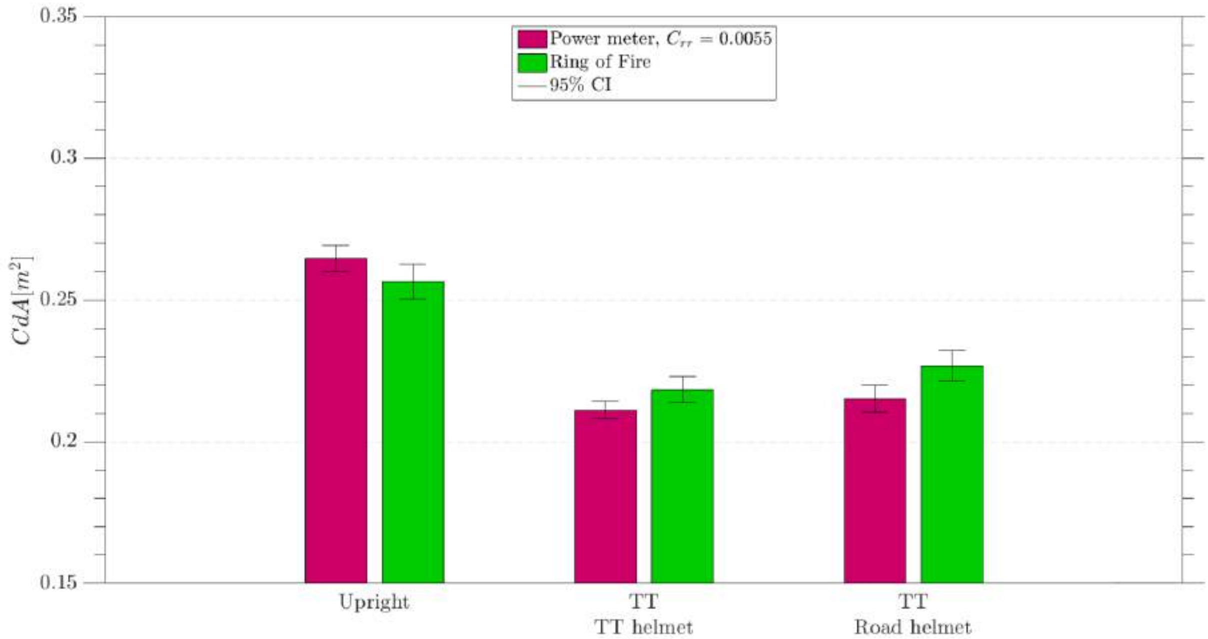

Fig. 3 Comparison of drag area coefficients between power meter and Ring of Fire.

Fig. 4 Impression of the experiment. Cyclist riding through the Ring of Fire.