Experimental evaluation of a computer-vision based method to assess the aerodynamic drag of cyclists

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Context: Reducing drag is a major challenge in cycling. In fact, it is a well-know fact that, on flat road conditions, aerodynamic drag represents about 80% of the total resistive forces applied to the cyclist. The aerodynamic drag is given by the following equation: $F_{aero} = \frac{1}{2}\rho AC_d V^2$, where ρ is the air density, A the cross sectional area or frontal area and C_d, the drag coefficient. In order to reduce the aerodynamic resistive forces, one search to minimize AC_d, which requires to be quantified. In the literature, different methods have been proposed; we can mainly quote: wind tunnel [1], dynamometric measurement [2], deceleration [3], linear regression [4], and 3D digitalization-based method [5-7].

We introduced previously a new computer vision-based method to assess the aerodynamic drag of cyclists [8,9]: first a dynamic 3D model (3D+t) of the cyclist in motion and his bike is built and thereafter this model is processed by a CFD solver to assess the aerodynamic resistive forces. This method offers a low cost alternative to the wind tunnel measurements and does not require any special infrastructure (track) like the linear regression technique. Moreover, it overcomes the limitations of the classic static «3D + CFD» methodologies that we investigated in a precedent work [8]. We also performed a first evaluation of the performances of our method [9] using a dataset, whose the precision was unfortunately impacted by the wind's influence (due to open-road records). In this work we create a new dataset recorded on an indoor track and use it to experimentally evaluate our method.

Experimental data: All data were recorded the same day on a 200m indoor velodrome (Bourges, France) for 4 different subjects. Power, speed, temperature, and pressure were measured using the following equipment: Rotor INpower (power), Garmin 010-12103-00 speed sensor (speed), and Bosch 280 (temperature and pressure). Each cyclist used his own bike and performed a particular sequence. The first subject rode four laps at two different speeds (25 and 35 km/h) and for 2 positions (upright and dropped positions). In order to properly evaluate the repeatability of the experimental data, this sequence was performed 6 times. The 3 others subjects rode 3 laps at 4 different speeds (25, 30, 35, 40 km/h). This sequence of 12 laps was performed for 3 different positions: upright, brake-hoods, and dropped position.

Data processing: To obtain the drag force from the experimental data, we considered the classic balance of forces opposing the cyclist's movement in the direction of motion [4] to which we added the force associated with the acceleration (the speed is not constant):

$F_{cyclist} = F_{aero} + F_{roll} + F_{acceleration}$ so $F_{aero} = \frac{P_{sensor}}{V} - C_r mg - ma$ with C_r the tires rolling coefficient (fixed as 0.004), m the cyclist's mass, a his acceleration, and $g = 9{,}81$.

Dynamic 3D models: 3D+t models of the 4 subjects were obtained using our real-time acquisition system. This system uses 4 low-cost RGB-D sensors (Microsoft Kinect V2).

Foremost the 3D data given by these sensors are merged in a unique 3D field. Then a human 3D body model is fitted from this field. Finally a 3D bike model is merged to the model of the cyclist. The whole process is fully automated and does not need human intervention.

CFD simulation: The CFD simulations were performed with the OpenFoam solver (ESI Group). The cyclist surface was discretized using a polyhedral surface mesh. The numerical wind tunnel consisted of a box with a cross section of 20 m by 15 m and a total length of 50 m. The k-ε turbulence model was used throughout the simulations.

Results: At first, we wish to underline the weakness of the repeatability of the experimental data. In fact, the standard deviation of the force data calculated by the regression method (see Table 1) averages 1.61.

		Force(N)			
Position	**Speed (m/s)**	**Mean**	**Min**	**Max**	**Std**
Upright	7,5	15,17	12,53	17,58	1,93
Upright	9,9	26,29	23,93	28,23	1,70
Dropped	7,6	16,21	13,85	18,24	1,71
Dropped	10,4	27,49	26,30	28,70	1,10

Table 1: Study of the repeatability of the experimental data.

However these data confirm a result obtained in [10]: the value of AC_d is not constant when the speed changes (see Figure 1).

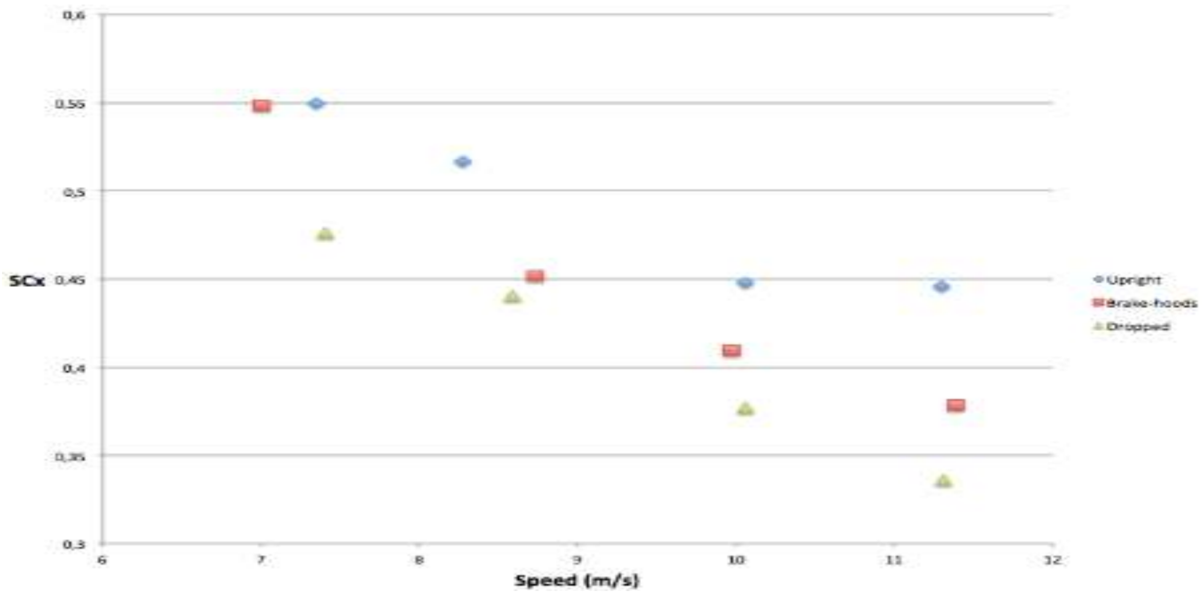

Figure 1: Experimental values of AC_d for different speeds and different positions

We used the experimental data of the first subject to optimize the different parameters of the simulation and calibrate our method, while the data of the 3 others subjects were used to evaluate the performance of the method. Figure 2 depicts the forces simulated by our method versus the forces computed from experimental data. It shows that there is a good correlation between the two sets of data. However, this correlation is limited probably because of the weak repeatability of the experimental data. We can indeed note that almost all points are contained in the space defined by 2 times the standard deviation of the experimental data (depicted as bars in the figure).

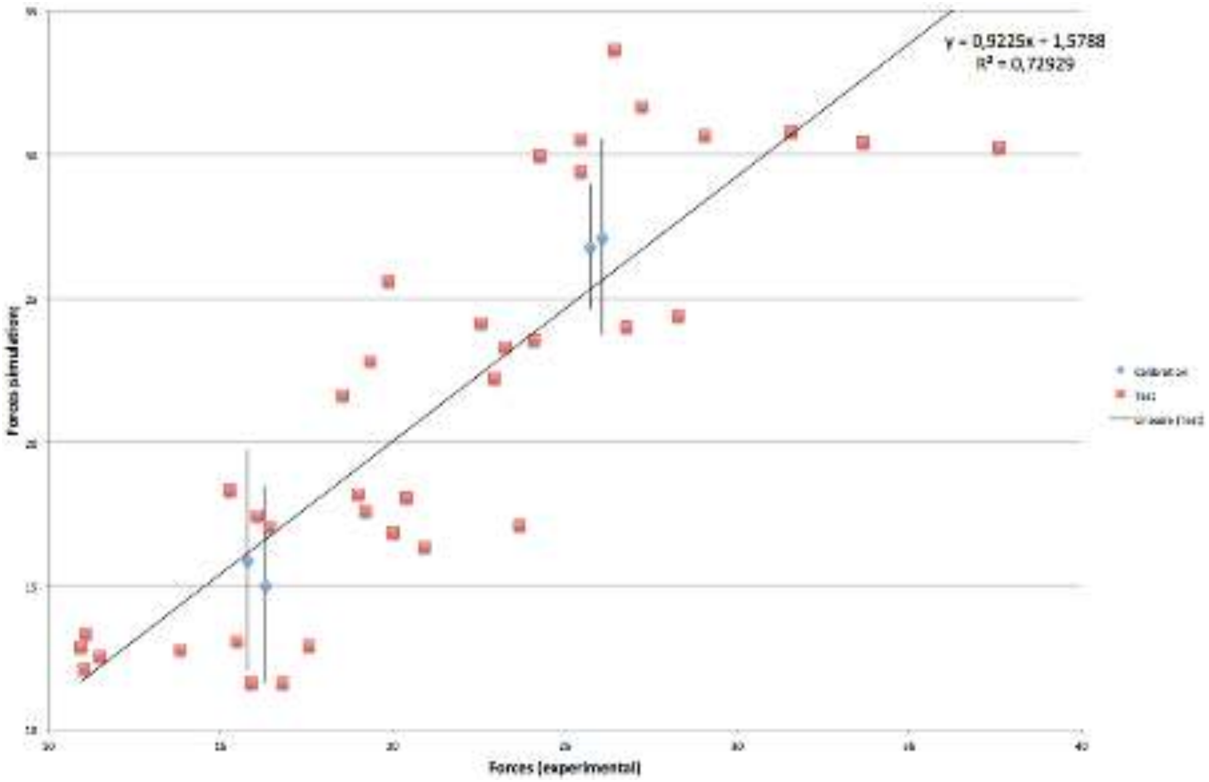

Figure 2: Experimental forces VS forces obtained with our method.

Conclusion: We propose in this work an experimental evaluation of a new method based on computer vision to assess the drag force. In this purpose, drag forces were experimentally measured using the protocol described in [4] and [5]. We showed that there is a good correlation between the results given by our method and the experimental data. Moreover this correlation is probably limited by the weak repeatability of the experimental data itself.

This experiment allows a global validation of our method but for a stronger validation, it will be appropriate in future works to use experimental data having a much higher repeatability. It will be necessary either to improve the experimental conditions allowing a better repeatability of the velodrome measurement method or to use data coming from a wind tunnel for which it will be also necessary to establish the repeatability in the cycling field because there are currently no bibliographic sources claiming this kind of results.

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Appendix:

3D+t: a 3D+t model is a dynamic 3D model, which evolves over time in order to take into account the deformation of the model due to the motion of the subject (here a cyclist).

3D+CFD: refers to a Computational Fluid Dynamic simulation dealing with a static 3D model.