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Conference Abstract

Validation of Body Rocket On-Bike Wind-Tunnel Technology: Drag Measurement Accuracy and Aerodynamic Gains Sensitivity

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Abstract: While body aerodynamics plays a major role in cycling performance, athletes can only measure their coefficient of aerodynamic drag (CdA) in wind tunnel sessions, i.e. far from actual racing conditions, or via methods that can infer CdA, but do not actually measure all the components of CdA. We present a novel device (Body Rocket) that, by using the same load cell technology as a wind tunnel, directly measures and displays in real time the drag force due to a rider's body only. We compare drag force measurements carried out simultaneously on a wind tunnel balance and the BR device. On average, the Body Rocket system agrees within 2.3% with the wind tunnel data, under different wind speed, yaw angles and body positions, and reliably detects aerodynamics gains due to positional/equipment changes. As a byproduct of its design, it also enables monitoring of cycling positions, providing valuable feedback otherwise not available to the athlete.

Keywords: Cycling Aerodynamics, Drag Force, Live-CdA, Real Performance Conditions, Embedded Sensors

1. Introduction

With drag force due a rider's body accounting for 80% or more of all resistive forces on a bike (e.g. Kyle & Burke 1984) large performance gains in cycling can be achieved through better aerodynamic knowledge and positional improvements. Although a cyclist's aerodynamic resistance (the coefficient of drag times the frontal area, or CdA) can be derived with a range of direct and indirect methods (see Malizia & Blocken, 2020 for a recent review), none is providing a direct estimate of the actual drag force in real road conditions.

Wind tunnel (WT) sessions directly measure the drag for cycling positions and equipment, but they only capture a snapshot in time from which actual performance on race days must be extrapolated. Body aerodynamics, however, is influenced by several external factors, such as wind speed and road condition, the ability to comfortably hold a position on prolonged efforts, fatigue, etc. It is hence necessary to assess the optimal cycling positions in real-world tests, that are as close as possible to actual racing conditions both in terms of environmental and human performance factors.

Field experiments to determine air resistance in indoor & outdoor cycle tracks, including classical techniques such as regression or coast down/deceleration methods (Candau et al 1999, Capelli et al., 1993, Martin 1998, Tengattini and Bigazzi, 2018), have been carried out routinely, but they do not provide a direct measure of the aerodynamic drag, which is instead inferred from energy balance considerations that require assumptions on other parameters. This is true even on currently available portable devices capturing live CdA during training, (e.g. Notio (Argon18®) —Millour et al 2023, Ordiñana-Pérez et al. 2023, Bruez et al. 2023), which rely on power meter measurements to infer CdA (a technique often referred to as 'Virtual Elevation' or VE, Chung 2012).

In this paper we present and test a new device for the direct measurement of a rider's drag force which has been developed by Body Rocket Ltd (Sussex, UK) using the same measurement methodology as a WT. We assess its reliability and accuracy through direct comparison with WT drag measurements.

2. Materials and Methods

2.1. Description of the testing device

The Body Rocket (BR) system consists of four load cell sensors which are placed at the touching points of the rider on the bike: the handlebar, the saddle, and the pedals. These sensors simultaneously record forces applied in the horizontal and vertical direction, "roll" and "pitch" moments, as well as the inclination of each sensor relative to the bike frame. In an environment with no external forces the sum of horizontal forces on the 4 sensors always sum to zero, and the sum of vertical forces equals the rider's weight. An external force applied to the system, as is the case for aerodynamic drag, is instead directly captured by BR device. The 4-sensor arrangement is effectively isolating the rider from the bike at all contact points enabling the measurements of the aerodynamic characteristics of the athlete only.

As the BR device captures drag force exactly as a WT, it can be fitted on a bike to measure the force due to the wind load simultaneously with the WT balance and hence perform a direct comparison of accuracy and sensitivity, as discussed below.

2.2. Wind tunnel testing protocols

Tests were carried out both at the University of Southampton's R. J. Mitchell WT (July 2022) and at the Silverstone Sports Engineering Hub WT (SSE, Sep 2023/May 2024), with different athletes and bikes. After prior informed consent of participants, we fitted the BR device to their bike and recorded WT and BR data simultaneously, for wind speeds in the range 11m/s to 16m/s. As the WT balance measures the drag force due to the combined bike plus rider frontal area, tare bike-only runs with no rider were taken at each wind speed and yaw and subtracted from the WT data. While this technique removes most of the bike contribution to the total bike+rider drag measured by the WT providing the equivalent of a rider-only drag force, as discussed in the next sections we believe it does not fully account for the interplay between rider and bike leaving small additional corrections to be considered.

At Southampton we carried out controlled experiments with a fixed yaw angle and the rider holding just 4 positions spanning a broad range of drag force. At SSE we allowed instead more subtle positional changes, including different helmets, as well as a varying yaw angle. For confidentiality reasons, details of the exact changes involved in these sessions cannot be made public. Were relevant, we therefore just refer to generic run IDs, highlighting whether they involved a positional or equipment change. On both test sites, the rider was asked to hold the position at their preferred cadence for about 30 to 100s, depending on the type of test.

3. Results

3.1. Accuracy at different wind speeds

Runs carried out at the Southampton WT involved four position changes at wind speeds 11m/s, 13m/s, and 15m/s. Each position & wind speed combination was repeated twice to assess the rider's consistency. Drag force measurements for each position, run and wind speed are summarised in Figure 1, while Table 1 provides averaged results. We find an overall good agreement between the BR- and WT-measured drag forces. Over the 24 data points for each combination of positions and wind speeds, the BR's device agrees within ±2.3% with the WT data.

We note that there is a wind-speed dependency of the measured difference between the BR and WT force, as illustrated in the bottom panel of Figure 1. We could not fully determine the causes of this trend. To exclude load cell calibration uncertainties and perform a more direct comparison between the WT and BR load cells sensitivity, we carried out "pull tests" where an external force was applied with the aid of an elastic band placed around the rider's waist, with no wind in the tunnel. In this configuration, the WT balance and BR system should measure the same force. Results indeed showed consistency within 0.2N (or 1%) on average. We note that this test was carried out at a single loading (20N), hence we cannot guarantee that the calibration of the two systems was consistent over the full range of forces seen in Figure 1. It also is possible that temperature or other time-dependent variables which we did not monitor played a role in the observed wind-speed dependence.

3.2. Sensitivity to positional changes at different yaw angles

In the tests carried out at SSE we analysed more subtle variations in positional changes, involving (overall drag span ~2N vs ~20N at Southampton) and different yaw angles, mimicking more closely real racing conditions. Two types of tests were carried out: a validation of the system general performance under different yaw angles (similar to what was done with the wind speed), and a comparison of the BR and WT sensitivity to different body positions.

In the yaw validation run, data was collected for a continuous yaw sweep between -20° and +20° (0.5°/sec rate) at a wind speed of 16m/s. This resulted in 10sec of data being collected for each yaw bin. The test was repeated for two different positions.

Similar to what was found in the previous section at the highest wind speed, these yaw tests carried an overall offset between the BR drag force measurement and the WT data under a wind load. Pull tests under a known load, but no wind, were gathered also this time, confirming agreement within less than 0.1N between the WT balance and the BR load cells. This again supports the idea that there is a speed-dependent offset that our bike-only taring technique may not be able to fully account for. We therefore removed this offset in the following results.

Figure 2 shows the percentage error relative to the wind tunnel drag force in yaw bins of 5deg. As found in the previous section, the agreement with the WT measurements is 2.5% or better. We note here that typical WT measurements are carried out over 30 seconds intervals at a fixed yaw angle. It is likely that some of the deviations seen in Figure 2 are due to increased noise in both the WT and BR data compared to standard procedures.

For the assessment of the positional sensitivity a total of 9 different positions+helmet combinations were tested at a wind speed of 13 m/s and yaw angle equal to 0°, 5° and 10°. We discuss in the following the 5° yaw results which is a typical non-zero yaw angle that a rider is likely to encounter, but similar conclusions were obtained at the two other yaw bins. The results of these runs are presented in Figure 3 and Table 2, where we show the percentage change in drag force relative to the baseline position, i.e. how much more aerodynamic each position was w.r.t the baseline.

Also in this dataset, the BR measurements follow closely the WT data in terms of overall drag trends and positions ranking. Maximum deviations from the WT changes in aerodynamic resistance changes are ~3.5% and on average 2% smaller than those derived from the WT (see Table 2). As discussed in the previous section, while we cannot exclude a small systematics in the BR device, this could also reflect the effect of real interactions between the rider and bike.

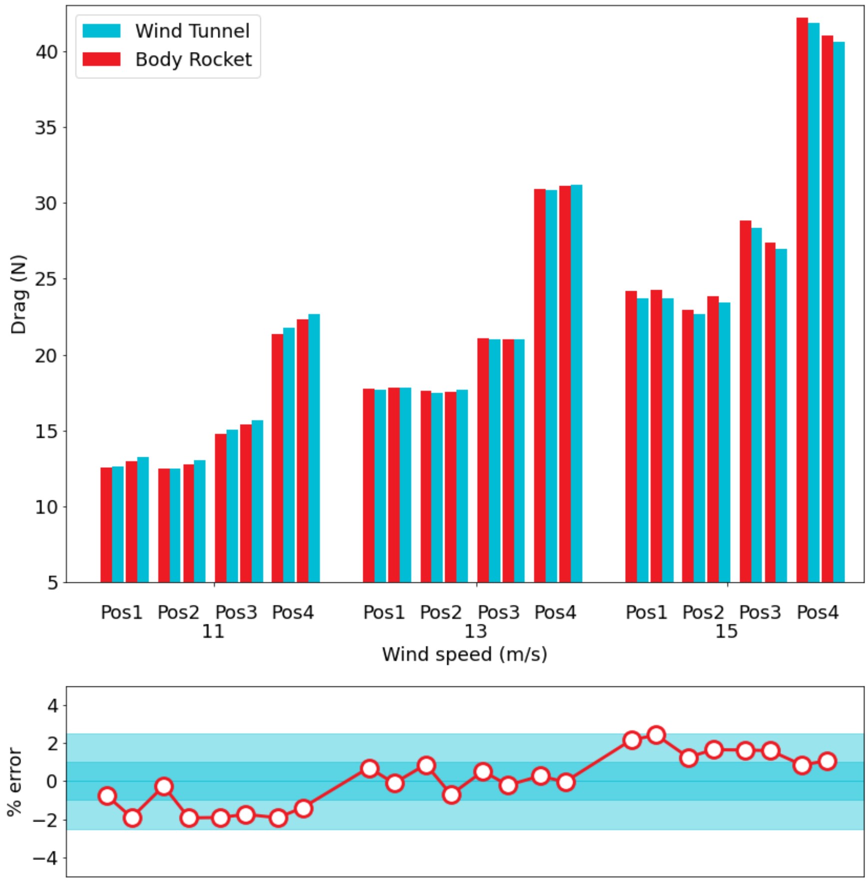

Figure 1. Drag force measured by the WT and BR system, at the Southampton test session. Data points for each wind speed (11m/s, 13m/s, and 15m/s) & position combination (positions 1 to 4) are shown. Top: absolute drag force comparison. Bottom: percentage error w.r.t. the WT data. Blue bands show 1% and 2.5% deviations.

Table 1. Drag force as measured by the WT and BR system at the Southampton wind tunnel, for each wind speed and position. Averages for the two repeated runs are provided. Absolute and percentage force difference of the BR data relative to the WT are given in the last two columns.

Speed	Position	WT drag (N)	BR drag (N)	Difference (N)	Perc. difference
11 m/s	1	12.78±0.32	12.95	-0.18	-1.35%
	2	12.61±0.33	12.76	-0.14	-1.12%
	3	15.09±0.34	15.37	-0.28	-1.83
	4	21.87±0.29	22.23	-0.37	-1.66%
	all	15.59±0.25	15.83	-0.24	-1.51%
13 m/s	1	17.81±0.37	17.76	0.05	0.29%
	2	17.58±0.37	17.57	0.01	0.08%
	3	21.05±0.36	21.02	0.03	0.15%
	4	31.02±0.31	30.99	0.03	0.11%
	all	21.87±0.26	21.83	0.04	0.18%
15 m/s	1	24.23±0.39	23.69	0.54	2.29%
	2	23.39±0.39	23.05	0.33	1.45%
	3	28.13±0.37	27.68	0.45	1.61%
	4	41.62±0.30	41.23	0.39	0.96%
	all	29.34±0.26	28.91	0.43	1.48%

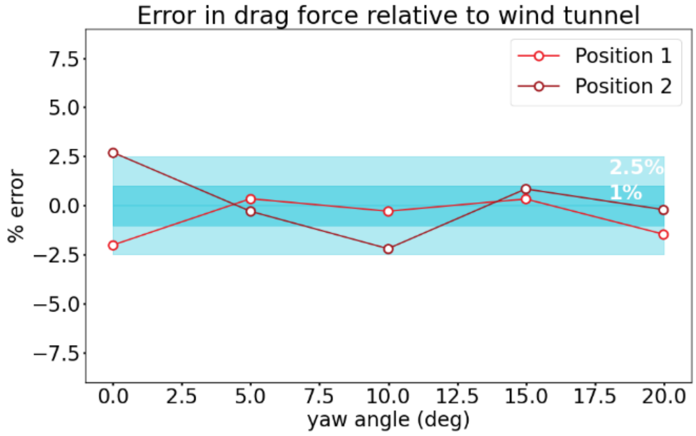

Figure 2. Percentage drag error in comparison to the wind tunnel measurement, for yaw angles up to 20 degrees. The two lines indicate two different rider positions. Data was collected in a continuous sweep between -20° and +20°, but is shown combining the left and right yaw directions (for this reason the 0° yaw bin has half the datapoints compared to the other yaw bins).

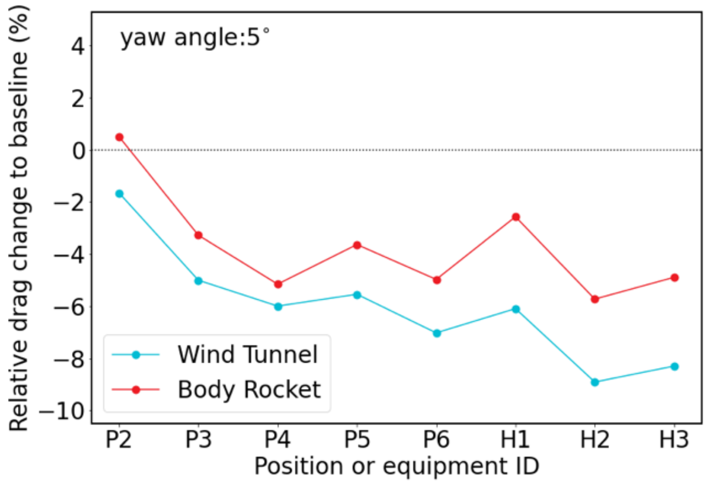

Figure 3. Percentage drag change relative to baseline for several different positions, as measured by the WT and BR system at the SSE Hub. Runs labelled P1 to P6 involved positional changes only, in H1 and H3 the rider was also wearing different helmets.

Table 2. BR sensitivity to positional changes. Positions are listed in column 2: P1 to P6 involved body adjustments only, three helmet changes were instead tested in runs H1 to H3. Columns 3 and 4 are the % variation in drag force w.r.t. to the baseline position, as measured by the WT and BR, respectively. The last column lists the fraction of total rider weight felt on the handlebar. Values are averaged over all 3 yaw angles studied.

Yaw	Position	WT change	BR change	% weight on bars
0-10°	Baseline	-	-	31
0-10°	P2	-1.7%	0.5%	34
0-10°	P3	-3.9%	-1.9%	32
0-10°	P4	-5.8%	-5.2%	33
0-10°	P5	-4.9%	-4.5%	32
0-10°	P6	-5.6%	-4.7%	35
0-10°	H1	-5.8%	-3.5%	34
0-10°	H2	-7.9%	-5.6%	33
0-10°	H3	-7.9%	-6.5%	33

4. Discussion

Our experiments indicate a good reliability of the BR aero device which displays the same sensitivity to positional changes as the wind tunnel, under different wind and yaw conditions. Given that an accurate drag force measurement requires full solution of all the forces applied to each sensor (see Sec. 2.1), by construction the BR system can also provide further valuable feedback about athletes' performance on the bike.

As an example, positional indicators, such as the weight distribution across the rider's touching points on the bike (pedal, saddle, and bars) are accessible in the BR dataset. In Table 2, we list the fraction of the rider's weight that went on the bars, at each of the position tested at the SSE session. With respect to the baseline, all other runs involved a more tucked-in position being held by the rider. This is captured by a larger weight on the bars, consistently with also an overall decrease in drag force at these positions (on both the WT and BR data).

A more in-depth analysis of the viability of using the BR device to detect positional changes on the bike is investigated in Barnes et al. 2023 and Barnes et al. in prep., where the data from the BR sensors is used to identify adjustments on the saddle and full body position changes.

5. Practical Applications

The Body Rocket aero system is designed to be integrated on the bike during training and to communicate with a Garmin device. Coupled with sensors monitoring environmental parameters (air speed and density), it enables the live display of a rider's CdA and hence the instantaneous assessment of aerodynamic gains associated to positional and equipment changes, as well as the factors affecting them during racing events. It therefore opens the possibility to make the WT experience accessible to all cyclists and triathletes, with similar accuracy but under real road conditions. By also monitoring positions on the bike, it can aid riders and coaches to evaluate the stability/comfort of chosen positions and inform pacing strategies.

6. Conclusions

BR has developed a novel technology to provide cyclists with real-time CdA during outdoor conditions. In this paper we presented the comparison between the drag force measured using the BR system and those simultaneously recorded at WT. Overall Body Rocket has shown to be a reliable system for measuring real-time drag force compared to the WT reference, with an overall average accuracy under the tested yaw and wind speeds which is typically 2.3% or better.

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Conflicts of Interest: Authors are affiliated to Body Rocket Ltd.

References

1. Kyle, C. R. and E. R. Burke (1984). "Improving the racing bicycle", Mechanical Engineering 106, pp. 34– 35.
2. Malizia, F. and B. Blocken (2020). "Bicycle aerodynamics: History, state-of-the-art and future perspectives". Journal of Wind Engineering and Industrial Aero- dynamics 200, p. 104134.
3. García-López, J. et al. (2014). "The Use of Velodrome Tests to Evaluate Aerodynamic Drag in Professional Cyclists". International Journal of Sports Medicine 35.05, pp. 451–455.
4. Martin, J. C. et al. (1998). "Validation of a Mathematical Model for Road Cycling Power". Journal of Applied Biomechanics 14.3, pp. 276–291.
5. Capelli, C. et al. (1993). "Energy cost and efficiency of riding aerodynamic bicycles". European Journal of Applied Physiology and Occupational Physiology 67.2, pp. 144–149.

6. Candau, R. B. et al. (1999). “Simplified deceleration method for assessment of resistive forces in cycling”. Medicine & Science in Sports & Exercise 31.10, p. 1441.
7. Tengattini, S. and A. Bigazzi (2018). “Validation of an Outdoor Coast-Down Test to Measure Bicycle Resistance Parameters”. Journal of Transportation Engineering, Part A: Systems 144.7, p. 04018031.
8. Millour, G., Plourde-Couture, F., & Domingue, F. (2023). “Cycling modelling under uncontrolled outdoor conditions using a wearable sensor and different meteorological measurement methods.” International Journal of Sports Science & Coaching 18(4), 1102-1112.
9. Bruez, A., Caillou, Q., Dugenne, T., Peron, T., Perrey, S., & Lambolais, T. (2023). “Reliability and Sensitivity of the Notio Device and Aeroscale Service to Quantify Cyclists’ Drag Coefficients in Outdoor Conditions.” Journal of Science and Cycling, 12(2), 18-20.
10. Ordiñana-Pérez M, Mateo-March M, Monteagudo P, Zabala M, Blasco-Lafarga C. “Validity of a novel device for indoor analysis of cyclists' drag area.” Eur J Sport Sci. 2023 Jan;23(1):1-7.
11. Chung, R. (2012). “Estimating cda with a power meter.” url: http://anonymous.coward.free.fr/wattage/cda/indirect-cda.pdf.
12. Barnes, C., Hopker, J., & Gibson, S. (2023). “To shuffle or not to shuffle”. Journal of Science and Cycling, 12(2), 28-30.