# BIOMECHANICAL ASSESSMENT OF AERODYNAMIC RESISTANCE IN PROFFESSSIONAL CYCLISTS: METHODOLOGICAL ASPECTS

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The aim of this study was to measure and compare the aerodynamic resistance (RA) in five different professional road cyclists obtained from a wind tunnel and to establish modification that into a performance improvement. Five professional cyclists from the Kelme-Costa Blanca Team were studied in five positions, four on the aerobike and one on the standard bike. From our results we conclude that establishing small modifications in the aerohandlebars, which result in a more profitable position, can reduce RA. The use of aerohelmet was not shown to be always useful. It is necessary to take into account the technique employed, corrected RA values with the anthropometric characteristics, static vs dynamic assessment when comparing professional cyclists RA.

**KEY WORDS:** cycling, aerodynamics, wind tunnel.

**INTRODUCTION:** Aerodynamic resistance (RA) can be assessed using different techniques: 1) the simplified deceleration, used since 1926 with trains and later on with cars and cyclists (Candau *et al.*, 1999). 2) The traditional traction resistance test (Capelli *et al.*, 1993), which consists on towing a bicycle and rider with a motorcycle via a nylon cable with a load cell mounted on. 3) A light force transducer attached to the shaft of the rear wheel (Max One, Look Corp., France), thus pedalling toque and force can be obtained (Grappe *et al.*, 1997). 4) A recently invented force transducer placed in the crank (SRM Science, SRM Corp., France) (Broker, Kyle, & Burke, 1999). 5) The appliance of metabolic rates and the power output obtained from laboratory tests to field tests (Padilla *et al.*, 2000) and, finally, 5) the wind tunnel (Jeukendrup & Martin, 2001). Among these methods the most valid and reliable one is the wind tunnel, as it has been proved that its variability is lower than 1%, besides it is sensitive to the usage of different kinds of handlebars, frames, wheels...in the same bicycle (Kyle & Caiozzo, 1986; Dal Monte *et al.*, 1987). Its main disadvantage is the high expenditure that requires, hence there are scarce published studies performed in a wind tunnel with professional road cyclists, and those published presented only one experimental subject (Padilla *et al.*, 2000; Jeukendrup & Martin, 2001). Furthermore, some had an educational purpose rather than scientific. That is why most RA values were not obtained from a wind tunnel, but from the different techniques described above. The aim of this study was to measure and compare the RA in five different professional road cyclists obtained from a wind tunnel, as well as to establish modifications in posture and use of the aeroequipment that leads into an improvement of the time trial performance.

**METHODS:** Five professional cyclists from the Kelme-Costa Blanca Team who took part in the Tour de France and Spanish Vuelta participated in this study. Direct measurements in a wind tunnel have been made with the rider-bike system placed upon a calibrated dynamically and statically force platform at a wind velocity of 15m/s (Fig.1). The positions that subjects were asked to maintain consisted of: 1) Static position on the aerobike, 2) Pedalling on the aerobike, 3) Pedalling on the aerobike with modifications of the handlebar supports in accordance with the International Cycling Union (UCI) regulations, 4) Idem without aerohelmet, 5) Pedalling on a standard racing bike. Subjects were filmed with a digital camera in order to analyse different kinematic variables such as (Fig2): a) profile height (1) and length (2); b) horizontal-torso (A), torso-arm (B), arm-forearm angles (C); c) crank-front shaft (3), crank handlebar lengths (4). Through the usage of Newton's equation, $RA=0.5xSC_x x \rho x V^2$ (where RA is aerodynamic resistance in Newton's, $\rho$ is air density at sea level: 1.22 kg/m$^3$, $SC_x$ is the aerodynamic drag coefficient and V is air velocity in m/s) $SC_x$ and F/Kg ratio were obtained. Statistical nonparametrics analysis consisted on paired t-tests

(Wilcoxon) and correlations "r" (Spearman) using Statitica-v4.0 software and a level of significance "p" less than 0.05.

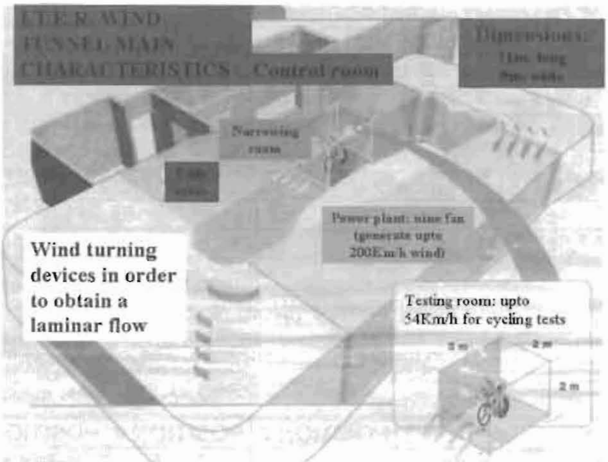


**Figure 1.** Structure of the I.T.E.R. wind tunnel.

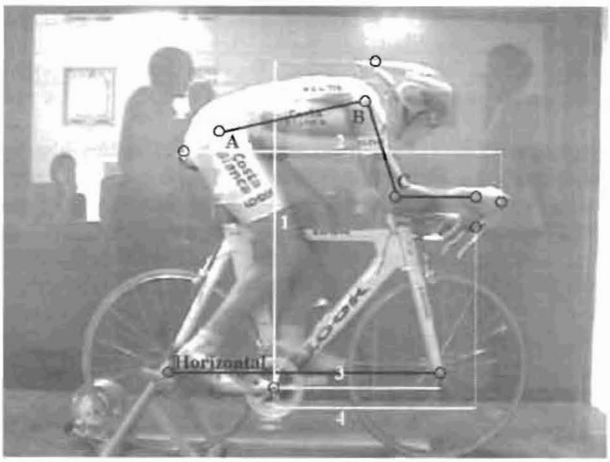


**Figure 2.** Main measurements digitised and analysed.

**RESULTS:** Mean values and standard error for the angles (A, B, C), length (1, 2, 3, 4) and factors which determine aerodynamic drag in the five riding positions are shown in Table-1. The AR values for position 1 are lower than for positions 2-5; for position 2 (46.8±1.8) the values are higher than for positions 3-5; there are no differences between positions 3 and 4. These differences can be observed for AR/Kg and SCx as they directly depend on AR, as well as on the horizontal-torso angle (A) and the profile height (1) Not all cyclists used the UCI's maximal distance crank-front shaft (0.6m).

Significant correlations for RA and horizontal-torso angle ($r=0.42$ and $p<0.05$) and profile height ($r=0.57$ and $p<0.01$) in positions 1-4, were found. RA/Kg ratio was negatively correlated to mass ($r=-0.54$ and $p<0.01$) and profile length ($r=-0.74$ and $p<0.001$).

**Table 1.** Mean values and standard error for the angles (A, B, C), length (1, 2, 3, 4) and factors which determine aerodynamic resistance in the five riding positions.

| VARIABLE | POSITION 1 | POSITION 2 | POSITION 3 | POSITION 4 | POSITION 5 |
|---|---|---|---|---|---|
| **AR (N)** | 35.7±1.5 | 46.8±1.8* | 40.2±0.4* | 40.8±1.7 | 66.0±2.3* |
| **AR/Kg (N/Kg)** | 0.50±0.02 | 0.66±0.04* | 0.56±0.02* | 0.57±0.03 | 0.92±0.01* |
| **$SC_X$ ($m^2$)** | 0.260±0.011 | 0.341±0.013* | 0.293±0.003* | 0.296±0.013 | 0.481±0.017* |
| **A (°)** | 16.9±1.2 | 19.2±1.2* | 15.4±1.5* | 15.8±1.4 | 23.1±2.2* |
| **B (°)** | 86.6±4.1 | 84.0±3.9 | 86.1±2.2 | 84.1±1.6 | 76.8±2.1* |
| **C (°)** | 106.8±3.9 | 109.6±4.1 | 107.8±2.9 | 108.8±4.0 | 119.8±7.7* |
| **1 (cm)** | 114.5±2.1 | 121.4±2.0* | 116.1±2.6* | 112.8±2.6 | 114.6±2.9* |
| **2 (cm)** | 89.4±3.4 | 85.4±2.1* | 87.3±1.7* | 85.5±1.8* | 85.7±1.9 |
| **3 (cm)** | 57.5±0.9 | 57.7±0.9 | 57.7±0.8 | 57.8±0.8 | 58.7±0.7* |
| **4 (cm)** | 71.2±2.3 | 71.3±1.8 | 73.0±2.3* | 73.2±2.0 | 68.9±2.1* |

* = significative differences with the position before ($p<0.05$).

**Table 2.** SCx values for the 5 subjects in the 5 positions analysed. The influence of the aerohelmet in RA (%).

| | POSITION 1 | POSITION 2 | POSITION 3 | POSITION 4 | POSITION 5 | HELMET |
|---|---|---|---|---|---|---|
| **Subject 1** | 0,237 | 0,366 | 0,292 | **0,255** | 0,469 | +14.5% |
| **Subject 2** | 0,276 | 0,307 | **0,299** | 0,315 | 0,521 | -5.1% |
| **Subject 3** | 0,291 | 0,321 | **0,299** | 0,306 | 0,515 | -2.3% |
| **Subject 4** | 0,237 | 0,377 | **0,293** | 0,326 | 0,469 | -10.1% |
| **Subject 5** | 0,259 | 0,333 | **0,283** | **0,283** | 0,428 | 0% |
| **MEAN** | 0,260 | 0,341 | 0,293 | 0,296 | 0,481 | -1.3% |

The most profitable position in bold type letters.

**DISCUSSION:** A professional cyclist from the Rabobank team also had his handlebar optimized, which resulted in a RA reduction of 11% (Jeukendrup & Martin, 2001). However, such modifications can not be standardized as they depend mostly on the cyclist's comfort when riding (Heil, 1997), it has been shown that huge modifications may end in a greater energy expenditure, and thus frustrate the aerodynamic improvements (Kyle & Caiozzo, 1986). That is why the subject's opinion was taken into account when the modifications were established. These modifications consisted on moving forwards the handlebar and lead to a lower position the forearm support. All cyclists had their handlebar shifted a mean value of 1.7 cm, obtaining a mean distance crank-brake levers of 73-73.2 cm (75 cm UCI limit). The mean distance crank-front shaft was 57.5-57.8 cm (60 cm UCI limit) due to the subjects' different anthropometric characteristics. It would be interesting to investigate whether a low stature rider could get used to a bigger size bicycle without an increase in energy expenditure, which would result in a lower horizontal-torso angle and a greater length of the profile, reducing, thus, his RA. These modifications imply a RA reduction of 14.5%, which also happens when comparing Upright Position, Dropped Position, Aero-Position and Optimized Position (Grappe *et al.*, 1997), this indicates that they have been quite successful. We have found problems when comparing SCx values, since the ones for the Upright and Dropped Position are in wide ranges (0.299-0.390 and 0.251-0.370 respectively) which means a 50% of variation for RA (Grappe *et al.*, 1997). Something similar happens to the Aero-Position and the SCx values which are in a range from 0.191 to 0.262, most of them are lower than the ones in our study. In order to compare values, the same technique must be used (wind tunnel), which only occurs in five studies (Broker, Kyle, & Burke, 1999; Dal Monte *et al.*, 1987; Menard, 1992; Padilla *et al.*, 2000; Jeukendrup & Martin, 2001); the SCx or F values must be expressed as corrected values by the body mass, as cyclists have different anthropometric characteristics. Finally dynamic positions must be adopted instead of static ones as our results show that dynamic positions jet higher RA values. Other studies show that rubber helmets decrease RA from 0.4 to 30% (Menard, 1992), and our results show that the use of an aerohelmet implies a non significant RA reduction of 1.3%, three of the cyclists would benefit from it and for another one it would be detrimental. It must be noticed that some studies were taken up in small size wind tunnels (61x81 cm), therefore dummies were used instead of actual cyclists (Kyle & Caiozzo, 1986). Testing performed by actual cyclists using four different helmet models stated that only one of the models reduced the SCx, but it was too flamboyant, thus the use of helmet was not advised (Dal Monte *et al.*, 1987). Therefore, the design of an aerohelmet must be custom-made according to the optimal position that the cyclist can maintain, which is very difficult to achieve as a maximal effort state is required. The cyclists in our study had to use their aerohelmet in real cycling conditions and showed that the optimal position was not always maintained because of the individuals' habits.

**CONCLUSION:** Modifications taken will increase the cyclists' performance, which could not be proved by the use of the aerohelmet. Increasing the crank-front shaft distance (UCI limits) will benefit the cyclists' performance, mostly to the lightest ones. It is necessary to take into account the effect of some error sources (technique employed, corrected RA and SCx values with the anthropometric characteristics, static vs dynamic assessment ...) when comparing professional cyclists RA.

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