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Conference Abstract

Measuring the Aerodynamic Drag Reduction Effects of Jerseys in Road Riding Experiments

Yi-Hsuan Lin [1,*], Jiun-Jih Miau [2], Chia-Hsiang Chen [3], Yng-Ru Chen [2] and Yu-Hsiang Chen [2]

[1] National Cheng Kung University; No.1, University Road, Tainan City 70101, Taiwan, R.O.C.
[2] National Cheng Kung University; No.1, University Road, Tainan City 70101, Taiwan, R.O.C.
[3] National Pingtung University of Science and Technology, Pingtung, 912301, Taiwan, R.O.C.

* Correspondence: (YL) tyu2542189@gmail.com

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Abstract: Road riding experiments were conducted to study the aerodynamic drag reduction with different jerseys on a cyclist. C_DA was reduced with a power-based calculation method based on the quantities measured including the cyclist's power output, the riding speed and the wind speed and direction. The results show a trend that as the riding ground speed increased, the influence of the crosswind effect is decreased. The C_DA values reduced from a self-made crank-type power meter were slightly higher than the values measured by a commercial pedal-type power meter. Nevertheless, the results reduced from the two power meters consistently indicate that the C_DA values of the two jerseys tested were differed by 10%. This study confirms that using the power-based calculation method with the instrument installed is capable of resolving the differences in the C_DA values for different jerseys on a cyclist.

Keywords: Cycling, Drag Reduction Effects, Power-Based Calculation Method, Power Meter, Three-Hole Pitot Tube Anemometer

1. Introduction

Drag Coefficient (C_D) has always been a crucial indicator for assessing the aerodynamic characteristics of cyclists. Nevertheless, most of the measurements were conducted with the wind tunnel experiments. In 2020, Chen [1] measured the C_DA values of different jerseys on a number of cyclists using a force balance platform in a large-scale environmental wind tunnel. Despite of the advantages of wind tunnel experiments featuring a controllable environment compared to road test, the latter provide the data sought eventually.

Road riding experiments for obtaining the value of the drag area (C_DA) are based on a distinctly different approach, namely, the power-based calculation method. In 1974, Whitt and Wilson [2] provided an equation in this framework for calculating the cycling power without the consideration of the effect of crosswind.

In 1998, Martin et al. [3] detailed the calculation method with the inclusion of various factors to improve the accuracy. In the method, it was identified that Total Aerodynamic Power (P_{AT}) consumption is one of the primary sources of power loss during free bicycle motion; P_{AT} typically is based on the factors in terms of cycling speed, air density, and riding posture. In 2014, Osman [4] referred the values measured by power meters as Direct Force Power Meters (DFPMs) against Opposing Force Power Meters (OFPMs) which consist of the components of air resistance, slope, speed changes, rolling resistance, and mechanical performance losses. Corrections were made to take into account of the effects due to crosswind on C_DA in outdoor environments.

2. Methodology

In this study, two experiments were conducted in December 2022 and March 2023, respectively. In the two experiments, the values of C_DA corresponding to two jerseys named jerseys I and II, respectively, on a male cyclist were reduced and compared. Jersey I uses a material with higher roughness at the waist, while Jersey II features uniform roughness. Below is Table 1 providing the physique information of the cyclist.

Table 1. Cyclist's physique information

Weight (kg)	Shoulder Width (cm)	Waist Width (cm)	Aspect Ratio
64.6±1.2	41	58	1.41

The instrument employed in this study included a self-made crank-based power meter, which had an effective force measurement range of 0 to 200 Newtons, and a set of Look Keo SRM EXAKT Power Pedals installed on a bike for comparison. Additionally, a self-made three-hole Pitot tube anemometer capable of measuring wind speed and direction was installed on the bike. The anemometer was calibrated in a wind tunnel beforehand, capable of measuring wind speeds within the effective range of 0 to 17 meters per second and wind direction angles within the effective range of ±20 degrees. Referring to figure 1, the three-hole Pitot tube anemometer actually provides the information of U_∞ and β. Moreover, the riding ground speed (V_{gs}) and gradient data (G) were provided by the Garmin Edge 830.

Reduction for the C_DA values was enabled by using a power-based calculation method. (1) describes that the power output by the cyclist P_{total} is balanced by the components of power losses including P_{drag}, $P_{gravity}$, $P_{Mech.loss}$, $P_{rolling}$ and $P_{acceleration}$.

$$P_{total} = (P_{drag} + P_{gravity} + P_{acceleration} + P_{Mech.Loss} + P_{rolling}) \quad (1)$$

$$P_{total} = F \times \omega \times L \quad (2)$$

$$P_{drag} = 0.5 \times C_D \times A \times \rho \times U_{rel}^{\ 2} \times V_{gs} \quad (3)$$

$$P_{gravity} = 9.8607 \times \sin(\tan^{-1}(\frac{G}{100})) \times W \times V_{gs} \quad (4)$$

$$P_{rolling} = 9.8607 \times \cos(\tan^{-1}(\frac{G}{100})) \times W \times Crr \times V_{gs} \quad (5)$$

$$P_{acceleration} = m \times a \times V_{gs} \quad (6)$$

Definitions of P_{total}, P_{drag}, $P_{gravity}$ and $P_{rolling}$ are given in (2) to (6), respectively. Note that the rolling resistance coefficient (Crr) in (5) was set 0.003, and the mechanical loss $P_{Mech.loss}$ was given as 2%.

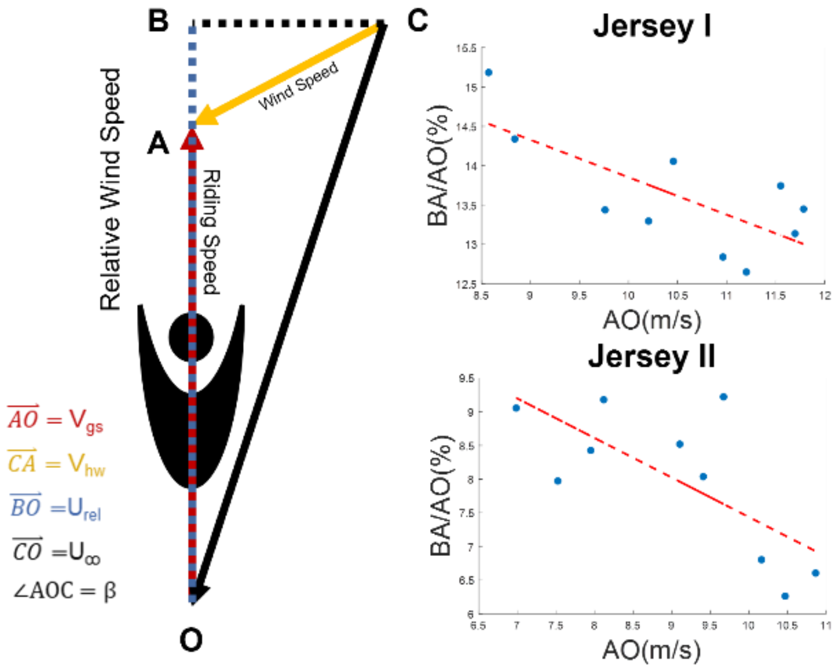

Figure 1. Coordinate definitions for road riding experiments and relations between U_{rel}, V_{hw} and V_{gs}.

3. Results and discussion

In this study, the value of C_DA was reduced from P_{drag} using (3), where P_{drag} was obtained from (1). Specifically, using (1) P_{drag} was resulted from the difference between P_{total} and a sum of $P_{gravity}$, $P_{Mech.loss}$, $P_{rolling}$ and $P_{acceleration}$, where $P_{gravity}$, $P_{rolling}$ and $P_{acceleration}$ were reduced according to (4), (5) and (6), respectively. Note that V_{gs} was provided by the Garmin Edge 830 on the bike. In (3), U_{rel} denotes the relative wind speed in the riding direction. Shown in figure 1, U_{rel} is a sum of V_{gs} and a component of the wind speed V_{hw} in the riding direction.

U_{rel} was reduced from the measurement of the three-hole Pitot tube. Shown in figure 1, the Pitot tube measured the wind speed U_∞ and the wind direction, β. Therefore, U_{rel} is actually a component of U_∞ in the riding direction.

In figure 1, two plots indicating the ratios of $\overline{BA}$ and $\overline{AO}$ on two jerseys are presented for comparison. $\overrightarrow{BA}$ represents the component of V_{hw} in the riding direction. Here, V_{hw} can be considered as a disturbance to U_{rel} for the crosswind effect. It is seen in the two plots that as V_{gs} gets higher, the relative importance of V_{hw} to U_{rel} gets less significant. Namely, the impact of the crosswind effect is less significant.

In Table 2, the C_DA values of jerseys I and II on the same cyclist reduced from the measurements in experiment A using the self-made crank power meter and in experiment B using both of the crank power meter and the commercial pedal power meter are presented for comparison.

Table 2. C_DA values from two power meter in Ex. A and Ex. B

	Ex. A Crank Power Meter	**Ex. B Crank Power Meter**	**Ex. B Pedal Power Meter**
Jersey I $C_DA(m^2)$	0.39±0.013	0.36±0.012	0.30±0.010
Jersey II $C_DA(m^2)$	0.35±0.012	0.33±0.011	0.27±0.009
Deviation (%)	11.4	9.1	10

According to Table 2, the calculated C_DA values by the crank power meter in both of Experiments A and B show that the aerodynamic performance of jersey II surpasses that of jersey I. The C_DA values reduced from the measurements of the pedal power meter in Experiment B also indicate that jersey II outperforms jersey I. Specifically, in both experiments the differences resulted by jerseys I and II are consistently substantial, with a margin of 10%. Although the calculated C_DA values might vary with the power meters used, a distinct difference regarding the aerodynamic performance of the two jerseys is confirmed.

4. Conclusions

The road riding experiments conducted in this work confirms that the power-based calculation method based on the data collected from the instrument installed is effective for studying the aerodynamic performance of a cyclist. Although different types of power meters employed might yield different C_DA values, the aerodynamic performance of the two jerseys on a cyclist can be differentiated.

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Conflicts of Interest: There is no conflict of interest, and the authors declare that they have no conflicts of interest.

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