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A full scale bicycle aerodynamics testing methodology

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Abstract

Aerodynamically efficient sport equipment/accessories and athlete's body postures are considered to be the fundamental aspect to achieving better outcomes. Like any other speed sports, the aerodynamic optimization is essential in cycling. A standard full scale testing methodology for the aerodynamic optimization of a cyclist along with all accessories (bicycle, helmet, cycling suit, shoes, goggle, etc.) is not well developed and standardized. This paper describes a design and development of a full scale testing methodology for the measurement of aerodynamic properties as a function of cyclist's body positions along with various accessories under a range of wind speeds. The experimental findings indicate that the developed full scale testing methodology can be used for the aerodynamic optimization of all cycling events.

Keywords: Wind tunnel; full scale test; aerodynamic drag; cycling; experimental measurement;

1. Introduction

Aerodynamics has been playing a key role in all speed sports including cycling since long. However, importance of aerodynamics was first recognized in cycling when the US cyclist Greg Lemond won the Tour de France in 1989 in a tight competition. In 2008 Beijing Olympic Games, it is also understood that the aerodynamics gains in bicycle racing are extremely important.

In cycling, many features including the cyclist, bicycle frame, wheels, helmet, suit, and water bottles directly interact with the oncoming airflow and generate a complicated and as yet still not fully understood aerodynamic phenomenon. Generally, the aerodynamic drag is one of the greatest obstacle to

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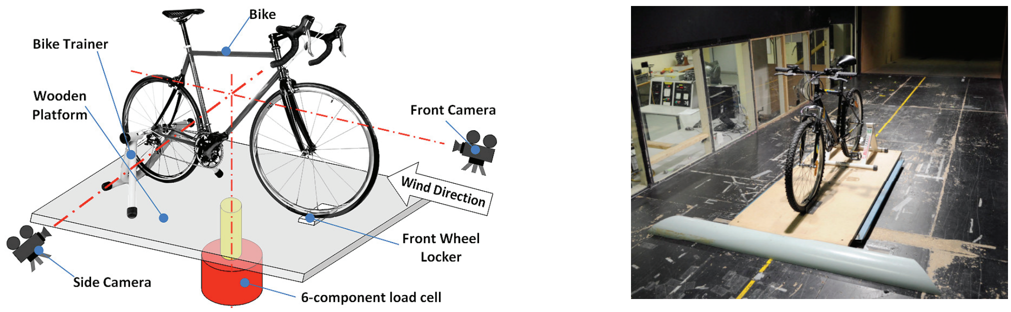
a cyclist's forward motion, accounting for almost 70% to 90% of the total resistance. Out of the total aerodynamic resistance, the bicycle accounts approximately 33% of the total aerodynamic resistance and the remaining is primarily from the body position of the cyclist, and a small contribution of the helmet, cycling suit, shoes, goggles, etc. Prior studies [3, 6, 7] reported by that the cyclist body position with an appropriate helmet and suit can significantly minimize the aerodynamic drag at all stages of a competitive racing. There are 3 main positions commonly used by professional cyclists depending on the type of racing and road profile. These 3 positions are: a) Upright Posture, characterized by the hands on the upper part of the handlebars, is mainly used when pulling up on the handlebars to cycle on hill terrain, b) Dropped Posture, the hands on the bottom of the handlebars, is adopted at high speeds to minimize projected frontal area, and finally Time Trial Posture when the elbows are placed on the pads of the handlebars. This is believed to be the best aerodynamic position to overcome the aerodynamic drag.

Recently conducted (July 2010) Tour de France results showed an average speed (of all 21 stages) was around 42 km/h. However, the speed in the Time Trial stage is over 55 km/h. Although the average speed in mountain stages is slightly below 40 km/h, the maximum speed in downhill stages can easily exceed to 100k/h. Prior studies [3, 6, 7] until recently looked predominantly at the physiological aspects of the professional cyclist. Studies by Brownlie *et al.* [3] and more recently by Chowdhury *et al.* [4, 5] indicate that the sports apparel can make impact on the aerodynamic drag reduction thus influence on the outcomes of the event. Additionally, studies by Alam *et al.* [2] showed that the helmet can produce up to 8% of the total aerodynamic drag depending on the shape and venting features of the helmet.

As mentioned earlier, scant information on detailed full scale testing (including cyclist body configuration, bicycle, suit, helmet, etc.) is readily available in the public domain. This study aims to develop a full scale experimental testing methodology for the aerodynamic performance evaluation of a cyclist in a wind tunnel environment. The developed experimental testing methodology will allow evaluating not only the aerodynamic properties of bicycles and the cyclist but also various add-ons including cycling suit and helmet. The developed methodology will allow evaluating the aerodynamic relationship between various cycling garments and the cyclist under a wide range of wind speeds and yaw angles to include crosswinds effects.

2. Methods

In order to have a reliable and accurate measurement system for aerodynamic properties, a full scale experimental setup has been developed at RMIT University. The developed setup and the measurement procedure are shown in Figure 1(a). The setup consists of a flat wooden platform (1800 mm × 850 mm × 30 mm) and a stand to support the bicycle and cyclist with the wooden platform firmly. The gap between the wooden platform and the tunnel floor is around 20 mm in order to avoid any interference between the floor and the wooden platform. A plastic fairing (shown in Figure 1(b)) is used at the front of the platform to minimize the flow separation from the leading edge of the platform. The whole platform is mounted on a 6-component force sensor (type JR3) via a 100 mm diameter strut (see Figure 1(a)) to measure the drag, lift and side forces and their corresponding moments simultaneously. All types of bicycles (recreational, road racing, time trial) along with the cyclist can be experimentally evaluated using this setup. The crosswind effects can also be evaluated using the arrangement. The developed system minimizes error in data recording due to extraneous cyclist movement or variations in weight distribution. The assembly is strong for both static (cyclist with no pedaling) and dynamic (cyclist with pedaling) loading. One of the main difficulties in the full scale testing is to keep the setup and the cyclist's body position at the same reference point during the test. A small position variation can generate significant errors in data acquisition. In order to address this problem, a video positioning system has also been developed. It consists of two high definition digital video cameras which are installed at 180° and 90° from the bicycle longitudinal axis, i.e. imaginary axis joining front and back wheel centers (shown in Figure 1(a)) for capturing the front and side views of the entire experimental setup simultaneously. Special software is used for live video monitoring. The cyclist position can be repositioned accurately by overlapping the images taken by these two digital cameras and by adjusting necessary feedback obtained through the monitoring system. It can minimize any error occurred due to the change of positions of the cyclist and equipment as minor position variation can significantly affect the measured aerodynamic data. This positioning system is intended to ensure the reproducibility of the cyclist position during the experimental procedure.



(a) Schematic of experimental set up (b) Real experimental set up

Fig. 1. Experimental set up in RMIT Industrial Wind Tunnel

The full scale experimental setup can be used in any wind tunnel that has a test section of at least 2m high by 2m wide. The developed experimental setup is well suited to the RMIT Industrial Wind Tunnel as it has 6 square meters rectangular test section with 3 meters wide, 2 meters high and 9 meters long. The tunnel is very suitable for the full scale bicycle (along with the cyclist) testing as the solid blockage ratio is negligible. The maximum speed of the tunnel is approximately 150 km/h. The tunnel air speed is measured with a modified National Physical Laboratory (NPL) ellipsoidal head Pitot-static tube (located at the entry of the test section) which is connected through flexible tubing with the Baratron^{TM} pressure sensor made by MKS Instruments, USA. In order to evaluate the RMIT developed experimental methodology and experimental setup, a series of experimental tests have been undertaken using live cyclist under a range of wind speeds (20 to 70 km/h with an increment of 10 km/h). More details about the tunnel can be found in Alam *et al.* [8]. The selected speed range is representative for all major cycling events (recreational to time trial cycling). The developed experimental setup was mounted through a mounting stud with the sensor (type JR3) as mentioned previously. The sensor was used to measure all three forces (drag, lift and side forces) and three moments (yaw, pitch and roll moments) simultaneously. Each set of data point was recorded for 30 seconds with a frequency of 20 Hz ensuring electrical interference is minimal. Multiple data sets were collected at each speed tested and the results were averaged for minimizing the further possible errors in the experimentally acquired data.

A recreational cyclist with a bicycle in the test section of the tunnel is shown in Figure 2(a). In addition, using a professional cyclist, the aerodynamic forces were measured for three widely used cycling positions. In these experimentations, racing bicycles along with appropriate helmets, cycling suits and other accessories were used to replicate the real cycling as possible. The measured 3 positions were: a) Upright position, b) Dropped Position, and c) Time Trial Position as shown in Figure 2(b), 2(c) and 2(d). For the time trial position, a Louis Garneau (time trial bicycle) and a Giro Advantage time trial helmet were used. For other two positions, an Orbea (road racing bicycle) and a Giro Atmos road racing helmet were also used.

(a) (b) (c) (d)

Fig. 2. Different cycling positions with recreational and professional cyclist.

Projected frontal area (A) of a cyclist is an important parameter for the accurate measurement of drag coefficient (C_D). In cycling, it is extremely difficult to measure the projected frontal area of the cyclist as the body configuration and physiological parameters vary significantly. There is no standard methodology and procedure to determine the cyclist's projected frontal area. It is also important to mention that the body position notably vary with the type of racing and profile of the terrain. In order to determine the projected frontal area at any given position, a digital image processing technology was employed. The digital image processing technology includes the following: a high resolution digital photograph needs to be taken from the front of the cyclist and the reference position for image taken must be in the centre and right angle to avoid parallax error. A typical reference position as such is shown in Figure 3. In order to obtain high quality image, a SLR (Single Lens Reflector) high resolution digital camera is highly desirable.

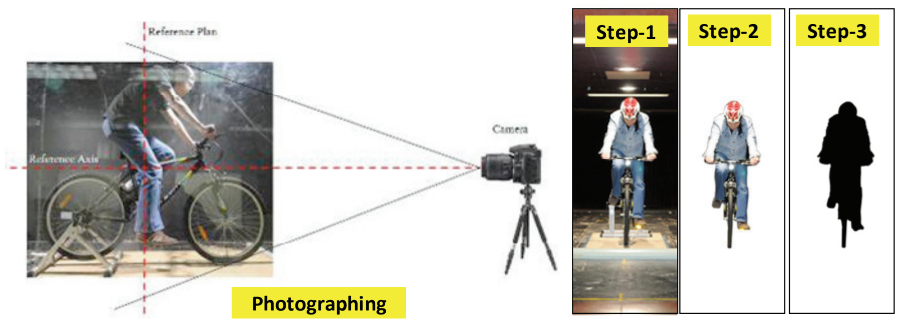


Fig. 3. Frontal area estimation method.

Later, an image processing software "ImageJ" can be used to measure the projected frontal area from the digital image taken previously [1]. It is a Java-based image processing program developed at the National Institutes of Health (NIH). It can handle 8-bit, 16-bit and 32-bit images with commonly used file format. The projected area can be determined with a known reference. To measure the projected frontal area, a high quality digital photograph (in 24 bit JPEG format) was taken with a known reference as shown in Figure 3. Later, the background was removed leaving the area occupied by the cyclist including cycle and the accessories. Finally, the projected frontal area (shown as the black shadow) was estimated with "ImageJ" software (Figure 3).

3. Results

As mentioned previously, aerodynamic measurements were conducted at speeds (20 km/h to 70 km/h with an increment of 10 km/h). The aerodynamic forces acting on the bicycle and cyclist were subtracted from the forces measured with the experimental setup, cyclist and the bicycle. The non dimensional drag coefficient (C_D) was computed using the following formula: $C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A}$; where, F_D, ρ, V and A are the drag force, density of air, wind velocity and frontal area respectively. The projected frontal area (A) of the recreational bicyclist at upright position is around 0.540 m² estimated using the method described in previous section. Using the same method, the projected frontal areas of the professional bicyclist at upright, dropped and time trial positions were also obtained and they are 0.410 m², 0.405 m² and 0.380 m² respectively. The drag and the C_D variation with speeds for the recreational and professional cyclists are shown in Figures 4(a) and 4(b) respectively.

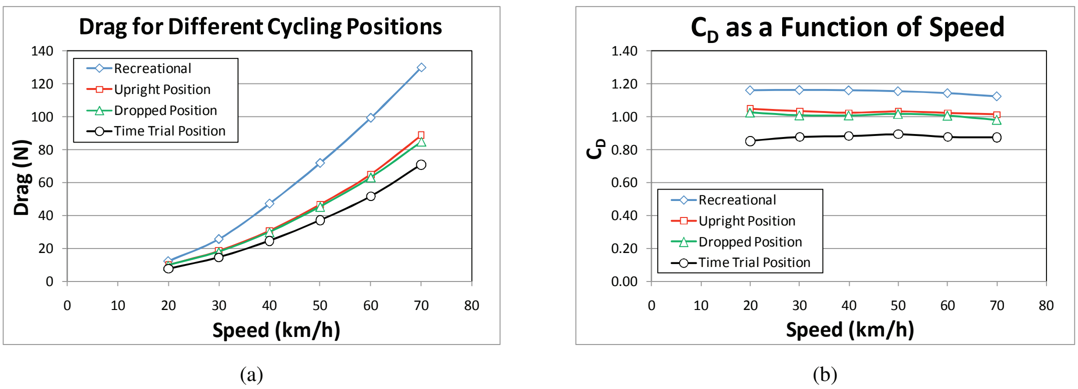


Fig. 4. (a) Drag variation with speed; (b) C_D variation with speed.

4. Discussion

With an increase of speeds, the drag increases for both cyclists and at all body positions. The increase of drag for the time trial position is minimum compared to other two positions of the professional cyclist and the upright position of the recreational cyclist. The degree of increase in drag for the recreational bicyclist at high speeds is much higher believed to be due to the un-streamlined cycling accessories including loose clothing. However, further investigation is underway to clarify it.

The C_D values are almost independent of speeds for the upright and dropped positions of the professional and the recreational cyclists at all speeds tested. A slight variation in C_D value at low speeds for the time trial position is evident. A minor difference of C_D value between the upright and drop position of the professional cyclist is also noted. It is clearly evident that the upright position generates more drag compared to other widely used body positions especially the time trial racing. As expected, the C_D value for the upright position of the recreational cyclist is notably higher compared to the same position of the professional cyclist primarily due to the cycling accessories (bicycle, suit, helmet, shoes, etc.) and the casual posture. The average reduction of drag for upright, dropped and time trial positions of the professional cyclist was found to be approximately 30%, 32% and 45% compared to the upright position of the recreational cyclist respectively. In the case of the professional cyclist, the average reduction of drag for dropped and time trial positions is around 3% and 21% respectively compared to the upright position.

5. Conclusions

The following conclusions have been drawn from this experimental work:

- The newly developed full scale experimental methodology and experimental setup performed well in the aerodynamic testing with confidence and accuracy.
- The experimental arrangement allows aerodynamic evaluation not only for the cyclist but also the bicycle, suit, helmet and other accessories with high level accuracy.
- The experimental setup and methods are simple and repeatable. The repositioning system developed here is simple, user friendly and accurate.
- The projected frontal area measurement technique used in this study is a quick and simple way to estimate an approximate frontal area. However, further evaluation is required for wider use.
- The developed experimental setup can also be used as a tool for airflow visualizations of cycling.
- For training, the experimental setup can be useful for the cyclist to be trained both psychologically and physically in a control environment.

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References

[1] Abramoff MD, Magelhaes PJ and Ram SJ. Image Processing with ImageJ. *Biophotonics International* 2004;**1**:36-42.

[2] Alam F, Chowdhury H, Elmira Z, Sayogoa A, Love J and Subic A. An experimental study of thermal comfort and aerodynamic efficiency of recreational and racing bicycle helmets. *Procedia Engineering* 2010;**2**:2413-2418.

[3] Brownlie LW, Kyle CR, Harber E, MacDonald R, Shorten MR. Reducing the aerodynamic drag of sports apparel: Development of the NIKE Swift sprint running and SwiftSkin speed skating suits. In: Hubbard M, Mehta RD, Pallis JM, editors. *The Engineering of Sport 5 (Volume 1)*, International Sports Engineering Association, UK; 2004, p. 90-96.

[4] Chowdhury H, Beneyto-Ferre J, Tate M, Alam F, Mainwaring D, Forster D and Subic A. Effects of Textile and Garment Design on Aerodynamic Characteristics Applied to Cycling Apparel. In: *The Impact of Technology on Sports III*, RMIT University, Australia; 2009, p. 131-136.

[5] Chowdhury H, Alam F and Subic A. Aerodynamic Performance Evaluation of Sports Textile. *Procedia Engineering* 2010;**2**:2517-2522.

[6] Faria E, Parker D and Faria I. The Science of Cycling Factors Affecting Performance – Part 2. *Sports Medicine* 2005;**35**:313-337.

[7] Jekendup AE and Martin J. Improving cycling performance: how should we spend our time and money. *Sports Med* 2001;**31**:559-569.

[8] Alam F, Zimmer G, Watkins S. Mean and time-varying flow measurements on the surface of a family of idealized road vehicles. *Experimental Thermal and Fluid Sciences* 2003;**27**:639-654.