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Aerodynamics of ribbed bicycle racing helmets

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Abstract

In competitive cycling, aero-helmets have been used around since 1980 to reduce aerodynamic resistance. Considerable design effort has been made to improve the aerodynamic efficiency of racing bicycle helmets over the years. However, the demand for further improvement has forced helmet manufacturers and designers to introduce new designs progressively. Recently several helmet manufacturers (e.g., LG, Lazer and Giro) have introduced dimples on the outer shell of helmet mimicking the so called 'Golf-ball' dimple effects with a view to further reduce aerodynamic drag of the helmet. However, no independently verifiable research so far has been reported in the public domain about the aerodynamic performance of ribbed bicycle helmets compared to smooth surfaced helmets. Hence, the primary objective of this work was to undertake an experimental study on four smooth aero-helmets including two latest model ribbed aero-helmets to understand their aerodynamic performance and the effect of dimples on helmets. The investigation was undertaken in an wind tunnel environment over a range of wind speeds, pitch and yaw angles. The experimental data indicate no measurable advantage between the smooth and ribbed helmets under varied pitch angles and at zero yaw angle.

1. Introduction

In bicycle racing, aerodynamics play a critical role as every moment can differentiate between the winner and losers. Studies by Alam *et al.* (2010, 2007), Booth (2007), Brühwiler *et al.* (2006), Kyle and Bourke (1984) found

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that at around 30 km/h speed, the aerodynamic resistance (drag) contributes almost 70-80 percent of total resistance and the remaining is rolling resistance. Out of total aerodynamic drag, the rider position counts approximately 65 to 80 percent depending on body position, helmet and clothing. The remaining drag is attributed from bicycle frames, wheels (mainly front wheels), and other components and add-ons. Alam *et al.* (2010, 2007, 2006) and Chowdhury *et al.* (2012) mentioned that at around 30-40 km/h speeds, the percentage of aerodynamic drag of the helmet is approximately 2 to 8 percent to the total drag depending on the aerodynamic shape of the helmets. Therefore, the use of an aerodynamically efficient helmet can play an important role by making an advantage in racing as well as in recreational riding.

Correct selection of helmet and right body position can assist a cyclist to reduce aerodynamic resistance (drag). In the 1989 Tour de France, the American cyclist Greg LeMond trailed two time champion French rider Laurent Fignon by 50 seconds prior to the final stage of a 24.5 km individual time trial racing event. Although the 50 seconds gap is negligible as LeMond required riding each kilometre distance by only 2 seconds faster than his competitor Fignon. Nevertheless, LeMond used an aerodynamically efficient helmet and aerodynamically efficient normal bicycle and was able to defeat Laurent Fignon by 58 seconds and subsequently won the 1989 Tour de France title by just 8 seconds. It was later revealed that the aerodynamic drag on Fignon's ponytail alone was enough to slow him down by the critical 8 seconds by which he lost the race. Although aerodynamics played an important role in time trial and road racing competitions around the world since long, the LeMond saga brought the aerodynamics to the limelight again.

Several studies by Alam *et al.* (2010, 2007), Chowdhury *et al.* (2012) and Bruhwiler *et al.* (2006) focused on aerodynamic drag for recreational and racing bicycle helmets. These studies indicated that time trial (so called aero) helmets possess a significantly lower aerodynamic drag (~40-50% less) than recreational helmets. Recently, helmet companies have started incorporating dimples onto time trial helmets with a view to have less aerodynamic drag. These dimples are similar to the dimples found on golf balls. Usually for a golf ball, these dimples help reduce drag by delaying the separation of airflow and increasing turbulent flow regime. Dimples generally work well on a spherical shape but its effects on oval shape objects like an aero-helmet remain unknown in the public domain and no study so far has been reported in the public domain on recently introduced and commercial available ribbed helmets. Additionally, no comparative study of aerodynamic performance of time trial helmets with and without dimples has been reported in the open literature. Therefore, the primary objective of this study was to understand the aerodynamic behaviour and effects of dimples by testing a series of commercially available time trial and road racing helmets in a wind tunnel environment.

2. Experimental procedure

A total of 6 helmets (four time trial, and two road racing) were selected for this study. Among 4 time trial helmets, two helmets (LG Vorttice and Lazer Tardiz 2) had dimples and other two helmets (Giro Advantage and LG Rocket Air) had no dimples. The Vorttice has dimples for a quarter of the frontal area of helmet whereas Lazer Tardiz 2 has dimples at the backside of the helmet (see Fig. 1). The road racing helmets are Lazer O2 and Giro Air Attack. The Giro Advantage has 6 air vents and mass 390 grams. The LG Air Rocket possesses 7 air vents and weighs around 429 grams. The Lazer Tardiz 2 has 6 air vents and 395 grams mass. The LG Vorttice possesses only 2 vents and mass of 426 grams. The Lazer O2 has 24 air vents and weighs around 310 grams. The Giro Air Attack has 6 air vents and weighs around 283 grams.

The aerodynamic study was undertaken in RMIT Industrial Wind Tunnel. Three forces (drag, lift and side force) and their corresponding moments were measured simultaneously using a six component force sensor type JR3. The force sensor measures forces and moments in all six degrees of freedom and resolves the forces and moments into the orthogonal aerodynamic co-ordinate system. The tunnel is a closed return circuit wind tunnel with a test section dimension of 3 metres wide, 2 metres high and 9 metres long, making the cross sectional area of 6 square meter. The wind tunnel, powered by a DC electric motor, is capable of generating free stream wind speeds up to 140 km/h, has a turbulence intensity of 1.8% and is fully equipped with wind control machines and data calibration reading machines. The air speeds were measure using the NPL ellipsoidal head Pitot-static tube located at the

entrance of the test section. The Pitot-static tube is connected to a MKS Baratron pressure sensor through flexile tubing.

a) **Giro Advantage**

d) **Lazer Tardiz 2**

b) **Louis Garneau Rocket Air**

e) **Louis Garneau Vorttice**

c) **Lazer O2**

f) **Giro Air Attack**

Fig. 1. Road racing and time trial helmets used in this study.

A purpose made mannequin was used to simulate the body position and size of a representative road cyclist (see Fig. 3). The mannequin body was made by polystyrene foam. Body measurements were taken of male cyclists and the averaged results were used to shape the model. As depicted in Fig. 3, the mannequin was connected to the force sensor via a sting. The sting is a single metal rod which transfers the generated aerodynamic forces from the mannequin to the force sensor. An adjustable neck has been incorporated into the mannequin to allow for variation in head pitch (head position). Time trial helmets are sensitive to pitch due to their elongated shape, and as such it is important to have the ability to test the effects of pitch on aerodynamics. During testing, the helmets were individually attached onto the head of the mannequin. As wind passes through the tunnel, the aerodynamic drag felt by the mannequin was measured by the JR3 force sensor. The repeatability of the measured forces was within ±0.01 N and the wind velocity was less than 0.027 m/s (e.g. 0.1 km/h).

Wind speeds ranging from 20 km/h to 60 km/h with a 10 km/h increment were used for study. Yaw angles of 0° to 45° with an increment of 15° to simulate the crosswind effects as shown in Fig. 2. Three pitch angles (0°, 45° and 90°) were considered for this study. The head position at each pitch angle is shown in Fig. 3. The projected frontal area of each individual helmet was determined using parallel light projection method. The frontal-area data for all 6 helmets are shown in Table 1.
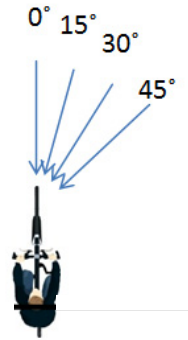
Fig. 2. Yaw angles representation.

Table 1. Projected frontal area of helmets (at 0° yaw and 0° pitch angle).

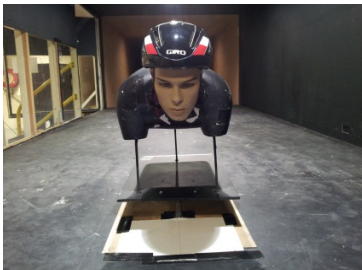| Helmet	Frontal area (m^2)
Advantage	0.0686
Rocket	0.0748
Tardiz	0.0711
Vorttice	0.0723
Attack	0.0692
O2	0.0736

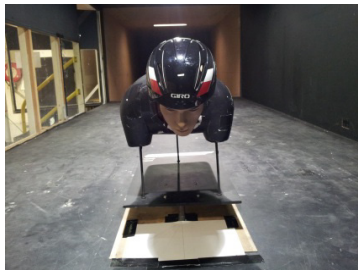a) Head Position 1, Pitch Angle: 0 deg   b) Head Position 2, Pitch Angle: 45 deg   c) Head Position 3, Pitch Angle: 90 deg

Side View

a) Head Position 1, Pitch Angle: 0 deg   b) Head Position 2, Pitch Angle: 45 deg   c) Head Position 3, Pitch Angle: 90 deg

Front View

Fig. 3. Head position under variable pitch angles.

3. Results and discussion

The aerodynamic drag for all helmets along with the bare head as a function wind speeds under 3 pitch angles (0º, 45º and 90º) at 0º yaw angle is shown in Fig. 4. As expected, the drag force increases with an increase of wind speed. The figures indicate that the Giro Advantage and LG Rocket Air produce pretty similar amount of aerodynamic drag and can be considered the benchmark of which the newer generation aero-helmets are based upon.
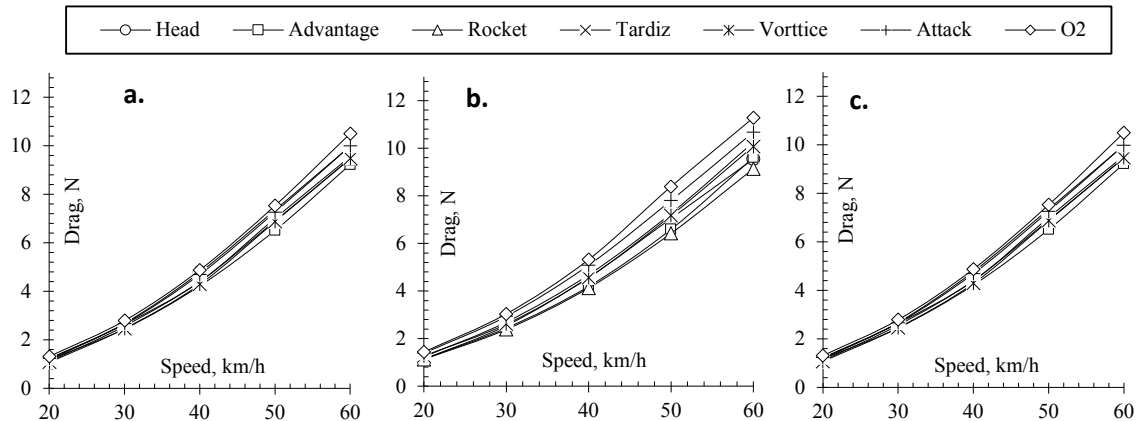

Fig. 4. Aerodynamic drag variation with speeds at: (a) Head Position 1; (b) Head Position 2; (c) Head Position 3.

At lower wind speeds (20 to 30 km/h), the drag forces for all helmets are comparably similar. The ribbed helmets: Vorttice and Tardiz prove to be very comparable with the non-dimpled Giro Advantage and LG Rocket Air at 0º and 45º pitch angles (i.e., Head Position 1 and Head Position 2) as shown in Fig. 4(a) and 4(b). The ribbed helmet Tardiz displayed significantly higher drag at pitch angle 90º (i.e., Head Position 3) compared to all other helmets.

The road racing helmet Giro Air Attack with 6 air vents fell in between the ranges of the time trial helmets and the road racing helmet as expected in Head Positions 1 and 2. It also generated less aerodynamic drag at Head Position 3 (i.e., pitch angle 90º) beating all time trial helmets with and without dimples. This is believed to be due to the smaller frontal area in Head Position 3.

As expected, the road racing helmet Lazer O2 with 24 air vents generates higher aerodynamic drag at all pitch angles (Head Positions 1, 2 & 3) compared to all other helmets. The vent generally increases drag as it creates local flow separation. However, the drag due to vents can be minimised by placing vents appropriately on the helmets.

No noticeable gain in aerodynamic drag reduction due to dimples was found. However, a slight gain was by the Vorttice helmet. Nevertheless, this gain is within experimental error.

The dimples on a golf ball work well because of its spherical shape and the dimples were situated throughout the surface of the entire ball. This is not the case for the Vorttice helmet. The Vorttice has the dimples for a quarter of the helmet frontal area which is oval shaped hence the effectiveness of the dimples could not be fully materialised.

The aerodynamic drag variation with yaw angles at 40 km/h under 0º pitch angle is shown in Fig. 5. The figure indicates that there is no noticeable difference in drag under lower yaw angles (i.e. ≤ 15º). Some variations in drag force are noted at high yaw angles. The helmets with dimples have shown mixed results. However, the bare head generates the lowest aerodynamic drag at all yaw angles tested. It may be noted that it is very unlikely that a cyclist will experience crosswinds under yaw angles over 15º.
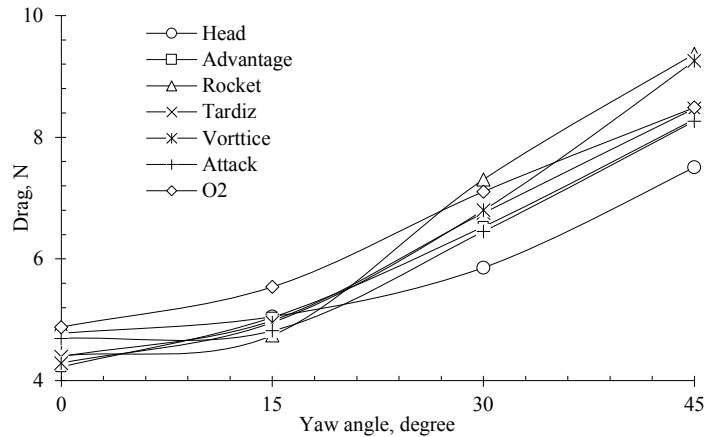
Fig. 5. Aerodynamic drag variation with yaw angles at Head Position 1 (0º pitch angle).

4. Concluding remarks

In this study, no significant aerodynamic gain was observed for the ribbed helmets. As helmet generates overwhelmingly the form or pressure drag, the frontal area plays a critical role. The dimples of Vorttice helmet may provide a marginal improvement to the aerodynamic performance, but this improvement does not offset the drag generated due to its larger frontal area. On the other hand, the Giro Air Attack helmet performed better at high pitch angles due to its lower frontal area. Furthermore, both two ribbed helmets have shown inconclusive results under crosswind conditions and there is no clear indication of aerodynamic advantage for dimples.

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