Aerodynamic Performance of Cycling Time Trial Helmets (P76)

Kim B. Blair, Ph.D.[1], Stephanie Sidelko[2]

Topics: bicycle.

Abstract: The aerodynamic performance of equipment is critical for cycling's "race of truth", the time trial, where time differences of seconds can separate the top finishers. Recently several manufacturers have developed aerodynamic helmets specifically for use during time trials. To date, a comprehensive study of the aerodynamic performance of these time-trial helmets has not been performed. In this study, the aerodynamic helmets were tested on a mannequin in the time trial positions over a range of yaw angles, from 0° to 15°, in increments of 5°. The helmets were tested at three head angle positions at each yaw angle in order to best mimic actual riding conditions. A control road helmet was used to serve as a comparative tool. The testing results showed that all of the aerodynamic helmets offer drag reduction over a standard road helmet. However, the ranking of helmets in order of performance varied depending on yaw angle and head angle.

Keywords: bicycling, helmets, aerodynamics.

1- Introduction

The disciplines of the time trial in cycling and the cycling leg of a triathlon (for non-drafting events) have the common goal of getting from the start of the event to the finish in the shortest time possible. In this event, nearly 90% of a cyclist's power output is used to overcome the resistance of aerodynamics (Blair, 2007). Even small reductions in the aerodynamic drag on the cyclist can result in the savings of seconds during the event. Consequently, a large market of commercial products exists to aid the cyclist in reducing aerodynamic drag, including aerodynamic bike frames, wheels, handlebars, and now helmets. Lukes, Chin and Haake (2005) have provided an overview of the pertinent literature in this domain.

While aerodynamic head fairings have been used for many years, the Union Cycliste *Internationale* recently enacted a requirement that all professional cyclists must wear protective helmets. Manufacturers were quick to respond to this requirement, resulting

---

1. Xenith, LLC, 672 Suffolk Street, Lowell, MA, USA - E-mail: kblair@xenith.com

2. Massachusetts Institute of Technology, Sports Innovation @ MIT, Cambridge, MA, USA -
E-mail: stephaniesidelko@gmail.com

in a wide variety of protective aerodynamic helmets becoming available for recreational cyclists and triathletes. Blair (2007) recently demonstrated that the reduction in drag afforded by an aerodynamic helmet is significant, with a larger impact than aerodynamic wheel sets. Thus, the aerodynamic helmet is a very effective tool for improving a cyclist's or triathlete's performance.

In this work we have compared the performance of several aerodynamic cycling helmets. Testing was carried out in a wind tunnel at varied yaw angles using a mannequin in an aerodynamic position. The wind speed was held constant and the yaw angle of the mannequin, as well as the angle of the helmet relative to the mannequin's back, was varied for each helmet tested.

2- Methods

Manufacturers donated ten aerodynamic cycling helmets for this project under the conditions of anonymity. Helmets that were supplied with face shields were tested both with and without the face shield. It was agreed that the results could be published, but that the specific identity of the helmets not be identified to protect proprietary data.

A standard road cycling helmet was also tested and used for a comparison. As the cyclist/triathlete is required to wear some form of helmet during competition, a comparison with a typical road helmet provides an indication of the improvement possible for competition.

Testing was completed in the Massachusetts Institute of Technology Wright Brothers Memorial Wind Tunnel. The wind tunnel is a closed return tunnel with a 2.1 m X 3 m oval test section. The tunnel data acquisition system records tunnel parameters of static and dynamic pressure, temperature and humidity at 1000 Hz. These values are used to calculate a humidity corrected tunnel wind speed (MIT, 2002).

The wind tunnel's pyramidal balance was used to collect the aerodynamic force data. This balance remains in a fixed position and thus measures the aerodynamic forces in the wind tunnel axes. The drag force, D_T is measured along the axis of the tunnel, with a positive direction to the rear of the tunnel, and the side force S_T is measured perpendicular to the flow positive direction to the right of the tunnel when viewed from the top. However, the aerodynamic forces of critical importance to the cyclist are the force acting against the rider's direction of motion D_R, and the force perpendicular to that force, S_R. The forces measured by the wind tunnel balance were converted to the rider's drag and side force values by the equations

$$D_R = D_T \cos\theta - S_T \sin\theta \qquad S_R = D_T \cos\theta - S_T \sin\theta \tag{1}$$

where T and R represent the tunnel axes and rider axes respectively and θ is the yaw angle of the rider, measured in a clockwise direction when viewed from the top of the rider. A 0° yaw angle means that the tunnel and rider axes are aligned, and the rider is facing directly into the wind. *For the remainder of this paper, the terms drag force and side force will refer to the forces in the rider coordinate system.*

Wind tunnel air speed was set to 13.4 m/s for all testing. This wind-speed has become somewhat of a de-facto industry standard. Yaw angles were varied from 0° to 15°, in increments of 5°.

In order to eliminate the test-to-test error inherent in using a cyclist, an upper body mannequin was used for the test program. The mannequin is in the time-trial cycling position as shown in Figure 1.

Figure 1 - Upper body mannequin in the wind tunnel. The lower half of the skin-suit was taped up behind the mannequin durng testing.

The effect of helmet position relative to the rider's back was also investigated in this study. As the mannequin did not have an articulated neck, the helmet was tipped in three different angles on the mannequin's head. As the helmets had a variety of tail shapes and lengths, it was determined that the most consistent method to set the helmet angle was to use lines on the mannequin's forehead to align the front edge of the helmet as shown in Figure 2. Position 1 results in the tail of the helmet being very close to the back, position 3 has the tail pointing nearly straight up in the air, as if the rider were looking straight down at the ground.

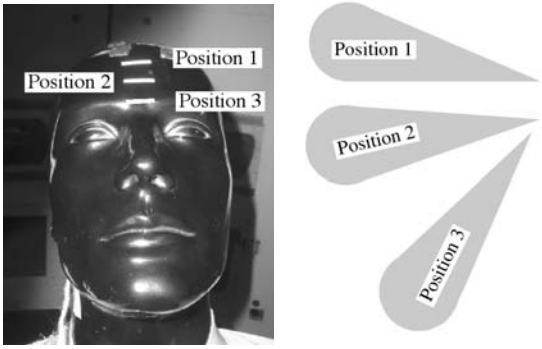

Figure 2 - Reference positions for helmet alignment.

A data set was recorded for each helmet at three different helmet positions at four different yaw angles yielding twelve data sets for each helmet. The helmets that have visors were tested both with and without the visor. Data was collected for 30 seconds at

1000 Hz for each test point. For each test point recorded, the drag value of the mannequin alone is subtracted from the result for the mannequin wearing the helmet. Thus, if the drag of the mannequin wearing the helmet is less than the mannequin alone, the result with be negative, indicating that the combination of the mannequin and helmet is "faster" (i.e. less drag) than the mannequin alone.

The potential performance benefit to a cyclist resulting from a reduction in aerodynamic drag afforded by an aero-helmet can be estimated in terms of the power savings available to the rider. While the benefit to a specific rider cannot be predicted without detailed knowledge for that rider, an estimate of the power savings for a professional and amateur rider can be estimated for illustrative purposes. For the professional cyclist, we assume a total drag of 22 N while wearing a road-race helmet, with the rider capable of sustaining 450 watts of power output over a long (40 km) time-trial. For an amateur cyclist, corresponding values of 27 N of drag and 225 W of power output can be assumed (Martin *et al.* 1998). Determining the percent reduction in drag and multiplying it by the rider's power output can calculate the power savings, P_s,

$$P_S = \frac{D_{RH} - D_{AH}}{D_{RH}} \cdot P_{Ave}, \tag{2}$$

where D_{RH} and D_{AH} represent the drag with a road helmet and aero-helmet and P_{Ave} is the rider's power output. Here the assumption is made that the rider's speed remains the same, so there are no other differential energy changes in the system.

3- Results

Figure 3(a) shows the results for each helmet in the three positions for the case of 0° yaw. Recall that the drag value of the mannequin alone is subtracted from the result for the mannequin wearing the helmet. Thus in Figure 3, the case of the mannequin without a helmet results in a drag value of 0. The goal is to reduce drag, so lower values indicate better performance.

Helmet A is the control helmet, a typical road-racing helmet. For 0° yaw with the helmet in position 1, with the tail laying nearly flat on the back, ten of the aero-helmets result in a lower drag than the case of the mannequin not wearing a helmet (drag < 0). For position 2, only eight of the aero-helmets show drag that is less than the mannequin without a helmet. For both positions 1 and 2, all aero-helmets show a lower drag than the control helmet. For position 3, the tail of the helmet pointing nearly straight up, none of the aero-helmets show a drag value less than the no helmet condition. Further, only nine of the aero-helmets result in a lower drag than the control helmet. For each test condition, the helmets rank in a different order for drag, with none of the helmets showing a consistently high performance across all head positions.

Figure 3(b) shows the results for each helmet in the three positions for the case of 5° yaw. Note that helmet A, the standard road helmet, shows substatially the same drag at all yaw angles. For the helmet in position 1, seven of the aero-helmets result in a lower drag than the case of the mannequin not wearing a helmet. None of the aero-helmets show less drag than the mannequin alone for positions 2 and 3. The control helmet shows the highest drag for positions 1 and 2. For position 3, only eight of the aero-helmets show a lower drag than the control helmet. For each position the helmets rank in a different order of performance, with helmet E showing good performance across all positions, with a rank of fourth, first and first.

Figure 3(c) shows the results for each helmet in the three positions for the case of 10° yaw. For this yaw angle, none of helmets show a lower drag than the mannequin without a helmet. For positions 1 and 2, all aero-helmets show a lower drag than the control helmet, with only eight aero-helmets performing better than the control for position 3. For this yaw condition, helmet L results in the lowest drag for each head position.

Figure 3(d) shows the results for each helmet in the three positions for the case of 15° yaw. As with the 10° yaw condition, none of helmets show a lower drag than the mannequin without a helmet. For positions 1 and 2, all aero-helmets show a lower drag than the control helmet, with only six aero-helmets performing better than the control for position 3. For this yaw condition, helmet L results in the lowest drag for head positions 1 and 3, and ranks fourth for position 2.

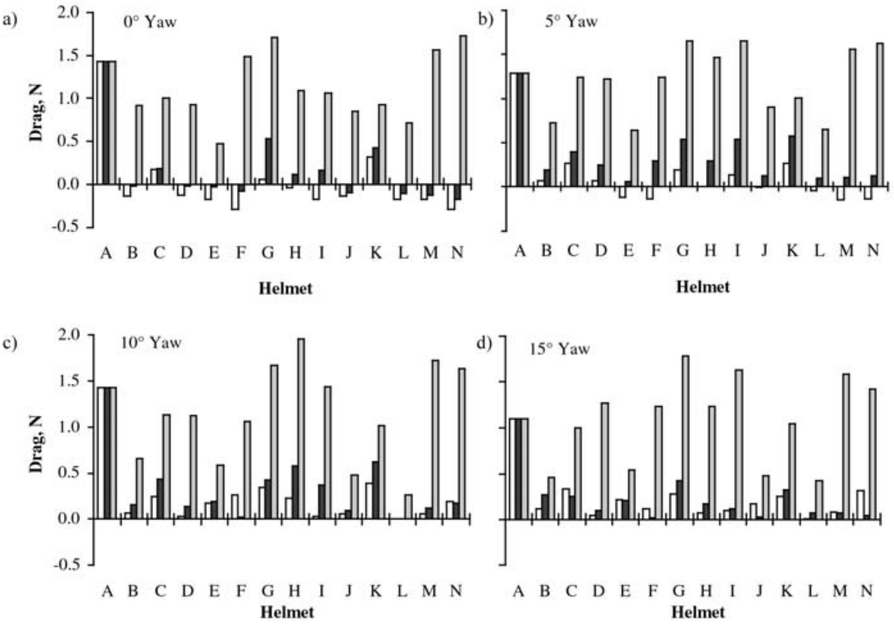

Figure 3 - Drag results for a) 0° yaw angle, b) 5° yaw angle, c) 10° yaw angle, and d) 15° yaw angle. Helmet position indicated as □ Position 1 ■ Position 2 ▨ Position 3.

The benefit of the reduction in drag by the use of an aero-helmet can be further illustrated by estimating the rider power savings resulting from the lower drag. Table 1 shows this power savings estimate calculated for the helmet that performed in the median for each test condition and for the case of both a hypothetical professional and amateur cyclist.

Table 1 - Power savings resulting from median aerodynamic helmet.

	Professional Rider		Amateur Rider	
Yaw Angle, Degrees	Drag Reduction, %	Power Savings, W	Drag Reduction, %	Power Savings, W
0	7.2	32	5.8	13
5	5.8	26	4.8	11
10	5.7	26	4.6	10
15	4.5	20	3.6	8

4- Discussion

The results clearly show that there is a significant reduction in aerodynamic drag resulting from the use of an aero-helmet as compared to a road-helmet. For some helmets, at low yaw angles and with the helmet in Positions 1 or 2, using an aero-helmet will result in a lower drag than the no helmet condition. The results show that there is no clear choice among aerodynamic helmets for all riding conditions represented by the range of yaw angles investigated herein. However, helmet L performed generally better at high yaw angles across all helmet positions.

Due to the differing performance of the helmets for each of the test conditions, a cyclist may want to select the helmet appropriate to their racing style and conditions. Factors to consider include rider speed, prevailing wind on typical racecourses, and a preferred head angle. Higher effective yaw angles can be expected from either a slower rider, or strong cross winds. If either of these conditions applies, the cyclist should consider helmets that perform well at high yaw angles. Further, if the rider cannot ride comfortably with the head looking up to maintain the helmet in Position 1, the cyclist should select a helmet that performs well in Position 2. The results clearly show that the cyclist should avoid looking down at the ground while racing, as the drag in Position 3 is higher across all helmets at all yaw angles.

Estimating the power savings resulting from the use of an aero-helmet clearly illustrates the benefit of these helmets, even for a median performing helmet. The potential to gain between 10 and 30 watts of power savings will allow a cyclist to significantly increase their racing speed while maintaining their optimal power output.

5- Conclusions

The benefit of aerodynamic helmets has clearly been demonstrated, although no helmet showed a clear performance advantage across all test conditions. However, the study is somewhat limited, in that a mannequin with a single body shape and riding position was used in this study. Unpublished proprietary results of working with cyclists in the wind tunnel has shown that there can be a significant interaction between the rider's body shape, the arch of the back, and riding position and the helmet that results in the lowest aerodynamic drag. To truly optimize the helmet selection, the cyclist will need to try each helmet of interest during a wind tunnel test.

The results of this study show that there is a potential to optimize the shape of aerodynamic helmets to work across a wider variety of conditions. In order to do so, a more detailed study of the flow characteristics of the flow field around the helmet will be required.

6- References

[B1] Blair K. B. Cycling Aerodynamics. Presented at Serotta International Cycling Institute, SICI Cycling Science Symposium and Expo. Hotel Boulderado, Boulder, CO. 23 January, 2007.

[LC1] Lukes R. A., Chin S. B., and Haake, S. J. The understanding and development of cycling aerodynamics. In Sports Engineering, 8(2): 59-74, 2005.

[MM1] Martin, J. C., Milliken D. L., Cobb, J. E., McFadden K. L., and Coggan A. R., Validation of a Mathematical Model for Road Cycling Power. In Journal of Applied Biomechanics, 14: 276-291, 1998.

[MIT1] MIT, Massachusetts Institute of Technology - Wright Brothers Wind Tunnel - Information for Use by Industry," http://web.mit.edu/aeroastro/labs/wbwt/index.html , 2002.