CYCLING AERODYNAMICS – DEVELOPMENT OF WIND TUNNEL TESTING PROTOCOLS

P.A. Hitchcock[2] , R.O. Denoon[1], Chi Wai Yu[2] & K.C.S. Kwok[2,3]

[2]CLP Power Wind/Wave Tunnel Facility and [3]Department of Civil Engineering, Hong Kong University of Science & Technology
[1]Ove Arup & Partners Hong Kong Ltd

Introduction

The aerodynamics of cycling can be very important to rider performance. For instance, at 40 km/h, over 90% of rider effort is expended in overcoming wind resistance. Clearly then, an improvement in aerodynamics can result in greater speed or endurance in cycling. Aerodynamic improvements can be made through the use of specially designed aerodynamic equipment, or by altering the riding position of the cyclist. However, care must be taken when altering riding positions to ensure that physiological efficiency is not compromised. This paper describes the development of apparatus and protocols for testing the aerodynamic characteristics of cyclists, with a view to improving cycling efficiency. The project was instigated by an approach from the Hong Kong Sports Development Board to the CLP Power Wind/Wave Tunnel Facility at the Hong Kong University of Science & Technology.

History of Cycling Aerodynamics

Until the 1980s, cycling aerodynamics was not much more than wearing a silk jersey tucked into the shorts rather than the usual woollen number. However, in 1984 Francesco Moser stunned the cycling world by appearing in aerodynamic clothing on an aerodynamic bicycle with disc wheels and shattering cycling's most prestigious record by riding 51.151 km in an hour on the velodrome. This started a trend of shaping frame tubes, wheels, and even water bottles for aerodynamic efficiency. However, it was soon found that many of these components were only useful in time trial situations where the rider was required to hold one position on the bike for a limited length of time. Most of this equipment was not compatible with road racing due to either a decrease in rider comfort or weight penalties.

The next major advance came when Greg Lemond famously won the Tour de France by 8 seconds in the final time trial stage. Lemond rode in an aerodynamic helmet and his bicycle was fitted with novel, and at the time controversial, 'triathlete handlebars'. These handlebars allow the cyclist to ride with forearms close together and supported on pads, and it was soon found that the aerodynamic advantage they conferred could be 2 seconds or more a kilometre. The aerodynamic efficiency of these handlebars is governed by the way in which they are set up, this being individual to a rider. As a result, professional cyclists started spending time in the wind tunnel during the off-season in an effort to optimise their aerodynamic efficiency.

Following the widespread adoption of the handlebar set-up used by Lemond, the development of aerodynamic bicycles was advanced further by the carbon monocoque frame ridden by Chris Boardman to the Olympic 4000m pursuit title in Barcelona in 1992. This prompted a spate of similar concepts, including Australia's Superbike.

At the time Boardman was winning the Olympic pursuit title, his British nemesis, Graeme Obree was preparing for an attack on the world hour record. Obree's attempt was notable for the fact that he was an amateur rider, and more significantly because he had a self-developed aerodynamic position which involved crouching down and resting his shoulders on his hands, which were on top of the handlebars. Obree sensationally broke the world hour record in 1993 and went on to win the world pursuit title. His position was soon banned by the UCI (cycling's world governing body) on the grounds of safety. However, Obree struck back with the 'Superman' position in which he won another world pursuit title. This position was then adopted by Boardman to set a new world hour record of 56.375 km in 1996. The UCI moved again shortly thereafter to ban this position as well. However, the record stood, and it appeared that it would stand forever, being out of reach of anyone in a more conventional cycling position.

Recently, the UCI moved to reinstate the world hour record as the athletes record by limiting it to entirely conventional bicycles of the sort used by Eddy Merckx when he set his world hour record of 49.432 km in 1972. However, these rules apply only to the world hour record, with aerodynamic aids still allowed in track pursuiting, road time trialling, and the separate sports governed by the International Triathlon Federation.

Rules and Regulations Pertaining To Cycling Aerodynamics

The rules about bicycle dimensions and aerodynamic aids are, for the sport of cycling, governed by the UCI (Union Cycliste Internationale). These are the rules that are relevant to the testing being conducted at the CLP Power Wind/Wave Tunnel Facility.

The rules that are most important to aerodynamics are:

1.3.006 "The bicycle is a vehicle with two wheels of equal diameter."

1.3.008 "The rider shall normally assume a sitting position on the bicycle. This position requires that he be supported solely by the pedals, the saddle and handlebar."

1.3.013 "The peak of the saddle shall be a minimum of 5 cm to the rear of a vertical plane passing through the bottom bracket spindle."

1.3.015 "The distance between the bottom bracket and the ground shall be between 24 cm minimum and 30 cm maximum."

1.3.016 "The distance between the vertical passing through the lower bracket spindle and the front wheel spindle shall be between 54 cm minimum and 65 cm maximum. The distance between the vertical passing through the bottom bracket spindle and the rear wheel spindle shall be between 35 cm minimum and 50 cm maximum."

1.3.018 "Wheels of the bicycle may vary in diameter between 70 cm maximum and 55 cm minimum, including the tyre."

1.3.022 "In races other than those covered by article 1.3.023, only the traditional type of handlebars may be used. The point of support for the hands must be positions in an area defined as follows: above, by the horizontal plane of the point of support of the saddle (B); below, by the horizontal line passing thorough the highest point of the two wheels (these being of equal diameter) (C); at the rear by the axis of the steerer tube (D) and at the front by a vertical line passing through the front wheel spindle with a 5 cm tolerance."

1.3.023 "For time trials and....pursuits..., an extension may be added to the steering system. The distance between the vertical line passing through the bottom bracket axle and the extremity of the handlebar may not exceed 75 cm, with the other limits set in article 1.3.022 (B,C,D) remaining unchanged. A support for the elbows or forearms is permitted."

The dimensions referred to by articles 1.3.013 to 1.3.018 are illustrated in Fig. 1, and the dimensions referred to by articles 1.3.022 and 1.3.023 are illustrated in Fig. 2.

Many of these rules were developed to prevent novel approaches to improving aerodynamics such as those introduced by Obree. The nett effect of these rules is that there are limitations to the aerodynamic adjustments that can be made, and different approaches may be needed for different rider sizes. For example, it used to be common to use a smaller front wheel on a time trial bike. Now, it is necessary to use equally sized wheels. This is a disadvantage to smaller riders, as no longer can a very small front wheel be used, meaning that the handlebars can not be set as low. However, for very small riders, the 75 cm rule means that a much more stretched out position can be adopted, approaching the 'Superman' position.

Basic Requirements of Testing for Cycling Aerodynamics

To successfully, and realistically, test cycling aerodynamics, it is necessary to using a dynamic cycling rig and to measure the other variables that contribute to cycling performance.

In the past, many cycling aerodynamics experiments have been conducted using static test rigs. That is, the rider sits in a fixed position on the bicycle and the drag is measured without any movement of the rider or the bicycle parts. This does not realistically simulation the interaction of the rider with the aerodynamic drag. To accurately measure changes in riding position or the effects of changes of equipment, it is necessary to have as realistic a simulation of the riding experience as possible. This means that not only should the rider be pedalling, but the wheels should be turning too.

Aerodynamics are not the only consideration in the speed of a cyclist over a flat course. Clearly, the rider's own physiology plays a large part in performance. While improving aerodynamics can not improve a rider's physiology, it can affect biomechanical efficiency. If for example, a rider's power output drops as a result of a more aerodynamic position, the relative effects of this change must be assessed. Thus, to examine fully the effects of aerodynamic improvement in performance, it is necessary to also measure physiological performance factors.

The third major issue to be considered is rider comfort. The importance of this is to some extent dependent on the length of the race. Over longer races, a rider with an uncomfortable riding position will move out of that position, potentially negating any aerodynamic benefits from adopting the position.

Taking into account the UCI cycling position and bicycle design regulations, the main area interest for a cycling aerodynamicist is handlebar set-up: height, reach and width. Riders can also be encouraged to make changes to head and back position. For biomechanical reasons, changes in saddle height and position are not generally possible and would, in any case, have smaller effects.

Development of the WWTF Cycling Aerodynamics Test Rig

The WWTF test rig is shown in Fig. 3. The rig is based on a set of traditional cycle training rollers mounted in a frame that is then fixed to the wind tunnel floor. A load cell is mounted on the wind tunnel floor behind the frame. At this time, only longitudinal loads are being measured. Initially, the legs of the frame were strain-gauged with the intention of directly using the flexure of the legs to measure drag. However, it was found that the fluctuating vertical component of the load due to rider pedalling forces, bicycle movement on the rollers, and vibration masked the drag component of the signal. The rig is also equipped with a resistance unit to vary the resistance of the rollers. This is included for physiological components of the testing as described below.

Testing Protocol

The primary aim of the test programme is to improve rider performance by improving aerodynamics. But, as described above, aerodynamics can not be examined in isolation from other performance aspects. The test protocol at the WWTF is to measure not only aerodynamic drag, but also power output and oxygen consumption of the rider. In this way, the effects of position on total efficiency (aerodynamic and biomechanical) can be measured.

To measure oxygen consumption directly would be inconsistent with the aerodynamic aims of the testing, but the relationship between oxygen uptake and heart rate is well defined. Heart rate can be measured simply using a telemetric heart rate monitor. Power output can be measured using a special 'SRM' crankset. Neither of these devices have any aerodynamic implications. Thus, by having the rider maintain a constant power output and cadence (gearing and roller resistance can be adjusted to achieve this), the effects of biomechanical and aerodynamic efficiency can be measured by restricting the variable to drag and oxygen uptake.

The period of testing is long enough (typically 5-10 minutes) to assess rider comfort. The effort intensity is sub-maximal to ensure that repeated tests can be conducted without introducing fatigue effects. After testing, riders will be encouraged to complete a race length trial on the road to confirm the comfort of the revised riding position.

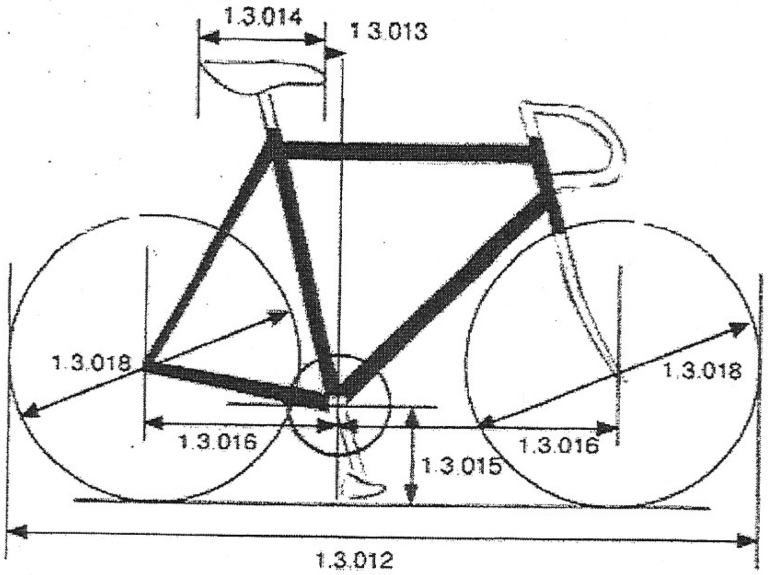

Figure 1 UCI regulation references

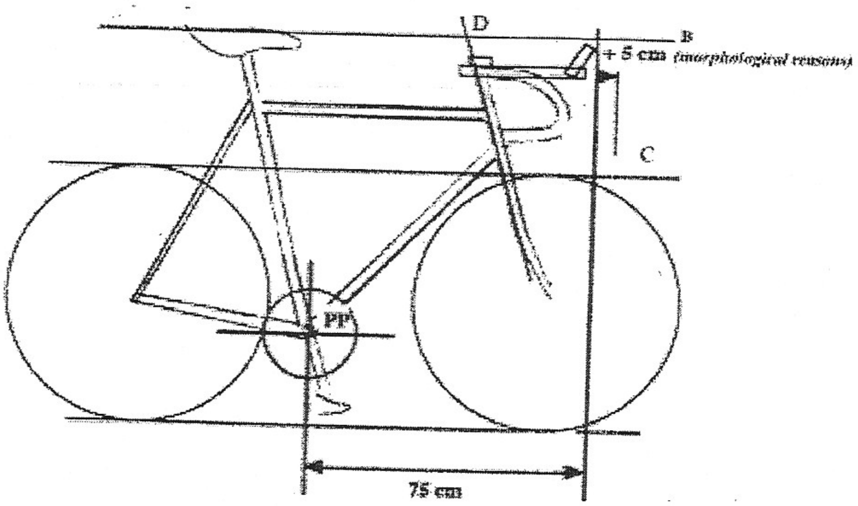

Figure 2 UCI bicycle set-up regulations

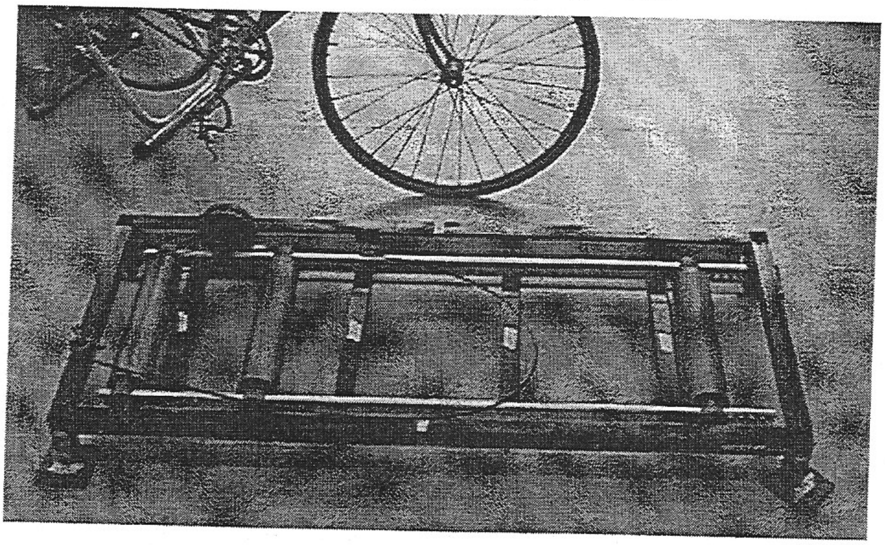

Figure 3 Test rig