

Benchmark of Aerodynamic Cycling Helmets Using a Refined Wind Tunnel Test
Protocol for Helmet Drag Research

by

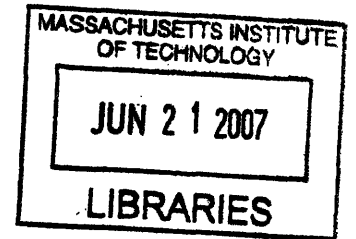
Stephanie Sidelko

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2007

©2007 Stephanie Sidelko. All rights reserved.



ARCHIVES

The author hereby grants to MIT permission to reproduce
and to distribute publicly paper and electronic
copies of this thesis document in whole or in part
in any medium now known or hereafter created.

Signature of Author: _____
Department of Mechanical Engineering
5/10/2007

Certified by: _____
Dr. Kim B. Blair
Lecturer, Sports Innovation @ MIT
Thesis Supervisor

Accepted by: _____
John H. Lienhard V
Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee

**Benchmark of Aerodynamic Cycling Helmets Using a Refined Wind Tunnel Test
Protocol for Helmet Drag Research**

by

Stephanie Sidelko

**Submitted to the Department of Mechanical Engineering
on May 11, 2007 in partial fulfillment of the
requirements for the Degree of Bachelor of Science in Engineering
as recommended by the Department of Mechanical Engineering**

ABSTRACT

The study of aerodynamics is very important in the world of cycling. Wind tunnel research is conducted on most of the equipment that is used by a rider and is a critical factor in the advancement of the sport. However, to date, a comprehensive study of time-trial helmets has not been performed. This thesis presents aerodynamic data for the most commonly used time-trial helmets in professional cycling.

The helmets were tested at a sweep 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. In order to maintain manufacturer confidentiality, the helmets were all randomly assigned variables. Thus, the thesis presents ranges of benefit and drag numbers, but does not rank by helmet name.

The testing results showed that aerodynamic helmets offer drag reduction over a standard road helmet. The best and the worst performing helmets are all more aerodynamic than a road helmet.

Thesis Supervisor: Kim B. Blair
Title: Lecturer, Sports Innovation @ MIT

TABLE OF CONTENTS

1. Introduction.....	5
2. Background.....	6
2.1 Drag.....	6
2.2 Coordinate System.....	7
2.2.1 Forces Acting On Rider.....	7
2.3 Wind.....	8
2.4 Current Protocol.....	9
3. Test Overview.....	9
3.1 Helmets.....	9
3.1.1 Helmet Acquisition.....	9
3.1.2 Control Helmet.....	10
3.2 Wind Tunnel Conditions.....	10
3.3 Helmet Mannequin.....	10
3.4 Helmet Positions.....	11
4. Testing.....	14
4.1 Test Sets.....	15
4.2 Testing Procedure.....	15
5. Results.....	15
5.1 Head-On Wind (0° Yaw).....	16
5.1.1 Helmet Position 1.....	16
5.1.2 Helmet Position 2.....	17
5.1.3 Helmet Position 3.....	17
5.2 Yaw of 5°.....	18
5.2.1 Helmet Position 1.....	19
5.2.2 Helmet Position 2.....	19
5.2.3 Helmet Position 3.....	20
5.3 Yaw of 10°.....	20
5.3.1 Helmet Position 1.....	21
5.3.2 Helmet Position 2.....	22
5.3.3 Helmet Position 3.....	22
5.4 Yaw of 15°.....	22
5.4.1 Helmet Position 1.....	23
5.4.2 Helmet Position 2.....	24
5.4.3 Helmet Position 3.....	24
6. Discussion.....	24
6.1 Drag Reduction and Power Savings.....	25
6.1.1 Professional Cyclist.....	26

6.1.2 Amateur Cyclist.....	27
7. Conclusion.....	28
7.1 Recommendations.....	29
Works Cited.....	30
Appendix A. Characteristics of the Mechanical Balance.....	31
Appendix B. Procedure.....	32
Appendix C. Ranking of Helmets at 0° Yaw.....	33
Appendix D. Ranking of Helmets at 5° Yaw.....	34
Appendix E. Ranking of Helmets at 10° Yaw.....	35
Appendix F. Ranking of Helmets at 15° Yaw.....	36
Appendix G. Standard Deviation and 95% Confidence Intervals for 0° Yaw.....	37
Appendix H. Standard Deviation and 95% Confidence Intervals for 5° Yaw.....	38
Appendix I. Standard Deviation and 95% Confidence Intervals for 10° Yaw.....	39
Appendix J. Standard Deviation and 95% Confidence Intervals for 15° Yaw.....	40

1. Introduction

The sport of bicycling has been witness to numerous technological advances over the years. More specifically, in the last few decades, engineering feats in this sport have driven riders to speeds that would have seemed unattainable one hundred years ago. A lot of the development can be attributed to advancements in the field of aerodynamics and the importance of this subject in the realm of cycling. Researchers have found that aerodynamics plays a huge role in the rider's ability to overcome drag and to produce power to travel at a higher velocity.

Wind tunnels have been used many times in various studies because they allow for testing to occur in a controlled environment. The researcher is capable of changing the apparent wind velocity and also the direction in which the wind hits the rider. This advancement has led to the testing of more and more of a cyclist's equipment. The core of this thesis will involve benchmarking aerodynamic bicycling helmets. The main helmets being used by professionals will be tested in the wind tunnel in three different head positions through a sweep of yaw angles. The significance of the helmet positions are discussed later in the paper.

This thesis provides the most comprehensive, unbiased side-by-side comparison of aero helmets. The results from this test allow for further understanding of the effect of the separation point on a helmet and how the flow stream affects drag. The results from this wind tunnel test substantially increases the amount of information about helmets and can allow for the advancement of helmet development. The data obtained quantifies exactly how much an aero helmet can benefit the rider and can be compared to other

pieces of cycling equipment, i.e. wheels, in order to better understand how much each piece of equipment can work to lower drag.

2. Background

In recent years, the sport of cycling has had a large focus on aerodynamics. Cycling equipment has improved dramatically since 1989, when American Greg LaMond used aero handlebars and an aero helmet to race in and win the Tour de France in the last stage. He was one of the first riders to race with aerodynamic equipment and won the Tour by eight seconds, the smallest margin of victory in the history of the Tour. Since then, a lot of research has been conducted on different pieces of aerodynamic equipment. To date, wind tunnel research has been conducted on almost all of a rider's equipment, ranging from wheels to jerseys. Now riders of all levels are aware of the benefits that it can provide.

2.1 Drag

Drag is the force that acts to oppose the motion of a solid object through a fluid (liquid or gas) and acts in the direction opposite to motion. When air flow encounters a blunt body, the body experiences drag. The drag is attributed to the formation and shedding of eddies created at sharp edges of the body ("Fluid Mechanics" 19).

Close to 90% of the power output by a cyclist is used to overcome drag (Martin et al 286). Sources of drag on the rider are attributed to everything on both the bike and rider, including bike frame, rider position, wheels, and helmet. Advancements in equipment technology have been made over the years to reduce the drag force felt by the rider.

2.2 Coordinate System

The coordinate system used in wind tunnel tests is shown in Figure 1. The wind axes are defined as follows: x points into the wind, y points to the right while facing the wind, and z points down. Aerodynamic forces are aligned with these axes. The lift, L , acts in the negative z direction, drag, D , acts in the negative x direction, and side force S , acts in the positive direction.

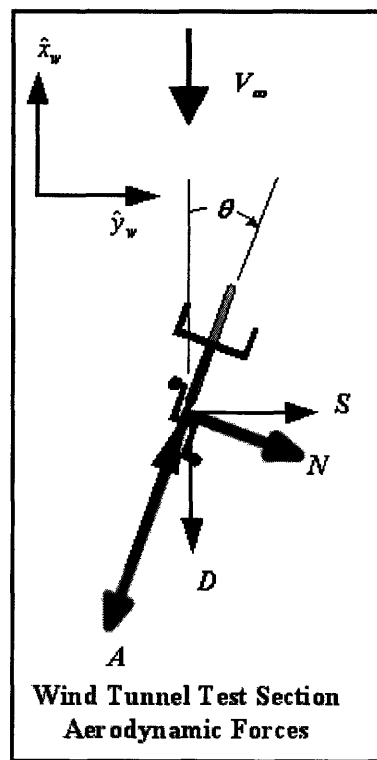


Figure 1: Coordinate system used in wind tunnel and aerodynamic forces acting on a rider (Blair).

2.2.1 Forces Acting On Rider

The forces are summed to show that the total force acting on the bike/rider due to wind is

$$\vec{F}_w = -D_{tot} \hat{x}_w + S_{tot} \hat{y}_w - L_{tot} \hat{z}_w \quad (1)$$

The apparent wind speed, which is the velocity the wind in the tunnel will be traveling at, can be calculated using simple geometry. Figure 2 shows a diagram of the relationship among the bicycle velocity, wind speed, and apparent wind speed.

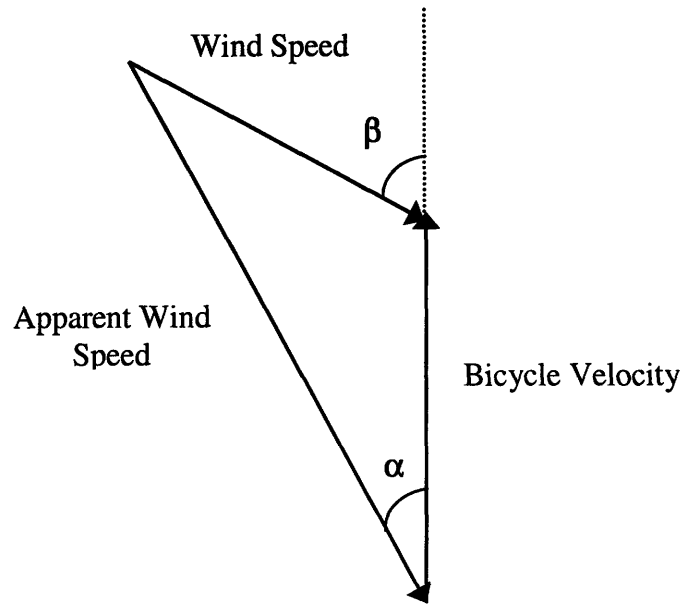


Figure 2: Correlation between rider speed, apparent wind speed and angle, and wind speed.

2.3 Wind

In real world conditions, wind speed varies in speed and incident angle on a daily basis. It is important to simulate these conditions as accurately as possible in wind tunnel testing. A Weibull distribution is a continuous probability distribution and is commonly used to describe real life data; a mathematical model of wind was created using a Weibull distribution with a shape coefficient of 2. The model showed that the average deviation of incident wind is about 14° .

The yaw angles used in wind tunnel tests should be guided by the mathematical wind model in order to reflect real world racing conditions. Oftentimes larger yaw angles

are used by manufacturers to emphasize the benefit of their aerodynamic product in larger crosswinds, when in actuality the real world conditions show that, on average, wind hits a rider at angles less than fifteen degrees.

2.4 Current Protocol

The test is conducted in a constant wind tunnel velocity that best reflects the apparent wind velocity that the rider would experience. Several factors influence this, but it is common that the tunnel runs at 30 mph to mimic the speed of a professional rider. In order to measure drag, the test subject is attached to a load cell in the wind tunnel. The test may be performed in head-on wind only, or performed through a sweep of yaw angles, depending on the purpose of the test.

3. Test Overview

3.1 Helmets

Ten aero helmets were acquired for this test. These ten helmets include the helmets most popular in the world of professional cycling. The other helmet tested was a standard road helmet. The road helmet was used in the test in order to compare the results from aero helmets to the results from the standard road helmet.

3.1.1 Helmet Acquisition

In order to run the most comprehensive helmet study to date, several key helmet manufacturers were contacted to submit their aero helmets for testing. These critical manufacturers submitted their helmets to the project, creating a very extensive helmet lineup for testing. The helmets tested include the most popular aero road helmets in current racing. Note that the helmets that have a face shield attachment were tested with and without the shield.

In order to keep the individual manufacturer's data private, the helmets were randomly assigned a variable. In the thesis the helmets are referred to by their designated variable.

3.1.2 Control Helmet

A standard road cycling helmet was used as the control in this experiment. The testing could have been conducted with a helmet-less head as the control; however, this method of testing would not demonstrate the benefit that an aerodynamic helmet can provide over a regular road helmet. By using a road helmet as a comparative tool, the test provides a quantified difference between aero and road helmets.

3.2 Wind Tunnel Conditions

The wind tunnel will be set up to most accurately mimic a professional rider; the wind tunnel speed is set to 30 mph, which is equal to 13.4 m/s. The helmets will be brought through a sweep of yaw angles from 0° to 15°, in increments of 5°. This sweep reflects relevant racing conditions for a professional rider.

3.3 Helmet Mannequin

As discussed earlier, wind tunnel tests provide a large amount of control in athlete testing. However, athletes themselves bring another source of error to the data sets because of human error. Though professionals may come very close to replicating their racing position time after time, there is still a slight discrepancy each time they reposition themselves. This uncertainty is avoided by using a stationary mannequin.

In these helmet tests, an upper body mannequin called Uri is used. Uri is bent forward at the waist and has his hands in front of him, as though he is on his aero bars.

He simulates a rider in the time trial position. The following figure shows the mannequin set up in the time trial position.



Figure 3: Picture of Uri the mannequin set up in the wind tunnel. He is in the aero position with his hands in front of him as though he were riding dropped down on aero bars.

3.4 Helmet Positions

The helmets are tested in three different positions – placed very close to the back with the tip almost touching, placed slightly away from the back, and placed with the tip straight up. These positions represent relevant riding conditions (Fig 4, Fig 5). Position 1, with the tip very close to the back, represents what is believed to be the most aerodynamic position for a rider. This is the way that most professionals race during time trials. The second position is with the tip slightly away from the back; this position replicates a rider moving away from the “ideal” position, due to fatigue or other factors.

The third and final position is with the tip straight in the air, which riders sometimes assume during a hill or mountain climb.

Safety is a critical factor in determining the validity of each helmet position. First and foremost, a helmet must provide a protective shell for the head. When placing the helmets on the head for testing, the researchers used the eyebrows as a reference line. The eyebrows serve as the line for position 2; position 1 was a measurable distance away from the eyebrows on the forehead. The placement for position 3 requires that the helmet is tipped straight up; however, because the neck of the mannequin is not a degree of freedom, the helmet is placed so that its brim touches the bridge of the nose.

These placement tactics ensure that the helmets meet their safety specifications. Figure 4 shows exactly where the helmets were placed on the head of the mannequin.

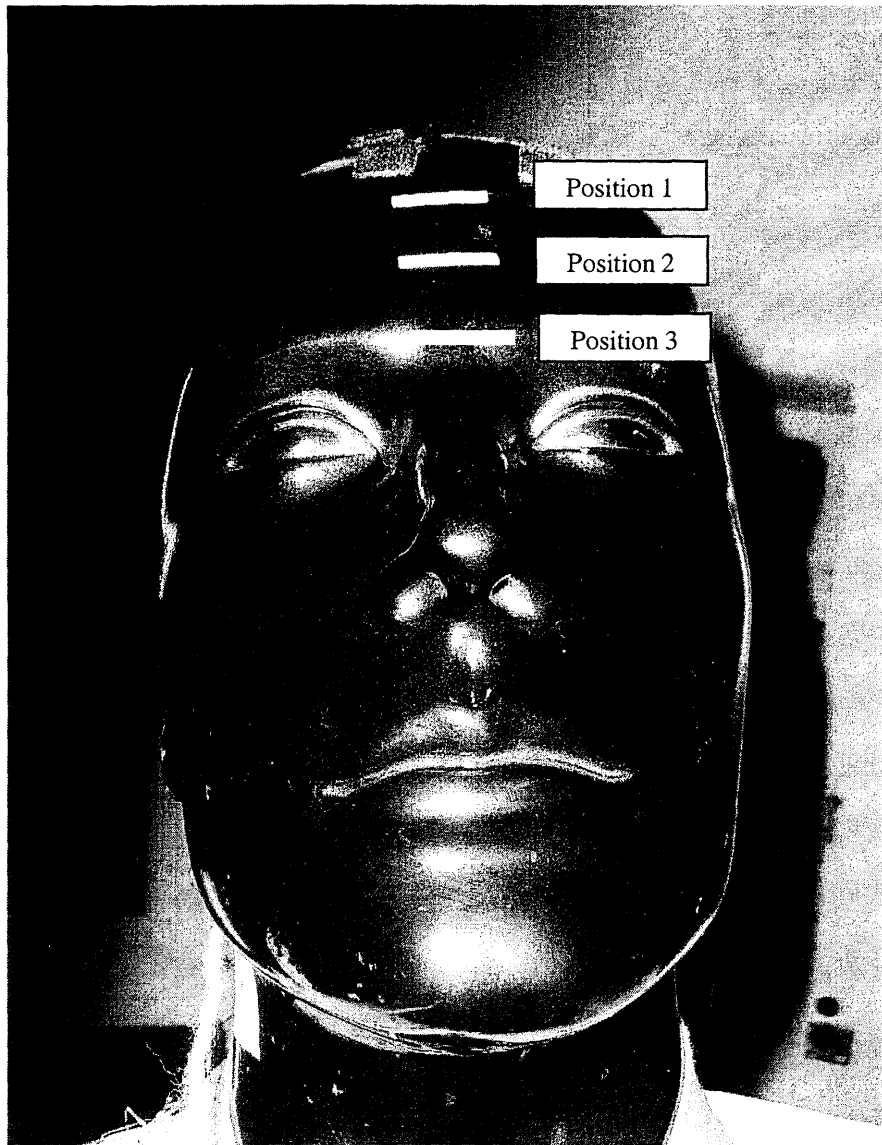


Figure 4: Picture of mannequin shows the reference lines on the forehead (in white) used in positioning the helmet in order to model racing positions 1, 2, and 3.

When the brim of the helmet is moved to different positions on the forehead, the back tail also moves. The following figure illustrates where the tail of the helmet is in relation to horizontal in each position.

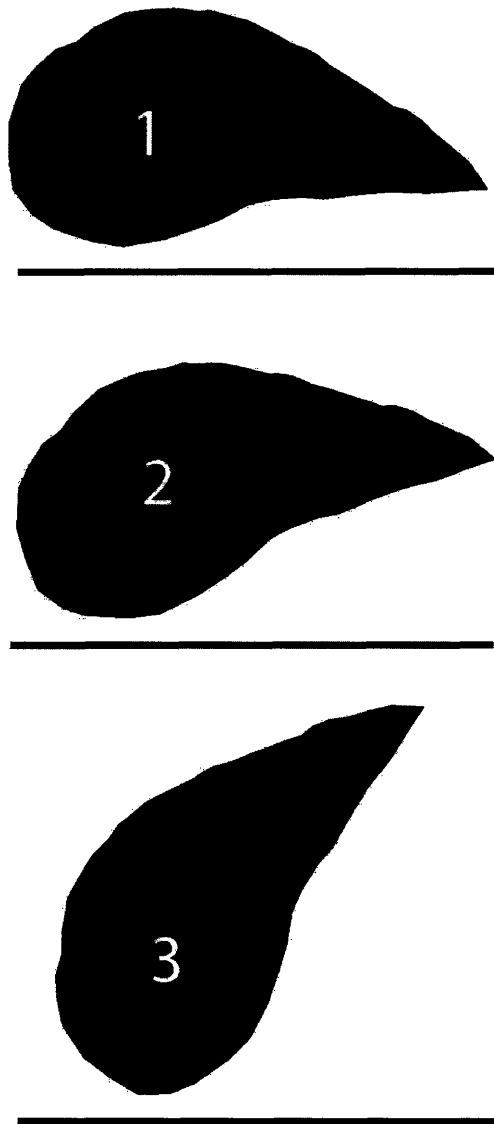


Figure 5: Sketch of tail position in each of the helmet positions. The horizontal lines are reference lines.

4. Testing

The balance system used in the wind tunnel is a 6 component pyramidal balance and consists of a mechanical beam for the yawing moment system and a resistance strain gauge for the side force system (“WBWT”). Appendix A contains a table showing the

range and accuracies of the balance. The mannequin is mounted on the load cell for testing.

4.1 Test Sets

The test set collects data for 30 seconds. During this time, the software is collecting data at 1000 Hz, recording tunnel wind speed, atmospheric conditions, and side force. A test sampling of 30 seconds provides enough data points to give confidence in the standard deviations and the error analysis.

4.2 Testing Procedure

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

All the helmets were tested in each position at each yaw angle before the table was moved to the next yaw position. Before moving to each yaw angle, the table was turned back to 0° and then moved to the desired position; this limited the possibility of propagating error through the test set by turning the table. Appendix B contains the procedure.

5. Results

This section includes the results from the twelve different data sets: three helmet positions at each of four different yaw angles. Section 5.1 goes through the results from head-on wind. The results from 5°, 10°, and 15° yaw are found in sections 5.2, 5.3, and 5.4, respectively. Complete helmet rankings can be found in appendices C-F. The standard deviations of each helmet test, as well as the 95% confidence intervals, are located in appendices H-J.

5.1 Head-on Wind (0° Yaw)

The drag results for the three different helmet positions in head-on wind are shown in figure 6.

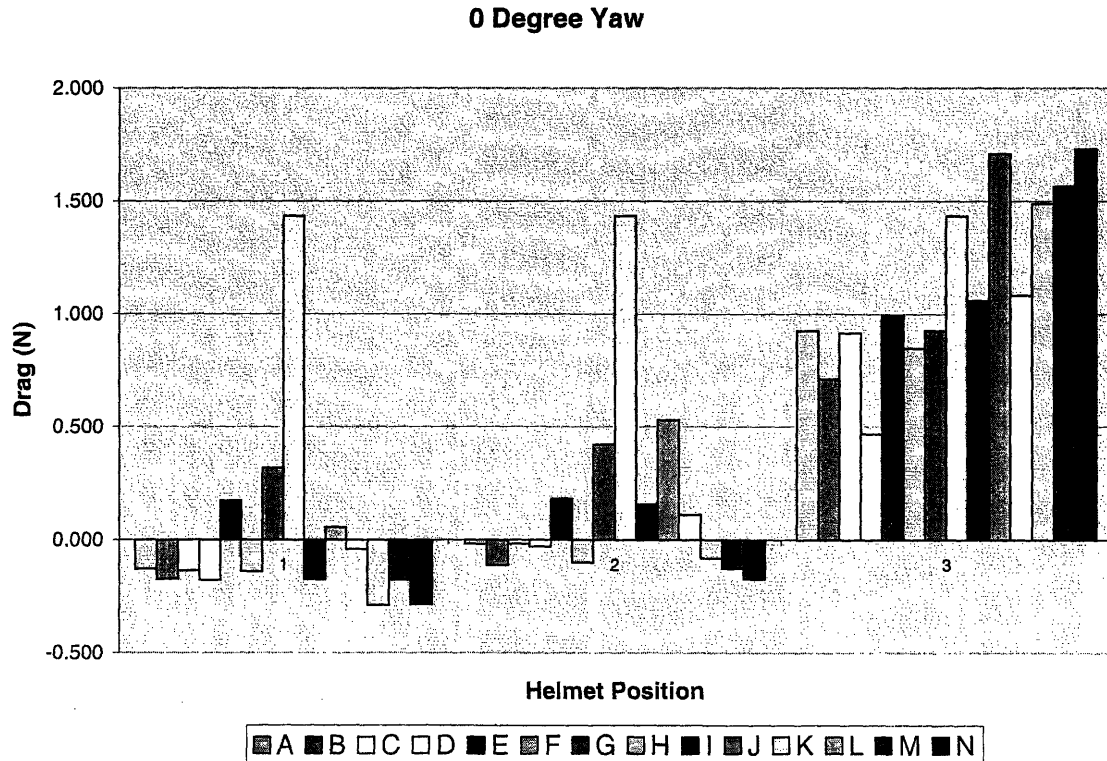


Figure 6: Drag values for each helmet in each of the three positions; the drag values shown are for the helmet itself. Note that helmet H is the control.

5.1.1 Helmet Position 1

In helmet position 1, the best performing helmet had a drag value of -0.288 N. The worst performing helmet had a drag value of 0.319 N. (Note that this is the drag value of the helmet by itself; drag associated with the mannequin was subtracted out from the final drag value leaving only the value of the helmet.) The control road helmet drag value was 1.433 N. The median drag value was -0.141 N. Table 1 summarizes these results.

Table 1: Helmet Position 1 with 0° Yaw

Road Helmet Drag (N)	1.433
Aero Helmet Drag Range (N)	-0.288 to 0.319
Median (N)	-0.141
Best Performing Aero Helmet	Helmet L
Worst Performing Aero Helmet	Helmet G

5.1.2 Helmet Position 2

In helmet position 2, the best performing helmet had a drag value of -0.175 N. The worst performing helmet had a drag value of 0.530 N. Table 2 summarizes these results.

Table 2: Helmet Position 2 with 0° Yaw

Aero Helmet Drag Range (N)	-0.175 to 0.530
Median (N)	-0.017
Best Performing Aero Helmet	Helmet N
Worst Performing Aero Helmet	Helmet J

5.1.3 Helmet Position 3

The drag value for the helmet with the lowest drag was 0.467 N, while the highest drag value measured for a helmet was 1.729 N. The median drag value was 0.996 N. Table 3 summarizes the key results from this data set.

Table 3: Helmet Position 3 with 0° Yaw

Aero Helmet Drag Range (N)	0.467 to 1.729
Median (N)	0.996
Best Performing Aero Helmet	Helmet D
Worst Performing Aero Helmet	Helmet N

5.2 Yaw of 5°

Figure 7 highlights the average drag values for each helmet at a yaw angle of 5° in each of the three positions that it was tested.

5 Degree Yaw

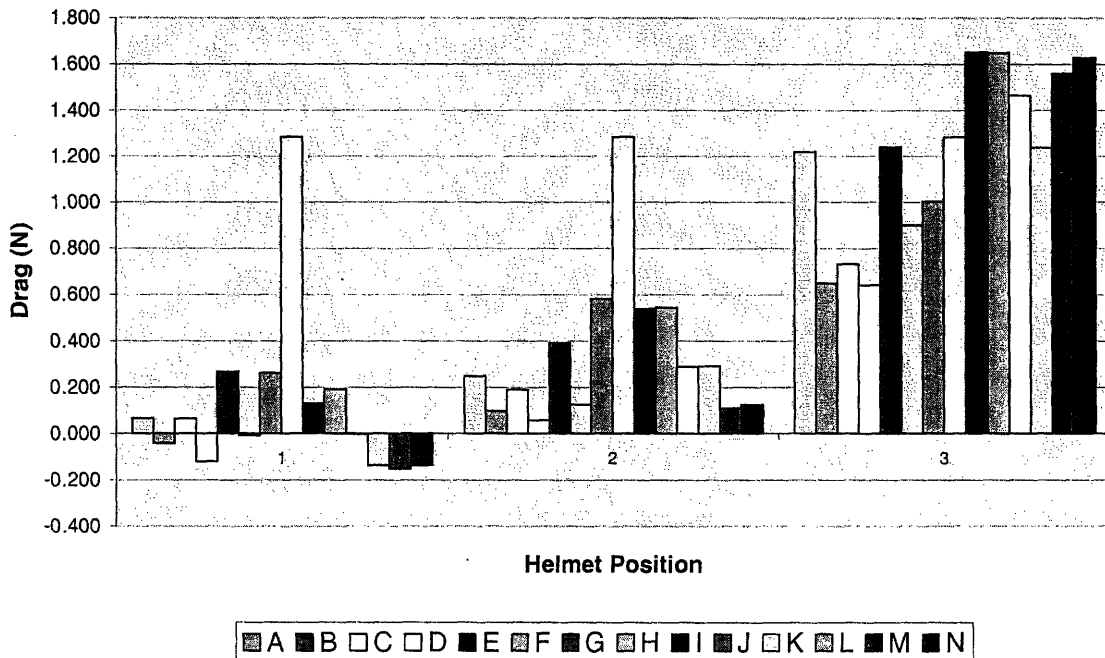


Figure 7: Drag values associated with each helmet at a yaw of 5° in each of the three helmet positions. Note that helmet H is the control.

5.2.1 Helmet Position 1

The drag value for the best performing helmet in position 1 at 5° yaw was -0.152 N, while the worst performing helmet had a drag value of 0.267 N. The median value for the helmet spread was -0.002. The control had a drag of 1.284 N. Table 4 highlights these results.

Table 4: Helmet Position 1 with 5° Yaw

Road Helmet Drag (N)	1.284
Aero Helmet Drag Range (N)	-0.152 to 0.267
Median (N)	-0.002
Best Performing Aero Helmet	Helmet M
Worst Performing Aero Helmet	Helmet E

5.2.2 Helmet Position 2

In helmet position 2, the drag value for the best performing helmet was 0.058 N, while the drag for the worst performing helmet was 0.581 N. The median value was 0.248 N. Table 5 summarizes these results.

Table 5: Helmet Position 2 with 5° Yaw

Aero Helmet Drag Range (N)	0.058 to 0.581
Median (N)	0.248
Best Performing Aero Helmet	Helmet D
Worst Performing Aero Helmet	Helmet G

5.2.3 Helmet Position 3

In position 3, the best performing helmet had a drag value of 0.641 N and the worst performing helmet had a value of 1.652 N. The median of this test set was 1.237 N.

The following table highlights these results.

Table 6: Helmet Position 2 with 5° Yaw

Aero Helmet Drag Range (N)	0.641 to 1.652
Median (N)	1.237
Best Performing Aero Helmet	Helmet D
Worst Performing Aero Helmet	Helmet I

5.3 Yaw of 10°

The helmets were tested in the three positions at a yaw angle of 10°. Figure 8 shows how each helmet performed in each position.

10 Degree Yaw

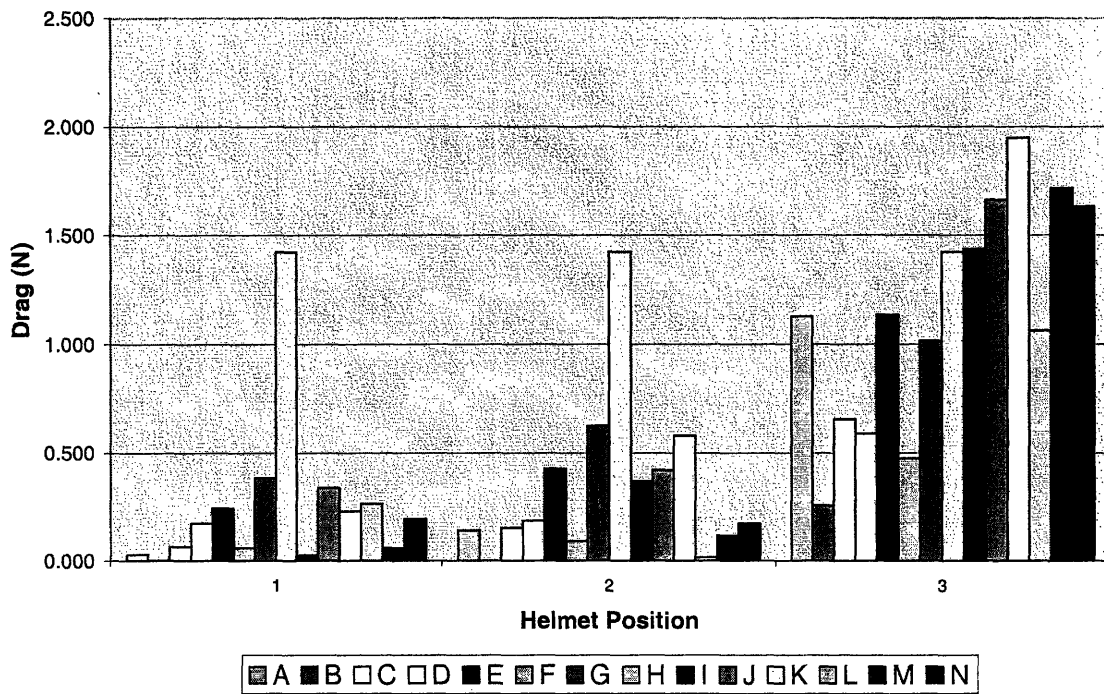


Figure 8: Drag values for each helmet in each position at a 10° yaw angle. Note that helmet H is the control.

5.3.1 Helmet Position 1

In helmet position 1 at 10° yaw, the best performing helmet had a drag value of 0.002 N and the worst had a value of 0.383 N. The median value was 0.174 N. The control road helmet had a drag value of 1.422 N. Table 7 summarizes these results.

Table 7: Helmet Position 1 with 10° Yaw

Road Helmet Drag (N)	1.422
Aero Helmet Drag Range (N)	0.002 to 0.383
Median (N)	0.174
Best Performing Aero Helmet	Helmet B
Worst Performing Aero Helmet	Helmet G

5.3.2 Helmet Position 2

The worst performing helmet in position 2 at 10° yaw had a drag value of 0.623 N while the best performing helmet had a drag value of 0.001 N. The median value was 0.174 N. The following table shows these results.

Table 8: Helmet Position 2 with 10° Yaw

Aero Helmet Drag Range (N)	0.001 to 0.623
Median (N)	0.174
Best Performing Aero Helmet	Helmet B
Worst Performing Aero Helmet	Helmet G

5.3.3 Helmet Position 3

In position 3, the best performing helmet had a drag value of 0.257 N. The worst performing helmet had a drag value of 1.950 N. The median value for this set was 1.125 N. Table 9 gives these results.

Table 9: Helmet Position 3 with 10° Yaw

Aero Helmet Drag Range (N)	0.257 to 1.950
Median (N)	1.125
Best Performing Aero Helmet	Helmet B
Worst Performing Aero Helmet	Helmet K

5.4 Yaw of 15°

All the helmets were tested at a yaw angle of 15° in three different positions. Figure 9 shows the results from this test set.

15 Degree Yaw

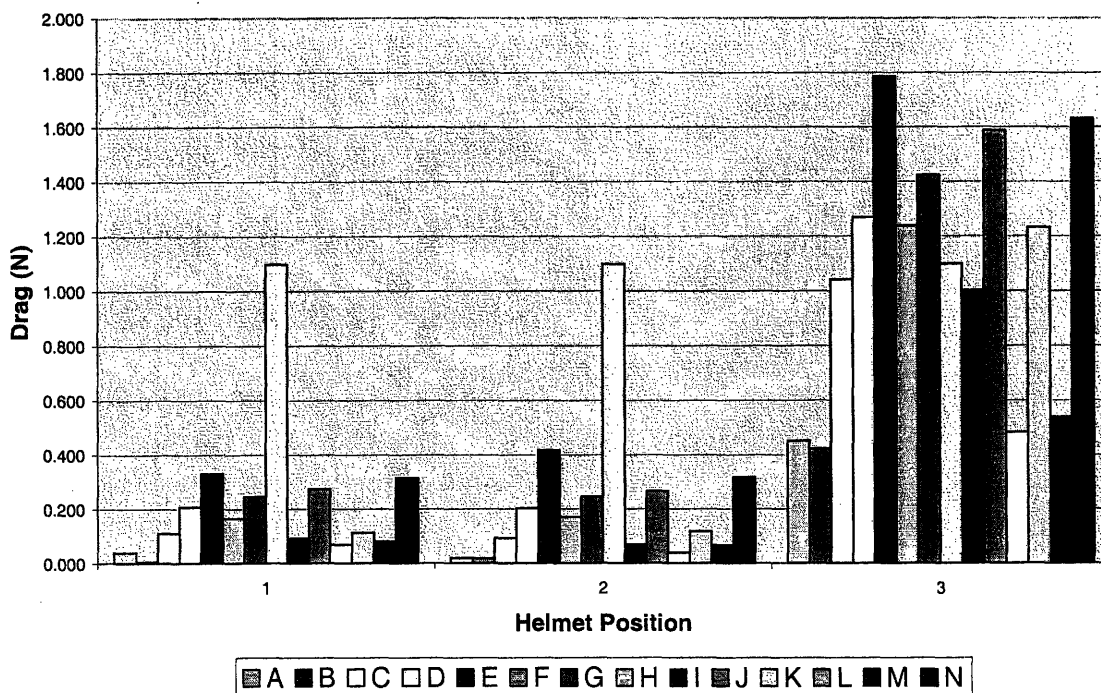


Figure 9: Data from 15° yaw test. The helmets were all tested in three different helmet positions on the head. Note that helmet H is the control.

5.4.1 Helmet Position 1

At a 15° yaw angle in position 1, the drag value for the best performing helmet was 0.006 N; the drag value for the worst performing helmet was 0.329 N. The median value was 0.113 N and the control helmet had a drag value of 1.097 N. Table 10 summarizes these results.

Table 10: Helmet Position 1 with 15° Yaw

Road Helmet Drag (N)	1.097
Aero Helmet Drag Range (N)	0.006 to 0.329
Median (N)	0.113
Best Performing Aero Helmet	Helmet B
Worst Performing Aero Helmet	Helmet E

5.4.2 Helmet Position 2

The worst performing helmet in position 2 at a 15° yaw angle had a drag value of 0.416 N while the best performing helmet had a drag value of 0.018 N. The median value was 0.118 N. These results can be seen in Table 10.

Table 10: Helmet Position 2 with 15° Yaw

Aero Helmet Drag Range (N)	0.018 to 0.416
Median (N)	0.118
Best Performing Aero Helmet	Helmet L
Worst Performing Aero Helmet	Helmet J

5.4.3 Helmet Position 3

In position 3 at a 15° yaw angle, the worst performing helmet had a drag value of 1.785 N. The best performing helmet in these conditions had a drag value of 0.423 N.

The median value was 1.232 N. Table 11 shows these results.

Table 11: Helmet Position 3 with 15° Yaw

Aero Helmet Drag Range (N)	0.423 to 1.785
Median (N)	1.232
Best Performing Aero Helmet	Helmet B
Worst Performing Aero Helmet	Helmet J

6. Discussion

Aerodynamic helmets do reduce a rider's drag when compared to a standard road helmet. Even the worst performing helmets in testing provide drag reduction from the

control. It is interesting to note that even though the range of drag values can be large for the helmet spread, the aero helmets still prove to have less drag than the road helmet.

6.1 Drag Reduction and Power Savings

An aero helmet lowers drag. Because drag is the majority of what a rider must overcome in order to move, a reduction in drag could equate to a power “savings” for that rider. To clarify, a rider would need less power in order to overcome drag. Sections 6.1.1 and 6.1.2 will show the power savings for two types of riders: professional racers and amateur cyclists. In order to analyze the relative power savings and drag reduction, two assumptions had to be made. The amount of drag that each type of rider typically has (including a road helmet) and the average power output over 40 km. It was estimated that an amateur cyclist has roughly 27 N of drag and has a power output of 225 Watts. The professional cyclist has 22 N of drag and a power output of 450 Watts. (Martin et al)

The percent drag reduction is given by

$$\frac{RoadHelmetDrag - AeroHelmetDrag}{TotalDrag} \times 100, \quad (2)$$

where the road helmet drag is given by the drag value for the control, the aero helmet drag is the drag associated with a particular aero helmet, and the total drag is the drag value for the rider and all associated equipment. In the following cases, the total drag is either 27 N or 22 N, depending on whether it is an amateur or professional rider, respectively.

The amount of power savings is determined by multiplying the percent drag reduction by the power output of a rider. The following equation shows how the power savings are calculated.

$$PowerSavings = \%Drag\ Reduction \times PowerOutput \quad (3)$$

6.1.1 Professional Cyclist

A typical professional cyclist has close to five pounds of drag (including a standard road helmet), which is 22 N, and outputs an average of 450 Watts during a time trial. This information can be used to compute exactly how much a pro would benefit from the use of an aero helmet. Tables 12, 13, 14, and 15 show the percent drag reduction and the power savings to pro riders if they switched from a road helmet to an aero helmet at 0°, 5°, 10°, and 15° yaw angles, respectively. It is interesting to note that even the worst performing aero helmet offers a benefit to the rider.

Table 12: Drag Reduction and Power Savings for a Professional Rider at 0° Yaw

<i>Pro: 22 N Drag and 450 Watts Power</i>	Best Helmet	Median Helmet	Worst Helmet
% Drag Reduction	7.8%	7.2%	5.1%
Power Savings	35.2 Watts	32.2 Watts	22.8 Watts

Table 13: Drag Reduction and Power Savings for a Professional Rider at 5° Yaw

<i>Pro: 22 N Drag and 450 Watts Power</i>	Best Helmet	Median Helmet	Worst Helmet
% Drag Reduction	6.5%	5.8%	4.6%
Power Savings	29.3 Watts	26.3 Watts	20.8 Watts

Table 14: Drag Reduction and Power Savings for a Professional Rider at 10° Yaw

<i>Pro: 22 N Drag and 450 Watts Power</i>	Best Helmet	Median Helmet	Worst Helmet
% Drag Reduction	6.5%	5.7%	4.7%
Power Savings	29.1 Watts	25.5 Watts	21.3 Watts

Table 15: Drag Reduction and Power Savings for a Professional Rider at 15° Yaw

<i>Pro: 22 N Drag and 450 Watts Power</i>	Best Helmet	Median Helmet	Worst Helmet
% Drag Reduction	5.0%	4.5%	3.5%
Power Savings	22.3 Watts	20.1 Watts	15.7 Watts

6.1.2 Amateur Cyclist

An amateur rider will also see power savings and drag reduction if they switch to an aerodynamic helmet. It is harder to define the “typical” amateur athlete than it is to define the “typical” professional in terms of power output and amount of drag associated with the riding position and equipment. For the purpose of this analysis, it is assumed that the average amateur athlete has roughly 6 pounds of drag, which is about 27 N, and can output an average of 225 Watts of power during a time trial.

Through the sweep of yaw angles, the median helmet saw an average of 4.7% drag reduction and a power savings of 8.3 Watts with an aero helmet. Tables 16, 17, 18, and 19 show the percent drag reduction and the power savings an amateur would see at 0°, 5°, 10°, and 15° yaw angles with an aero helmet versus a road helmet.

Table 16: Drag Reduction and Power Savings for an Amateur Rider at 0° Yaw

<i>Amateur: 27 N Drag and 225 Watts Power</i>	Best Helmet	Median Helmet	Worst Helmet
% Drag Reduction	6.4%	5.8%	4.1%
Power Savings	14.3 Watts	13.1 Watts	9.3 Watts

Table 17: Drag Reduction and Power Savings for an Amateur Rider at 5° Yaw

<i>Amateur: 27 N Drag and 225 Watts Power</i>	Best Helmet	Median Helmet	Worst Helmet
% Drag Reduction	5.3%	4.8%	3.8%
Power Savings	12.0 Watts	10.7 Watts	8.5 Watts

Table 18: Drag Reduction and Power Savings for an Amateur Rider at 10° Yaw

<i>Amateur: 27 N Drag and 225 Watts Power</i>	Best Helmet	Median Helmet	Worst Helmet
% Drag Reduction	5.3%	4.6%	3.8%
Power Savings	11.8 Watts	10.4 Watts	8.7 Watts

Table 19: Drag Reduction and Power Savings for an Amateur Rider at 15° Yaw

<i>Amateur: 27 N Drag and 225 Watts Power</i>	Best Helmet	Median Helmet	Worst Helmet
% Drag Reduction	4.0%	3.6%	2.8%
Power Savings	9.1 Watts	8.2 Watts	6.4 Watts

7. Conclusion

Ten aerodynamic helmets were tested side by side in an extensive wind tunnel study. These helmets were compared to a standard road helmet and it was found that aerodynamic helmets provide drag reduction versus the road helmet. While there may be a significant range of performance between the helmet spread, all of the helmets offered a benefit over a road helmet.

By wearing an aero helmet, a rider can save a considerable amount of power and can also substantially reduce his overall drag. This study quantified the benefit of wearing an aero helmet and gives important data that can be compared to the rest of cycling

equipment. Also, the test protocol used in this study can be applied to any future helmet tests.

7.1 Recommendations

Ideally, more extensive research will be conducted on helmets. The research could be expanded in order to better understand the theory behind helmets and their sources of drag and drag reduction. This type of testing would entail flow visualizations, pressure measurements, and could lead to the discovery of the most ideal helmet shape.

A study in which the specific helmet names can be published would be beneficial. This would allow for the researcher to theorize what particular helmet shapes work best in drag reduction and why this happens. It would also allow for better understanding of the theory behind helmet drag and could be used to make athletes faster.

Works Cited

- Blair, Kim. "Cycling Aerodynamics." Serotta International Cycling Institute, SICI Cycling Science Symposium and Expo. Hotel Boulderado, Boulder, CO. 23 January, 2007.
- "fluid mechanics." Encyclopedia Britannica. 2007. Encyclopedia Britannica Online. 8 May 2007. Online Academic Edition. <<http://www.search.eb.com/eb/article-77496>>.
- Martin, James C., Douglas L. Milliken, John E. Cobb, Kevin L. McFadden, and Andrew R. Coggan. "Validation of a Mathematical Model for Road Cycling Power." Journal of Applied Biomechanics. 14 (1998): 276-291
- "WBWT Information for Industry." MIT's Wright Brothers Wind Tunnel. July 2002. 10 May 2007 < <http://web.mit.edu/aeroastro/www/labs/WBWT/>>

Appendix A. Characteristics of the Mechanical Balance

(From the MIT's Wright Brothers Wind Tunnel Information for Industry Article – July 2002)

CHARACTERISTICS OF THE MECHANICAL BALANCE

Model Mounts

Standard 3 Strut - Two forward plus a tall strut for angle of attack control.

Available spacings:

Front trunnions - 28 to 42 inches (reducible to 4 1/2 to 11 1/2 with special slant trunnions)

Rear strut - 20 to 36 inches

Single central strut - a plus aft tail strut for angle of attack control

Balance type - 6 component pyramidal

	Range	Accuracies ⁽²⁾
Angle of attack ⁽¹⁾	-30° to +30°	0.1°
Angle of Yaw	-20° to +20°	0.1°
Lift	0 to 3000 lb	0.5 lb
Drag	0 to 600 lb	0.03 lb
Side force	-300 to +300 lb	0.1 lb
Pitching moment	-350 to +350 lb	0.2 ft lb
Rolling moment	-350 to +350 ft lb	0.2 ft lb
Yawing moment	-300 to +300 ft lb	0.2 ft lb

Sting balances are available

(1) For 30-inch spacing between front and rear support

(2) These differences include known nonlinearities and repeatability

Appendix B. Procedure

1. Place helmet A on mannequin in helmet position 1.
2. Run a 30 second test set.
3. Record drag values and standard deviations.
4. Move helmet A into position 2.
5. Repeat steps 4 and 5.
6. Move helmet A into position 3.
7. Repeat steps 4 and 5.
8. Remove helmet A from mannequin.
9. Run 30 second test set on mannequin alone.
10. Repeat steps 1 through 11 on helmets B through N.
11. Yaw table to 5° and do steps 1-12.
12. Yaw table to 0° .
13. Yaw table to 10° and do steps 1-12.
14. Yaw table to 0° .
15. Yaw table to 15° and do steps 1-12.

Appendix C. Ranking of Helmets at 0° Yaw

Helmet Position 1

<u>Rank</u>	<u>Helmet</u>	0 Degree Drag (N)
1	L	-0.288
2	N	-0.286
3	D	-0.179
4	M	-0.176
5	I	-0.175
6	B	-0.174
7	F	-0.141
8	C	-0.136
9	A	-0.129
10	K	-0.042
11	J	0.055
12	E	0.175
13	G	0.319
14	H	1.433

Helmet Position 3

<u>Rank</u>	<u>Helmet</u>	0 Degree Drag (N)
1	D	0.467
2	B	0.713
3	F	0.847
4	C	0.914
5	A	0.926
6	G	0.927
7	E	0.996
8	I	1.060
9	K	1.083
10	H	1.433
11	L	1.488
12	M	1.565
13	J	1.708
14	N	1.729

Helmet Position 2

<u>Rank</u>	<u>Helmet</u>	0 Degree Drag (N)
1	N	-0.175
2	M	-0.127
3	B	-0.112
4	F	-0.100
5	L	-0.082
6	D	-0.029
7	C	-0.017
8	A	-0.017
9	K	0.112
10	I	0.158
11	E	0.183
12	G	0.422
13	J	0.530
14	H	1.433

Appendix D. Ranking of Helmets at 5° Yaw

Helmet Position 1

<u>Rank</u>	<u>Helmet</u>	<u>5 Degree Drag (N)</u>
1	M	-0.152
2	L	-0.138
3	N	-0.137
4	D	-0.121
5	B	-0.042
6	F	-0.008
7	K	-0.002
8	C	0.065
9	A	0.066
10	I	0.130
11	J	0.192
12	G	0.262
13	E	0.267
14	H	1.284

Helmet Position 3

<u>Rank</u>	<u>Helmet</u>	<u>5 Degree Drag (N)</u>
1	D	0.641
2	B	0.649
3	C	0.731
4	F	0.900
5	G	1.003
6	A	1.218
7	L	1.237
8	E	1.241
9	H	1.284
10	K	1.464
11	M	1.558
12	N	1.627
13	J	1.648
14	I	1.652

Helmet Position 2

<u>Rank</u>	<u>Helmet</u>	<u>5 Degree Drag (N)</u>
1	D	0.058
2	B	0.098
3	M	0.109
4	N	0.123
5	F	0.125
6	C	0.190
7	A	0.248
8	K	0.288
9	L	0.290
10	E	0.392
11	I	0.539
12	J	0.544
13	G	0.581
14	H	1.284

Appendix E. Ranking of Helmets at 10° Yaw

Helmet Position 1

<u>Rank</u>	<u>Helmet</u>	10 Degree Drag (N)
1	B	0.002
2	I	0.026
3	A	0.030
4	F	0.059
5	M	0.059
6	C	0.064
7	D	0.174
8	N	0.194
9	K	0.230
10	E	0.244
11	L	0.264
12	J	0.338
13	G	0.383
14	H	1.422

Helmet Position 3

<u>Rank</u>	<u>Helmet</u>	10 Degree Drag (N)
1	B	0.257
2	F	0.473
3	D	0.588
4	C	0.654
5	G	1.015
6	L	1.061
7	A	1.125
8	E	1.134
9	H	1.422
10	I	1.436
11	N	1.633
12	J	1.663
13	M	1.718
14	K	1.950

Helmet Position 2

<u>Rank</u>	<u>Helmet</u>	10 Degree Drag (N)
1	B	0.001
2	L	0.017
3	F	0.090
4	M	0.117
5	A	0.140
6	C	0.153
7	N	0.174
8	D	0.186
9	I	0.368
10	J	0.421
11	E	0.426
12	K	0.578
13	G	0.623
14	H	1.422

Appendix F. Ranking of Helmets at 15° Yaw

Helmet Position 1

<u>Rank</u>	<u>Helmet</u>	15 Degree Drag (N)
1	B	0.006
2	A	0.040
3	K	0.069
4	M	0.080
5	I	0.092
6	C	0.111
7	L	0.113
8	F	0.166
9	D	0.208
10	G	0.246
11	J	0.274
12	N	0.314
13	E	0.329
14	H	1.097

Helmet Position 3

<u>Rank</u>	<u>Helmet</u>	15 Degree Drag (N)
1	B	0.423
2	A	0.451
3	K	0.482
4	M	0.538
5	I	1.002
6	C	1.041
7	H	1.097
8	L	1.232
9	F	1.237
10	D	1.269
11	G	1.423
12	J	1.588
13	N	1.631
14	E	1.785

Helmet Position 2

<u>Rank</u>	<u>Helmet</u>	15 Degree Drag (N)
1	B	0.018
2	A	0.020
3	K	0.038
4	M	0.066
5	I	0.070
6	C	0.093
7	L	0.118
8	F	0.171
9	D	0.203
10	G	0.245
11	J	0.267
12	N	0.317
13	E	0.416
14	H	1.097

Appendix G. Standard Deviation and 95% Confidence Intervals for 0° Yaw

Helmet	Helmet Position	0 Degree Drag (N)	0 Std Dev (N)	0 95% Confidence
A	1	-0.129	0.062	0.045
	2	-0.017	0.102	0.074
	3	0.926	0.089	0.065
B	1	-0.174	0.067	0.049
	2	-0.112	0.062	0.045
	3	0.713	0.085	0.062
C	1	-0.136	0.071	0.052
	2	-0.017	0.076	0.056
	3	0.914	0.080	0.058
D	1	-0.179	0.053	0.039
	2	-0.029	0.071	0.052
	3	0.467	0.058	0.042
E	1	0.175	0.067	0.049
	2	0.183	0.058	0.042
	3	0.996	0.089	0.065
F	1	-0.141	0.053	0.039
	2	-0.100	0.116	0.085
	3	0.847	0.129	0.094
G	1	0.319	0.062	0.045
	2	0.422	0.093	0.068
	3	0.927	0.093	0.068
H	1	1.433	0.067	0.049
I	1	0.055	0.067	0.049
	2	0.530	0.044	0.032
	3	1.708	0.062	0.045
J	1	-0.042	0.076	0.055
	2	0.112	0.071	0.052
	3	1.083	0.053	0.039
K	1	-0.175	0.111	0.081
	2	0.158	0.080	0.058
	3	1.060	0.071	0.052
L	1	-0.288	0.053	0.039
	2	-0.082	0.138	0.101
	3	1.488	0.125	0.091
M	1	-0.176	0.107	0.078
	2	-0.127	0.076	0.056
	3	1.565	0.093	0.068
N	1	-0.286	0.067	0.049
	2	-0.175	0.076	0.056
	3	1.729	0.080	0.058

Appendix H. Standard Deviation and 95% Confidence Intervals for 5° Yaw

Helmet	Helmet Position	5 Degree Drag (N)	5 Std Dev (N)	5 95% Confidence
A	1	0.066	0.111	0.081
	2	0.248	0.085	0.062
	3	1.218	0.098	0.071
B	1	-0.042	0.062	0.045
	2	0.098	0.089	0.065
	3	0.649	1.704	1.244
C	1	0.065	0.098	0.071
	2	0.190	0.107	0.078
	3	0.731	0.071	0.052
D	1	-0.121	0.080	0.058
	2	0.058	0.076	0.055
	3	0.641	0.116	0.084
E	1	0.267	0.089	0.065
	2	0.392	0.080	0.058
	3	1.241	0.107	0.078
F	1	-0.008	0.062	0.045
	2	0.125	0.085	0.062
	3	0.900	0.085	0.062
G	1	0.262	0.102	0.075
	2	0.581	0.076	0.055
	3	1.003	0.102	0.075
H	1	1.284	0.067	0.049
I	1	0.192	0.089	0.065
	2	0.544	0.093	0.068
	3	1.648	0.111	0.081
J	1	-0.002	0.085	0.062
	2	0.288	0.080	0.058
	3	1.464	0.125	0.091
K	1	0.130	0.089	0.065
	2	0.539	0.076	0.055
	3	1.652	0.080	0.058
L	1	-0.138	0.093	0.068
	2	0.290	0.085	0.062
	3	1.237	0.102	0.075
M	1	-0.152	0.076	0.055
	2	0.109	0.089	0.065
	3	1.558	0.116	0.084
N	1	-0.137	0.098	0.071
	2	0.123	0.102	0.075
	3	1.627	0.085	0.062

Appendix I. Standard Deviation and 95% Confidence Intervals for 10° Yaw

Helmet	Helmet Position	10 Degree Drag (N)	10 Std Dev (N)	10 95% Confidence
A	1	0.030	0.067	0.049
	2	0.140	0.093	0.068
	3	1.125	0.107	0.078
B	1	0.002	0.080	0.058
	2	0.001	0.080	0.058
	3	0.257	0.076	0.055
C	1	0.064	0.067	0.049
	2	0.153	0.085	0.062
	3	0.654	0.067	0.049
D	1	0.174	0.067	0.049
	2	0.186	0.076	0.055
	3	0.588	0.089	0.065
E	1	0.244	0.071	0.052
	2	0.426	0.076	0.055
	3	1.134	0.076	0.055
F	1	0.059	0.071	0.052
	2	0.090	0.067	0.049
	3	0.473	0.076	0.055
G	1	0.383	0.067	0.049
	2	0.623	0.085	0.062
	3	1.015	0.089	0.065
H	1	1.422	0.080	0.058
I	1	0.338	0.067	0.049
	2	0.421	0.058	0.042
	3	1.663	0.085	0.062
J	1	0.230	0.076	0.055
	2	0.578	0.080	0.058
	3	1.950	0.116	0.084
K	1	0.026	0.080	0.058
	2	0.368	0.098	0.071
	3	1.436	0.102	0.075
L	1	0.264	0.062	0.045
	2	0.017	0.067	0.049
	3	1.061	0.093	0.068
M	1	0.059	0.053	0.039
	2	0.117	0.071	0.052
	3	1.718	0.093	0.068
N	1	0.194	0.067	0.049
	2	0.174	0.071	0.052
	3	1.633	0.089	0.065

Appendix J. Standard Deviation and 95% Confidence Intervals for 15° Yaw

Helmet	Helmet Position	15 Degree Drag (N)	15 Std Dev (N)	15 95% Confidence
A	1	0.040	0.076	0.055
	2	0.093	0.062	0.045
	3	1.269	0.258	0.188
B	1	0.006	0.049	0.036
	2	0.066	0.062	0.045
	3	0.423	0.058	0.042
C	1	0.111	0.071	0.052
	2	0.267	0.062	0.045
	3	0.451	0.071	0.052
D	1	0.208	0.058	0.042
	2	0.203	0.062	0.045
	3	0.538	0.089	0.065
E	1	0.329	0.049	0.036
	2	0.245	0.071	0.052
	3	1.002	0.071	0.052
F	1	0.166	0.058	0.042
	2	0.020	0.076	0.055
	3	0.482	0.080	0.058
G	1	0.246	0.076	0.055
	2	0.317	0.076	0.055
	3	1.041	0.076	0.055
H	1	1.097	0.071	0.052
	2	0.274	0.062	0.045
	3	1.785	0.085	0.062
I	1	0.416	0.085	0.062
	2	0.069	0.053	0.039
	3	1.232	0.062	0.045
J	1	0.069	0.053	0.039
	2	0.171	0.076	0.055
	3	1.232	0.062	0.045
K	1	0.092	0.058	0.042
	2	0.118	0.053	0.039
	3	1.631	0.071	0.052
L	1	0.113	0.067	0.049
	2	0.018	0.067	0.049
	3	1.237	0.085	0.062
M	1	0.080	0.044	0.032
	2	0.070	0.067	0.049
	3	1.588	0.053	0.039
N	1	0.314	0.071	0.052
	2	0.038	0.085	0.062
	3	1.423	0.076	0.055