Aerodynamics of Time Trial versus Road Configurations (Transition vs. Tarmac SL2)
Studies conducted July 29-30, 2008
Report prepared by Mark Cote, Specialized Bicycle Components

Technical Summary

Aerodynamics tests were conducted July 29-30, 2008, comparing the aerodynamic performance of two different configurations of equipment and rider positioning representing a road racing scenario and a time trial scenario.

Road Configuration

- **Bike** - Specialized Tarmac SL2 with HED Bastogne wheels, 23 mm clincher tires, Shimano Dura-Ace SRM crankset, typical road componentry
- **Gear** - bib shorts, short-sleeve jersey, Specialized S-Works road helmet

Time Trial Configuration

- **Bike** - Specialized Transition with HED3 Deep Tri-Spoke wheels, 21mm clincher tires, Shimano Dura-Ace SRM crankset, HED aerobars, typical time trial componentry
- **Gear** - short-sleeve skinsuit, Specialized TT3 aerodynamic helmet

Testing Scenarios

The aerodynamic performance of each configuration was measured both in the A2 Wind Tunnel and on two closed loop tracks (Asheville, 0.5 km and Lowe's Motor Speedway, 2.3 km) in North Carolina by riding at fixed velocity while measuring rider power output (and vice-versa). Wind tunnel data was acquired for yaw angles between -25 and 25 degrees, and real world crosswind data was collected via an aerodynamic probe mounted to a control bicycle.

Findings

- Wind tunnel results showed a 33% reduction in aerodynamic drag at 40kph when compared to the road configuration (0 degree yaw)
- 1 km tests on the Asheville track at 40 kph showed total power output savings of 24.1%
- 16.1 km (10.0 mi) tests on Lowe's Motor Speedway at 40 kph showed total power output savings of 21.7%
- Riding at same power output, test rider was able to maintain speeds of about 4.1 kph (2.5 mph) faster, which amounted to a measured time difference of 1:58 over 16.1 km
- Repeated wind tunnel tests with the athlete yielded standard deviations equivalent to 0.75% of total power (n=3; 2.2 W of 291.1 W simulated power)
- Repeated 1km track power tests yielded standard deviations equivalent to 1.99% of total power (n=3; 5.8 W of 291.1 W)

Executive Summary for July 2008 North Carolina Aero Tests

Dates: July 29-30, 2008

Locations: Wind Tunnel Testing: A2 Wind Tunnel, Mooresville, North Carolina
Track Power Testing: Asheville, North Carolina
Road Power Testing: Lowe's Motor Speedway, South Concord, North Carolina

Sponsors: A2 Wind Tunnel, Specialized Bicycle Components, SRM, HED Cycling, North Carolina Time Trial Association (NCTTA)

Involved: Mike Giraud, A2 Wind Tunnel, Test Engineer and Test Rider
Dave Salazar, A2 Wind Tunnel, Test Engineer
Mark Cote, Specialized Bicycle Components, Test Engineer/Aerodynamicist
Nathan O'Neill, Test Rider
Steve Hed, HED Cycling, Advisor

Goals:

1. Determine the aerodynamic advantage available from an optimized rider position and aerodynamic equipment by comparing a mass-start road position and equipment to a time trial position and aerodynamic time trial equipment.
2. Evaluate the measurement precision of aerodynamic testing in a wind tunnel and on a closed-loop road.

Test Configurations:

Road
Specialized S-Works Tarmac SL2 (54cm)
Specialized S-Works Road Helmet
HED Bastogne Road Wheels
Specialized Mondo 23mm clincher, 115 psi
Shimano Dura-Ace SRM Crank
Rider in drop bars

Time Trial
Specialized S-Works Transition (M)
Specialized TT3 Helmet
HED3 Deep Tri-Spoke Wheels
Specialized Mondo 21mm clincher, 115 psi
Shimano Dura-Ace SRM Crank
Rider in aerobar

0 deg yaw aerodynamic test of road configuration at the A2 Wind Tunnel

0 deg yaw aerodynamic test of time trial configuration at the A2 Wind Tunnel

Test Configuration	Test Length	Crosswind (Yaw)	Coefficient of Drag	What It Tells Us
Road	2 x 20 sec samples averaged	-25 to 25 degrees, 5 deg increments	being measured	**Baseline aerodynamic drag**
Time Trial	2 x 20 sec samples averaged	-25 to 25 degrees, 5 deg increments	being measured	**Aerodynamic drag % saved over the road configuration**

Why do these tests? To collect aerodynamic data for both test configurations in multiple crosswind scenarios in a controlled environment.

Specifics: Wind set at 48.3 kph (30 mph); wheels spinning at 48.3 kph (30 mph); rider pedaling against nominal load; control bike instrumented with an aerodynamic probe to measure real-world wind speed, with direction calibrated in the wind tunnel.

What's going on in the picture: Control rider, Mike Giraud (A2), holds his position in the wind tunnel during calibration of the aerodynamic probe

Track Power Testing **500m Track, Asheville, NC**

Test Configuration	Test Length	Average Velocity	Average Power	What It Tells Us
Road	3 x 1 km	Goal: 40 kph	being measured	**Baseline power at 40 kph**
Time Trial	3 x 1 km	Goal: 40 kph	being measured	**Power saved at 40 kph over the road configuration**
Time Trial	3 x 1 km	being measured	Goal: Same as road configuration at 40 kph*	**Time saved over the road configuration at constant power**

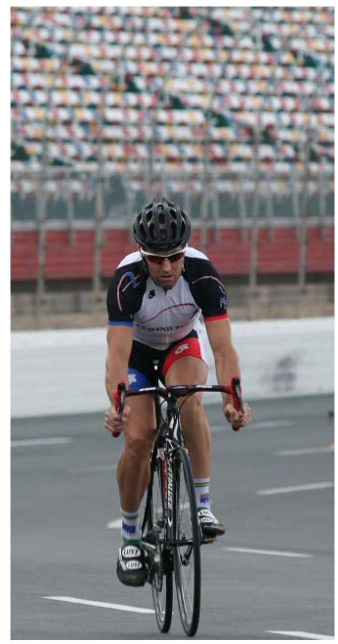
Why do these tests? To collect power and speed data for both test configurations with several test repeats.

Specifics: Control rider riding at 35 kph constant velocity during all tests; control bike instrumented with aerodynamic sensors to monitor wind speed and direction during all tests; monitoring of weather conditions every minute; 1 km tests were 2 laps long, intervals run from a flying start.

What's going on in the picture: Test rider, Nathan O'Neill, rides by at speed on one of his 1 km time trial configuration tests.

Road Power Testing **Lowe's Motor Speedway, South Concord, NC**

Test Configuration	Test Length	Average Velocity	Average Power	What It Tells Us
Road	1 x 16.1 km (10.0 mi)	Goal: 40 kph	being measured	**Baseline power at 40 kph**
Time Trial	1 x 16.1 km (10.0 mi)	Goal: 40 kph	being measured	**Power saved at 40 kph over the road configuration**
Time Trial	1 x 16.1 km (10.0 mi)	being measured	Goal: Same as road configuration at 40 kph*	**Time saved over the road configuration at constant power**



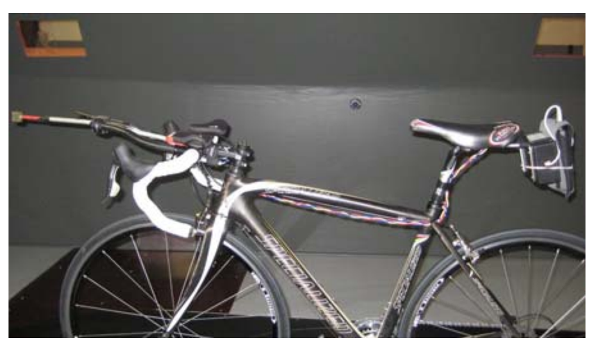
Why do these tests? To collect power and speed data for both test configurations over 10 mile time trials.

Specifics: Control rider riding at 31.5 kph constant velocity during all tests; control bike instrumented with aerodynamic sensors to monitor wind speed and direction during all tests; monitoring local weather conditions every minute; 16.1 km (10.0 mi) tests were 7 laps long, intervals run from a flying start; time splits were via race radio at each lap.

What's going on in the picture: Nathan rolls through on one of his seven road configuration laps at Lowe's Motor Speedway.

*For the third track and road test, data from the wind tunnel and first two power tests were used to calculate a desired average velocity that would require the same power as the road configuration. It was much easier for the test rider to maintain an average velocity than an average power, since even subtle variations in road gradient and wind affected the power output required to hold a fixed speed.

Wind Speed and Direction Measurement



During all on-road tests, a control rider rode an instrumented Specialized Tarmac SL2 at a fixed velocity. The bike was instrumented with an SRM power meter and an aerodynamic probe and data acquisition system capable of measuring relative wind speed and direction.

This data was used to evaluate the relative yaw angles experienced by the test rider during each interval.

Test Results:
Performance Measurements

Aerodynamic Drag in the Wind Tunnel
Figure 1 shows drag force (in grams) normalized to 40 kph for the road and time trial configurations. Figure 2 shows the percentage of aerodynamic drag saved between the road and time trial configurations.

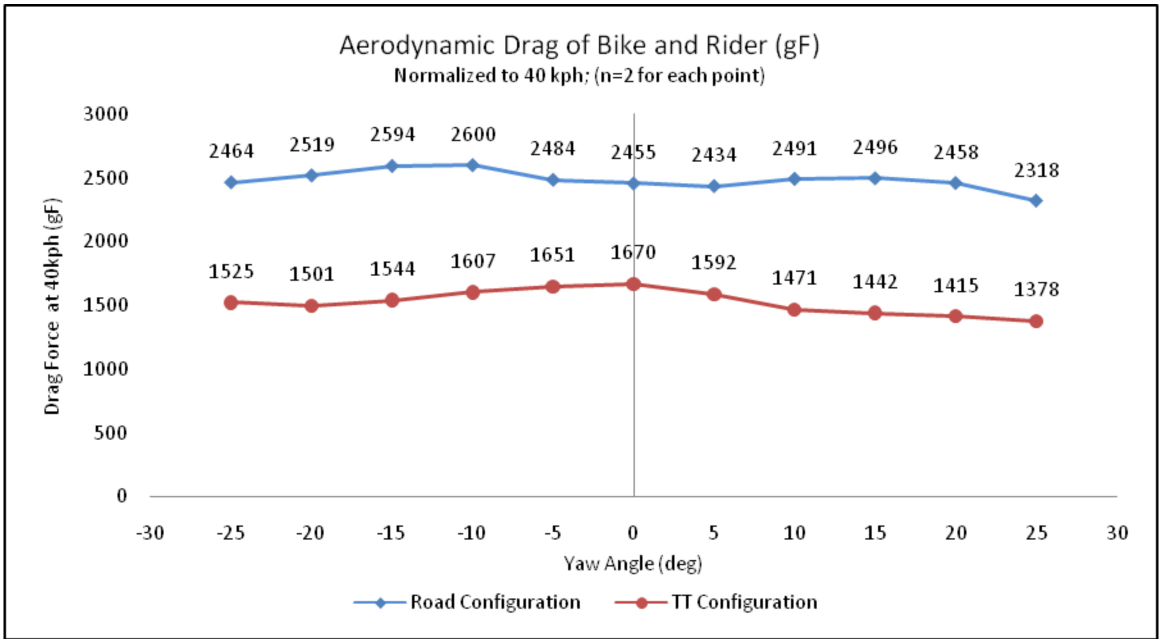


Figure 1: Aerodynamic drag of bike and rider in grams of force (gF), normalized to 40 kph

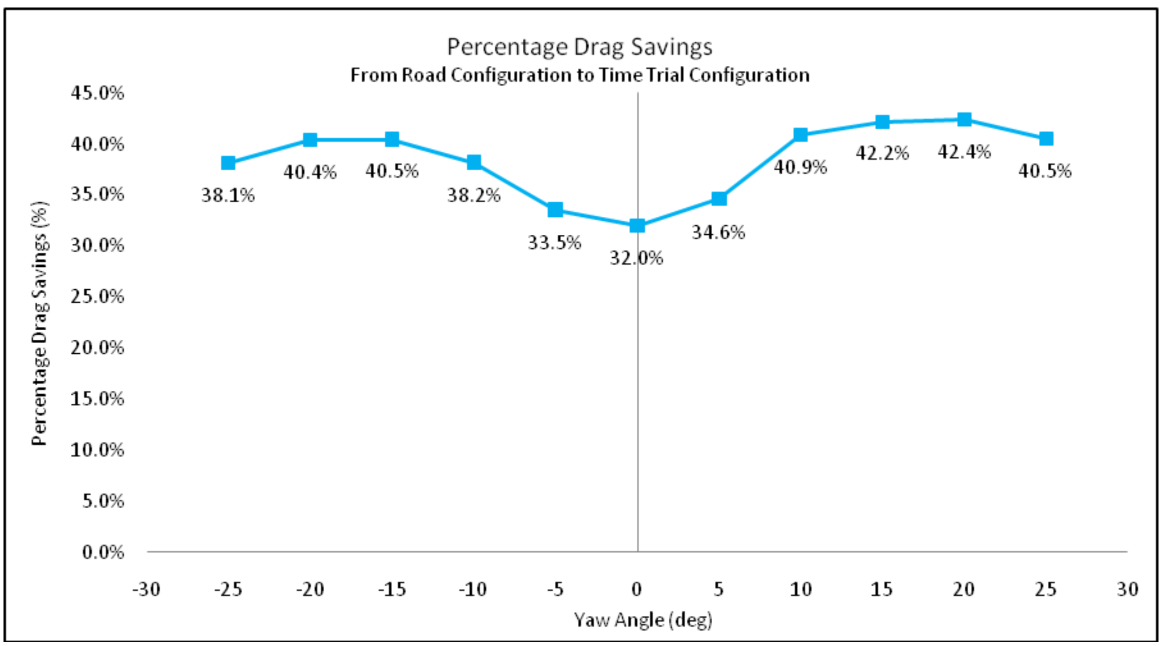


Figure 2: Percentage drag savings from road to time trial configurations

Power and Bike Velocity on the Track/Road

Tables 1 and 2 summarize the results of the track and road power tests. 24.1% and 21.7% total power savings were measured with the time trial configuration over the road configuration at 40 kph, respectively. Holding power roughly constant, the test rider was able to ride 4.7 kph and 4.1 kph faster in the time trial configuration.

Table 1: Track Power Testing **500m Track, Asheville, NC**

Test Configuration	Test Length	Average Velocity (kph)	Average Power (W)	Std Dev Power (n=3) (W)	What It Tells Us
Road	3 x 1 km	40.07	291.1	5.8	**Baseline power at 40 kph**
Time Trial	3 x 1 km	39.92	220.8	4.2	**At the same speed, the time trial configuration saved 24.1% total power output**
Time Trial	3 x 1 km	44.76	296.1	3.8	**At the same power, the time trial configuration was 4.7 kph faster**

Table 2: Road Power Testing **Lowe's Motor Speedway, South Concord, NC**

Test Configuration	Test Length	Average Velocity (kph)	Average Power (W)	10 mile TT Time	What It Tells Us
Road**	1 x 16.1 km (10.0 mi)	40.09	279.1	**24:01.5**	**Baseline power at 40 kph**
Time Trial	1 x 16.1 km (10.0 mi)	40.06	218.5	**24:04.3**	**At the same speed, the time trial configuration saved 21.7% total power output**
Time Trial	1 x 16.1 km (10.0 mi)	44.18	280.4	**22:03.8**	**At the same power, the time trial configuration was 4.1 kph faster; over 10 miles this was 1 minute, 57.7 seconds faster**

**With the exception of this interval, all tests conducted during the two days of power testing saw very little ambient wind speed or temperature variation. The Asheville tests were completed during the middle of the day on July 29 with ambient temperatures holding steady at 31° Celsius (88° Fahrenheit). The Lowe's Motor Speedway tests were completed in the evening on July 30 with temperatures dropping throughout the night. Average temperatures of 38° C (101° F), 31° C (88° F), 30° C (87° F) were recorded for each time trial, respectively, settling out to the same temperatures experienced in Asheville. Thus, the only major variation in ambient conditions was the higher temperature experienced during the first Lowe's time trial. For all on-road power tests where data is quoted (above), ambient wind conditions remained fairly calm.

Aerodynamic Control Measurements

Relative Wind Speed

Figure 3 shows plotted wind speed from the A2 Wind Tunnel over a 10 minute period. The tunnel wind speed was set to 48.3 kph (30 mph) and held that wind speed consistently. Figure 4 shows the relative wind and bike speed for the control rider during the first interval at Lowe's Motor Speedway. Since the control rider was traveling slower than the test rider, he only completed 6 laps (as opposed to 7 for the test rider) per interval. As shown by the hills and valleys on the graph, the rider experienced a headwind on one side of the track and a tailwind on the other side. Both figures show data measured with the aerodynamic probe with the control rider pedaling at power on the instrumented test bike.

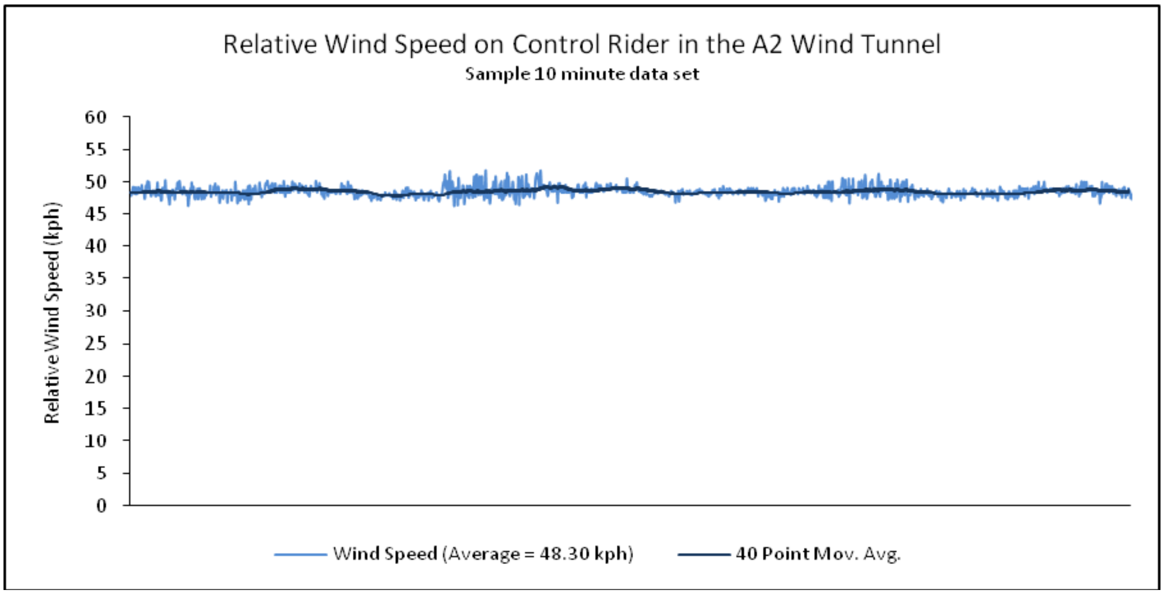


Figure 3: Relative wind speed in the wind tunnel, set to 48.3 kph (30 mph)

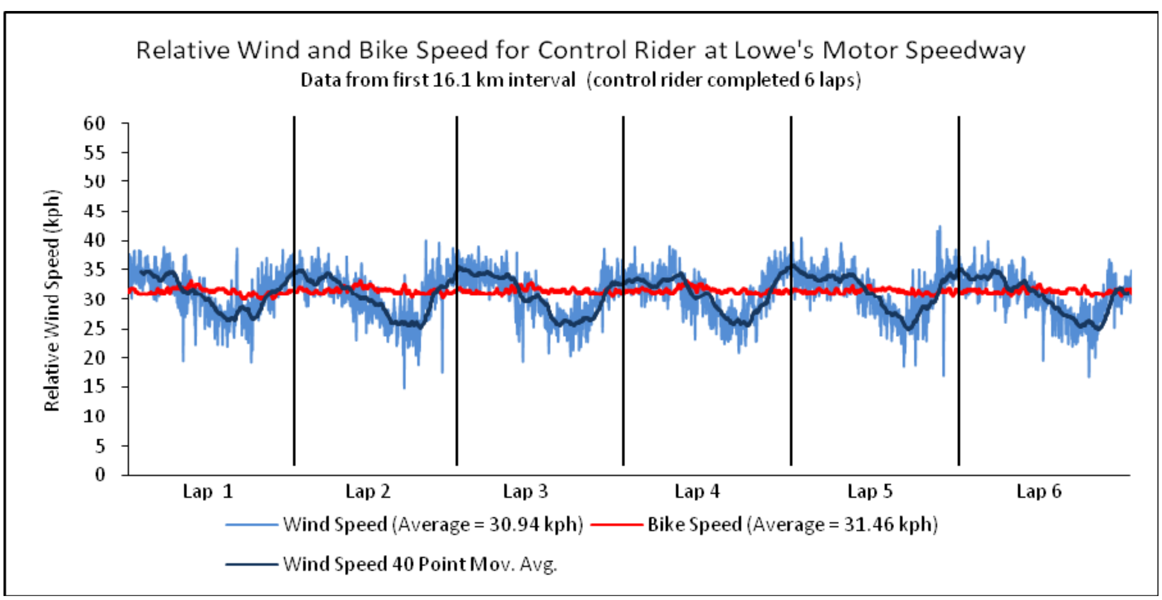


Figure 4: Relative wind and bike speed for the control rider at Lowe's Motor Speedway

Relative Wind Direction (Yaw Angle)

The aerodynamic probe mounted on the control rider's bike collected relative crosswind angle (yaw) data that is rarely available for testing of this type. Figure 5 shows results of the probe in the wind tunnel, with each step representing roughly 15 seconds at yaw angles from -25 (driveside) to 25 degrees (non-driveside) at 5 degree increments. Figure 6 offers crosswind angle data from the same Lowe's test shown in Figure 4. It is clearly shown that the control rider experienced a +/- 7 degree range of yaw centered around 0 degrees. Since the control rider was riding slower than the test rider (31.5 kph versus 40 kph, respectively), it can be deducted that the test rider saw the same or tighter range of crosswinds (the vector math alluded to here is not discussed in this paper). Thus, it is fair to assume that the test rider spent most of his time in roughly a +/- 5 degree yaw range. Both figures show data measured with the aerodynamic probe, with the control rider pedaling at power on the instrumented test bike.

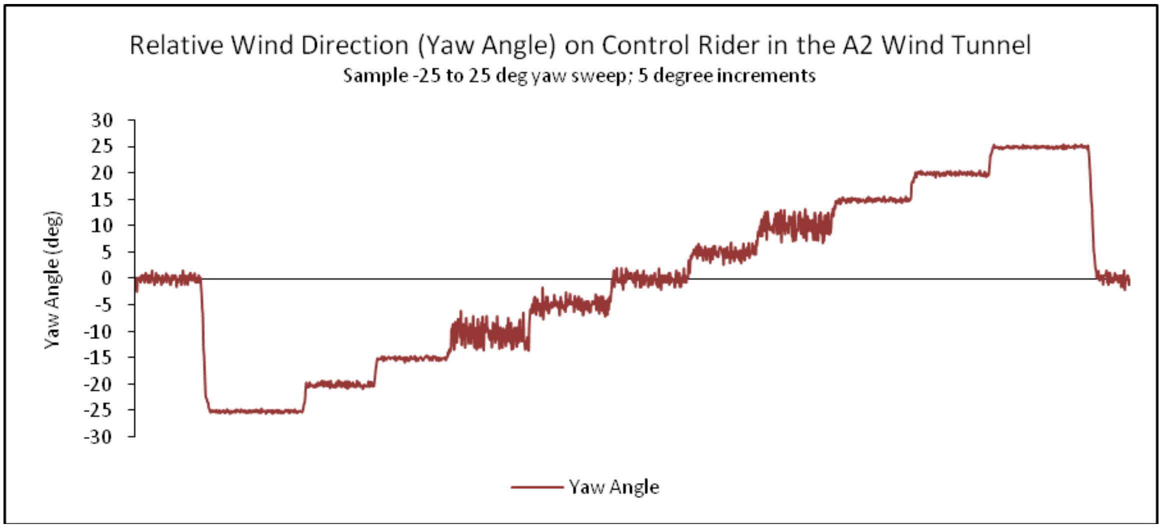


Figure 5: Yaw angles measured with the aerodynamic probe in the wind tunnel; each yaw step represents a 15 second data set

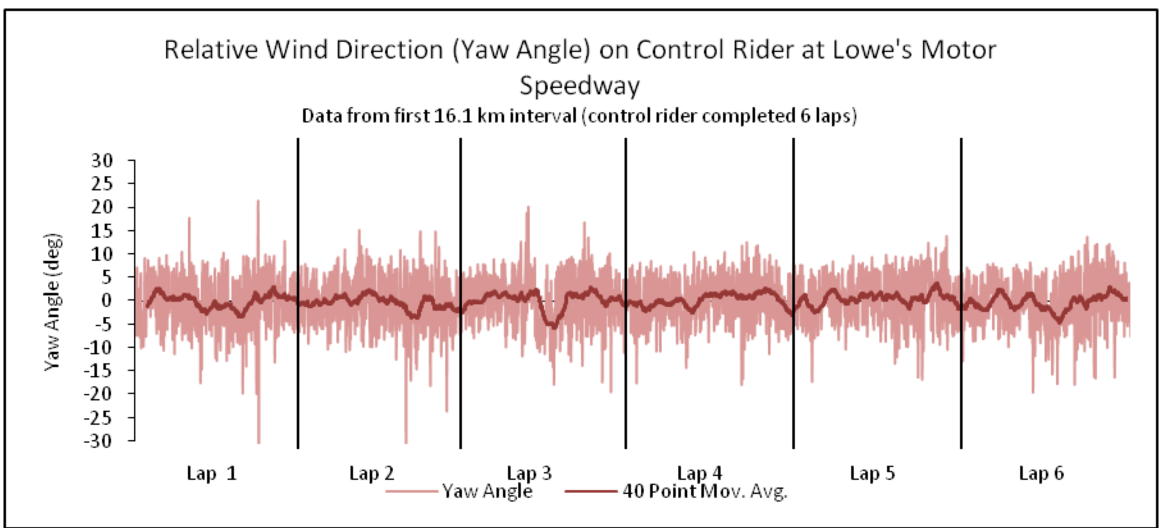


Figure 6: Relative yaw angle experienced by the control rider during the first test interval at Lowe's Motor Speedway

Discussion:

Performance Measurements

In all of the tests conducted, the performance benefits of the time trial configuration were substantial. Though this test represented two drastically different configurations, the results still point to the undeniable fact that aerodynamic drag plays a huge role in a rider's performance. The track and road tests analyzed two specific cases—the required power output to maintain a fixed speed and the speed increase (or time saved) given a fixed power output.

Aerodynamic Efficiency: Power to Maintain a Constant Speed

Aerodynamic efficiency during these tests can be thought of as the amount of power output required to ride at a constant speed. The lower the required power, the more aerodynamically efficient the rider is. There are several times in every type of bike race when an athlete would like to go the same speed with less effort. It is often the most efficient racers during the first half of a race that are the athletes to look for coming across the finish first. Additionally, triathletes who conserve energy on the bike are often stronger on the run.

Table 3 summarizes the results of rider efficiency during the track and road tests.

Table 3: Aerodynamic Efficiency Results

Test	Average Velocity (kph)	Average Power (W)	Energy Expended (kJ)	Average Heart Rate (bpm)
1 km Road Config (Avg. of 3)	40.07	291.1	26.0	145.0
1 km Time Trial Config (Avg. of 3)	39.92	220.8	20.1	140.6
1 km Difference	**0.15 kph (0.3%)**	**70.3 W (24.1%)**	**5.9 kJ (22.7%)**	**4.4 bpm (3.0%)**
16.1 km Road	40.09	279.1	402.4	150.0
16.1 km Time Trial	40.06	218.5	318.8	141.3
16.1 km (10 mi) Difference	**0.03 kph (0.1%)**	**60.6 W (21.7%)**	**83.6 kJ (20.8%)**	**8.7 bpm (5.8%)**

The test rider held a very consistent speed for all tests and saw dramatic decreases (21-24%) in required power in the time trial configuration. Over a 16.1 km (10 mi) time trial, 83.6 kJ were saved (20 Calories in nutritional terms). Over an Iron-distance triathlon (180 km, 112 mi), about 230 fewer calories would need to be consumed. While the test rider saw 20-22% total effort savings, his heart rate was marginally lower as well.

These tests monitored aerodynamic efficiency and not physiological efficiency. Power output was measured at the cranks, and velocity was measured relative to the road. The only human factors collected during these tests were heart rate and power output. There were no parameters which told how hard the rider's body was working to produce a specific power.

Race Performance: Speed Maintained at a Constant Power

Though efficiency is an important factor to examine while training and racing long distances, athletes working on their aerodynamics are often more interested in the “free speed” gained from the aerodynamic enhancements. Table 4 shows calculated times and time savings over various distances based upon the average speeds held at 280 watts average on Lowe’s Motor Speedway.

Table 4: Calculated Time Savings Between Configurations at 280 Watts Average Power Output (Based on Road Power Testing Average Velocities)

Configuration	Average Velocity (kph)	Average Velocity (mph)	1 km Time (1.6 mi)	16.1 km Time (10 mi)	40 km Time (Olympic)	90.1 km Time (Half Iron)	180.2 km Time (Ironman)
Road	40.09	24.92	1:30	24:05	59:52	2:14:51	4:29:42
Time Trial	44.18	27.46	1:21	21:51	54:19	2:02:22	4:04:44
Difference/ Time Savings	**4.09 kph (10.2%)**	**2.54 mph (10.2%)**	0:00:09	0:02:14	0:05:33	0:12:29	0:24:58

Looking at the test results from a velocity perspective, the athlete was able to ride 10.2% faster in the time trial configuration than the road configuration. On a flat course, this represents 9 seconds saved per kilometer. Over an Olympic distance triathlon, the time trial configuration would be 5 minutes and 33 seconds faster. In an Ironman distance race, the athlete would be nearly 25 minutes faster!

As this is based upon the Lowe’s Motor Speedway tests, where the athlete experienced very shallow crosswind angles, even greater time savings should be expected in situations where the athlete would experience wider crosswind angles. This is clear when looking at the wind tunnel data in Figure 2: -5 to 5 degrees of crosswind (as on the track) showed 33% aerodynamic improvement, whereas higher yaw angle ranges (10 to 20 degrees) show aerodynamic improvements up to 42%.

Aerodynamic Testing and Measurements

While wind tunnel and road power tests both resulted in similar outcomes, there are advantages and disadvantages to each form of testing.

Wind Tunnel Testing

Advantages

- Tight control on environmental variables (wind speed, direction)
- Ability to test at any relative crosswind
- Very time efficient
- Excellent measurement precision
- Able to isolate aerodynamic variables

Disadvantages

- Challenging to convince riders of actual real world improvements
- Fixing bike to measurement balance does not replicate steering and leaning

Track/Road Power Testing

Advantages

- Tests are conducted in near real-world race situations
- Riders generally are convinced of the results more than wind tunnel testing

Disadvantages

- Rider speed or power needs to be lower than a race situation to repeat tests without fatigue
- Poor measurement precision makes it challenging to measure many important aerodynamic factors
- Unable to control environmental variables (unless testing indoors)
- Unable to measure crosswind effects at high yaw angles
- Unable to entirely isolate aerodynamic variables

Even with a smooth pedaling, professional cyclist (Nathan O'Neill) test riding on very calm days, the measurement error on the track was significantly higher than in the wind tunnel. 1 km repeats of the road configuration at the Asheville track resulted in standard deviations of 1.99% of total power (n=3; 5.8 W of 291.1 W). Tests of the identical case in the wind tunnel yielded standard deviations equivalent to 0.75% of total power (n=3; 2.2 W of 291.1 W simulated total power). The precision of these measurements were good enough for this test, but the track test protocol would not be precise enough to measure the difference between many subtle position and equipment changes.

While track testing helped to validate the wind tunnel results, it also took much longer to conduct the test. Fortunately the conditions stayed constant during the several hours of ride intervals at the Asheville track and Lowe's Motor Speedway, but had the wind picked up, testing would have to be discontinued.

Thus, track power testing clearly validates wind tunnel results and reinforces the importance of aerodynamics on the test rider. But since power testing lacks measurement precision and takes a lot of time to execute properly, rider positioning and equipment testing should primarily be conducted in a good wind tunnel.

Conclusion:

Aerodynamics plays a huge role in cycling efficiency. Our time trial (aero) configuration showed an aerodynamic savings of 33% over the road configuration, meaning that roughly 70% of the test rider's power on the track went into overcoming aerodynamic resistance—a number generally agreed upon by bicycle scientists.

Based on wind tunnel data and estimated rolling resistance coefficients, Excel simulations of the track tests predicted total power savings of 25%, compared with 24.1% and 21.7% from the actual track tests. These numbers tell us that wind tunnel and real world testing can yield fairly comparable results, but there are still undeniable challenges with real world testing, including environmental variables.

Though our tests obviously determined that time trial positions are much more aerodynamic than road positions, future tests will focus on yielding more precise measurements by looking deeper into the individual effects of position changes and equipment changes, including helmets, frames, wheels, etc.