

Aerodynamic Summary and Development

Our goal with the i9 Road Disc series was to produce wheels with exceptionally low drag numbers, while minimizing side loads and keeping these loads consistent as wind angles increase. From the initial phases of development on the i9 Road Disc lineup we knew that aerodynamics was the ultimate key to the performance of our wheels when considering pure speed. On flat to rolling terrain up to 80% of a rider's energy is used to overcome wind resistance and wheels are the single largest contributor to aerodynamic drag other than the rider's body. The key to reducing this load is designing a rim profile that minimizes the turbulence and accompanying drag that the rim creates as it passes through the air. Deeper section rims are generally more efficient, as they allow the air to stay attached to the rim longer, reducing the amount of turbulence the rim creates.

Designing an aero rim that works well in low wind conditions is relatively easy. However, in reality riders regularly experience a variety of wind conditions, with wind angles often exceeding 10 degrees or more. While the average wind angles that are typically experienced on rides are typically under 10 degrees, the best aero rims perform well in a wide range of wind conditions. In fact, a well designed aero rim can actually start to produce "lift" as wind angles increase and in a similar manner to the sail on a sailboat - actually helping to propel the rider forward.

There is typically a trade off in handling that accompanies deeper section wheels. As wind angles increase, side loads on rim increase as well, which can affect the bikes handling and make many deep section wheels unstable or unsafe to ride in windy conditions.

To accomplish our aerodynamic goals we enlisted the help of Reynolds Cycling. Reynolds has extensive experience with developing aero products, including powerful computational tools, and in-house staff that specialize in aerodynamics. During the early phases of development with each of the new rims, multiple digital models were created and then run through advanced CFD (computational fluid dynamics) software in order to determine the fastest overall shapes. The advantage this offers is that multiple shapes can be tested in a short period of time vs. the time and cost associated with wind tunnel testing.

After reviewing multiple iterations of rim designs in the CFD software, we chose rim profiles that offer the best balance of drag and handling. From there it was time to move to validation in the field and in the wind tunnel.

Wind Tunnel Testing

While modern CFD is an excellent tool when it comes to developing aerodynamic profiles, the wind tunnel (and field testing) are the ultimate measure of a wheel. In order to evaluate how the wheels would perform in a range of wind conditions, we made a trip to the [A2 Wind Tunnel](#) in Mooresville, NC. The A2 Wind Tunnel is considered a low speed wind tunnel which makes it a perfect environment to test bicycle wheels (at a speed of 30mph, which has become the adopted industry standard).

We had several goals for our test session. We wanted to measure how all three of our wheels performed with multiple tire widths at a range of 0-20 degrees of yaw and how they compared to our high performance alloy rimmed wheel, the [AR25](#).

However, we also wanted to see how our wheels stacked up vs comparable products from a major competitor. We chose to also test two models from Zipp, which has long been considered the industry benchmark for aero wheels. We selected the latest tubeless ready versions of the Zipp 303 and 404 disc brake wheelsets. The 303 and 404 product lines closely match up to our i9.45 and i9.65 wheelsets in terms of depth and intended use.

Test Procedures and Protocol

In order to ensure a level playing field and consistent data, we made sure that all of the wheels were set up identically. All five wheelsets were tested with the same brake rotors installed - SRAM centerline 140mm rotors. We used two different width tires for the primary tests - Continental Grand Prix 4000S tires in 23 and 25mm versions. All 23mm tires were tested at 90 psi and all 25mm tires were tested at 80 psi. We tested the same respective 23mm and 25mm tire on each wheel since even small variations can occur from tire to tire.

Specific targets for the test session were:

- 1. How the i935, i945 and i965 compare to one another in terms of axial drag and side force.
- 2. What effect tire size has on the wheel's aero performance.
- 3. How does the i935, i945 and i965 compare to the benchmark Zipp 303 and 404 wheels in terms of axial drag and side force

To round out the test we also tested our AR25 wheelset, which features an aero profile as well, in order to determine the aerodynamic benefit our new carbon wheels product can provide vs. a high performance alloy rimmed wheelset.

Test Results

Wheel Drag Performance

In order to illustrate the results in a meaningful format, we are providing the wheel drag in watts, which is the common measure of a cyclist's power output. This is commonly known as axial drag as it is measuring the force created by air resistance that is transferred through the axle to the rest of the bike. For reference a relatively fit 160lb rider can average around 250 watts for an hour effort. An elite cyclist of the same weight could average 350 watts or more for the same duration. In real world terms each watt of drag that is saved represents a time savings of 4-7 seconds per hour. While we conducted our testing with front wheels only as they are the biggest contributor to drag on a bike, the time savings our i9 Road Disc series offers become even greater once the rear wheel is factored in.

In summary, all three of our wheels exceeded our expectations in the wind tunnel testing offering exceptionally low drag while maintaining consistent, low side forces. Here are the results of our testing for our road disc line up in terms of drag:

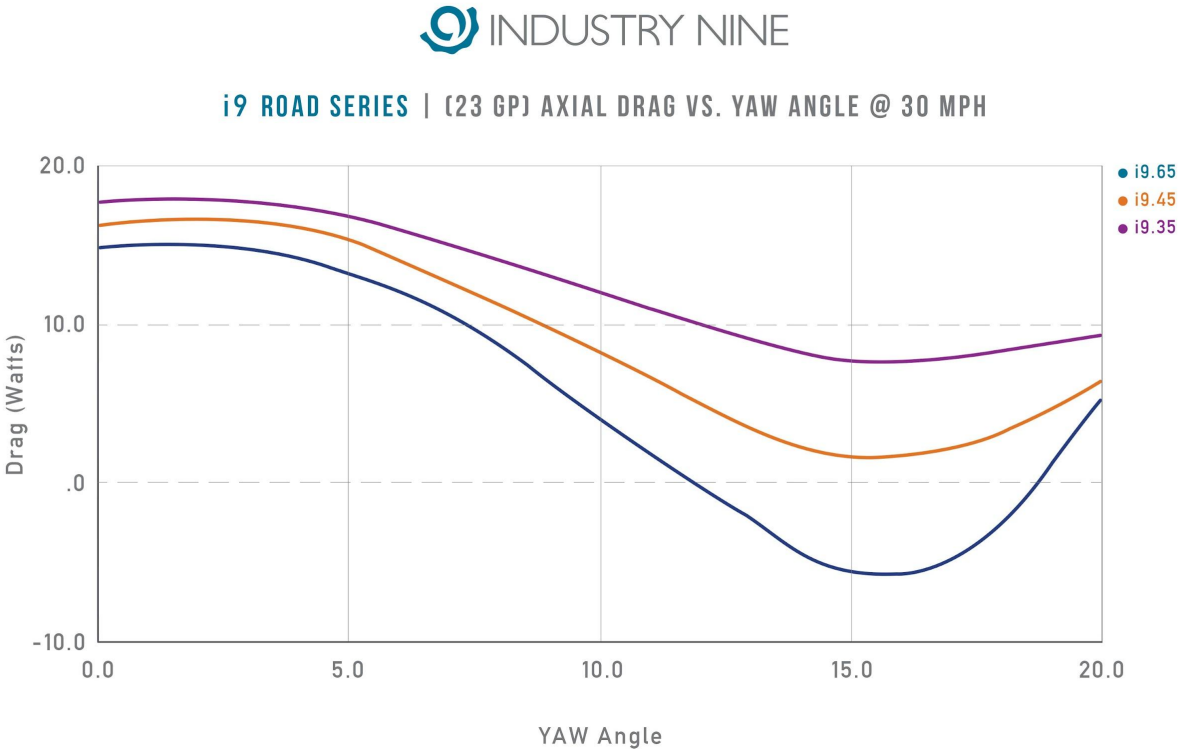


Figure 1: Industry Nine Road Disc with Continental GP 4000 S 23mm (tires measured 27mm wide at 90 psi)

As you can see from the data all three wheelsets exhibit a reduction in drag as the yaw angle increases as they are actually producing lift. In the case of our i9.65 wheeset the total wheel drag actually drops below zero watts from 12-18 degrees of yaw - at those wind angles the wheelset is actually helping propel the rider forward.



i9 ROAD SERIES | (25 GP) AXIAL DRAG VS. YAW ANGLE @ 30 MPH

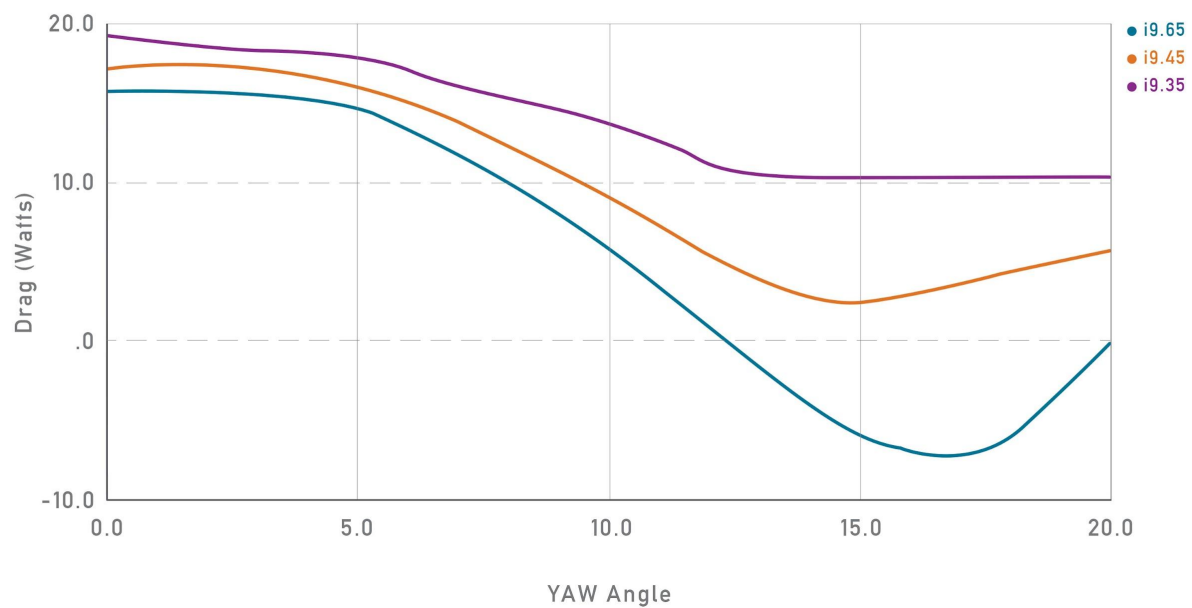


Figure 2: Industry Nine Road Disc with Continental GP 4000 S 25mm (tires measured 29mm wide at 80 psi)

When tested with the wider 25mm tires (which actually measured 29mm at the test pressure) you can see that there is almost no loss in efficiency.

Comparison VS. Zipp 303 and 404

When compared to the benchmark product from Zipp the testing demonstrated a significant advantage that a rider on the new i9 Road Disc wheels (of similar depth) would experience in a range of wind conditions.

Industry Nine i9.65 VS Zipp 404



i9.65 - ZIPP 404 | (23 GP) Axial Drag vs. YAW Angle @ 30 mph

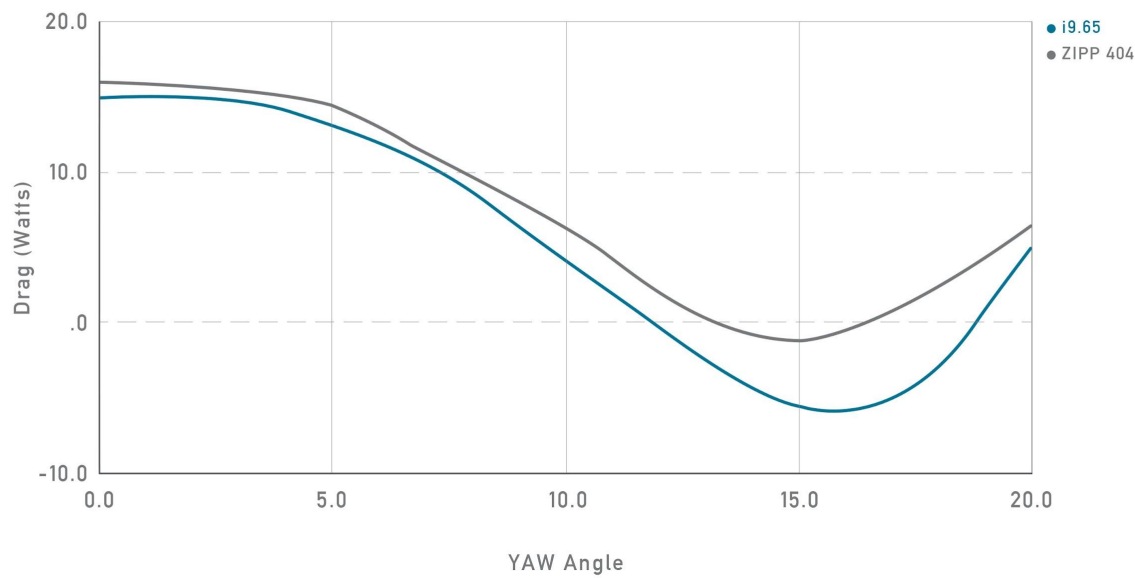


Figure 3: Tested with Continental GP 4000 S 23mm - at 80psi measures 27mm on i.65 and 25.5mm on Zipp 404 (due to narrower inner rim width)

i9.65 - ZIPP 404 | (25 GP) Axial Drag vs. YAW Angle @ 30 mph

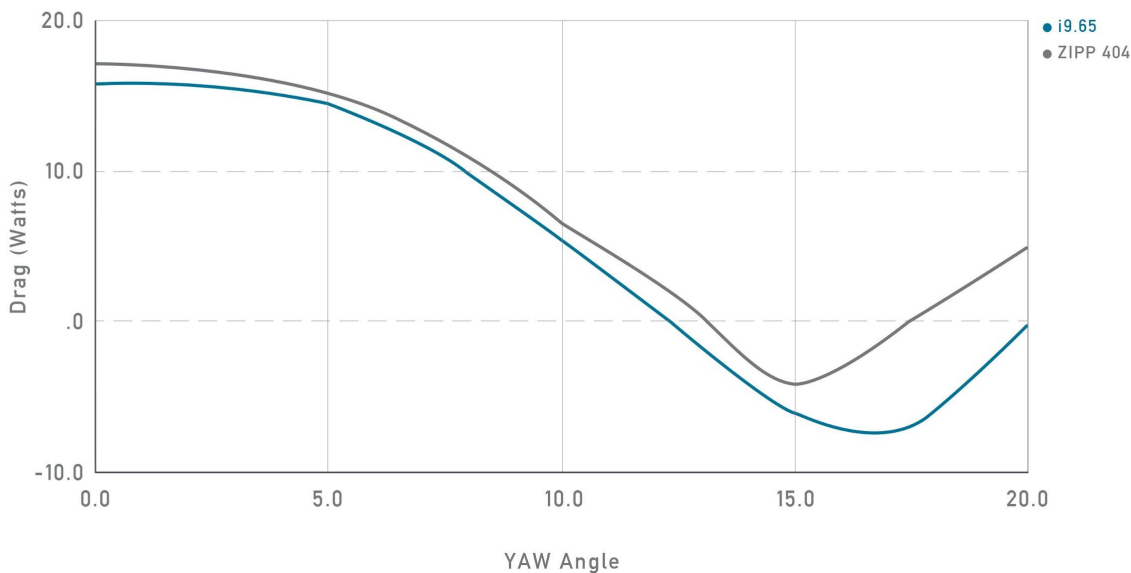


Figure 4: Tested with Continental GP 4000 S 25mm at 80psi - measures 29mm on i.65 and 27.5mm on Zipp 404 (due to narrower 19mm inner rim width)

When compared to the 404, the i9.65 was faster at all tested wind angles. Whether tested with the 23 or 25mm tires. Also of note the i9.65 exhibited a significantly later stall angle than the 404, which means that it maintains its aero performance even at high wind angles. Additionally at 1555 grams vs.1715 for the 404s the i9.65 offers a huge aero-to-weight ratio advantage as well.

Industry Nine i.45 VS. Zipp 303

i9.45 - ZIPP 303 | (23 GP) Axial Drag vs. YAW Angle @ 30 mph

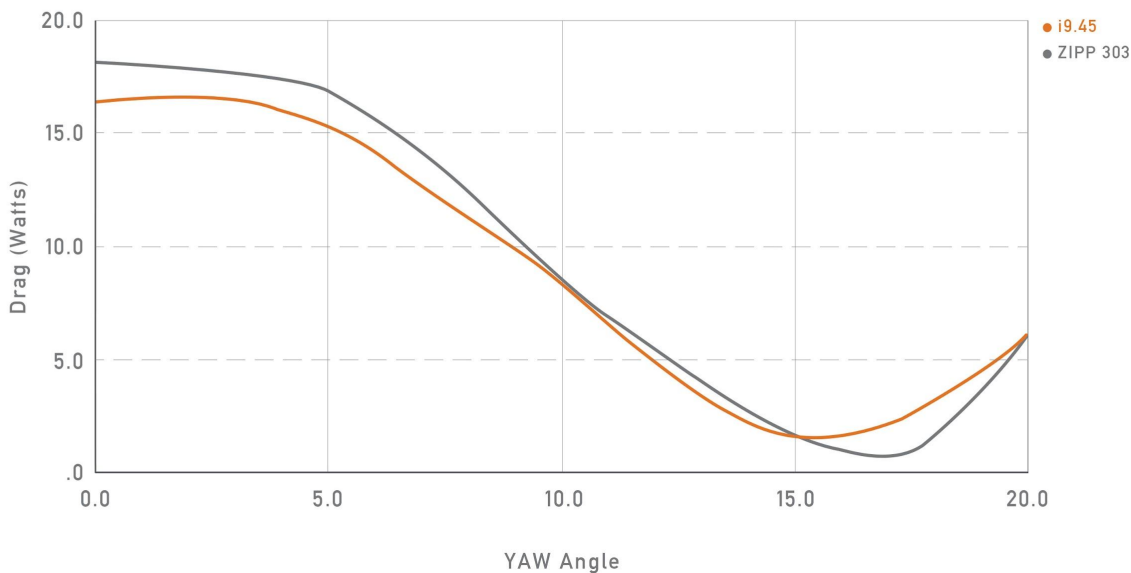


Figure 5: Tested with Continental GP 4000 S 23mm - at 90psi - tire measured 27mm on both wheels

i9.45 - ZIPP 303 | (25 GP) Axial Drag vs. YAW Angle @ 30 mph

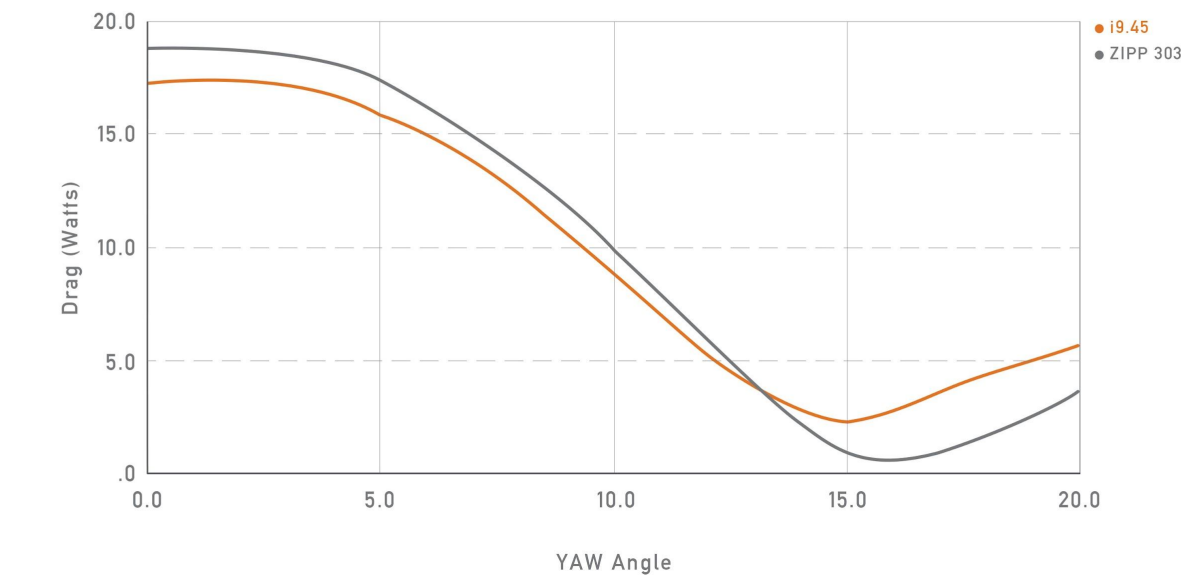


Figure 6: Tested with Continental GP 4000 S 25mm at 80psi - tires measured 29mm on both wheels

In reviewing the data from the comparison vs. the 303, the i9.45 yielded excellent results as well exceeding the performance of the Zipp wheel up to around 15 degrees of yaw. Keeping in mind that recent studies have shown average ride conditions see wind angles in the 0-10 degree range 80 percent of the time and under 15 degrees over 90 percent of the time, the i9.45 is significantly faster than the 303 in typical real world conditions.

ALL ROAD WHEELS | (25 GP) AXIAL DRAG VS. YAW ANGLE @ 30 MPH

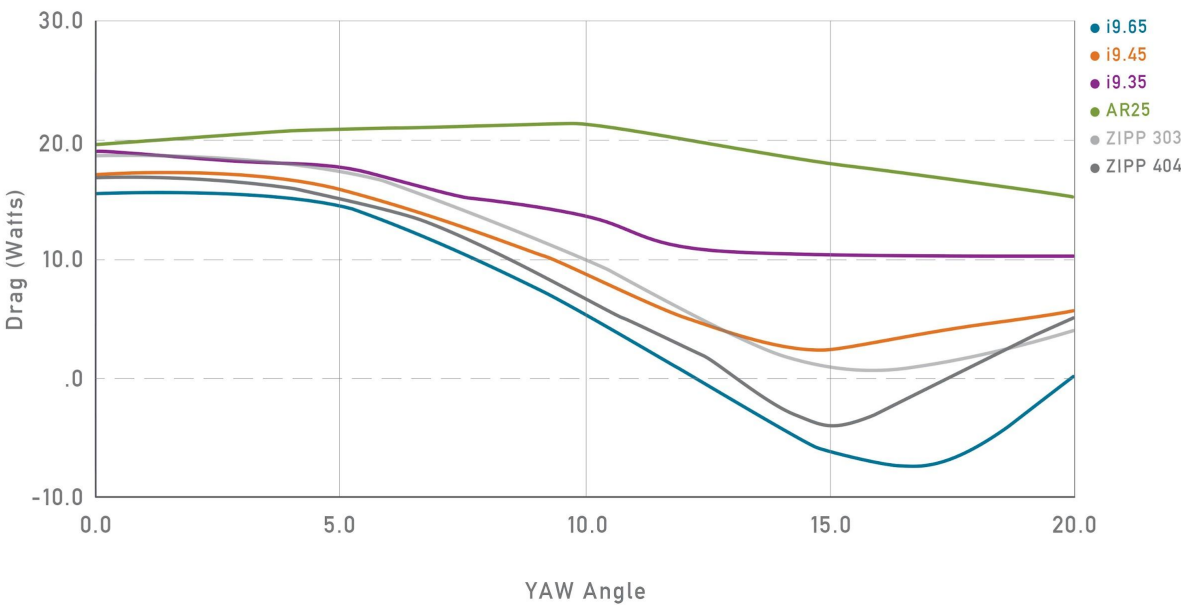


Figure 7: Industry Nine Road Disc full lineup VS. Zipp 303 and 404 Tested with Continental GP 4000 S 25mm at 80psi

When reviewing the full line up of wheels some significant trends are demonstrated. While the AR25 is reasonably competitive at zero degrees of yaw, as expected, it quickly falls behind the deeper profile rims as crosswind angles increase. The i9.35 rim is very close in performance to the Zipp 303 up around 7.5 degrees of yaw where the deeper Zipp rim starts to pull away. The i9.45 demonstrates a significant advantage over the benchmark 303 wheelset over the most common wind angles and even holds its own against the deeper 404 at shallower wind angles. When it comes to the i9.65 it has a clear advantage over the other wheelsets at all wind angles.

Wheel side-force comparison

When it comes to side force there are two critical factors that determine a wheel's performance. The first is the instantaneous side force loads that the wind exhibits on a wheel. The higher the load the more of a force the rider will feel pushing against wheel and the more effort that will be required to keep the bike steering in the intended direction. However, of equal importance, is the side force curve. Even if a wheel has higher side loads as long as the force curve is consistent and predictable, it is relatively easy to compensate with rider input as the wind angle increases. However, wheels that exhibit abrupt changes in side force loads as the wind angle increases are going to be harder to control as the steering input required can vary significantly even with small changes in wind angle.

Here are the results of our testing for our road disc line up in terms of drag:

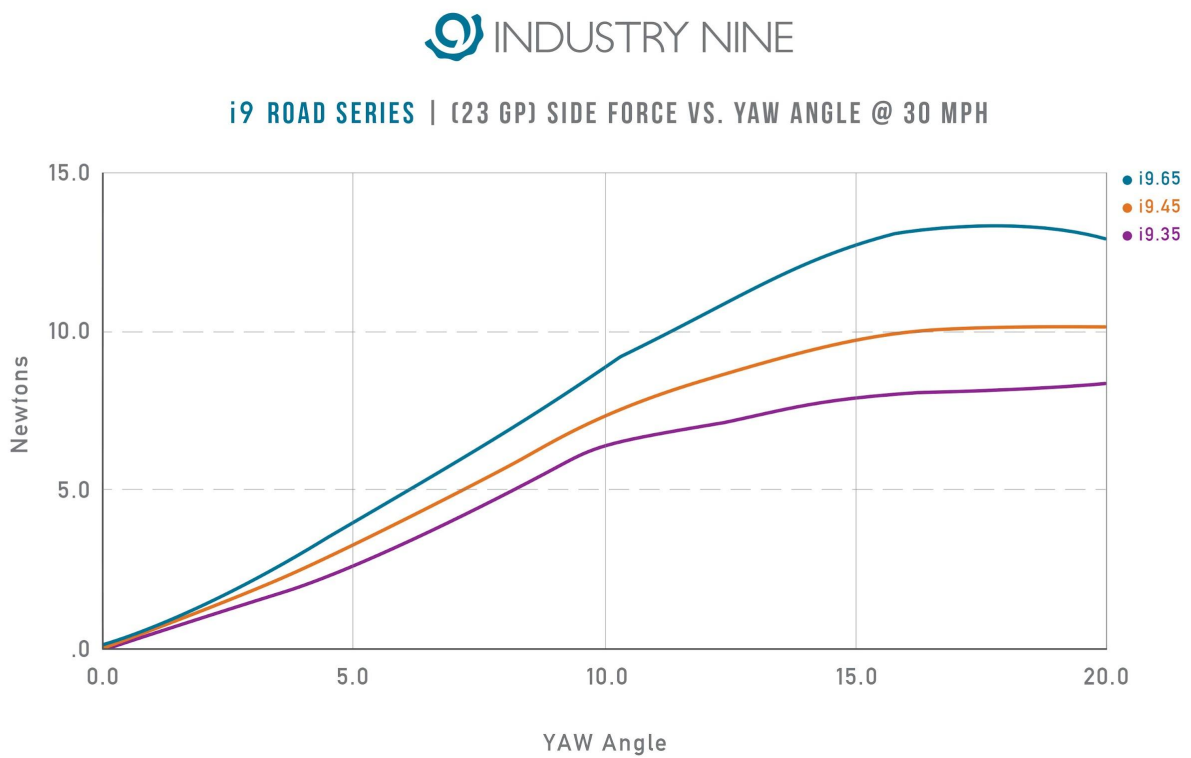


Figure 8: Industry Nine Road Disc with Continental GP 4000 S 23mm - measured 27mm wide at 90 psi

When reviewing the data, as anticipated the deeper section i9.45 and i9.65 exhibit higher side forces than the shallower i9.35. However of note, all of the wheels exhibit predictable behavior with a steady increase in side loads throughout most of the range of wind speeds.

Industry Nine i.45 VS. Zipp 303

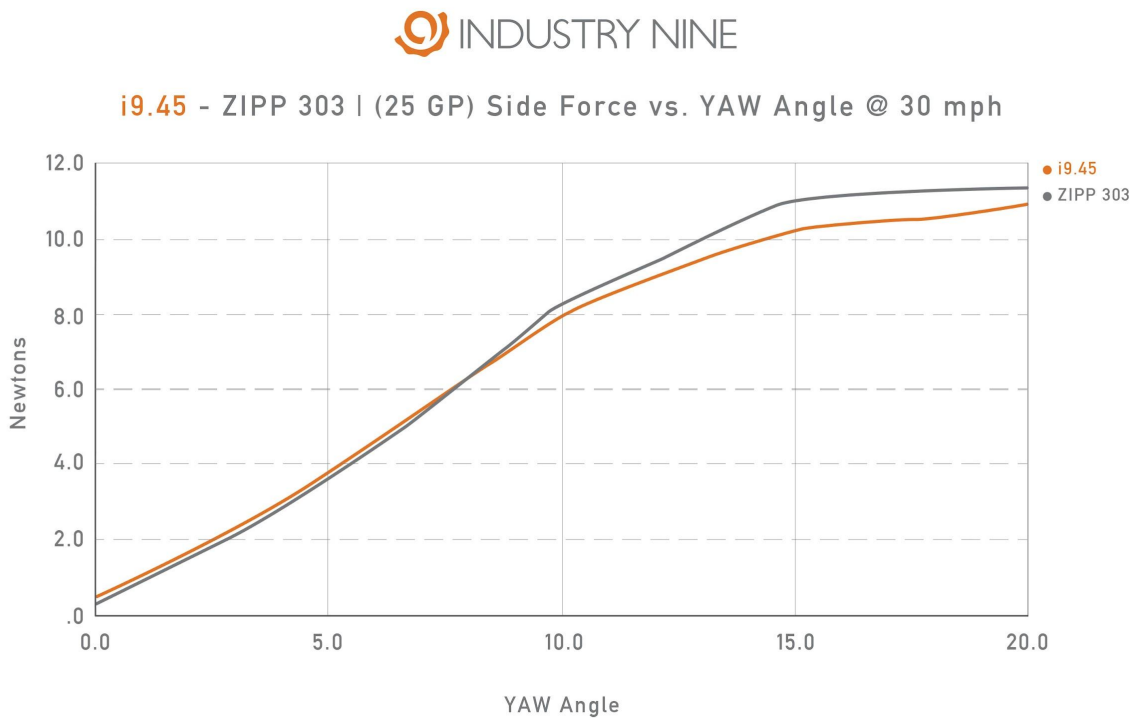


Figure 9: Tested with Continental GP 4000 S 25mm - at 80psi tire measured 29mm on both wheels

When compared to the Zipp 303, the I9.45 matches the 303 up to 8 degrees but yields lower side loads at higher wind angles. In this case the both rims exhibit a consistent side load curve, which is not surprising as that was a major focus of Zipp's design with the 303 Firecrest profile.

Industry Nine i.65 VS Zipp 404

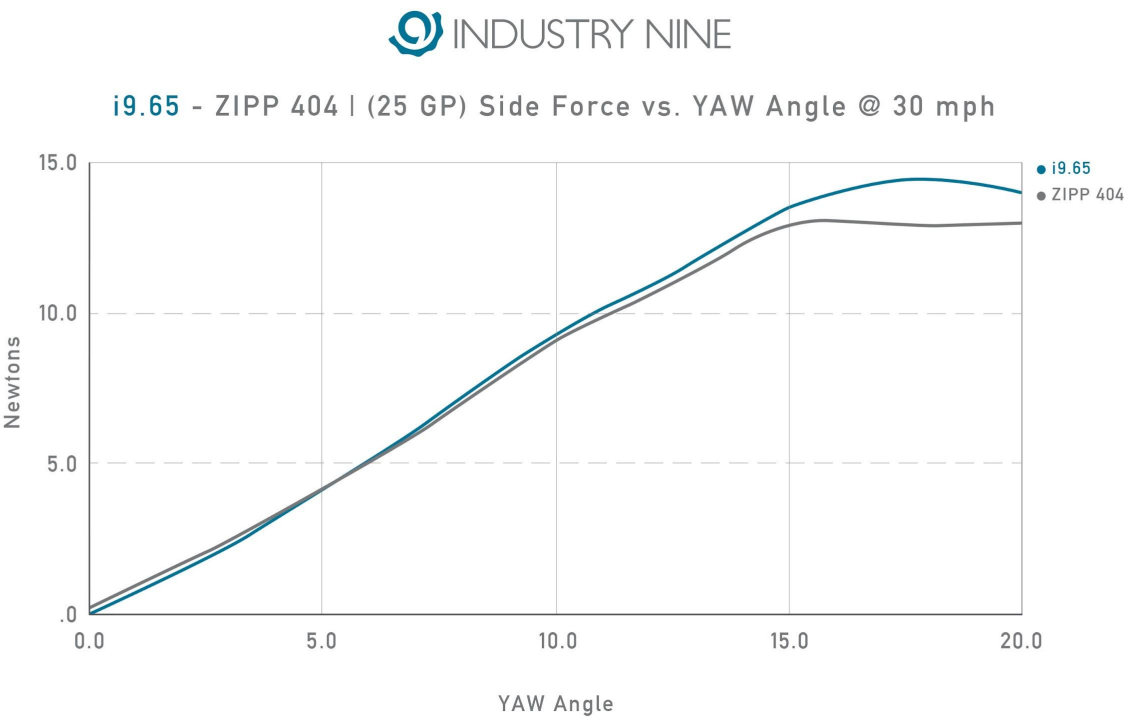


Figure 10: Tested with Continental GP 4000 S 25mm - at 80psi measures 29mm on i.65 and 27.5mm on Zipp 404 (due to narrower inner rim width)

When tested against the 404 the i9.65 offers nearly identical side load figures up to 15 degrees which is impressive considering the fact that the i9.65 is 7mm deeper than the Zipp rim. The Zipp rim does have lower side loads past 15 degrees as a result of its lower profile and due to the fact that it has stalled at 15 degrees (see figure 4 for reference). However, when comparing the side load curves we noted that while the i9.65 provides a steady curve from 0-20 degrees of yaw, the 404 makes a fairly abrupt shift in its side load curve at 15 degrees which may yield less consistent handling in gusty wind conditions.

Conclusion:

In summation, our i9 Road Disc series accomplished our goals. They offer world class aerodynamics and exceptional stability. We are confident that they are some of the fastest wheels on the planet. While there are a lot of strong contenders in the aero field, if you are riding a disc brake equipped road bike, choosing an i9 Road Disc wheelset will make you a faster rider, while offering an unmatched ride quality and class leading weights.