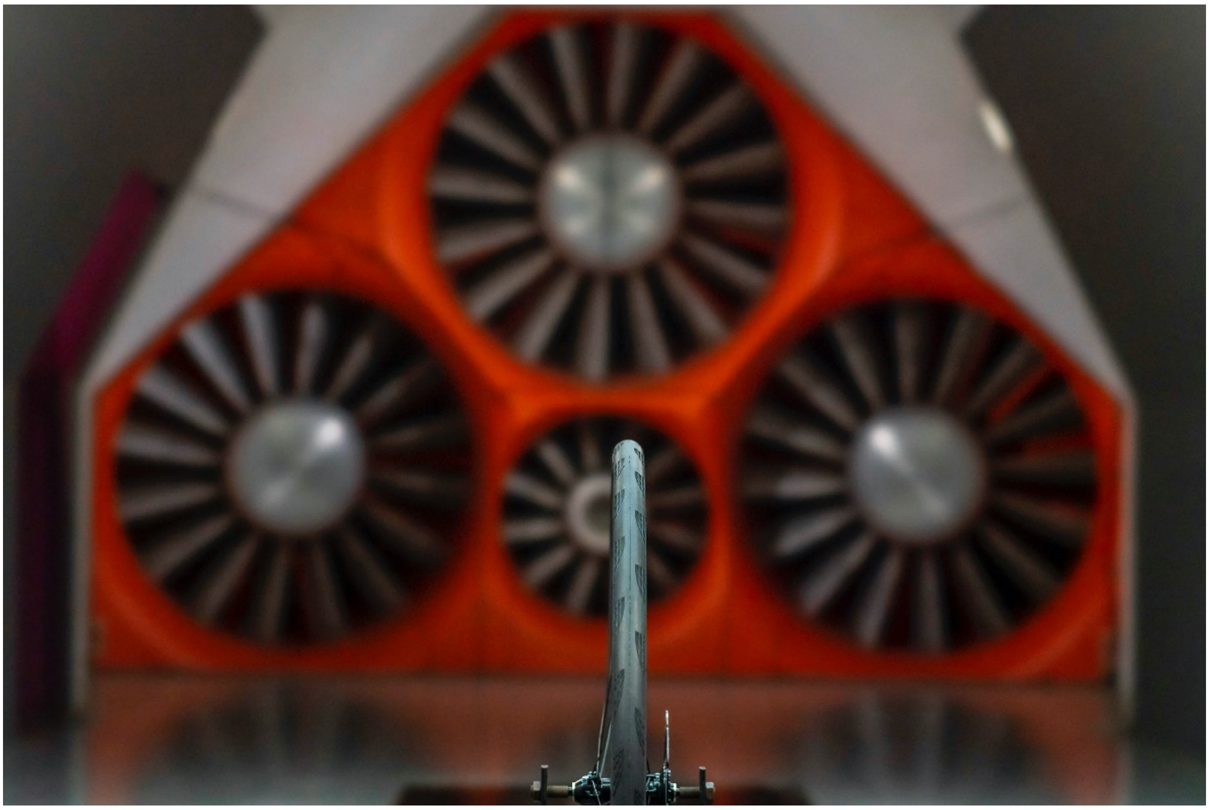
parcours

STRADE WHEEL DEVELOPMENT – WHITE PAPER
November 2019



BACKGROUND

The adoption of new technologies in road cycling has accelerated rapidly over the past few years. As recently as 10 years ago, the vast majority of frames and wheels were designed and optimised for a maximum tyre width of 23mm. This setup would be run at >100psi, with either a clincher or tubular tyre, and with braking provided at the rim.

Tyre width

However, it has become increasingly apparent that there are a number of advantages to running a wider tyre:

1. **Reduced rolling resistance**: a number of published studies have shown a reduction in the coefficient of rolling resistance (CRR) as tyre width increases[1].
   The wider tyre will have a shorter and wider contact patch with the road than an equivalent narrower tyre. This in turn reduces the friction and hence energy loss.

2. **Ride comfort and traction**: as a result of (1) above, riders are able to reduce tyre pressure, whilst still maintaining a suitably low CRR. One study has shown that the new Continental GP5000 tyre will deliver the same rolling resistance at 81psi in a 28mm version as at 92psi in a 23mm version[2].
   Reducing pressure improves ride comfort, as it increases the suspension effect of the tyre. This reduces the strain placed on the rider's body, especially over rougher road surfaces.
   Finally, a reduced tyre pressure will improve traction by slightly increasing the contact patch with the road. Whilst this does increase CRR (as per (1) above), it is a worthwhile trade-off, for example in wetter conditions where grip is key.

Tubeless tyres

The introduction and adoption of tubeless tyre technology has only furthered the benefits of a wider tyre (and hence the demand with riders). Eliminating the inner tube from the system entirely removes the risk of a pinch flat where a tube could be "pinched" between the rim edge and road when run at a lower pressure.

Disc brakes

However, whilst the benefits of a wider tyre have become established, wheel designers were for a time still constrained by rim design. A traditional rim brake caliper would only allow up to a c.28mm rim width before the rim would no longer fit between the brake pads. This created an issue, as in order for the wheel/tyre system to maintain its aerodynamic benefits, the rim width must measure c.105% of the tyre width. The "Rule of 105" limited tyre widths to c.25mm.

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[1] Tour Magazine, Wide tyre test (January, 2014)
[2] Bicycle Rolling Resistance: https://www.bicyclerollingresistance.com/specials/grand-prix-5000-comparison

The final piece of the puzzle has been the shift to disc brakes in road cycling. Whilst the UCI have only recently approved disc brakes for racing, riders have been increasingly moving to disc brake setups over the past few years, so much so that many of the leading bike manufacturers are now releasing disc brake-only frame designs.

Moving the braking force from the rim to the hub has allowed for far greater flexibility and innovation in rim design. Firstly, the rim width is no longer constrained to the c.28mm clearance of a brake caliper. The rim edge can also be more aggressively contoured as there is no longer a requirement for a flat (or close to flat) contact area for the brake pad to exert a frictional force against. Finally, as no frictional force is exerted at the rim, there is no longer a need for heat-resistant properties at the outer edge of the rim. This is a benefit as the heat-resistant resins that are used in a carbon fibre brake surface are more rigid and therefore less resistant to impact.

PROJECT GOALS

Based on the shift in tyre and braking technologies, at the outset of the Strade design project we set out to develop a wheel that is:

1. **Aerodynamically optimised for a 28mm tyre**
2. **Tubeless-ready**
3. **Disc brake-specific**

We would use the current Passista Disc (56mm rim depth) wheelset as the design benchmark, with a goal of delivering a wheel that, when fitted with a 28mm tyre, exceeds the aerodynamic performance of a Passista Disc fitted with a 25mm tyre.

In addition, we wanted to benchmark against both the weight and handling of the Passista Disc, to provide comparable performance.

DESIGN PROCESS OVERVIEW AND CONTRIBUTING FACTORS

Tyre width – stated versus measured

Before setting out to begin design work on a new rim profile, we wanted to fully understand the tyre specifications we were designing for. Whilst tyre manufacturers will give a stated tyre width, this can vary depending on the rim to which it is ultimately fitted. There is a well-understood interaction between the internal rim width of a wheel and the measured width of a tyre – a wider internal rim will cause a tyre to inflate to a wider measured width.

The first step was to select a tyre to base our design around. Of the newest wave of tubeless-compatible tyres to be launched, the Continental GP5000TL has consistently been rated as offering the best blend of low rolling resistance and a decent level of puncture resistance and longevity. This, combined with Continental's focus on tyre aerodynamics, led us to choose this tyre as the baseline for our rim design.

We collected a number of data points from other studies, reviews and real-world measurements, to establish a relationship between the stated 28mm width of a Continental GP5000TL, and the actual measured width.

External versus internal rim width

Using the relationship derived above, we could therefore begin to define the requirements for the external rim width of the wheel versus the internal rim width. Given the relationship between internal rim width and measured tyre width, this gave rise to an interesting iterative dilemma.

In order to provide a sufficiently wide external rim width to maintain the "Rule of 105" with measured tyre width, we would need to increase the internal rim width. However, doing so would then increase the measured tyre width and therefore increase the required external rim width. Quite quickly, this would spiral to the point of unrealistically wide designs!

As a further constraint, there comes a point at which it is no longer safe (as defined by ETRTO standards) to run a specific tyre width on too wide an internal rim measurement, as the tyre would not sit correctly against the bead and could potentially come off the rim.

We needed an anchor for the analysis, so it was decided that we would fix the internal rim width at a maximum of 22.5mm to allow the safe running of a 25mm tyre.

Internal rim width:	22.5mm
Implied measured width for a Continental GP5000TL 28mm tyre:	30.3mm
Implied 105% outer rim minimum width:	31.8mm

Rim depth

From our previous wind tunnel testing (and according to the commonly-accepted industry view), we know that the deeper the rim, the greater the aerodynamic benefit. However, we also know, based on the development of our 2019 Chrono front wheel, that it is possible to maintain a given aerodynamic benefit on a shallower rim design by moving the widest point of the rim.

To anchor our rim depth analysis, we looked at the relationship between front and rear rim depths from our Chrono rim design, as well as the existing Passista Disc rim depth.

Front / rear rim design

As part of our technical partnership with the Sports Engineering department at Nottingham Trent University, we have been conducting an analysis of real-world wind conditions that would impact wheel design. Specifically, this has involved collecting wind angle data from sensors located at both front & rear wheels, across real-world riding conditions as well as controlled (wind tunnel) conditions.

The most interesting finding of this study to date has been the difference in observed wind conditions between front and rear wheels. The average yaw angle at the front wheel is consistently higher than at the rear. Initial suggestions point to the airflow at the rear wheel being disturbed by the front of the bike and rider interaction (predominantly legs, feet and pedals).

In order to maximise the aerodynamics of the front wheel (versus rear), it would need to perform better at higher observed yaw angles, whereas the rear would need to be optimised for lower yaw conditions. Prior analysis has shown that a more "blunt" U-shaped rim is more suited to higher yaw, whilst a "sharper" V-shaped rim is better at lower yaw. In addition, the crosswind performance at the rear wheel is significantly less important given the wheel is not free to move on its axis for steering.

Weight saving

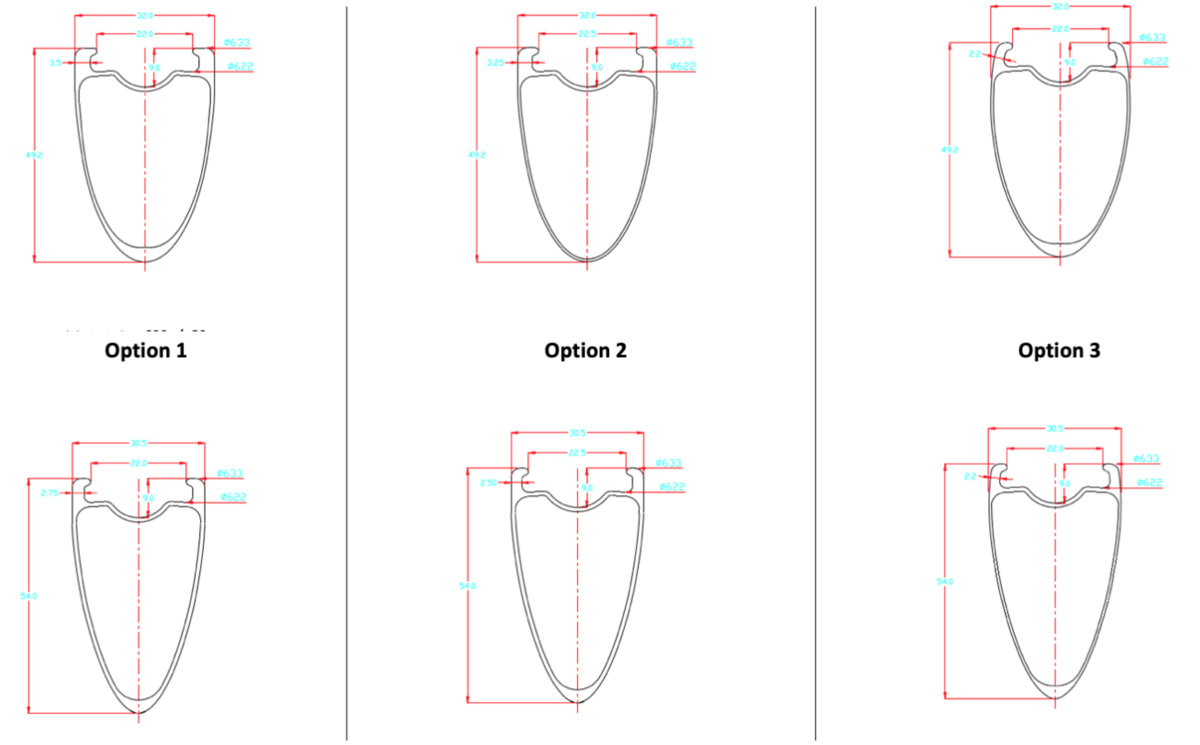
Taking the measurements above:

min external width:	31.8mm
internal width:	22.5mm

suggests a rim wall width of >4.5mm on each side. This is significantly higher than we use across the rest of the Parcours range and the increased volume of material would increase rim weight. It is also a substantial margin thicker than is required from a safety and strength perspective for the bead hook of the rim.

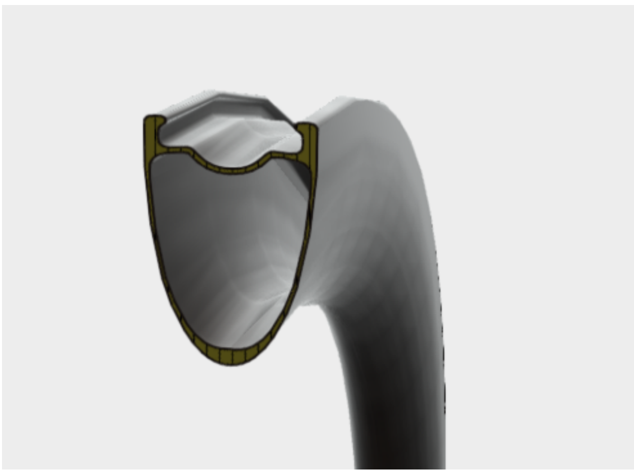
The initial designs for the rim wall led to an implied rim weight that would leave the new wheelset's overall weight substantially higher than the existing Passista Disc (>15% increase) which would not sit well against our target benchmark.

Instead, a number of CFD iterations were tested with a curved rim wall. This was only possible given this would be a disc brake-specific rim design. By allowing the external rim profile to curve inwards from the widest point towards the tyre bed, the rim wall is maintained at an appropriate thickness, without redundant rim material being added or the inner rim width becoming overly wide.



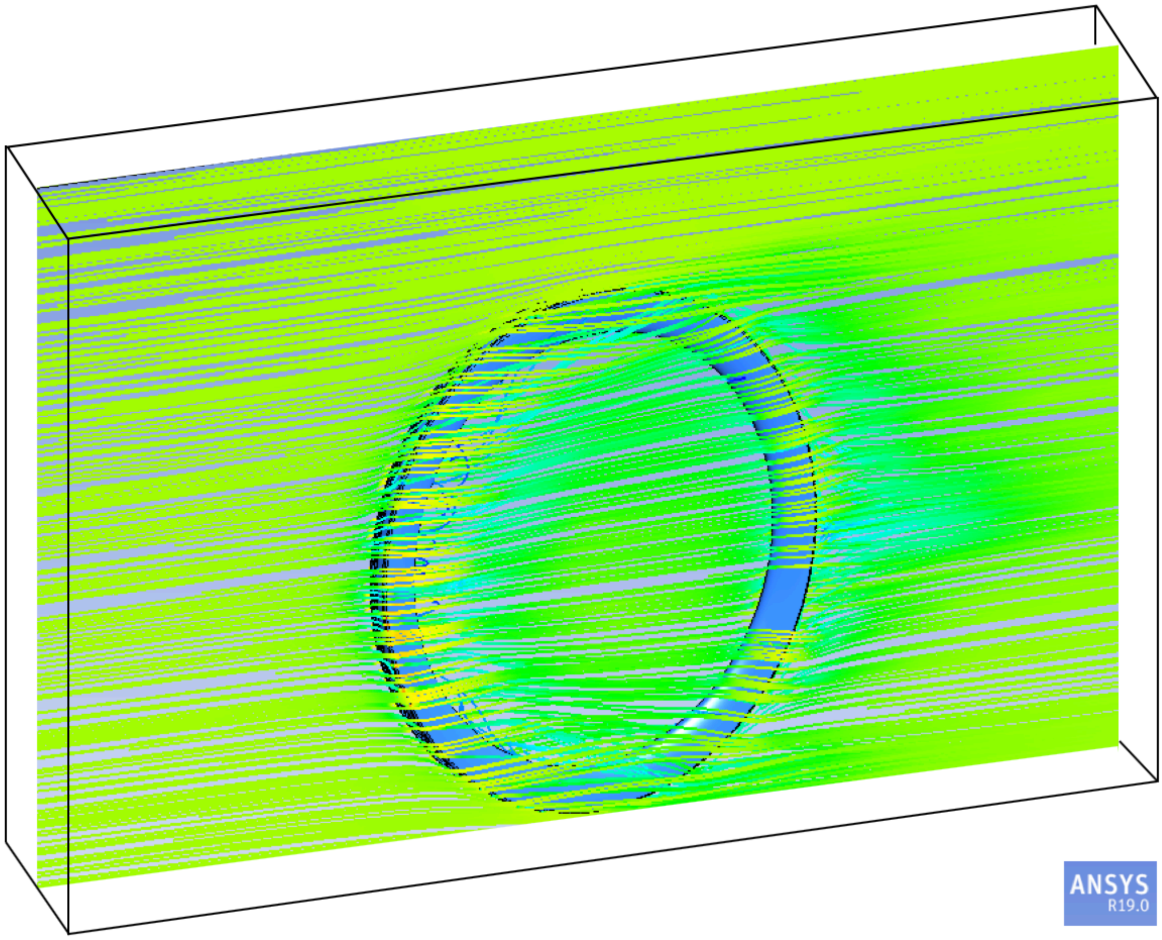
CFD design iteration

Each stage and iteration of the design process began as a 2D profile cut-out, which was then modelled in 3D CAD (Solidworks).



A 3D rendering of a 28mm diameter tyre was then fitted to the rim profile for the purpose of the following analysis.

The 3D rim shapes were then run through CFD simulations at a range of yaw angles (0 to 20 degrees, at 5 degree increments) under simplified conditions. These indicative results allowed us to narrow the options down to two prototype profiles each for the front and rear wheels.



Prototyping

Finally, 4 prototype rims were moulded for final testing and validation in the wind tunnel:

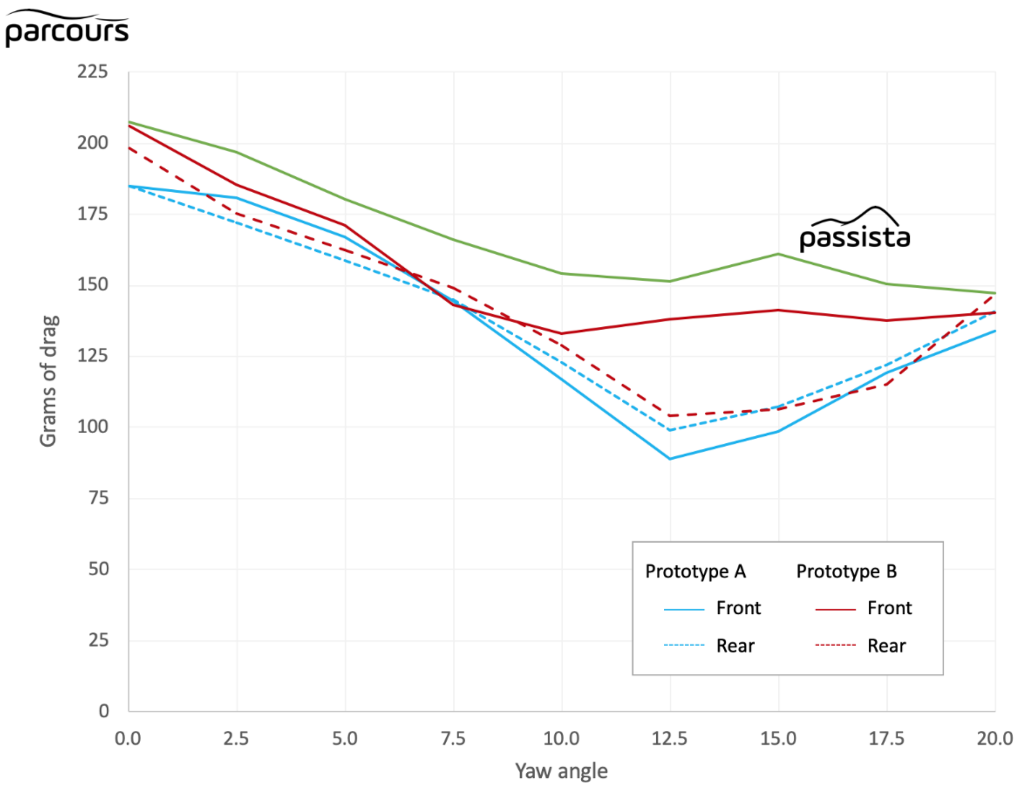
- Parcours Strade prototype front wheel A (49mm depth / 32.0mm width)
- Parcours Strade prototype front wheel B (50mm depth / 31.5mm width)
- Parcours Strade prototype rear wheel A (54mm / 30.5mm width)
- Parcours Strade prototype rear wheel B (54mm / 31.8mm width)

WIND TUNNEL TEST RESULTS

Once the prototype designs were finalised, we took a range of wheels to the A2 Wind Tunnel in North Carolina to test.

TEST ONE: AERODYNAMIC PERFORMANCE

Drag chart:



Prototype A came out ahead for both the front and rear wheel.

For the front wheel, the wider rim of Prototype A ensured that the stall angle was higher than Prototype B – particularly important for a front wheel with the higher observed yaw angle.

Whereas for the rear wheel, the slightly narrower Prototype A performed better at all yaw angles up to 15 degrees. Given the lower observed yaw angles at the rear wheel, this was a preferred performance characteristic.

Savings versus baseline wheelset:

WHEEL	TYRE	TIME SAVINGS OVER 40KM	WATTS SAVED (AT 30MPH)
passista	GP5000TL 25mm	54s	17.9W
passista	GP5000TL 28mm	37s	12.3W
strade	GP5000TL 25mm	56s	18.6W
strade	GP5000TL 28mm	58s	19.2W

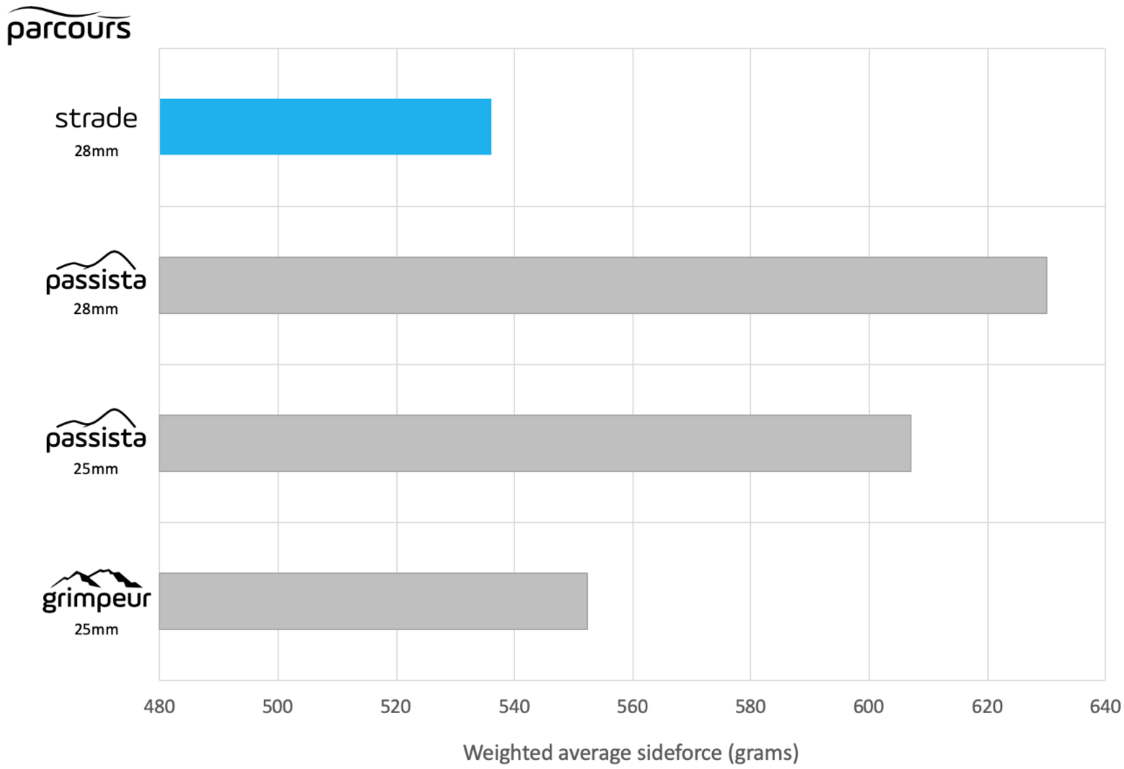
Note: all savings are taken versus a baseline Fulcrum Racing 5 wheelset.

When put up against a Passista Disc wheelset with the same Continental GP5000TL 28mm tyre, the Strade Prototype A wheelset was significantly faster – a saving of 6.9W. What was more interesting was that, when tested against the same Passista Disc wheelset with a narrower Continental GP5000TL 25mm tyre, the Strade was still faster – a saving of 1.3W.

This means a rider would be able to switch to a wider tyre, whilst still reducing their overall drag. The final sensitivity shows that the Strade is relatively agnostic to tyre width. It will still outperform the Passista Disc with a Continental GP5000TL 25mm tyre, but increasing tyre width will actually improve overall aerodynamic performance.

TEST TWO: HANDLING PERFORMANCE

Side force chart:



Having also set out to benchmark crosswind performance against the existing Passista Disc, we next compared the sideforce generated at yaw. Again, the Strade front wheel outperformed the Passista Disc by a wide margin, showing a 15% reduction in sideforce when compared to the Passista Disc fitted with the same 28mm tyre, and a 12% reduction with the Passista Disc fitted to a narrower 25mm tyre. In fact, the new Strade front wheel is so stable that it produces over 3% less sideforce than we measured in a previous test of the Grimpeur Disc. Quite an achievement given the disparity in rim depth (40mm versus 49mm).

Test protocol:

- Front wheels only were tested
- Each wheel was tested from 0-20 degrees of yaw, at 2.5 degree increments
- Positive yaw angles cover non-drive side (i.e. brake rotor, where relevant, exposed to the wind)
- Each test sweep was conducted twice, with results averaged
- Test wind velocity was at 30mph
- The same Continental GP5000TL 28mm tyre was used throughout, inflated to 80psi

Note: we did not remove tare (i.e. subtract the drag from the wheel clamp) for two reasons:

1. In real-world riding, the wheel will have the fork supporting it.
2. As the wheel is rotated into the wind at higher yaw angles, one of the clamp posts will become increasingly "hidden" from the wind. Subtracting a simple tare value could therefore be misleading at higher yaw angles.

The wheels we tested were:

- Parcours Strade prototype front wheel A (49mm)
- Parcours Strade prototype front wheel B (50mm)
- Parcours Strade prototype rear wheel A (54mm)
- Parcours Strade prototype rear wheel B (54mm)
    - Note: the rear rims were laced to a Parcours front hub to isolate the impact of the rim profile
- Parcours Passista Disc front wheel (56mm)
- Fulcrum Racing 5 disc brake clincher (chosen as the standard baseline wheel that a bike will ship with)

Note: we measured against the Fulcrum wheel design which has the same spoke count as the two aero wheels, rather than a commonly used box rim with a 32 spoke count. We believe this is more representative of the real-world benefits riders will see from an upgrade.

CONCLUSION

The production version of the Strade wheelset (based on Prototype A) has been shown to outperform the existing Passista Disc in all respects.

Wind tunnel data shows that the Strade wheelset, fitted with a 28mm tyre, represents the new benchmark for a mid-depth disc brake wheelset. This setup has been proven to be faster than our existing Passista Disc wheelset even if fitted with a narrower 25mm tyre. It will also provide more stable handling than the shallower Grimpeur Disc (40mm) wheelset.

Having taken the insight gained to date from our collaboration with Nottingham Trent University on observed yaw angles and combined this with our existing development of rim profiles for the new Chrono front wheel, we now have a proven front/rear rim profile relationship which can be applied to future wheel development.

Further analysis of the observed yaw angle data will ultimately also enable us to apply an updated average yaw angle weighting to front and rear wheel test data.

APPENDIX

INTERPRETING A DRAG CHART

YAW ANGLE

When riding a bike, the wind a rider feels can be split into two main components:

- Wind resistance from the rider's forward motion. As a rider rides forwards, they (and their bike) are moving through the air in front of them, creating drag. Rather than riding forwards, this is simulated in a wind tunnel
- Impact of the wind that is blowing that day (i.e. the weather). Clearly this can act upon a rider from any direction, depending on the conditions

The two components combine to give the effective wind that a rider will encounter. To model it in the wind tunnel, we need to understand both how strong the wind is, and from what direction it is felt – the yaw angle. Given that most riders will be travelling significantly faster than the wind is blowing, the wind resistance makes up the larger share of the effective wind. It also concentrates the yaw angles seen when riding into a small arc in front of the rider. As a result, wheels are tested between 0 and 20 degrees of yaw angle, reflecting the yaw angles seen in the real world.

GRAMS OF DRAG

In order to quantify wind resistance resulting from a wheel, we measure the drag force it exerts when exposed to wind. The wind tunnel measures the force on the wind axis (i.e. based on the direction the effective wind is travelling in), which is then converted to the body axis (i.e. based on the direction the rider is travelling in).

The drag chart shows the drag force exerted against the direction of travel for the rider. This is the component of the drag force that slows the rider down whilst riding. The higher the drag force, the more energy is needed to overcome it and move the rider forward. When reading a drag chart, this means that the lower the line, the more aerodynamic the wheel is. However, it is worth remembering that, when comparing wheels, a wheel may show a lower drag at one yaw angle, but a higher drag at another.

CALCULATING TIME SAVINGS

Using the drag chart, we can compare the drag force from two different wheels. However, we then want to be able to understand what difference this will make in the real world, i.e. how much time a rider will actually save. To do this, we need to understand two things:

1. How a unit of drag translates to a unit of time saved
2. What the "average" yaw angle should be

Fortunately, both of these factors are becoming increasingly well understood.

1. CONVERTING DRAG SAVINGS TO TIME SAVINGS

The drag equation states that drag force is determined by 4 things:

- Air density
- Frontal area of the object moving through the air
- Speed
- Drag coefficient

For the purposes of cycle testing, we can assume the first two remain broadly constant. We can therefore calculate the drag coefficient for a particular speed. Reducing the drag force by a known amount (e.g. 100g) at that particular speed will then give a lower drag coefficient which we can use to calculate a higher speed that would be achieved by saving that known amount of drag. By knowing the increase in speed, we can see how much time would be saved over a defined distance (e.g. 40km).

That may sound relatively straightforward, but it is complicated by the fact that the increase in speed will also have a slight impact on drag force. However, for the range of speeds we would consider achievable on a bike (i.e. not considering 100kph+!), this has a very slight effect. To put this another way, a faster rider may see a higher reduction in drag than a slower rider, but the slower rider will have their benefit for longer.

This is how we are able to reach the "rule of thumb" that a 100g reduction in drag will result in a 40 second time saving over 40km.

2. AVERAGE YAW ANGLE

A number of studies have been conducted by both frame and wheel manufacturers to evaluate the "average" yaw angle seen by riders. Recent research and testing has shown that cyclists and triathletes are exposed to lower yaw angles than previously believed. However, this will be impacted by weather conditions – if you ride a very windy course you will see a far wider range of yaw angles than on a completely still day.

We have taken the findings from these studies and applied them to our wind tunnel results. Rather than taking a simple average for each wheel, we have given a higher weighting to the more commonly occurring yaw angles to more accurately reflect the real world. As a result, the time savings for each wheel design reflect a weighted average yaw angle of 6-7 degrees.

Further, based on our own research in conjunction with Nottingham Trent University, we now have a template overlay to show the difference in average yaw angle seen at the front wheel and the rear wheel. Our data shows that the rear wheel will see, on average, yaw angles of c.1 degree less under identical overall wind conditions.