HUNT 4AM and 5AM Limitless Wheelset White Paper

Development process for two different depth road racing wheels designed to be the fastest in the world in their respective depths. Including development data and technical specification choices for carbon spoke and steel spoke models.

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Introduction

For the HUNT 5AM Limitless the purpose was to produce the fastest wheelset in the world for all-round UCI road races, while the 4AM was designed to be the ultimate wheel for the queen stage of a grand tour. We defined fastest as a combination of aerodynamic drag, wheelset weight, as well as being the most stable wheelset at its depth. The wheelsets are both primarily designed around 30mm tyres but must still offer exceptional performance with 28mm tyres. Some data and discussion around the spoke count and material will be included as well as the reasoning behind other design choices made on this product.

HUNT's Five Key Stages of Aerodynamic Development

For this project we went through 5 key stages of aerodynamic development, including 6 wind tunnel trips and 132 different CFD simulation runs (totalling 80,000 Core hours of computation).

Stage 1 – Computational Fluid Dynamics (CFD)

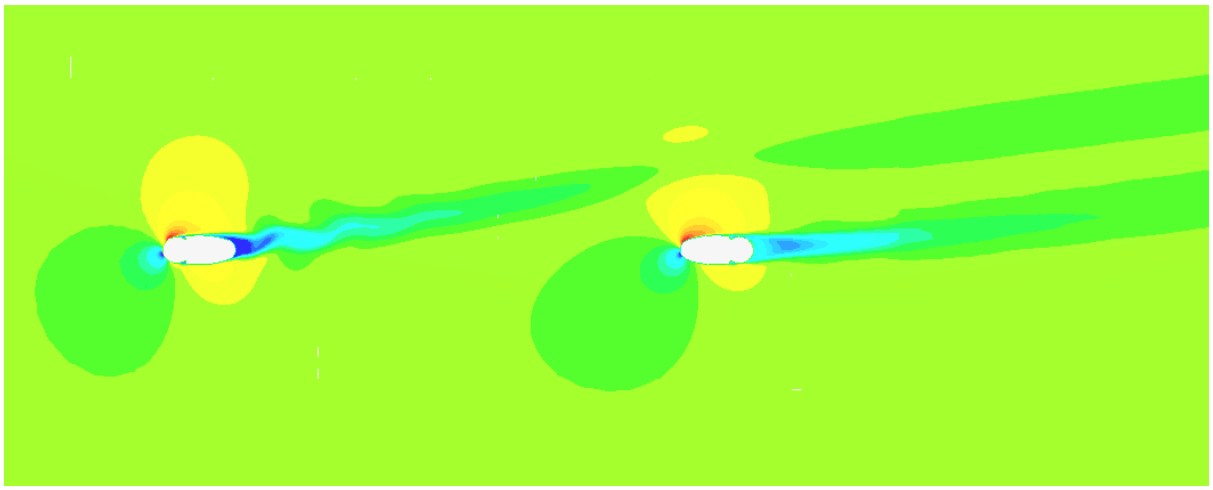

Figure 1- Post processing visualisation of air speed around a 34mm wide profile with a 7.5 degree yaw angle

CFD is a simulation tool that allows us to quickly run through a range of profiles without investment in physical prototypes. Using this method we have achieved good correlation with wind tunnel results of wheel-only testing. However, this is a simplified RANS model (Reynolds-Averaged Navier-Stokes) without spokes. This does not have the capability to model turbulent transition flows, which is becoming significant at the speeds we are starting to test at.

Stage 2 – Wind Tunnel: Experimentation and single wheel testing

This is where we use existing profiles or 3D printed prototype wheels not fitted to a bike to allow us to gather data with less noise and complexity, aiding us to make decisions to improve the final design of the wheelset in a simplified test environment.

Stage 3.1 – Wind Tunnel: Full bike testing with 3D printed prototypes

This is where we use our internal 3D printing capabilities to test the best performing prototypes from the simulation in a real bike with a range of real tyres fitted. The Formlabs 3L SLA printer that we use can print with a layer thickness of 0.05mm allowing us to make very accurate models that can be built with the correct number of spokes and can withstand a tyre inflated to normal pressures. This allows a range of rim profiles to be tested without tooling investment. These 3D printed prototypes have been tested alongside their carbon counterparts and have been found to perform to a level where the difference lies within the bounds of wind tunnel uncertainty and thus the 3D printed rims are very useful for early shape development purposes.



Figure 2 - 3D printed prototype being fitted to test bike at GST tunnel

Stage 3.2 – Wind Tunnel: Full bike testing with first-off mould final specification wheels

This is where we validate the performance of our final carbon wheelset against a range of other high-performance wheelsets in the controlled, repeatable and simplified environment of the wind tunnel. This takes into consideration the interaction of the rotating wheels and bike frame, but not interaction with a pedalling rider.

Stage 4 - Wind Tunnel: Full bike testing with a pedalling rider on the bike in full appropriate riding clothing and helmet

This testing allows us to consider the turbulence caused by the pedalling rider as well as the bike frame and wheels, this is particularly important when looking at the aerodynamic performance of the rear wheel.

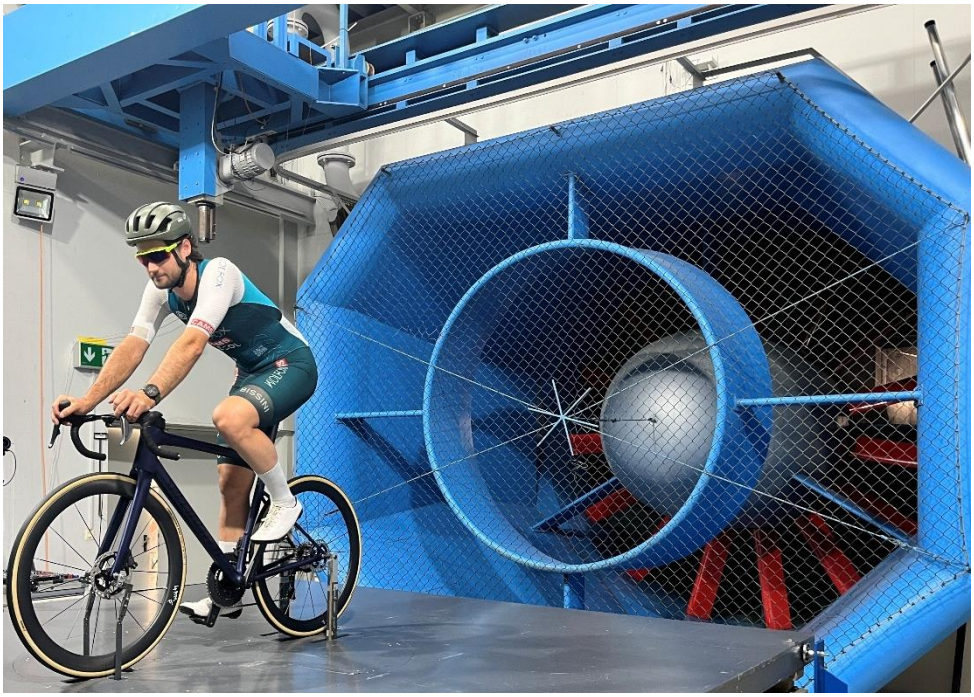

Figure 3 - Rider on wind tunnel testing

Stage 5 – Outdoor: Real world testing

We have spent a year working with an Aero Sensor system to enable the capture of real-world data which most closely resembles the wheelset's performance in competition. The downside of this is that with extra complexity more noise is added into the results, and this can only be countered with multiple baseline tests and test repeats. This then limits the amount of testing that is possible in one day due to rider fatigue. We also must consider that once the rider is no longer able to hold their repeatable riding position any further, the testing is meaningless.

A systems engineering approach was taken for the development of the 5AM Limitless wheelset, where every aspect of the wheel was looked at to reduce the weight of the wheel system. This system engineering approach led us to use a new spoke technology from Vonoa with spokes weighing as little as 1.7g per spoke, as well as a highly weight-optimised version of our 48-tooth ratchet hub. A high modulus T40 carbon fibre in the rims was also utilised, with co-moulded carbon spoke hole inserts providing extra strength around the spoke interaction areas of the rim. The wheels have a spoke count of 15 front wheel and 18 rear wheel. Each HUNT Ti_UD Carbon spoke by Vonoa has a breaking strength of 450 kgf (kilo grams force) breaking strain, whereas leading stainless steel aero spokes fail at around 290-300 kgf.

CFD

Over 50 iterations of each of the respective front rims were tested virtually to select the profiles to be taken forward to wind tunnel testing.

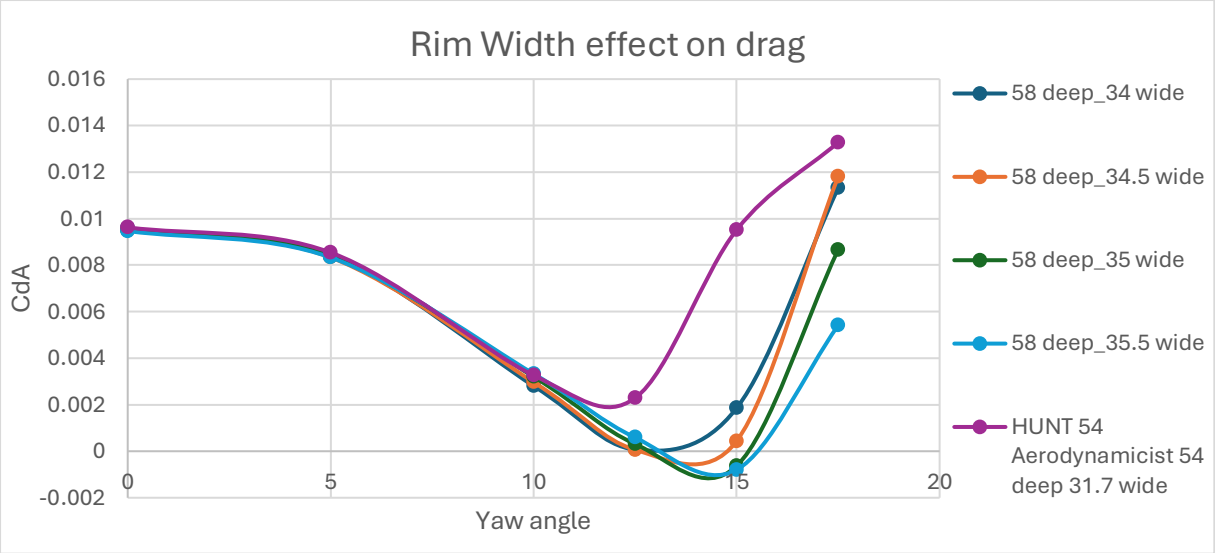

Figure 4-Effect of width on drag 0-20 degrees

Figure 4 is an example of the differences seen in the simulation where the new 58mm profiles, through a range of widths, can perform better at higher yaw angles (angle of wind that the profile is experiencing). You can see clear separation between the performance of the HUNT 54 Aerodynamicist (31.7mm wide) to the potential new shapes, which are made possible using HUNT LIMITLESS Technology. (CdA is the coefficient of drag or how aerodynamically efficient an objects shape is, times it's frontal area, which then gives the total aerodynamic drag.)

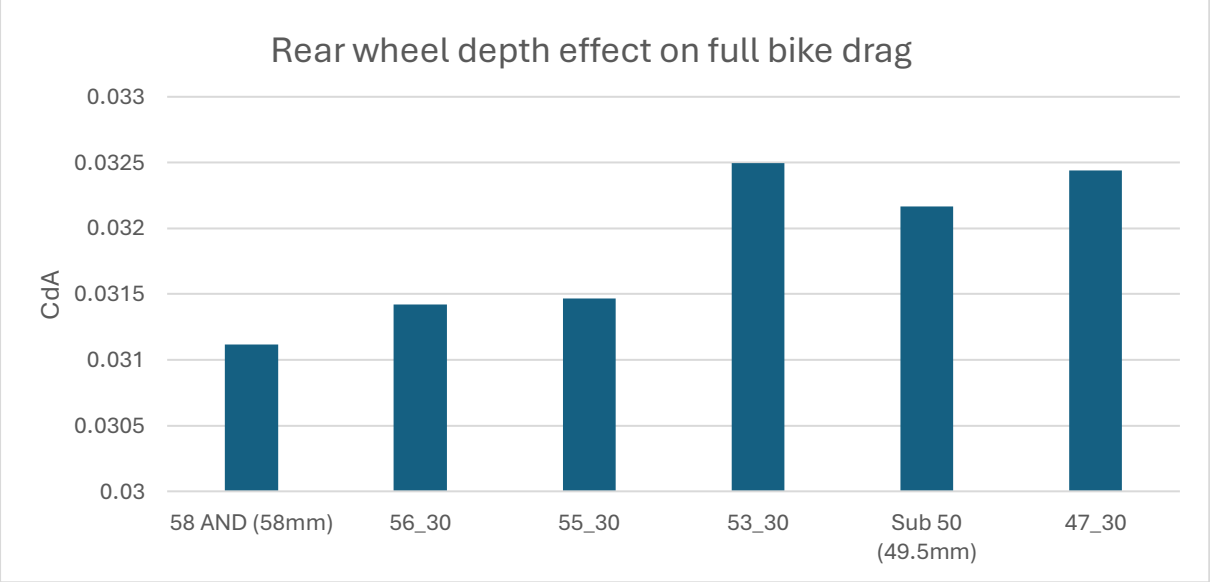

Figure 5 - effect of rear rim depth on wheel and bike drag

Figure 5 shows how the rear wheel depth effects the system drag, all the profiles are 30mm wide to control this factor and the pattern is clear, with slightly shallower wheels being less aerodynamically efficient, as would be expected. However, the differences are small with all the rear profiles being within 0.95% of each other, this difference would be within the uncertainty of the simulation, or due to unaccounted for bike-specific interactions.

Plastic Prototype testing and experimentation in the tunnel

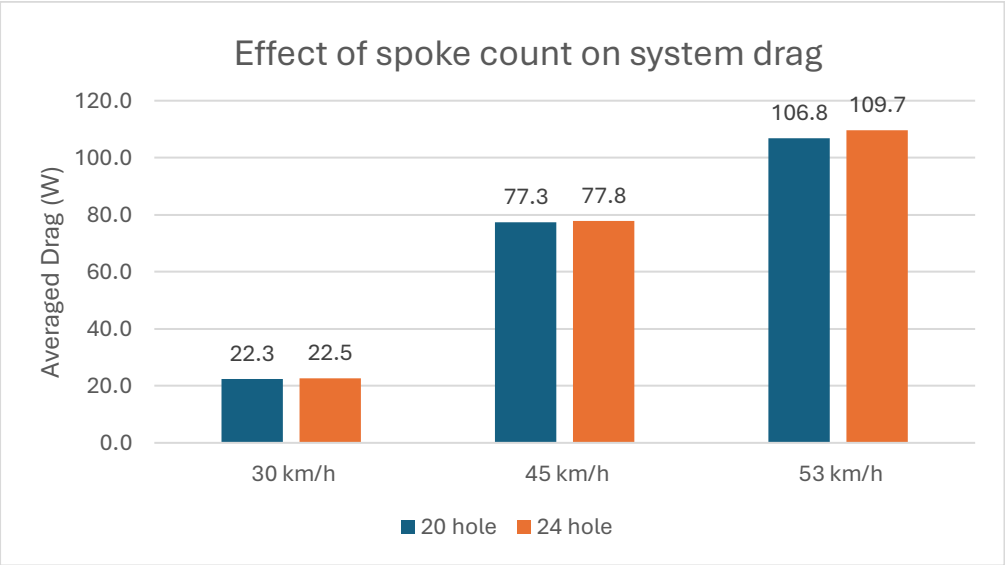

Figure 6 - effect of front spoke count on wheelset drag

We tested two HUNT 60 limitless wheels with identical rims, built with 20 or 24 holes and spokes. (HUNT Sprint Hubs with Steel Pillar Wing 20 spokes). Each wheel was tested with a wind speed matching that of the wheel speed in a bike. (with 53 Km/h being the highest wheel speed that was achievable at the GST Wind tunnel)

At all three speeds the lower spoke count had a lower drag, this difference grew as the speed increased, as we theorised. The theory is that the spokes at the top of the wheelset are moving through the air at twice bike speed and since drag increases by a square of speed, the result should be that a small amount of additional drag from a spoke can become significant. This is especially so when you consider that at 45 Km/H each spoke is pushing through the fork at approximately 90 Km/h, 350 times a minute or 21,000 times in an hour. This means that a slight reduction in spoke count can lead to a meaningful reduction in drag.

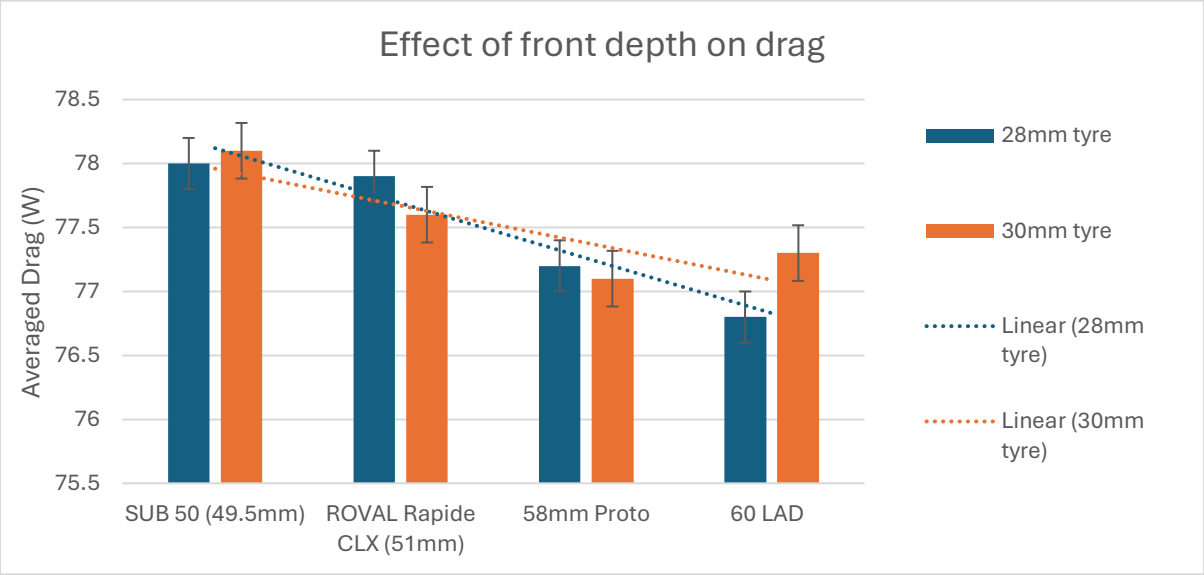

Figure 7 - Effect of front wheel depth on bike drag

Figure 7 shows all the front wheels that were tested, with a 28mm and 30mm tyre and a HUNT Sub 50 as the rear wheel. All front wheels are 34-35 mm wide externally and 21-23mm wide internally. As there are some small variations in width and shape some rims perform better with certain tyre widths, such as the 60 Limitless with the 28mm tyre. On average there is about a 1-watt difference between the 50 and 60mm deep wheelsets or 0.1 of a watt per mm of drag reduction per mm of extra depth between optimised rim shapes.

Averaged drag is calculated using the Mavic wind averaged drag weighting, where the importance of each is weighted by how often it is seen in real life, further details on this are in the appendix.

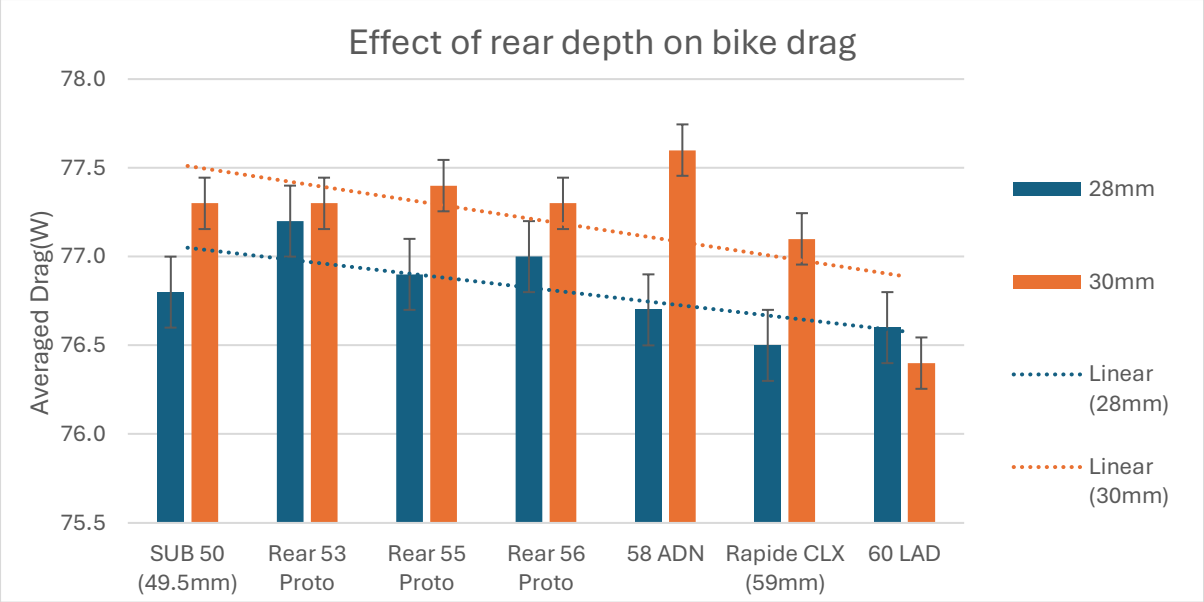

Figure 8-Effect of rear depth on bike drag

Figure 8 shows a range of rear wheels that are all 23mm wide internally apart from the Roval Rapid CLX and 60 Limitless which are both 21 mm wide. We see here that deeper wheels are on average more aerodynamic, but this time the difference between the 50mm rim and the 60mm rim is only about 0.4 watts, or 0.04 watts per mm of rim depth. This is also possibly exaggerated due to the slightly narrower internal width of the two deepest wheels.

Front wheel	Rear wheel	Drag (W)	Test Configuration
HUNT Sub 50	HUNT Sub 50	350.8	SL8 + Rider
HUNT Sub 50	HUNT TT disc	349.3	SL8 + Rider
HUNT Sub 50	HUNT Sub 50	78.4	SL8 No rider
HUNT Sub 50	HUNT TT disc	72.0	SL8 No rider

Table 1 - Rear wheel drag with and without rider

Table 1 is the outcome of a test to validate if the differences seen in bike-only testing showing that deeper rear wheels are more aerodynamic, are maintained when a pedalling rider is present on the bike. After initial experimentation we managed to achieve a repeatability with the rider in an aero hoods position of 2-3 watts.



Figure 9 - Smoke visualisation of the drag introduced by a rider's leg

To make the test effective when considering the 2-3 watt repeatability, we chose to test a 50mm deep spoked rear wheel (HUNT Sub 50 rear) and a solid disc rear wheel (HUNT TT Disc). The disc rear wheel is clearly faster than the Sub 50 rear when tested bike alone and with no rider, showing a 6.4 watt difference. However, once a pedalling rider is present this difference is significantly reduced to 1.5 watts. Even when considering the 2-3 watt repeatability, it does seem likely that the difference has closed significantly and that the benefit seen by the solid disc rear wheel are minimised when a rider is present and pedalling on the bike.

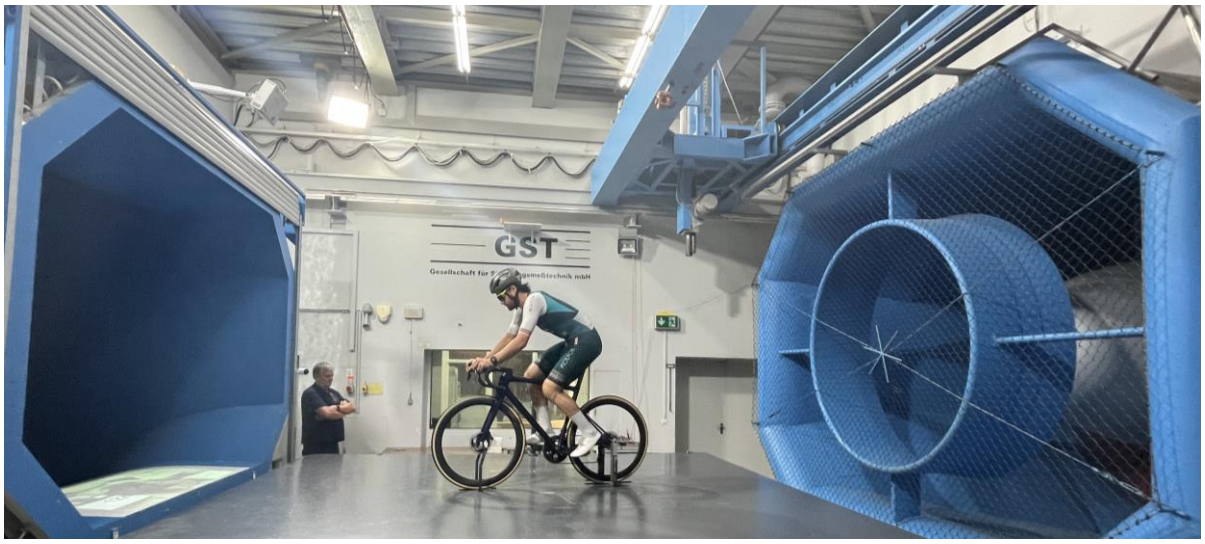

Figure 10- Rider on test set up at GST

This experimentation led us to the aero maximised front wheel concept, as we understood that weight can be saved across the total wheelset system by reducing the rear wheel depth with a negligible aerodynamic penalty. We repeatedly saw that when there are a pair of legs spinning at 90-100 rpm creating turbulence across the bike frame

and rear wheel, a few more mm of extra rear wheel depth cannot be seen to give an aerodynamic improvement.

Carbon Prototype wind tunnel testing

1st Wind tunnel - GST June 2025

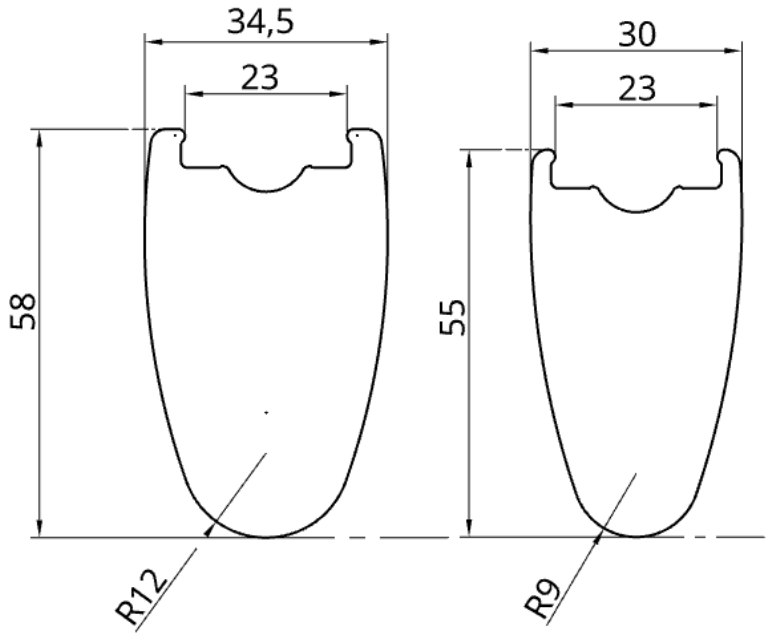

Figure 11-5AM Final rim shapes selected

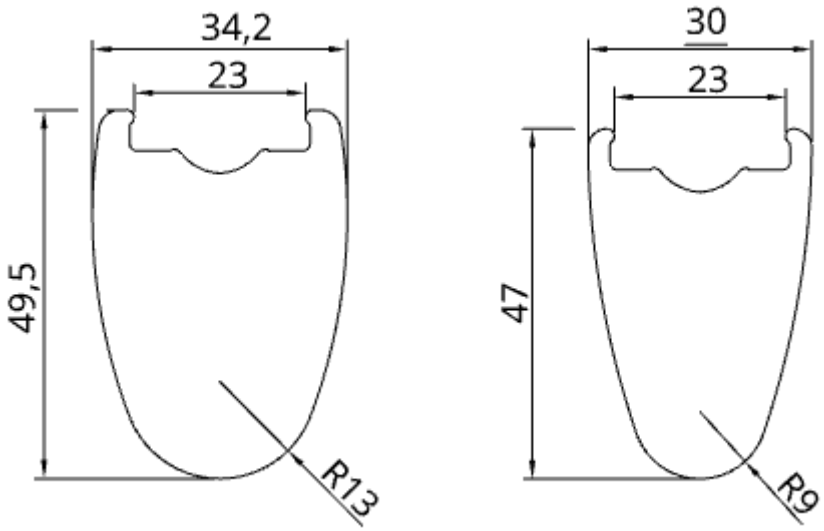

Figure 12- 4AM Final rim shapes selected

The final rim profiles chosen for the 5AM Limitless were a 58mm deep front rim with a 34.5mm external width, and a 30mm wide and 55mm deep rear rim, this gives a 40 gram saving for the rear rim when compared to the front rim.

The HUNT 4AM limitless wheels have front rim that is a little narrower at 34.2mm wide as well as being shallower at 49.5mm deep. The rear wheel is the same width at 30mm wide and 47mm deep, but with a slightly more aggressive V shape to the profile than the one seen on the 5AM limitless rear.

These rims were then combined with the new 1.7 gram titanium mandrel UD Carbon fibre spokes and built into 15 spoke front wheels and 18 spoke rear wheels in the case of the Ti_UD models. As can be seen in the testing results, this reduction in spoke count has led to a significant reduction in total wheel system drag.

The steel spokes used in this project are the Pillar Superwing, and they have the longest aerodynamic bladed section on the market. This gives the maximum aero performance for a steel spoke due to the longer aerofoil shaped bladed section exposed to the wind. We have also combined these with a new internal nipple that further reduces turbulence at the spoke bed.

All carbon protypes were run at 45 km/h with the exact same tyres being used in both sizes for all the comparative testing. As tyres are a handmade, moulded product, they have some small shape variances that can give large impacts on the wheelset drag. We have seen bike and wheel drag results differ by up to 2 watts between two tyres of the same brand, model and size, so where possible we remove this uncertainty.

49mm-60mm Testing with 30mm Schwalbe Pro One					
Wheelset	Front depth (mm)	Rear depth (mm)	Power watts (mavic WAD)	Wattage Delta	Weight (g)
Hunt 5AM Ti_UD	58	55	75.06	0.00	1212
Hunt 4AM Ti_UD	49.5	47	76.48	-1.42	1156
Hunt 60 Limitless	60	60	76.83	-1.77	1669
Roval Rapide CLX II	51	60	77.02	-1.96	1520
HUNT 54_58 Aerodynamicist Steel spoke	54.5	59	77.18	-2.12	1468
Enve SES 4.5	50	56	77.48	-2.42	1452
DT Swiss Dicut DB ARC 62	62	62	78.86	-3.80	1676
ZIPP 404 Firecrest	58	58	78.98	-3.92	1450
Shimano Dura-Ace R9270 C60	60	60	79.42	-4.35	1659
ZIPP 454 NSW Disc Brake	58	58	79.70	-4.64	1428

Table 2- 49-60mm depth testing with a 30mm Schwalbe Pro One

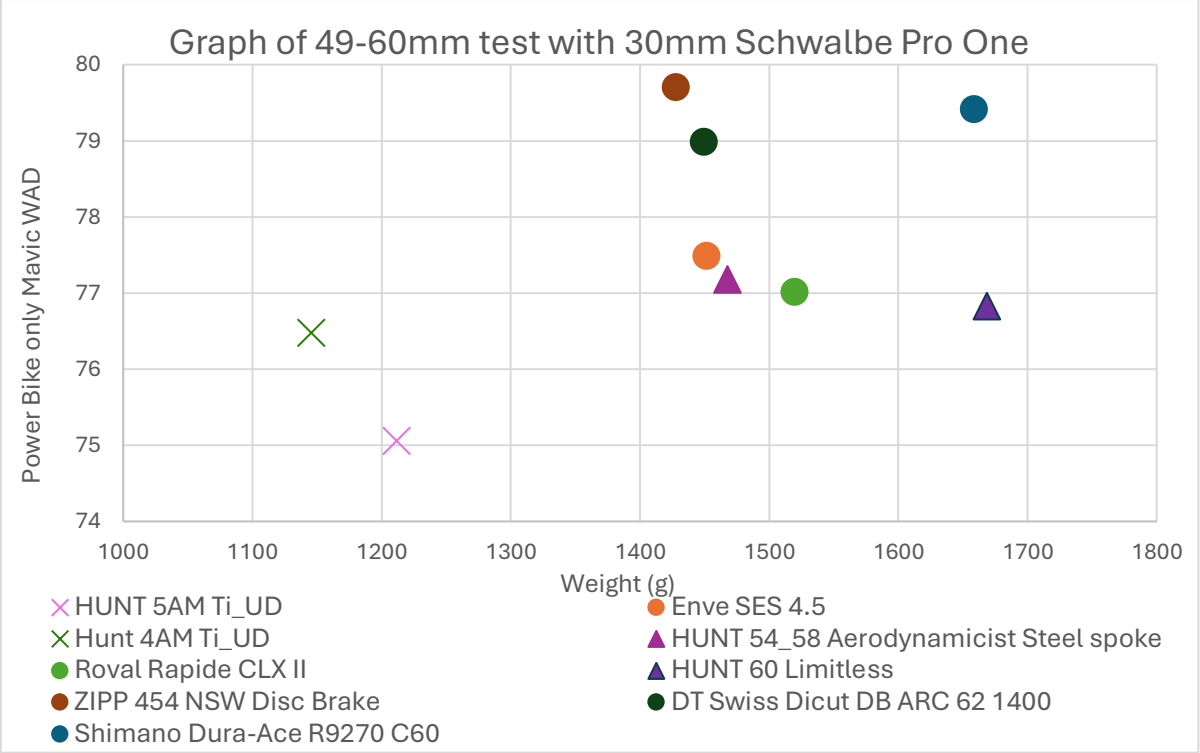

Figure 13 - Weight Vs Averaged Drag Mavic Wad 49-60mm depth test with a 30mm Schwalbe Pro One tyre

With a 30mm tyre the HUNT 4AM and 5AM Limitless Ti_UD are the lightest in this depth class of wheels being 200g lighter than anything else on test. The Hunt 5AM Limitless Ti_UD is also the most aerodynamic by 1.96 watts over the nearest non-HUNT competitor (Roval Rapide CLX ii). The 4AM Limitless Ti_UD is the second fastest but leading a tighter grouping of 4 wheels that all tested within one watt of each other, the 4AM Limitless Ti_UD being the shallowest of this grouping whist also being 300 g lighter.

40mm - 50mm Testing with 30mm Schwalbe Pro One					
Wheelset	Front depth (mm)	Rear depth (mm)	Power watts (mavic WAD)	Wattage Delta	Weight (g)
HUNT 4AM Ti_UD	49.5	47	76.54	0.00	1156
HUNT SUB 50 UD	49.5	49.5	78.33	-1.79	1380
HUNT 44_46 Aerodynamicist Steel spoke	44.5	46	79.02	-2.48	1346
Vision Metron 45 RS	45	45	79.33	-2.79	1290
Scope Artech 4	45	45	79.48	-2.94	1120
Light Bicycle Falcon AR50	50	50	80.47	-3.92	1246
ZIPP 353 NSW Disc Brake	40	40	80.60	-4.06	1310

Table 3 - 40-50mm depth testing with a 30mm Schwalbe Pro One

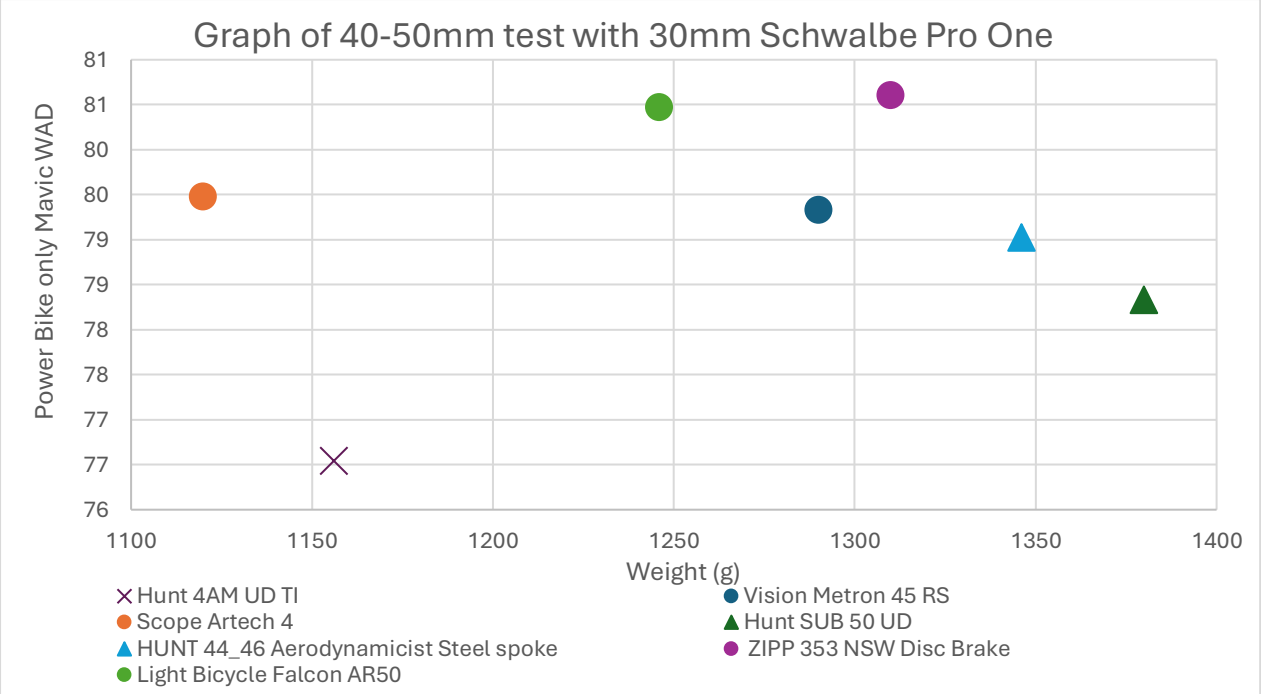

Figure 14- Weight Vs Averaged Drag Mavic Wad 40-50mm depth test with a 30mm Schwalbe Pro One tyre

With the 30mm tyre the HUNT 4AM Limitless Ti_UD has the lowest drag, with a 2.94 watt advantage over the Scope Artech 4, which is the only wheelset tested that was lighter. The HUNT 4AM Limitless Ti_UD showed 2.79 watts less drag than the Vision metron 45 RS, the closest non-HUNT competitor.

49mm-60mm Testing with 28mm Vittoria Corsa Pro					
Wheelset	Front depth (mm)	Rear depth (mm)	Power watts (mavic WAD)	Wattage Delta	Weight (g)
Hunt 5AM Ti_UD	58	55	73.22	0.00	1212
Enve SES 4.5	50	56	74.92	-1.70	1452
Hunt 4AM Ti_UD	49.5	47	75.02	-1.80	1156
HUNT 54_58 Aerodynamicist Steel spoke	54.5	59	75.25	-2.03	1468
Roval Rapide CLX II	51	60	75.34	-2.12	1520
Hunt 60 Limitless	60	60	75.47	-2.26	1669
ZIPP 454 NSW Disc Brake	58	58	76.26	-3.05	1428
DT Swiss Dicut DB ARC 62 1400	62	62	76.28	-3.06	1676
ZIPP 404 Firecrest	58	58	76.30	-3.09	1450
Shimano Dura-Ace R9270 C60	60	60	76.98	-3.76	1659

Table 4-49-60mm depth testing with a 28mm Vittoria Corsa Pro

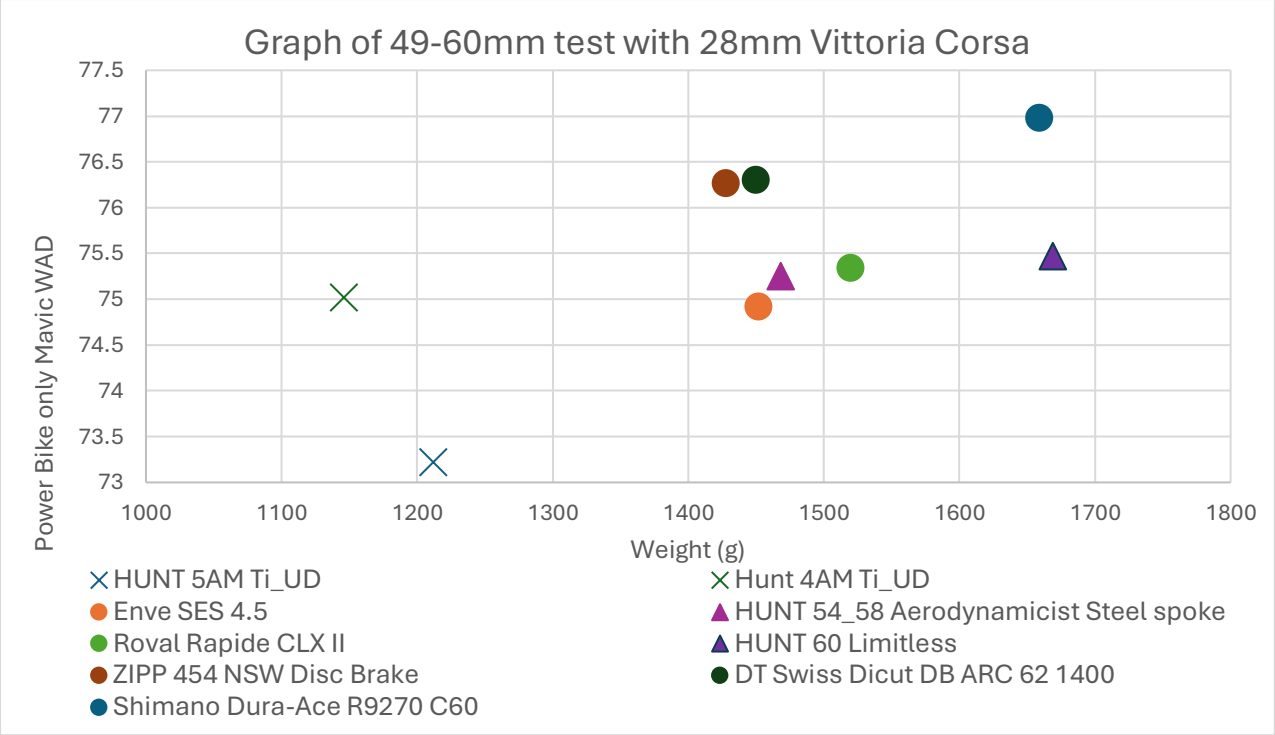

Figure 15 - Weight Vs Averaged Drag Mavic Wad 49-60 depth test with a 28mm Vittoria Corsa Pro tyre

The HUNT 5AM Limitless TI-UD is also the fastest with the 28mm tyre with a 1.7 watt margin to the Enve 4.5 which is the second most aerodynamic, while the 5AM TI-UD is 230g lighter. When compared to the Zipp 454 NSW the difference is 3 watts, which is 4% of the total bike and wheel drag. The HUNT 5AM TI-UD is also 216g lighter than the Zipp 454 NSW, a product that has been proven at the very highest level in cycling.

The HUNT 4AM TI-UD is found in a tight grouping of wheels that are deeper and heavier, consisting of the ENVE 4.5, Roval Rapide CLXii and the Hunt 54_58 aerodynamicist, all these wheels are within 0.42 Watts of each other and so not outside of measurement uncertainty. Therefore, we can be confident to say that the 4AM TI-UD is as fast as all these top competitors while being significantly lighter.

40mm - 50mm Testing with 28mm Vittoria Corsa Pro					
Wheelset	Front depth (mm)	Rear depth (mm)	Power watts (mavic WAD)	Wattage Delta	Weight (g)
HUNT 4AM Ti_UD	49.5	47	75.41	0.00	1156
Vision Metron 45 RS	45	45	76.35	-0.95	1290
Scope Artech 4	45	45	76.70	-1.29	1120
HUNT SUB 50 UD	49.5	49.5	76.93	-1.52	1380
HUNT 44_46 Aerodynamicist Steel spoke	44.5	46	77.63	-2.22	1346
ZIPP 353 NSW Disc Brake	40	40	78.12	-2.71	1310
Light Bicycle Falcon AR50	50	50	79.02	-3.61	1246

Table 5-40-50mm depth testing with a 28mm Vittoria Corsa Pro

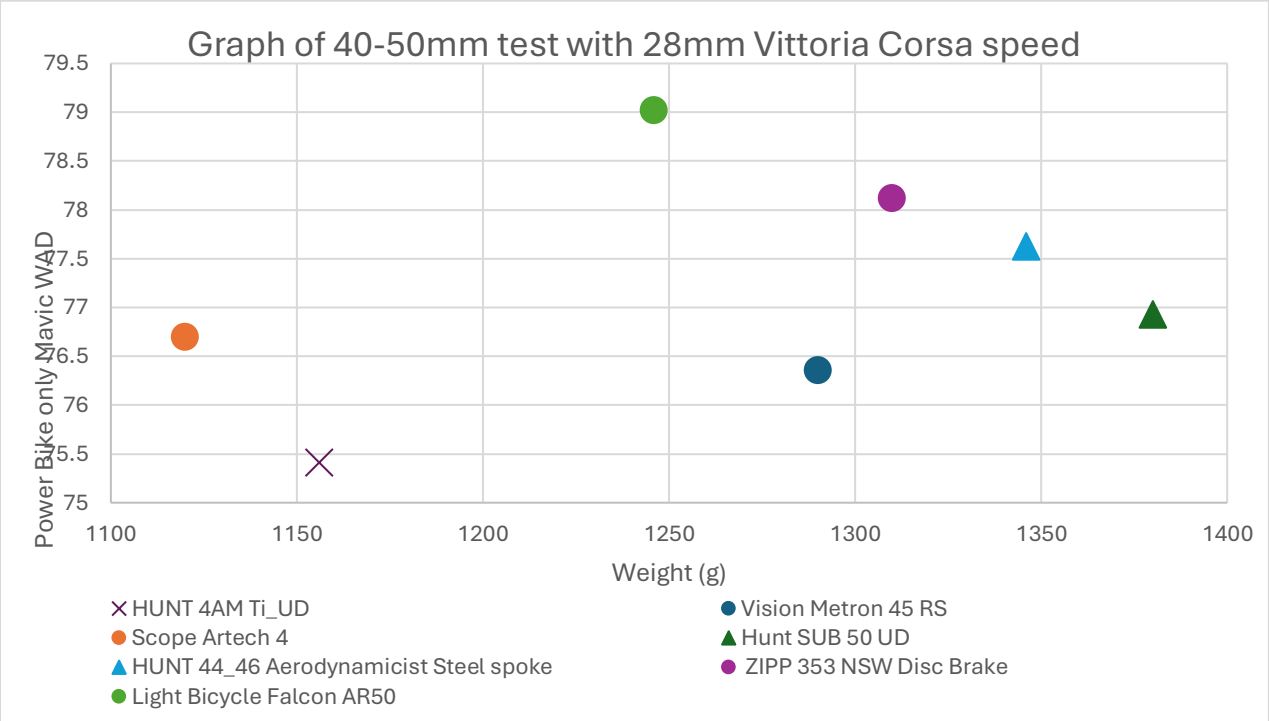

Figure 16-Weight Vs Averaged Drag Mavic Wad 40-50 depth test with a 28mm Vittoria Corsa Pro tyre

With a 28mm tyre the difference between the HUNT 4AM Limitless Ti_UD and the competition narrows, with the Vision Metron 45 being only 0.95 Watts slower and 134g heavier, and the Scope Artech 4 being 1.29 watts slower and 36g lighter.

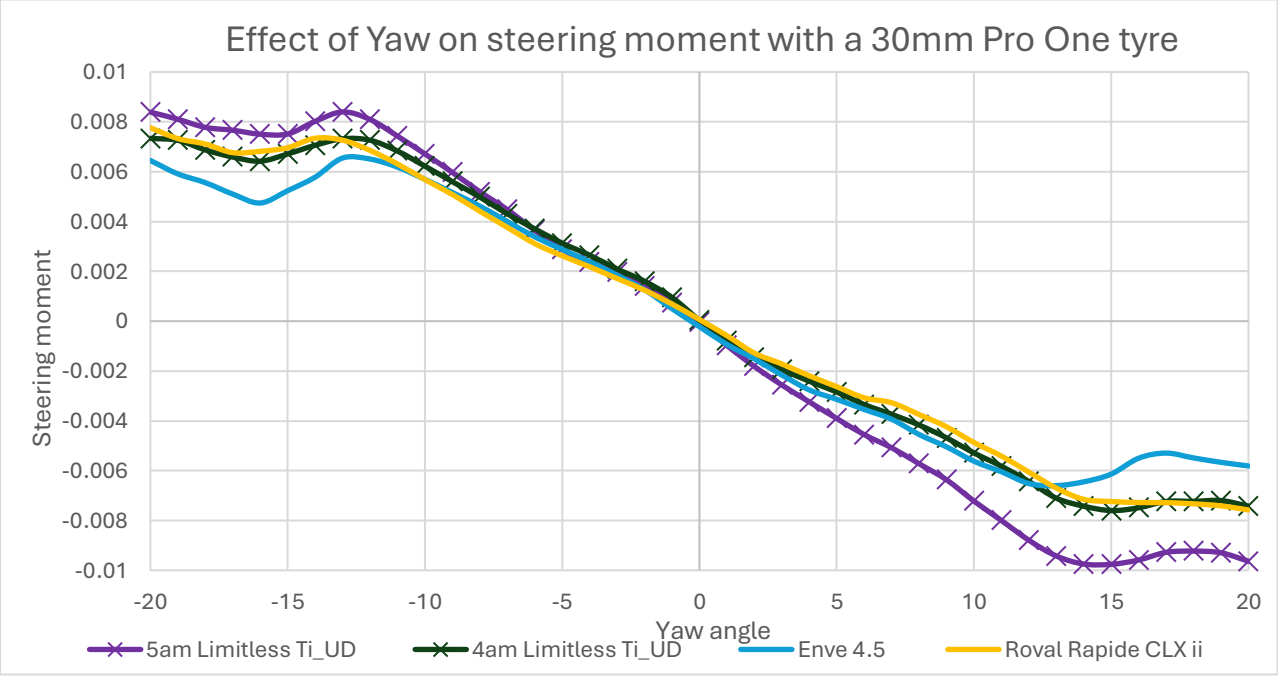

Figure 17- Graph of the change in of steering moment through a -20 to 20 degree yaw sweep

Figure 17 shows a range of steering moment plots, deeper wheels will typically show a higher peak force as they have a larger cross-sectional area. It is Hunt's philosophy that optimising for a lower peak side force is less beneficial than designing for a less violent stall condition, as we believe the force acting around the steerer axis is low and the rate of change of steering input force is a bigger issue. A smoother stall condition allows the rider to have a more predictable steering load when hit by a gust, as the steering response is proportional and linear with the force of the wind.

The Hunt 4AM limitless and Roval Rapide have a very similar steering moment trace where the profiles both stall at 15 degrees and have a smooth transition after stalling, this is likely due to both profiles being wider than more conventional wheels such as the Enve 4.5, and this extra width helping to control the airflow flow better at higher wind yaw angles. The opposite can be seen with the Enve 4.5 wheels where a sharp drop off between 12-16 degrees can be seen, this will lead to a sharper change in steering input.

2nd Wind tunnel – Silverstone Sports Engineering Hub January 2026



Figure 18 - Test wheels at SSE Tunnel

The first GST wind tunnel was completed shortly before other wheel brands refreshed their range of wheels, with Roval, Scope and Enve releasing new or updated versions of their 50+mm deep products. As such we felt it was appropriate to complete another test against these new products.

This test was carried out using the 30mm Schwalbe pro one tyre at 45 km/h, a more detailed method can be found in the appendix.

Wheelset	Mavic WAD (W)	Front Depth (mm)	Rear Depth (mm)	Wattage Delta	Spoke Material	Weight (g)
HUNT 5AM Limitless Ti-UD	97.94	58	55	0.00	Titanium Carbon	1212
HUNT 5AM Limitless Steel Spoke	99.62	58	55	1.68	Stainless Steel	1369
Roval Rapide Sprint	99.69	63	58	1.74	Carbon	1395
Scope Artech 6	99.93	65	65	1.99	Carbon	1244
Roval Rapide CLX iii	99.96	51	48	2.02	Carbon	1305
HUNT 4AM Limitless Ti-UD	100.89	49.5	47	2.95	Titanium Carbon	1156
Reserve 57/64 Turbulent Aero	100.96	57	64	3.02	Stainless Steel	1554
DT Swiss 55 ARC DICUT DB	100.99	55	55	3.04	Stainless Steel	1479
HUNT 4AM Limitless Steel Spoke	101.16	49.5	47	3.22	Stainless Steel	1283
Enve 4.5 Pro	102.29	49.8	54.2	4.35	Stainless Steel	1295
Roval Rapide CL ii	103.75	51	60	5.80	Stainless Steel	1590
DT 470	119.88	23	23	21.93	Stainless Steel	1850

Table 6- Full bike testing with 30mm Schwalbe Pro One



Figure 19- SL8 Test bike in the SSE tunnel with 5AM Ti_UD wheels fitted

The performance benefit of the HUNT Ti_UD 15/18 spoke system is clear in these results, with the HUNT 5AM Limitless Ti_UD being 1.68 Watt's faster than its steel spoke counterpart. For the 4AM Limitless Ti_UD, the difference is 0.27 watts. This is less than we would have expected and could have been due to some specific interaction with the

tyre chosen. From this data there is clearly a significant advantage to the Ti_UD system that is worth roughly one watt of drag which is 1% of the bike system drag.

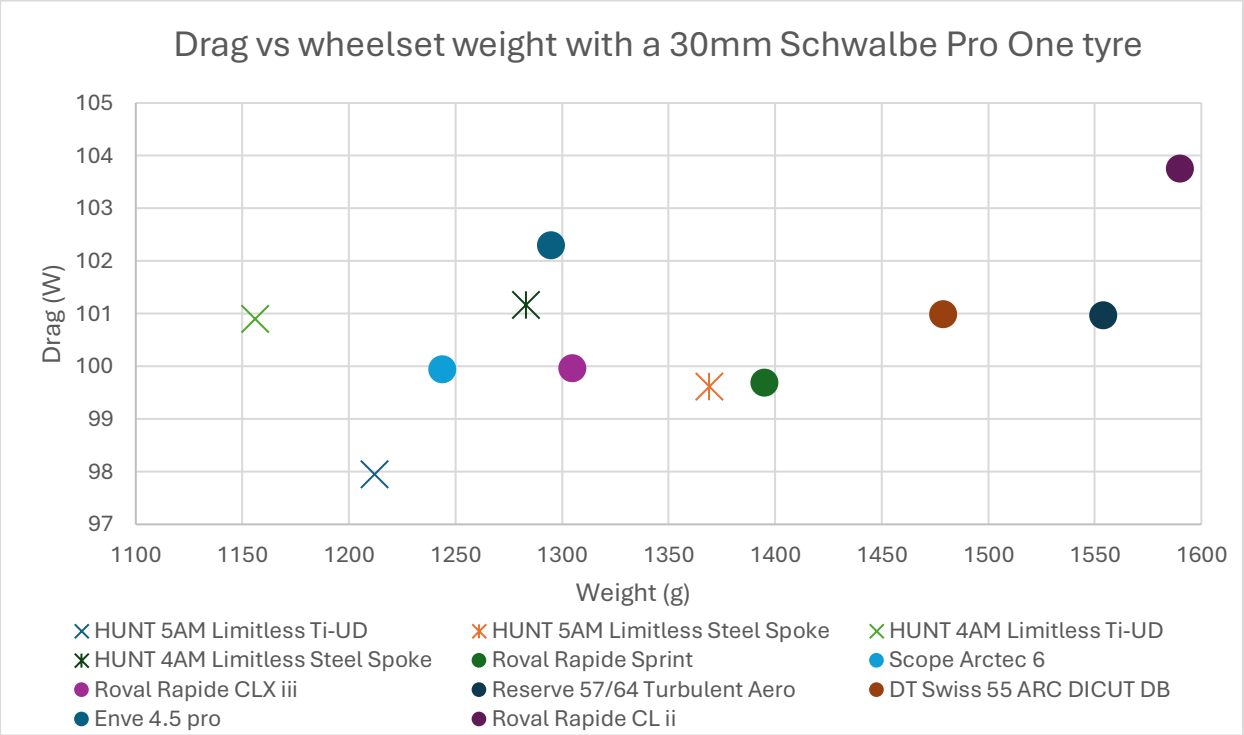

Figure 20 - Drag vs Wheelset weight, with 30mm Schwalbe Pro One tyre

With the Schwalbe 30mm tyre, the HUNT 5AM TI_UD is still the most aerodynamic of the group on test, while the HUNT 4AM Ti_UD is the lightest. The total magnitude of measured drag for bike and wheels is about 25% higher at the SSE tunnel vs the prior GST testing, this is likely due to the larger and wider stanchions used to support the bike in the SSE tunnel. However, the magnitude of the deltas between the wheelsets in each different tunnel are comparable.

The closest wheel to the HUNT 5AM TI_UD is the Scope Artech 6, which is heavier as well as being 7mm deeper on the front wheel. This extra depth will have an impact on the stability of the rim in crosswinds; this is shown in the steering moment graph (Figure 17) where the Scope Artech 6 has a higher peak steering moment at any wind yaw angle. This will mean that a greater steering input force is required with the Scope Artech 6 vs the HUNT 5AM TI_UD when riding in any given wind condition.

The HUNT 5AM steel spoke is the only wheel in the top 6 in terms of drag that uses steel spokes and is both lighter and at least as aerodynamic as the Roval Rapide sprint, while being 5mm shallower on both rims.

The HUNT 4AM Limitless Steel Spoke is middle of the pack in terms of aerodynamic performance, being roughly one watt faster than the Enve 4.5 Pro's, one watt slower than the Roval Rapide CLX iii, and almost the same as the DT Swiss 55 ARC Dicut, all while being the shallowest and lightest wheels in this key competitor set.

All the deep carbon wheels show a large improvement over the DT Swiss 470 DB, this is an alloy rim OEM spec wheel, it has not been shown on figure 20 to better display the rest of the data. The Roval Rapide CL II is the wheel fitted to this bike by the bike manufacturer (Specialized SL8 Pro 2024) and are a notable step behind the rest of the deep carbon wheels, in fact they are the heaviest and least aerodynamic carbon wheelset on test.

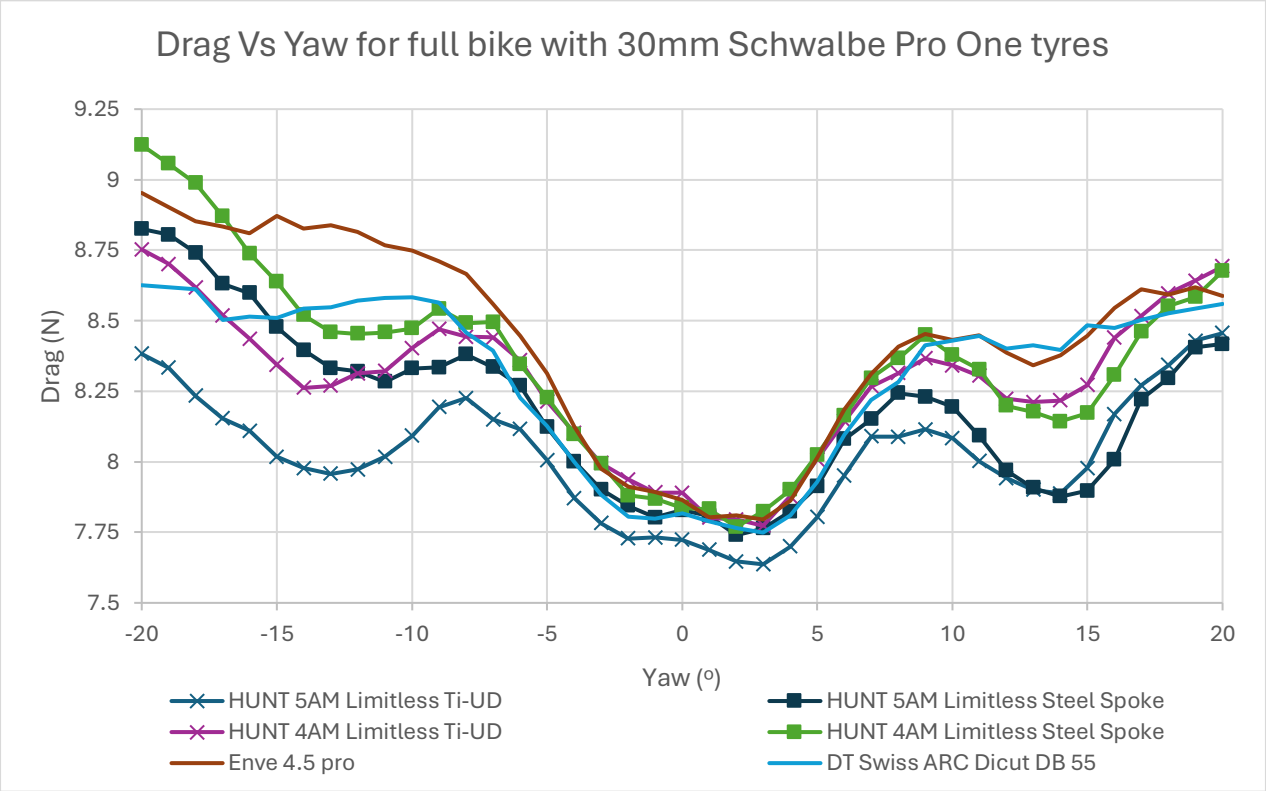

Figure 21-Drag across a -20 to 20 degrees yaw, with a 30mm Schwalbe Pro One

The sailing effect can be seen clearly with the HUNT 5AM Limitless Steel in figure 21, this is an effect where the drag on a tyre and rim can be seen to dramatically drop at specific yaw angles, typically somewhere between 7 to 15 degrees yaw.

The HUNT 5AM Limitless Steel spoke sails the best out of the wheels shown on this chart, with real separation over the competition between 7 to 20 degrees. The DT Swiss ARC Dicut DB 55, is close at low yaw to the 5AM, but clearly does not sail as well above 7 degrees. The 4AM Limitless, both steel spoke and TI_UD, as you would expect, have a very similar drag profile to one another but with a slight offset across the whole sweep, with the Ti_UD being slightly lower drag almost everywhere. The Enve 4.5 Pro is very similar to the 4AM wheels until 7 degrees, where the drag can be seen to continue to

increase, whereas both of the HUNT 4AM Wheels begin to sail and the drag does not continue to increase.

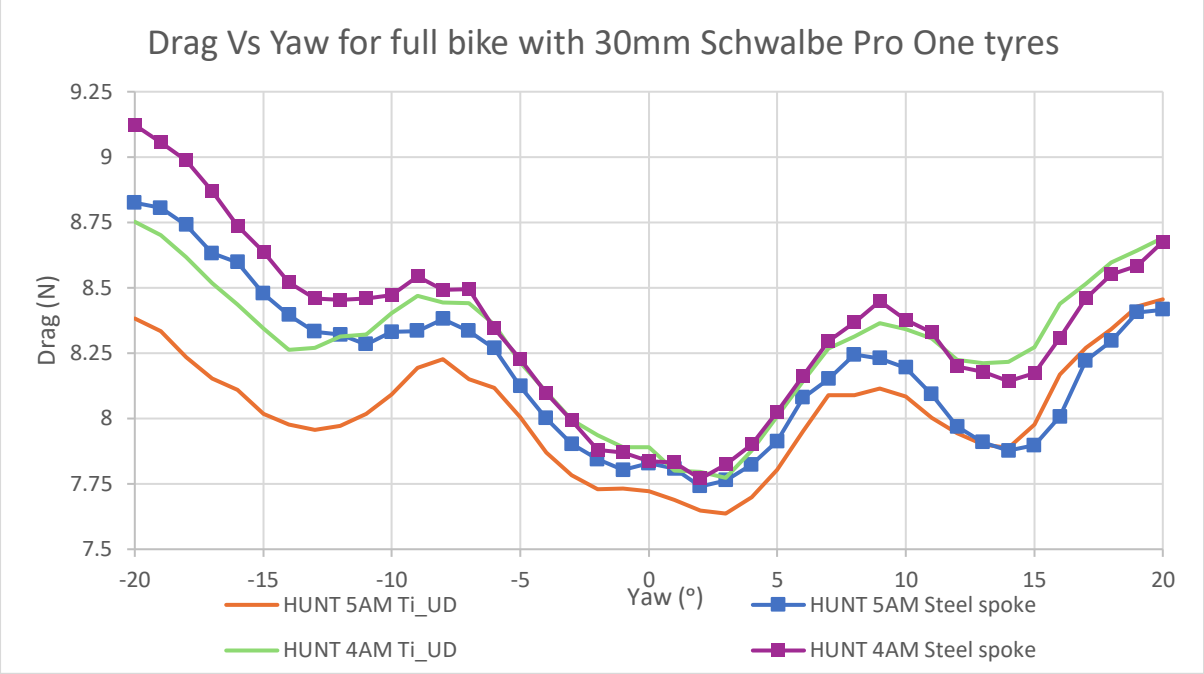

Figure 22-Drag Vs Yaw with 30mm Schwalbe Pro One tyre to compare spoke type

Figure 22 shows clearly that the HUNT 4AM and 5AM limitless wheels built with Ti_UD spokes are more aerodynamic than their respective steel spoke versions. It can also be seen that there is a bigger advantage seen by the Ti_UD spokes between -5 to -20 degrees, these yaw angles are where the bike is presenting the drive side to the wind. The Ti_UD spoke versions of the 4AM and 5AM wheels have just 5 radial spokes on this side of the front wheel, we believe this why there is this reduction in drag between -5 to -20 over the 10 Super Wing spokes used on the Steel spoke versions.

Outdoor testing

Outdoor test 1

The final validation testing that we completed was outside full bike and rider testing using an Aerosensor aerometer system, we have been developing this capability over the past year with the support of Aerosensor founder Dr Barnaby Garrood.

With this equipment we have been able to repeat three runs of the baseline test within +/- 1% at a target speed of about 41kph (320-335 watts was required for this speed), this then gives a margin of uncertainty of +/- 3 watts. More information about the test setup can be found in the appendix.



Figure 23- Aerosensor fitted, and test location at Dunsfold Airfield

All the wheels were tested with 30mm GP5000 STR tyres and using 60ml of sealant. Unlike with our wind tunnel testing protocol, the exact same tyres cannot be used for every test as it would just take too long to change tyres and sealant between every run. This extra time would also increase the chances that the environmental conditions could change over the course of a test period.

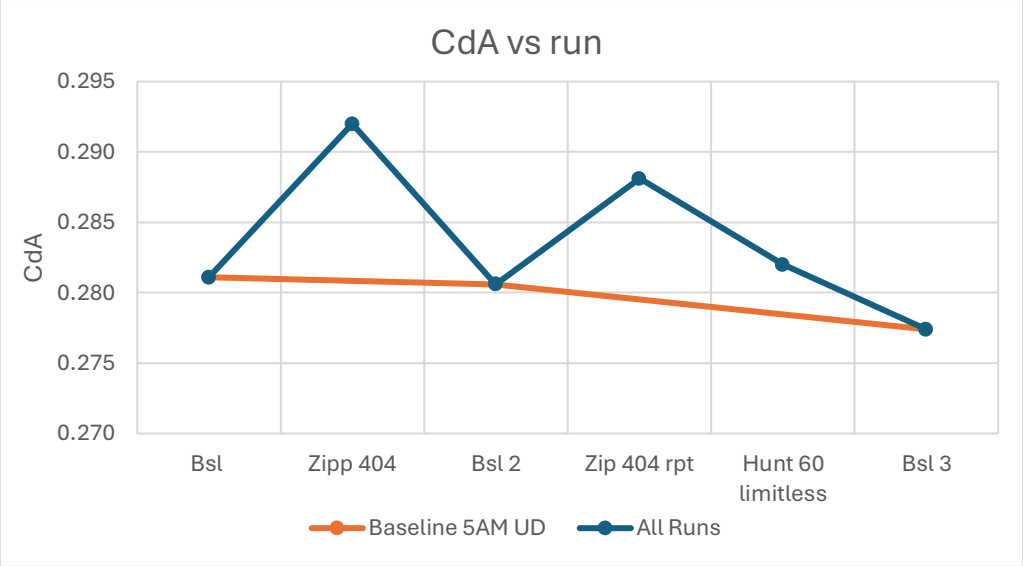

Figure 24- CdA for each run with Baseline trend

	CdA	dCdA	Watts@40kph	% difference
Baseline HUNT 5AM TI_UD average (F58/55R mm deep)	0.280		0	
Zipp 404 Firecrest average (58mm deep)	0.290	0.010	8.5	3.7%
HUNT 60 Limitless	0.282	0.002	1.9	0.8%

Table 6- Outdoor testing, with 30mm Continental GP5000 STR

The first test we did on the Dunsfold Aerodrome runway allowed us to get repeatable results with a clear difference being shown between both the HUNT 60 limitless and the 5AM Ti-UD, with all three of the 5AM Ti_UD runs being faster than the run of the 60 limitless and 8.5 watts faster than the Zipp 404 Firecrest.



Figure 25 - Testing on Dunsfold runway

Outdoor test 2

	CdA	dCdA	Watts@40kph	% difference
Baseline HUNT 5AM Limitless Ti_UD	0.339		0	
Scope Artech 6 w/carbon spokes	0.346	0.007	5.9	2.1%
HUNT 5AM Limitless steel spokes	0.343	0.004	3.5	1.2%

Table 7- Outdoor test 2 with 30mm Continental GP5000 STR tyres

A second test was run with the same set up, but in much colder weather meaning the test rider had to be in full winter kit rather than a skin suit, this accounts for the 0.059 change in CdA between the baselines on the two different test days. In this case we see the 5AM Ti-UD to be 2.1% faster as a percentage of total system drag. This is just under a 6 watt saving compared to the 2 watts seen in the wind tunnel using the same bike. The cause for this bigger performance difference could be due to the fact it was a very still night for the second test and the 5AM Ti_UD offers exceptional low yaw performance.

The HUNT 5AM steel spoke is between the carbon spoke version and the Scope Artech 6, this mirrors what was seen in the wind tunnel, with both spoke variants being faster than the Scope. With the level of uncertainty in these results, and the noise in the system we can be confident to say that both the 5AM wheels are at least as fast as the Scope Artech 6 and probably faster.

Also worth noting that in the SSE wind tunnel a tare run is taken with the wind turned off, but with the bike wheels spinning. This is done every time before a wind on measurement is taken, resulting in some of the aerodynamic forces required to drive the wheels through the air not being accounted for during the wind on run as they are removed with the tare.

Outdoor testing 3

	CdA	dCdA	Watts@40kph	% difference	Wheelset weight (g)
4AM Limitless Ti_UD (3 run average)	0.2985	0	0.00		1156
Enve 4.5 Pro	0.299	0.0005	0.41	0.002	1295
HUNT 4AM Limitless Steel Spoke	0.302	0.0035	2.88	0.012	1283

Table 7-Outdoor test 3 with 30mm Continental GP5000 STR tyres

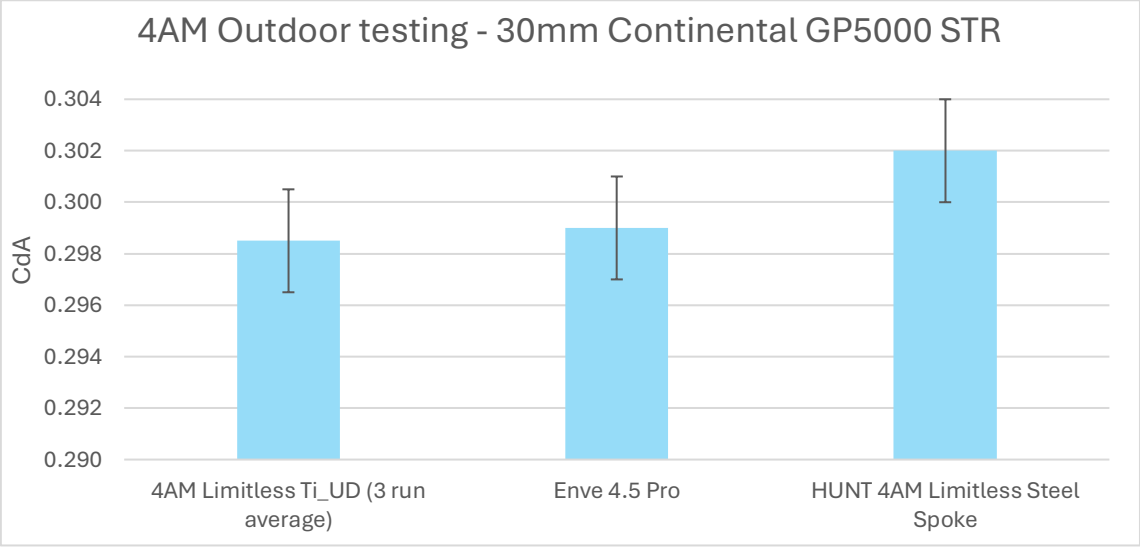

Figure 26-Outdoor test 3 results Continental GP5000 STR tyres

The 4AM Limitless Ti_UD was the baseline for this test, and it was not possible, within the error of the test, to be able to say if any of the wheels were faster or slower with a reasonable level of confidence.

The performance of the Enve 4.5 Pro and the HUNT 4AM Limitless Ti_UD are very similar in terms of aerodynamic drag, so considering the fact that the HUNT 4AM is 140 grams lighter, it would offer a performance gain in almost any race scenario.

Conclusion

The Goal of this project was to develop the fastest all-round road racing wheelset on the market and the perfect wheelset to ride on a grand tour queen stage. From the data presented in this paper it is clear this goal has been met.

In all but one wind tunnel test, the HUNT 5AM Ti_UD wheels are the most aerodynamically efficient when compared to a large range of competitor wheels, showing a clear drag advantage at all wind angles from -20 to +20 degrees. They are also the lightest wheels tested, especially impressive when considering that many of the competitors wheelsets have shallower rims.

The HUNT 5AM Ti_UD wheels also show class leading stability, demonstrated by a lower side force at every wind angle vs the tested competition. They also demonstrate a smoother transition from laminar to turbulent airflow, and at higher yaw angles than the competition. This has then also been observed in real world rider testing, where the stable handling of these wheels has been subjectively confirmed vs the competitor wheels.

The HUNT 4AM Ti_UD performed excellently and throughout the testing was not outperformed aerodynamically by a wheel that was lighter or shallower. It was also very stable so will perform equally well on climbs and descents.

The 15 front/18 rear Ti_UD carbon spokes have also been shown to be more aerodynamically efficient than 20 front/24 rear Super Wing stainless steel spokes when built into both the 5AM and 4AM wheelsets. The Super Wing stainless steel spokes when combined with hidden nipples in the HUNT 5AM steel spoke wheelset have also proven particularly efficient, showing lower drag than all other tested carbon spoked wheelsets other than the HUNT 5AM Ti_UD.

These results were then confirmed in a real-world scenario using the Aerosensor system, showing that the exceptional wind tunnel performance has translated to a clear measurable advantage in the real world. After thousands of hours of real-world rider testing completed, including race wins on multiple continents, we are confident that the combination of low drag and low weight means that both wheelsets will excel on all types of road racing courses.

Appendix

Wind tunnel set up

The wind tunnel has been an extremely useful tool in measuring the performance of a wheelset in a controlled environment and therefore an integral part of the development process.

Two Tunnels were used over the course of this project:
-The GST WindKanal in Immenstaad Germany
-The SSE (Silverstone Sport Engineering hub)
We transferred our test methodology from GST to SSE, as the dynamic sweep is the most efficient and accurate way to collect drag data for a bike only in our opinion,

Both wind tunnel tests:



Figure 27 – Cannondale System 6 used for the 2023 wind tunnel testing.

Bike: Specialized SL8 Pro 2024
Tyres used: Schwalbe Pro One 30, Vittoria Corsa Pro 28mm
Tyre Pressures: 50 Psi
Wind and Roller Speed: 45 kph
Yaw Angles: -20° to 20° dynamic sweep

Outdoor test set up

Outdoor testing:

Sensor: Aerosensor aerometer (with Aerodrome lap trigger and Aerobody laser position sensor)
Bike: Specialized SL8 Pro 2024
Tyres: Schwalbe Continental GP5000 STR 30mm
Tyre Pressures: 50 Psi
Target Speed: 41 kph
Power meter: Fevaro Assioma Pro RS-2
Protocol: Out and back 3x over a 600m to 1000m course with an Aerosensor aerodrome trip sensor to accurately start and stop test runs.
Location: Dunsfold aerodrome runway (Top Gear test track!)



Figure 28 - Aerosensor fitted, and test location at Dunsfold Airfield

The Aerosensor system measures wind speed with their aerometer and accounts for any gusts or variations in conditions over the test period. Fevaro Assioma Pro RS-2 power meter pedals were used to collect the power measurements and are calibrated before every run. Total system weight and tyre circumference are measured before every run and twinned with a wheel magnet speed sensor; this allows us to very accurately measure the speed of the bike and the distance travelled.

An aerodrome trip strip is laid down at either end of the test course, this starts and stops the run when the rider crosses each line, allowing perfect lap triggering for every lap. All of this data is then collected on a Garmin 840 head unit.

The rider is instructed to hold the same position and the handlebars are marked with tape so that the hands can be placed in the same position every run. A laser body position sensor is also mounted on the stem with measurements taken for the head and chest position of the rider to a 0.1mm accuracy, these measurements are visible during the run so that that rider can maintain position.

All of this means that the inputs are very tightly controlled, meaning that we can solve the virtual elevation equation (otherwise known as the Chung method) which is done within the Aerosensor portal, giving a CdA value for every run.

Mavic Wind averaged drag

When assessing the aerodynamic performance of a wheelset, it is necessary to consider the performance of the wheel in a variety of different 'yaw angles' – i.e. the effective angle of wind the rider is experiencing as they ride. Because the rider is moving forwards this will be affected by the rider's speed, the wind angle and the wind speed.

The time spent at any given yaw angle will be different, depending on the conditions and route. In order to give a consistent method for combining these yaw angles into a single wind averaged drag (WAD) value Mavic has developed and published a 'ponderation law'.

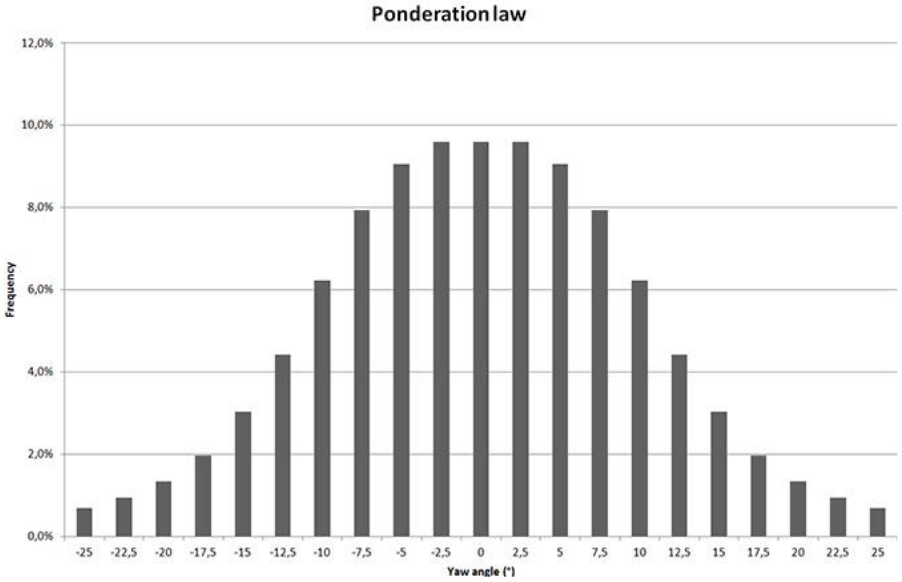

Figure 29- Mavic chart showing their assessment of time spent by riders experiencing different yaw angles.

The GST and Silverstone wind tunnel is able to take measurements between -20^0 and + 20^0, so the values above and below 20^0 have been removed from the weighting.