***WARNING:** Tyre Brands, models and widths used for testing purposes are not a validation or approval for fitment on a Hunt wheel. We share this data in an open format so you the Rider can see how we have worked through the process to bring the wheels to market. Please always check tyre/rim compatibility with the tyre manufacturer. In addition, always read your wheel's user-guide. Failure to do so could result in catastrophic failure and serious injury or death.*

# Delivering Limitless technology to a deeper, aerodynamically optimised, and stable system for Criterium, Road and Triathlon Racing: The HUNT LIMITLESS 60 AERO DISC

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## Abstract

Taken from 48 Limitless Research Paper, "Further Work" [1]
*"The LIMITLESS technology will be applied to other rim depths to provide a wider range of wheel options suitable for different racing styles and wind conditions, providing even more benefits to riders."*

The acceptance of the combined benefits of wider tyres for rolling resistance and comfort for all levels of cyclists, coupled with the adoption of disc brakes in professional and amateur road cycling has sparked a new era of wider, aerodynamically optimised rim profiles. The authors took this aerodynamic performance to the highest level with the 48 Limitless Wheelset, achieving very low drag at minimal compromise with weight.

Transferring the knowledge and LIMITLESS technology (patent pending), the authors set out to deliver the aerodynamic profile advantages to an even more critical system balancing weight, drag, and stability associated with a deeper profile specifically dedicated to criterium, road racer, and triathlon riding.

The developed 60mm deep and 34mm wide rim profile used on the 60 LIMITLESS AERO DISC wheelset was tested against a range of the world's leading wheelsets at and around the 60mm depth. All data is processed using the wind averaged power analysis proposed by Mavic. The data show the 60 Limitless Aero Disc wheels to be extremely competitive aerodynamically with superior stability characteristics when tested with both 25mm and 28mm tyres, within 0.35W of the fastest wheels tested.

## 1. Introduction

Bicycle wheel aerodynamics have been an active area of research and development since the late 1970s and the developments made have seen huge improvements in both the aerodynamic performance but also the durability and usability of aerodynamic wheels.

In the 2010's most major wheel manufacturers settled on designs based around a few commonly accepted design features for optimum aerodynamics:

- Using the maximum depth permitted by the conditions of use – since larger rims depths have typically higher mass, are more sensitive to crosswinds, and have at times been banned in some competitions.
- A maximum rim width that is close to or greater than the width of the tyre.
- A large radius of curvature at the spoke bed.

Many wheel and bike companies provide only limited wind tunnel and aerodynamic data, typically with a small number of data points and often comparing only to the company's own previous models. This makes it difficult for riders to compare the performance of products and make informed choices about what they ride. In this paper the authors aim to be as open as possible in providing meaningful data and comparisons to similar wheels currently available to riders from other companies. The authors have also included details of the development process and prototype testing results so that riders may see each step leading to the finished wheels.

### 1.1 The adoption of disc brakes in road cycling

In 2016 cycling's governing body the UCI began trialling the use of disc brakes in road cycling, and this technology became fully authorised in 2018.

While initially perceived as having poorer aerodynamic performance resulting from the presence of the disc rotors; disc brakes have become the default option for newly released aerodynamic road bikes, with the latest aerodynamic bikes from most major bike manufacturers being released only in disc brake format.

These bikes have benefited from the greater flexibility of design that comes with use of disc brakes – which no longer require the fork and seat stays to sit close to the wheel in order to mount a brake caliper. Additionally, brake calipers for disc brakes are placed behind frame structures for improved aerodynamic performance without compromises on braking performance and ease of use which have been typical of hidden rim brake designs.

Similar and even greater advantages exist in designing aerodynamic disc brake wheels themselves. In rim brake systems the need to use the rim surface for braking imposes several design limitations:

- The maximum width of the rim in the area immediately below the tyre is limited to ensure the rim can fit between the brake calipers.
- The braking surface must be flat, and parallel or close to parallel to achieve good contact from the brake pads.
- The braking surface needs to be engineered to cope with the significant heat build-up from braking on long descents, as well as having sufficient thickness to cope with abrasion from braking on the surface.

By designing a wheelset and rim shape that is fully optimised for disc brake use, the authors were able to ignore these previous limitations of rim design with the intention to greatly improve on the performance of currently available disc brake wheelsets.

### 1.2 The increasing use of wider tyres and tubeless technology in road racing

Several companies, groups and individuals have been carrying out testing on the effects of using larger tyres with lower tyre pressures and the benefits that this offers to riders. [2][3] The benefits gained in grip and handling are widely accepted, but recent testing has also shown that wider tyres with lower pressures can also reduce rolling resistance. In addition, in certain cases the market leading performance tubeless tyres offer lower rolling resistance than tubular tyres that have been traditionally been favoured by professional road racers. [4]

Increasing numbers of professional riders have begun using larger tyre sizes with 25mm now the norm and many riders choosing to use 28mm tyres, particularly in races with cobbled or gravel road sections. Current wheel designs have typically been optimised around the use of a 23mm tyre. When used with wider 25mm or 28mm tyres, the excess difference between the tyre width and the external rim width often results in poorer aerodynamic performance when used with wider tyres. If rims are correctly optimised for wider tyres the aerodynamic differences between wider and narrower tyres will be reduced, and may be eliminated all-together, especially at higher yaw angles where the aerodynamic performance is more dependent on overall rim shape than frontal area.

Tubeless tyres are also becoming more popular in the professional peloton because of rolling resistance benefits and the fact that tubeless tires can prevent punctures that might otherwise cost a rider a race victory. [5]

Considering the benefits of wider tyres and tubeless technology, the new HUNT wheelset would be optimised for use with 28mm tyres and fully compatible with 25mm tyres. The wheelset would also be fully compatible with all tubeless tyres as well as non-tubeless clincher tyres.

## 2. The purpose of the wheels

The team established a design brief for the project:

- A wheelset specifically designed for criterium and mass start road racing.
- Optimised for the best aerodynamic performance with wider 25mm and 28mm tyres (with main focus on 28mm).
- A rim designed specifically for disc brake bikes.
- Use of a hooked rim design to ensure compatibility with tubeless and non-tubeless clincher tyres.
- A tyre bed design compliant with the latest ETRTO tubeless standards.

Key dimensions for the wheelset were determined:

- The rim depth was set at 60mm, providing exceptional aerodynamic performance whilst maintaining the handling, stability, and low mass required for professional, elite, and amateur road racing.
- The internal rim width was set at 21mm – providing a stable tyre profile with a wide base whilst still ensuring a safe and secure tyre fit.

Importantly, the extent of the external rim width was not specified at this point – building on the knowledge of previous research, the design would be chosen through prototype wind tunnel testing.

## 3. Design principles and initial proposed designs

The knowledge and experience gained during the 48 Limitless Project, confirming the aerodynamic performance of a wider profile with a high curvature spoke bed, led to a head start in the design phase of this project. This enabled the team to focus on only two possible profile designs, based on these key design features:

- Use the shape of the rim in combination with a tyre to create an approximation of a National Advisory Committee for Aeronautics (NACA) published aerofoil shape, but with a truncated trailing edge. This truncated shape ensures that the rim design will perform well at a wide range of wind yaw angles.
- The use of this NACA profile places the widest point of the whole cross section slightly below the base of the tyre, with this point wider than the tyre width by approximately 4mm.

Within these principles, proposed rim shapes were developed combining elements of different widths, radii of curvature on the sidewall and rim bed, and different shapes around the rim-tyre interface.

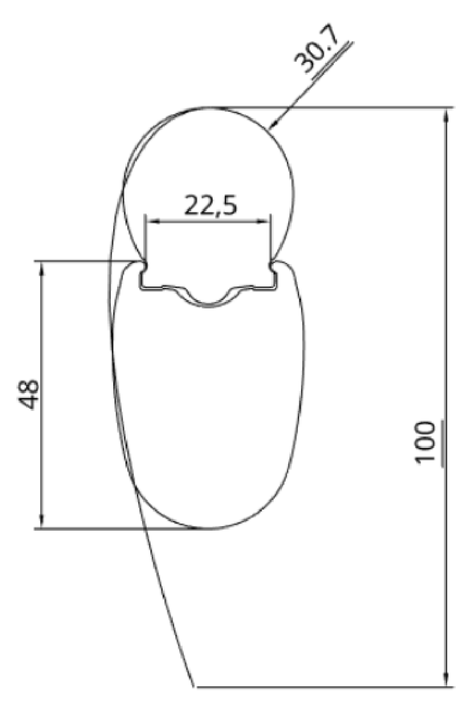

*Figure 1 Illustration example of the truncated NACA profile approximation as used in the 48 Limitless Project*

Two prototypes with a small change in sidewall radius and external width were tested as below:

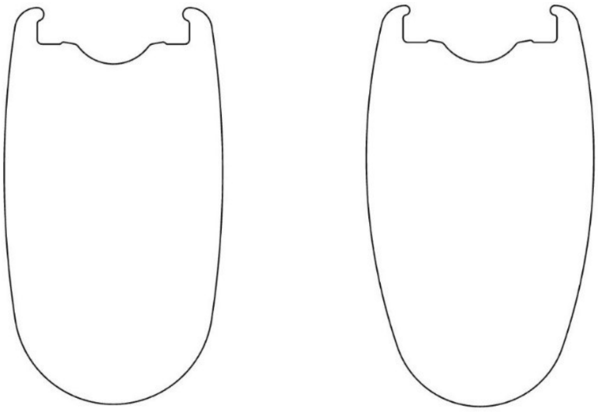

*Figure 2 Cross-sections of the 2 initial proposed rim designs (Left Proto 1, Right Proto 2)*

## 4. Patent pending LIMITLESS Technology

As discussed, the evidence of a wider profile creating a smoother transition of airflow around the increasingly popular wider tyre (with rolling resistance and comfort benefits), therefore improving aerodynamic efficiency is well known.

In applying these design characteristics to a deeper profile due to the additional material involved, the resulting weight is also increased. Furthermore, mass located at the outer edge of a rotating object negatively impacts the overall wheel performance. The application of the LIMITLESS technology is therefore even more significant and important in achieving an aerodynamically optimised profile without affecting other ride characteristics.

The technology as used previously in the 48 Limitless Project and described below, was modified and optimised for the 60 Limitless profile, ensuring weight, stiffness and impact performance criteria were met.

LIMITLESS technology comprises the application of a low density expanded polymer, which can be comoulded into a groove formed in the widest part of the rim. The polymer is carefully selected with the desired density, water resistance, strength and compliance to perform well when moulded into the side of a carbon fibre rim. The polymer has a density of $0.7gcm^{-3}$, compared to approximately $1.6gcm^{3}$ for the carbon fibre/epoxy resin composite used in the rest of the rim structure. This allows weight saving while the design still maintains the same thickness of carbon fibre composite in all the key structural areas when compared to a traditional rim design.

## 5. Testing method

There are three primary tools currently used for measuring aerodynamic drag when developing bicycle components:

1. Wind tunnel testing – widely accepted as the industry standard for testing completed products. It generates reproducible and reliable results and allows testing over a range of wind yaw angles.

2. GPS based track testing – Uses a GPS locator combined with power data to measure aerodynamic drag. Cannot be used to measure drag at non-zero yaw angles and relies on consistent rider position to measure component performance.
3. Computational fluid dynamics (CFD) – uses a finite volume analysis to compute the airflow through a 'mesh' constructed around computer generated model of the shape. CFD capabilities are being developed in-house at HUNT. Several simulations were run after this project with the primary goal of validating against the wind tunnel results to prepare a reliable and accurate model for future projects.

As in previous tests the independently operated and validated GST Wind Tunnel in Immenstaad, Germany, was chosen to test the 60 Limitless. GST is a low speed, open wind tunnel, constructed in 1986 for use by Airbus Defence and Space and well suited for bicycle testing – used and recognised widely in the cycling industry for independent and product development testing alike.

### 5.1 Wind Tunnel Setup

During the development of the 60 Limitless Aero Disc, three test sessions were performed.

1. Prototype Test, January 2020
2. Pre-production Model Test, August 2020
3. Production Model 28mm Tyre Test, November 2020

Prototype testing was conducted with the Scott Foil Disc Bike and all remainder tests with the Canyon Aeroad Disc road bike. For all tests, wheelsets were fitted with Shimano 140mm centre lock disc rotors.

Control tyres were selected:

- Schwalbe Pro-One 25mm
- Schwalbe Pro-One 28mm

Each tyre had the mould flashings removed with sandpaper before testing and the same individual tyre was used to test all the wheelsets.

From previous testing, it was known that most of the aerodynamic difference between rim designs resulted from the front wheel since the rear wheel is largely shielded from the airflow which has also been disturbed as it passes over the bike and rider. To this end, the prototype wind tunnel test was carried out using an ENVE 5.6 SES DISC as a control rear wheel fitted with a Schwalbe Pro-One 25mm tyre. Production model tests were carried out to compare the final performance of the front and rear wheel together.

### 5.2 Testing procedure

The bicycle was mounted on a rotating table, fitted with front and rear rollers. For each run the wheels were driven by the rollers at 45 kmh$^{-1}$ and air was passed through the tunnel at a constant speed of 45kmh$^{-1}$. The turntable was then rotated continuously through yaw angles between -20° and +20° to the oncoming airflow.

*Figure 3 Wind Tunnel Setup (60 Limitless Rear / 48 Limitless Front)*

Before each test tyres were inflated to 60psi and the tyre widths were measured at four points around the rim. Pressures were set lower than normal riding pressures in order to prevent damage to the 3D printed prototypes.

Pressures for the pre-production and production tests were set to 6bar.

## 5.3 Development and testing of prototypes

The two defined 3D printed rim prototypes were produced in ABS polymer, and then assembled with Pillar wing spokes into complete wheelsets for testing in the tunnel against each other and a range of class leading competitor wheelsets. The test results against competitor wheels can be found in section 8.1.

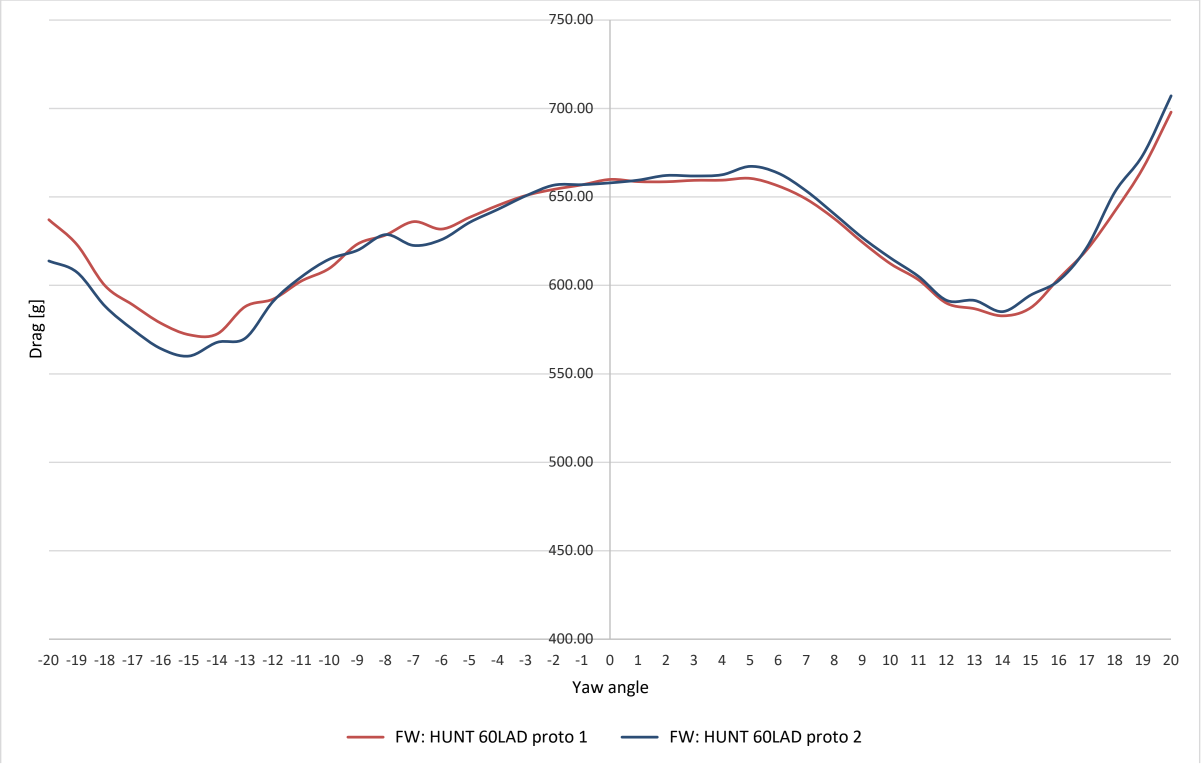

*Figure 4 Drag [g] vs yaw angle [°] for two HUNT 60 LAD prototypes with control Schwalbe Pro One 25mm Tyre*

*Figure 5 Photograph of the 3D printed ABS prototypes during the prototype Wind Tunnel Test*

The results showed that proto 2 performed superior to proto 1 as well as other tested competitors when combined with the ENVE 5.6 SES DISC rear wheel. Looking deeper into the drag curve results, in general the proto 2 exhibits lower drag at higher yaw angles and hence this was chosen to move forward into pre-production testing.

## 6. Analysis of results

### 6.1 Yaw angles

A key factor in aerodynamic performance of bicycle wheels is how they perform not only when travelling straight on into the wind, but their performance when riding into a cross wind. When riding in real world conditions the wind approaches the rider from a given angle, α. When the vector of the bicycle's velocity, Vb, is added to the vector of the wind, w, the rider experiences wind at the yaw angle, β.

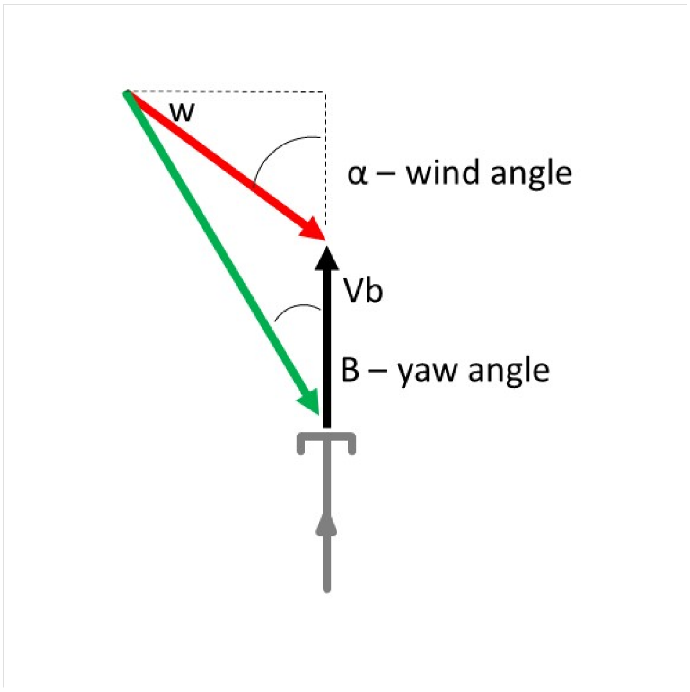

*Figure 6 Diagram showing the relationship between rider velocity, Vb, wind velocity, w, wind angle, α, and yaw angle, β.*

When running the test in the wind tunnel, the bike is held stationary so the yaw angle β is simply the angle the bike makes to the oncoming airflow.

### 6.2 Wind averaged power / wind averaged drag

Methods for making an absolute ranking of the aerodynamic performance of bicycle wheels are an area of debate in the industry, however it is widely accepted that the performance of wheels should be considered at a range of wind yaw angles. To do so quantitatively requires calculation of a weighted average of drag or power based on the relative time a cyclist may experience wind at a particular yaw angle while riding. This process is referred to as calculating a wind averaged power or wind averaged drag.

In order to allow the best comparison of our data with those of other wheel companies yaw angle weightings have been calculated using the 'ponderation law' proposed by Mavic [6]. This was produced using a bike mounted sensor on a time trial bike in a variety of locations.

The Mavic distribution is shown below. The 22.5° and 25° points have been omitted in our calculation because the wind tunnel turntable allows data collection only up to 20°.

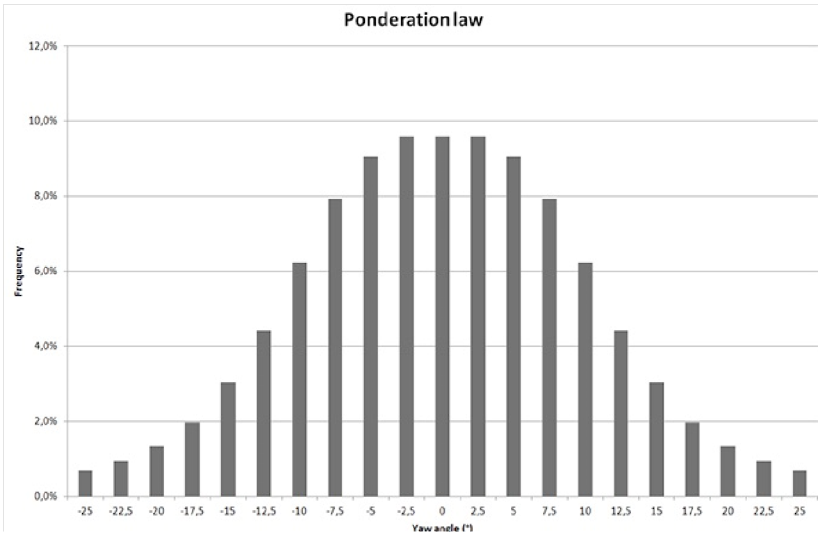

*Figure 7 Yaw angle distribution proposed by Mavic, after carrying out measurements on a time trial bike with a bike mounted wind sensor.*

## 7. Side Wind Stability

The analysis of side forces or steering moment has been increasingly studied in recent years. When determining the aerodynamic performance of the HUNT 60 LIMITLESS Wheelset, the authors present and consider the effect of both drag and side wind stability as both variables are important in understanding the overall performance of the wheels in a real-world situation.

Ensuring consistent and predictable bike handling during varying side wind conditions is key to inspiring confidence in the rider to maintain the most aerodynamic position on the bicycle and utilise fully the benefits of the optimised aerodynamic drag of the wheels.

When handling becomes unmanageable riders may need to sit up to control the bicycle resulting a heavy CdA penalty. This could cost a race – there is little point in designing the fastest wheels if the rider is unable to confidently stay in their aero position.

A well-known consequence of riding a deeper wheel is increased side forces caused by the larger surface area in contact with the incoming airflow. This increased side force can affect the stability of the wheelset for the rider. It is also observed through wind tunnel testing that side force increases with yaw angle and that the greatest instability is seen when passing through the stall angle, where sudden pressure changes mean unpredictable side forces.

The authors set out to create a wheel that performs well not only in minimising drag but creates a stable and predictable ride resulting from more consistent side forces as the oncoming yaw angle of the wind changes. A consequence of a wider, truncated and larger radius spoke bed is superior high yaw angle drag performance. As a result, the stall point is shifted to a higher yaw angle and the side force changes are more consistent over a large range of yaw angles meaning the rider will not feel as many sudden changes in handling.

From previous wind tunnel tests, it was clear that the major changes in the side force curve were seen in competitors from as early as 12 degrees yaw. Using the Mavic distribution law above, the percentage time spent above +12 degrees and below -12 degrees yaw was ~21%, this is a significant time and outlines the importance of the results presented later in this white paper.

## 8. Testing results

Throughout the development process, wheels were tested against class-leading competitors. Not all competitor products were readily available for all tests, and only best performing wheelsets were retested against the final production versions of the HUNT LIMITLESS 60 AERO DISC. The full testing results are shown in the tables and charts below.

A note; the wheelsets tested against have a range of depths influencing a wheel's performance both in terms of drag and side force, this must therefore be considered when comparing results directly.

### 8.1 3D Printed Samples Competitor Results

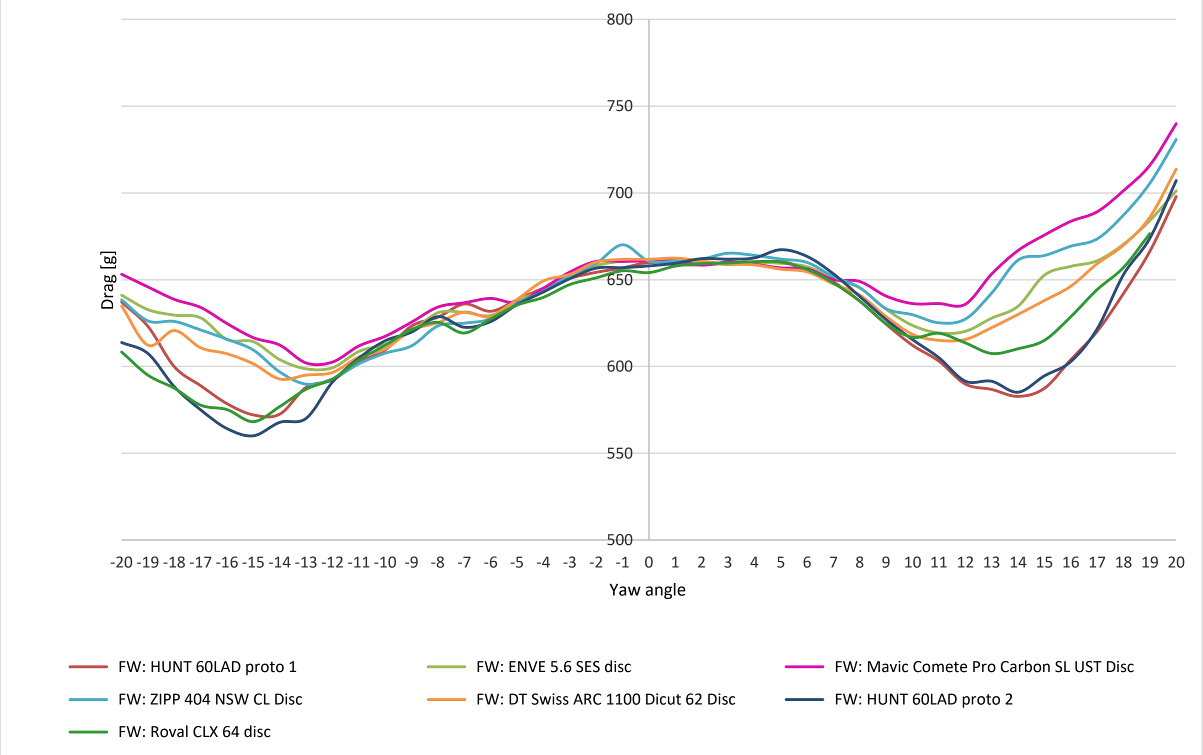

*Figure 8 Drag [g] vs yaw angle [°] from first wind tunnel test January 2020 showing HUNT LIMITLESS 60 AERO DISC prototypes against competitor wheelsets using a Schwalbe Pro One 25mm tyre with control ENVE 5.6 Rear Wheel*

| Configuration with Pro One 25 | Average Power [Watt] @45km/h | **ΔP tot or power loss [Watt]** |
|---|---|---|
| HUNT 60 LAD Proto 2 | 76.55 | **0.00** |
| HUNT 60 LAD Proto 1 | 76.70 | **0.16** |
| Roval CLX 64 Disc | 76.91 | **0.36** |
| DT Swiss ARC 1100 Dicut 62 Disc | 78.07 | **1.52** |
| ENVE 5.6 SES Disc | 78.51 | **1.96** |
| ZIPP 404 NSW CL Disc | 78.83 | **2.28** |
| Mavic Comete Pro Carbon SL UST Disc | 79.67 | **3.12** |

### 8.2 First pre-production wind tunnel test – August 2020

The first round of testing was conducted to validate the prototype samples as a front and rear combination against the competitors. All competitors were tested with the 25mm tyre and the best performing were selected to be tested with the 28mm tyre.

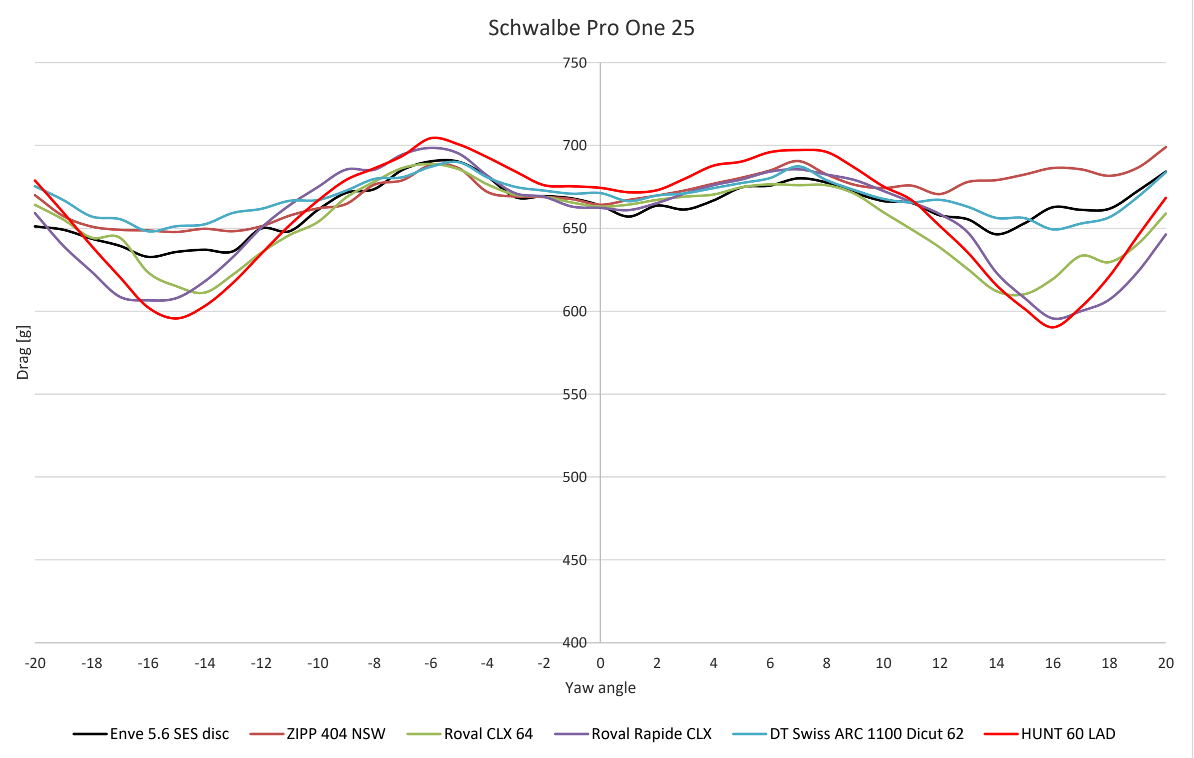

*Figure 9 Drag [g] vs yaw angle [°] from first wind tunnel test August 2020 showing HUNT LIMITLESS 60 AERO DISC against competitor wheelsets using a Schwalbe Pro One 25mm tyre*

| Configuration with Pro One 25 | Mavic calc WAD Power [Watt] @45km/h | Mavic calc WAD Drag [g] | **ΔP tot or power loss [Watt]** | ΔF tot or drag loss [g] |
|---|---|---|---|---|
| Roval CLX 64 Disc | 26,08 | 212,66 | **0,00** | 0,00 |
| Roval Rapide CLX Disc | 26,25 | 214,05 | **0,17** | 1,38 |
| Enve 5.6 SES Disc | 26,29 | 214,41 | **0,21** | 1,75 |
| HUNT 60 LAD | 26,41 | 215,34 | **0,33** | 2,68 |
| DT Swiss ARC 1100 Dicut 62 | 26,48 | 215,91 | **0,40** | 3,25 |
| ZIPP 404 NSW Disc | 26,48 | 215,96 | **0,40** | 3,30 |

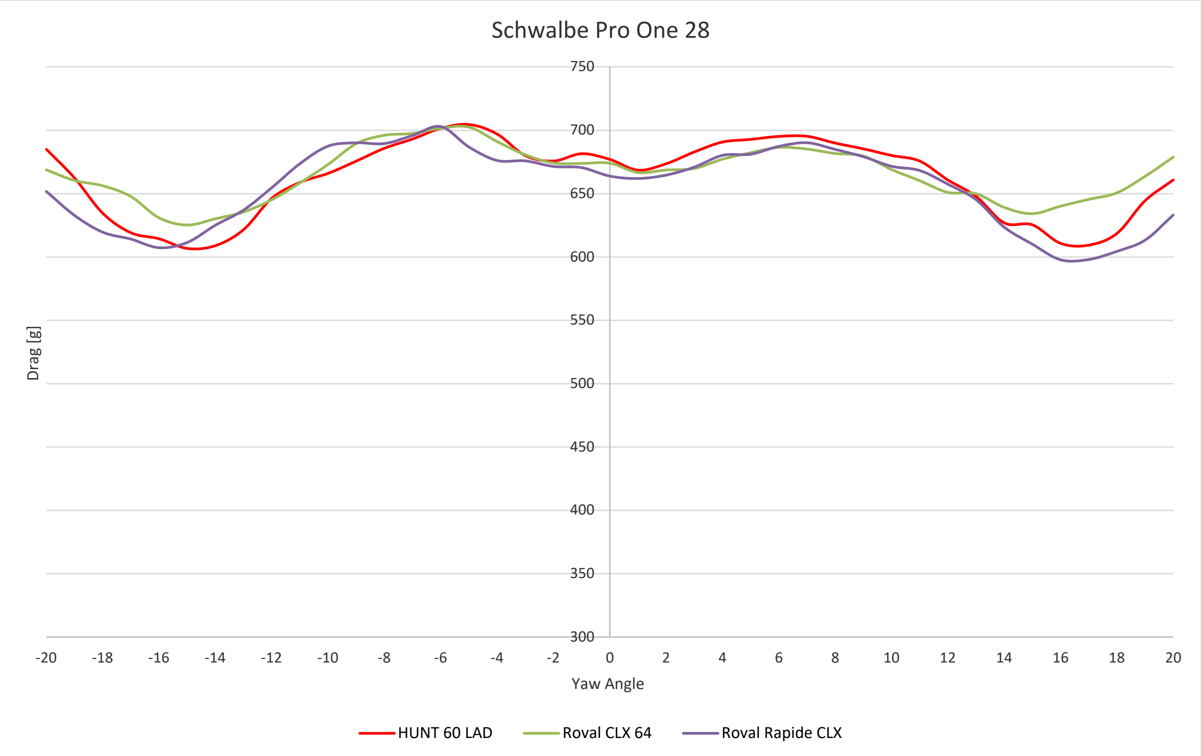

*Figure 10 Drag [g] vs yaw angle [°] from first wind tunnel test August 2020 showing HUNT LIMITLESS 60 AERO DISC against the best competitor wheelsets using a Schwalbe Pro One 28mm tyre*

| Configuration with Pro One 28 | Mavic calc WAD Power [Watt] @45km/h | Mavic calc WAD Drag [g] | **ΔP tot or power loss [Watt]** | ΔF tot or drag loss [g] |
|---|---|---|---|---|
| Roval Rapide CLX | 26,29 | 214,36 | **0,00** | 0,00 |
| Roval CLX 64 | 26,48 | 215,97 | **0,20** | 1,61 |
| HUNT 60 LAD | 26,53 | 216,32 | **0,24** | 1,96 |

### 8.3 Production Wind tunnel test – November 2020

A final visit to the Wind Tunnel was made to validate production results and to test further wheels with the 28mm tyre.

*The Roval CLX 64 was not obtainable for this test.

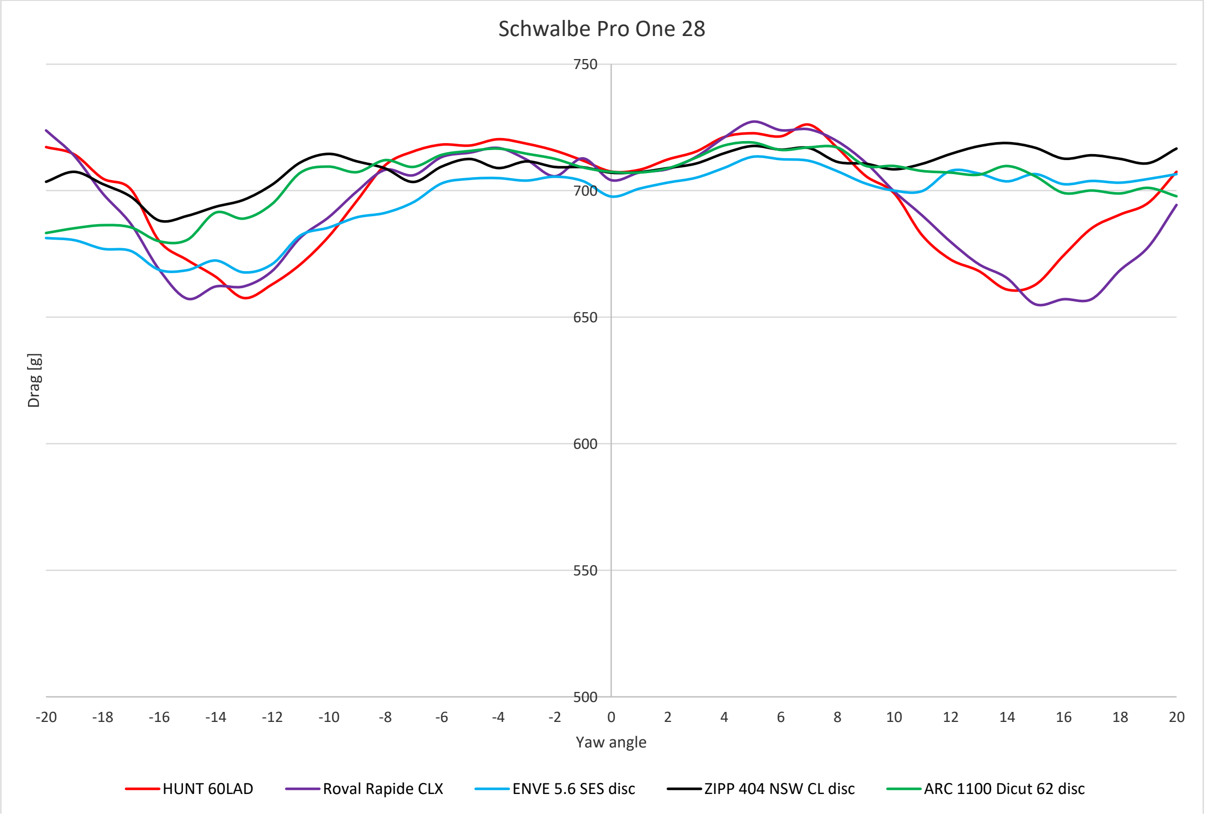

*Figure 11 Drag [g] vs yaw angle [°] from final wind tunnel test November 2020 showing HUNT LIMITLESS 60 AERO DISC against competitors using a Schwalbe Pro One 28mm tyre*

| Configuration with Pro One 28 | Mavic calc WAD Power [Watt] @45km/h | Mavic calc WAD Drag [g] | **ΔP tot or power loss [Watt]** | ΔF tot or drag loss [g] |
|---|---|---|---|---|
| ENVE 5.6 SES Disc | 48.59 | 396.28 | **0.00** | 0.00 |
| Roval Rapide CLX Disc | 48.73 | 397.38 | **0.13** | 1.10 |
| HUNT 60LAD | 48.94 | 399.11 | **0.35** | 2.83 |
| ARC 1100 Dicut 62 Disc | 49.22 | 401.37 | **0.62** | 5.08 |
| ZIPP 404 NSW CL Disc | 49.31 | 402.13 | **0.72** | 5.85 |

### 8.4 Side Force and Stability

The below graph details the side forces on the wheelsets versus different yaw angles for both 25mm and 28mm tyres.

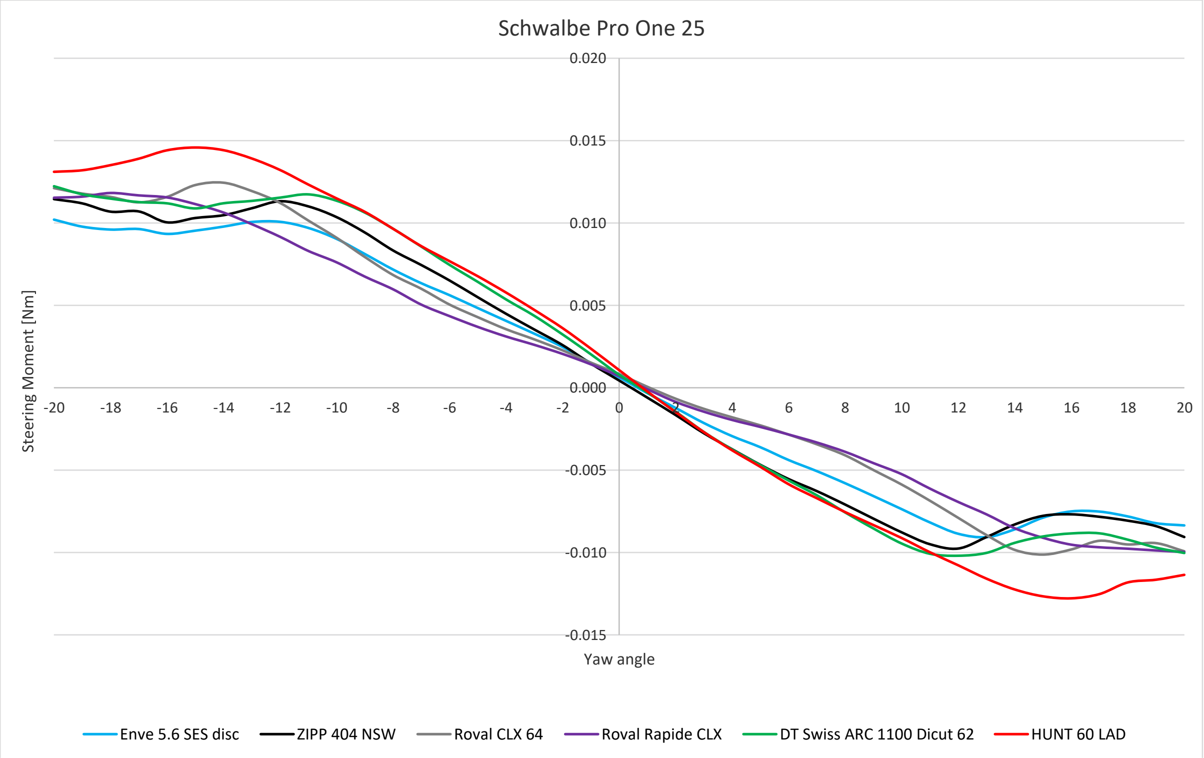

*Figure 12 Steering Moment [Nm] vs yaw angle [°] from final wind tunnel test August 2020 showing HUNT LIMITLESS 60 AERO DISC against competitors using a Schwalbe Pro One 25mm tyre*

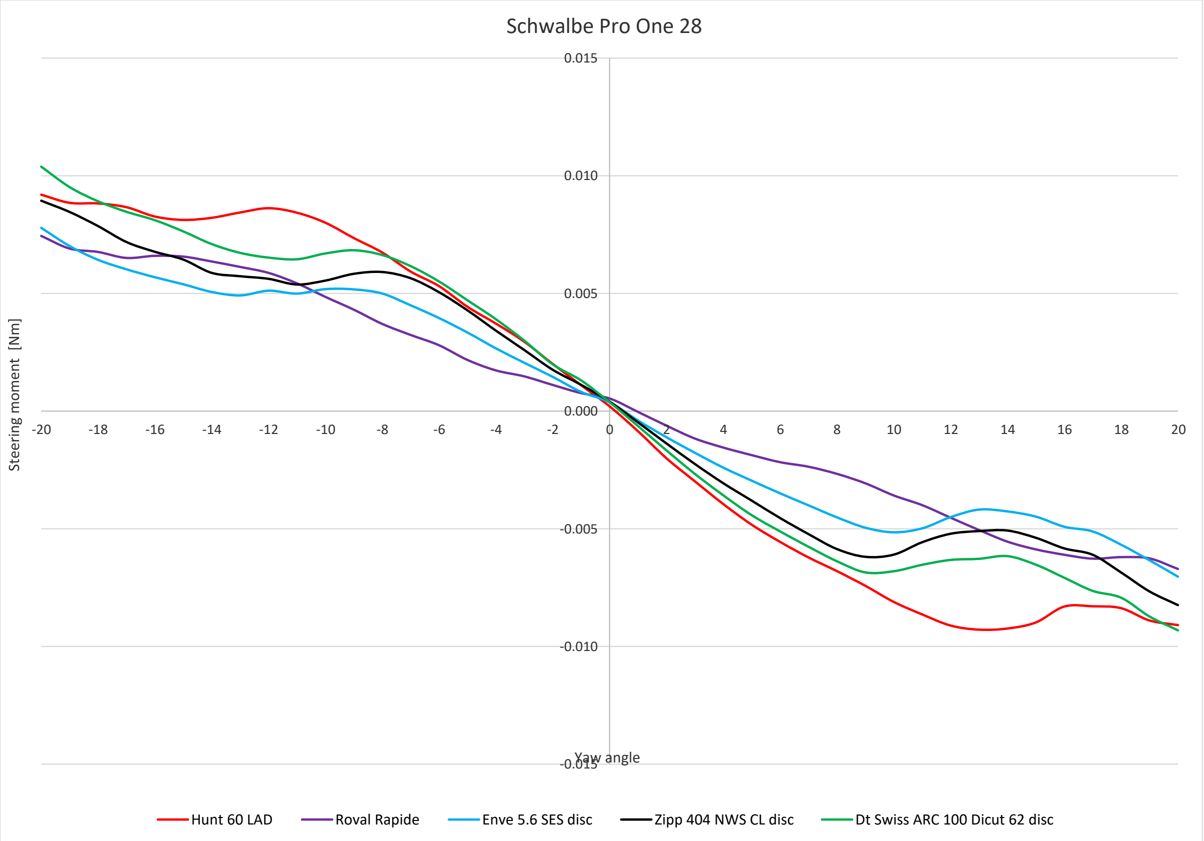

*Figure 13 Steering Moment [Nm] vs yaw angle [°] from final wind tunnel test November 2020 showing HUNT LIMITLESS 60 AERO DISC against competitors using a Schwalbe Pro One 28mm tyre*

## 9 Conclusions

The HUNT 60 LIMITLESS AERO DISC wheelset has been tested extensively in the wind tunnel, and the data shows competitive performance against a number of leading aerodynamic wheel manufacturers. When paired with the optimal Schwalbe Pro One 28mm tyre they are the 3rd fastest wheelset when tested against the leading competitors* (*versus those available at time of wind tunnel test in November 2020).

The power data from the tunnel was analysed with a set of yaw angle weightings independently published by Mavic and shows that the wind averaged power difference of 0.35W between the HUNT 60 LIMITLESS AERO DISC and ENVE 5.6 SES DISC and 0.22W between HUNT 60 LIMITLESS AERO DISC and ROVAL RAPIDE CLX as well as comfortably outperforming the other wheelsets on the test.

The Steering Moment analysis clearly confirms the predictable and stable handling characteristics of the 60 LIMITLESS AERO DISC notably at yaw angles greater than 10 degrees where the trend in side force is consistent to a higher yaw angles than observed in the competitor wheelsets. Additionally, the magnitude of the changes in side force through the stall point is lower than observed in the DT Swiss, Enve and Zipp wheels.

The further development and testing of a profile where the external width of the rim exceeds the width of the tyre has once again shown the performance benefits, especially at higher yaw angles, which are experienced more frequently by drop bar road racers and riders in real world riding.
The use of the patent pending LIMITLESS technology is even more crucial in a wheelset of this depth and has permitted the manufacture of the 60 LIMITLESS AERO DISC without increasing the rim mass significantly over a traditional rim construction method.

## Further work

Further work will be carried out on yaw angle analysis to propose a new wind averaged power weighting, available to all cycling companies, which is more representative of the wind conditions experienced in drop bar road racing and riding.

## Acknowledgements

Thank you to Ernst Pfeiffer at GST for all of his patience, hard work and good humour when we have been working together at the tunnel.

We would like to thank Canyon Bicycles UK for repeatedly loaning us the Aeroad Disc used for the wind tunnel testing.

We would also like to thank Schwalbe for assisting us with creating our CAD models for the wheel and tyre which were essential in generating the correct rim shapes used in all of our rim development to date.

Thank you to all of the staff at the Rider Firm every one of whom have contributed hugely to getting this project to where it is today.

Lastly and most importantly, an enormous thank you to all the dedicated and enthusiastic HUNT riders out there who have supported us, encouraged us and driven us to keep improving what we do for riders every day. Without you, this project would not have been possible.

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***WARNING:*** *Tyre Brands, models and widths used for testing purposes are not a validation or approval for fitment on a Hunt wheel. We share this data in an open format so you the Rider can see how we have worked through the process to bring the wheels to market. Please always check tyre/rim compatibility with the tyre manufacturer. In addition, always read your wheel's user-guide. Failure to do so could result in catastrophic failure and serious injury or death.*