Aerodynamic optimisation using Computational Fluid Dynamics paired with Wind Tunnel Validation delivering two world leading HUNT Aerodynamicist wheelsets

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Abstract

The authors present a complete aerodynamic optimisation study using newly applied in-house computational analysis techniques (CFD) coupled with extensive wind tunnel tests in-order-to develop a trio of aerodynamically advanced bicycle wheels. The aerodynamic design approach addresses the differing aerodynamic demands of front and rear wheels as part of the whole system to deliver maximum confidence in handling and exceptional speed to the criterium, time trial (TT) or triathlon rider.
The Hunt 8387 Aerodynamicist Wheelset (1796g) combination paired with the 25mm tyre follows the leading DT Swiss Dicut 80mm Wheelset (1777g) by 0.17W according to the Mavic Std WAD (Wind Averaged Drag).
However, when simulating the performance considering the asymmetric wind conditions at KONA (World triathlon Championships), the HUNT 8387 Aerodynamicist is the leading in class wheelset against those tested.
The shallower Hunt 7387 Aerodynamicist Wheelset (1776g) performs only 0.35W slower than the deeper offering in the same conditions whilst minimising steering forces.
Each offering provides world class aerodynamic performance for the rider against the tested competitors whilst delivering stable and predictable handling characteristics.

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1. Introduction

The aerodynamic profiles of deep section wheels used for TT and Triathlon have been traditionally conservative in their design approach however, there have been a few recent examples of steps towards the aerodynamic advantages associated with wider rims.
When designing wheels for long distance triathlon events the authors saw significant potential for wider rims to enable superior speed and with considerable time savings accumulating.

While cycling, aerodynamic drag typically accounts for between 70% and 80% of the drag on the rider and bicycle, with the wheels and tyres contributing approximately 10% of the aerodynamic drag. In the case of TT or triathlon, this requirement competitors to optimise their head and body position for the lowest coefficient of drag x area (c_dA), but importantly also ensuring that their chosen position can be held consistently throughout the cycling leg as movement away from the best position is likely to result in a significant increase in c_dA.
The wheels perform a dual role, firstly in minimising the drag of the wheels as part of the system and importantly to provide predictable and stable handling feedback to enable the rider the confidence to stay in the most aerodynamic position.

Typically, in order to achieve the best aerodynamic performance, the deepest possible wheel section will be used, but these deeper sections will tend to increase the side forces which impact steering when affected by a crosswind. Minimising the steering moment, and steering moment variability, experienced in crosswinds was an important design consideration for this project.

As ever, the authors aim to deliver a transparent overview of the complete development process undertaken by the engineering and product team at The Rider Firm, providing meaningful data and comparisons to similar wheels currently available to riders from other companies.

1.1 TT, Triathlon and Tyres

Modern road racing has recently transitioned towards the use of disc brake bikes in the peloton and there has been a significant uptake recreationally.
This resulted in an intense period of rim profile development as the dimensional constraints of rim brake calipers were removed and the benefits of wider tyres, such as reduced rolling resistance and ability to run lower pressures, became more widely recognised.
The authors were early adopters of this opportunity with the innovative 48 Limitless Aero Disc [1], optimised for wider tyres and the most aerodynamic disc brake wheelset up to 50mm in depth when tested against a range of the leading competitors.
The authors highlighted the slower uptake of more specific TT and triathlon disciplines to disc brake because of their lower frequency of use and therefore the significant opportunity to design a set of very deep wheels to excel in their category. With weight being a relatively smaller aspect of the equation in overall system performance, the authors were determined to push the aerodynamic limits in these disciplines and realise the potential with wider 25 and 28mm tyres.

1.2 The KONA Ironman World Championships, Hawaii

The pinnacle of triathlon competition is undeniably the Ironman World Championships, held in KONA annually and attracting the top multi-discipline athletes from across the World.
Since 1981 it has resided on Big Island, Hawaii, and is renowned for the inclement weather and notorious crosswinds reaching over 45kph and of course being on a Volcano!

The bike course, at 180 kilometres, takes the fastest riders over 4 hours to complete, presenting an opportunity to maximise the aerodynamic efficiency of the system as even small gains can result in minutes saved over such a distance.
If considering ultimate aerodynamic drag efficiency, the fastest wheelset combination would be a front and rear Disc Wheel. Front disc wheels are however extremely vulnerable to side forces which can result in riders forced metres offline during unexpected gusts. The World Championships is unique among the qualifying events such that fully clad Disc Wheels are outlawed, both front and rear helping to reduce related accidents.

This explains the drive to consider the rulings associated with the KONA bike course during the design, delivering a fast and stable setup that is just as at home on any TT or triathlon course due to its exceptional aerodynamics.

It is a key to note the unprecedented circumstances that have led to the World Championships being held in Utah in May 2022 before their return to Hawaii in October 2022.

1.3 A front and a rear make a pair

As the air flows around an object the (generally) laminar nature of the airflow is disturbed and any object behind must instead deal with disordered flow of different speeds and directions.
Applying this to cycling and, in particular, to bicycle wheels, it can be clear that both front and rear wheels have different aerodynamic roles to play in the system because they are dealing with very different flow conditions. It follows that a rim designed to be optimal at the front of the bike may not perform optimally at the rear of the bike where the flow is greatly affected by all the objects up stream. This white paper goes on to conclude these thoughts during the prototype development phase, leading different design objectives for each wheel.

1.4 A New Approach: HUNT's in-house CFD Analysis

Hunt has invested in evolving its research and development capabilities to deliver high performance wheels to their riders with development led by science and engineering. One key focus has been to build expertise in using computational fluid dynamics (CFD) modelling techniques in the aerodynamic design of performance bicycle wheels.

This resulted in a 2-year development program to deliver in-house CFD as a crucial tool for optimizing the aerodynamic profile of a bicycle wheel for specific conditions and use cases.

CFD is the analysis of fluid flow around an object using numerical methods and a computational model in order to replicate the desired conditions (i.e., a bicycle wheel in a wind tunnel) and assess the aerodynamic performance. It is not a replacement for wind tunnel testing which combined with real-world rider testing is the final validation of product performance but there are some key benefits as explained below.

Historically aerodynamic profile development has been conducted in a wind tunnel. This has meant manufacturing a multitude of prototypes to test theories and profiles which often means approaching a wind tunnel test without clear indication of the results, followed by a time and resource consuming process of repeated prototyping and testing to find the optimal solution - this is where CFD can be most beneficial.

In the time it takes to manufacture and test a 3D printed prototype, a reliable CFD model enables testing of tens of designs in order to realise the best prototypes to validate in the wind tunnel.

Additionally, the wind tunnel test is approached with predictions of the performance outcome. This not only speeds up the process but helps validate the accuracy of the CFD model.

Another key benefit of CFD is the capability to visualise fluid flow through pressure, velocity and streamline plots to analyse results and contributing to profile modifications. The authors present in this paper how this process resulted in the performance improvements, additional background information on CFD use can be found here in our CFD Explainer [2].

2. The purpose of the wheels

Purpose:

Through CFD and Wind Tunnel Development, design:
A trio of wheels for TT and Triathlon, optimised for 25 and 28mm tyres, with maximum aerodynamic efficiency and confidence inspiring handling.

Key Design Objectives:

a. *A pair of front rim profiles designed for maximum speed efficiency at two depths for differing wind conditions, with smooth and stable steering moments.*
b. *A singular rear rim profile maximized for the aerodynamics experienced at the rear of the bike and optimal lateral stiffness for efficient power transfer*

Design Parameters:

- A rim designed specifically for disc brake bikes with 20mm internal width.
- Use of a hooked rim design to ensure compatibility with tubeless and standard clincher tyres.
- A tyre bed design compliant with the latest ETRTO/ISO 5775-2 tubeless standards.

3. Initial Profiles and Concepts

With the extensive research conducted in the GST Windkanal in past projects delivering the Limitless Range (48, 60 and 42) the engineering team had a-number-of innovative design concepts to apply to this project utilising the powerful CFD process. Using the computational model created with the Argon 18 E119+ Tri Bike, it was possible to test these theories and as described below complete the iterative optimisation of a trio of new deep section wheels.

An example of 3 of the early Aerodynamicist designs taken to the first Wind Tunnel trip are shown below.
The lower profile features the greatest width at 32mm but with the natural reduction in drag offered by additional depth the 83mm profile is reduced to 29.5mm width. At the rear, the profile width is minimised because of the different flow conditions at the rear and emphasis on a stiff and responsive wheelset.

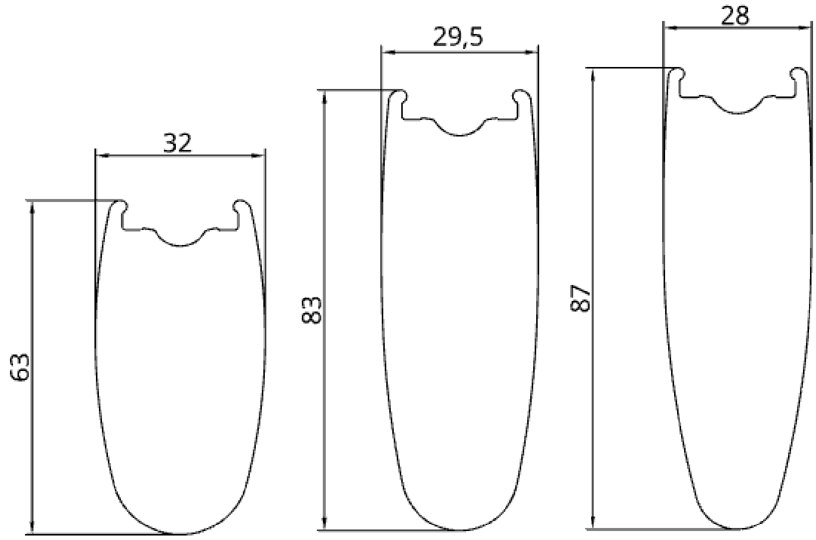

Figure 1 – The initial profiles designed by the HUNT aerodynamic team

4. Performance Analysis

4.1 Aerodynamic Drag – Mavic Ponderation Law

The ultimate aerodynamic drag performance across a range of wind conditions of the presented trio of wheels is measured using the Mavic std Average Drag, a weighting method
The Mavic Ponderation Law describes the measured distribution of yaw angles between -20 and +20 degrees experienced on average by a cyclist.

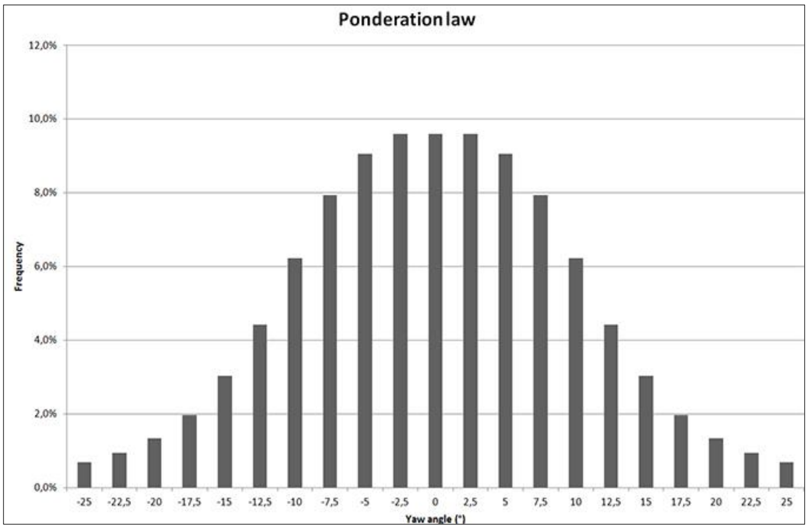

Figure 2 – The Mavic Standard WAD (Wind Averaged Drag) Distribution

It is important to equate the drag reductions to the tangible benefit, therefore the authors will calculate the net difference in Force required to overcome the Drag Force the time savings between wheelsets based on the 2019 cycling leg time (4:16:02).

4.2 Steering Moment and Stability

As described in the purpose, an important characteristic of the two front wheels is minimising steering force and enabling predictable and stable handling across all yaw angles and conditions.
The below formula explains how deeper section wheels are affected by side wind forces due to the greater area over which they act - Side Force (F_s) is directly correlated to Area (A):

$$F_S = \frac{1}{2}\rho\, V^2 C_s A$$

Where:
F_S is the Side Force
ρ is the density of air
V^2 is the Velocity of the squared
C_S is the side force coefficient
A is the reference cross sectional area

Forces applied to the rim side result in a response acting around the steering axis which are directly transferred to the handlebars.
Drag and steering force characteristics are interlinked; whilst the airflow around the rim stays attached, the magnitude of the steering moment grows until the airflow stalls. The nature of the response defines the predictability and stability of handling, where a non-linear response reflects an unexpected handling feeling. Therefore, a linear response is sought for an extended range of yaw angles which is achieved through delaying stall and resulting in predictable characteristics.

5. Development and Optimisation Process

As discussed above, the early development of the trio of rims was to be conducted using HUNT's in-house aerodynamics team and CFD optimisation. This would be combined with wind tunnel testing sessions to provide CFD model validation and comparison against competitors. Initial tests used 3D-printed prototypes with a final test to validate all results with production samples in the finalised rim profiles.
Two computational models would be used during the iteration stage, a wheel only (combining rim and tyre profiles) and latterly, for further detail and particular focus on the rear profile development, a full bike and wheel model was applied.

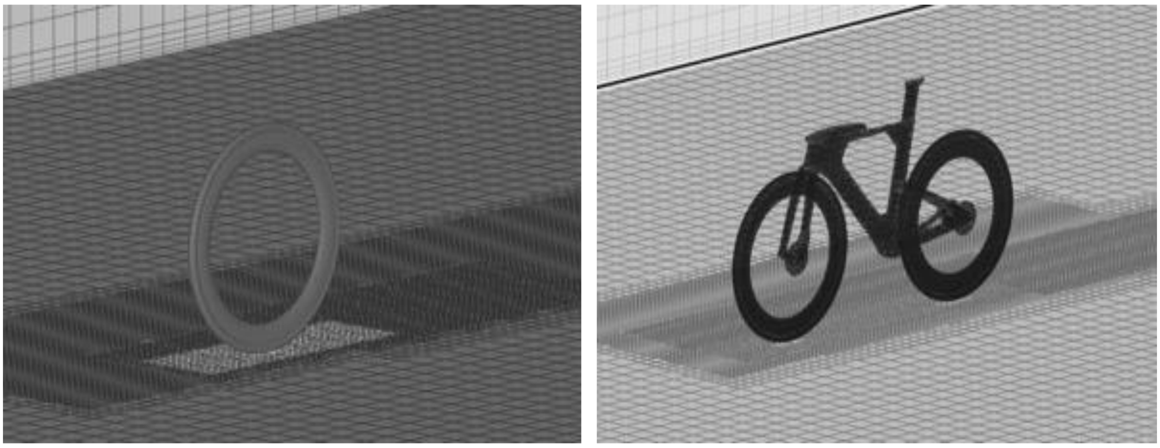

Figure 3 – CFD mesh visuals detailing the two "wheel alone" and "in bike" models

Both models simplify the wheel system, no spokes or hub are used in the model for a few reasons. Firstly because of the relatively costly computational requirements needed to run the model and as all models would have consistency of these parts, a control condition could be applied. The trends and rankings achieved could be closely linked to those extracted from the wind tunnel from the first prototype test and were therefore extremely useful in the project.

The wheels were given a rotational speed (equal to the ground and air speed (12.5 ms^{-1}) applied to the model.

In total 349 individual simulations were run in this project across the three depths considering both wheel alone and bike models. Each change in profile requires a new mesh taking approximately one hour to complete and on average each simulation time is 4.5 hours when leveraging cloud computing resources. With tens of simulations able to run simultaneously, the actual time to obtain the results is significantly reduced.

5.1 CFD Modelling – Wheel Only

The wheel only model is placed part way into the computational wind tunnel domain and with a clearance to the ground plane.
A significant amount of work is undertaken in developing the optimal mesh for the problem. A mesh convergence is carried out where different parameters are iteratively modified resulting in different sized meshes whilst considering efficiency and using known wind tunnel results to validate simulation accuracy. The initial and boundary conditions which define the constraints of the external aerodynamic analysis of a bicycle wheel (replicating wind tunnel conditions and surface modelling) are applied and simulations are run.

The wheel is simulated over a range of yaw angles and the raw drag and side force values are extracted from the profile. Since the model is a symmetrical wheel only design, only positive yaw angles are required. Simulations are run to 15 degrees, this is to capture the stall point dynamics and the yaw angles after this represent flow separation and are both difficult to model and can generally be considered uncontrollable by a rim profile therefore is not necessary to model.

5.2 CFD Modelling – Complete Bike

Having shortlisted the best performing profiles, these were brought forward to complete analysis using the Argon 18 E119+ Bike to understand if the results from the wheel only test transfer directly and providing a closeness to wind tunnel results.

Again, here it was decided to focus on positive yaw angles (the non-drive side) for efficiency of both the optimisation process and computational time.

5.3 Wind Tunnel Testing & Setup

The wind tunnel is an extremely useful tool in measuring the performance of a wheelset in a controlled environment and therefore an integral part of the development process with the complete bike setup.

The authors returned to the GST Windkanal for this project, 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. GST was the ultimate testing facility for the Aerodynamicist rims, with three trips as detailed below made to test and finalise designs.

The Argon 18 E119+, for which a prototype model was kindly lent for all tests by Argon 18, was used during all the wind tunnel tests.

Figure 4 - GST Windkanal December Test

Prototype Wind Tunnel Setup (April 2021):
Bike: Argon 18 E119+
Tyres: Schwalbe Pro 1 25 and 28mm TL
Tyre Pressures: 3D printed prototypes ~ 3-4 bar to avoid damage (other wheels 25mm @ 6bar, 28mm @ 5bar)
Wind and Roller Speed: 45 kph
Yaw Angles: -20 to 20 degrees.

Remainder of tests were as follows (Sept 2021, Dec 2021)
Bike: Argon 18 E119+
Tyres: Schwalbe Pro 1 25 and 28mm TL
Tyre Pressures: 25mm @ 6bar, 28mm @ 5bar
Wind and Roller Speed: 45 kph
Yaw Angles: -20 to 20 degrees.

5.4 Prototyping

The authors have been utilising 3D printing technology to manufacture the prototypes for the wind tunnel for several projects. The prototypes for this test were manufactured with the latest in 3D printing technology maximising the reliability and accuracy of the data achieved from prototype testing.

6. Profile Development

As with any test, it is important to understand there is error associated with wind tunnel-based measurements and simulation approximations from CFD. For example, variation in external environment conditions, changes from prototypes finish to carbon etc. There can be fluctuations between one wind tunnel test and another, these are expected to result in less than 0.5 Watt differences.

During the prototype wind tunnel test in April 2021, the same v5 front profile was used as the rear profile.

6.1 Hunt 73mm Profile

6.1.1 Initial CFD Development

The shallowest profile started as 63mm in depth, chosen to minimise the sensitivity to side forces whilst maximising aerodynamic efficiency in a straight line.
Knowing the wind tunnel performance of the 60 Limitless Aero Disc this was a fantastic benchmark for the 63mm profile therefore early simulations included verifying the performance.

Below you will see the simulation result between the first 63mm profile and the 60 Limitless Aero Disc profile.

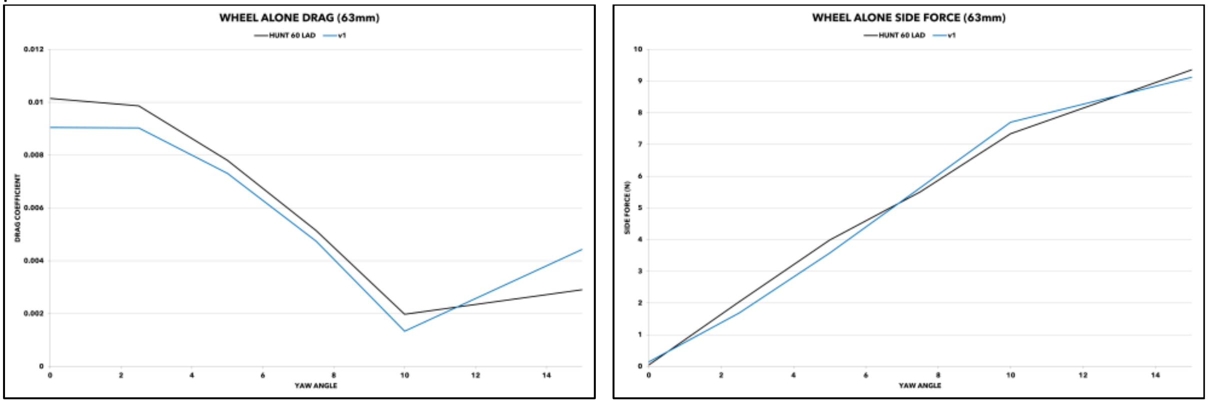

Figure 5 – CFD model validation and initial profile simulation results

The 63mm rim represents an impressive low drag profile with marginally reduced side force, which as mentioned, is a characteristic important to minimise in TT/Triathlon.

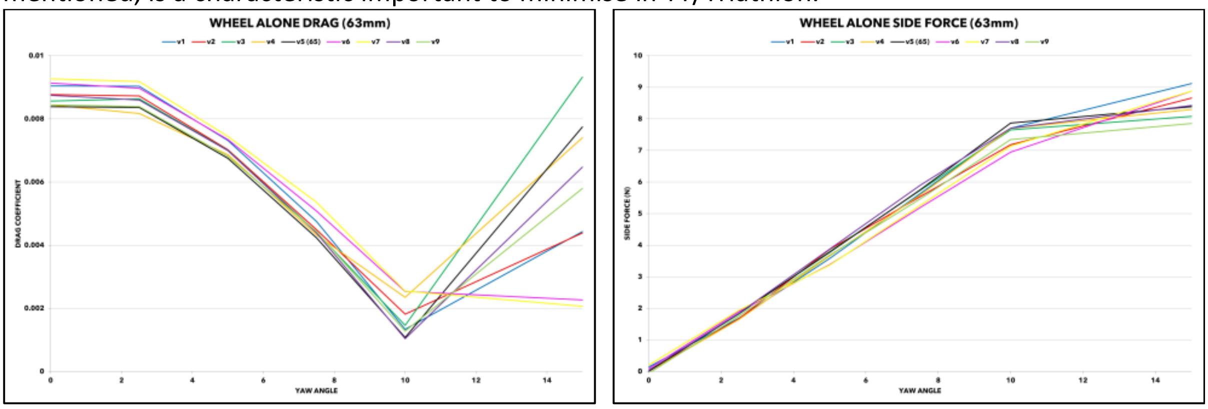

Figure 6 – Hunt 63mm profile iteration history

Therefore, the first profile was a very good starting point, however quite conservative in terms of maximum width. The next eight iterations examined how modifying a few key dimensional parameters affected the drag and side force components of performance, with differing outcomes.
These highlight how elements of the drag profile across the range of yaw angles, including the stall point could be modified, notably with v6 and v7 experiencing delayed separation of flow as anticipated. When analysing the pressure and velocity distributions, the authors could pinpoint which geometrical features attributed to stall, as shown below between v3 and v6 with velocity plots.

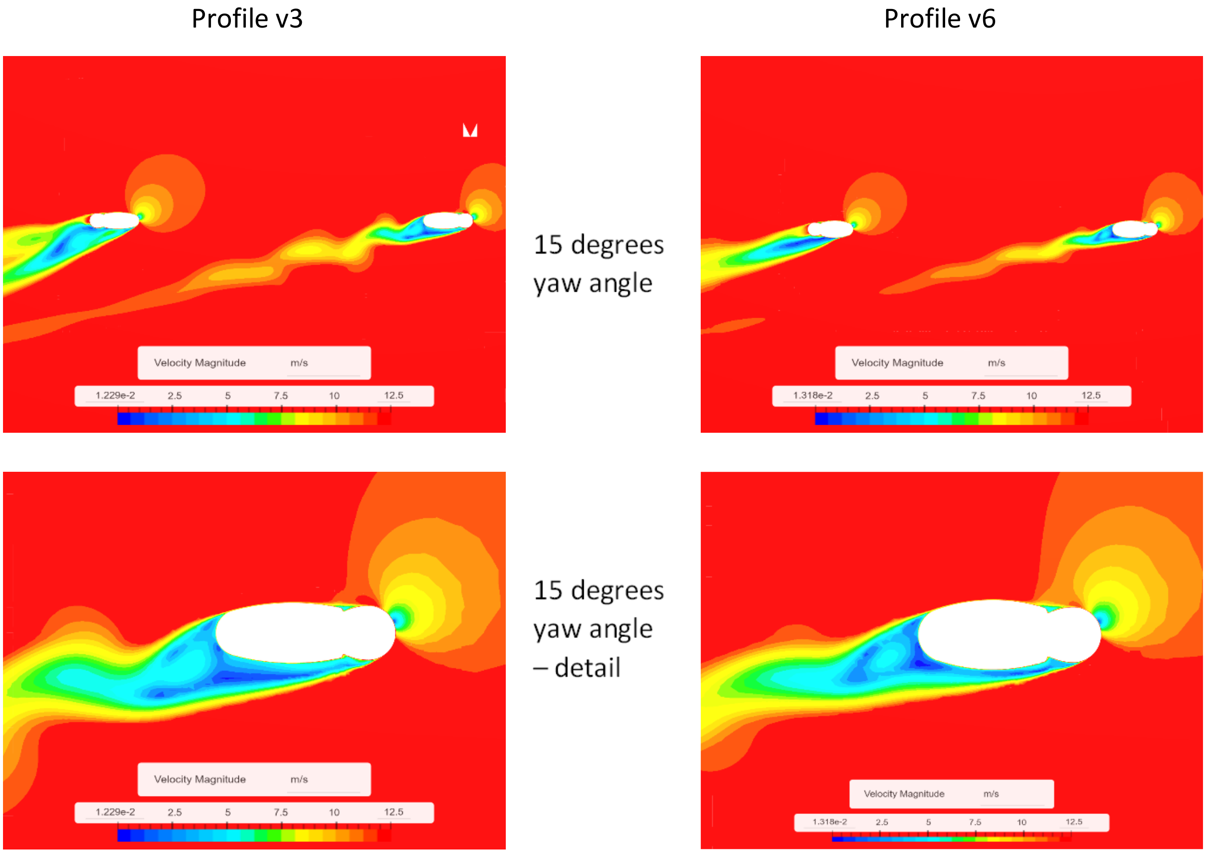

Figure 7 – Velocity plot visualisation used for profile analysis

The plot at 15 degrees yaw angle is very informative in explaining the difference in drag due to profile characteristics which result in abrupt stall of v3 compared to v6.
When considering the tyre as the leading edge, although showing small differences, the plot indicates the superior performance of the v6 profile interacting with the flow and minimising the low velocity region behind. Most significant is the rim-bed leading edge aerodynamics as this shows the critical stall and flow separation of v3, resulting in a large increase in drag at this yaw angle.
Other analysis of the flow fields was undertaken with the in bike CFD model to further understand the interaction of the flow in the wheel and bike system.

The side force plots above show, as yaw angle increases, the differences between profiles become most notable.
Using the data and tools available, it was possible to extract interesting trends and resulted in a new understanding how certain geometrical characteristics can significantly affect the key performance characteristics. This learning during the shallow profile development was directly applied to the other depths and accounts for the impressive performance seen at the wind tunnel.

To process the raw data, the Mavic Std WAD weighting was applied to each yaw angle and the weighted average calculated. The results showed v6 to exhibit the least drag followed by v9 and v2.

6.1.2 Prototype Wind Tunnel Test – April 2021

Both v6 and v9 were chosen to be 3D printed for the wind tunnel to aid CFD model validation and examine performance across the full range of yaw angles.

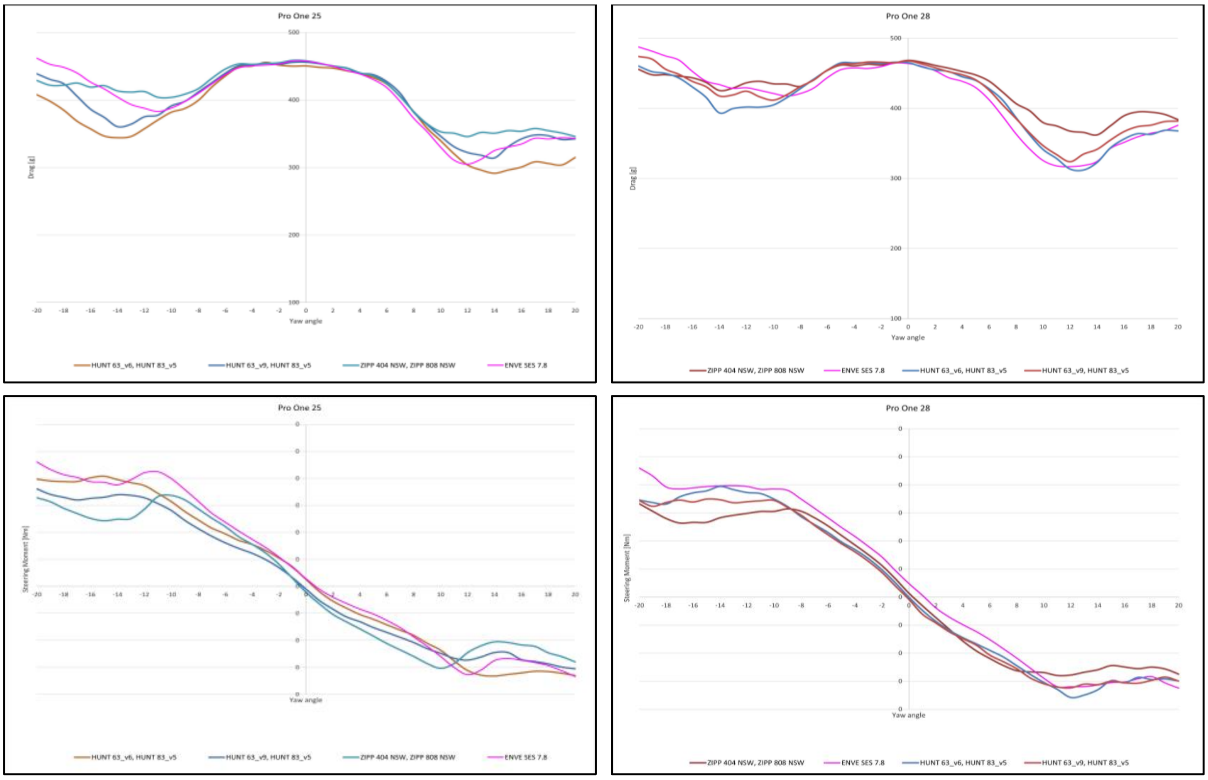

Figure 8 – Hunt 63 Prototype wind tunnel test Drag and Steering Moment graphs – April 2021

The results obtained from the test were extremely optimistic with the expected trends between v6 and v9 reflected closely. In the case of 0 degrees, the differences were visibly much smaller and in the region of only 1%, compared to ~8% in the wheel alone model but expected given the relationship with the rest of the system components. The v6 profile can be seen to perform exceptionally over v9 at yaw angles greater than +/-10 degrees yet maintaining very competitive low yaw angle performance.

When considering the steering moment, both the 63mm profiles are extremely impressive, exhibiting a smoother steering moment curve than both the Zipp and Enve models as well as lower magnitudes than even compared to the shallower Zipp 404.

This provided good validation to the CFD model and confidence of its use in profile development. The wind tunnel results helped to affirm a number of design requirements and principles which would be further explored with additional CFD simulations.

6.1.3 Back to CFD: 63mm becomes 73mm

Discussions and analysis at the wind tunnel led to some exciting ideas the engineers wanted to test in CFD, this resulted in two further profiles, v10 and v11 because of the impressive results achieved. Notably it was theorised that due to the impressive stable and low magnitude steering moment of the 63mm profile, the same geometrical characteristics could be applied to a deeper profile, maximising aerodynamics without compromising on the stable steering moment.

A 73mm depth profile was developed, key dimensions were fixed and the recent learnings applied, meaning only three profiles were needed to iterate in the CFD using the complete bike setup with Argon 18's E119+ Tri. This model was dedicated to calculating the smaller difference and detail between profiles with improved detail, also reducing low yaw angle sensitivity seen in the wheel alone tests.

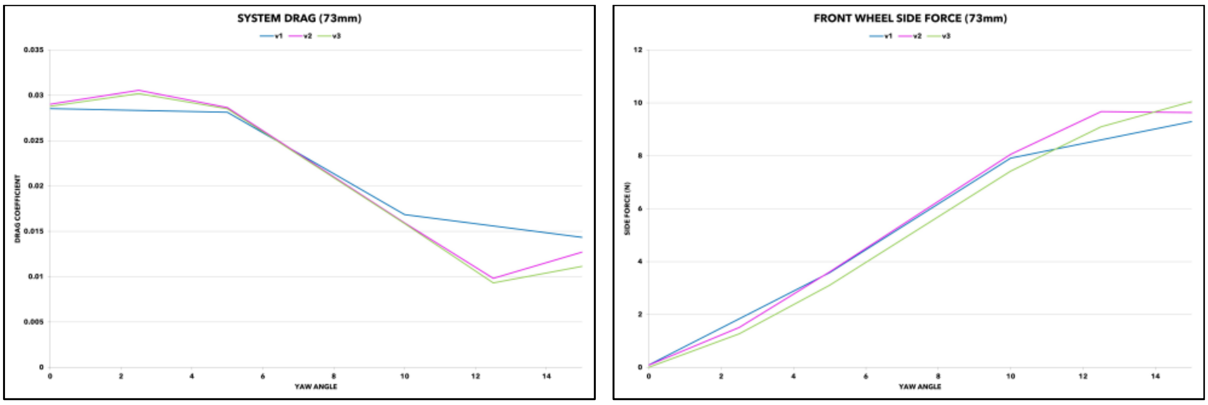

Figure 9 – Hunt 73 CFD Optimisation

The first iteration v2.1 was quickly seen to be low performing and to conserve time it was limited in the yaw angles analysed.
Models v2.2 and v2.3 had only small geometrical changes with v2.3 proving overall the superior profile. Incremental improvements in drag especially at higher yaw angles are achieved and through the learnings of the 63mm profile, the impact of steering moment has been greatly reduced.

At this point the lower depth rim design was frozen and v2.3 taken through to following wind tunnel tests.

6.2 Hunt 83mm Profile

6.2.1 Initial CFD Development

The initial design philosophy for the deeper profile began more traditionally in terms of width. However, the path of the development of this profile demonstrates the power of both CFD and wind tunnel testing to rapidly develop and iteratively improve the performance of rim designs.
Single wheel testing was carried out using CFD on 6 profiles in total, with the following results:

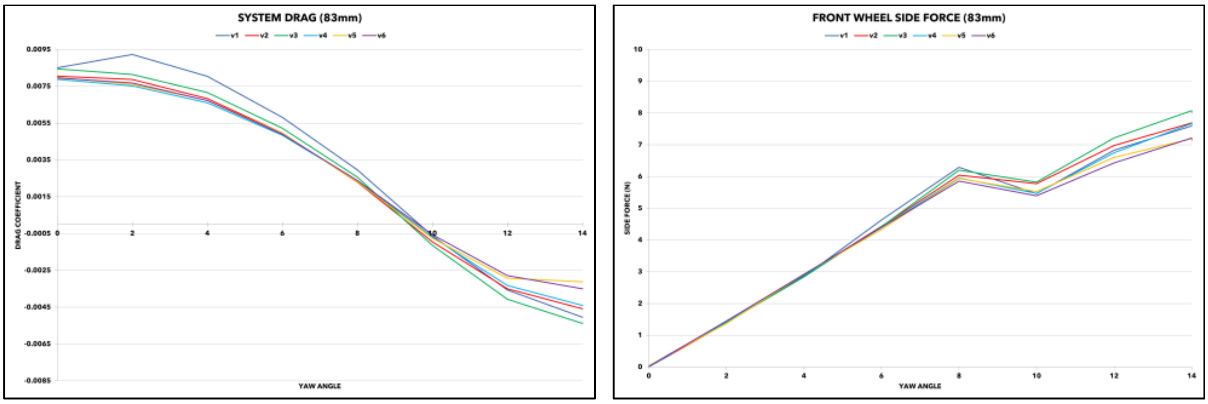

Figure 10 – Hunt 83 Profile CFD Simulation results

With differing profiles and showing superior drag performance at different yaw angles, there was interest to test v3 and v5 and at a slightly wider profile, v6, at the wind tunnel. This would enable analysis of frame and fork interaction as well as the ascertain the real differences in steering moment.

6.2.2 Initial Wind Tunnel test – April 2021

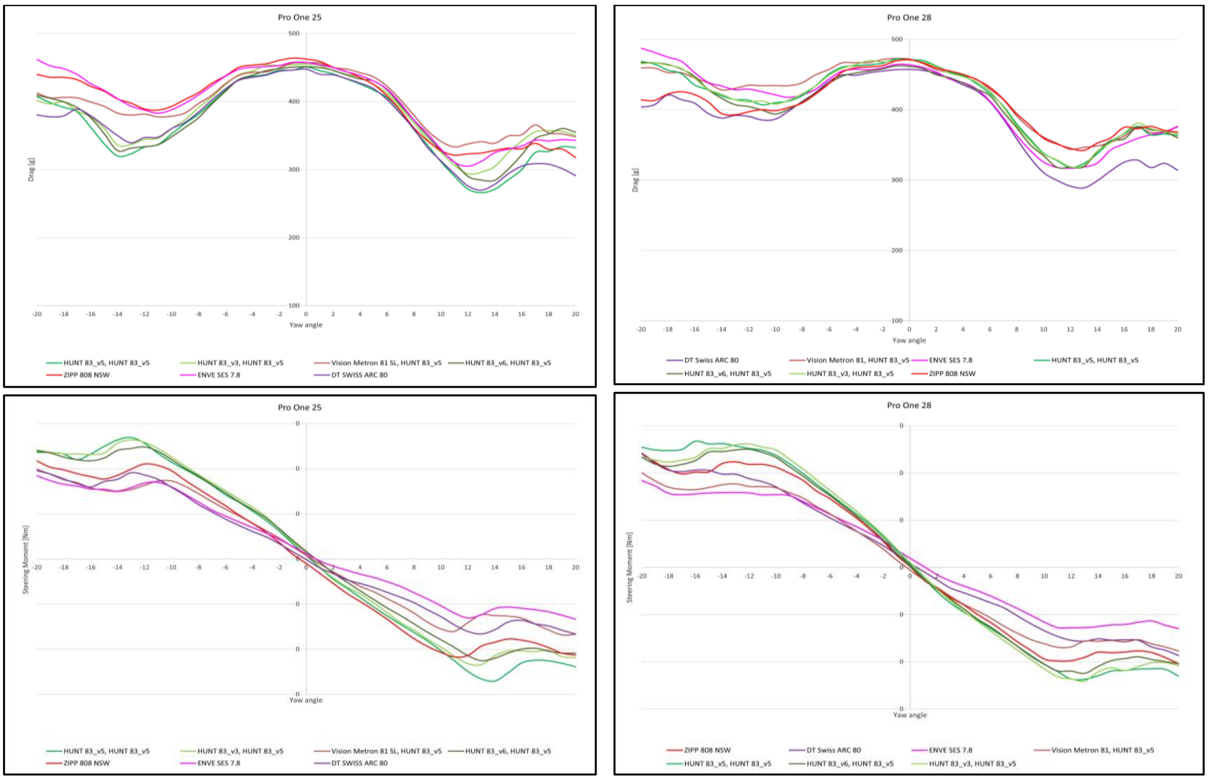

Figure 11 – Hunt 83 Prototype wind tunnel test Drag and Steering Moment graphs – April 2021

The wind tunnel tests indicted superior performance versus key competitors Zipp, Enve and Vision and confirmed assumptions that v5 and v6 profiles (sharing similar characteristics) outperformed v3, with its different geometrical attributes, with both the 25mm and 28mm tyre. The DT Swiss Arc 80 displayed competitive performance and emerged as a leader at this depth.
The steering moment despite being stable was somewhat greater in magnitude than hoped, however learnings from the 63mm profile highlighted at the same test meant the engineers were confident both steering and drag forces could be reduced with further CFD analysis and profile development.

6.2.3 Final CFD Simulations

The v5 profile was taken forward to iterate using the system bike and wheels model and 2 more iterations were produced, examining effect of maximum width and other characteristics.

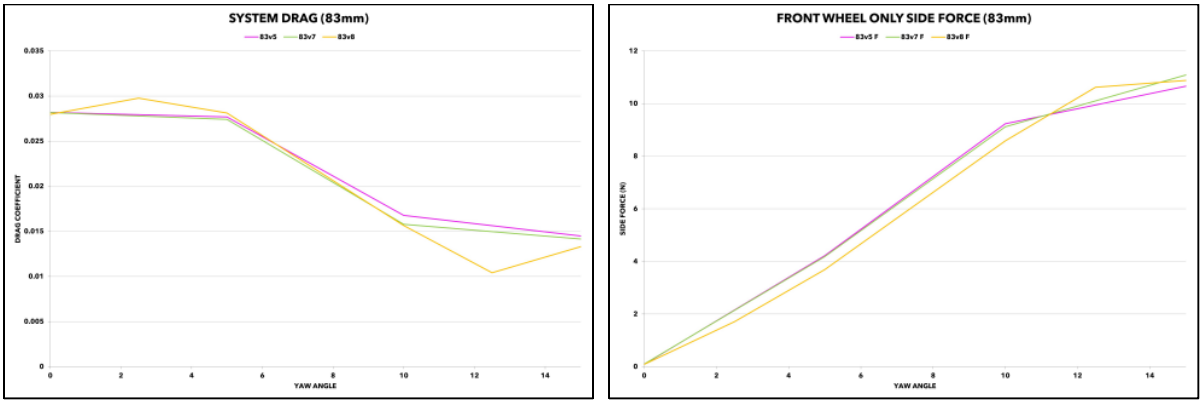

Figure 12 – Hunt 83 CFD iterations bike model

A smaller number of data points initially were applied for efficiency, but it was quickly apparent that although good drag reduction was achieved using v7, it still suffered from greater side forces therefore more knowledge from the 63mm profile was applied.
The result was profile v5 which after minor geometrical changes resulted in reduced drag at higher yaw angles, competitive at low yaw angles but notably reduced side forces, a key aim after the wind tunnel test. Hence the profile was selected to take forward to the pre-production carbon rim test.

6.3 Hunt 87 Profile

A single rear profile was chosen to maximise the aerodynamic performance of the system, within the rules of the KONA triathlon world championships (prohibiting deep section disc wheels) and to importantly enable riders to use the chosen combination in any UCI level race. Further, as explained earlier, the rear wheel has no impact on the steering moment of the wheelset, so the depth was maximised.
With the rear wheel dealing with the turbulent flow reaching the rear of the bike, the effect of change in depth (relative to depth) was interesting to examine. With the 83mm front profile a minimum 83mm rear would be applied and it was decided 87mm would sit within the aims of the wheelset and hence the effect of a 4mm difference would be examined.

The 87mm profile was iterated 4 times using CFD with emphasis on maintaining a competitive drag and weight performance.

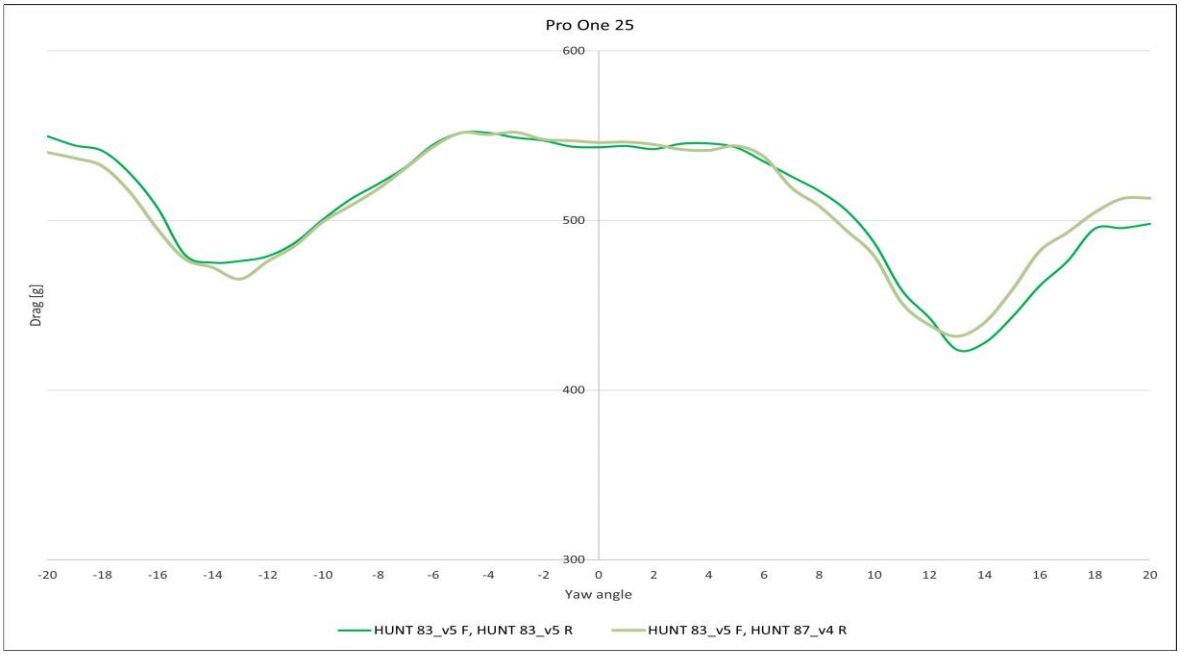

Figure 13 – 83mm versus 87mm Rear Wheel Drag performance

The results obtained showed a maximum difference of 0.02W between rear wheels (controlled front wheel) when applying the Mavic Std WAD, however with the 87mm profile consistently superior, albeit by a small margin.

7. Pre-Production and Final Validation Sample Wind Tunnel Tests

As explained, the learnings from the prototype wind tunnel test in April lead to further profile developments tested in September along with all the key competitors.

7.1 Pre-Production Wind Tunnel Test – September 2021

7.1.1 7387 Aerodynamicist

Taking the newly developed 73mm profile to the wind tunnel was important step in confirmation of our 73mm profile performance, now a pre-production carbon model.

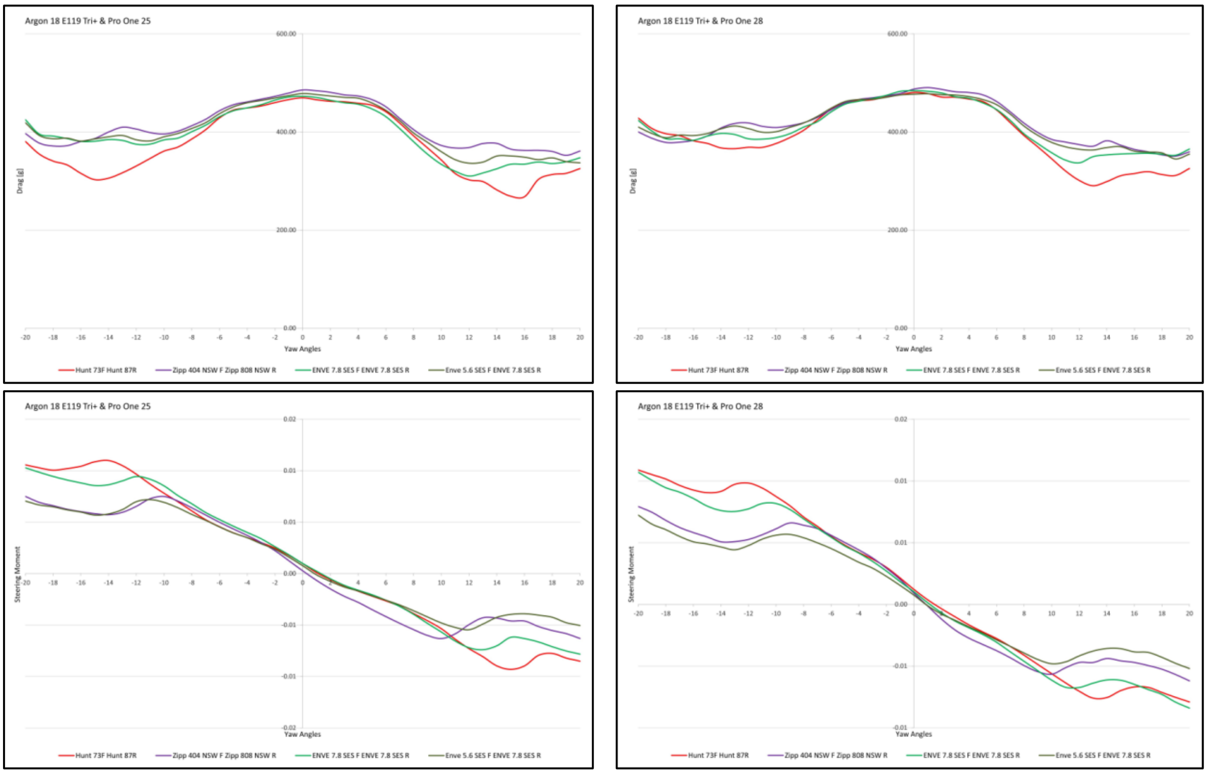

Figure 14 – Hunt 7387 pre-production Wind Tunnel Test Drag and Steering Moment Graphs – September 2021

Analysing the drag curves, the 73mm Aerodynamicist wheel exhibits competitive performance across the complete range of yaw angles with notable performance at yaw angles between 12 and 18 degrees.

The steering moment observed for the 73 Aerodynamicist is both smooth, showing stability in changeable yaw angles, and low in magnitude meaning the forces transferred to the rider are comparable to front wheels tested up to 15mm shallower in depth, ensuring stable handling performance.

Applying the Mavic Standard WAD to both the 25mm and 28mm, the following results were obtained:

MAVIC STD WAD				
Pro One25	**Av Pwr [W]**	**Av drag [g]**	**ΔP tot or power loss [W]**	**ΔF tot or drag loss [g]**
Hunt 73F/87R	28.10	229.19	0.00	0.00
Enve 7.8 SES F/7.8R	28.83	235.12	0.73	5.93
Enve 5.6 SES F/7.8R	29.51	240.62	1.41	11.43
Zipp 404 NSW F/808R	30.06	245.13	1.96	15.94

Table 1 – Hunt 7387 Standard WAD results with Schwalbe Pro One 25mm Tyre

The 73 / 87 Aerodynamicist is the fastest wheelset combination tested paired with the 25mm tyre by 0.73W to the nearest tested competitor, exhibiting low drag across a range of yaw angles.

MAVIC STD WAD				
Pro One28	**Av Pwr [W]**	**Av drag [g]**	**ΔP tot or power loss [W]**	**ΔF tot or drag loss [g]**
Hunt 73F/87R	29.20	238.10	0.00	0.00
Enve 7.8 SES F/7.8R	29.74	242.55	0.54	4.45
Enve 5.6 SES F/7.8R	30.20	246.28	1.00	8.18
Zipp 404 NSW F/808R	30.52	248.90	1.32	10.80

Table 2 – Hunt 7387 Standard WAD results with Schwalbe Pro One 28mm Tyre

When pairing with a 28mm tyre, the 73 / 87 combination also outperforms the other offerings by 0.54W.
With the 73 profile showing itself to be a highly performing rim profile with both tyre widths and excelling with the preferred 25mm tyre, the engineers froze the development of this profile for production.

7.1.2 8387 Aerodynamicist

With the profile development after the initial prototype wind tunnel test, this was a good opportunity to analyse performance upgrades, with results as follows:

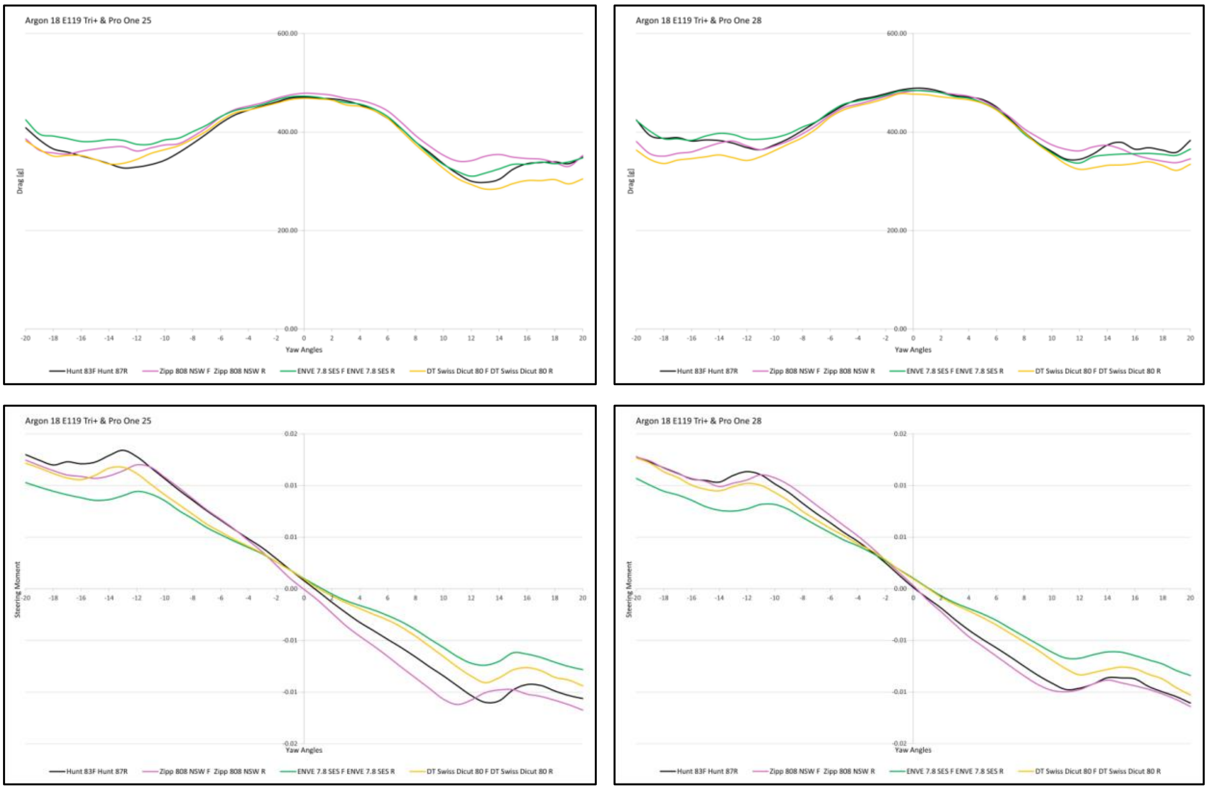

Figure 15 – Hunt 8387 pre-production Wind Tunnel Test Drag and Steering Moment Graphs – September 2021

The results show strong aerodynamic performance with the optimal 25mm tyre as designed across the range of yaw angles. When considering the steering moment, compared to wheels of the most similar depth (Zipp 808), the 83 Aerodynamicist exhibits lower magnitude and stable response to side forces.

When evaluating these using the Mavic Standard WAD:

MAVIC STD WAD				
Pro One25	**Av Pwr [W]**	**Av drag [g]**	**ΔP tot or power loss [W]**	**ΔF tot or drag loss [g]**
DT Swiss Dicut 80 F/80R	27.99	228.29	0.00	0.00
Hunt 83F/87R	28.11	229.24	0.12	0.95
Enve 7.8 SES F/7.8R	28.83	235.12	0.84	6.83
Zipp 808 NSW F/808R	29.10	237.31	1.11	9.02

Table 3 - Hunt 8387 Standard WAD results with Schwalbe Pro One 25mm Tyre

When considering the 25mm tyre, the 83mm AD profile exhibits a low average drag compared to the competitors, marginally slower by 0.12W than the DT Swiss Dicut 80 Wheelset.

MAVIC STD WAD				
Pro One28	**Av Pwr [W]**	**Av drag [g]**	**ΔP tot or power loss [W]**	**ΔF tot or drag loss [g]**
DT Swiss Dicut 80 F/80R	28.80	234.84	0.00	0.00
Zipp 808 NSW F/808R	29.59	241.28	0.79	6.44
Enve 7.8 SES F/7.8R	29.74	242.55	0.94	7.71
Hunt 83F/87R	29.84	243.32	1.04	8.48

Table 4 - Hunt 8387 Standard WAD results with Schwalbe Pro One 28mm Tyre

It can be seen when considering the 28mm tyre, the level of performance is not reflected in the weighted drag results.
In designing the 83mm profile, the engineers had been working to balance the different performance characteristics given from the design however these results showed that some further improvements could be made to enhance the aerodynamic performance. Therefore, the engineers worked on a few minor profile modifications testing two more iterations in CFD prior to taking the rim to the December wind tunnel test. (see appendix).

The above results show that in their respective depth class, the 73/87 and 83/87 Aerodynamicist outperformed the offerings from Zipp, Enve and Vision during the September test hence the nearest competitor*, the DT Swiss Dicut 80mm was used for efficiency of the final validation test.

7.2 Production Wind Tunnel Test – December 2021

Below are the finalised profiles and it can be seen clearly how the profiles have developed hugely since the initial profiles at the beginning of the project.

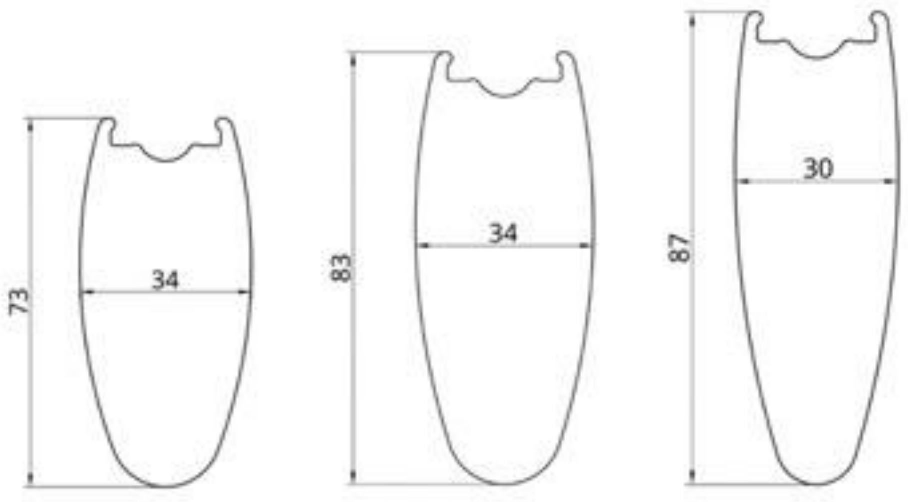

Figure 16 – Hunt's finalised 73, 83 & 87 Profiles

Firstly considering the results with the Schwalbe Pro 1 28mm Tyre in the graphs below:

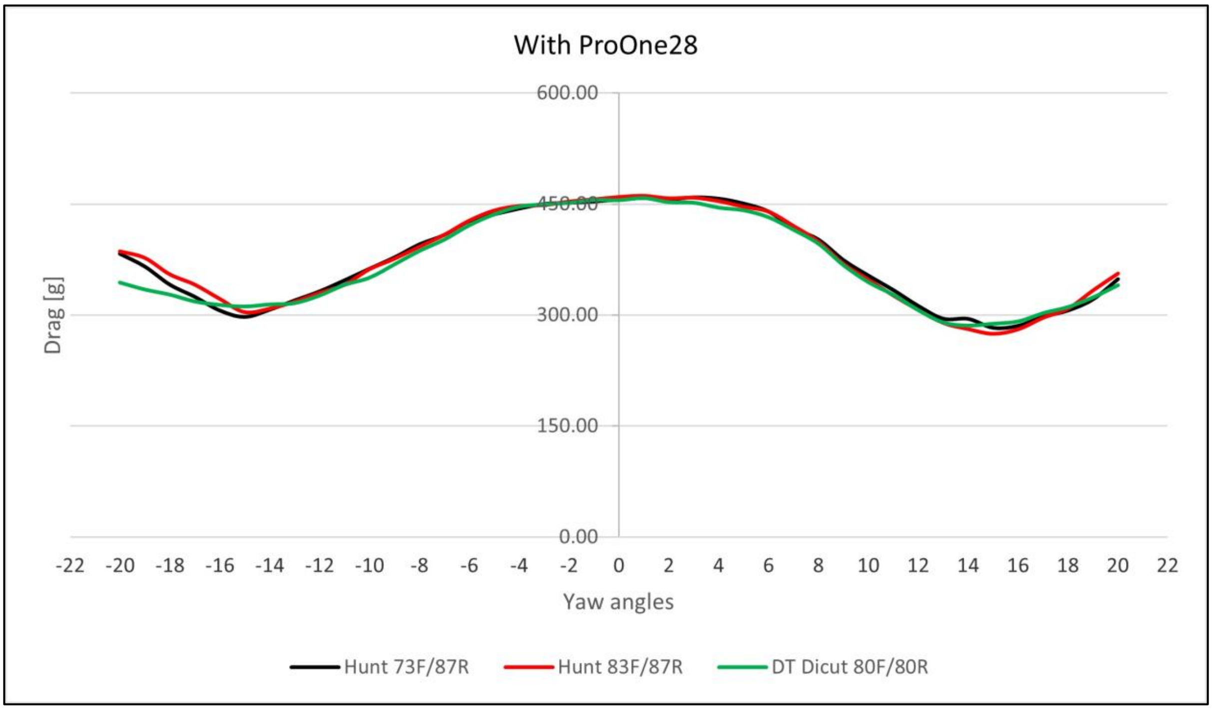

Figure 17 – Drag graph depicting finalised wheel models and nearest competitor with Schwalbe Pro One 28mm Tyre

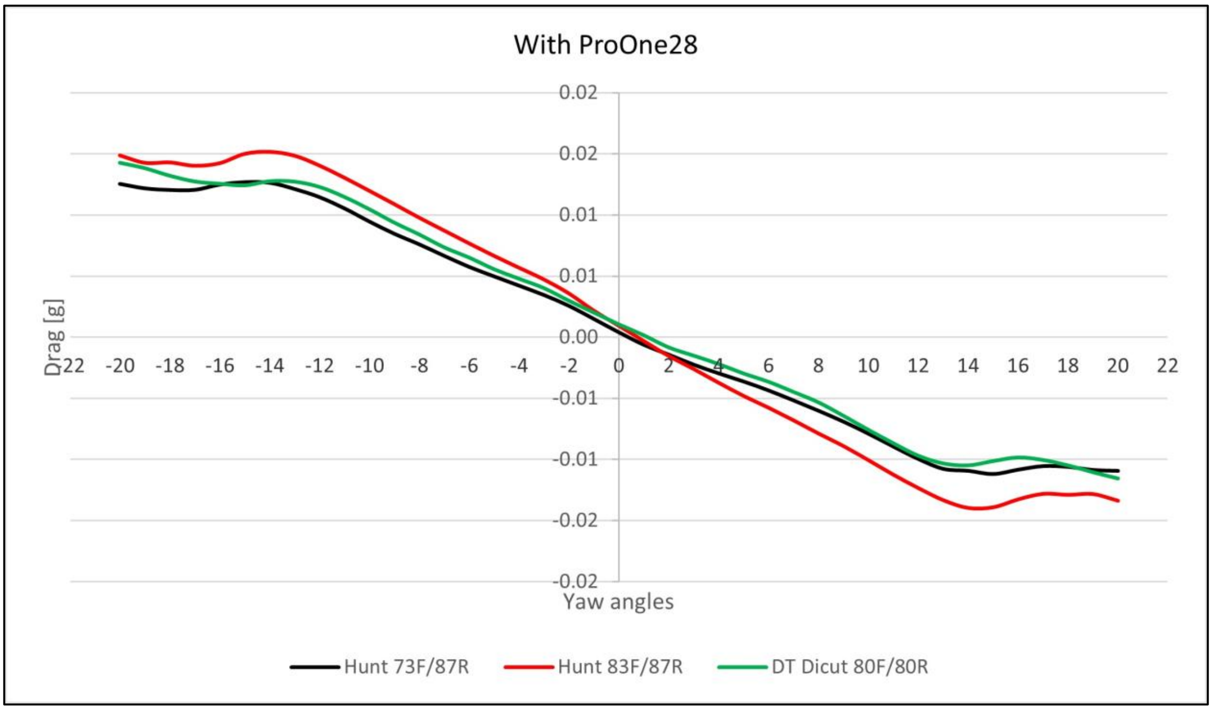

Figure 18 – Steering Moment graph depicting finalised wheel models and nearest competitor with Schwalbe Pro One 28mm Tyre

MAVIC STD WAD				
Pro One28	**Av Pwr [W]**	**Av drag [g]**	**ΔP tot or power loss [W]**	**ΔF tot or drag loss [g]**
DT Dicut 80F/80R	27.67	225.62	0.00	0.00
Hunt 73F/87R	27.97	228.12	0.30	2.50
Hunt 83F/87R	27.99	228.22	0.32	2.60

Table 5 - Hunt 7387 & 8387 Standard WAD results with Schwalbe Pro One 28mm Tyre, Production Test December 2021

Previously the gap between the DT Dicut 80mm and HUNT 83 was 1.04W and comparatively the Zipp 808 was 0.79W behind the DT Dicut 80mm. Post final profile developments, the engineers have significantly narrowed the gap to DT Swiss, now 0.30W, and replaced the Zipp as the second fastest offering.

With this wider 28mm tyre, the HUNT 7387 Aerodynamicist excels in its performance to match the 8387 profile.

The lowest aerodynamic drage was found with the Schwalbe Pro 1 25mm Tyre, firstly studying the graphs:

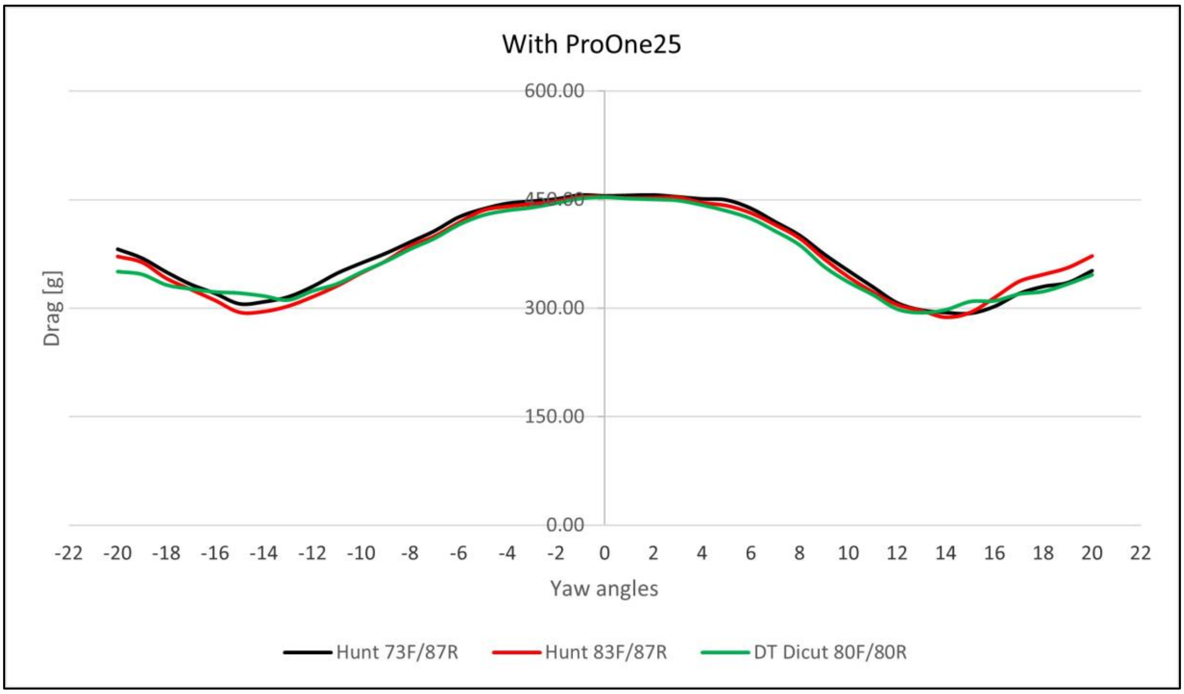

Figure 19 - Drag graph depicting finalised wheel models and nearest competitor with Schwalbe Pro One 25mm Tyre

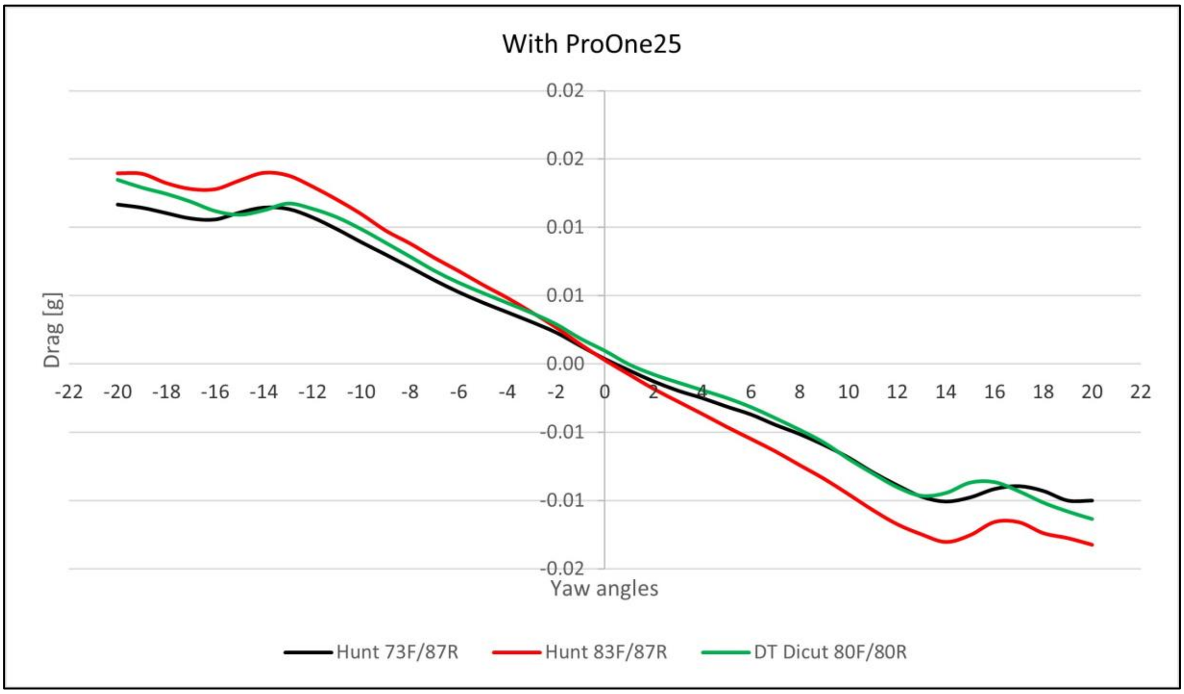

Figure 20 – Steering Moment graph depicting finalised wheel models and nearest competitor with Schwalbe Pro One 28mm Tyre

MAVIC STD WAD				
Pro One25	**Av Pwr [W]**	**Av drag [g]**	**ΔP tot or power loss [W]**	**ΔF tot or drag loss [g]**
DT Dicut 80F/80R	27.48	224.13	0.00	0.00
Hunt 83F/87R	27.65	225.48	0.17	1.35
Hunt 73F/87R	28.00	228.35	0.52	4.22

Table 6 - Hunt 7387 & 8387 Standard WAD results with Schwalbe Pro One 28mm Tyre, Production Test December 2021

The results above show that the HUNT 8387 combination maintains its high level of performance after profile modification. The combination is comfortably faster than the key tested competitors of Zipp and Enve and only 0.17W away from the leading competitor, the DT Swiss Dicut 80.

This validates the improvements seen in the simulations and further highlights the exceptional performance of the shallower 73mm rim.

8. Conclusions: The Finalised 73, 83 & 87 Aerodynamicist Profiles

The HUNT 7387 Aerodynamicist and 8387 Aerodynamicist wheelsets display excellent performance in respect of both aerodynamic drag and steering stability across both tyre combinations.
The authors have been able to show the class leading potential for criterium, TT and triathlon applications of both HUNT Aerodynamicist combinations when paired with a 25mm tyre whilst maintaining strong performance paired with a 28mm tyre.
DT Swiss post very competitive drag figures throughout with the Dicut 80mm offering with what is an overall impressive level of performance.
Analysing the results, firstly focussing on the 73/87mm profile; the lowest offering and aimed at maximising aerodynamics with minimal steering moment magnitude.

The September and December results show that the Hunt 7387 Aerodynamicist wheelset exhibits very low steering moment given its depth easily outperforming the offerings of Zipp and Enve in both stability and minimising aerodynamic drag.
Comparing to the highly performing DT Swiss Dicut 80mm, the HUNT 7387 Aerodynamicist is within 0.52W with both 25 and 28mm tyre setups.

Notably the 28mm tyre performs marginally better (0.03W) than the 25mm tyre. The authors have always promoted the use of wider tyres along with the benefits to rolling resistance associated with wider tyres and lower pressures. With vibration research having been conducted by the authors suggesting the further benefit of reduced energy loss in the human body to absorb these movements, the 73/87 combination provides an exceptional all-round wheelset.

The outstanding performer was the 83/87mm combination which succeeds in providing those marginal gains when it comes to all out speed.
With 25mm tyre combination, the HUNT 8387 Aerodynamicist challenges DT Swiss's offering and with significant gap to other competitors along with a stable steering moment profile resulting in predictable handling.
Due to the purposeful design differences, combining with the 25mm tyre is the ultimate setup, however very competitive performance is still achieved with the 28mm tyre with maximal differences of 0.34 Watts.

The HUNT aerodynamic design team have been able to apply a combination of computational development and validating wind tunnel testing to deliver two highly performing wheelsets.
The Hunt 7387 Aerodynamicist excels in changeable crosswind conditions with reduced steering force magnitudes and predictable handling due to its profile whilst offering very low aerodynamic drag numbers.
The HUNT 8387 Aerodynamicist delivers those marginal gains where all out speed is involved whilst maintaining the profile characteristics to achieve stable handling in crosswind conditions.

9. KONA Simulation

As mentioned, the KONA World Triathlon Championship course is an out and back route resulting in a unique distribution of wind yaw angles compared to the bell shape of the Mavic Standard WAD. Mavic also presents a distribution highlighting the asymmetric wind yaw angles present at KONA which is described below.

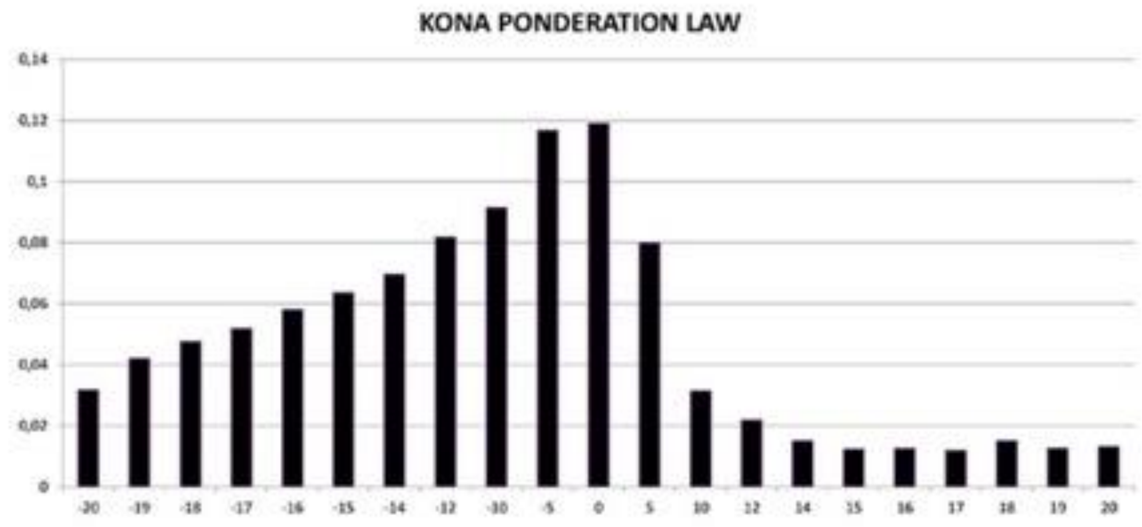

Figure 21 – Mavic Wind Averaged Drag Distribution Devised for the conditions in KONA

Given the adverse conditions at KONA, the HUNT 7387 and 8387 Aerodynamicist has significant potential with its stable and predictable handling and strong aerodynamic efficiency. When applying the specific weightings given by the Mavic KONA distribution, the following results are obtained.

MAVIC KONA WAD							
Pro One25	**Av Pwr [W]**	**Av drag [g]**	**ΔP tot or power loss [W]**	**ΔF tot or drag loss [g]**	***Required force to overcome the Drag Force [g]**	**Time [s]**	**time loss [s]**
Hunt 83F/87R	2.120	17.29	0.00	0.00	2607.03	15367.55	0.00
DT Dicut 80F/80R	2.123	17.31	0.003	0.02	2607.05	15367.71	0.16
Hunt 73F/87R	2.158	17.60	0.038	0.31	2607.34	15369.38	1.83

Table 7 - Hunt 7387 & 8387 KONA WAD results with Schwalbe Pro One 28mm Tyre, Production Test December 2021

These results show that the HUNT 8387 Aerodynamicist Wheelset is the class leading wheelset option for the KONA World triathlon Championships with very tight margins to the highly performing DT Dicut 80mm wheelset.

Appendix

1. Final 83mm Depth CFD development

The below graph highlights the significant improvement seen in CFD from the 83v8 profile to the finalised 83v10 profile and linked to the December Wind Tunnel Test confirming a major improvement.

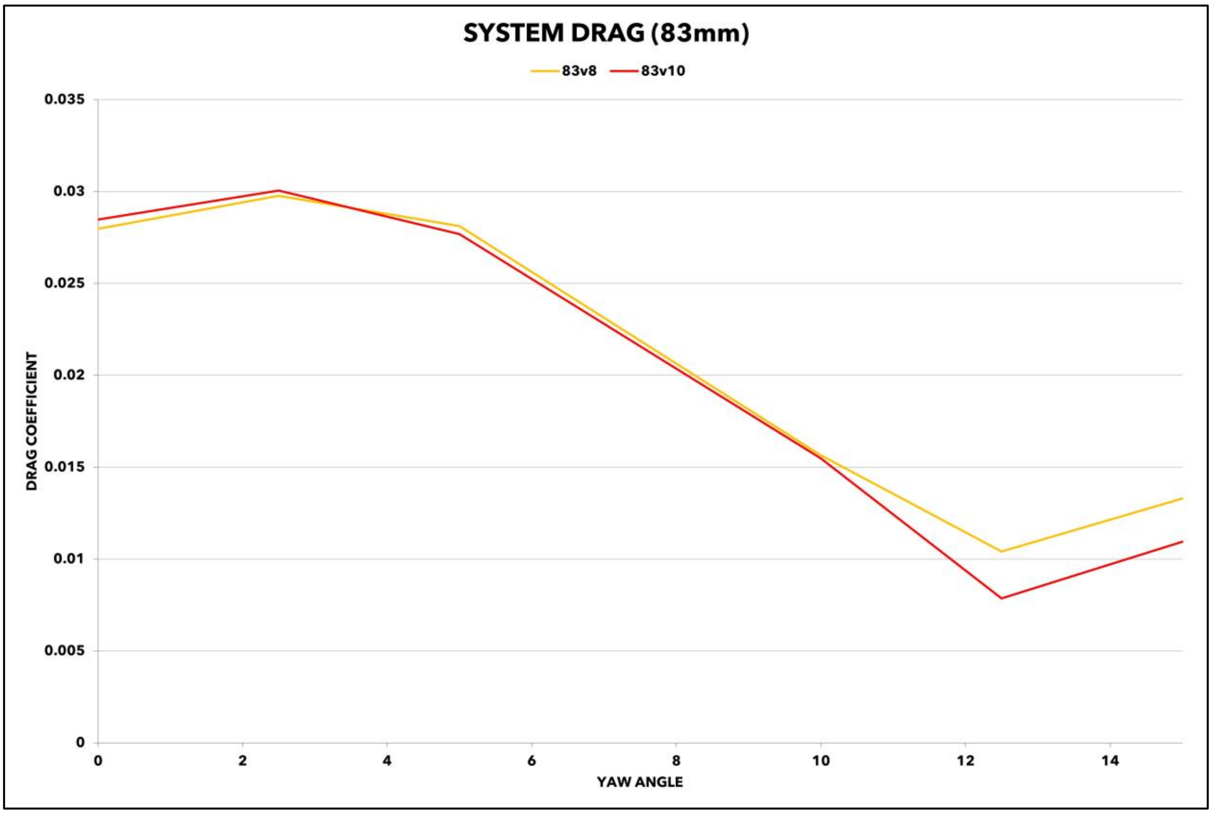

Figure 22 – Additional CFD Optimisation of the HUNT 83mm profile

2. Discwheel Comparison

The primary goal for the rear wheel was to obtain performance as close to a rear Disc Wheel as possible whilst offering a lighter weight, KONA legal wheel. The authors wanted to determine how close this performance would be, the below graphs the difference between a 73F when combined with a 87R and a Disc Wheel rear.

Figure 23 – Comparison between HUNT 87mm Rear Wheel and Rear Disc wheel drag performance

The Disc wheel setup is calculated to be 1.45W faster which shows the efforts to bridge the performance gap.

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 Argon 18 for supplying their prototype E119+ Tri Bike for each Wind Tunnel test and their CAD model for running the CFD analysis.

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 projects like these would not be possible.

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