Nitrogen Pro White Paper

NOW, YOU CAN HAVE IT ALL.

ARGON 18

Table of contents

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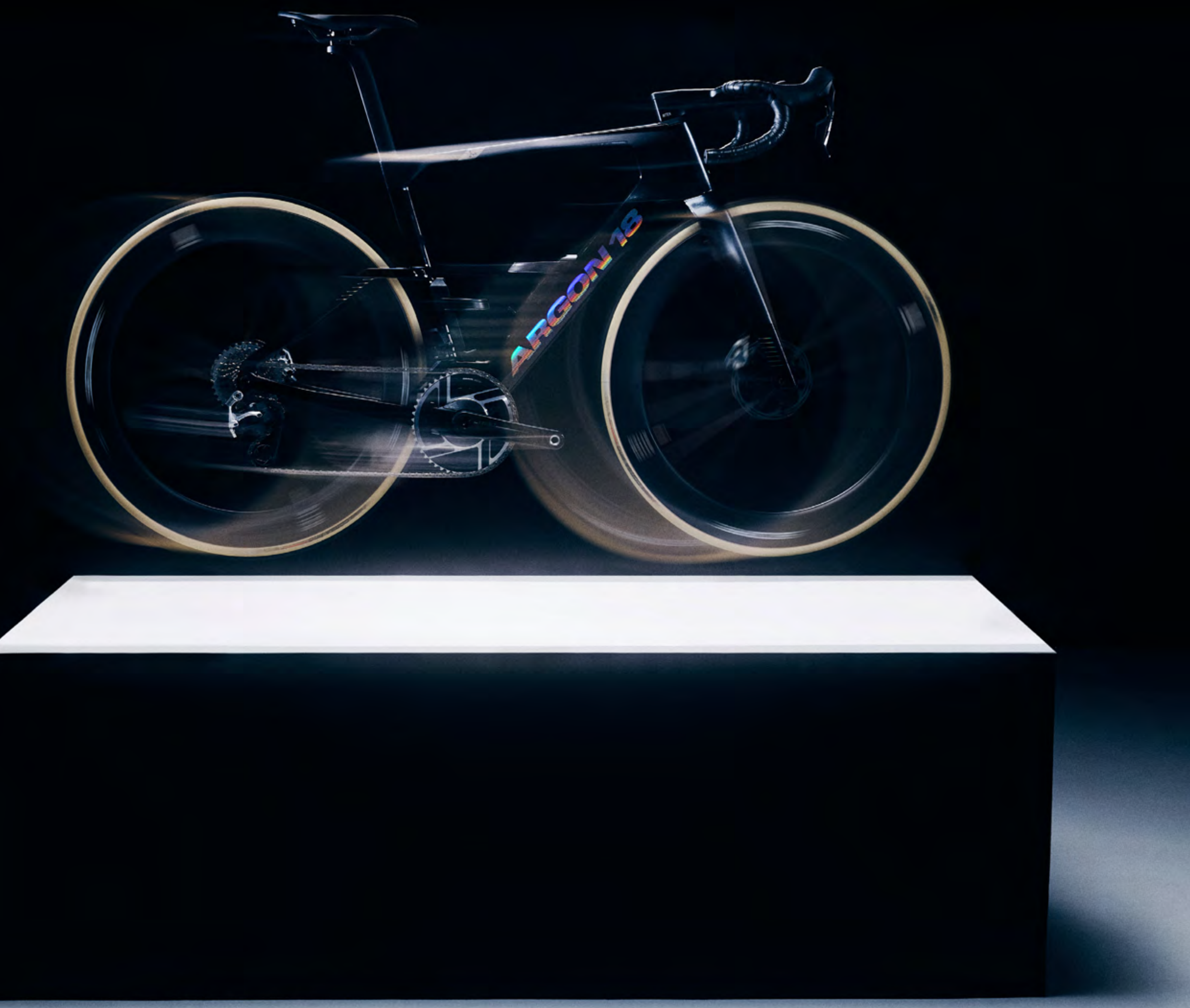
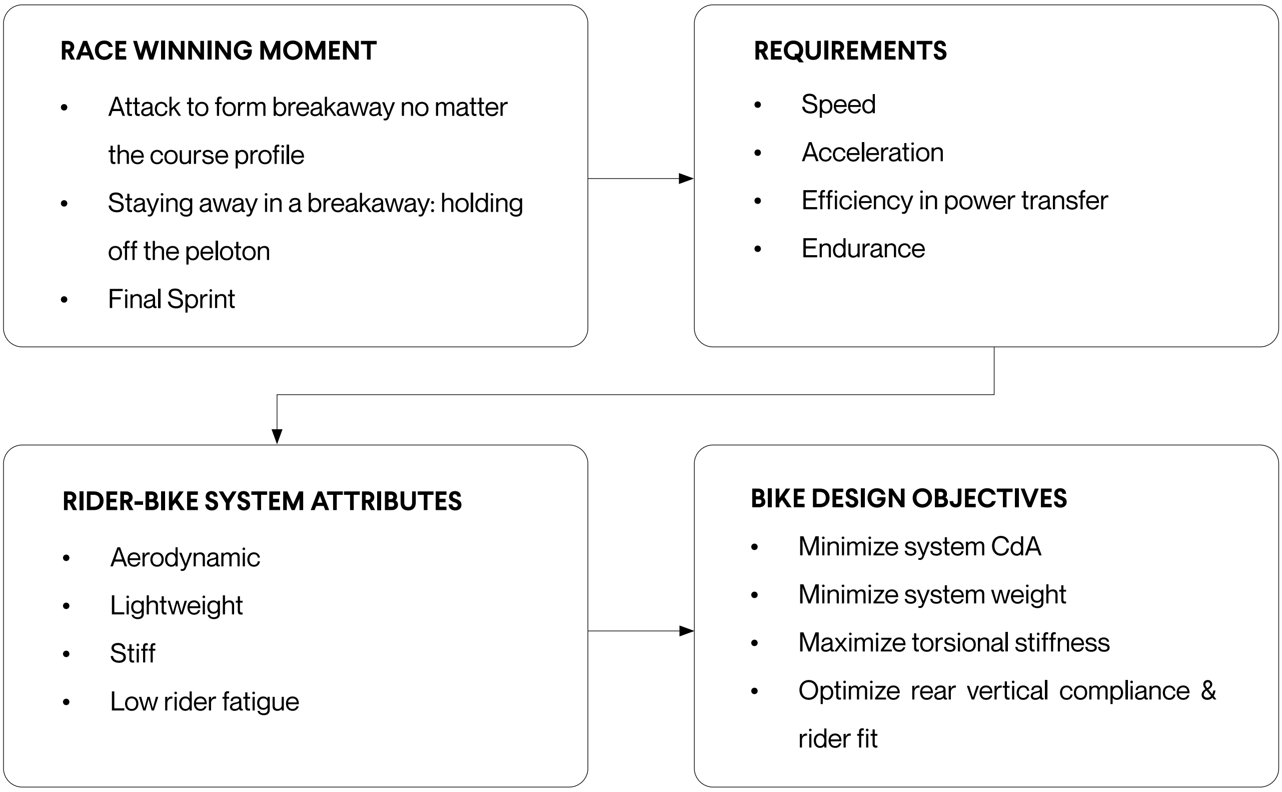
1.

INTRO DUCTION



As the margins of road races become increasingly small [1], bicycle technology and design must evolve in an attempt to provide any possible advantage to be successful in a bike race. The Nitrogen Pro is a result of exploring how bike races are won, and how to provide any possible advantage during the key instants that comprise what we refer to as 'race-winning moments'.

Looking specifically at what defines a race-winning moment allows us to become very selective in how we can optimize a bike's performance for these exact requirements.



"An initial hypothesis suggests that each requirement, system attribute, and design objective can be analyzed in terms of the individual components of the rider-bike system and their interactions. Optimizing the objective in each zone of the rider-bike system should provide the greatest opportunity to have success in what defines a bike race: the race-winning moments."

CdA

Coefficient of drag multiplied by frontal area. The coefficient of drag of an object is a dimensionless measure essentially representing how aerodynamic the shape or object is. When this shape function is multiplied by the frontal area, it gives CdA. CdA is then used to calculate the force of drag, and power required to overcome drag, using calculations which involve speed and air density as inputs.

Drag

Force that opposes an object's (in this case, rider and bike) motion through a fluid (in this case, air).

Yaw

The angle between a rider direction of motion and the relative wind direction, where the relative wind direction is a vector addition of the rider's speed and absolute wind speed.

Wind-averaged drag

An averaging method by which results of drag at various yaw angles can be weighted according to a probability distribution. In other words, accounting for rider speed, this weighted average places a higher importance on yaw angles that will be more likely to occur in real-world riding. The result is that drag values measured at several yaw angles can be described by one single value [2;3].

Computation Fluid Dynamics (CFD)

An averaging method by which results of drag at various yaw angles can be weighted according to a probability distribution. In other words, accounting for rider speed, this weighted average places a higher importance on yaw angles that will be more likely to occur in real-world riding. The result is that drag values measured at several yaw angles can be described by one single value [2;3].

Finite Element Analysis (FEA)

A computer simulation method that is used to analyse structural behaviour (among other physical effects) of an object. For Argon 18 it allows for a preliminary prediction of stiffness and whether the object will fail during safety testing.

Carbon Layup

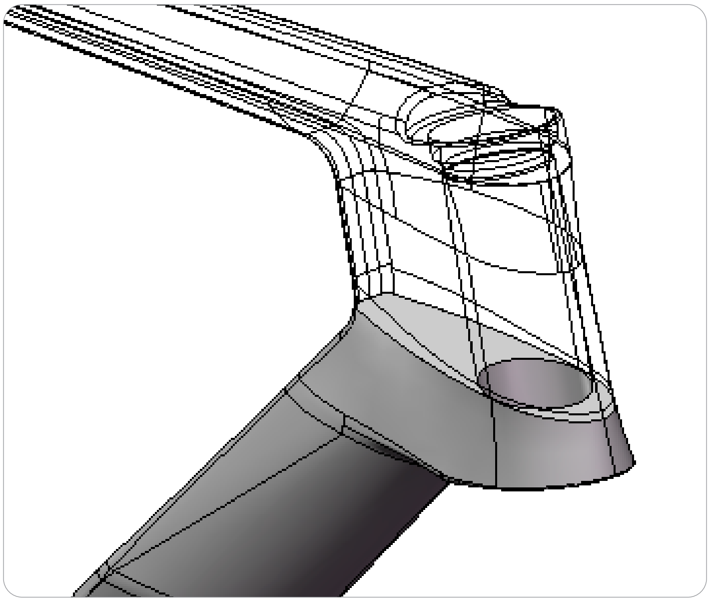
A generalized term for the placement of the many layers of carbon fiber composite material. The 'layup' comprises many pieces of carbon fiber reinforced plastic (CFRP). CFRP is made up of carbon fibers, which provide strength and rigidity while the epoxy resin matrix binds the fibers together, distributing loads and protecting the fibers from damage. The layup will consist of a variety of fiber types, orientations and thicknesses, selected specifically to result in a component that matches both our performance and safety requirements.

NACA

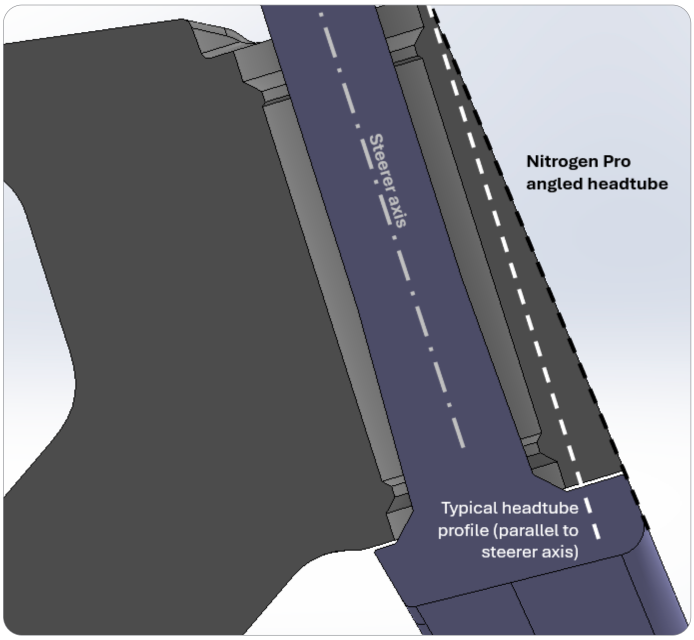
NACA stands for National Advisory Committee for Aeronautics. NACA shapes are commonly used as a description of an aerodynamic shape known as an airfoil. NACA represents a way to standardize the airfoil shape, representing the shape by various properties that describe length, curvature, etc.

2.
FRAME

The headtube is arguably the most important aerodynamic feature of the bike itself. It's the first point of contact that the frame makes with the wind and unlike the fork and seat post, the headtube sees a less disturbed airflow, meaning the flow is more controlled, or laminar as we refer to it. The flow behaviour surrounding this zone means that we can properly treat it like the airfoil shapes we typically see in the world of aerodynamics. As a result, the team implemented an internal study to optimize the dimensions and characteristics of these truncated NACA-based airfoil profiles. Testing over 130 different profiles enabled an ability not just to determine the fastest option in a single test, but to develop numerical relationships in the data to consider weight and crosswind effects.



Section view of the continued NACA profile as a function of the headtube's length.

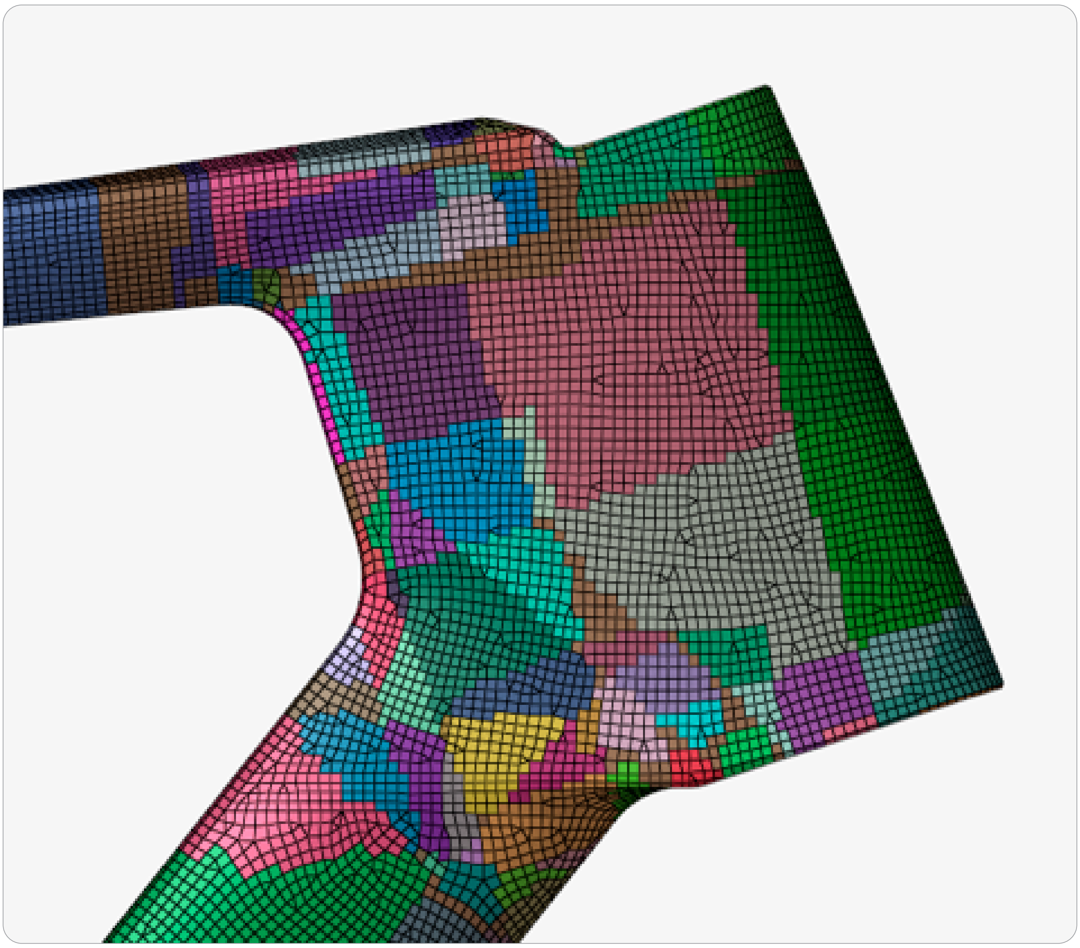


Vertical section view, showing the off-axis nature of the headtube.

The head tube was designed off-axis relative to the steerer tube, allowing an increase in the slope at the front surface of the bike, further reducing stagnation points at the leading edge. The steerer was even positioned slightly further backward relative to the headtube's leading edge, meaning the optimized profile could be maintained as a function of the headtube's height, essentially allowing for a more pointed leading edge to help cut through the wind.

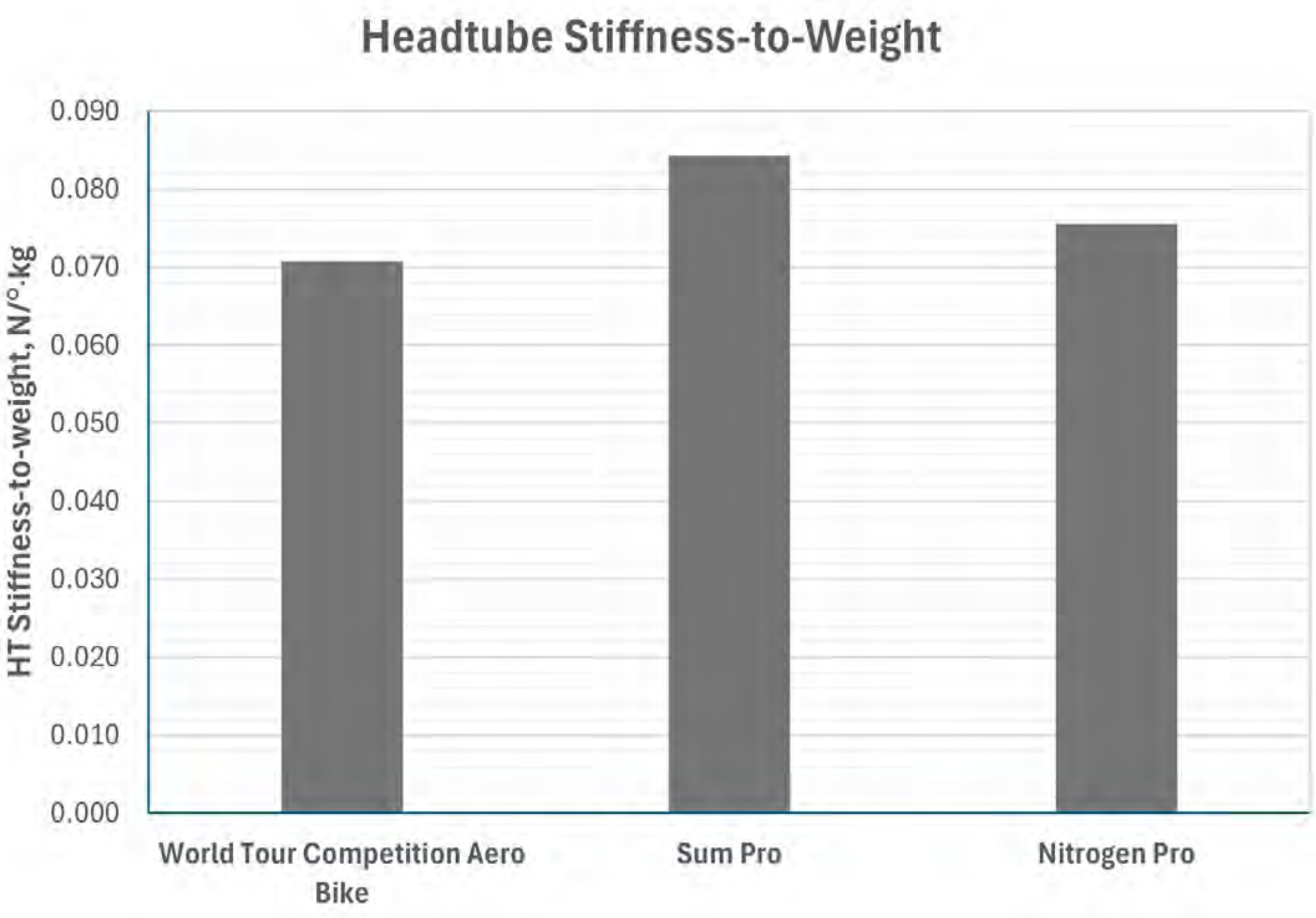
Prioritizing the aerodynamics of this undisturbed region presents challenges in maximizing what is a key requirement for sprint efficiency: a high headtube stiffness. Stiffness at the headtube area not only impacts how the headtube resists a rider's torque on the bars, but also influences bottom bracket stiffness, and therefore overall power transfer. It is known that a very thin shape naturally leads to relative weak resistance to torsion [4]. In this case, the challenge for the team was to design a thin headtube that could also resist torsional twisting. For this reason, the headtube relies on its unique carbon fiber layup development to maintain power transfer and create a responsive feeling when getting out of the saddle; arguably one of the most notable ride characteristics of the Nitrogen Pro.

Using Finite Element Analysis to simulate the structural behaviour of the frame during a sprint, the team was able to create many layup iterations, ensuring that ply by ply, the headtube met our stiffness requirements. Using the results of our FEA simulations, we worked closely with our manufacturing teams to validate that our computer models match the tests performed on the manufactured physical frame. Only then could we proceed to road tests, where we confirmed that our target stiffness matched the desired ride feel, in a double-blind layup ride test.



Overlap of indivividual material plies modeled in finite element analysis.

To quantify the Nitrogen Pro's headtube stiffness, the team performed an in-house test, where a torque is applied at the end of the headtube with the rear dropouts fixed. Below is a comparison of headtube torsional stiffness-to-weight between the Nitrogen Pro, the Sum Pro, and a World Tour Competition Aero Bike. Although stiffness-to-weight is the primary metric presented, it should be noted that the absolute headtube stiffness measurement indicates a 6% increase for the Nitrogen Pro compared to the Sum Pro.

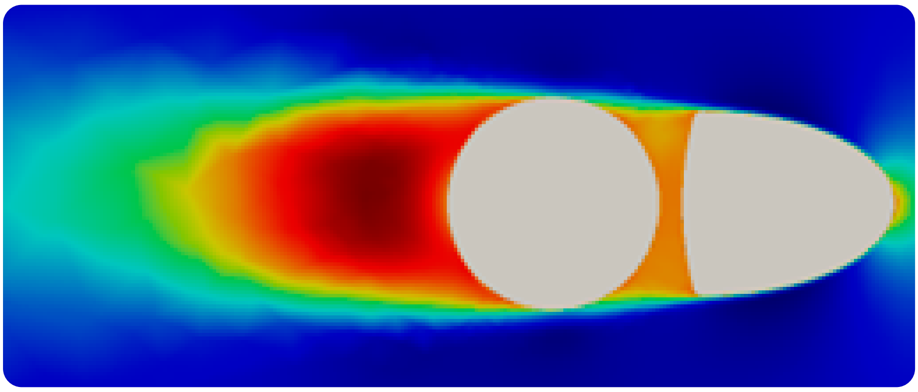


Headtube stiffness values normalized by frame weight giving stiffness-to-weight.

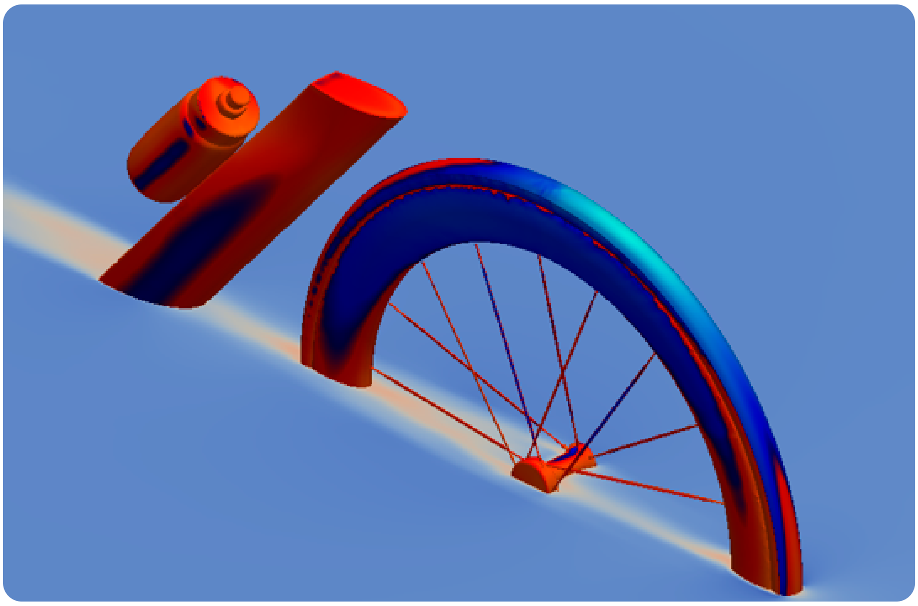
The Nitrogen Pro's downtube features a bold design, carefully engineered to meet multiple objectives. In particular, the downtube's variable width comes as a result of two principal effects:

1. The aerodynamic behaviour with a water bottle
2. A requirement for high bottom bracket stiffness

With the decision to forego model-specific water bottles as a function of accessibility, simplicity, and versatility, the profile study discussed in Chapter 2.1 was recomputed entirely, this time based on a shape that mimicked the presence and gaps of the downtube water bottle. The result was a shape with a reduced apex ratio (the distance from the leading edge to the widest point) compared to the headtube's traditional truncated NACA-based shape, enabling the trailing edge to tightly integrate with the bottle, while its overall width and leading edge allow for longer flow attachment. Keeping in mind the importance of maintaining airflow along the entire system shape - including the frame, bottle, and cage - led to the development of integrated bottle cages. These act as a bridge between the outer surface of the frame and the bottles, without requiring a specific bottle. All in all, the combination of downtube and bottle aims to form a single continuous optimized NACA-based profile.



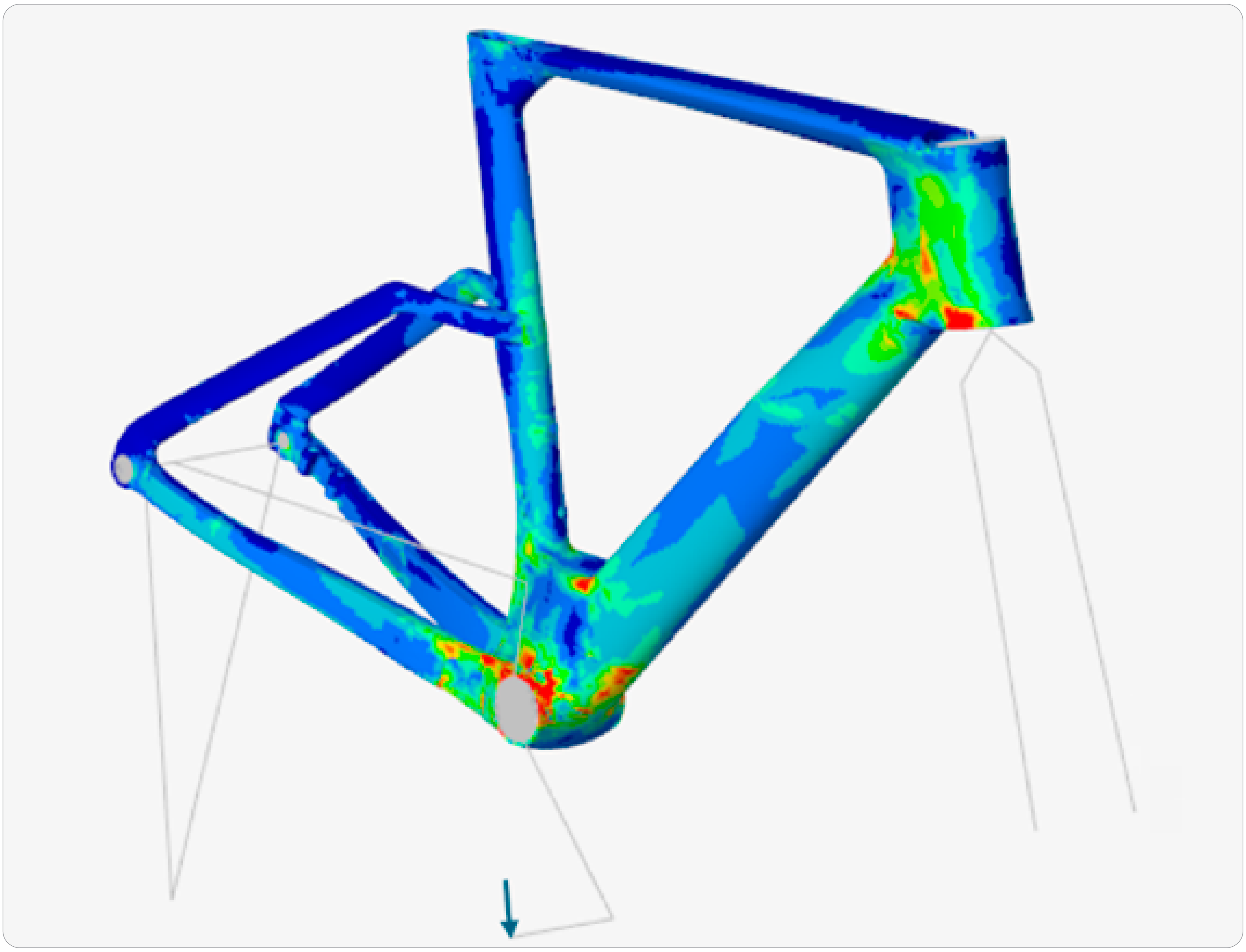
Section view of velocity profile around a tested dowtube profile with a bottle placed downstream.



Velocity profile of the downtube/bottle in the turbulent wake of the front wheel, with shear stress shown on the surfaces.

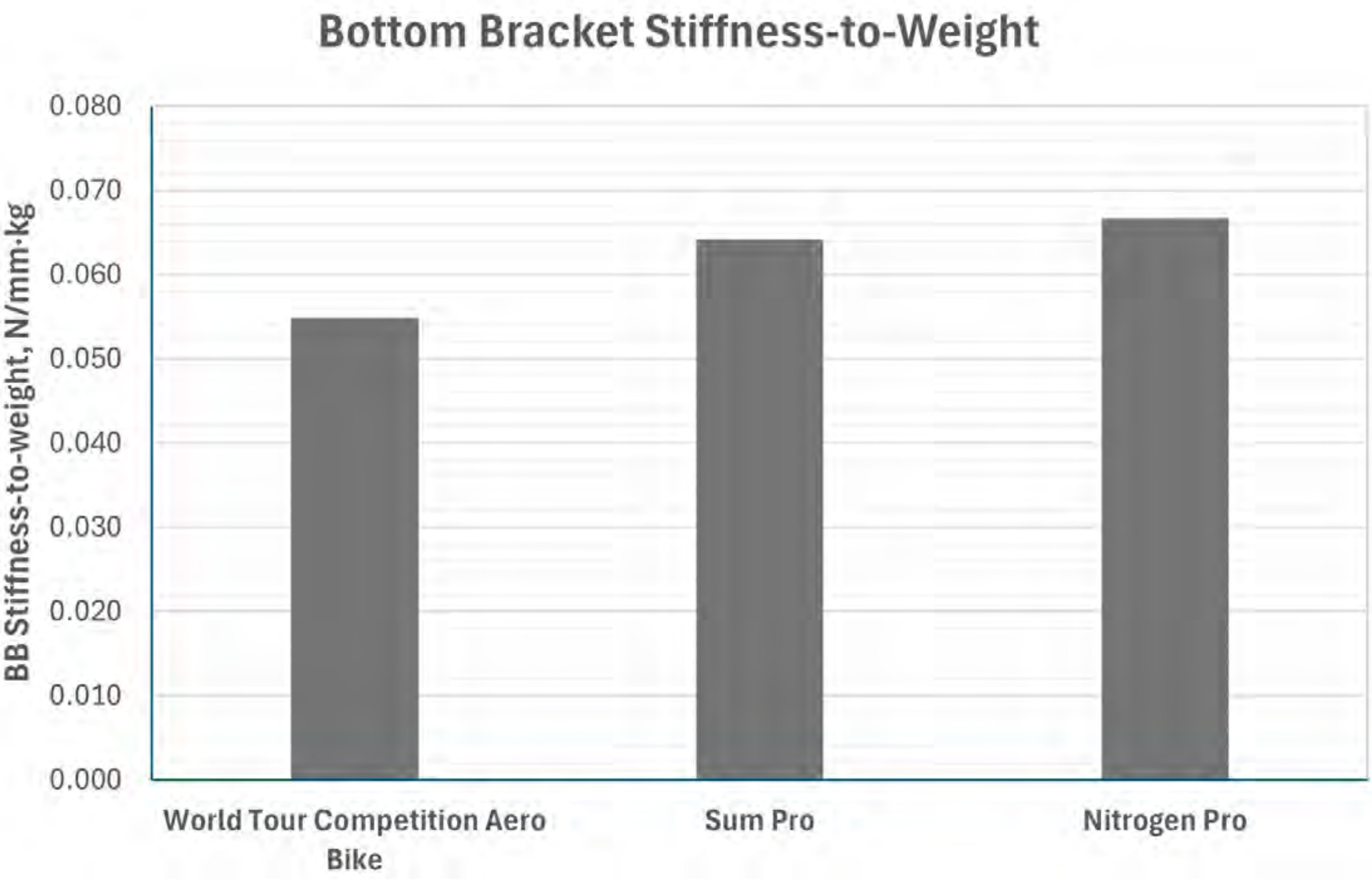
The real-world design of the Nitrogen Pro's downtube was put to the test in the wind tunnel, measuring the difference between the presence of two bottles, compared to no bottles or cages (representing an optimized yet unrealistic setup). In this test, the Nitrogen Pro was compared with a traditionally thin aero frame. The results of the tests indicate that with a traditional aero shape, adding bottles can cost between 4 and 9 W at 45 km/h, depending on wind direction. Conversely, the Nitrogen Pro, with its proprietary bottle cages and unique downtube design, is penalized only 0 to 3 W when adding two bottles. For more information regarding the Nitrogen Pro's proprietary aero cages development, please see Section 6.

Aerodynamics, however, only tells half the story. The lower downtube is the portion of the frame that most significantly contributes to bottom bracket stiffness and therefore arguably has the greatest impact on the rider's power transfer. Opposite to the aforementioned thin headtube, a much wider downtube naturally promotes higher torsional rigidity [4].Choosing a geometry that offers a higher resistance to torsional deflection reduces the amount of reinforcing plies required, thereby reducing the weight in this zone, all while providing a significant absolute bottom bracket stiffness increase (23%) with respect to the Sum Pro.



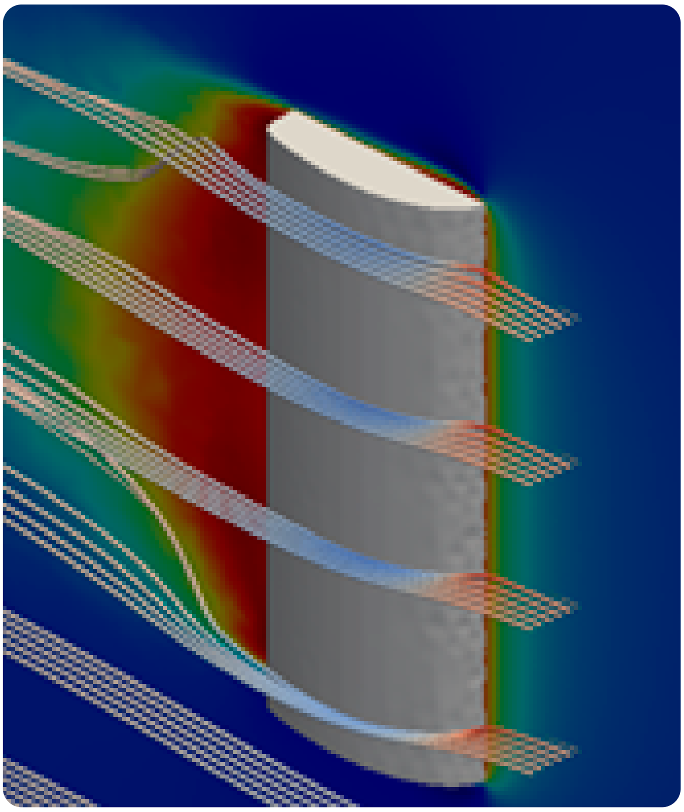
Finite element analysis showing stress results during a bottom bracket stiffness test.

The bottom bracket stiffness was quantified in Argon 18's in-house laboratory test facility. The test involves a force applied on a rigid crank-arm, simulating the force applied during a pedal stroke, while the fork and rear dropouts are fixed relative to one another. Bottom bracket stiffness-to-weight results of the Nitrogen Pro, Sum Pro, and World Tour Competition Aero Bike can be seen below:



Bottom bracket stiffness values normalized by frame weight giving stiffness-to-weight.

The seatpost design of the Nitrogen Pro checks a polyvalent list of functions to help reach each of its intended demands set forth in the design brief. First, with aerodynamics paramount to the design of the system, an optimized profile was calculated based on the team's initial profile optimization study, once again being the result of over 130 different profiles tested. Relative to the Sum Pro, the frontal area was lowered by reducing the overall width, while airflow attachment was enhanced by changing the frontal curvature and the overall length.

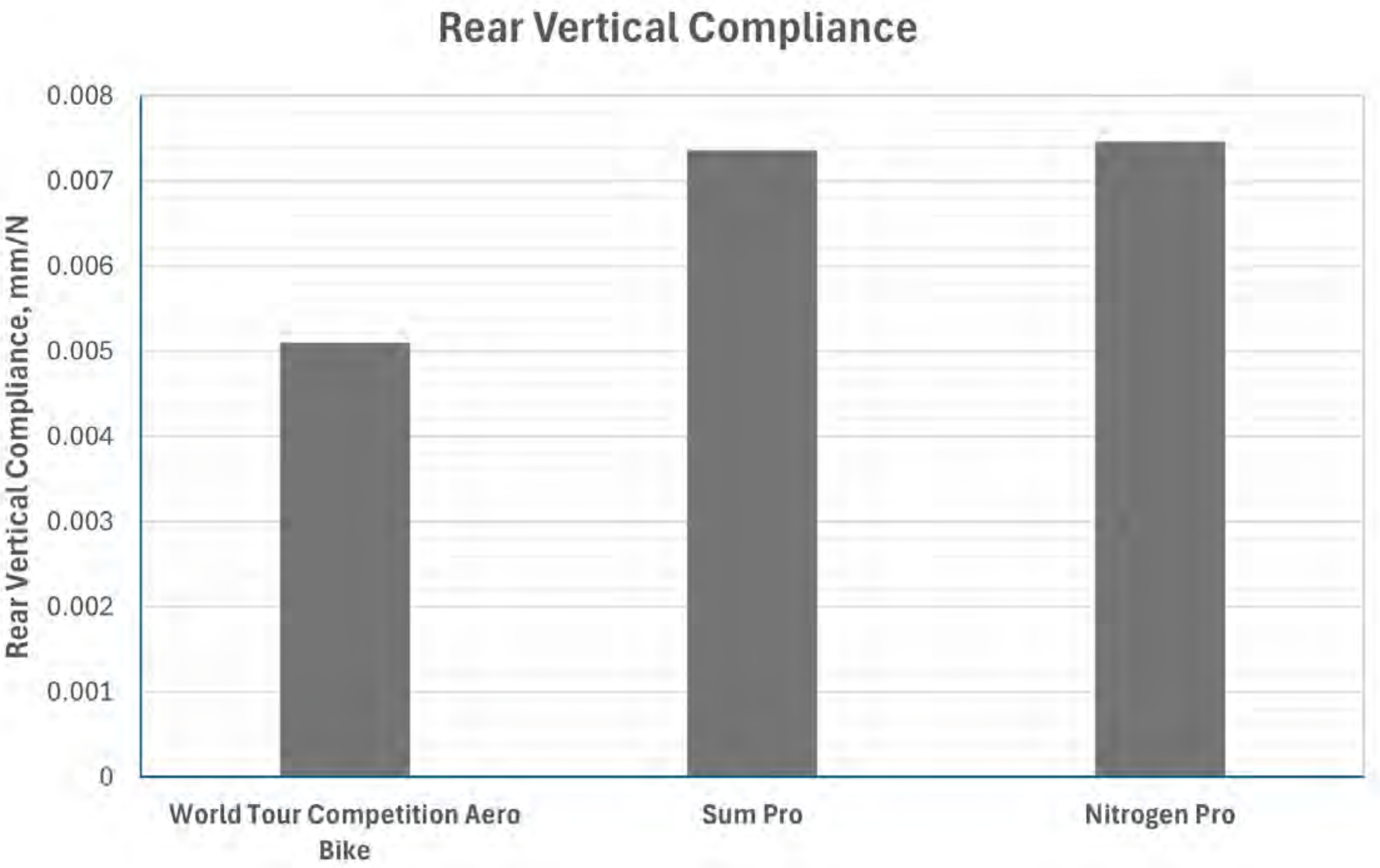


Flow around a simplified profile; part of the 130 profile iterations tested.

The seat post contributes not only to the aerodynamic performance of the system, but also towards the energy saved throughout a race by absorbing much of the rider's weight, certainly while encountering road bumps and vibrations. As a result, the overall profile depth of the seatpost was carefully calibrated to balance two factors: it needed to remain deep enough to provide an aerodynamic advantage, while keeping in mind that an excess of seat post depth would lead to an overly rigid and heavy design. Analogous to the removal of a rider's saddlebag, weight savings further away from the rider and bike's 'pivot points' are required to maintain a nimble, light feeling when sprinting out of the saddle.

While traditional aero bikes are typically known for their harsh ride feel, the Nitrogen Pro's ability to absorb vibrations and provide voluntary deformation through rugged conditions contribute to energy savings over the course of a race. While a high stiffness is desired in the headtube and bottom bracket area, the seat post contributes very little to power transfer. As such, low stiffness is desired in this area to provide voluntary deflection and therefore increased ride comfort.

Compliance, by definition, is the inverse of stiffness. A high compliance value allows for more deflection upon the application of an equivalent force. As mentioned above, this is correlated with an increased ride comfort and pedalling efficiency. As a means of quantifying this effect, a rear vertical compliance test was performed in Argon 18's in-house test facility in which a force is applied on the seat post, with the front and rear dropouts fixed.

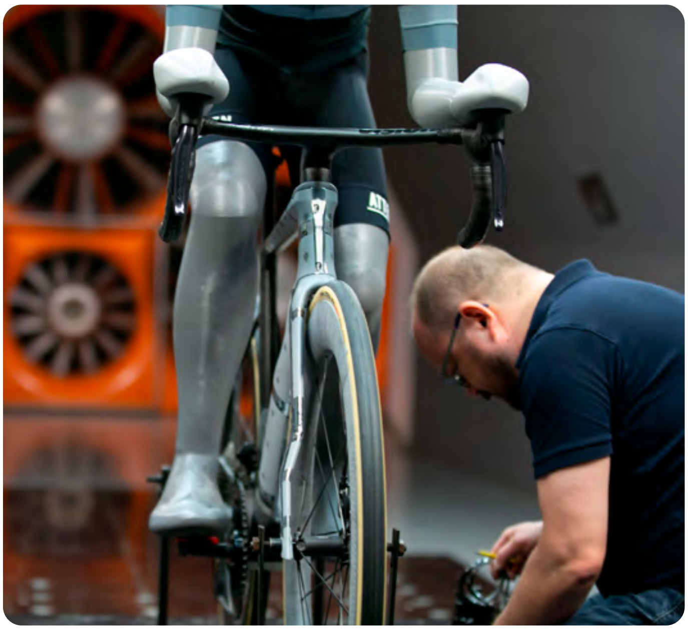


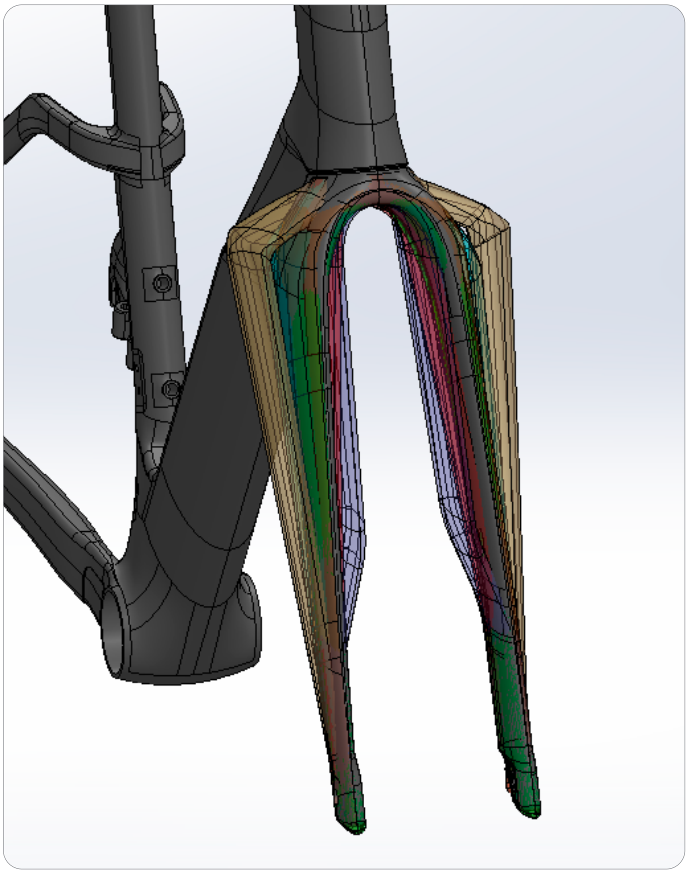
Rear vertical compliance test results. Higher values mean more deflection upon the application of an equivalent force, leading to a more compliant and therefore more comfortable ride.

3. FORK

When designing the bike in the context of an overall system, it was essential to consider interactions between each of the components. This effect of creating the best overall solution and subsequently designing as a function of neighbouring or downstream components is evident in the fork's unique shape.

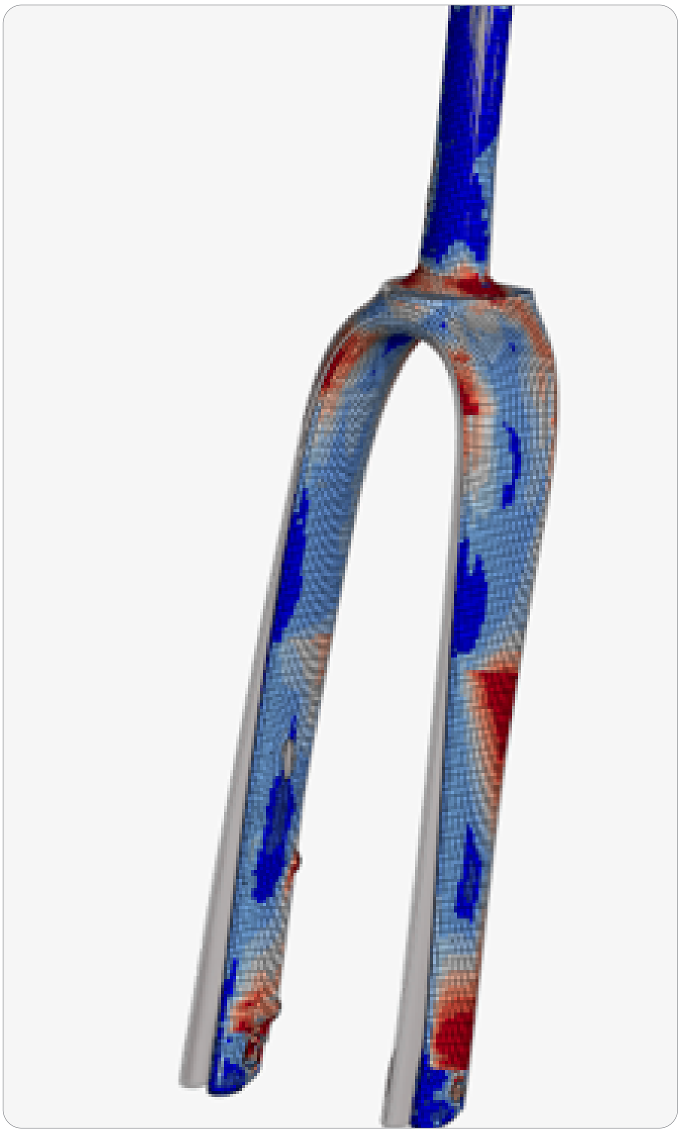
With 25 different tested prototypes in several rounds of CFD simulations and three separate wind tunnel test sessions, the conclusion regarding fork design, particularly concerning blade-to-blade width, was clear: a wider fork allowed for the blades to distance themselves from the turbulent air created by the wheel's spokes, while simultaneously decreasing the pressure seen by the rider's legs, all in all resulting in a lower aerodynamic drag.





Overlay of various forks tested throughout the development of the Nitrogen Pro. The final version provides an optimal blend of aerodynamic efficiency, reduced weight, and high lateral stiffness.

What was less straightforward was creating a wide fork design that provided exceptional lateral stiffness and low weight. The result was a solution that best satisfied the aerodynamic and structural requirements: fork blades that are distanced from the wheel, with a semi-compact crown, acting more as a 'triangular' structure and less like a 'rectangular' structure upon lateral load application. Since the shape of the crown favours higher lateral stiffness (and lowers surface area compared to a 'wide' crown) the target stiffness can be obtained with less reinforcing material, and therefore a lower overall weight.



Lateral stiffness testing of the Nitrogen Pro's fork in FEA.

4.
WHEELS

It is essential to reiterate the importance of the Nitrogen Pro's performance, considered as a full system. One key aspect of the system's synchronous evolution is the collaboration wheelset, developed in conjunction with Scope Cycling, an industry leader in wheel development and creators of the fastest wheel on the market [5].

The development of the ATTEN X Scope Artech 6.A+ wheelset was multidirectional, meaning both the wheels and frame were designed as a function of one another. The wheels use Scope's revolutionary Artech ideology, yet with a rim profile that is specific to the Nitrogen's Pro build. At the same time, the Nitrogen's aerodynamic tests were always performed with the most up-to-date iteration of the wheelset, meaning the frameset is truly optimized with these wheels . An example of this can be noted in the fork design, the region where wheel and frameset interact.

The texture of the Artech wheels promotes early transition from laminar to turbulent flow, thereby resulting in an earlier reattachment downstream, and generating a smaller overall wake. The Nitrogen Pro's wide fork distances itself from this phenomenon, meaning the wheel's texture effect can properly take place, relatively uninfluenced by the airflow surrounding the fork blades. The resulting smaller wake created by the Artech technology means a lower overall drag at a key aerodynamic region of the rider-bike system.

Not only was the wheelset specifically designed in conjunction with the Nitrogen Pro's fork and frame, it was also designed as a function of the specific tire model and width. The ATTEN x Scope Artech 6.A+ rim's internal and external widths were carefully selected based on nominal width characteristics of the Vittoria Corsa Pro 30c tire, ensuring the combination of tire and rim leads to improved airflow at their junction.

While the system is optimized for 30c tires, it can take up to 32c, making it ideal for modern road racing, where the race winning moment may occur on any given terrain.

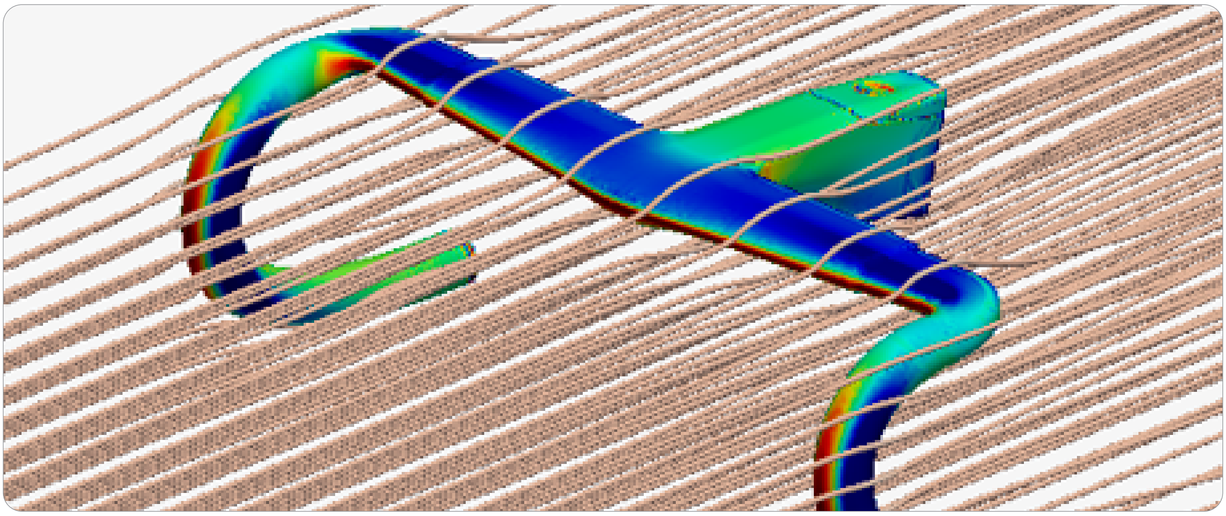
AEA
ALGORITHM ENHANCED AERODYNAMICS

AEROSCALES

The ATTEN x Scope Artech wheelset was designed in parallel with the Nitrogen Pro; taking a true full system approach.

5.
COCKPIT

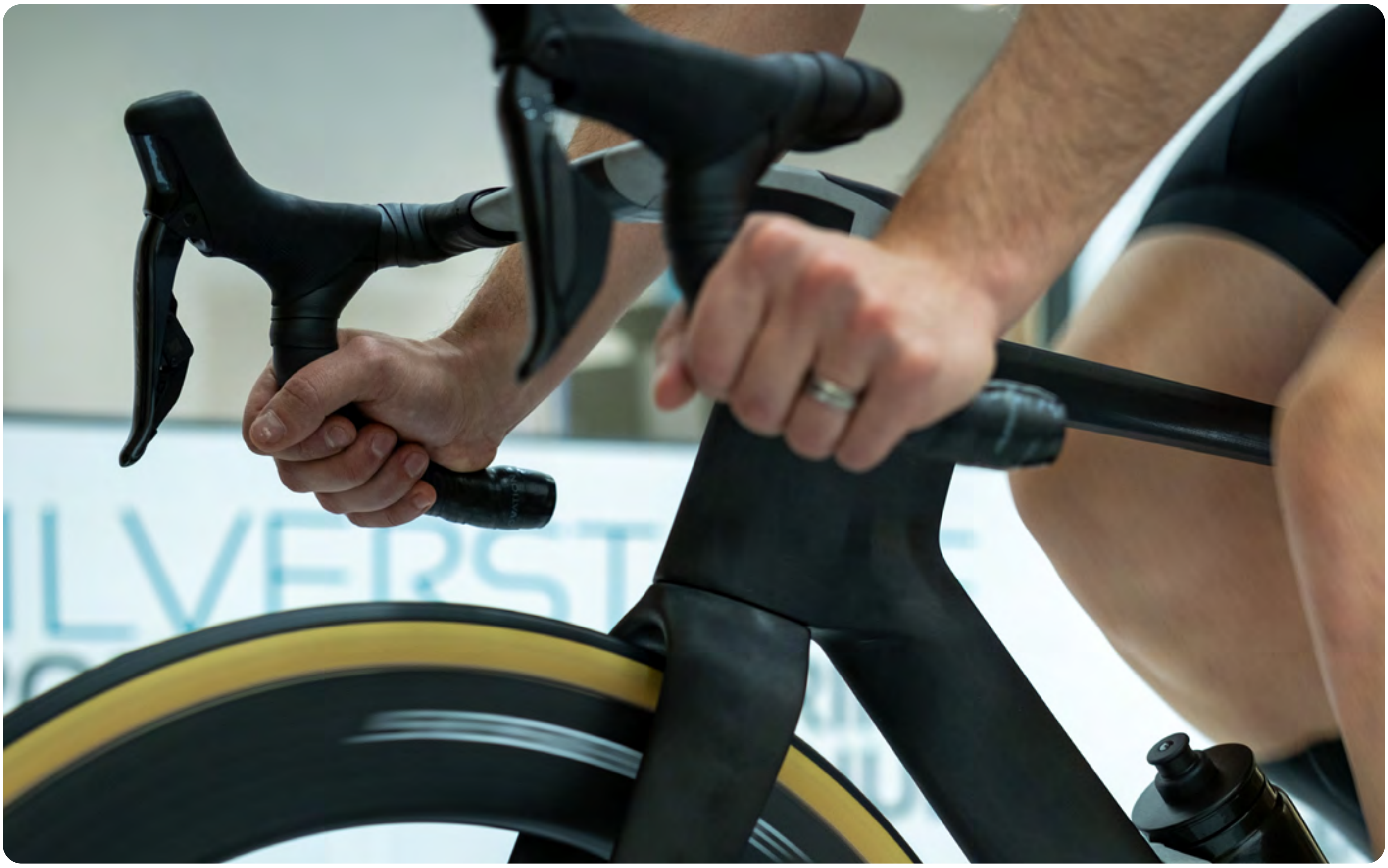
Adding to the complete system of the Nitrogen Pro is the ATTEN one-piece cockpit. Seeking high performance aerodynamics, the cockpit uses an extremely slim design to reduce frontal area, and achieves an aggressive leading edge, once again optimized with our study of over 130 individual profile iterations. The unique consideration of an arrow-like shape provides marginal gains by reducing stagnation points along the leading edge, allowing for a more favourable pressure gradient at the leading edge in more frequently seen yaw angles. At 45 km/h, wind tunnel tests show that the cockpit saves 6.7 W (wind-averaged) compared to a standard bar/stem solution, and 4.3 W (wind-averaged) compared to the Vision Metron 5D.



CFD analysis showing pressure and airflow behaviour around the ATTEN cockpit.

Once again, with the bike's requirement to rapidly accelerate, to maximize the rider's power generated during an attack or final sprint, the cockpit was geometrically designed in a way that would minimize torsional deflection, while the carbon layup and precision in manufacturing is what gives its light weight. The ability of the stem to be rigid in torsion with a low weight was an especially important task, given the modern fit trends, particularly in the professional peloton. A long stem will, based on solid mechanics theory [4], increase the angle of twist when a torque is applied, compared to a shorter stem. Lengthening the stem can also significantly increase the weight of the system if a high-density material or high wall thickness is required.

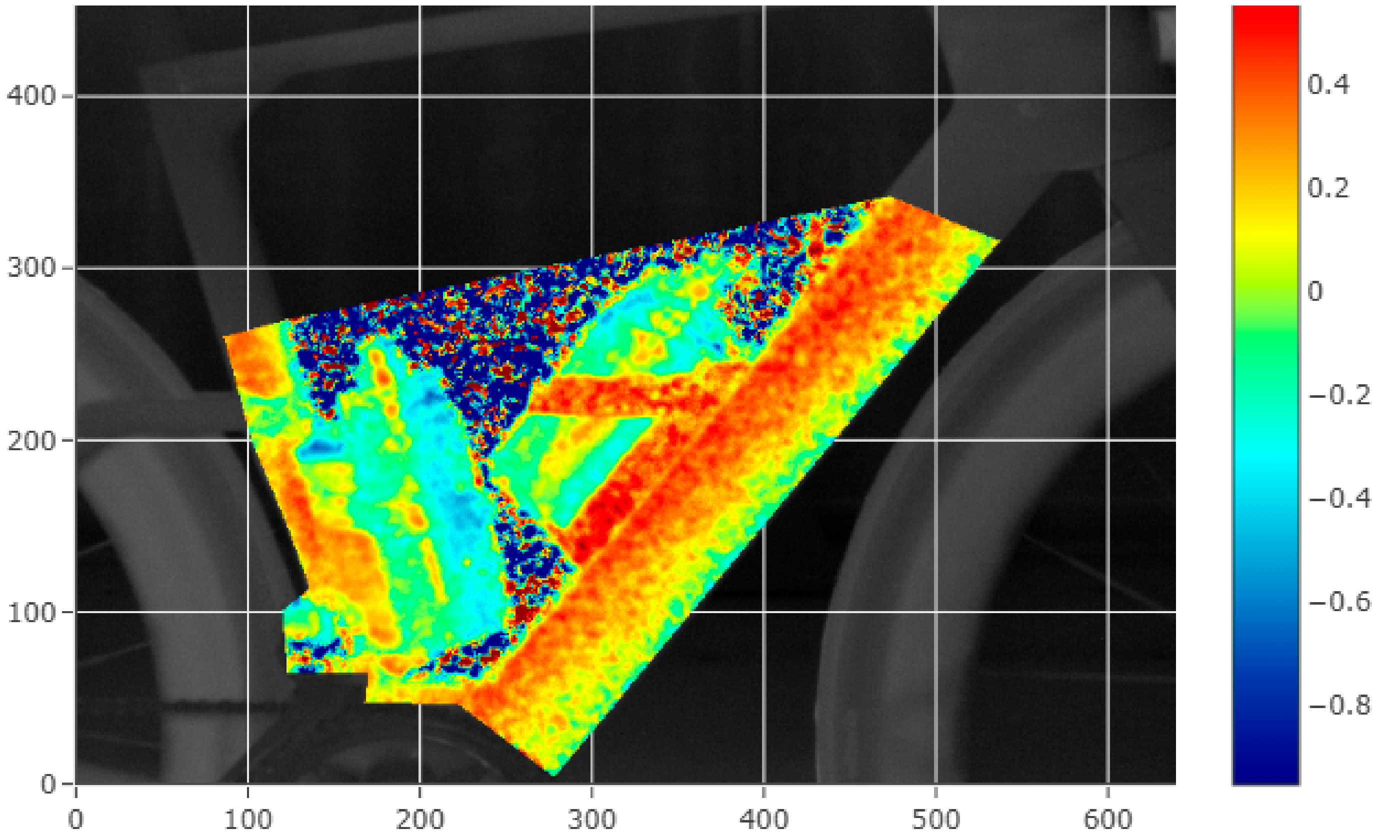
For this reason, careful consideration was made when designing the geometry of the stem and stem/bar transition, in order to offer a geometrically stiff solution, and to ensure that such a complex geometry could be manufactured effectively without adding unnecessary weight. The final design enables riders of all fits to have the explosiveness, responsiveness, and acceleration that is required throughout key moments of a race.



6. ACCESSORIES

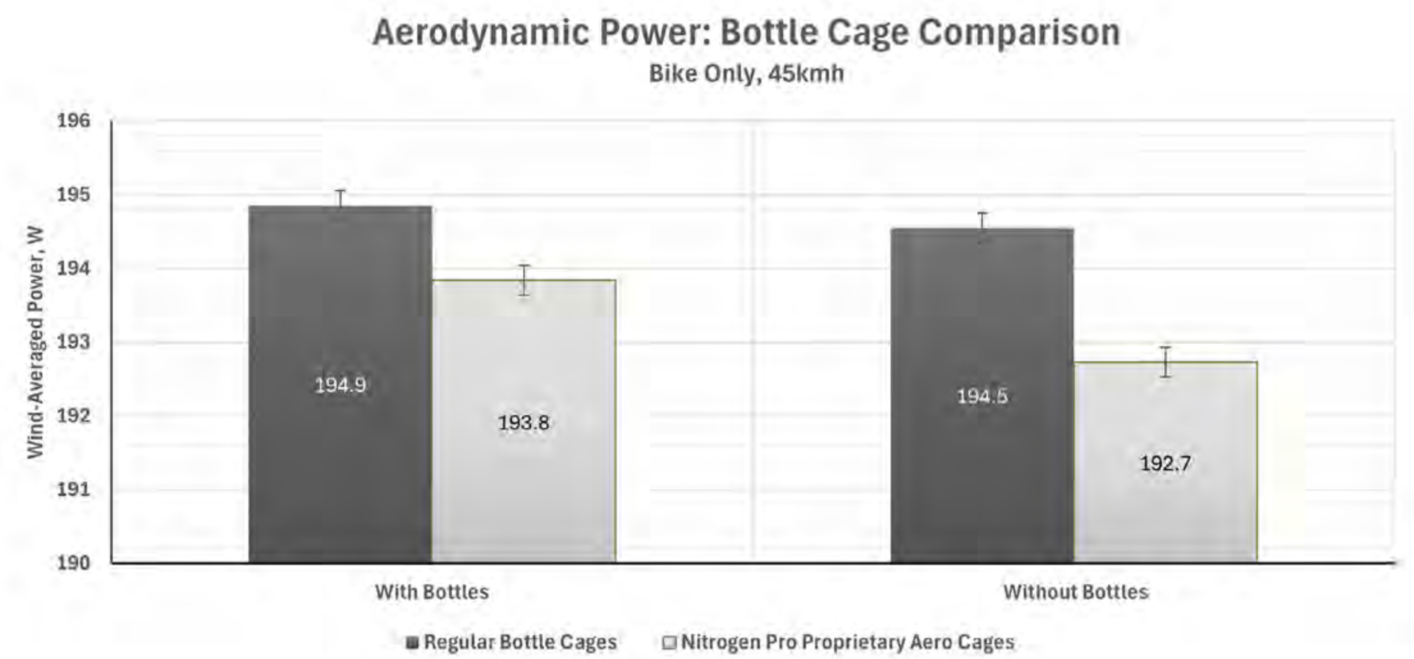
The ATTEN aero cages on the Nitrogen Pro provide a real-world, straightforward solution to improve aerodynamics of the system without the complications of bike-specific bottles.

As discussed in section 2.2, the aerodynamics in this zone were approached from multiple directions: creating a downtube profile that was optimized given the constraint of the bottle, as well as creating a transition joining the tube to the bottles created by the ATTEN aero cages. The downtube cage provides a nearly tangent continuation of the downtube's profile, thereby maintaining flow continuity between the downtube and cage. Sitting snug to the bottle, the cage also reduces the frontal area exposed by the standard water bottle and removes small turbulent zones that would otherwise be created by the gaps between frame and bottle.



Thermal decline tomography imaging on the integrated bottle cages, performed using Silverstone Sports Engineering Hub's Boundary Layer Camera.

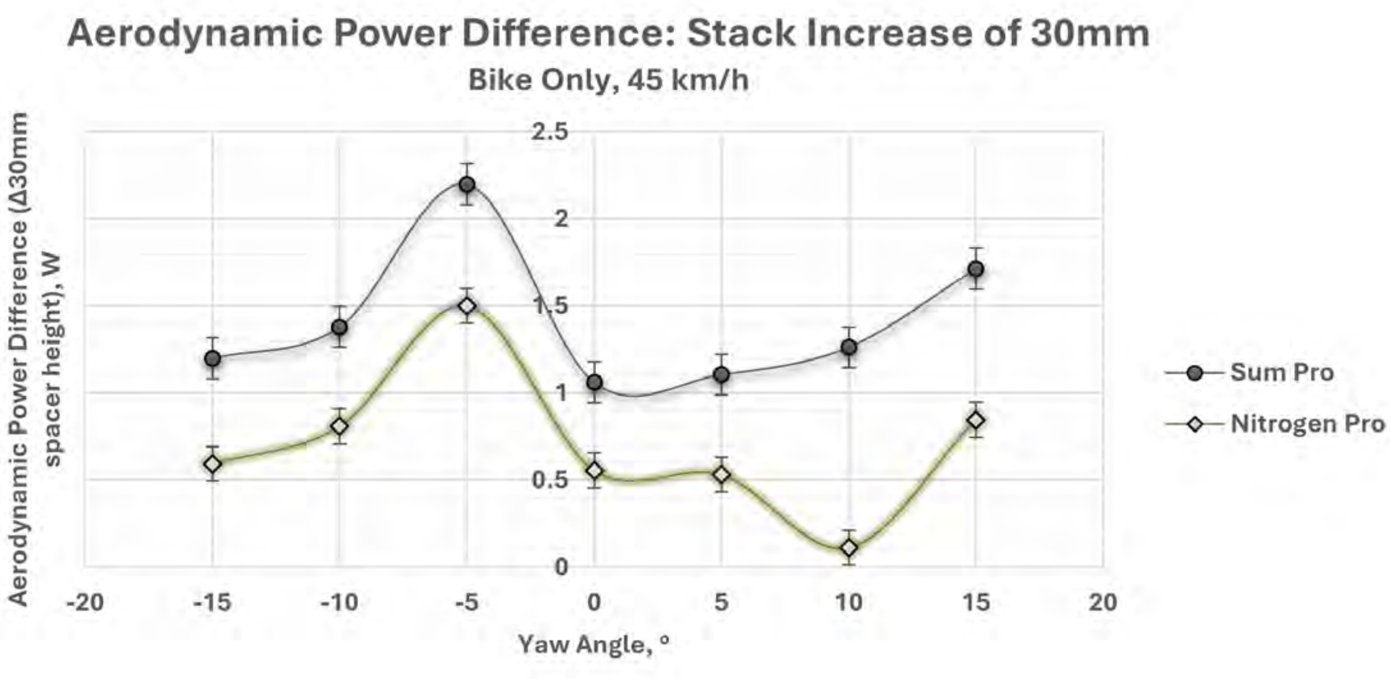
While the front aero cage was developed primarily with the mindset of improving the Nitrogen Pro's aerodynamic performance with a bottle, it must be considered that the rear cage will not always hold a bottle in the crucial moments of the race. For this reason, the rear cage consists of a unique design allowing it to provide aerodynamic benefits both with and without a bottle. When a bottle is present, the increased width of the rear aero cage means that flow attachment from the bottle to the aero cage is maintained for longer. When there is no bottle present, the vents allow for a reduction in frontal area while maintaining this wide geometry, as well as channeling flow around the rear wheel. Overall, the aero cages show savings of 1.1 W with bottles, and 1.8 W when the cages are empty (power calculated using wind-averaged drag).



Wind tunnel test results showing the aerodynamic advantage offered by the proprietary integrated bottle cages. Lower value indicates less power required to maintain equivalent speed.

The Nitrogen Pro doesn't compromise when it comes to providing optimal performance for all athletes. As the full system also includes the rider, it was important that each and every rider, regardless of position, would not have their aerodynamic efficiency limited by the bike. Knowing that the rider position is the most important aspect of the system as a whole, it was of key importance to design the fit system in a way that would allow the rider to maintain an efficient, sustained and ergonomic position. Part of this challenge was providing a stack system that allows riders to reach their optimal fit while maintaining aerodynamic efficiency.

The spacers, however, provide a challenge in that there is an inherent increase in frontal area. As such, based on the profile study in which over 130 iterations were performed, an optimized aerodynamic NACA-based profile was established as the cross-sectional geometry of the spacers. They provide a significant improvement when compared to the spacer system of the SUM Pro. When increasing the stack height by 30mm, the SUM Pro's spacer system results in a 1.4 W penalty (wind-averaged); while only a 0.7 W penalty is seen using the Nitrogen Pro's spacer system for the same stack increase. The difference in aerodynamic drag (represented by power required) for the 30mm stack increase on the SUM Pro and the Nitrogen Pro, respectively, can be seen in the following plot:



Wind tunnel test results showing the aerodynamic advantage of the aero spacers compared to the Sum Pro's spacers, at various yaw angles. Lower value indicates lower difference in power required to maintain equivalent speed.

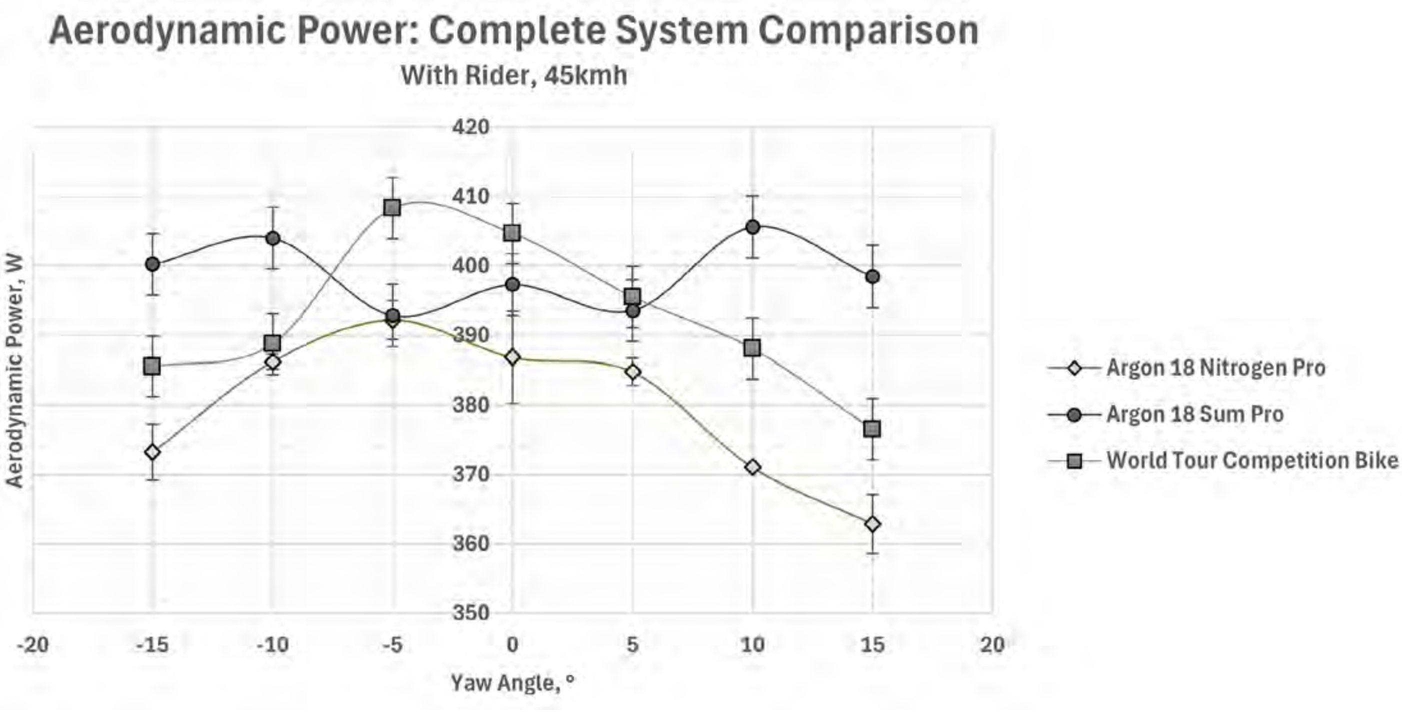
7. FINAL PRODUCT

An initial hypothesis suggested that an overall system could be engineered and designed to maximize success in race-winning moments. This initial hypothesis consisted of an analysis by parts of certain zones of the rider-bike system, in addition to their respective interactions, in order to fulfill the following objectives:

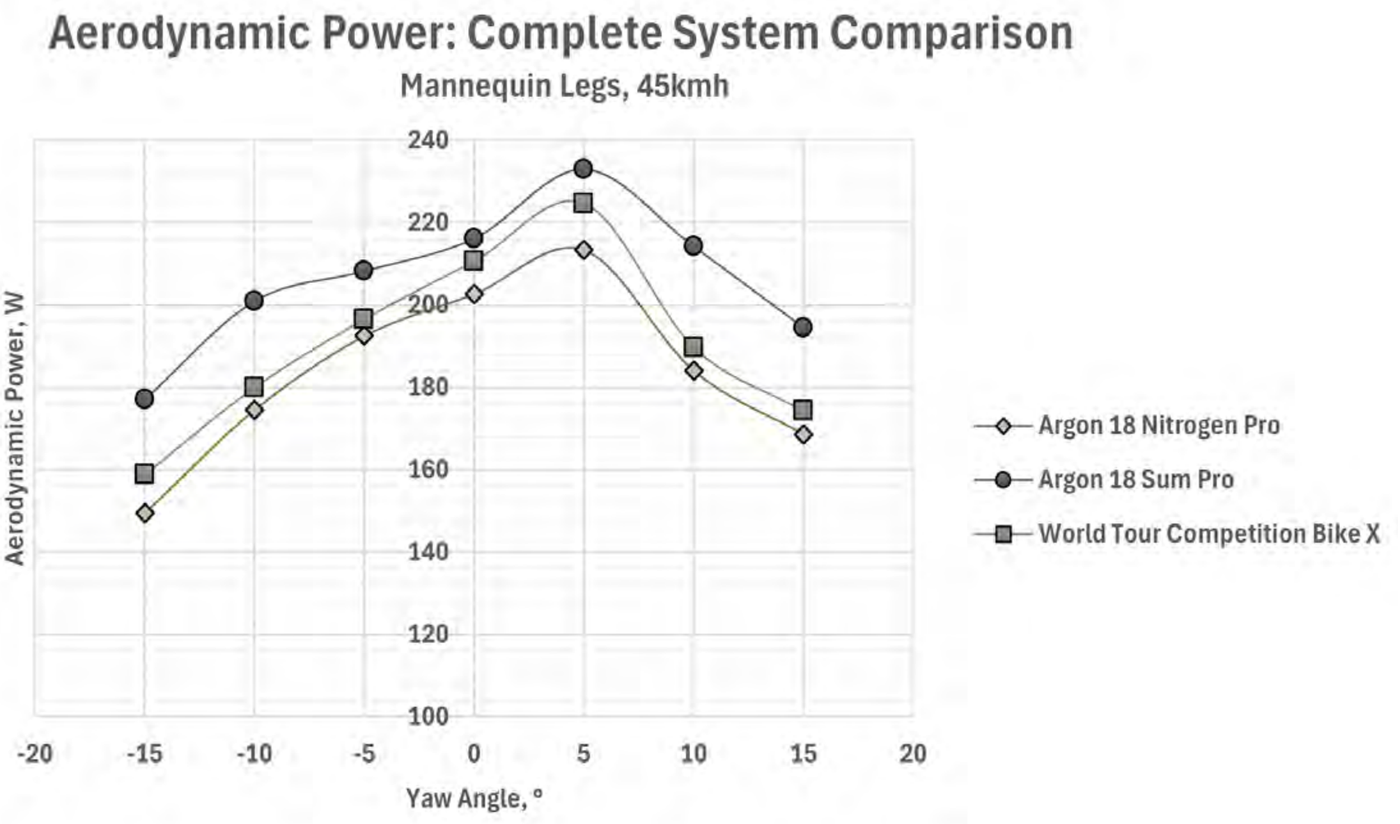
- Minimize aerodynamic drag
- Minimize system weight
- Maximize torsional stiffness
- Minimize rider fatigue

7.1 Aero comparison VS SUM Pro & Worl Tour Competition Aero Bike

The system underwent three separate wind-tunnel test sessions throughout the development of the project. As part of one of these test sessions, the final product was tested against the Sum Pro, and against a competitor brand's flagship dedicated aero bike, which we call 'World Tour Competition Aero Bike'. Keep in mind that lower aerodynamic power means the rider needs to produce less power to maintain the same speed. The results below were tested both with a pedaling rider and with static mannequin legs.



Wind tunnel test with rider. Comparison of the Nitrogen Pro, SUM Pro, and World Tour Competition Aero Bike, tested at 45 km/h. Lower result means more aerodynamic (less power required at equivalent speed).



Wind tunnel test with mannequin legs. Comparison of the Nitrogen Pro, SUM Pro, and World Tour Competition Aero Bike, tested at 45 km/h. Lower result means more aerodynamic (less power required at equivalent speed).

7.2 Weight

The overall system weight of the Nitrogen Pro comes extremely close to the UCI weight limit of 6.8 kg. The result of hundreds of hours in FEA simulation analysis yielded a sub 950 g frame, a sub 415 g fork (both frame and fork size medium, painted), a 160 g seat post (including clamp), and a 320 g cockpit (380 x 100 mm size). Using SRAM Red AXS groupset, Vittoria Corsa Pro tires, and Repente Quasar CR saddle, the Nitrogen Pro complete system weights in at 6.95 kg (medium size, painted, with TPU tubes).

At this weight, the stiffness-to-weight ratio remains high due to the frame's optimized carbon layup and the structural efficiency of ATTEN's one-piece cockpit. Torsional stiffness around the bottom bracket and head tube has been preserved while minimizing unnecessary material in low-stress zones, resulting in a system that approaches the UCI minimum weight without compromising power transfer and aero dynamic performance.

7.3 Stiffness

Argon 18's internal mechanical testing facility allows us to accurately measure and quantify frame stiffness. Typical power transfer is often correlated to certain tests in particular; namely bottom bracket stiffness and headtube stiffness. As discussed in Sections 2.1 and 2.2, the Nitrogen Pro makes significant strides in improving power transfer efficiency with respect to the Sum Pro, increasing headtube stiffness by 6%, and bottom bracket stiffness by 23%.

This, combined with the stiffness of the ATTEN x Scope Artech 6.A+ wheels, and the ATTEN cockpit, provides an unparalleled system stiffness designed to optimize power transfer in race winning moments.

As a means of quantifying mitigation of rider fatigue, rear compliance is a standard metric that can be quantified using Argon 18's in-house test facility. Referring to Section 2.3, it is seen that the Nitrogen Pro maintains and even provides slight reductions in rear vertical stiffness (meaning an increase in compliance, and therefore comfort), all while significantly improving bottom bracket and headtube stiffness.

The Nitrogen Pro's geometry stays true to Argon 18's fit window while also developing aerodynamic spacers to maintain performance regardless of rider position. Finally, the ability to fit up to 32c tires means that rider fatigue is minimized no matter the terrain. Between rear compliance, aerodynamic fit considerations, and increased tire clearance, riders can expect to save up every last watt for the race winning moment.

8 References

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RIDE OUT OF THE ORDINARY