BOLIDE F HR 3D

WHITE PAPER 1.0

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1. INTRODUCTION

Constant innovation and research are the foundations of success if you want to build the fastest time trial bike for the track. From Miguel Indurain's World UCI Hour Record timed by Tissot to the recent gold medals in the team pursuit in Tokyo, Pinarello has a leading role in this segment. And the result of that extreme research, the spirit of innovation it engenders, and the technology it produces is then spread through the whole range of Pinarello products.

All cyclists always want to ride the best bike available, especially when it comes to aerodynamic performance and power transmission. But for this unique project, the demands are even higher than usual.

The Bolide F HR 3D needed a totally perfect fit, designed around the rider, conforming to Filippo's unique anatomy to maximise both his comfort and overall aero performance. Comfort is often underrated, but when it comes to an UCI Hour Record timed by Tissot attempt it is absolutely crucial because it allows the athlete to go faster for longer.

The importance of stiffness is also often underestimated for track bikes, but any flex under power causes the wheels to scrub, losing the athlete crucial centimetres every time they push the pedals.

With that in mind, this project needed to blend strength and stiffness with aero gains, with a production method that would allow for millimetre-perfect sizing and the full utilisation of everything Pinarello's engineers learned from months of intense research.

Now, Pinarello is proud to introduce a world-first: A 3D printed frame, designed for a world champion and for his UCI Hour Record timed by Tissot attempt. It will be available for Filippo Ganna and for the global market.

3D printing allowed us to introduce new shapes and features that are impossible to replicate with existing carbon fibre techniques. With this new method we have created a unique aerodynamic shape and reached an incredible level of stiffness.

Moreover, it made it possible to add internal reinforcement, create a totally new shape of head tube and importantly, it also drastically cut development time because we were no longer held back by the traditional time constraints of mould production for a carbon fibre frame.

Such a unique project has to be considered as the beginning of a new manufacturing process. The next steps are to make it more affordable, by finding ways to scan riders with cheaper equipment and automatically design the bike for each rider. From a world champion for a unique event to each world tour cyclist to eventually, to every rider one day.

The following pages are a summary of the improvements that the whole Pinarello team worked on, trying to push forward the knowledge, and understanding of what makes a bike fast and how a human being, by only using their own power, can move as fast as possible, or in this case travel as far as possible.

This white paper is not intended to be a technical document. It is, rather, telling the story of the endeavours of a team of people that can never sit still or rest on their laurels.

2. AERODYNAMICS

Aerodynamics is everything for the UCI Hour Record timed by Tissot. Well, this is mostly true if all other parameters such as weight, strength, stiffness, and usability are kept within reasonable limits. So, for the purposes of this document, we can assume that all other important parameters are kept constant, and that aerodynamic resistance is the main enemy that we need to tame. The UCI Hour Record timed by Tissot bike is very similar to a road Time Trial bike, but there are two important differences.

Firstly, there are no brakes and no multiple gear systems. It is literally, a bare-bones, pure-speed machine in its simplest form. A set of wheels, just two gears connected by the chain, a saddle, a handlebar, cranks and pedals connected to a frame and a fork. How hard can it be?

Secondly, the bike hits the air head-on or nearly head-on all the time. This is because there are no side winds to take into account. When a bike is designed for the road, the engineer has to calculate the probability of encountering side winds. Here, things are simpler, but not easier.

The last fifteen years or so, top-end bicycle designers made significant use of modern aerodynamic research methods that were previously used on aerospace and Formula One applications, especially CFD.

The improvement of technology in the recent years allowed CFD to transition from a being a research tool to becoming a design tool. Cloud computing and web-based solutions allow now infinite computational power without the need to purchase and learn complex software. Our simulations were run on AeroCloud provided by the Norwegian company NablaFlow. AeroCloud runs completely on AWS (the preferred cloud solution by many F1 teams and FIA for their CFD simulations) and it allowed us to run multiple configurations simultaneously, providing detailed aero data used in the design and validation phase. The streamlined configuration implemented allowed the models to be seamlessly uploaded and the results to flow directly into the design process, allowing us to look for marginal gains.

Just a few years ago, in 2020, www.cyclist.co.uk asked Have we reached peak aero? By that time, any half-decent bike used truncated airfoil sections on the frame and fork tubes, smooth transitions and some parts integration.

Then a few things changed. The UCI relaxed the regulations a bit and removed the 3:1 tube section requirement and a new wheel rim with a bumpy inner edge started gaining some popularity. Maybe we can apply these ideas on a frame and fork.

CFD is the go-to method for aerodynamic development these days. Done well, it can closely approximate reality. So, we used CFD to explore ideas; some good, some unusual and some, let’s call them strange.

A. THE CONDITIONS

On the track, the rider spends about 55% of their time in the corners and about 45% on the straights. The angle of yaw in the corners is somewhere between 3° and 6°. This has some effect on the bike performance, so it was taken into account in our optimisation.

The bike, of course, doesn't go around the track on its own, so we have to include the rider in our CFD simulation. A realistic rider model will have to mimic the pedalling motion of the rider with legs going up and down as well as the cranks going around in circles. Although this is technically possible today, it will require enormous computing power and the simulations will be too slow to give us results in a reasonable time using a fine-enough resolution to get a reasonable approximation. We therefore opted for a simplified method that positions the rider in several different leg positions, and then averaged the results.

Some may say that this approach is not as accurate as it can be, and we agree with them. All researchers struggle with this question of accuracy vs number of iterations. Experience shows that you can arrive at a better overall result by doing a lot of carefully considered and reasonably accurate simulations rather than very few super-accurate ones. The main reason is that by doing many different iterations and analysing the results, it helps the engineers to come up with ideas, then try them and keep iterating. Even so, we always run out of time and budget before we run out of ideas.

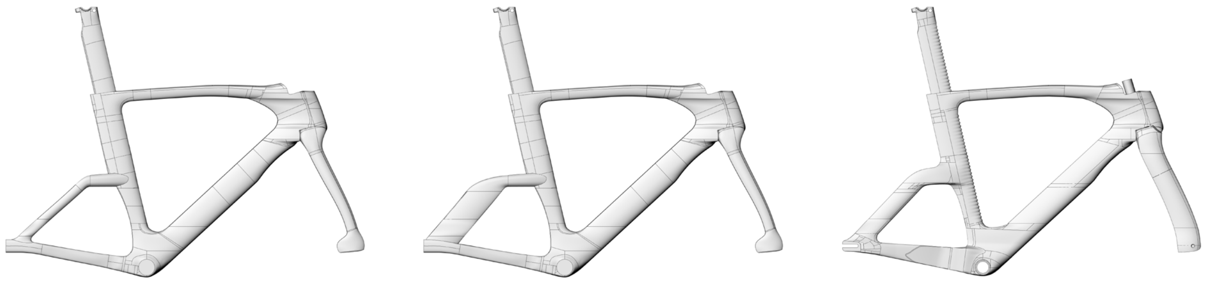
To help detect small changes the bike and the rider are split into individual parts and their contributions to the overall drag are recorded. In reality, the "secret sauce" is how you add these parts together, how you prioritise them and how you decide what the next steps should be. Pinarello and Metron have developed and refined the method over ten years working together, so, the improvements are still coming; we are nowhere near "peak aero", not yet.

B. FINDINGS

WHEN YOU LOOK, YOU FIND. LET'S START WITH THE EASY ONES

Minimising the frontal area is one of the approaches that works well. So, there were some substantial gains from making the wheel hubs as well as the bottom bracket (BB) narrower than normal. The BB was narrowed down to 54mm (from 70mm), the wheel hubs from 120mm down to 89mm on the rear, and from 100mm down to 69mm on the front.

The next obvious improvement was to take advantage of the removal of the 3:1 regulation. This allows longer and slimmer airfoil sections to be used. It is very well known that airfoil sections that have an aspect ratio of 6:1 or even 8:1 do perform significantly better than the old 3:1 ratio. Easy gains there, so, thank you UCI for allowing this.



A BIT MORE COMPLICATED

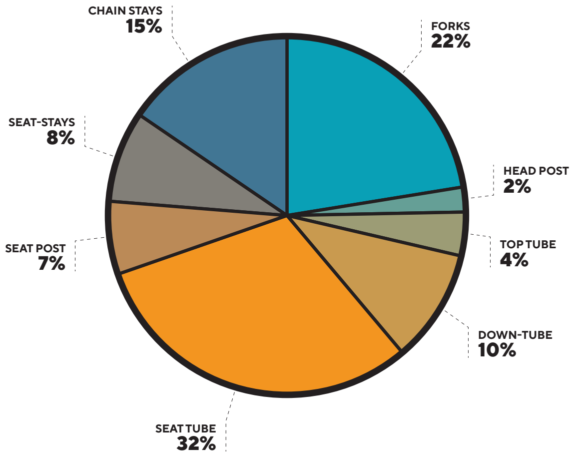
What do you do with the fork and the seat stays? We've all seen bikes recently with very wide forks and seat stays. Do they work? Well, maybe. The evidence that we managed to gather so far was not clear-cut. A system like that will have to be designed to reduce the overall system drag of the bike and rider. In general, in a design like that, the bike will actually create more drag but, if refined enough, should drop the drag of the rider more than the drag penalty on the bike. In our case, the results were too unstable, and the potential gains were not consistent enough to adopt such a design.

So, we went with the classic and proven method of narrow fork and seat stays, both of them being close to the disc wheels. This method also creates a low weight solution as well as has no unknowns in terms of manufacturing.

NOW THE COMPLEX PART

The legs of the rider are moving up and down all the time in a rather complex but very repeatable path. In the early days, when we were developing the original Bolide in the late 2012, it was realised that the air flow around the seat tube and seat post is never straight. In reality, it is always alternating as the rider's legs are constantly deflecting the air around them. This alternating airflow makes it very difficult for the air to stay attached on the seat tube. The consequence is that the airflow is constantly separating from the seat tube, creating a large low-pressure area around it which in turn creates large amounts of drag. This is partly why the combined drag of the seat tube and seat post is almost 40% of the total drag of the frame and fork. manufacturing.

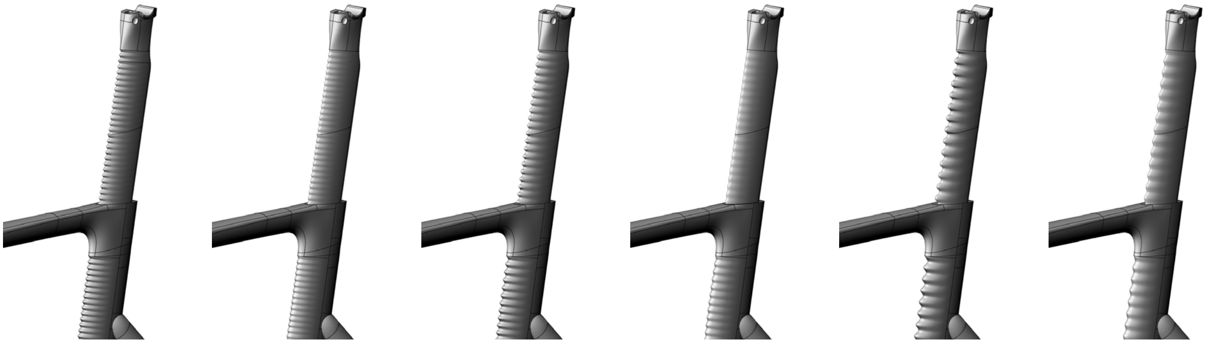
DRAG DISTRIBUTION ON A BIKE FRAME AND FORK



So, that makes the seat tube drag reduction an obvious target. What can we do to make the air stay attached on the seat tube to minimise the drag? Enter the University of Adelaide, and their extensive research into how humpback whales manage very tight manoeuvres in the oceans. Nature has great way of natural development and has been doing it for millions of years.

Humpback whales are well known for their ability to perform very tight turns as well as spectacular jumps out of the water. Researchers have found that the tubercles (protrusions in the front of their flippers) contribute significantly to this ability. In fact, researchers at the University of Adelaide have been working on tubercles since 2006, first using them on aircraft wings and fans and then on bicycle frames, filing an international patent application for a “bumpy” bicycle frame in 2016.

They also observed that the airflow around the seat tube alternates through a wide angle, leading to separated flow and increased drag. They found that tubercles are able to minimise this separation effect and reduce the drag by generating streamwise vortices in the troughs between the bumps, causing the flow behind the peaks to stay attached. Using an optimised design, valuable drag reductions were achieved on their own prototype frame.



But things are never simple. Unfortunately, just putting a few bumps on the front of the seat tube is not enough to make anyone faster. So to optimise our HR bike, Pinarello and its aerodynamic R&D partner NablaFlow ran many simulations, finding some effective designs, and some less so.

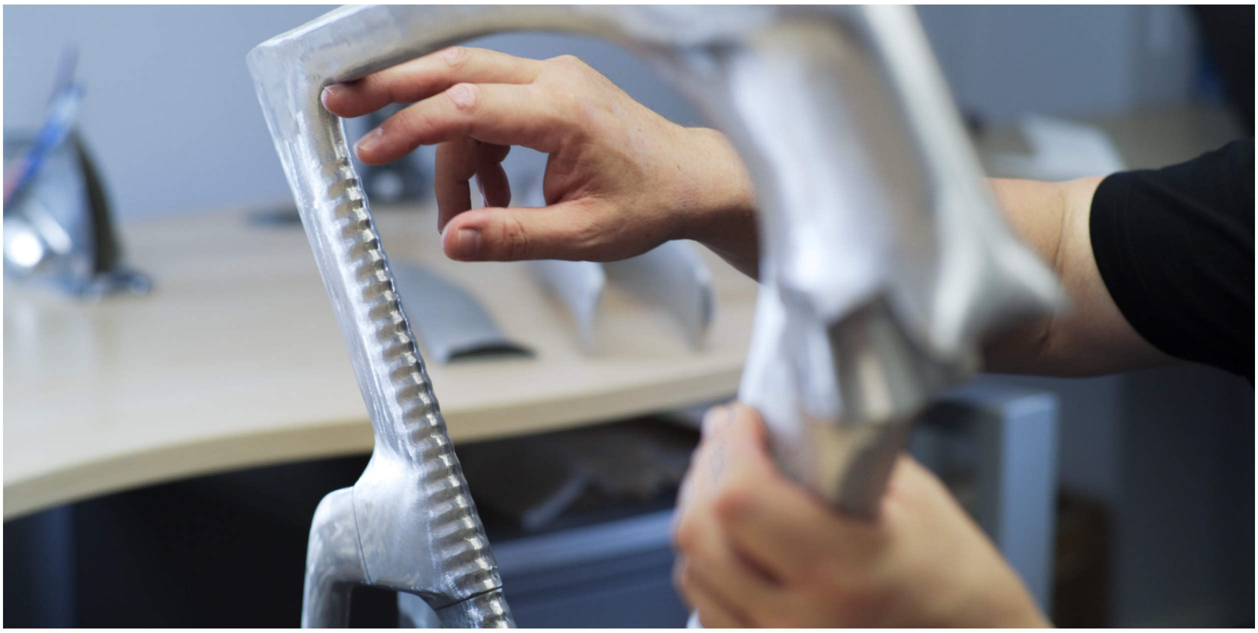
After extensive CFD and wind tunnel testing with live riders, our new AirStream technology was born, incorporating a unique pattern of AeroNodes on the frame that takes full advantage of the University of Adelaide's pioneering research.

3. MANUFACTURING

Carbon fibre is a great material to make a light weight and strong bicycle frame. The vast majority of today's high-end bicycle frames and forks are made using carbon fibre. But making the fine, repetitive pattern of the AeroNodes required a different approach.

Metal 3D printing was first pioneered by Pinarello at world-class level in 2015 when the handlebar for the UCI Hour Record timed by Tissot bike for Bradley Wiggins was raced to a record distance. 3D printing is well known for its ability to create difficult shapes with ease. To find the expertise, the knowledge, and the appropriate equipment we had to go to Metron A.E. in the U.K.

The HR bike's frame and fork were designed to take advantage of a new alloy called Scalmalloy; a high strength Scandium-Aluminium-Magnesium alloy that is specifically designed for 3D printing. The choice of material and machine is crucial here. If you use a lower-grade material, you will need to use more to compensate for the lower strength. If you use a normal-size 3D printer, then the frame will need to be made in too many parts, thus making it difficult to join.



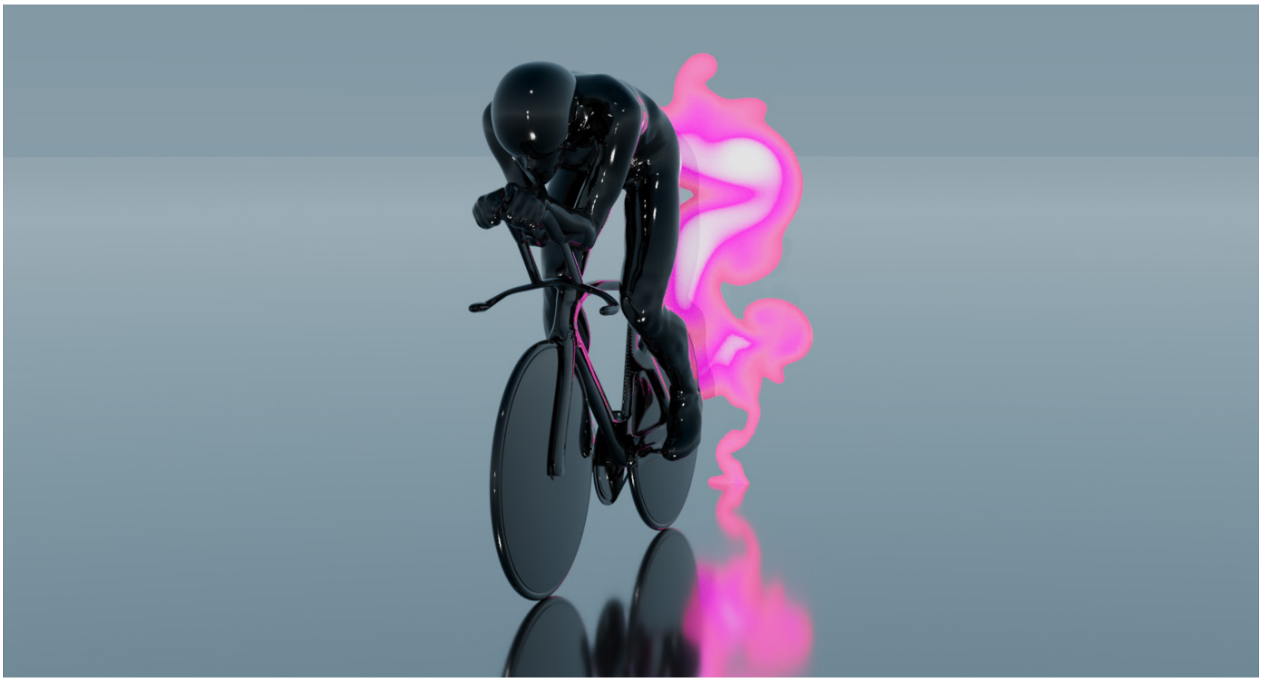
Metron used a large format EOS M400 machine to 3D print the Scalmalloy parts. Indeed, the frame was only five parts, with the front triangle made in three pieces and the seat-stays / chain-stays as two more pieces. These pieces were made individually and after meticulous cleaning and support removal, the parts were bonded together using an aerospace-grade epoxy.
But this was not the end of the process. A bike that is destined to be ridden by a world champion, besides having exceptional aerodynamics, must also have extraordinary strength. So, an exact copy of the frame used in the UCI Hour Record timed by Tissot attempt was send to EFBE in Germany for an independent strength test. The frame, fork and seatpost were put under a gruelling test regime that included the full range of fatigue, impact and torsion tests as specified by ISO4210.

That was a time when we were holding our breath. At the end of the day, nobody had ever before made a fully ridable, UCI-compliant aerodynamic bike pass the ISO4210 and be ridden by a world champion on a world record attempt.

And as we were about to turn blue, the news came in that all the parts passed all the tests. Now we could move on with the rest of the bikes. Once more, Pinarello is ready to write another page in the history of cycling.

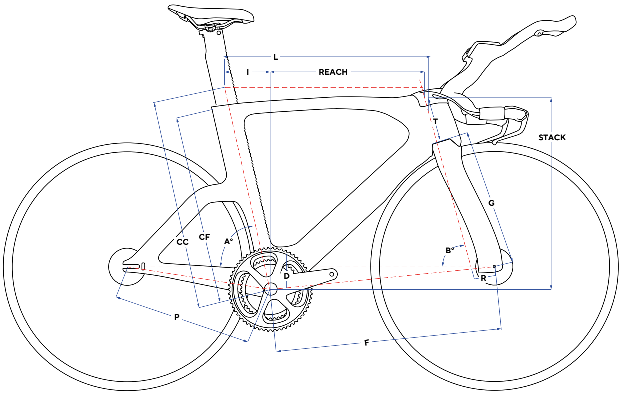
4. HANDLEBAR

A 3D PRINTED TITANIUM HANDLEBAR THAT IS DESIGNEDTO HAVE MINIMUM DRAG IS “SO 2015”
The understanding of aerodynamics has moved on since then. Today, it is understood that we must reduce the total drag of the rider and bike together, rather than just focusing on the bike, because at the end of the day, there is always a rider. As mentioned earlier, some solutions involve a potential increase in drag of some of the bike parts but with the aim of the overall drag reduction. The new handlebar was designed to achieve exactly that.



After several rounds of CFD optimisation, a handlebar geometry was created that improves the drag of the rider more than the drag penalty imposed by the unconventional shape. Overall, the drag is reduced. Again, 3D printing was required to manufacture this extraordinary shape. Of course, it can be made using other methods, like casting or CNC machining or even moulded carbon fibre. But for all of these methods it will be either too slow (e.g., casting) or too expensive (e.g., carbon fibre will require a mould) to do that. With 3D Printing, complex shapes can be manufactured in relatively short periods of time (days instead of months) and cheaper (compared to a metal mould to make a small number of carbon parts).

5. GEOMETRY



CE	CC	L	A [°]	B [°]	P	T	D	R	G	REACH	STACK
481	450	486	77	72	390	70	62	43	368	377	469
506	525	512	77	73	390	90	62	43	368	402	492
521	550	542	77	73	390	106	62	43	368	430	508

CE: SEAT TUBE CENTER - END **| CC:** SEAT TUBE CENTER - CENTER **| L:** TOP TUBE CENTER - CENTER **| A[°]:** SEAT TUBE ANGLE **| B[°]:** HEADTUBE ANGLE **| P:** CHAINSTAY **| T:** HEADTUBE **| D:** BB DROP **| R:** FORK RAKE **| G:** FORK HEIGHT **| REACH | STACK**

CICLI PINARELLO SRL
Viale della Repubblica 12
31020 Villorba (TV) Italy
tel. +39 0422 420877 fax +39 0422 421816
infobike@pinarello.com
www.pinarello.com