cervélo

S5

THE SOLOIST IN AERO ROAD

CONTENTS

Summary . . . 3
Introduction . . . 4
Rider Needs . . . 4
Aerodynamics . . . 4
Stiffness . . . 5
Ride Quality . . . 5
Usability . . . 5
Key Component Advances . . . 5
A History of Speed . . . 6
2002: The Pioneering Origin . . . 8
2011: A Radical Departure . . . 8
2014: Refinement through Integration . . . 8
2019: Boundary-busting Systems . . . 8
S5 Design Strategy . . . 9
Bike + Rider = Breakthrough . . . 9
The Rider: In the Flow . . . 9
The Bike: Back to Fundamentals . . . 9
The Components: New Territory . . . 10
Goal 1: Aero Performance . . . 10
Aero Design Approach . . . 11
Aero Design Solutions . . . 13
Fully Integrated and Concealed Control Lines . . . 13
Redesigned Steering (Headset Bearing and Fork) . . . 14
Redesigned Handlebar/Stem Integration . . . 15
Redesigned Stem . . . 16
New Handlebar Aero Form . . . 19
Frame Refinements . . . 20
Bottom Line: Drag Reduction of 42 Grams . . . 20
Goal 2: Stiffness and Weight . . . 22
Frame Torsional Inertia Stiffness . . . 22
External Steerer and Fork Lateral Stiffness . . . 23
Thru Axle and Wheel-to-Fork Clamping Stiffness . . . 23
Bottom Bracket Stiffness . . . 23
Weight . . . 24
Goal 3: Ride Quality . . . 24
Fit . . . 24
Handling . . . 26
Goal 4: Usability Standards & Trends . . . 28
Disc Brakes and Axle . . . 28
Tire Clearance . . . 28
Conclusions . . . 29
Rider-Focused Design: A Glossary . . . 30
Further Reading . . . 30

LIST OF FIGURES

Figure 1 Aero performance of 2019 Gen III S5 compared with standard 2014 Gen II S5 equipped with AB04 handlebar. Wind tunnel testing conducted at RWDI (Guelph, Ontario, Canada). 4

Figure 2 Performance improvement of 2019 S5 (on a scale of 10). 5

Figure 3 Silhouette evolution of the S5 aero road bike. 6

Figure 4 Aero zones used in Cervélo development.. 11

Figure 5 Wind tunnel test setup with S5 and anthropomorphic rider model. 13

Figure 6 Aero cockpit with fully integrated cabling: (a) electronic; (b) mechanical.(Hydraulic brake hoses follow similar path.) 14

Figure 7 (a) Hollow headset bearing assembly, with compression cap (top) and internal tensioning rod. (b) Cable path through top bearing.. 15

Figure 8 Spacers in two locations permit height adjustment of up to 32.5 mm of as-delivered stem and bar. Spacers slip in for adjustment without disassembly under (a) stem and (b) handlebar. 16

Figure 9 Bar placement identical in as-delivered (outline) and standard (shaded) configurations. 16

Figure 10 Standard stem adapter.. 16

Figure 11 Quantification of aero performance gain due to new CS28 stem design. Study conducted at RWDI, Guelph, Ontario, Canada. 17

Figure 12 Air flow visualization showing smoother flow over new stem. (a) Standard configuration: S5 stem adapter, 3T ARX stem, and AB04). (b) Eng spec S5 configuration: CS28 stem with AB08 bar.. 18

Figure 13 Velocity contours showing reduced wake region as a result of unimpeded flow over new stem. (a) Standard configuration: S5 stem adapter, 3T ARX stem, and AB04). (b) Eng spec S5 configuration: CS28 stem with AB08 bar. 19

Figure 14 Nearly equal pressure distribution on top and bottom surface of AB08 bar, demonstrating that bar creates negligible lift. 19

Figure 15 Available tilt adjustments on AB08 bar. 20

Figure 16 Wind tunnel comparison of S5 model years 2014 (FM105, equipped with 3T ARX stem, AB04 bar, rim brakes) and 2019 (FM125, Cervélo Eng Spec configuration). Conducted at RWDI (Guelph, Ontario, Canada). 21

Figure 17 Dimensions for specifying cycle geometry. 25

Figure 18 Frame stack and reach for competitive aero road bikes.. 25

Figure 19 Trail vs. reach for competitive aero road bikes.. 27

Figure 20 ISO compliant tire clearance on 2019 S5.. 29

LIST OF TABLES

Table 1 Design Evolution of the S5. 7

Table 2 Performance Evolution of the S5 7

Table 3 Cervélo “Engineering Spec” Build Kit for Standardized Wind Tunnel Testing 12

Table 4 Summary of Wind Tunnel Tests to Quantify Stem Performance.. . . . 17

SUMMARY

The 2019 S5 is the outcome of a comprehensive redesign that married Cervélo's leading aerodynamics research/knowledge with an acute focus on the rider's experience and needs. First, we went back to the aerodynamics drawing board and challenged ourselves to see every component's shape in fresh ways. But then, instead of continuing to refine components, we changed our focus in two ways: (1) we considered entire zones on the bike and (2) we minutely examined how bike and rider work as a total aerodynamic system. Expanding our thinking this way gave our teams far more design space in which to balance stiffness, handling, and comfort while—always and above all—delivering fast. The result is the fastest and most comfortable aero road bike Cervélo has ever created.

Aerodynamics

- Aerodynamic savings of 5.5 watts (42 grams of drag) achieved, compared to the 2014 S5 with AB04 (build standardized).

Stiffness

- Head tube stiffness increased by 13% to improve handling.
- Bottom bracket stiffness increased by 25% to increase pedal input and support the additional head tube stiffness.

Ride Quality

- Bottom bracket dropped to lower the rider's centre of gravity, providing greater stability during high speeds and turning.
- Trail length increased to provide greater stability.
- Trail values unified across all sizes, for superior ride and handling qualities at all frame sizes—a particular benefit for smaller frames.

Usability

- Aero cockpit comprehensively redesigned to allow concealment of both mechanical and electronic control cables, while allowing easy adjustability.
- Stem stack range of up to 30mm (in 5mm increments).
- Handlebar stack range of 2.5mm, independent of stem.
- Handlebar pitch adjustment in two steps, to 2.5 degrees or 5 degrees.
- Compatibility with standard stems and handlebars to accommodate the widest fit range possible.

INTRODUCTION

In this paper we describe the development process that produced the latest generation of our flagship aero road bicycle, the new 2019 Cervélo S5. The achievements embodied in this bicycle have emerged from our evolving engineering and design approach that now integrates our industry-leading aerodynamics with an athlete-centred focus on ride quality. Our goal was to deliver our fastest and most comfortable aero road bike ever.

To get there, we drew on years of aerodynamic and structural experience, plus extensive testing and feedback from both Pro Tour and amateur riders. The result is not only the fastest road bike we have ever made, but one that is also lighter, stiffer, and more comfortable than the previous generation. We've also built in the newest industry standards, such as hydraulic disc brakes, internal cables, thru axles, and wide tire clearance. Through it all, our mindset has been "remove limitations," whether in our design process or in the bike itself. We ruthlessly targeted anything that could be a technical obstacle to achieving one's personal best.

RIDER NEEDS

The design journey to the new S5 was complex, touching nearly every aspect of the bike. Before we start to trace that journey, we'll do a big-picture review of the performance improvements, to serve as a roadmap to our eventual destinations. These improvements are summarized in Figure 2 at the end of this section.

Aerodynamics

- The aerodynamic savings is 42 grams of drag—equivalent to 5.5 watts to the rider (compared with a standard Gen II S5 equipped with AB04 handlebar).

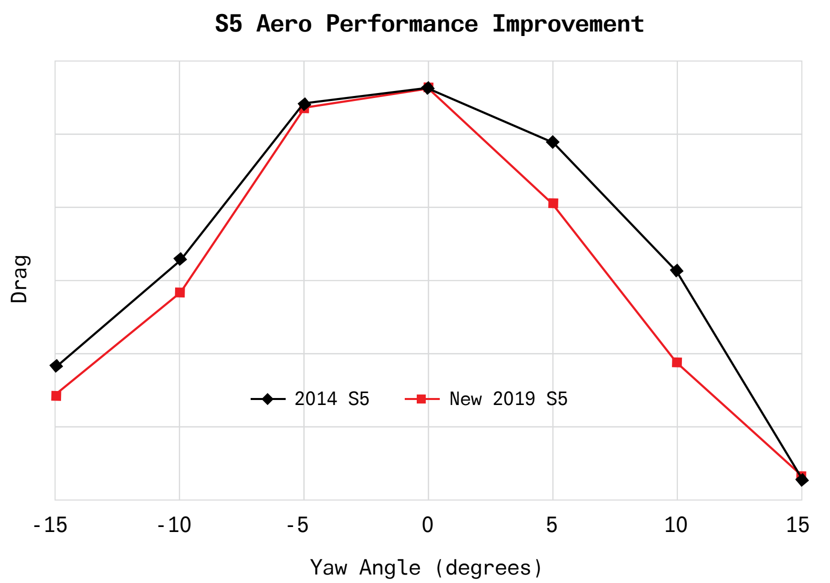


Figure 1. Aero performance of 2019 Gen III S5 compared with standard 2014 Gen II S5 equipped with AB04 handlebar. Wind tunnel testing conducted at RWDI (Guelph, Ontario, Canada).

Stiffness

- The head tube stiffness was increased by 13% to improve handling.
- The bottom bracket stiffness was increased by 25% to increase pedal input and support the additional head tube stiffness.

Ride Quality

- The bottom bracket was dropped to lower the rider's centre of gravity, providing greater stability during high speeds and turning.
- The trail length was increased to provide greater stability.
- Trail values were unified across all frame sizes, for superior ride and handling qualities at all sizes—a particular benefit for smaller riders. Excessive trail (often found on small-sized bikes) requires the rider to overcome the tendency for the steering to dive, as well as to expend extra effort on returning the steering to centre.

Usability

- The aero cockpit was comprehensively redesigned around a new aerodynamic concept for the stem. After significant engineering challenges were overcome, this new design is both superbly aerodynamic and remarkably rider friendly.

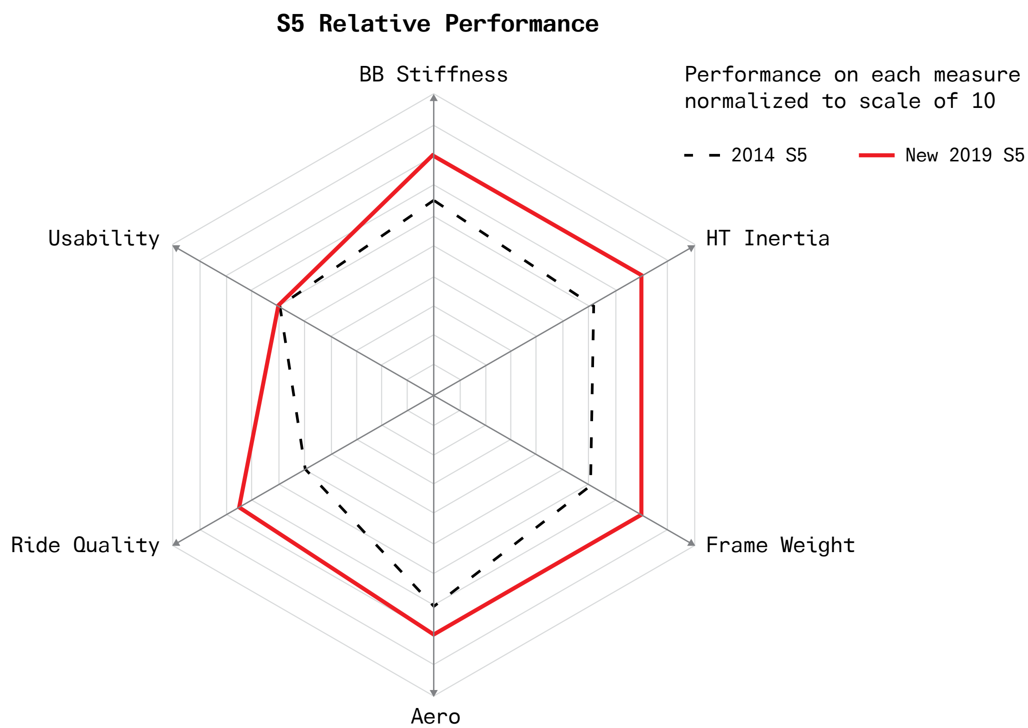


Figure 2. Performance improvement of 2019 S5 (on a scale of 10).

KEY COMPONENT ADVANCES

In keeping with our whole-system design philosophy, performance improvements in the new S5 are not simply a one-to-one result of component improvements. Nevertheless, it is helpful to focus on some of the more visible differences in the new design.

- Steering control is moved away from the bearings with a new external steerer fork (FK60) .
- A patent-pending V-shaped stem (CS28) reduces drag by both: allowing unimpeded airflow along top tube, and providing hidden and low-friction cable paths for all types of cabling systems, maintaining cable performance.
- A redesigned aero drop bar (AB08) reduces drag with an airfoil that is twisted from centre to edge to optimize its orientation to the local air flow.
- Use of a cutaway seat tube shape (pioneered for the P3C) improves flow across the wheel by moving the tire closer to the frame.

A HISTORY OF SPEED

To understand why the design process for the new model is a departure, it is important to understand the context from which it developed. Figure 3, Table 1 and Table 2 summarize how the S5 has evolved since its introduction in 2011.

Gen I S5, 2011(FM70)

Gen II S5, 2014(FM105)

Gen III S5, 2019(FM125)

Figure 3. Silhouette evolution of the S5 aero road bike.

Table 1. Design Evolution of the S5

Generation	Launched	Model No.	Design Focus	Achievement
Gen I	2011	FM70	Aero performance	Fully aero frame shapes Low weight Improved stiffness
Gen II	2014	FM105	Ride quality & usability	Maintained aero performance and weight 64-gram savings from new AB04 handlebar Ride quality/usability enhancements: • Improved torsional stiffness (key for WorldTour) • Compatibility with trend to wider wheels/tires • Improved bottom bracket stiffness
Gen III	2019	FM125	Bike + rider zoned design	Entirely new, integrated aero cockpit with hidden cables: • External steerer fork (FK60) • New V-shaped stem (CS28, patent pending) • New AB08 aero drop bar • Slip-in spacers for height and tilt adjustment Disc brakes Tire clearance of 38mm New aero seat post Uniform performance at all frame sizes

Table 2. Performance Evolution of the S5

Generation	Frame Weight, Size 56 Frame (g)	Bottom Bracket Stiffness (N/mm)	Torsional Inertia Stiffness (Nm/deg)	Drag Savings (g)
Gen I	1060	190	76	200-300 g (26–40 W) OTB*
Gen II	1065	200	100	213 g (28 W) OTB*
Gen III	975	251	115	42 g (5.5 W) Eng. Spec.**

** "Out of the Box "(OTB) reflects how the bike is delivered to the market.*

***For the current Cervélo Engineering Specification, see Table 3 in the section "Wind Tunnel Tests in the Design Process." The engineering specification used in 2011 and 2014 is not directly comparable to the current specification.*

2002: The Pioneering Origin

Back in 2002, Cervélo invented the modern aero road bike, with the introduction of the original Soloist. Over the years, the Soloist evolved into the Soloist Carbon, SLC-SL, and S3, reflecting the move from aluminum to carbon and continued improvements to aerodynamic performance. Our focus in those days was primarily on technical advances in aerodynamics.

2011: A Radical Departure

In 2011 Cervélo made a quantum leap in the design of aero road bikes by launching the first-generation S5. Its success drew both on years of experience refining the Soloist series and on the game-changing aerodynamic designs of the P4 time trial/triathlon bike. Prior to the S5, aerodynamic road bikes were generally just classic road bikes that had some tubes with aero profiles. For the Gen I S5, Cervélo rethought the entire frame design—but still within the UCI rules. At the time, the S5 was considered radical, and many people questioned whether consumers would ever accept such a shape. Time has since answered that question.

2014: Refinement through Integration

The second-generation S5, launched in 2014, represented an important change in Cervélo's approach to design. Not content with reducing weight and improving stiffness and aerodynamics, we added an unprecedented focus on ride quality and usability. Also, for the first time, an S model departed from the geometry of the R series, gaining a more aggressive (lower and longer) fit.

As we developed the Gen II S5 within the UCI design parameters, it became very clear that we were hitting some fundamental obstacles. Even with our advanced technical capabilities, we were fast approaching the limits to aerodynamic improvements that could be attributed to frame shapes in isolation. For that reason, in tandem with the 2014 S5 project, we developed the AB04 handlebar, which alone saved 64 grams of drag compared with a standard round handlebar. This was Cervélo's first foray into a deeper system integration for aerodynamic road bikes.

2019: Boundary-busting Systems

The all-new 2019 S5 is the third generation of Cervélo's class-leading aero road bike. The Gen III S5 carries much of the visual heritage of the original S5 but improves on every measure. Breakthroughs came through seeing not a bike, but a bike+rider—a total system. In the next section, we'll discuss how that change of viewpoint played out in specific design challenges.

The most noticeable visual and performance change comes at the front of the bike. An entirely reconceptualized aero cockpit achieves significant improvements in aero performance. Fully internal cable routes are provided for both electrical and mechanical shifting, while maintaining ease of adjustments. Slip-in spacers can be used to adjust stem height and bar tilt without detaching any cables, making adjustment far simpler than in a typical aero bike. Importantly, the V-shaped stem made it possible to fully hide mechanical shifting cables. The stem was specifically designed to minimize the angle of cable bends, so riders get both perfect shifting/braking and the full aero benefit of hidden cables.

S5 DESIGN STRATEGY

Bike + Rider = Breakthrough

In the Cervélo engineering and design teams, we knew we had to do some out-of-the-box thinking to get new inside-the-UCI-box performance from the S5. As we scrutinized our own product, as well as leading aero-road offerings from the field, we realized that we needed to address not only drag reduction but also the simplicity of service, ride quality, and ease of fitting. We challenged ourselves to do things differently:

- Organizationally, we reconfigured our design process throughout the company. Everybody now contributes on every product, and staff from every discipline—aerodynamicists, engineers, designers, sales and marketing pros—are in the conversation at all stages. Any product can draw on technical advances and understanding from any other product, and fresh eyes and different training can uncover "impossible" solutions.
- We began thinking of bikes in terms of zones rather than components.
- We minutely examined how bike and rider work as a total aerodynamic system.

Expanding our thinking this way gave the S5 team far more design space in which to balance stiffness, handling, and comfort while—always and above all—delivering speed.

The Rider: In the Flow

A bike doesn't ride itself! Cervélo has long realized how the symbiotic relationship between bike and rider affects aero performance; this is why we've used an anthropomorphic rider model as part of our design process and our wind tunnel testing protocol for many years. In the tightly coupled bike+rider system, geometry changes in one area can indirectly affect the flow and resulting forces elsewhere. The key is to make design changes that trade aero gains and losses across all components of the bike+rider system to achieve a net performance improvement. For the 2019 S5, we made it one of our top priorities to examine every aerodynamic change in relation to the rider.

Of course, there are many other dimensions to the rider experience that figure into our design equation. Chief among them are ride quality, torsional inertial stiffness, bottom bracket stiffness, usability, and comfort. (Please see Rider-Focused Design: A Glossary p. 30, for reference) As we discuss the design solutions in the new S5, we'll relate them to these dimensions.

The Bike: Back to Fundamentals

The S5 owes its new speed to fundamental research and rigorous testing of conceptual designs. About six months before we began the actual S5 redesign project, we started with a company-wide research project. Its purpose was a back-to-basics consideration of the interdependence of shape and air flow. We all dusted off our previous blue-sky concepts (and brainstormed a lot of even bluer ones) and collaborated with our aerodynamicists, who used computational fluid dynamics (CFD, for reference see our AeroTech paper [1]) to evaluate the concepts' potential. This kind of computational evaluation is highly resource-intensive (and expensive)—testing a single design at three yaw angles can take hundreds of CPU hours—so we approached it with a rigorously structured experimental design. In this way, we made sure our later optimization efforts would take the most productive direction. From our sales and marketing teams, we also knew some of the "must haves" and included those considerations in our research design.

The engineering and design choices made on the 2019 S5 are responses to this expanded research, verified in extensive CFD and wind tunnel testing and directed overall by the reimagining of design opportunities within the confines of the UCI rules.

The Components: New Territory

From this design strategy and research evaluation, we identified the following design goals for the 2019 S5:

- Reduce aerodynamic drag (as tested with rider model)
- Increase head tube inertia stiffness to R-series levels
- Increase bottom bracket stiffness to ProTour levels
- Maintain the same or lower weight than the Gen II S5
- Add flat-mount disc brakes
- Fit 38mm tire clearance, incorporating ISO 4210 requirements
- Incorporate fully internal cable routing with easy position adjustment
- Ensure consistent handling and feel across the full size range

The following sections discuss how we achieved these goals within the context of these aspects of the rider experience:

- Aero performance
- Stiffness and weight
- Ride quality
- Industry standards and trends

GOAL 1: AERO PERFORMANCE

Goal	Decrease drag as much as possible while excelling in all other design goals.
Approach	Zoned strategy for aero development Efficient high-performance techniques for computational fluid dynamics (CFD) modelling Rigorous wind tunnel protocols yielding repeatable results that are valid for guiding development decisions
Innovations & Solutions	Fully enclosed cable path in an integrated aero cockpit design, enabled by: • Optimized positioning of disc brakes • Fork design that moves steering outside bearings • New open bearing structure enabled by external steering fork • New aero form for stem • New aero form for handlebar

Aero Design Approach

Aerodynamic Zones

Cervélo's top-down approach to aero development begins with a high-level conceptual design phase using zones that delineate aerodynamically significant regions on the bike (Figure 4). Design concepts are investigated for each zone in turn, moving generally from the front of the bike to the rear. Our premise is that concepts for drag reduction should be proven to be effective in the presence of flow as it is shaped by upstream design changes. We rely heavily on CFD in this early stage to rapidly evaluate design concepts that arise from the zone investigation. Preliminary concepts that show promise to improve performance are verified with wind tunnel testing and carried forward for refinement during the detailed design phase. As the design matures, the focus shifts more toward wind tunnel testing as production prototypes of bike components become available. The strongest combination of design concepts ultimately become the final form of the bike.

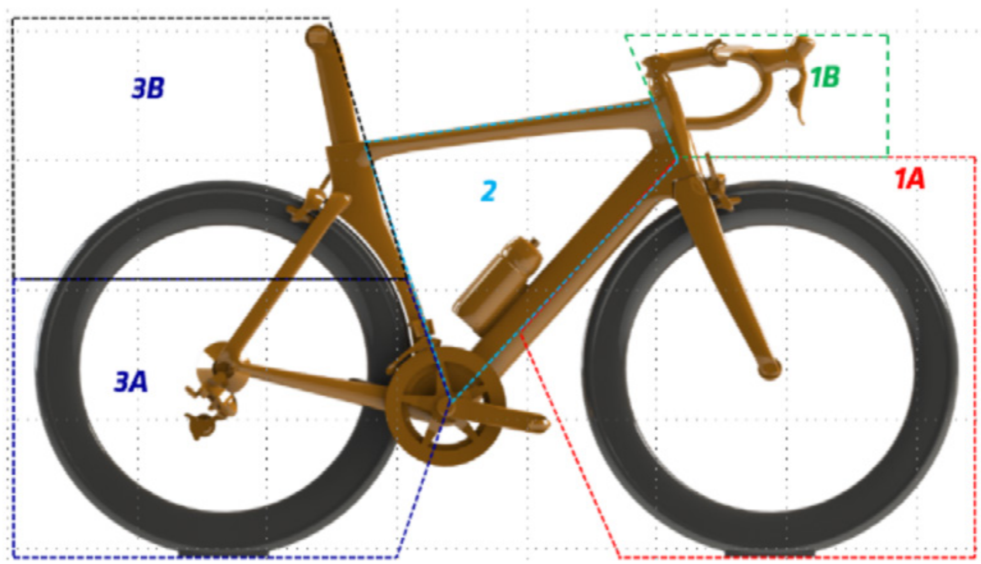


Figure 4. Aero zones used in Cervélo development.

CFD in the Design Process

As an early adopter of CFD technology, Cervélo has developed industry-leading expertise in the field that allows us to simulate the flow of air around the bike+rider system in order to accurately predict its aerodynamic performance. (For details of our CFD methods, see our AeroTech paper [1].)

In a CFD approach, complex phenomena are simulated by estimating conditions in small volumes called cells; many cells are grouped in a larger representation called a mesh. Our goal is to produce simulations that accurately predict the relative differences in aero performance between different component geometries or bike configurations. With standard computing techniques, these computations take far too long for commercial design timelines. To make CFD practical for our design process, we split the computation over many processors running simultaneously in a high-performance computing cluster. The cell calculations on sections of the mesh are performed in parallel, then brought together to form a complete solution. Thus, it becomes practical for us to evaluate concepts and designs more quickly and in greater number. The CFD simulations for the S5 aero development were performed with StarCCM+ on a high-performance computing cluster using 252 compute cores.

Wind Tunnel Tests in the Design Process

We use wind tunnel tests for three purposes: (1) to understand the competition, (2) to guide development, and (3) to quantify the performance of as-delivered products. Our wind tunnel tests are always done under a tightly controlled methodology to ensure accuracy and repeatability. (For details of our wind tunnel methodology, see our Aero Tech paper [1].)

Like our riders, we study the competition. We have a control group of competitors' products for benchmarking, but at the time of our early wind tunnel tests for the S5, no updated comparable products were commercially available. So—in the spirit of pure athleticism—we had to compete against ourselves.

When we need results to guide development, our first task is to establish a baseline against which we quantify the change resulting from a given modification. For this baseline to be meaningful, all bikes measured must be equal except for the variation being tested. Thus, we've developed a protocol to ensure fairness and equality in wind tunnel testing. Each bike in a test is assembled with the same components (as far as feasible). We call this the Engineering Spec (Eng Spec) build kit. Table 3 lists the current Eng Spec build kit. By normalizing all of the variables possible, we are able to use the wind-tunnel as a development tool, because any variability in values can be attributed solely to the study subject and not to variations in other aspects of the bike. The test configuration usually includes a rider model (Figure 5). Again, a bike doesn't ride itself! All results reported in this paper include the rider model.

Table 3. Cervélo "Engineering Spec" Build Kit for Standardized Wind Tunnel Testing

Wheels	HED Jet 6 wheels (disc and rim brake versions share the same rim profile)
Rim Brakes	Complete Shimano Dura Ace 9050 component group
Disc Brakes	Shimano Dura Ace BR-9170
Bar/Stem	42cm bar, 120mm stem (usually a proprietary design but same across a given test session)
Tires	Continental GP4000 II (installed the same way each time, with the control-room side identified on each)

Figure 5. Wind tunnel test setup with S5 and anthropomorphic rider model.

When we want to demonstrate actual performance, we test with the Out of the Box specification, which reflects how the bike is delivered to the market. In the industry, the OTB spec is a popular choice for public-facing materials because it can highlight the advantages contributed by the choice of components (and can sometimes de-emphasize the aerodynamics of the engineered product). The OTB spec is not as relevant as a development tool because of its inherent inconsistencies and uncontrolled variations.

Aero Design Solutions

Fully Integrated and Concealed Control Lines

An early aero advantage identified by Cervélo was that drag could be reduced by concealing the control cables. The introduction of our fourth-generation internal cable stop (ICS4) on the Gen II S5 (FM105), saved around 40 grams of drag over traditional exposed gear cables, while still offering simple service and fitting access.

Optimizing the handling of control cables was a top priority that drove much of our thinking. This task was simplified—just a bit—by the move to disc brakes. Disc brake hoses allow more flexibility in routing, and we leveraged this to enable better internal routing for all types of control lines, including electronic shift wires and mechanical cables. To capitalize on the re-routed control lines, we designed new strategies in three areas: (1) integration of the headset bearing and fork, (2) integration of bar and stem, and (3) the form of the stem.

All these strategies were driven by our decision to address the difficult challenge of integrating mechanical shifting along with newer technologies. Many new aero road bikes conceal cables to reduce drag, but these designs either don't work with mechanical cables or they require extreme bends in the cables. Excessive bends reduce shift quality and can make the bike hard to set up and adjust. We felt it was important to offer the same performance advantages to all our riders, not just those who choose the latest electronic systems. The resulting cable paths are shown in Figure 6.

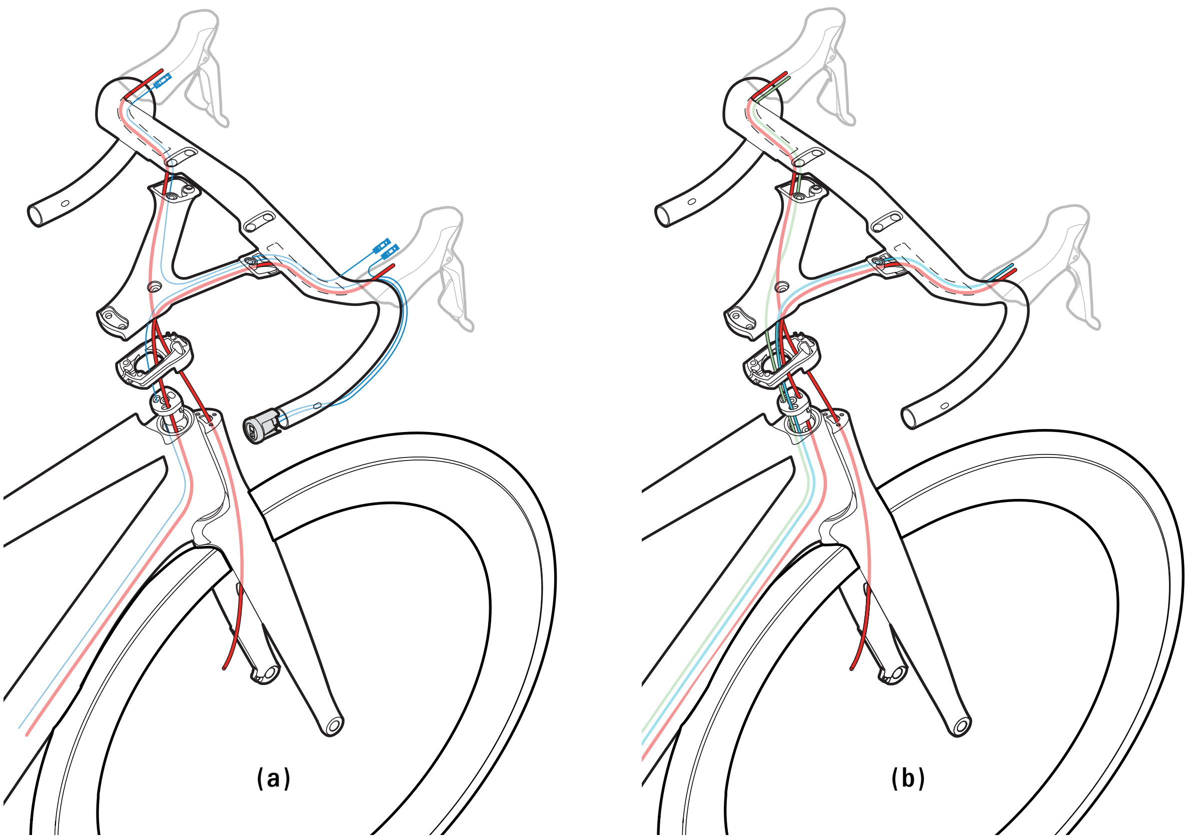
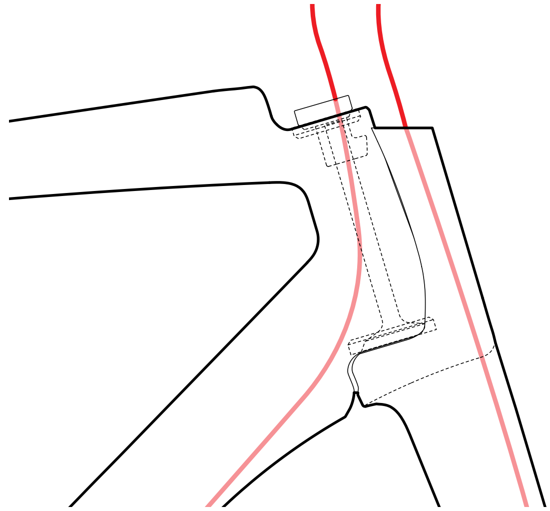


Figure 6. Aero cockpit with fully integrated cabling: (a) electronic; (b) mechanical.(Hydraulic brake hoses follow similar path.)

Redesigned Steering (Headset Bearing and Fork)

In a standard steering assembly, the fork steerer tube is an obstacle to better cable routing. We opened space in this assembly by moving the steering structure to the outside of the headtube (in a fork design similar to that used on the P5X). Cables can now pass with ease into the frame without excessive bending and resultant friction. In an adaptation of a standard threadless headset, the headset bearings are held in tension by a compression stem cap and internal tensioning rod, instead of a full steerer (Figure 7a). The rod helps support the bearing preload but also gives plenty of room inside the head tube for running cables from the stem to the rear of the bike. The cap (also referred to as the fork topper) connects the external fork steerer and tensioning rod but also has several other functions. Along with the tensioning rod it helps creating bearing preload; it incorporates cable guide holes; and it provides a fork stop to prevent over-rotation. The guide holes help the rear brake and shift cables pass inside the upper bearing. Figure 7b shows the cables passing through the centre of the upper bearing and on through the space liberated within the head tube. This design eliminates the swiping of the cables found in many designs and ensures that the fork and bar rotate freely, regardless of cable setup.

(a)



(b)

Figure 7. (a) Hollow headset bearing assembly, with compression cap (top) and internal tensioning rod. (b) Cable path through top bearing.

Redesigned Handlebar/Stem Integration

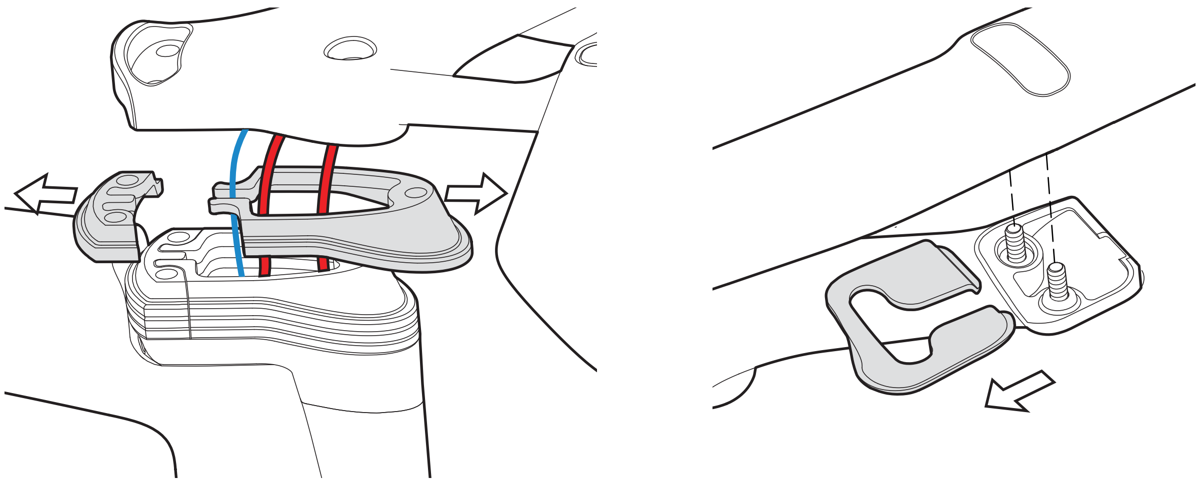
Conventional bar and stem systems are popular because riders can select stem length independently of handlebar width and can also micro-adjust the bar position. However, we determined early in development that we could not meet all our design goals with a standard bar and stem configuration, for two reasons. First, we decided that fully internal cable routing, including mechanical cabling, would be unworkable in a standard configuration because assembly and adjustment would become too complex. Second, it was clear early on that standard bar and stem systems have a definite negative impact on aero drag. As a result, we investigated a new aero form for a unified bar and stem module. This form was both cable-friendly and aerodynamically favourable. In the end, however, we rejected it because adjusting height and tilt would not be as simple as in a standard system.

The solution was to slice the unified module into two components—and then refine their forms so they still look to the wind like a single unit. These two components, the AB08 bar and V-shaped CS28 stem, were designed to integrate with the external steerer fork system to allow smooth, easily assembled cable paths and a broad range of adjustability.

In a satisfying design twist, the solution to cable routing—the decision to slice up the unified bar and stem module—also provided a solution to adjustability. At the slice separating the bar from the stem, the rider can insert a spacer for fine adjustment of bar height and tilt (Figure 8). Three spacer options are available: one for height (2.5mm) and two for tilt (2.5 or 5 degrees). Each spacer has its own corresponding handlebar fixing nut, and only one spacer can be used at a time. The spacers are molded in lightweight nylon and can be slipped into place without removing cables. This solution was extended to allow further height adjustments: An additional 30mm of 5mm thick spacers can be installed between the top cap and stem to fine-tune the bar stack.
The S5 is delivered with this proprietary bar and stem configuration, but we understand that some riders may still prefer, or need, to use a standard stem. Thus, the new stem design places the handlebar in the same location as a traditional 6-degree stem of the

same length (Figure 9) when installed with a Cervélo stem adapter, offered separately (Figure 10).

The following two sections discuss the specifics of the design process and innovations for the new stem and bar.



(a) (b)

Figure 8. Spacers in two locations permit height adjustment of up to 32.5 mm of as-delivered stem and bar. Spacers slip in for adjustment without disassembly under (a) stem and (b) handlebar.

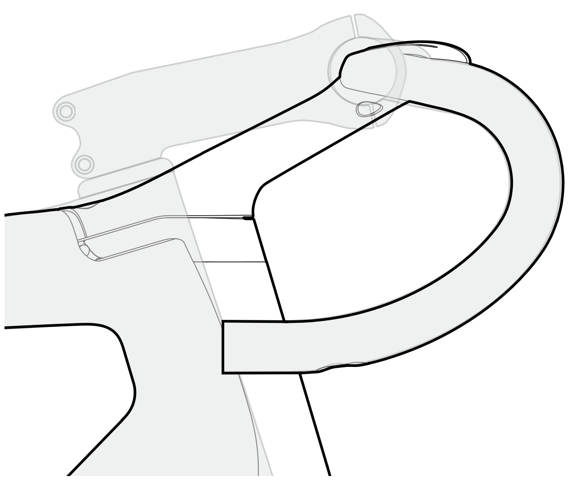


Figure 9. Bar placement identical in as-delivered (outline) and standard (shaded) configurations.

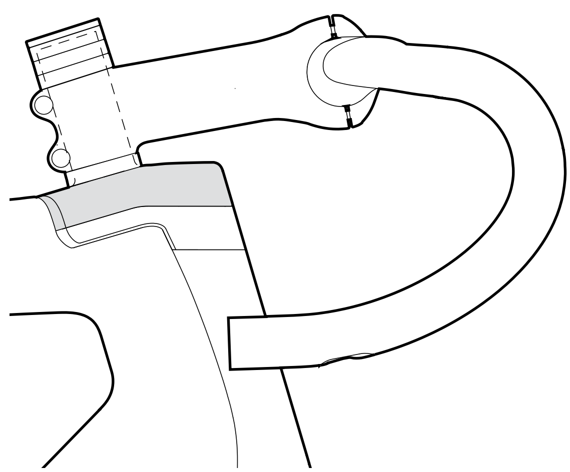


Figure 10. Standard stem adapter.

Redesigned Stem

The CS28 stem was inspired by the V-shaped riser introduced with the P5. This V shape was widely recognized as a key contributor to the industry-leading aerodynamic performance of the P5. However, its design was the result of trial-and-error testing in the wind tunnel and thus its contribution remained generally unquantified. In developing the CS28 stem, we built upon the solid aero performance of the P5 bar geometry [2] and leveraged the visualization and analysis capability of CFD to understand the "why" behind these performance gains. After clarifying the source of the gains on the P5 bar, we transferred these elements to a V-shaped stem design. The geometry of the stem and its careful integration with the top tube create a smooth and steady airflow through the stem.

When the design of the 2019 S5 as a whole was complete, we undertook a wind tunnel study to quantify the aerodynamic performance benefit of the CS28 stem. The results showed that a 2019 S5 configured with the CS28 stem and the AB08 bar (discussed in the next section) reduced total system drag by 30 grams compared with the same bike configured with a standard 3T ARX stem (mounted with the S5 stem adapter) and AB04 handlebar. Of this 30 grams of drag reduction, 13 grams is due to the internal cable routing made possible by the CS28 stem compared to the standard stem's exposed cabling; the remaining 17 grams is due to the stem's unique geometry. Figure 11 and Table 4 show the wind tunnel results for tests of the drag reduction by the S5 stem.

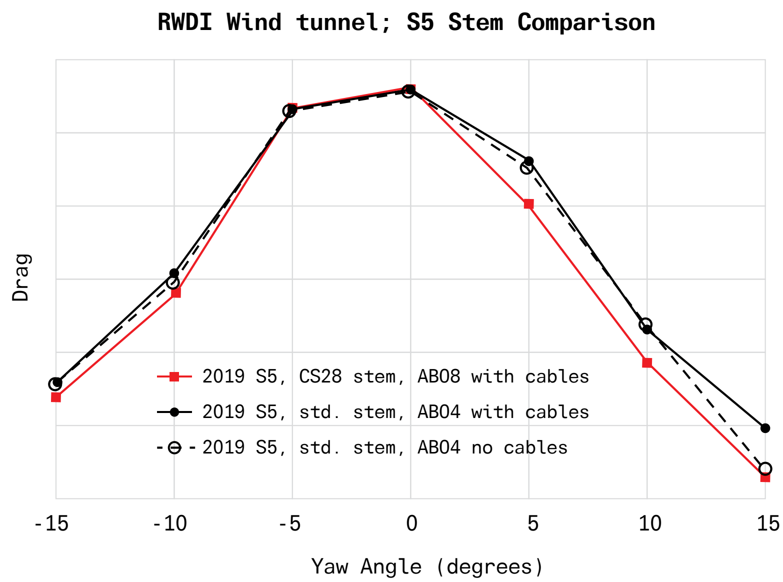


Figure 11. Quantification of aero performance gain due to new CS28 stem design. Study conducted at RWDI, Guelph, Ontario, Canada.

Table 4. Summary of Wind Tunnel Tests to Quantify Stem Performance.

Run Number	Configuration Tested	Change in Drag with Respect to Baseline
20180620-007	2019 S5, CS28 stem, AB08, with cables (Baseline)	—
20180620-009	2019 S5, standard stem (3T ARX), AB04, no cables	+17
20180620-008	2019 S5, standard stem (3T ARX), AB04, with cables	+30

In addition to hiding the cables, the V-shaped geometry of the stem contributes to the overall reduction of drag by presenting less obstruction to the oncoming high-velocity airflow between the rider's arms. The flow velocity images in Figure 12 illustrate the flow difference between a standard configuration (S5 stem adapter, 3T ARX stem, and AB04) and the Eng spec S5 configuration (CS28 stem with AB08 bar).

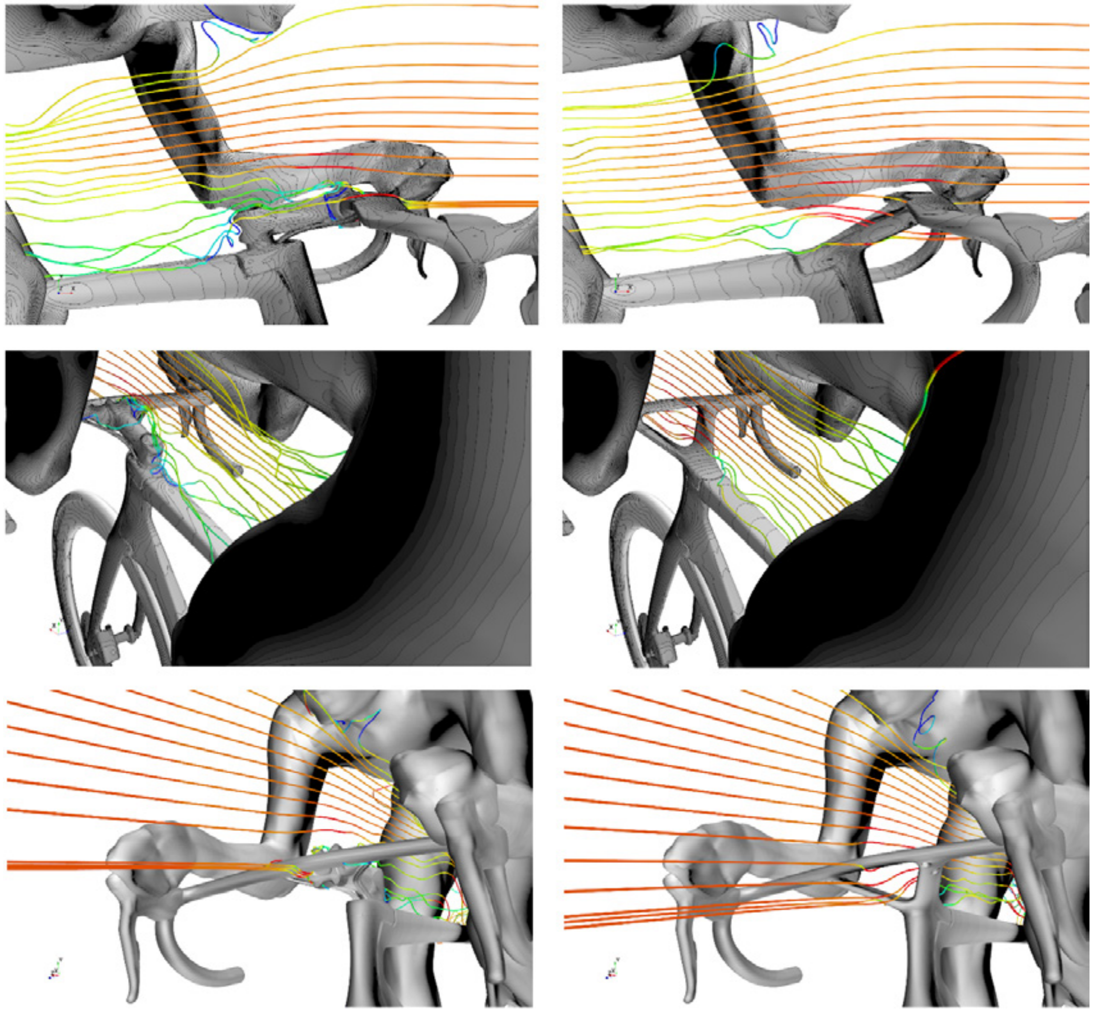
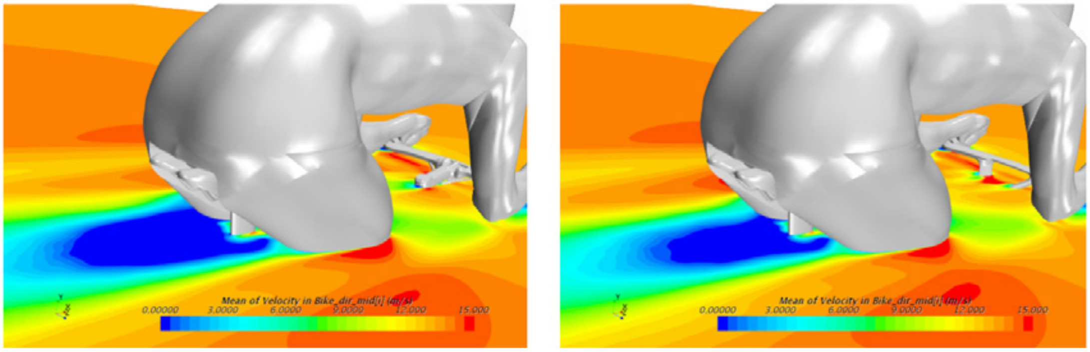


Figure 12. Air flow visualization showing smoother flow over new stem. (a) Standard configuration: S5 stem adapter, 3T ARX stem, and AB04). (b) Eng spec S5 configuration: CS28 stem with AB08 bar.

The unimpeded high-velocity flow is maintained as it travels along the top tube, through the thighs of the rider, and past the seat post. When compared with a standard stem system, the increase in flow velocity past the seat post results in a smaller low-pressure wake region behind the thighs and reduces drag. Figure 13 shows a comparison of velocity contours for the standard-style and Eng spec stems. The figure shows that the wake region (in blue) using the CS28 stem is significantly smaller than for the standard stem. Also worth noting in this figure is the high-velocity flow (in red) passing through the central V of the new stem.

In terms of usability, the stem was designed for fit customization and is available in a wide range of lengths that replicate the range available in standard stems. Six stem lengths are offered, ranging from 80mm to 130mm in 10mm increments. In addition, the design's shallow angle in both the horizontal and vertical planes (Figure 6) minimizes the bend in control cables, for easier installation and adjustment and better operation.



(a) 3T ARX stem   (b) CS28 stem

Figure 13. Velocity contours showing reduced wake region as a result of unimpeded flow over new stem. (a) Standard configuration: S5 stem adapter, 3T ARX stem, and AB04). (b) Eng spec S5 configuration: CS28 stem with AB08 bar.

New Handlebar Aero Form

The AB08 handlebar design is the result of understanding how the direction of airflow in the vicinity of the handlebar is shaped by the presence of the rider's arms, head, and shoulders, as well as by the flow patterns produced by rotation of the front wheel. Wind tunnel testing and CFD analysis helped us understand these significant interrelationships in more detail. The results led us to a slightly twisted profile for the handlebar. This optimized twist takes the form of airfoil sections with non-zero angles; that is, the orientation of the airfoil is tuned so that it aligns parallel not with the ground but with the local velocity vectors. Figure 14 shows the pressure distributions on the surfaces of the handlebar; these data demonstrate that the surface pressure at the top and bottom surfaces is nearly equal. This result indicates that the bar creates a negligible amount of sectional lift, thus minimizing drag.

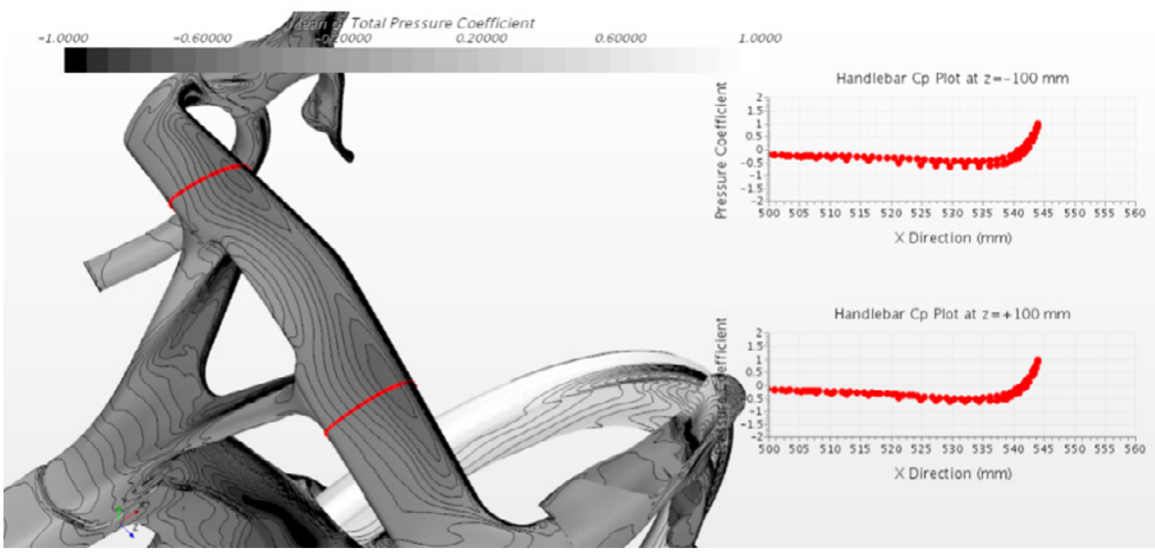


Figure 14. Nearly equal pressure distribution on top and bottom surface of AB08 bar, demonstrating that bar creates negligible lift.

As with the stem, we were mindful to retain or expand the rider's options for fitting and customization and to improve ease of service. The new bar uses the same drop design as the successful AB04. The flattened aero shape of the bar tops is also similar to the AB04, with two refinements. The cutaway on the rear corners has been increased for better wrist clearance in the drops, and the bar tops have been adapted to allow a better fit for smaller hands, in line with our commitment to excellent fit for all riders. Grooves for cabling form part of the integrated cable paths into the stem and frame, as discussed previously.

The base bar is available in four widths, from 38cm to 44cm. The AB08 bar mounts to the CS28 stem by means of a pair of aluminum nut plates (handlebar fixing nuts) that mount flush to the top of the bar and give easy access to the mounting bolts from below. The handlebar can be rotated up to +5 degrees, in 2.5-degree increments (Figure 15). The bar can be placed in any of these three positions by using one of the three separate handlebar fixing nuts and an associated spacer. However, we recommend leaving the bar at 0 degrees to achieve the maximum aero advantage.

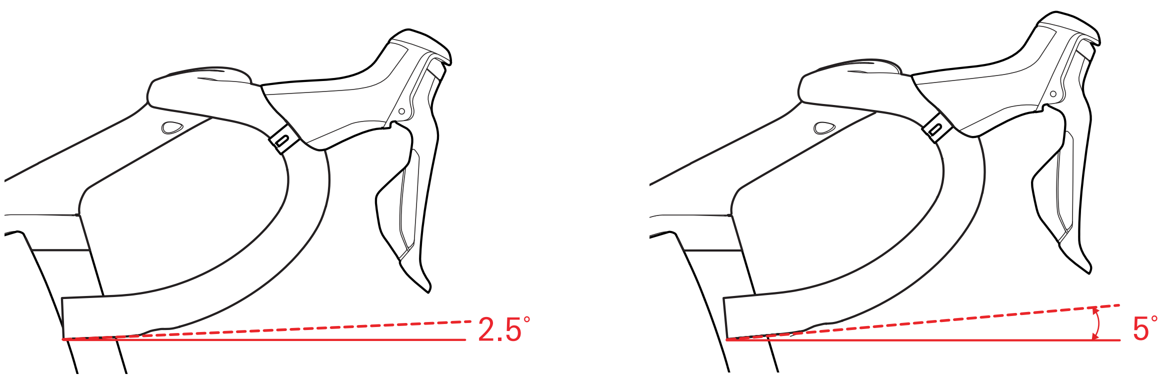


Figure 15. Available tilt adjustments on AB08 bar.

Frame Refinements

The new S5 frame follows the design cues of the previous generations, with the extended seat tube cutout, dropped down tube, BBRight™ bottom bracket, and our TrueAero™ shapes for the frame, fork, bar, and seat post. The front wheel cutout is based on a true airfoil section. With the elimination of the UCI's "3:1 rule," which limited the ratio between the length and width of the frame, we were able to make two small but aerodynamically advantageous changes at the front and back of the bike. Working in the space freed by the move to disc brakes, we made a more aerodynamic shape for the fork crown and the blend from seat stay to seat tube. The 2019 S5 frame is fully UCI approved in all sizes, making it race ready right out of the box.

Bottom Line: Drag Reduction of 42 Grams

In the past, research into drag reduction resulted in single features that delivered profound savings. However, it is broadly understood that, within the confines of the UCI design controls, opportunities for distinct feature-driven aerodynamic savings are becoming increasingly challenging. It is now essential to understand components and interactions within the context of the entire system: bicycle and rider. Thus, the reduction in drag realized on the 2019 S5 is the result of many improvements made in each of five distinct aero zones (Figure 4).

Figure 16 summarizes the achievements of our aerodynamic redesign of the S5, comparing the Gen II S5 (2014) with the new Gen III model (2019). The wind tunnel tests were executed with a rider model in place (Figure 5) and the wheels and drivetrain were standardized per our Eng Spec bike configuration (Table 3). The results validate our research in CFD and show an overall drag reduction of 42 grams of drag.

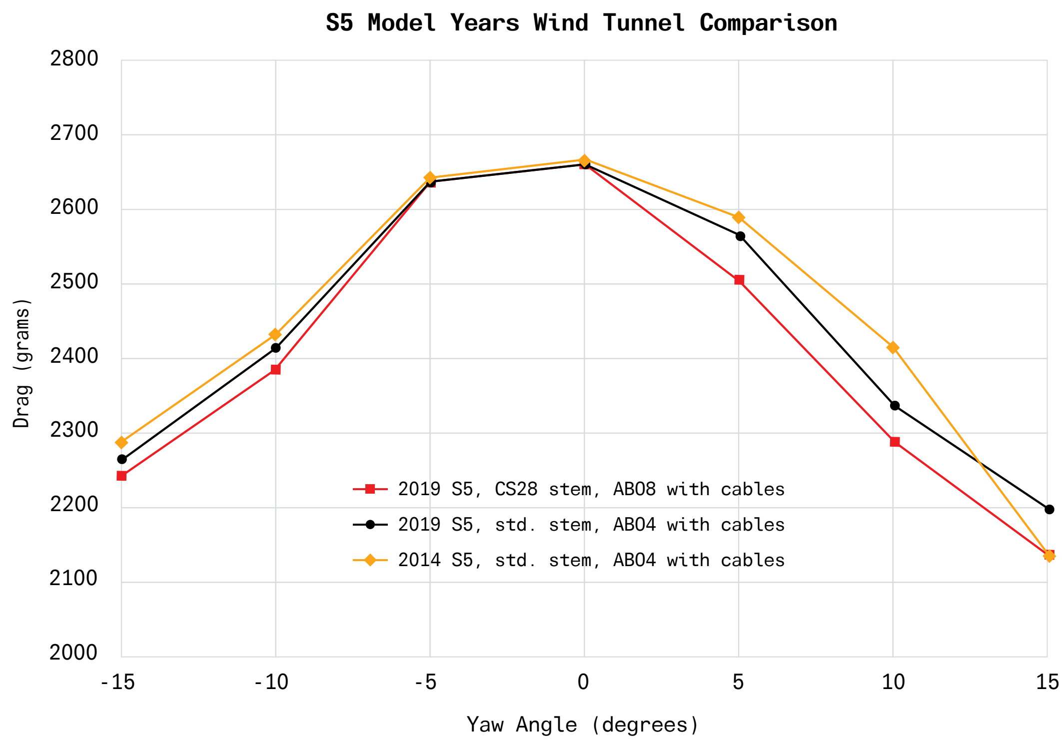


Figure 16. Wind tunnel comparison of S5 model years 2014 (FM105, equipped with 3T ARX stem, AB04 bar, rim brakes) and 2019 (FM125, Cervélo Eng Spec configuration). Conducted at RWDI (Guelph, Ontario, Canada).

GOAL 2: STIFFNESS AND WEIGHT

Goal	Increase head tube inertia stiffness to R-series levels Increase bottom-bracket (BB) stiffness to ProTour levels Maintain the same or lower weight than the Gen II S5
Approach	Finite element analysis of frame shape and composite layup New apparatus to measure torsional inertia stiffness of assembled frame and fork
Innovations & Solutions	Incorporated external steerer fork within UCI limits on head tube depth: Improves combined frame/fork stiffness Refined frame shape and composite layup Reduced frame weight by 100 grams

Obviously, for an S series bike, aerodynamics is the most important parameter. However, in the case of the 2019 S5, our goals for structural performance were more important than is typical for a Cervélo aero bike. The motivation for this focus was feedback from ProTour riders and from our sponsored professional triathletes, who often ride S5's in training. Data and first-hand experience from this group of riders clearly showed us that, while the S5 was always a very fast bike, it no longer met the ride quality requirements of our elite athletes. As each generation of Cervélo bikes is developed, we have sought to match the stiffness profiles to the use case; thus, at the elite end, the requirement to corner and accelerate more aggressively requires substantial increases in stiffness. In our previous "lab vs. reality" testing, we found that the high-speed descent performance of a bike is most directly related to three characteristics: frame torsion inertia stiffness, fork lateral stiffness, and wheel-to-fork clamping stiffness. For the Gen III S5 we addressed all of these, as described in more detail in the following sections.

Frame Torsional Inertia Stiffness

The major factor affecting the overall bike torsional stiffness is the frame itself. Because this factor is so critical, Cervélo has been using a proprietary inertia stiffness test for many years. With results from this test, Cervélo has continued to refine methods for designing frame shapes and composite layups that maximize the inertia stiffness of the frame without unduly affecting weight or aerodynamics. Experience with bikes such the Rca and R5 was used to increase the inertia stiffness of the new S5 by 13% compared to the previous generation.

One of the key tools that enabled us to increase this stiffness value was finite element analysis (FEA). Cervélo uses Altair Hyperworks v14 advanced FEA software. This tool allows us to evaluate different frame shapes to determine their structural efficiency. A particular advantage of the Hyperworks software is the ability to perform analysis on the full composite layup of the frame as well.

External Steerer and Fork Lateral Stiffness

Development of the new fork design (FK60) again used all of our composite knowledge and structural FEA capabilities. The external steerer design (previously discussed in the context of the new aero cockpit) was chosen not just for the flexibility of the internal cable routing but also for improved system stiffness. From our work to design an external steerer fork for the P5X triathlon bike, we knew the stiffness benefits of this strategy. We demonstrated that the new P5X fork design not only increased fork stiffness but also significantly improved the overall system stiffness of the frame and fork in the lateral direction. As a follow-up to that work, we developed a fixture for directly measuring the torsional inertia stiffness of the assembled frame and fork. Detailed testing with this new fixture confirmed that the external steerer fork design does improve the combined stiffness of the frame and fork, beyond simply the separate improvement to each component. This experience with the P5X led to an early decision to incorporate an external steerer fork on the S5 as well.

However, using an external steerer fork on a road bike is much more complex than on a time trial (TT) bike. The UCI rules treat TT (and track) and road bikes differently. For TT bikes, a maximum head tube depth of 160mm (from leading edge to back) is allowed, and any external steerer must fit within this dimension. In this space it is relatively straightforward to fit both a head tube and an external steerer fork. However, for a UCI-legal road bike, the maximum head tube depth (including the external steerer fork) is only 80mm. This restriction makes it difficult to fit in both a head tube and an external steerer. It took a lot of detailed engineering design and careful analysis of geometry, as well as in-depth structural analysis, to ensure that a properly designed external steerer fork could fit within the UCI dimensional boxes. It was also important to ensure that the frame and fork weights were still competitive and did not add too much mass to the bike.

An additional contribution to stiffness comes from a new aero seat post designed for the S5. It features our TrueAero™ shape, with a truncated rear edge for increased inertial stiffness and more comfort. The seat post head incorporates a new two-bolt clamp system for improved clamping, easier adjustment of saddle position and angle, and more secure retention.

Thru Axle and Wheel-to-Fork Clamping Stiffness

One further area where the overall torsional inertia stiffness can be improved is at the axles. From work on our previous thru axle bikes (and, even before that, from research performed many years ago), we have learned that the 12mm thru axles used on our disc-brake bikes contribute further improvement to the overall system stiffness. The larger axle diameter and more rigid connection to the fork (compared with a quick-release axle) both work to make the bike stiffer laterally.

Bottom Bracket Stiffness

Top Pro Tour riders have highlighted pedaling stiffness as one of the strengths of the Gen II S5 (FM105). The many sprint victories by Pro Tour riders on this bike testify to its level of stiffness, which derives from the BBRight™ bottom bracket design and Cervélo's composite knowledge. For the 2019 S5, the goal was to outdo our own demanding standard. This was achieved through the careful use of FEA to evaluate designs and through Cervélo's industry-leading experience in designing composite layups.

Weight

The project goal to maintain or reduce frame weight was not a simple one. The external steerer fork, disc brake mounts, and increased torsional inertia stiffness all contributed weight, so it was necessary to reduce frame weight just to prevent a net weight increase. For example, the addition of the external steerer to the fork increased the fork weight slightly, by 7 grams, over the 2014 S5 fork. Even so, the aerodynamic and system stiffness advantages of the external steerer fork made the decision to use it an easy one. Using all of our previous experience with making the world's lightest bikes, the R5ca and its successor the Rca, we reduced the overall frame weight of the new S5 by almost 100 grams: from 1067 to 975 grams (white-painted 56cm qualification frame, without metal parts). The result is an S5 that is lighter than all previous versions, even while offering all the advances that have already been described.

GOAL 3: RIDE QUALITY

Goal	Ensure consistent handling and feel across the full size range
Approach	Maintain consistent stack:reach and reach:trail relationship at all sizes
Innovations & Solutions	Fork customized to each frame size to maintain correct trail: 5 different forks offered Bottom bracket lowered for greater stability at smaller sizes

Ride quality is very subjective and is linked closely to several parameters (please see Rider-Focused Design: A Glossary p. 30, for reference). In terms of frame design, we can divide these parameters into two general categories: fit and handling. For the S5, a top design priority was to improve the ride experience for smaller riders by paying close attention to fit and handling across the entire size range. Cervélo has a long history of supplying high-performance bicycles to smaller riders, both male and female. However, during the development of the R series, our smaller test riders acknowledged the reality that is was the first time that they had experienced handling so predictable or stable. By extending the strategies we began using with the R series, we were able to continue that experience with the new S5.

Fit

The 2019 S5 was designed to offer a proportional fit across the full size range. The stack and reach coordinates are the same as the Gen II S5. The S5 fit profile, called Pro Fit, offers the lowest stack values in the Cervélo road family but can easily be adjusted to meet a broad range of fit requirements. The Pro Fit stack is 16mm lower than the Elite Fit profile found on the S3, a critical difference because it complements the lower, more aerodynamic body positions often employed by more performance driven athletes. The effective seat tube angle remains at 73 degrees, but both 25mm and 0mm setback seat posts are available.

Industry-wide data on geometry for small sizes shows that many small-sized bikes deviate from the ideal and reflect compromises in fit and handling. Figure 17 summarizes the terminology of bicycle geometry. Figure 18 illustrates the design challenges involved in delivering smaller sized bikes with consistent and predictable fitting geometry. Because Cervélo has always started designs from stack and reach coordinates, we are able to focus our attention on the fit of each bike individually, rather than allowing arbitrary measurements such as seat-tube length or head-tube length to dictate the way a bike fits the rider. The straight red line in Figure 18 shows how Cervélo's stack and reach coordinates progress logically together, whereas those of competitors can have a radical disparity in the fit across the size range.

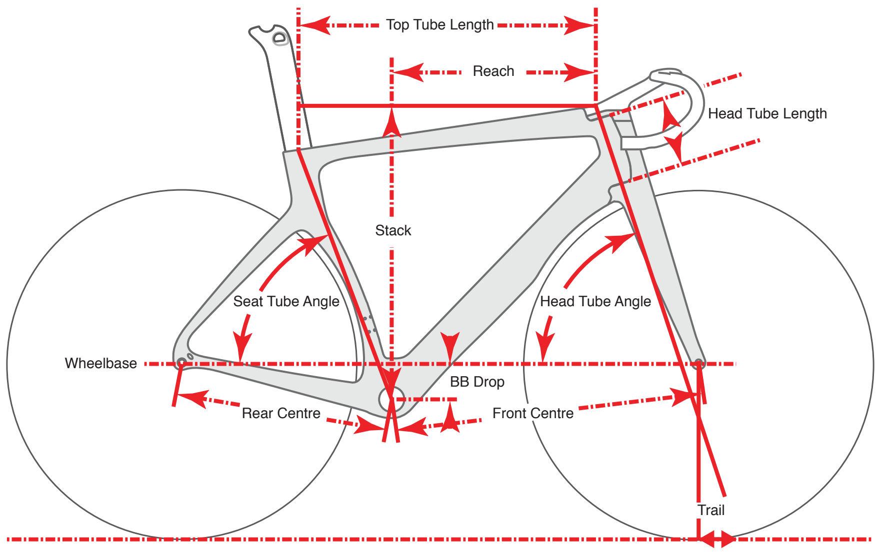


Figure 17. Dimensions for specifying bicycle geometry.

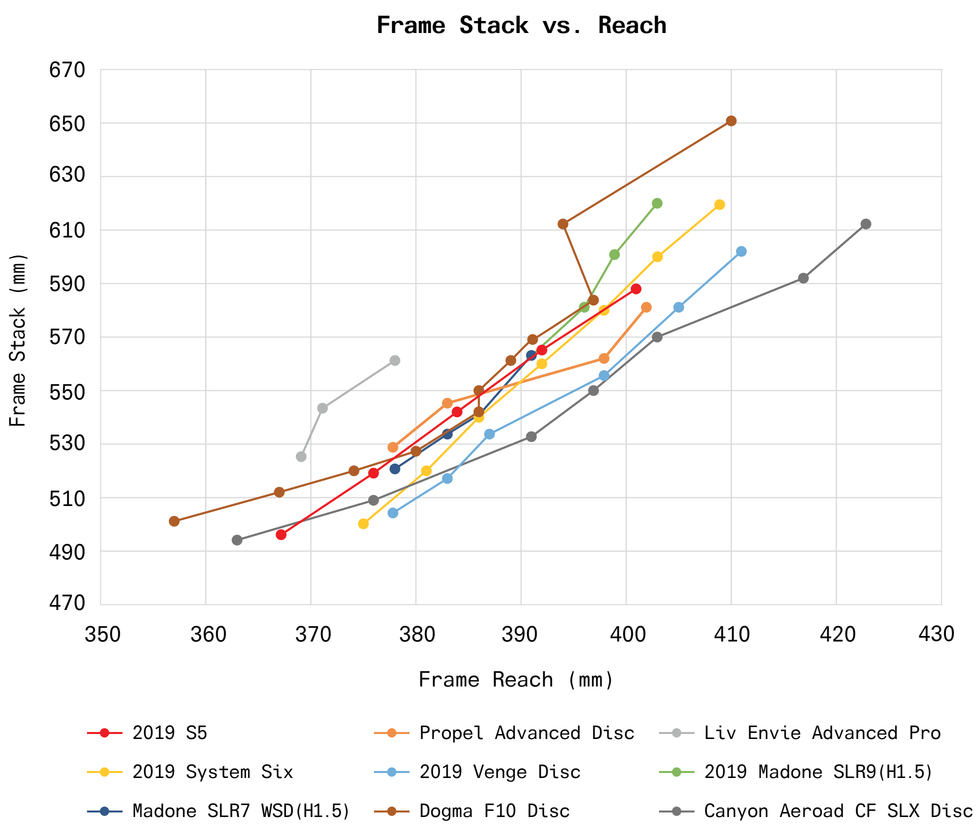


Figure 18. Frame stack and reach for competitive aero road bikes.

Handling

A correct relationship between stack and reach is important for fitting. However, reach coordinates are important in themselves, due to their relative relationship to trail, and therefore, handling. As such, the drive to shorten reach for smaller riders, can often present design challenges, if handling is considered. As shown in Figure 17, trail defines the distance between the virtual steering axis and the tire contact point.

To show the design implications of reach, we first need to show how it affects trail, especially in small sizes. Reach coordinates are established at the centre of the upper head-tube bearing. As a result, reach can be artificially shortened by angling the head tube more sharply toward the rider. This modification is an effective way to avoid toe overlap on smaller sizes, but it means that the fork must also be modified to offset any increase in the trail.

The trade-off between reach and trail is critical—far more so than is generally appreciated—because trail relates directly to the handling experience: It is responsible for the restorative torque imparted to the steering mechanism (the front wheel in this case) and dictates the stability and sensitivity of the bike. Having too much trail is a particular problem in high-performance applications because it causes the steering head to drop during turning. The greater the distance between the steering axis and the wheel centre, the greater the drop. It is important to distinguish between the consequences of excess trail and those of gravitational torque. During gravitational torque, the act of leaning the bike promotes the inclusion of the wheel weight in the steering inputs, forcing the rider to resist the turning process. In contrast, when the steering head is dropping during the turning action, the rider must lift the steering mass to restore the steering to centre. When trail is too long, the rider has extra work to overcome gravitational inputs plus extra work to stabilize the bike.

There are benefits to an artificially high trail number in specific applications, but, in general, trail should remain constant even as reach changes. Frequently, a manufacturer's ideal trail value appears on (or around) a size 56cm frame, but compromises are made on smaller sizes. Figure 19 shows the relationship between reach and trail across a selection of aero road bikes. The horizontal red line in Figure 19 represents the trail values of the Cervélo 2019 S5 in relation to its reach values. This line clearly shows how Cervélo has normalized trail across all sizes to ensure that smaller riders experience the same desirable handling characteristics as larger riders. In the data for other leading aero bikes, we can see the radical inconsistencies in trail that plague the ride experience of smaller riders.

There are many reasons for this industry-wide phenomenon, but the primary one is cost. It is far cheaper to design forks in only one or two sizes (offsets) to work for all six (or more) frame sizes. Cervélo has done this in the past, and most others still do. However, these limited fork/frame pairings create sub-optimal trail geometry for riders of many sizes, particularly those who are smaller. The issue is compounded by the fact that when smaller frames are equipped with 700c wheels, toe overlap can become a problem.

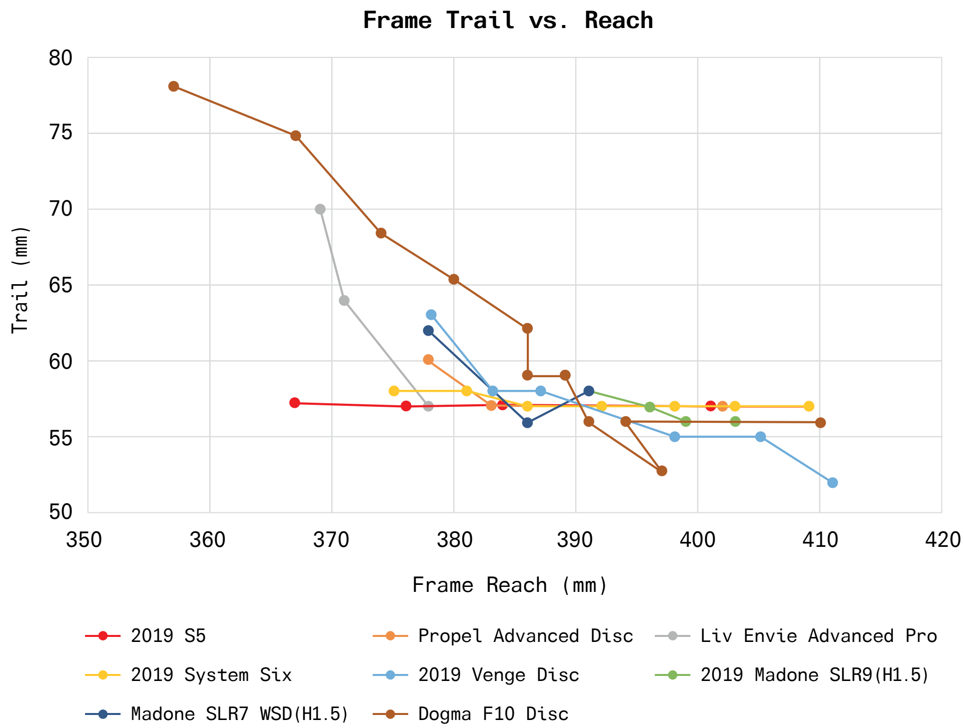


Figure 19. Trail vs. reach for competitive aero road bikes.

On the 2019 S5, we achieved consistent trail—and consistent handling—across all sizes by designing a specific fork for each frame size: five forks instead of the usual one or two. The design and manufacturing costs of this choice are significant. We think it was worth it, though, and all of our smaller test riders have agreed completely.
The other area of the geometry that was changed for handling was the bottom bracket drop. Following the design of the new R series bikes, the BB drop was increased slightly compared with the Gen II S5. A lower bottom bracket lowers the rider's centre of gravity, helping stability in high-speed cornering, which was particularly needed in the smaller sizes.

The success of our approach to the relationships among stack, reach, and trail was validated by the same internal test riders who first flagged the issues to the engineering team. When they were able ride the new R5 and S5, in which the geometry had been adjusted so that their frame size had an appropriate trail value, they were completely shocked and amazed by how well the bikes rode. After years of riding small bikes with non-ideal trail values, they finally knew how riding a "correct" design could feel!

GOAL 4: USABILITY STANDARDS & TRENDS

Goal	Make the new S5 fully compatible with the latest trends and developments in road cycling
Approach	Add room for wider rims and larger tire sizes with appropriate clearance Add flat-mount disc brakes Incorporate fully internal cable routing with easy position adjustment
Innovations & Solutions	Frame and fork shapes deliver 38mm of space between the stays; ISO 4210 requirements incorporated in wheel recommendations Brake positions opened design flexibility for other components while hiding hydraulic lines to maximum extent Integrated aero cockpit can be adjusted for stack without taking apart the whole bike

Cervélo has designed the 2019 S5 to be at the forefront of all facets of the industry, so our design goals of course included changes to reflect new standards and trends. Most have already been discussed, but here we give some additional details of the S5's updated braking and tire specs.

Disc Brakes and Axle

The new 2019 S5 incorporates an industry-standard flat-mount brake design on both fork and frame. The move to disc brakes provides maximum braking confidence in all weather conditions without negatively affecting aero drag. We have used the knowledge gained over years of developing flat-mount disc brakes for road bikes (R3, P5X, C5, R5, S3) to ensure excellent braking performance and rider control. The brake design incorporates the Cervélo rapid axle technology (RAT) thru axle. As with our other bikes using this axle technology, the system stiffness is vastly improved (relative to quick-release axles) while still making wheel changes easier and faster. In addition, the new 2019 S5 is compatible with Cervélo's new Aero Axle conversion kit, which provides a more aerodynamic thru axle option.

Tire Clearance

The 2019 S5 has been designed to use the latest wide wheels and tires. Because the S5's disc brakes allow more clearance than rim brakes, riders can choose to use wider tires. The design allows for allows for 38mm of room between the chainstays (Figure 20). This clearance incorporates the ISO-mandated 4mm clearance to the frame (ISO 4210), so the available tire size clearance is 30mm. (Riders should bear in mind that actual tire size will vary with wheel design and pressure and does not necessarily correspond to the size written on the tire sidewall. See our paper "Clarity on Tire Clearance" for more details [3].)

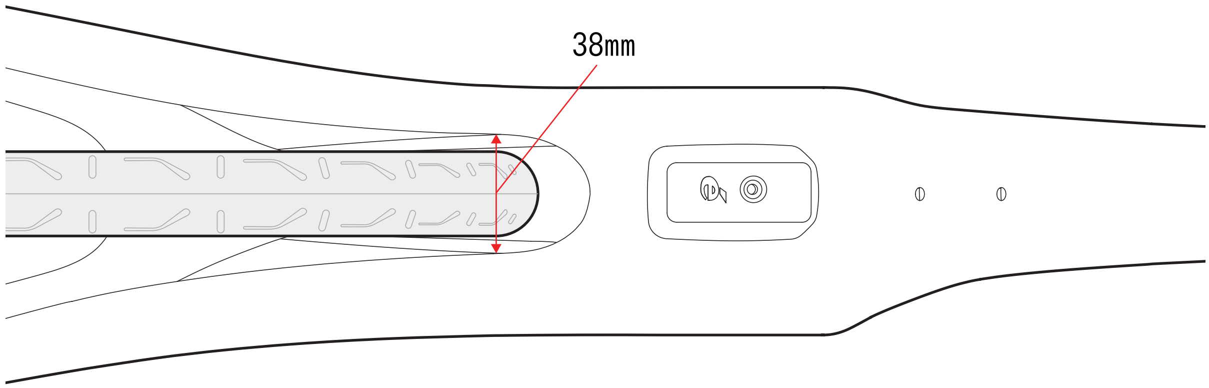


Figure 20. ISO compliant tire clearance on 2019 S5.

CONCLUSIONS

This paper has summarized the all-new features that make the Cervélo 2019 S5 the fastest and most comfortable aero road bike we've ever made—and the technical imagination, determination, and rigor that got us there. We started by reimagining how we work together—and then used the same open-mindedness to reimagine how all the elements of our new bike could work together. The mantra was always "How can we remove every technical excuse and obstacle to human performance?" The answer, both in our work process and in the concept for the bike, was to unify.

We unified the design process across all our offerings and across disciplines. We shifted our focus to a complete consideration of the bike+rider as an aerodynamic whole. And within that, we unified components into aerodynamic zones. Rigorous simulation and repeated wind tunnel testing guided us to new solutions in each zone.

The result is most visible in a radically unified front end. Handlebar, stem, headset, and external steerer fork—all new—work together to fully hide all types of cables. Riders get the big aero gains of hidden cables with no downside: All cable systems (including mechanical ones) work without excess friction; assembly is straightforward; fit can be adjusted without disassembly.

Sometimes though, all-in-one isn't the best solution. We met our goal of unifying rider experience by diversifying one component: Each frame size has a customized fork offset. The result is a consistent fit—stack, reach, and trail—across all frame sizes, giving smaller riders comfort and performance like they've never experienced.
But riders come to us first and foremost for speed. As engineers and designers, we were excited when the wind tunnel graph showed 42 grams less drag. We'd once again broken the limits of incremental aero gains. But what really made our hearts race (because most of us ride ourselves) was knowing we've given our riders back 5 watts of power. We can't wait to see what limits they break.

RIDER-FOCUSED DESIGN: A GLOSSARY

Ride quality: The management of the materials used, the stiffness profile, and the handling, which come together to help affect the overall ride experience. These three factors work in unison: balancing them determines the way the bike feels for a specific use case.

Torsional inertia stiffness: The force required to twist the top tube and move the steering mechanism out of plane with the seat tube. Also known also as headtube stiffness or steering stiffness. The goal of managing torsional inertia stiffness is to keep the wheels tracking in line under heavy handling loads, yet still allow the bike to manage deviations in rider input and pavement variability.

Bottom bracket stiffness: A measure of the force required to deform the frame tubes connecting at the bottom bracket shell. The goal of managing Bottom Bracket stiffness is to maximize the responsiveness to pedaling input, as well as offering stability under high loads.

Usability: The decisions made to design technical solutions that are easy to service, easy to adjust, and adapted to the lifestyle requirements of the athlete.

Comfort: A subjective aspect of a rider's experience which Cervélo believes can be analysed in three ways: physical, neurological, and psychological. Physical comfort is understood to be affected by road input (i.e. bumps and vibration). Neurological comfort is linked to fit and the qualities of the component–rider interface: bar position, saddle position, appropriateness of the saddle, etc. Psychological comfort entails management of rider nervousness or anxiety resulting from the handling profile as the rider experiences it. The degree to which cyclists experience these factors individually and how the three interact will vary by rider.

Aerodynamics: The interactions of the bicycle and rider with the air they travel through. As Cervélo has shown in many articles, aerodynamic resistance is the cause of most of a rider's effort—so reducing it helps riders go faster. More details of the Cervélo approach to aerodynamics and testing are given in our AeroTech paper [1].

FURTHER READING

[1] "Introduction to Aerodynamic Development at Cervélo," 2018.

[2] D. Rinard and P. White, "Cervélo P5 Technical White Paper,." 2012.

[3] "Clarity on Tire Clearance," September 15, 2015.

V1 2018-09-28

www.cervelo.com