Executive Summary

Aero Performance
Averaging between +15 and -15 degrees of yaw, the Cervélo S5 measured:

- **92 grams less drag** than the S3 and
- **Up to 300 grams less drag** than typical road bikes.
  - This is a savings of **9-32 Watts**.  
  - Drafting? Still save **6-22 Watts**.

This world-beating aerodynamic performance is thanks to these features:

- Dropped down tube
- Built for bottles
- Extended seat tube cutout
- Shielding seat stays

Stiffness & Weight

- The Cervélo S5 is 12% stiffer than the Cervélo S3. Remember, the S3 is stiff enough for Thor Hushovd to have won World Championships in a sprint finish, the TdF green sprinter’s jersey, etc.
- The Cervélo S5 frame weighs as little as 990 grams (54cm VWD edition, with paint and all hardware). (Reference: Cervélo S3 is about 80 grams more.)

This new benchmark in stiffness and light weight is thanks to Cervélo’s Project California technology:

- Anaglyph “Laminate Tools”: advanced composite structural analysis software
- BBright.net: Asymmetric, Stiffer, Lighter
- Smartwall™: increases stiffness while adding little weight

Road Geometry

Pure road geometry: Same classic handling and fit as the Cervélo R-series.

- 73 degree effective seat tube angle.
- Two position post ranges up to 20mm forward and 20mm rearward from a traditional 20mm offset post (zero offset through 40mm offset).
- Stack & Reach based proportional sizing enables outstanding fit for all riders, especially smaller riders and women.

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1 In this paper we use the following rule of thumb to convert measured grams of drag to other relevant units, such as power saved in Watts and time saved in seconds per kilometer: 100 grams = 10 Watts = 1 second per kilometer. (Martin et. al., “Validation of a Mathematical Model of Road Cycling Power”, 1998)
**Introduction**

Cervélo pioneered the modern aerodynamic road bike in 1996. In recent years other bike companies have finally started to understand the advantages of an aero road bike and have begun introducing aero-styled road bikes. At the same time, Cervélo has extended our technological lead with the S5, the next generation of aero road bike. The innovations engineered into the Cervélo S5 define it as the ultimate road bike.

**Aero Road Bike Benchmarks**

The Cervélo S5 sets a new benchmark for aero road bikes. That should be no surprise – it’s an evolution of the Cervélo S3, the bike on which Thor Hushovd sprinted to a Green Jersey at the Tour De France and to the World Championship victory. The S3 is also *Bicycling Magazine*’s “Editors Choice” as “Best Race Bike,” *VeloNews*’ “Editor’s Pick” and the readers’ choice as “Best Team Bike” six years running at *CyclingNews.com*. So it is little wonder that other companies have finally started to target the S3’s performance. However, while the S3 is others’ target, it’s our starting point for engineering the next generation of aero road frames. The new S5 is a significant leap ahead.

To be recognized as the “Best Race Bike” by the media, the industry and riders, a bike has to be built on a solid foundation – it has to be stiff, light, comfortable, as well as aero. The challenge in moving the goalposts ahead is to improve on the performance of the S3 in every area: the new Cervélo has to be stiffer, lighter, and more aero.

**Cervélo S5 Stiffness & Weight**

The Cervélo S5 is 12% stiffer than the Cervélo S3.

The Cervélo S5 frame weighs as little as 990 grams (54cm VWD edition, with paint and all hardware). (Reference: Cervélo S3 is about 80 grams more.)

To achieve these numbers we used the Project California engineering tools developed and showcased in the R5ca.

**Project California engineering tools**

The engineers that worked on Project California were assigned the mission to bring highest level composites engineering know how internally to Cervélo and to apply that across the model line. The R5 California frameset is incredibly light and stiff, yet still meets Cervélo’s internal strength standards that are significantly higher than industry standards. The challenge became how to apply that technology to an aero road frame.

To achieve the lightest, stiffest aero road bike we’ve ever produced, Cervélo engineers leveraged the unique engineering tools developed during Project California:
Anaglyph “Laminate Tools” in conjunction with the NEi NASTRAN solver and FEMAP pre- and post-processing: F1 composite analysis software tools. Cervélo is the only bicycle company we’re aware of to use this level of engineering simulation software in house. Unique benefits of Laminate Tools include:

- Individual ply definition and draping simulation onto complex shapes.
- The ability to analyze strength and stiffness criteria on a ply by ply basis, which allows us to pinpoint the effects that individual plies have on frame performance.
- Cuts down on development time, so we can run several iterations in one day and understand the effects of each individual change made; it can take 4 days or more to “make it and break it” and without the high fidelity results analysis provides.
- Efficiency of the laminate is improved by being able to pinpoint where on the frame material can be used most effectively to meet stiffness goals. An example would be the use of 2.5 grams of material to gain 8% increases in stiffness for the BB bulkhead (S5 VWD model).
- Complex ply shapes can be translated into flat patterns for manufacturability but also allow the use of fewer plies, reducing overlaps and thus weight as well.

- BBright.net: Asymmetric, Stiffer, Lighter
- Smartwall™: increases stiffness while adding little weight

The direct result of applying Project California engineering tools to the development of the S5 is that while the S5 is significantly more aero than the previous generation S3, it is simultaneously both stiffer and lighter than the S3. Like all Cervélos, the S5 achieves these performance advances while still meeting Cervélo’s in-house strength requirements, all of which significantly exceed industry standards.

Lab vs. Reality
While there are a variety of different ways to measure frame stiffness in the laboratory, the question is does the lab stiffness test match the real world? The engineers working on Project California applied strain gages to real bikes ridden by various pros and amateurs through a wide variety of uses and conditions while measuring and recording the strains in various areas of the frame. Then they developed a lab test for stiffness that actually matched the way the bike is ridden in the real world – one that also included the weight and inertia of the rider. Including the weight & inertia of the rider may seem rather basic but the traditional industry lab tests do not take them into account. The result of this engineering work is that while the new S5 frame has become lighter, at the same time the stiffness has increased by 12% over the World Championship and TdF Sprint jersey winning S3 frame.

Why is this important?
Stiffness and weight are important because, in general, stiffer and lighter bikes climb better and handle better; they’re more fun to ride, and reward riding hard. As a result of the engineering tools pioneered in Project California (and showcased in the R5ca), the Cervélo S5 is the stiffest and lightest aero road

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[^2]: [www.BBright.net](http://www.BBright.net)
bike we’ve ever made. The Cervélo S5 approaches the low weight and high stiffness of the R-series bikes, yet provides better performance on the road thanks to its unmatched aerodynamics.
Cervélo S5 Aero Performance
Averaging between +15 and -15 degrees of yaw, the Cervélo S5 measured:

- **92 grams less drag** than the S3 and
- **Up to 300 grams less drag** than typical road bikes.
  - This represents a savings of **9-32 Watts**.
  - Drafting? Still save **6-22 Watts**.

The data and discussion below cover the multiple trips to the wind tunnel that document this benefit.

2011 Wind Tunnel Data

![Aerodynamic drag force comparison chart](image)

**Figure 1:** Aerodynamic drag force of the Cervélo S5 compared to the Cervélo S3. Tested at UWAL June 2011.

The figure above is a yaw-drag chart, a typical way of comparing the aerodynamic drag forces of different bicycles with a rider. Less drag (lower on the chart) is better. The vertical axis shows the drag force in grams, measured along the axis of the bike (not wind axes). This is the opposing axial force the rider feels due to the wind. The horizontal axis shows the yaw angle, or crosswind angle, in degrees. This is the angle the net wind makes with the rider, including both the wind created by the rider’s motion along the riding direction, plus any atmospheric wind (cross wind). Positive yaw (right side of the horizontal axis) is with the oncoming wind on the rider’s right side; negative yaw (left side of the axis) is with the oncoming wind on the rider’s left side. There are two data series in this figure, the Cervélo S3 and the Cervélo S5. The data for these two bikes shows that the Cervélo S5 has about 90-100 grams less
drag than the Cervélo S3 at most yaw angles. In fact, averaging data from -15 to +15 degrees of yaw, the Cervélo S5 has 92 grams less drag than the S3.

To put this 92 gram reduction in aerodynamic drag into perspective we’ll compare this data to older measurements including several other road bikes.

2009 Wind Tunnel Data

![Aerodynamic drag chart](image)

**Figure 2: Aerodynamic drag force of several road bikes tested at LSWT February 2009.**

The figure above is another yaw-drag chart, again with drag on the vertical axis and yaw on the horizontal axis. Less drag (lower) is better. This chart gives the drag for various road bikes without a rider. This data is from 2009, and shows that the Cervélo S3 had the lowest drag among the bikes tested. All the other bikes had more drag than the Cervélo S3, roughly between 100 to 200 grams more drag. The new Cervélo S5 didn’t exist in 2009, so is not included in this data.

This data generally agrees with *VeloNews’* wind tunnel data, which showed that when all bikes were equipped with the same wheels the Cervélo S3 had the lowest drag of all the bikes in the test.³

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These two sets of wind tunnel data are not directly comparable: among other differences, they come from two different wind tunnels, and in one test the rider is included and in the other, the rider is not. By 2009 we had already been testing time trial and tri bikes with our DZ mannequin and found slight changes in drag depending on whether there was a rider on board or not. So when we began the S5 project we included our mannequin in our wind tunnel tests on road bikes as well. However, despite these differences there is a bike in both data sets that can serve as a reference: the Cervélo S3. So instead of comparing the data from the two sets directly, we can use the Cervélo S3 as a reference to compare differences in drag. Using the S3 as a reference, we see (from the 2011 data) that the S5 had 92 grams less drag than the S3, and (from the 2009 data) the S3 had about 100 to 200 grams less drag than typical road bikes. Adding these differences together suggests that the S5 has roughly 200 to 300 grams less drag than typical road bikes. The figure below illustrates this concept.

![Figure 3: A simplified representation of the differences in the ranges of data from the 2009 and 2011 wind tunnel tests.](image)

In summary, averaging from +15 through -15 degrees of yaw, the Cervélo S5 measured:

- **92 grams less drag** than the S3 and
- **Up to 300 grams less drag** than typical road bikes.
- At 40 km/h this is a **savings of 9 Watts to the S3 and up to 32 Watts** for typical road bikes.

**Why is this important?**
Of all the sources of resistance encountered while riding, aerodynamic drag consumes the largest portion of the rider’s power: more than stiffness, more than weight, more than mechanical friction and more than rolling resistance; in fact, more than all those combined. Typically, 70-88% of power is used to overcome aerodynamic drag on flat ground.

![Power requirements of a conventional racing bicycle](image)

**Figure 4**: Power output required to propel a typical road bike (Rainer Pivit, 1990). At 40 km/h (25 mph), aerodynamic drag consumed about 88% of this rider’s total power output, more than all other resistance combined.

The founders of Cervélo knew that aero drag was the main source of resistance to riders even before they started designing bikes 16 years ago, and we’ve been engineering the world’s most aerodynamic bikes ever since. Cervélo riders understand this and benefit by winning the world’s top road races, time trials and triathlons.

Aerodynamic design is clearly important in timed races like time trials and triathlon, but riders who understand that aerodynamics still counts at lower speeds, while climbing, and even while drafting, can benefit by choosing an aero bike for any ride. Reducing aerodynamic drag buys these riders a performance boost: free speed, energy savings, power savings, and time savings. Whichever way you want to slice it, a good aero bike lets the rider choose how to spend the aero dividend.

**Example: 100 kilometer road ride**
If you ride a Cervélo S5 alone for a typical 100 kilometer (60 mile) road ride, say a solo training ride, then compared to riding a previous generation aero road bike you could either:

- Arrive one and a half minutes sooner (for the same power output),
• Arrive at the same time while saving 9 Watts continuously during the ride, or,
• Arrive a little sooner while saving energy.

What about drafting?
Even though drafting reduces aerodynamic drag, the benefits of an aero design still help the rider. Riding in a pack generally means you can draft much of the time, which reduces aerodynamic drag and saves you energy. However, when you’re drafting, a more aerodynamic bike still gives you an advantage. Although an aero bike’s advantage is reduced in a group, it doesn’t vanish. Even in a group, aerodynamic drag is still the biggest source of resistance a cyclist has to overcome.

The power required while drafting is about 25-30% less than that which is needed to ride solo, but aerodynamic drag is still the dominant source of resistance. This means that even when drafting, a rider on the S5 keeps 70-75% of the aero benefit, still saving between 6 and 22 Watts, compared to the S3 or typical road bikes, respectively.

Obviously, saving power continuously like this gives the Cervélo S5 rider an energetic advantage over riders of other road bikes that can be spent tactically any way the rider chooses: arrive sooner, arrive fresher, attack, or maintain contact during critical moments, climb stronger, sprint stronger, etc.

Aero Summary
The aero benefits of the Cervélo S5 are large and clear, whether riding alone or in a group. The chart below summarizes the power output required to ride at various speeds.

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4 Jeukendrup, *High-Performance Cycling*, p. 73
Figure 5: Power required to ride at various road speeds. Above: power required while riding alone. Below: power required while drafting in a group.

From the figure above you can see that at a speed of 40 km/h (25 mph) the Cervélo S5 saves the rider between 9 and 32 Watts while riding alone, and between 6 and 22 Watts while drafting in the pack.

The table below summarizes the power the Cervélo S5 saves its rider, compared to the Cervélo S3 reference bike and other typical road bikes.

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<thead>
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<th></th>
<th>vs. Cervélo S3</th>
<th>vs. typical road bikes</th>
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<tr>
<td>Cervélo S5</td>
<td>9 Watts</td>
<td>32 Watts</td>
</tr>
<tr>
<td>advantage</td>
<td></td>
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Table 1: Power saved on the Cervélo S5 relative to the Cervélo S3 and typical road bikes.
Cervélo S5 Features
The Cervélo S5’s record-setting low aerodynamic drag is the result of integrating years of aerodynamic research using wind tunnel testing, Computational Fluid Dynamics (CFD) aerodynamic analyses, field testing and pro athlete feedback. The Cervélo S5’s design features work together with each other and with other bike components to contribute to the low aero drag. Five design features illustrate the S5’s aero integration especially well. All these features operate on aerodynamic principles to both (a) alter the pressure distribution over the bike’s surfaces and (b) eliminate turbulence to reduce aerodynamic drag. The S5’s design reduces both the high pressure on leading edges and the wake and turbulence on trailing edges. Both changes work together to reduce the total aerodynamic drag of the bike.

Dropped down tube

Figure 6: Cervélo’s CFD analysis results show the smooth airflow around the Cervélo S5’s fork crown and dropped down tube. The left image shows streamlines on the Cervélo S3. The right image shows improved airflow on the Cervélo S5.

The S5’s dropped down tube smooths the airflow from the fork to the down tube, filling in the turbulent air gap behind the fork crown. By filling this space with the down tube:

i. We “hide” the down tube in dirty air, reducing the high pressure normally found on the down tube’s leading edge, and

ii. Eliminate the low pressure air that normally pulls rearward on the fork crown.

Built for Bottles
As with every road bike Cervélo engineers have tested in the wind tunnel over the years, adding regular water bottles to the S5 adds aerodynamic drag. But a road bike like the S5 is seldom ridden without any bottles; there’s usually at least one. Cervélo engineers took this into account and designed the S5 to harmonize with the presence of bottles to incur minimal aero penalty.

This is accomplished on the S5 by:

- Widening the down tube’s trailing edge near the bottle to smooth airflow onto the bottle and
Reducing the streamwise gap between the bottle’s trailing edge and the seat tube (the wider bottle smooths the airflow onto the seat tube).

Figure 7: Cervélo S5 in the UWAL wind tunnel with the water bottle in the “low” position for on the down tube.

The Cervélo S5 fits two water bottles in the usual positions: one on the seat tube, one on the down tube. In the standard 2-bottle arrangement, the bottles fit together tightly with each other and with the frame, reducing the gaps where turbulence forms and improving the aero performance.

In addition, an extra bottle boss on the down tube creates a new lower position for a single bottle. Using the low position on the down tube saves 14 grams of aero drag, a reduction of about 1.4 Watts, compared to a bottle in the usual position.

The lowest drag bottle for the S5 is an Arundel Chrono on the seat tube, which added no measurable drag in our wind tunnel testing. An Arundel Chrono on the down tube added only a few grams.

Extended Seat Tube Cutout

Figure 8: The Cervélo S5’s extended seat tube cutout forms an ideal leading edge for the rear wheel.

The Cervélo S5’s seat tube was engineered to maximize the coverage of the rear tire and wheel while ensuring ease of wheel removal. Simply looking at side view profiles of other bikes demonstrates that the S5 has by far the most rear wheel coverage of any aero road bike. Not only is the length of coverage
at a maximum, but the thickness of the seat tube is matched to the tire and constant along the length of the cutout as well, providing the most coverage in three dimensions of any road bike. By designing the seat tube’s trailing edge to act as a shield in front of the rear tire, the seat tube smoothes the airflow onto the rear wheel, reducing the high pressure a rear tire typically experiences at its leading edge, thus reducing the aerodynamic drag. Likewise the rear tire fills the gap behind the seat tube, reducing the magnitude of the low pressure typically found behind normal seat tubes, again reducing total aerodynamic drag.

**Shielding Seat Stays**

![Figure 9: Cervélo’s CFD analysis shows that the shielding stays cleanly direct the air flow past the rear brake.](image)

The Cervélo S5’s frame was engineered to hide the rear brake behind the shoulders of the seat stays. The seat stays’ shape provides an aero profiled leading edge upstream of the brake, thus smoothing airflow from the frame onto the brake. Once again, placing components behind each other simultaneously reduces high pressure on the trailing component’s leading edge and reduces the magnitude of the low pressure on the leading component’s trailing edge, resulting in a reduction in drag of each part and an even greater reduction of the combined system.

**BBright**

The Cervélo S5 uses the BBright bottom bracket standard. BBright™ is the only Bottom Bracket standard that incorporates an oversize 30mm axle and oversized frame tubes. The left chain stay can be up to 11mm (or 65%) wider and the down tube can be 11mm (or 16%) wider. From an engineering design point of view, this means that the stiffness (as measured by the larger moment of inertia) can be increased by up to 381% compared to standard bottom brackets. More details of the benefits of BBright™ can be found at [www.BBright.net](http://www.BBright.net) and in this “Ask the Engineers” blog post.

BBright™ is asymmetric and oversized where it matters and creates the optimal combination of stiffness and weight for the overall system (crankset and frame together), but what about aerodynamic effects?
Compared to typical bottom brackets, BBright adds no aerodynamic drag\textsuperscript{5} because the small increase in frontal area of the larger diameter BB bearings (52mm vs. 44mm) is offset by the improved shape of the chain stay filling in the turbulent area behind what would have been external BB cups. With BBright, the left chain stay is now 11mm wider, so the surfaces of the frame there can perfectly complete the trailing edge of the left bearing. The left chain stay now drafts behind the left bearing eliminating the turbulence typically found in the low pressure zone there.

These two opposing effects cancel each other for a net zero effect of BBright on aerodynamic drag.

\textsuperscript{5} LSWT, October 2010
Cervélo S5 Geometry

Same classic road handling and fit as the Cervélo R-series.

- 73 degree effective seat tube angle.
- Two position post ranges up to 20mm forward through 20mm rearward from a traditional 20mm offset post (zero offset through 40mm offset). The forward clamp position is on the 73 degree seat tube angle.

![Cervélo S5 Frame Geometry](image)

**Figure 10: Cervélo S5 frame geometry**

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<th>Head Tube Length*</th>
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*Note: Head tube length is 6mm longer than the Cervélo R-series because the S5 fork is 6mm shorter axle-to-crown.

**Table 2: Cervélo S5 frame geometry dimensions**

Why is this important?
The Cervélo S5 is a pure road bike, designed for mass start races and fast group rides, and the handling and fit reflect that. The frame’s handling is purpose-engineered to provide the neutral and responsive steering needed for effortless stability and nimble reaction, whether riding alone or in a bunch.

The frame dimensions that affect the S5’s fit are a product of Cervélo’s Stack & Reach based proportional sizing. This enables outstanding fit for all riders, especially smaller riders.

These fit dimensions are the same as the Cervélo R-series bikes, with one additional degree of freedom: The S5’s seat post has two clamp positions. The post clamps the saddle rails in either the “zero offset” or “40mm offset” position, relative to a traditional 73 degree seat tube angle. The two positions give the rider freedom to position the saddle in a range up to 20mm ahead or 20mm behind the traditional position (i.e. 20mm offset), plus the adjustment range the saddle rails permit.

![Cervélo S5 two-position seat post](image)

**Conclusion**

The Cervélo S5 raises the bar for aero road bikes in all the important performance measures: stiffness, weight, aerodynamics, handling and fit.

The Cervélo S5 is 12% stiffer than the already stiff Cervélo S3. The S5 frame weighs as little as 990 grams (VWD edition, with paint and all hardware). This is the lightest and stiffest aero road bike Cervélo has ever produced. This stiffness and light weight is thanks to Cervélo’s Project California technology: Anaglyph “Laminate Tools”, BBright.net and Smartwall™.

Thanks to the dropped down tube, Built for Bottles down tube, extended seat tube cutout and shielding stays, the Cervélo S5 saves the rider energy at the rate of 9 to 32 Watts (depending on which bike it is being compared to), and saves another 1.4 Watts of drag when using a single round bottle low on the down tube.
The Cervélo S5 is the ultimate road bike: it shares the same handling and fit as the Cervélo R-series, including a classic 73 degree effective seat tube angle. A unique two position post extends saddle position options 20mm forward or 20mm rearward from a traditional offset post (zero offset through 40mm offset). Cervélo’s unique Stack & Reach based proportional sizing enables outstanding fit for all riders, especially smaller riders.