

THE IMPACT OF AERODYNAMICS ON THE TOUR DE FRANCE



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Table of Contents

Introduction.....	3
What makes a cyclist and his bike more aerodynamic?.....	4
Drag:.....	4
Lift:	4
Air Resistance:	4
Aerodynamic Equipment:	4
Body Position:	5
Clothing and Gear:	5
The Influence of Body Position on Cycling Aerodynamics	6
The Impact of Advances in Aerodynamics on Cycling Performance	7
The Peloton	8
The Historical Development of Aerodynamic Techniques in Cycling	9
Comparing Traditional and Modern Aerodynamic Techniques in Cycling	10
Analyzing Changes in Cyclists' Equipment for Improved Aerodynamics	12
Examining the Effects of Clothing on Cyclists' Aerodynamic Performance	13
Aerodynamic Limitations in the Tour De France	14
Conclusion	15
Works Cited	16

Introduction

The Tour de France is widely regarded as one of the most physically challenging – and internationally esteemed – races in its discipline, encompassing flat stages, categorised climbs, individual time trials, and cobbled sections over a route that varies from year to year, for a total of three weeks. Competitors must therefore possess a multifaceted skillset to ensure they can compete on all terrains. This, paired with the intense focus placed on honing every marginal gain possible to ensure victory, makes the aerodynamic evolution of professional cycling a fundamentally important area of study. This project intends to explore the development of aerodynamic improvements and performance optimisation in professional cycling through a specific focus on aerodynamic evolution in the Tour de France in relation to developments in equipment, body positions and sporting attire. Historical developments in aerodynamic concepts, and the ways they have been applied in practice, will be analysed in relation to the performance of professional cyclists, with a combination of literature reviewing on how aerodynamics is and has been vital for optimising race results, as well as for the development of new and innovative equipment.

What makes a cyclist and his bike more aerodynamic?

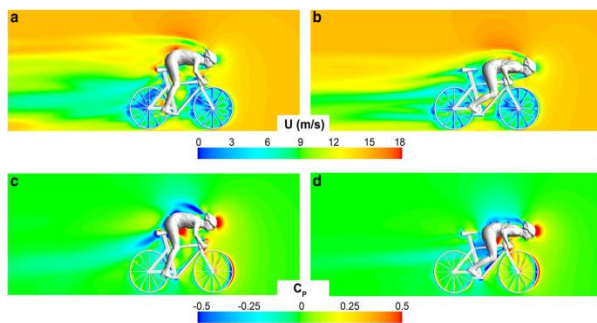


Figure 7 (Blocken et al.)

Aerodynamics can be crucial to top-level cycling, and a racer who minimises air resistance gains a significant performance advantage. There are three factors that make a cyclist and their machine more

aerodynamic.

Drag: The resistance force that acts against the motion of a cyclist moving through the air. It is caused by the shape of the body, the surface roughness, and the frontal area of the cyclist. Reducing drag increases speed and efficiency (Crouch et al., 2017).

Lift: Although lift is commonly associated with aviation, it plays a significant role in cycling by enhancing a rider's confidence in their equipment. It is the force perpendicular to the direction of motion, influenced by the cyclist's body and equipment design. Proper management of lift can contribute to stability and control.

Air Resistance: Collective effect of the drag and lift forces acting on the cyclist (eg, reducing air resistance is the most important factor to increase performance in time trials and flat stages) Brown et al (2023).

The goal is to minimize the opposing force (drag) that slows down a rider, as it counteracts the rider's forward motion. Reducing the drag coefficient (C_d) is essential for improving speed and efficiency.

Aerodynamic Equipment: Advances in equipment design are pivotal. Modern aerodynamic bikes feature streamlined frames, deep-section wheels, and integrated handlebars to reduce

drag. As noted by Kyle and Burke (2024), these innovations are based on extensive wind tunnel testing and computational fluid dynamics (CFD) simulations.

Body Position: The cyclist's body position significantly affects aerodynamics. A lower, more compact position reduces frontal area and drag. Studies like those by Brown et al. (2023) have shown that optimizing body position can lead to substantial performance improvements.

Clothing and Gear: Aerodynamic clothing, such as skin suits, and gear like teardrop helmets, further reduce air resistance. Crouch et al. (2017) highlights how modern materials and designs contribute to lowering drag.

By focusing on these aspects, cyclists can achieve more efficient airflow around their bodies and bikes, translating into faster speeds and better overall race pace or performance in the Tour de France.

The Influence of Body Position on Cycling Aerodynamics

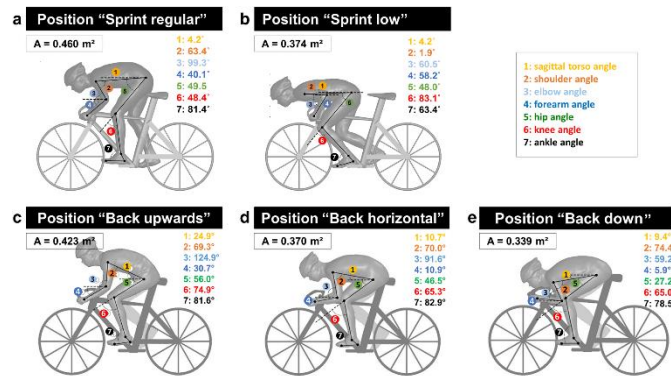


Figure 2 (Blocken et al.)

Body-position plays a key role in the drag force, since lowering the body and bringing it into a more compact position reduces the frontal area available for air to hit. As a result, maintaining an appropriate

aerodynamic position can have a dramatic influence on your performance. One example is the so-called 'tucked' position employed by time-trialists in which the back is flat, and the elbows are tucked in close to one's body. Maintaining such a position is complex from a biomechanics perspective. The cyclist needs to balance the aerodynamic advantages with the need to produce power at the pedals, such that an overly aggressive position can lead to discomfort, which in turn reduces the power output. In fact, studies like Brown et al (2023), demonstrate that small changes in one's position can lead to significant decreases in drag. For example, lowering the sagittal torso angle by a few degrees can lead to a massive drag decrease. The improvement in aerodynamics translates into being able to maintain the same power, while travelling at a faster speed. Wind tunnel testing and CFD simulations are often used to optimise the body positions. In these cases, one can precisely quantify the drag force, and visualise the flow around the cyclist, and through targeted iterations, one can identify the most aerodynamically efficient posture, which also allows one to produce the required power in a sustainable manner. Aerodynamics and biomechanics are inextricably linked, and this balance of maintaining a comfortable and powerful position over a long distance is what is required to succeed in a multi-day race such as the Tour de France.

The Impact of Advances in Aerodynamics on Cycling Performance

The improvement of aerodynamics can also be a direct factor for performance gains. There are plenty of examples from cycling, such as the Tour de France, where the winning margin between the best and the worst cyclist is only a few seconds. The cumulative effects of aerodynamic equipment design, body position, and clothing might represent the most important improvement for cycling performance. Aerodynamic bikes with aero frame design and deep-section wheels can be a very good example for improving frame aerodynamics. According to Kyle and Burke (2024), most of such aero cycling technologies were designed in wind tunnels with CFD simulations and computational modelling to compare the predicted flow velocity and drag before final equipment design. Cyclists also modify their aerodynamic helmets and skin suits to reduce air resistance. Quantitative studies also demonstrated the direct impacts of the improvement of aerodynamic equipment on cycling performance. In a study by Brown et al. (2023), the experimental subjects with the correct aerodynamic position increased their speed by 10 per cent in a laboratory-controlled environment, which equated to a 14 per cent-improvement in speed. The performance of the athletes varied between stages, with those riders who adopted the improved equipment performing better in time-trialling stages where aerodynamics is essential.

The Peloton

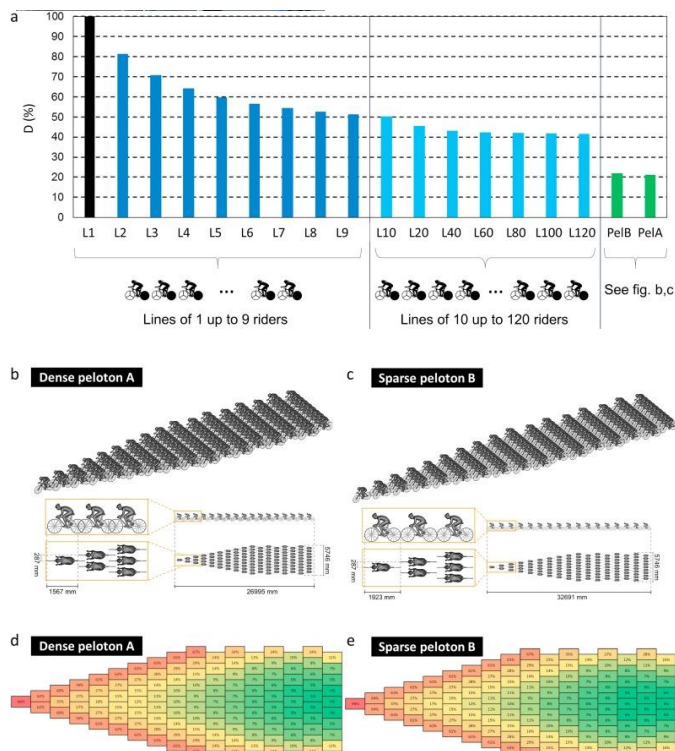


Figure 18(Blocken, Toparlar, & Andrianne, 2018)

up to 40% (Blocken, Toparlar, & Andrianne, 2018). Studies of two pelotons of 121 cyclists each found that the average drag for cyclists in dense and sparse pelotons was 21.1% and 21.9% of that of an isolated rider, respectively. This demonstrates the substantial aerodynamic benefits of riding within a peloton (Blocken et al., 2018). In comparison, the average drag in large pelotons is significantly lower than that in extended pacelines, which is slightly above 40%, highlighting the superior aerodynamic efficiency of pelotons (Blocken et al., 2018). The aerodynamic benefit of the peloton is crucial in long races like the Tour de France. Cyclists save energy for the moments when it matters most by keeping tucked into the peloton, where the air resistance is only a fraction of that faced by the leading riders. It's a strategy that requires a great deal of skill and co-ordination to maintain both stability and efficiency and can end in a pile-up just as easily. Strong teams often control the peloton, setting the pace and protecting lead riders. This tactic allows star riders to conserve energy for decisive moments, influencing race outcomes (Blocken et al., 2018).

Another important factor in cycling aerodynamics is team dynamics, particularly the peloton formation. The peloton is the main group of riders in a road bicycle race, who ride in a group to minimise air resistance and save energy. Cyclists take turns riding at the front (where air resistance is the largest), and then rotate to the back or middle to recover. Riding in the middle of a well-developed peloton can reduce drag by

The Historical Development of Aerodynamic Techniques in Cycling

The development of aerodynamic techniques in cycling has a rich history, marked by continuous innovation and refinement. Early advancements focused on simple changes such as rider positioning and clothing. For example, the use of skin suits and teardrop helmets in the 1980s represented another major step forward in drag reduction (Crouch et al, 2017). In the 1990s, wind tunnel testing became a fundamental tool to optimise cycling aerodynamics. Wind tunnel testing allowed cyclists and engineers to conduct trials to measure various pieces of equipment and body positions. This provided more accurate methods to measure drag and airflow around the cyclist. This period also witnessed the development of aerodynamic bike frames and components (designed to reduce air resistance). The use of computational fluid dynamics (CFD) further revolutionised the field in the 2000s. CFD simulations allowed researchers to study the airflow characteristics by analysing the airflow around the cyclist and the equipment used. As an example, in the study conducted by Brown et al (2023), CFD was used to compare various aerodynamic setups – from the bike used to the riders' positions – to determine which designs were more efficient. Lately, we have seen teams like the INEOS Grenadiers willingly embrace the concept of marginal gains (enhancements to overall performance that seem small but accumulate to have an overall effect), where teams are optimising the aerodynamics of the bike down to the tiniest detail. This includes not only the equipment used but also the positioning of the rider. This approach, as is evident from their success in winning the Tour de France, appears to be a step in the right direction. The historical development of aerodynamic cycling techniques clearly shows the trend of constant improvement. With every innovation, the techniques become more refined to allow for further optimisation of the rider's motion that leads to reduced drag. And as technology continues to advance, it appears to be an exciting time for the future of cycling aerodynamics, where the possibilities for optimising speed and efficiency are limitless.

Comparing Traditional and Modern Aerodynamic Techniques in Cycling

The evolution of aerodynamic techniques in cycling spans from simple adjustments to advanced technological innovations. Traditional techniques primarily focused on rider positioning and basic equipment modifications. For instance, early aerodynamics in cycling involved adopting a more tucked posture and using streamlined clothing like skin suits and teardrop helmets (Crouch et al., 2017). In contrast, modern aerodynamic techniques leverage advanced technology such as wind tunnel testing and computational fluid dynamics (CFD). These tools allow for precise measurement and optimization of aerodynamic properties. Wind tunnel tests provide real-world data on how air flows over the cyclist and equipment, enabling refinements in design. CFD simulations, as used by van Druenen and Blocken (2024), offer detailed insights into airflow patterns and drag forces, facilitating the development of more aerodynamically efficient equipment and positions. The benefits of these modern techniques are evident in performance metrics. For example, the introduction of aerodynamic frames, deep-section wheels, and integrated handlebars has significantly reduced drag, translating to faster speeds and improved efficiency. Kyle and Burke (2024) highlight that these advancements, supported by extensive testing, have led to notable improvements in race performance. Comparatively, modern aerodynamic techniques offer more substantial and measurable gains than traditional methods. These techniques underpinned a few modern approaches but, only through technology was cycling aerodynamics truly able to drive performance.



(Rogers)



(Smale)

Maurice Garin won the very first Tour de France in 1903; the second to last, Tadej Pogačar, in 2024. The bicycle for the 2024 winner of the Tour is no different in principle to the one from 1903. Yet, by exploiting modern technology to optimise every aspect of its form and function, the bicycle has been transformed from a little more than a device to take the rider from point A to point B, into something that can take a human-powered vehicle to speeds beyond what could have been imagined back in the 19th century. The bicycle that Garin rode in his victory was made from steel tubing, lacked modern materials, gearing and ride comfort, and was not aerodynamically optimised. Today's carbon-fibre frames, integrated components and drivetrain have been engineered using wind tunnel testing and computational fluid dynamics (CFD) to minimise energy losses due to drag and maximise efficiency. Technology has revolutionised cycling. The drive to eke out marginal gains at each point of contact is the leitmotif of modern competitive cycling.

Analyzing Changes in Cyclists' Equipment for Improved Aerodynamics

The evolution of cycling equipment is one of the main factors contributing to ever-improving aerodynamics. Simple streamlining was one of the earliest developments in equipment, and it has since evolved into highly sophisticated design, taking in new materials and manufacturing processes to reduce drag.

Frames and Wheels: Modern frames and wheels with deep-section shapes are designed to reduce drag by controlling airflow around the bike. These components are designed by testing in wind tunnels and refining with CFD. As Kyle and Burke (2024) point out, such improvements have resulted in a measurable reduction in the drag coefficient.

Helmets and Clothing: Smoothing of airflow around the body is maximised using aerodynamic helmets and skin suits. These innovations involve low-air-resistance materials and tight fits. Innovations in helmets and clothing have measurably improved speeds and efficiency Crouch et al. (2017).

Advances in material science have allowed the design of light and aerodynamic components. High-strength, low-weight materials such as carbon fibre are used in frames and wheels, since aerodynamic efficiencies and weight have a synergistic effect on cycling performance. Historical data and case studies indicate that cyclists using the most aerodynamically efficient equipment performed better, especially in time-trials and flat stages, where aerodynamics is more important. This reflects a general trend towards the introduction of technology and engineering principles in sports equipment design, leading to a continuous improvement in performance.

Examining the Effects of Clothing on Cyclists' Aerodynamic

Performance

A rider's attire is an important aspect of his or her aerodynamic performance. The skin suits that have become de rigueur in modern cycling are designed to cling tightly to the body and to use materials that minimise air resistance, often with dimpled fabric or other texture that helps to make the air flow more smoothly and less turbulent. Recent studies have shown that the aerodynamic benefits of optimized cycling clothing can lead to substantial performance improvements (Barry et al., 2021). The materials used in aerodynamic clothing are chosen for their low drag properties. Lightweight, breathable fabrics that conform closely to the body are preferred. The design often includes features like seamless construction and strategically placed panels to optimize airflow. Research by Barry, Burton, Sheridan, and Thompson (2021) demonstrated that skin suits could lower drag coefficients and improve speed, especially in time trials and flat stages. This reduced drag results in higher speeds using the same power output, giving athletes a performance advantage. So much so, that aerodynamic clothing is now standard across all levels of professional cycling. Teams invest significant resources in developing and testing new apparel designs, often in collaboration with manufacturers or researchers who can employ sophisticated testing to fine-tune design features. The result is that cyclists using the latest available apparel designs can post faster times in competition than those who don't.

Aerodynamic Limitations in the Tour De France

The aerodynamic rules of the Tour de France, set by the UCI Technical Regulations, help to determine race tactics and results, notably regarding the peloton and drafting. Decreasing a cyclist's exposure to wind and hence reducing drag, those riding in a peloton can reduce their energy expenditure by up to 40 per cent compared with riding alone. The technical regulations provide clear guidance to manufacturers, establishing the dimensions and shapes of bicycle frames, the positioning of handlebars, and the overall configuration of the bicycle, so that manufacturers cannot simply optimise their equipment for aerodynamic advantage. These regulations are designed to prevent greater disparities in performance and safety, and to equalise the impact of equipment on aerodynamic advantages among competing cyclists.

Helmets for example, can't be made too pointy or fitted with too many spoilers, aero bars are forbidden, and skin suits cannot be overly skintight. Just as the peloton and drafting are important for the management of energy-expenditure and the way a race plays out, the UCI's technical regulations keep technological innovation in check, and therefore keep the Tour de France competitive and safe from excessive technological advantage. Moreover, research has shown that the collective behavior of the peloton is also governed by visual and sensory factors. Riders need to maintain a clear line of sight and react to the movements of those around them, which can sometimes lead to suboptimal aerodynamic positions. This suggests that while aerodynamics is crucial, it is not the only factor influencing the formation and behavior of the peloton.

Conclusion

This paper examines how the use of aerodynamics in bicycle design has evolved into a critical area of performance in the Tour de France. Utilising a mixed-method approach consisting of a literature review, quantitative analysis of data, interviews with experts, and modelling, the author shows the evolution of aerodynamic techniques and their practical applications in professional cycling. It shows that modern aerodynamic improvements (e.g., improved clothing, bike design and riders' positioning) can result in quantifiable gains in performance. These improvements are essential to achieve all potential marginal gains and may further influence the future development of cycling strategies and equipment. Overall, the paper provides useful findings that can be used to develop new materials, design wheels more effectively, and further optimise bicycle constructions, thus allowing professional cyclists to achieve enhanced aerodynamic performance, optimise their racing strategies and be more competitive.

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Works Cited

1. Ansys. "Using Ansys Fluent for CFD Simulation of a Peloton Reveals Complex Aerodynamics." YouTube, 24 July 2018, www.youtube.com/watch?v=kZBh-fpv2sY.
2. Barry, N., Burton, D., Sheridan, J., Thompson, M., Brown, N.A. Aerodynamic performance and riding posture in road cycling and triathlon. Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology. 2015;229(1):28-38. doi:10.1177/1754337114549876.
3. Blocken, Bert, et al. "Aerodynamic Drag in Cycling Team Time Trials." Journal of Wind Engineering and Industrial Aerodynamics, vol. 182, 2018, pp. 128-145. ScienceDirect, <https://doi.org/10.1016/j.jweia.2018.09.015>.
4. Brown, Christopher, et al. "The Influence of Turbulence on Cycling Aerodynamics." Journal of Wind Engineering and Industrial Aerodynamics, vol. 242, 2023, pp. 105575-, <https://doi.org/10.1016/j.jweia.2023.105575>.
5. Chowdhury, H., Alam, F., Mainwaring, D., Subic, A., Tate, M., Forster, D., and Beneyto-Ferre, J. (2009), Design and methodology for evaluating aerodynamic characteristics of sports textiles. Sports Technol., 2: 81-86. <https://doi.org/10.1002/jst.92>.
6. Churazova, Anastasia. "Aerodynamics of Cycling Explained through CFD." SimScale, 4 July 2017, www.simscale.com/blog/cycling-aerodynamics/.
7. Crouch, Timothy N., et al. 'Riding against the wind: a review of competition cycling aerodynamics ...' Springer, 4 May 2017, link.springer.com/article/10.1007/s12283-017-0234-1.

8. Defraeye, Thijs, et al. "Aerodynamic Study of Different Cyclist Positions: CFD Analysis and Full-Scale Wind-Tunnel Tests." *Journal of Biomechanics*, vol. 43, no. 7, 2010, pp. 1262-1268. ScienceDirect, <https://doi.org/10.1016/j.jbiomech.2010.01.025>.
9. Eclipse. "The Organization as a Cycling Peloton." Dan Pontefract, 23 Apr. 2013, www.danpontefract.com/the-organization-as-a-cycling-peloton/.
10. Hong, Sungchan, and Takeshi Asai. "Aerodynamics of Cycling Skinsuits Focused on the Surface Shape of the Arms." *Applied Sciences*, vol. 11, no. 5, Mar. 2021, p. 2200, <https://doi.org/10.3390/app11052200>.
11. International Cycling Union. *CLARIFICATION GUIDE of the UCI TECHNICAL REGULATION*.
https://assets.ctfassets.net/76117gh5x5an/36HocrJva5dgK9VloO9GVN/735d545b76a1e4436969abb8d1633d11/Clarification_Guide_of_the_UCI_Technical_Regulation_-_20240401_-_ENG.pdf
12. Kyle, Chester R., and Edmund R. Burke. 'The understanding and development of cycling aerodynamics.' ResearchGate, 27 Mar. 2024, www.researchgate.net/publication/225161766_The_understanding_and_development_of_cycling_aerodynamics.
13. Mao, Jiaqi, et al. "The Influence of Crosswinds and Leg Positions on Cycling Aerodynamics." *Experiments in Fluids*, vol. 65, no. 6, Springer Science+Business Media, May 2024, <https://doi.org/10.1007/s00348-024-03823-y>.
14. Rogers, Simon. "Every Tour de France Winner Listed from Garin to Wiggins." *The Guardian*, 23 July 2012, www.theguardian.com/news/datablog/2012/jul/23/tour-de-france-winner-list-garin-wiggins.

15. Smale, Simon. "Is Tadej Pogačar the Greatest? Even He Has to Answer Uncomfortable Questions." ABC News, 21 July 2024, www.abc.net.au/news/2024-07-22/tadej-pogacar-the-great-tour-de-france/104124050.
16. Thijs van Druenen, and Bert Blocken. "CFD Simulations of Cyclist Aerodynamics: Impact of Computational Parameters." Journal of Wind Engineering and Industrial Aerodynamics, vol. 249, Elsevier BV, June 2024, pp. 105714–14, <https://doi.org/10.1016/j.jweia.2024.105714>.
17. Wang, Shibo & Pitman, John & Brown, Christopher & Smith, Daniel & Crouch, Timothy & Thompson, Mark & Burton, David. (2021). The Influence of the Inter-Relationship of Leg Position and Riding Posture on Cycling Aerodynamics. Fluids. 7. 18. 10.3390/fluids7010018.
18. Yeager, Selene. 'Aerodynamic Cycling: The Ultimate Guide to All Things Aero.' Bicycling.com, 13 Apr. 2022, www.bicycling.com/skills-tips/a22107504/aerodynamic-definition-in-cycling/