

The 2009 Formula 1 Double Diffuser: Aerodynamics, Regulation and Championship Impact

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Abstract: In 2009, Formula 1's governing body, Fédération Internationale de l'Automobile (FIA), rewrote its technical regulations in a bid to reduce downforce. One of the components affected by this was the rear diffuser of the car, which is a vital component creating downforce. Brawn GP, Toyota and Williams race teams found and exploited a regulatory loophole that allowed them to add a second airflow path above the primary channel. While conforming to the FIA's diffuser dimensions, the diffuser was able to create additional downforce. This paper will address how the diffuser exploited the regulatory loophole that allowed it to continue, and how it impacted the 2009 championship. It will explain the aerodynamic ideas behind the diffuser and use published wind tunnel and computational fluid dynamics (CFD) research on diffusers to explain why it was effective. It will then expand on the controversy through the protest from the other teams, the FIA mid-season decision, and a rush for all the other teams to follow suit. Using the 2009 Drivers Championship Standings, this paper will demonstrate how Brawn GP's early-season success using the modified diffuser led to Jenson Button winning the Drivers Championship. Finally, this paper will look at the FIA's response to the loophole in 2011 and how they rewrote the rules without outright banning the diffuser, and how it led us to the present-day aerodynamic innovation in Formula 1.

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I. INTRODUCTION

The FIA released a new set of technical regulations in a bid to reduce the aerodynamic downforce generated by the rear diffuser in 2009. The diffuser played a key role in producing a significant portion of the car's downforce and overall traction throughout the circuit. The new rules were put in place to slow down the cars after the past few years had made the diffuser even more complex every season. However, three teams (Brawn GP, Toyota, and Williams) discovered a loophole in the regulations that allowed them to build a "double diffuser": a two-chamber design stacked on one another that produced significantly more downforce than the FIA intended. This design became one of the biggest engineering loopholes in all of Formula 1's history as it led to a team that was facing a financial crisis winning a world championship. The principles of fluid dynamics that made the double diffuser effective, the subsequent changes in regulations, the controversy and litigation led by the other teams, and how it affects how the FIA writes its technical rules to this date will be discussed.

➤ The Function and Regulation of the Diffuser

A diffuser is an aerodynamic section of a Formula 1 car's underbody which is positioned behind the rear axle. Its main purpose is to manage the fast-moving air flowing underneath the car and to seamlessly join it back to normal

atmospheric pressure without causing separation between the airflow and the body of the car. As air moves underneath the flat underbody, it is forced through the narrow opening between the underbody and the track (30 to 50mm). According to the equation of continuity in fluid mechanics, $A_1 v_1 = A_2 v_2$, when a fluid passes into a narrowing passage, its velocity increases, and according to

Bernoulli's principle, when there is an increase in the speed of a fluid, there is a decrease in pressure. This change in pressure between the low-pressure air system beneath the car and the higher atmospheric pressure is what generates downforce and acts like a suction, pushing the car into the track and allowing the car to have better traction on the track throughout the circuit. A 2020 computational fluid dynamics study of a 2017 F1 car found that the underbody, comprised of the floor, the plank and the diffuser, was responsible for roughly 60 percent of the car's total downforce. This made it the largest margin of a single aerodynamic region of the vehicle (Fig. 1) (Guerrero & Castilla, 2020).

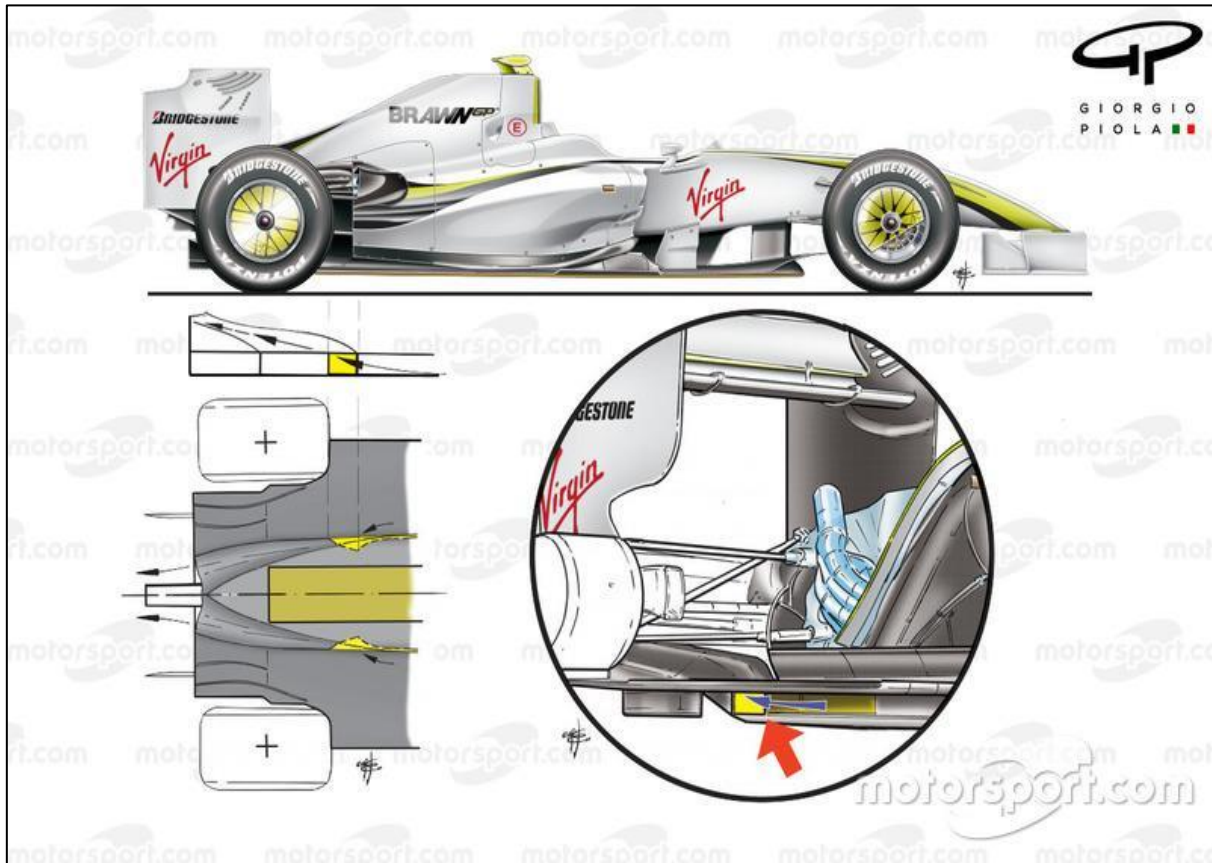


Fig 1 Technical Illustration of the Brawn GP BGP 001 Showing the Rear Diffuser and Surrounding Underbody Aerodynamic Components. The Illustration Provides Multiple Views of the Diffuser's Location And Geometry.

Source: Motorsport.Com / Giorgio Piola

The diffuser's main role is to manage the low-pressure air once it reaches the rear of the car. If the underbody airflow were to be released without a smooth transition, it would separate from the surface of the vehicle and form turbulence and would destroy the difference in pressure created. Instead, the diffuser will gradually expand as it moves further toward the rear of the car, which in turn will lead to the velocity of the air moving to decrease and return to atmospheric pressure in a controlled manner. However, the size of the diffuser needs to be properly designed: if the ramp angle is too steep, it will cause the speed of airflow to be disrupted, and the air will separate from the surface too early, causing the diffuser to not work as intended, similar to an airplane stalling when its wings are angled too high. A 2018 review on the ground effect diffuser aerodynamics demonstrated that the performance of a diffuser is highly impacted by the ride height and the ramp angle (Whirim, Knowles & Saddington, 2018). Formula 1 engineers must thus balance diffuser height, length, and ramp angle to minimize the risk of a break in the surface and to maximize the low-pressure effect created.

Because the diffuser makes up a large portion of the car's overall downforce, the FIA has always placed very tight restrictions on the dimensions. Regulations usually put a maximum height on the diffuser so that it can only reach above a certain reference point on the car's underbody and the point along the car's length from where it is allowed to begin. The two variables, the starting point of the diffuser and

maximum height, directly control the downforce it can generate. The FIA limited this to control how much downforce could be generated from one component, the underbody, and thereby modify performance.

➤ 2009 Regulation Change and Loophole

The FIA rewrote the technical regulations in 2009 to reduce overall downforce to encourage more competitive racing by bringing the field closer together. The front and rear wings were simplified while the diffuser was moved further back and up on the car. This restricted its height and the position of the sloped surfaces in the central section between the rear crash-structure mounting points. It was intended to cap the downforce that any team could generate from this area.

However, the regulations did not account for every possible geometrical configuration and defined the restricted area using a reference plane and measurement points. Engineers at Brawn GP, Toyota and Williams realized that the rules only restricted the height of the diffuser when measured from the reference points but did not rule that a secondary channel above the main diffuser was allowed. Because the second channel was above the height reference point, it was not in the restricted area even though it increased the diffuser's size, which was what the FIA was trying to prevent with the regulation change (Fig. 2).

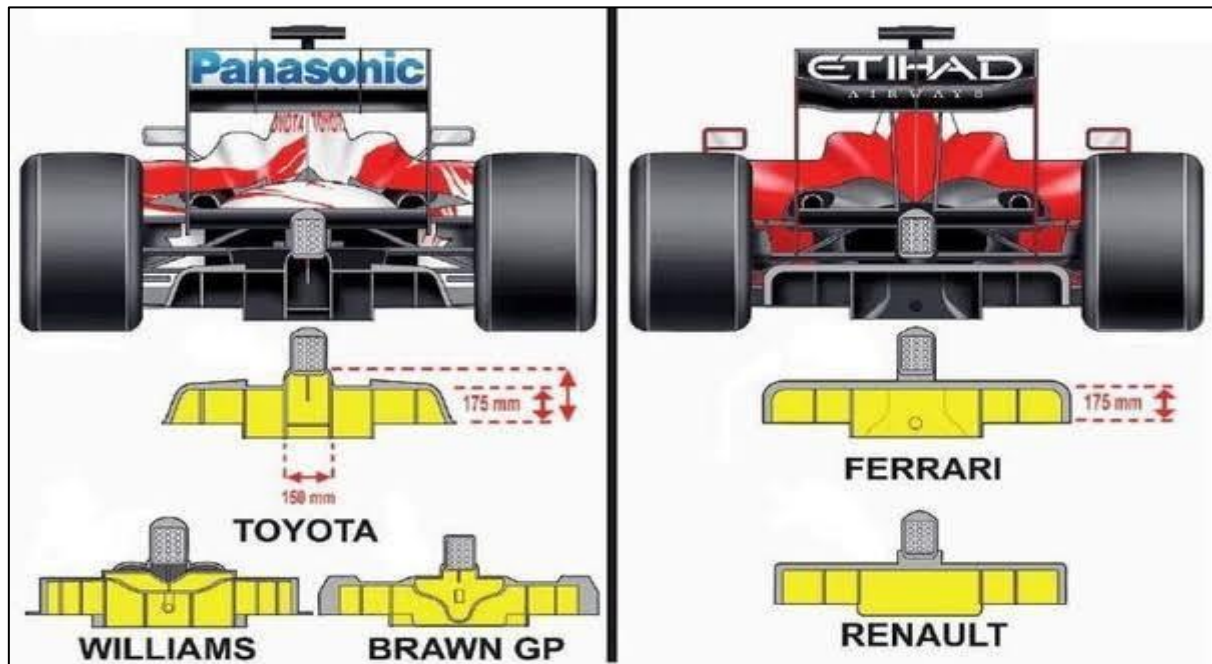


Fig 2 Comparison of Rear Diffuser Geometries Used by Formula 1 Teams During the 2009 Season. The Different Configurations Illustrate how Teams Interpreted the FIA's Dimensional Restrictions on Diffuser Height and Geometry.

Source: Formula One Simplified (2011)

The double diffuser works by creating another flow path that takes additional air from the upper body and guides it through another slot near the rear crash structure into an existing diffuser tunnel. The second airflow increases the total amount of air moving through the diffuser and increases the expansion ratio without, crucially, exceeding the maximum height. In the end, the engineers were able to achieve a larger and more gradual expansion when compared to a single-tier diffuser used by the other teams and therefore create more downforce from the same underbody area. The three teams (Brawn GP, Toyota, and Williams) that started the season with this design gained a higher rear downforce advantage over their competitors, which led to higher cornering speeds in high- and medium-speed corners where the downforce of the car is the most critical.

➤ Controversy and Legal Ramifications

The double diffuser system was recognized very early, with its advantage over the single-tiered diffuser being noticeable even during pre-season testing. Within days of the three teams with the double diffuser unveiling their cars, seven other teams contacted the FIA regarding the diffuser regulations. During the season opener at the Australian Grand Prix, an official complaint was lodged against the double diffuser, saying that the design did not conform to the technical regulations.

The FIA examined and ruled the cars legal, which made the seven teams who protested escalate their challenge to the FIA's International Court of Appeal. The case went before the court during the third round of the season, the Chinese Grand Prix, and on April 14, 2009, a ruling was made that the double diffuser conformed to the regulations (BBC Sport, 2009). This ended the legal fight but led to other teams that had previously not used the design to develop their own

versions as quickly as possible, knowing that without the double diffuser meant that they were at a disadvantage. Though most of the teams had developed their own version of the double diffuser, Brawn GP, Toyota, and Williams had already had a major head start toward the championship.

➤ Impact on the Championship

Brawn GP had the most to gain from the double diffuser. Brawn GP only had weeks before the season began to develop the diffuser after Honda withdrew from Formula 1 due to the global financial crisis. Operating on a tight budget compared to the rival teams, Brawn GP was not widely expected to be competitive. However, the team won the first race with Jenson Button and Rubens Barrichello coming in a one-two finish in Australia. Jenson Button went on to win six out of the first seven races in the season.

The scale of the early head start in championship points was decisive (Fig. 3). Button's points across the 2009 season were ahead of his closest rival and second in the standings, Sebastian Vettel in the Red Bull. By the end of round seven, Button had a huge advantage that was built primarily from the opening few races of the season before the other rivals developed their own double-diffuser system. As those developments were put in the rival cars, the championship gap closed up. Vettel and Red Bull won eight of the remaining ten races. It led to a title fight that was not resolved until the penultimate round in Brazil. Button's early-season advantage proved to be decisive in the drivers' championship as the gap built was ultimately larger than possible for Vettel and Red Bull. Button won the World Drivers' Championship with 95 points to Vettel's 84, and Brawn GP won the Constructors' Championship in the only season they competed before being bought by Mercedes in 2010.

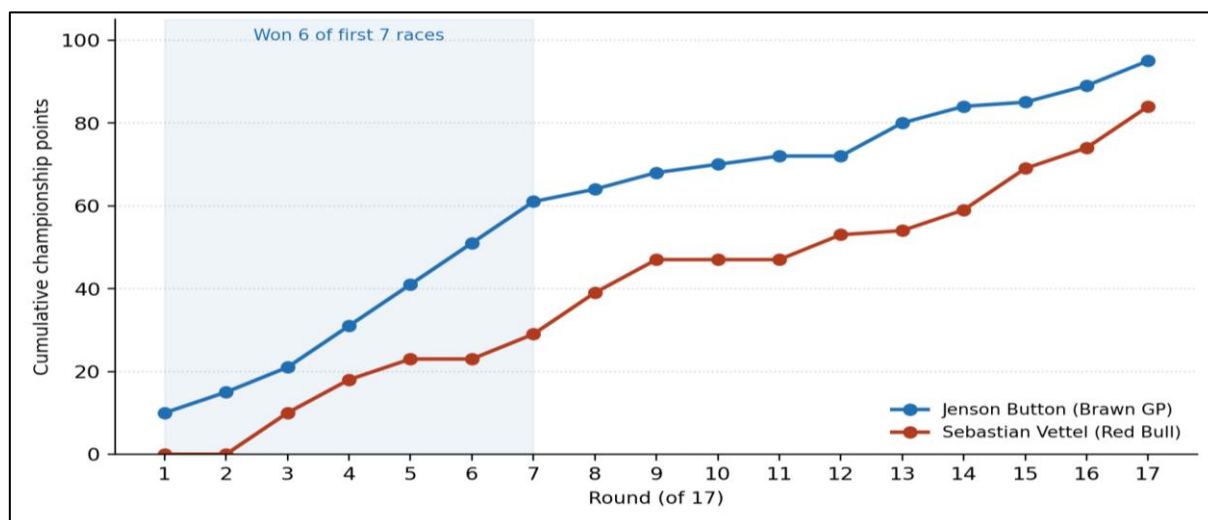


Fig 3 Cumulative Formula 1 Drivers' Championship Points for Jenson Button and Sebastian Vettel Across the 2009 Season. Button's Decisive Lead was Built Almost Entirely in the Double-Diffuser-Powered Opening Stretch of the Season, Before Rival Teams Had Caught Up with their Own Versions of the Design.

The additional rear downforce from the double diffuser also improved traction and stability under acceleration out of corners, which reduced tire degradation over a race distance, allowing Brawn to convert their qualifying pace to race results.

II. LIMITATIONS

It is difficult to say that the exact contribution to Brawn GP's performance in the championship is solely from the double diffuser. Many factors influence performance, like the chassis, tires, driver, car reliability, and many others. This championship series underscores a strong relationship between the success of Brawn GP and the double diffuser advantage, but it cannot solely prove that the diffuser alone caused the championship victory.

➤ Aftermath

Following the 2011 season, the FIA closed the loophole. They rewrote the measurement rules, redefining the reference plane and the restricted area so that a secondary channel cannot be added and still adhere to the regulations. The FIA targeted fixing the uncertainty surrounding the rules of the diffuser rather than trying to stop the double diffuser altogether, which would have been much harder to enforce.

The double diffuser is a clear example of recurring changes made in the regulations. Formula 1 teams work to find any advantages that are available within the rules, and because the regulations are so precise, small loopholes in the rules are bound to be discovered and exploited by engineers. The FIA will then respond by rewriting the specific regulation that allowed such a thing to happen. The development of aerodynamic innovation and rule changes defines how the sport's technical regulations evolve.

III. CONCLUSION

The double diffuser is a very simple application of fluid dynamics: adding a secondary airflow channel leads to a greater diffuser expansion ratio without exceeding the height restriction. Brawn GP, Toyota, and Williams were able to make the most use out of the FIA's 2009 regulations regarding the diffuser. The protest, legal process, and mid-season scramble to follow the double diffuser made it one of the closest championships with engineering controversies in the sport. Brawn GP, an underdog, was able to win an unlikely championship through this. Beyond the 2009 championship, this event shows us how technical regulations are effective only based on the precision of the regulation, and any ambiguity left eventually will be found.

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