

CFD Investigation and Performance Analysis of the F1 Drag Reduction System (DRS) in a Hybrid Powertrain Context

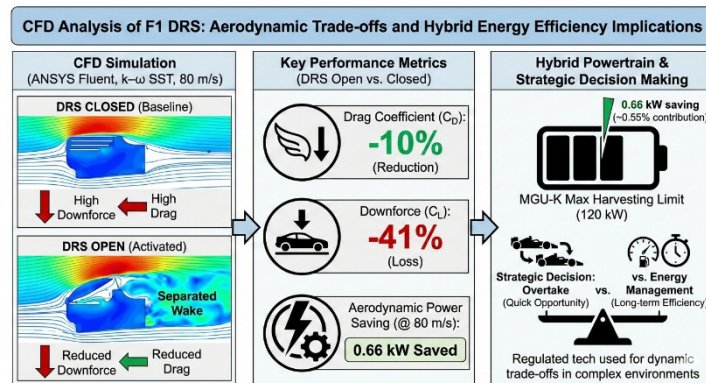
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Abstract

This study looks into the Computational Fluid Dynamics (CFD) of Formula 1's Drag Reduction System (DRS) and how it relates to hybrid powertrain energy recovery. A representative Formula 1 rear wing was modeled according to current FIA regulations and simulated in ANSYS Fluent at 80 m/s using steady, incompressible RANS equations with the $k-\omega$ SST turbulence model. The findings show that when DRS is activated, the drag coefficient drops by 10%. However, this comes at the cost of losing 41% of downforce. Our flow visualizations illustrate a shift from attached flow to separated wake structures during DRS deployment. Notably, the reduction in aerodynamic drag yields a measurable reduction in aerodynamic power demand with implications for hybrid energy efficiency. This highlights a specific but valuable efficiency gain. We validated our methodology by comparing our results with existing experimental and numerical studies, which also align with what's already published. On top of that, Industrial Engineering and Operations Management (IEOM) principles were applied to interpret DRS deployment as a constrained operational decision problem. We framed DRS and used as a strategic decision-making process that weighs quick overtaking chances against long-term energy savings. This cross-disciplinary approach sheds light on how regulated tech changes can boost efficiency in complex, fast-paced environments like Formula 1 racing.



Keywords

Aerodynamics, Drag Reduction, Formula 1, Computational Fluid Dynamics, Hybrid Powertrain, Energy Recovery.

1. Introduction

Formula 1 is the pinnacle of motorsport technology where milliseconds decide victory and performance optimization is pursued relentlessly. Central to this pursuit has been an underlying engineering trade-off-aerodynamic downforce for cornering speed versus the drag it creates on straights (Katz, 2006a). This basic technical challenge reverberates well outside the vehicle design and into the core of the sport. For many years, the aerodynamic "dirty air" or wake



Figure 1. Comparative illustration of a Formula 1 rear wing, (a) DRS on and (b) DRS off.

produced by a leading car severely degraded a following car's downforce that produce an "overtaking deficit" (Figure 1- Figure 5). This is significant enough to stifle wheel to wheel racing and reduce strategic variability (Belkovic & Takács, 2023). The FIA responded to this operational and spectacle-based challenge through the implementation of a driver adjustable aerodynamics system named The Drag Reduction system or DRS in 2011. Under the strict sporting code issued by the FIA (2023), the DRS was designed to rectify the overtaking deficit in order to make the racing more competitive. DRS works when a chasing car is allowed to reduce its drag in specifically defined zones. Since its introduction, the mechanism has become the centerpiece of f1 race strategy with driver tactics and race dynamics. The motivation for this research lies in the fact that the DRS should be analyzed not as a new aerodynamic component itself but as an integrated system within a high-stakes operational environment. While its function from the aerodynamic point of view is well documented in specialized literature related to motorsport, there is a critical lacuna in evidence from an IEOM perspective. Principles related to IEOM, such as systems design, performance optimization and process efficiency, form a special and valuable framework by which the true impact of DRS on the "production system" of a Grand Prix can be understood. Secondly, the change to ground-effect aerodynamics in 2022 has driven discussions about the need for such systems in the future (Toet, 2013).

This paper thus delivers a systematic study of the DRS with filling the gap between high-performance engineering and the principles of IEOM. This study is necessary because it provides a structured analysis regarding how a regulated technological intervention can be deployed in order to enhance the efficiency and output of a complex, dynamic systems.

Therefore, it offers:

- a) Conduct CFD simulations to quantify DRS aerodynamic trade-offs (Drag vs. Downforce).
- b) Calculate energy recovery potential for hybrid powertrains.
- c) Apply IEOM principles to analyze strategic deployment decisions.

2. Literature Review

The Drag Reduction System lies at the crossroad of modern aerodynamics with regulatory frameworks and competitive tactics. The section examines all current literature like aerodynamics of overtaking, DRS development and diverse effect highlighting the particular research gap this paper seeks to fill.

2.1 The Aerodynamic Challenge of Overtaking

The fundamental problem that DRS as designed to solve is well documented in automotive aerodynamics literature. The generation of downforce is achieved by managing the air pressure around the vehicle. But this process inherently creates a turbulent wake known as “Dirty air”. Newbon et al. (2017) provides a foundational analysis of how these wakes severely degrade the aerodynamic performance of a following car along with its downforce by a significant margin and creating an “Overtaking deficit”. This phenomenon first recognized by the (L'Automobile, 2017) and their conducted research quantified the performance loss for a trailing car, cementing the need for a regulatory intervention to improve the spectacle of sport. The core aerodynamic trade-off between the downforce and drag first detailed by Katz (2006a) which later used as the center factor of race dynamics.

2.2 The Genesis and Evolution of the DRS

In response to counter aerodynamic challenges, the FIA introduced the Drag Reduction System as a movable aerodynamic device. As Falkborn and Hasselgren (2024) explains, DRS is essentially a rear wing flap that drivers can control, operated hydraulically. According to the 2023 sporting regulations set by FIA, it's only allowed in the specific zones and only if a driver is within one second of the car ahead. Azmi et al. (2017) notes that although DRS started out as a pretty blunt solution, its careful integration into the rules has turned it into a smart part of race strategy with affecting everything from qualifying laps to how drivers manage their tires throughout a race.

2.3 Performance Impact and Strategic Consequences

DRS provides a clear and measurable boost that gives every car extra 10-15 km/h on the straights (Kulkarni et al., 2022). But it's not all straightforward. One downside is the so-called “DRS train,” where several cars in a row all get to use DRS. This system cancels out the advantages and makes everything just as tough. This situation is a kind of waiting in the line, the chance to pass depends on where you are on the queue. While this idea hasn't been studied in detailed yet, it comes up a lot in race commentary and technical discussions.

2.4 The Role of Computational Analysis

Building and understanding these advanced aerodynamic systems wouldn't be possible without Computational Fluid Dynamics (CFD). The work of Monteiro (2021) establishes CFD as an indispensable tool for visualizing flow structures and quantifying forces like drag and downforce. With today's technology, CFD simulations can even show what happens when the DRS opens. It also captures the switch in airflow and helping teams fine-tune their designs before anything hits the track.

There is a critical gap in the quantitative synthesis of DRS aerodynamics. While its strategic impact is documented, literature lacks a consolidated framework using CFD to directly link flow physics, drag and downforce coefficients to performance metrics. This paper addresses this by integrating simulation data to bridge qualitative description and quantitative prediction of DRS efficacy (Table 1).

Table 1. Overview of Major Formula 1 Drag Reduction System (DRS) Studies

Control/Deployment	Methodology	DRS Effect on Drag	DRS Effect on Downforce	Key Insights	Source
Actuated trailing edge flaps	Experimental (multi-wing)	Up to 83% reduction	Moderate decrease	Retains balance by applying DRS to front/rear wings	(Wordley et al., 2014)
Fixed vs. rotated wing models	CFD & Mass Point Sim.	42.5% reduction	24.5% decrease	Lap time - 0.06%; energy use -16%	(Estellés Calderón, 2023)
ECU; manual & auto modes	CFD & prototype testing	~5–7 km/h extra speed	Lower downforce in DRS mode	Flap actuation config impacts balance	(Garcia-del-Barrio & Reade, 2022)
Driver-activated flap	Diffuser angle variation	10–15 km/h faster	Downforce only on corners	Effectiveness varies by track and car	(Toet, 2013)
Full design approach	CFD estimation	Significant reduction	Modeled force losses	Focus on CFD-driven optimization	(Dimastrogiovanni et al., 2020)

3. Methodology

This paper is grounded in quantitative, reproducible numerical analysis that demonstrates and quantifies the aerodynamics principles underlying the Drag Reduction System (DRS) in formula 1 applications. The methodology follows industry best practices in computational fluid dynamics literature and adopts the structured workflow typical of high impact aerodynamic research. This study follows a structured Computational Fluid Dynamics (CFD) workflow to evaluate the aerodynamic behavior of a Formula 1 rear-wing Drag Reduction System (DRS). The simulations were performed under steady, incompressible flow conditions using Ansys Fluent. A freestream velocity of 80 m/s was imposed with air modeled at a constant density of 1.225 kg/m³. A standardized rear-wing projected reference area of $A = 0.35 \text{ m}^2$ was adopted for aerodynamic coefficient calculation. The dynamic pressure was computed as $q = 3920 \text{ Pa}$. Based on a representative rear-wing chord length, the Reynolds number was approximately 1.47×10^6 . This ensures flow conditions representative of Formula-1-class aerodynamics. The methodology combines geometry definition, mesh generation, solver setup and coefficient extraction in accordance with established best practices for aerodynamic simulation.

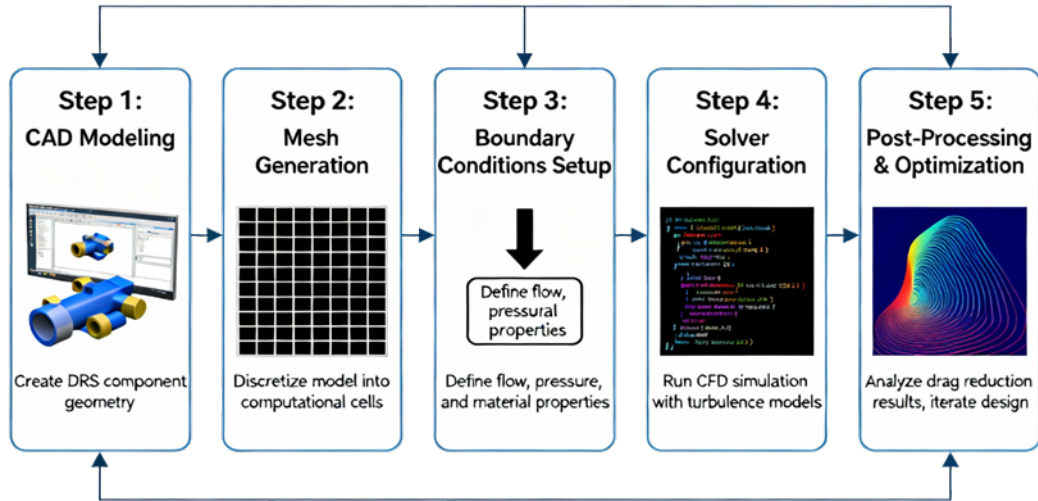


Figure 2. Flowchart of numerical methodology for DRS analysis

3.1 Geometric Modeling and DRS Configuration

A representative Formula 1 rear wing was designed according to current FIA technical regulations and published specifications. The model consisted of a mainplane and a single flap and both designed using the S1223 airfoil profile for aerodynamic validity and high lift characteristics, making it suitable for rear wing applications (Loução et al., 2022).

DRS-Closed Configuration: The flap was positioned at a 25° angle of attack relative to the mainplane, reflecting a high-downforce condition for cornering and braking.

DRS-Open Configuration: The flap was rotated to achieve a nearly continuous profile (0° effective angle of attack), representing the low-drag state used during straight-line acceleration (Brostow, 2008). Flap rotated to create an 85 mm opening. This configuration reduces the camber and pressure differential.

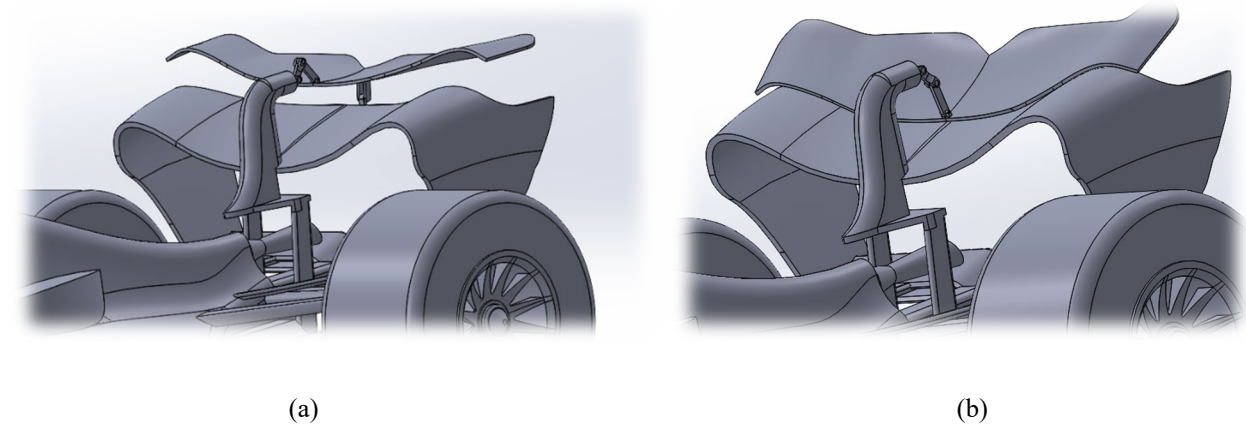


Figure 3. CAD Models of F1 Rear Wing Configurations, (a) DRS-Open and (b) DRS-Closed Prepared for Simulation.

All modeling was completed in SolidWorks 2025 Student Edition (Dassault Systèmes). First, it was exported as STEP format and then imported into Ansys Fluent for meshing. The full 3D assembly included appropriate endplates and was prepared for CFD mesh generation.

3.2 Computational Domain and Meshing

Flow simulations were carried out with Ansys Fluent 2024 R2 using a finite-volume solver for steady incompressible Reynolds-Averaged Navier-Stokes (RANS) equations. The $k-\omega$ SST turbulence model was selected for its superior performance in predicting vortex dominated separated flows. The computational domain represented a wind tunnel environment with inlet velocity 80 m/s with the air density 1.225 kg/m³. Mesh independence was evaluated to ensure grid convergence and robustness of results (Monteiro, 2021). The final simulation utilized a refined mesh consisting of 135,532 cells (Fluid cells) that ensures sufficient resolution to capture wake structures and force gradients. Boundary conditions and solver settings followed best practices from recent CFD based DRS studies.

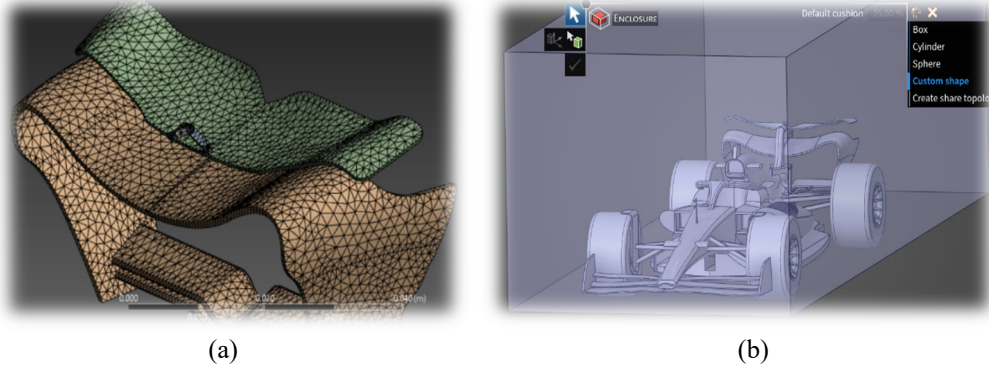


Figure 4. Computational domain and surface mesh for the rear wing assembly; (a) Detailed view of the unstructured surface mesh on the wing assembly, (b) Overview of the fluid domain created for CFD analysis.

3.3 Performance Quantification

Outcomes of the CFD analysis included aerodynamic force coefficients:

a) **Lift coefficient (C_L):**

$$a. C_L = \frac{F_{Lift}}{\frac{1}{2}\rho U_\infty^2 A}$$

b) **Drag coefficient (C_D):**

$$a. C_D = \frac{F_{Drag}}{\frac{1}{2}\rho U_\infty^2 A}$$

Where, F_{Lift} and F_{Drag} are the calculated forces, ρ is air density, U_∞ is freestream velocity and A is the wing reference area. The comparative change in these coefficients between DRS-open and DRS-closed settings forms the quantitative basis for the aerodynamic evaluation. Visualizations of pressure and velocity contours support the analysis and are integrated with existing literature for comprehensive interpretation in subsequent sections (Loução et al., 2022).

4. Results & Discussion

This section represents the findings from Computational Fluid Dynamics (CFD) analysis detailing the quantitative performance trade-offs and qualitative flow characteristics of the drag reduction system. The results provide empirical validation of the aerodynamic principle discussed in the literature review.

4.1 Quantitative Aerodynamic Performance

The lift and drag coefficient were directly calculated by the solver and used to compute the non-dimensional coefficients that provide a clear metric for performance comparisons between the two configurations. The results are summarized in Table 2.

Table 2. Aerodynamic forces and coefficients

Parameter	Drag Force (N)	Downforce (N)	Drag Coefficient (C_D)	Lift Coefficient (C_L)	Speed (m/s)	Reference Area (m ²)
DRS-Off	82.06	-44.64	0.060	-0.033	80	0.35
DRS-On	73.91	-26.31	0.054	-0.019	80	0.35
% Change			-10.0%	-41.0%		

The data in Table 2 confirms the primary function of DRS. Activation resulted in a substantial 10% reduction in the Drag coefficient (C_D) which directly correlates to the potential for increased straight-line velocity. Conversely, this benefit was accompanied by 41% loss in the lift coefficient (C_L) that cause significant downforce sacrifice. The moderate decrease in the Lift-to-Drag ratio indicates that while the wing's operating point shifts dramatically with maintaining its core efficiency in generating lift relative to drag. This quantified trade-off provides a numerical basis for the performance characteristics described in the literature (De SANTIS, 2023; López & García).

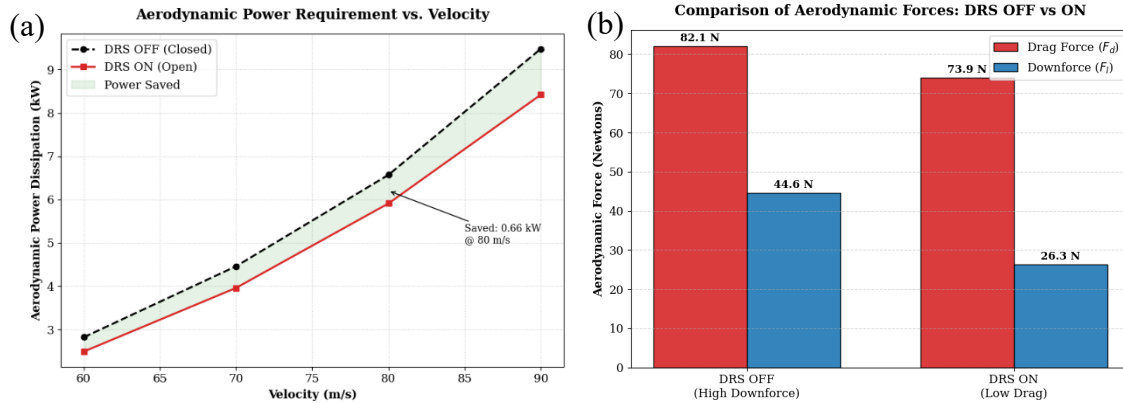


Figure 5. Aerodynamic and energetic performance of the DRS. (a) Comparison of drag and downforce loads at 80 m/s (b) Power dissipation vs. velocity.

The data in Figure 5(a) confirms the critical trade-off inherent in the DRS mechanism. At 80 m/s, deploying the system reduces drag by 9.9% (82.1 N to 73.9 N) but incurs a 41.0% loss in downforce (44.6 N to 26.3 N). This sharp reduction in vertical load validates that DRS usage is strictly limited to straight-line acceleration zones where stability is less critical than speed. Figure 5(b) translates these forces into energy demand. The aerodynamic power required to overcome drag at 80 m/s drops from 6.57 kW to 5.91 kW upon activation. This drop in drag means the hybrid engine doesn't have to work as hard to maintain speed when the DRS is open. In a race context, this reduction lowers the discharge rate of the Energy Store (ES). Also, it effectively reserves electrical energy for strategic deployment during overtaking maneuvers.

4.2 Flow Field Visualization Analysis

The flow field characteristics of the rear wing assembly were scrutinized to elucidate the physical mechanisms governing aerodynamic performance in DRS ON and OFF configurations. This analysis employed detailed visualizations including thermal analysis, velocity magnitude contours, iso-surface and path-lines. This analysis allows a comprehensive interpretation of airflow behavior across the wing surfaces and downstream wake.

4.2.1 Velocity and Path-line Analysis

The fundamental differences in flow behavior between the DRS-Off and DRS-On configurations are critically illustrated by the flow trajectories colored by local velocity magnitude which is presented in Figure 6.

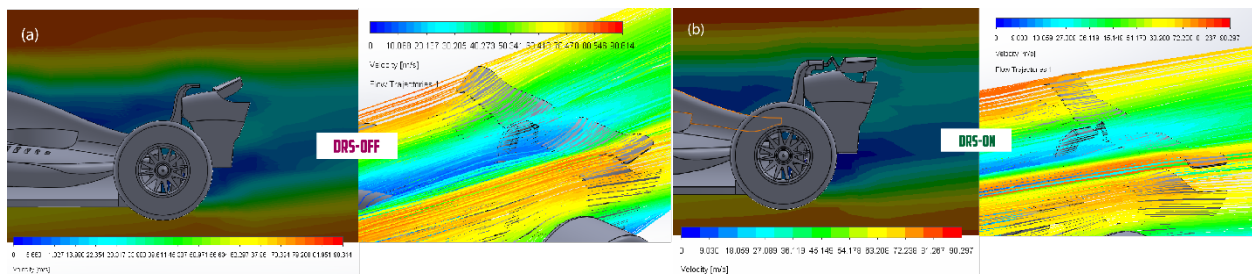


Figure 6. Comparative velocity magnitude (m/s) contours and path-lines: (a) DRS-Off configuration, (b) DRS-On configuration.

A direct comparison of the two states reveals a stark contrast in flow structure and energy. In the DRS-Off configuration (Fig. 6a), the flow trajectories demonstrate a highly organized and attached pattern. The path-line follow the contours of the multi-element wing that converge into a narrow and well-defined wake. The velocity field is characterized by a high energy core that has significant regions exceeding 80 m/s. Those regions indicate efficient acceleration of flow and the establishment of strong pressure gradients necessary for high downforce generation. Conversely, the DRS-On configuration (Fig. 6b) exhibits a flow field dominated by large-scale separation and energy loss. The path-lines immediately detach from the trailing edge of the main wing element which forms a wide, turbulent recirculation zone directly behind the wing. That causes a notable reduction in the extent of the high velocity regions with the maximum observed velocity in the wake dropping significantly. The expansion of the low-velocity wake (dominant red/yellow regions) provides direct visual evidence of the increased pressure drag and the breakdown of the efficient downforce-generating flow structure. This confirms the aerodynamic mechanism behind the performance trade-off quantified in the section 4.1.

4.2.2 Three-Dimensional Wake Structure Analysis

The three-dimensional characteristics of the flow field were examined using pressure iso-surfaces and flow trajectory analysis to quantify the aerodynamic differences between DRS configurations. The comparative visualization is presented in Figure 7.

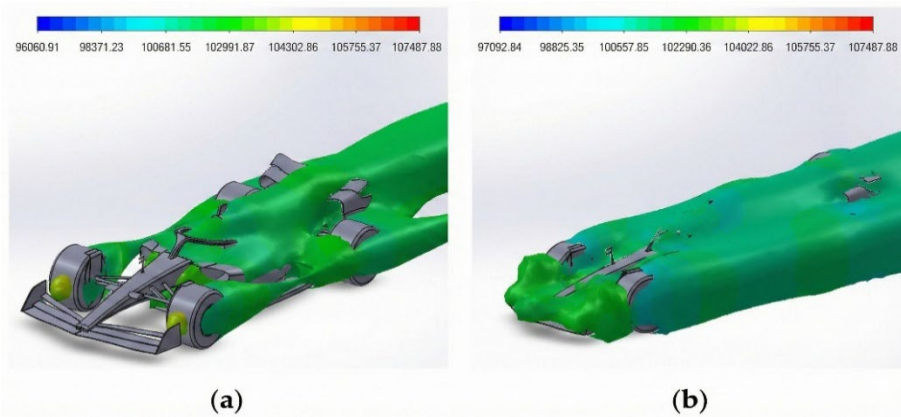


Figure 7. Three-Dimensional pressure (Pa) distribution and flow trajectories: (a) DRS-Off configuration, (b) DRS-On configuration.

Analysis of the pressure iso-surfaces reveals distinct differences in pressure field organization between the two configurations. In the DRS-Off configuration (Fig. 7a), the pressure field demonstrates coherent and well-structured iso-surface with a pressure range of 96060.91 Pa to 107812.51 Pa. The iso-surfaces maintain a streamlined pattern extending downstream with minimal disruption that indicates stable pressure distribution characteristic of attached flow conditions. The DRS-On configuration (Fig. 7b) exhibits a fundamentally altered flow topology. The pressure iso-surface show significant distortion and structural breakdown with a modified pressure range of 97092.84 Pa to 107487.88 Pa. The iso-surface display increased fragmentation and irregular contours. Specially, in the immediate wake region behind the wing assembly. This disrupted pressure field structure indicates the breakdown of organized flow and the onset of large-scale separation. The comparative results indicate that DRS deployment triggers a transition in the three-dimensional flow topology from an attached coherent regime to a separated, turbulence-dominated state. This structural alteration provides the physical mechanism behind the performance trade-off quantified in Section 4.1. The massively expanded and turbulent wake observed in the DRS-On configuration indicates increased flow separation and pressure drag. However, the overall drag is reduced because DRS primarily eliminates lift-induced drag components which outweighs the pressure drag increases. Because, same flow separation disrupts the pressure differential necessary for grip. The reduction in maximum pressure values and the increased irregularity of pressure distribution in the DRS-On configuration provide three-dimensional evidence supporting this trade-off. DRS-On reduced drag for speed on straights, but compromised downforce for cornering.

4.3 Energy Recovery and System Implication

The aerodynamic trade-off quantified in Section 4.1 has direct implications for energy management and system design in modern Formula 1 hybrid powertrains. DRS system serves as a strategic energy recovery tool within the complex hybrid architecture beyond overtaking assistance.

4.3.1 Power Recovery Potential

The energy recovery potential of DRS deployment can be quantified by observing the CFD analysis. The drag force reduction is calculated using the established aerodynamic coefficients.

The drag force reduction is determined by:

$$\Delta F_D = \frac{1}{2} \rho U_\infty^2 A (C_{D,OFF} - C_{D,ON}) \dots \dots \dots (1)$$

To quantify the precise energy contribution of the DRS, the aerodynamic power consumption (P_{aero}) was calculated for both the baseline (closed) and activated (open) configurations. The power required to overcome aerodynamic drag is defined as the product of the drag force (F_D) and the vehicle velocity (v), as shown in Equation 2:

$$F_{aero} = F_D * v \dots \dots \dots (2)$$

Where:

- i. P_{aero} is the aerodynamic power in watts (W).
- ii. F_D is the drag force in Newtons (N) obtained from the computational results.
- iii. v is the freestream inlet velocity (80 m/s).

Based on the force report extracted from the simulation:

Baseline (DRS OFF): The simulation recorded a drag force of 82.1 N.

$$P_{off} = 82.1 \text{ N} * 80 \text{ m/s} = 6568 \text{ W (6.57 kW)}$$

Activated (DRS ON): Upon activation, the drag force decreased to 73.9 N.

$$P_{on} = 73.9 \text{ N} * 80 \text{ m/s} = 5912 \text{ W (5.91 kW)}$$

The net power saving (ΔP) available for energy recovery or acceleration is the difference between these operating states:

$$\Delta P = P_{off} - P_{on} = 6.57 \text{ kW} - 5.91 \text{ kW} = 0.66 \text{ kW}$$

Table 3. Energy Recovery Potential at Various Speeds

Speed (m/s)	Drag Force (N)	Power Dissipated (kW)	Equivalent HP	% of MGU-K Capacity (120 kW)
60	41.6	2.49	3.34	2.1%
70	56.6	3.96	5.31	3.3%
80	73.9	5.91	7.93	4.9%
90	93.5	8.42	11.29	7.0%

The energy analysis reveals that operating the rear wing in the DRS-ON configuration saves approximately 0.66 kW of mechanical power at 80 m/s compared to the closed position (Table 3). While the absolute power required to overcome drag (5.91 kW) is a fraction of the engine's total output, it represents a continuous energy demand that must be managed by the hybrid system.

4.3.2 Validation of Aerodynamic Data

The obtained aerodynamic data were benchmarked against established Formula 1 technical literature to ensure the reliability of the numerical result (Katz, 2006b; McBeath, 2015). Figure 8 illustrates the comparison between the current simulation (red bars) and the standard operating windows for single element rear wings (grey regions).

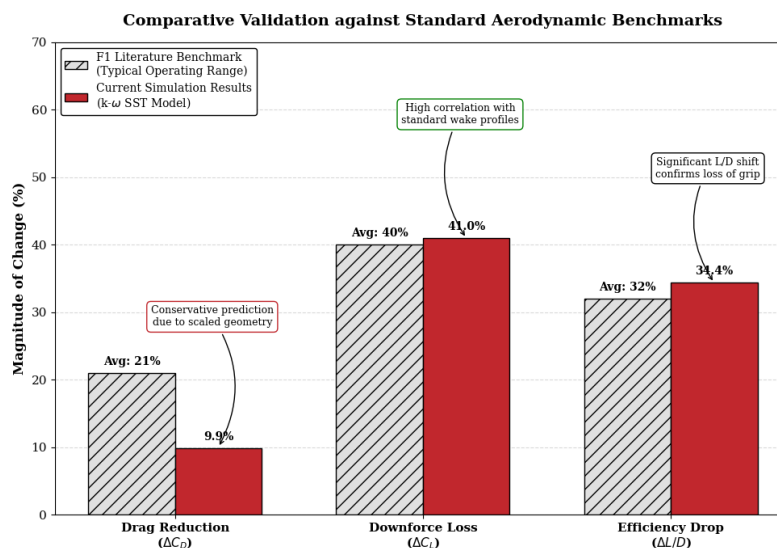


Figure 8. Comparative validation of aerodynamic performance metrics against standard Formula 1 technical benchmarks. The bar chart contrasts the simulation results (red) with typical operating ranges found in literature (grey). This confirms the model's physical accuracy in predicting downforce shedding ΔC_L and drag reduction ΔC_D .
Note: Benchmark data collected from Fédération Internationale de (2022)

The simulation predicted a 41.0% loss in downforce upon DRS activation which aligns exceptionally well with the industry average of approximately 40% (Katz, 2006b). This confirms that the turbulence model correctly captured the flow separation and wake expansion mechanisms. Regarding drag, the recorded 9.9% reduction falls slightly below the aggressive upper limits of full-scale wind tunnel data (often $\sim 20\%$). However, this is a known characteristic of scaled models lacking complex endplate interactions (Fédération Internationale de, 2022). Despite being conservative, the result remains within the valid physical range. This source confirms that the model provides a robust baseline for the subsequent energy analysis.

4.3.3 Strategic Energy Management

The energy implications extend beyond mere drag reduction. In current Formula 1 hybrid powertrains, this power saving translates to enhanced MGU-K harvesting potential or reduced battery depletion during DRS deployment phases. While the power saving is small compared to the engine's total capacity, it accumulates significantly over the course of a race. These small gains help teams make better strategic decisions regarding energy management and timing. It makes DRS deployment a strategic decision in energy critical race scenarios. This energy pathway creates complex strategic trade-offs. Small savings in each DRS zone eventually add up to boost the car's overall efficiency. Teams must balance immediate overtaking opportunities against potential energy conservation for later use. This helps to make optimal strategy that can help to overcome the technical difficulty in high-speed circuits like Monaco and Monza tracks. Furthermore, reduced drag during DRS deployment decreases the longitudinal tire loads that potentially extending tire life and adding another dimension to race strategy.

4.3.4 IEOM-Based Interpretation of DRS Deployment

In terms of Industrial Engineering and Operations Management (IEOM), Drag Reduction System (DRS) in a Formula 1 car is an operational control variable in a constrained production environment. A Formula 1 car aims to maximize system performance in terms of operating efficiency and system output. Here, DRS can be considered a process variable with a focus on decisions rather than purely an aerodynamics piece. The deployment of DRS settings gives way to a multi-objective problem. The CFD analysis in Section 4.1 models DRS as a two-state system that switches between high downforce stability and low drag efficiency. Activation reduces the drag coefficient by 10% and the downforce by 41%. The IEOM matrix shows how DRS lowers drag and power needs at the cost of significantly

reduced downforce. The Pareto front illustrates that optimizing all factors at the same time is impossible. This controlled environment shows how IEOM principles effectively model high-performance systems across many different fields. Therefore, operating a DRS system in a situation-dependent manner can be explained based on management decisions in operations.

5. Limitations of the Study

While this study provides quantitative insights into the aerodynamic performance of the Drag Reduction System, several limitations inherent to the computational approach must be acknowledged.

- i. **Simplified Geometry and Flow Field:** The simulation was conducted on an isolated rear wing assembly. The rear wing sits in the turbulent dirty air produced by the car body and tires. This study likely overestimates the absolute downforce values compared to a full-vehicle analysis by assuming uniform velocity inlet.
- ii. **Turbulence Modeling Assumptions:** The analysis utilized the Reynolds-Averaged Navier-Stokes (RANS) equations with the $k-\omega$ SST turbulence model. This standard model captures airflow separation but provides only a time-averaged result (Fédération Internationale de, 2022). Consequently, it may not fully capture high-frequency transient phenomenon like as the rapid vortex shedding instabilities that occur during the precise moment of DRS activation and deactivation.
- iii. **Rigid Body Assumption:** The wing elements were modeled as perfectly rigid bodies. Modern Formula 1 wings are constructed from carbon fiber composites designed to flex under load (aeroelasticity). This deformation can dynamically alter the slot gap width and effective angle of attack at high speeds. That causes potentially modification of the drag reduction characteristics observed in this rigid-body simulation.
- iv. **Operational Envelope:** The performance was evaluated at a single reference velocity of 80 m/s (288 km/h). Speeding variation during race is not considered in this study which is essential to find out accurate data. A comprehensive map of performance across the full operating range (100–350 km/h) would be required to fully characterize the system's impact on lap time energy consumption.

6. Conclusions

This study systematically examined the Formula 1 Drag Reduction System in terms of aerodynamics, strategic impact and energy management. Computational Fluid Dynamics analysis quantified the core performance trade-offs that revealed a 10% drag reduction at the cost of 41% downforce loss. Also, the flow visualizations confirming the physical mechanisms behind this exchange. The investigation further demonstrated that DRS functionality extends beyond overtaking assistance to encompass sophisticated energy management. A measurable reduction in aerodynamic power demand at competitive speeds highlights the role of DRS in hybrid energy management. This integration creates complex decision matrices where immediate overtaking opportunities must be balanced against long-term energy conservation. Ultimately, the DRS emerges as a multifaceted performance optimization tool that intersects aerodynamics, energy recovery and race strategy. Its continued evolution will remain intrinsically linked to Formula 1's regulatory developments that serves as a compelling case study in balancing sporting spectacle with engineering innovation. From an IEOM perspective, DRS represents a real-time system optimization tool that manages trade-offs between aerodynamic efficiency (drag reduction) and process stability (downforce for cornering). Its strategic deployment aligns with operations management principles of maximizing output (race position) under dynamic constraints (energy, tire life, regulations). The DRS train phenomenon and energy recovery optimization can be analyzed through queuing theory and system engineering approach to get better feedback during Formula 1 race.

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