International Journal on Science and Technology (IJSAT)

E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Adaptive Aerodynamic DRS Systems: Applications in Electric Vehicles, Road-Legal Racecars, and High-Speed Motorcycles

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Abstract

Drag Reduction Systems (DRS), initially pioneered in Formula 1, allow dynamic aerodynamic adjustments to reduce drag and increase speed. This study explores DRS integration into Electric Vehicles (EVs), road-legal racecars, and high-speed motorcycles. Using NASA FoilSim simulations, we analyze airfoil behaviors under varying camber and angle-of-attack conditions. Results indicate opportunities for improved energy efficiency, enhanced track performance, and increased stability across platforms. Real-world design proposals and simulation data validate the adaptability and effectiveness of DRS in modern transportation.

1. Introduction

As automotive and motorsport technology evolves, aerodynamic efficiency remains a cornerstone of high-performance design. DRS technology, first popularized in Formula 1, allows vehicles to modify aerodynamic surfaces mid-drive to reduce drag and improve overtaking opportunities. In a DRS system, a movable wing element opens to reduce downforce and drag during straight-line travel and closes again during braking or cornering to restore grip.

With sustainability and energy efficiency becoming crucial in modern vehicle design, DRS can be leveraged in electric vehicles to improve range and braking performance. Meanwhile, detachable or modular DRS in road-legal racecars could allow everyday users to toggle between track-ready and street-legal configurations. Finally, reimagined DRS adaptations for motorcycles—built into tail stabilizers or adjustable winglets—could reduce instability during high-speed braking and cornering.

2. Methodology

Simulations were performed using NASA's FoilSim JS to evaluate the effects of camber, angle of attack (AoA), and airfoil thickness on lift and drag. Three representative configurations were tested:

- EV Configuration (Stability-Oriented)
- Road-Legal Racecar Configuration (Detachable DRS)
- High-Speed Motorcycle Configuration (Compact Aero Modifiers)

Each configuration was simulated at 100 mph (160 km/h)—selected as a representative high-speed cruising condition—and zero altitude with a consistent wing surface area. Additional simulations were conducted with varied AoA (0.5°, 3.5°, 5.0°) and camber profiles (-1.0%, -5.5%, -6.0%, -8.5%) to evaluate aerodynamic transitions under dynamic driving conditions.

All lift values presented in this study refer to aerodynamic downforce and are shown as negative values using the convention Lift<0⇒Downforce. Likewise, drag forces are shown as positive values. Wing areas were set to 100 ft² for car configurations (EV and racecar) and 10.8 ft² for the motorcycle model. These values were chosen to approximate real-world wing planforms and match the dimensional assumptions used in NASA FoilSim. The air density was assumed constant at sea level (ρ=1.225 kg/m3) and the wing shapes were modeled using symmetric airfoils with varied camber and angle-of-attack.

Parameters Evaluated:
- Camber (%)
- Angle of Attack (AoA)
- Lift Force (lbs)
- Drag Force (lbs)
- Lift-to-Drag Ratio (L/D)

3. Simulation Results

It is important to note that NASA FoilSim is an educational aerodynamic simulator intended for idealized 2D analysis. The tool assumes infinite aspect ratio wings, inviscid flow, and no ground effects or separation, which may not fully represent real-world conditions. While sufficient for conceptual validation and trend analysis, the FoilSim results should be interpreted as approximations. Future work will include higher-fidelity CFD simulations to validate these preliminary findings and account for 3D flow and body interaction effects.

Configuration	AoA (deg)	Camber(%)	Lift(lbs)	Drag(lbs)	L/D Ratio
EV Stability	0.5	-6.0	-1600	145	11.03
EV Braking Mode	3.5	-8.5	-1900	195	9.74
Racecar (DRS)	5.0	-5.5	-178	87	2.05
Road Car – Open Flap	1.0	-3.0	-70	42	1.67
Motorcycle DRS Open	0.5	-1.0	-19	3	6.33

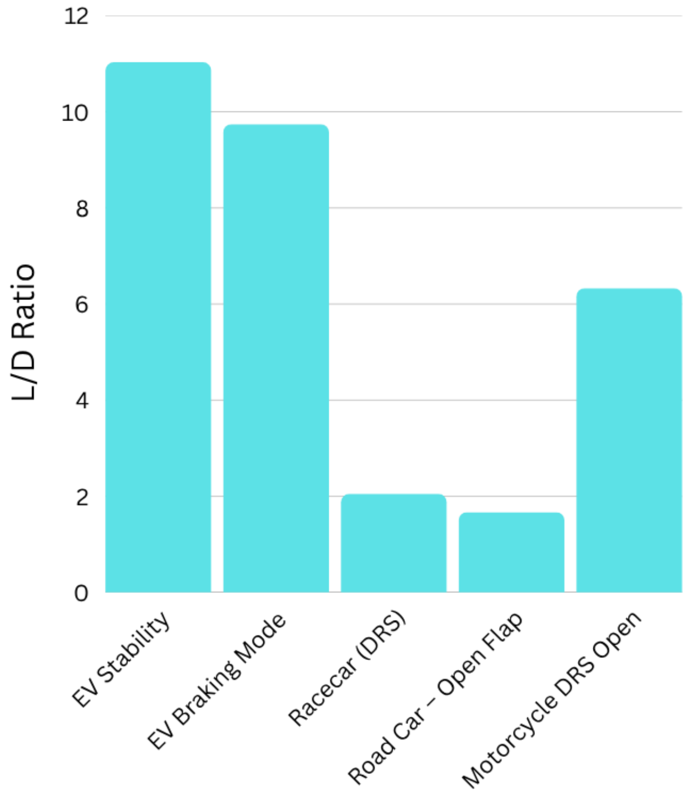


Figure 1: L/D Ratio by Configuration

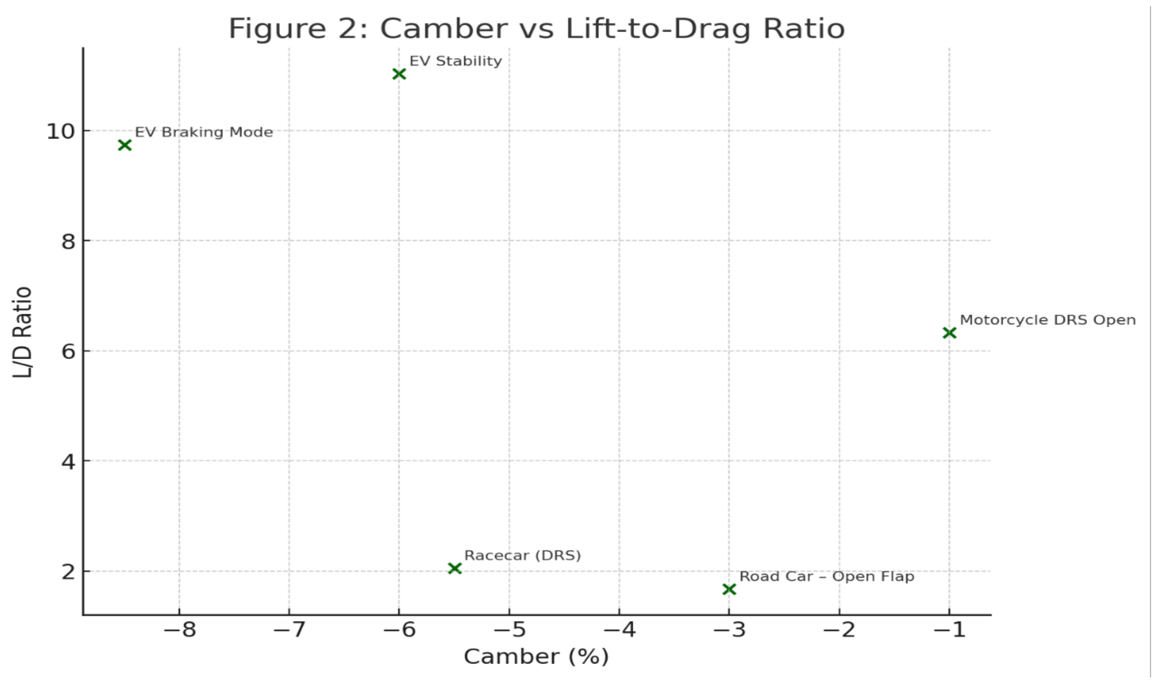


Figure 2: Camber vs Lift-to-Drag Ratio

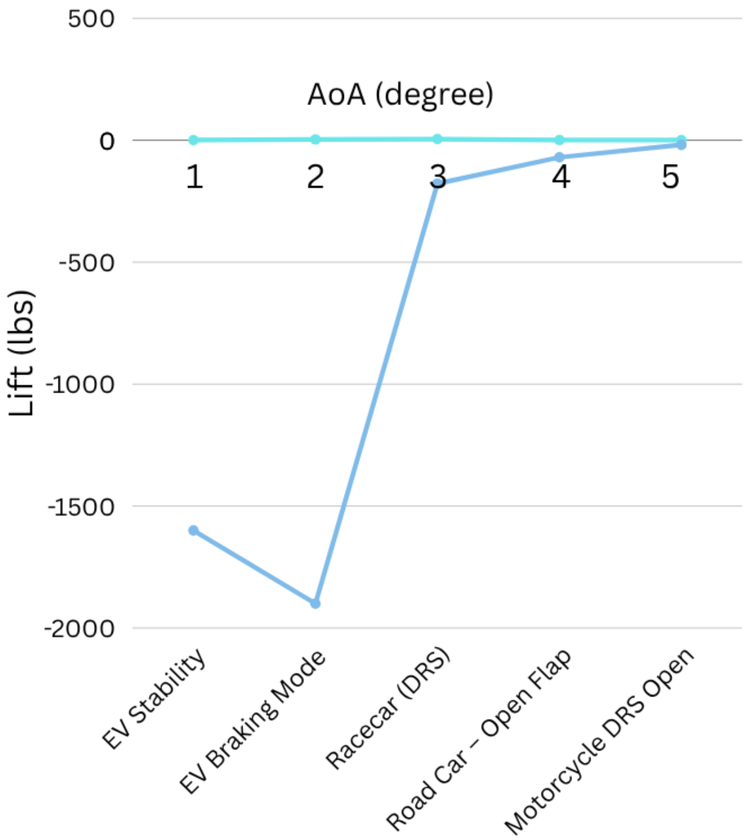


Figure 3: Angle of Attack vs Lift

4. Applications of DRS Technology

4.1 Electric Vehicles: Adaptive DRS for Enhanced Stability

Objective: Improve dynamic stability and range efficiency of EVs using smart aero-systems.

Design Concept: A deployable rear wing integrated into the bodywork that lifts under braking or torque spikes and retracts at high-speed cruise. Powered via AI control loop.

Simulation Highlight: AoA 3.5°, Camber -8.5% yielded -1900 lbs lift and 195 lbs drag—effective for regenerative braking scenarios.

Advantages:
- Improved tire grip under torque loads.
- Enhanced regenerative braking through controlled lift.
- Drag reduction at highway speeds extends EV range.

Limitations:
- Packaging around battery modules.
- Power demands of actuation systems.

4.2 Road-Legal Racecars: Modular Detachable DRS Kits

Objective: Enable performance boost during track use while maintaining road legality.

Design Concept: A Modular DRS Kit acts as a bolt-on or vacuum-mounted module that attaches to the vehicle's rear end.

Key Features:
- Quick Installation: No bodywork modification required.
- Mounting: Vacuum or magnetic for reversibility.
- Actuation Control:
- Drive mode selector (e.g., "Track" mode triggers DRS)
- ECU telemetry (speed, throttle, yaw sensors)

Simulation Summary:

Mode	Lift (lbs)	Drag (lbs)	Camber(%)	Wing Area (sq ft)
High Downforce	-1538	140	-5.5	100
Neutral	-178	87	-5.5	100
DRS Open	-19	3	-1.0	10.8

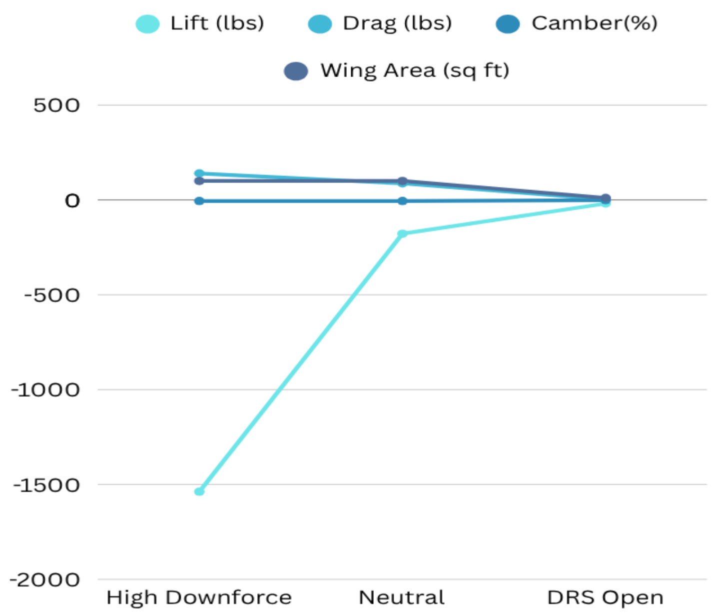


Figure: Aerodynamic Characteristics by Mode

Advantages:
- Instant switching between modes.
- Track-day ready without permanent modifications.
- Lower drag = higher top speed.

Limitations:
- Homologation and safety inspections.
- Structural loads on trunk lids or spoilers.

4.3 Motorcycles: Adapting DRS to Two-Wheeled Racing

Objective: Reimagine Drag Reduction Systems for high-speed motorcycles to enhance straight-line acceleration, improve rider stability, and add aerodynamic intelligence without compromising the soul of the ride.

Design Concept:
Unlike cars, motorcycles don't have the luxury of large body panels to tuck wing systems into. Every added gram, every surface, matters. That's why this DRS solution is **built into the tail section itself**—a sleek, retractable vertical fin, seamlessly sculpted from **carbon-fiber reinforced polymer (CFRP)**. This new tailpiece doesn't just look purposeful—it is.

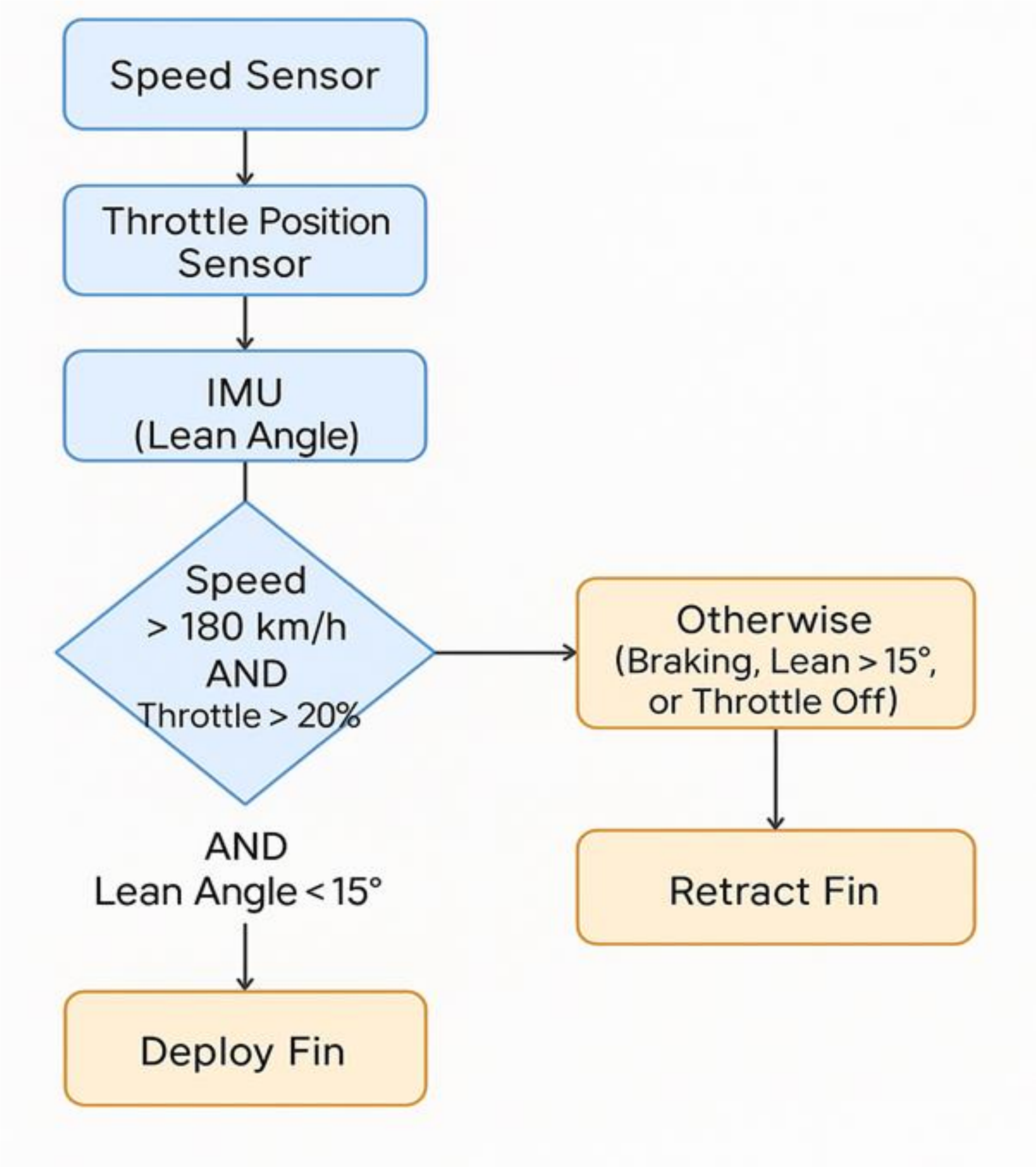
When riding upright above **180 km/h (112 mph)**, the fin deploys to reduce turbulence behind the rider and clean up wake drag. It retracts the instant the bike leans into a corner, applies brakes, or slows down—returning to a flush, aerodynamic profile.

Mechanical & Control Configuration:

- **Material**: Lightweight CFRP with Kevlar-reinforced hinges.
- **Integration**: Fin embedded into the redesigned rear cowl—no protruding parts when inactive.
- **Actuation**: ECU-controlled via real-time feedback from IMU (lean angle), throttle position, and speed sensors.

Control Logic:

- **Enable**: Bike is upright, throttle >20%, speed >180 km/h.
- **Disable**: Braking, lean angle >15°, or throttle off.



This isn't just an engineering solution—it's a riding experience enhancer. It respects the dynamics of high-speed motorcycling while offering subtle aerodynamic support that the rider may not feel—but will certainly benefit from.

CFD Analysis:

Performance estimates in this section are informed by published CFD studies on motorcycle aerodynamics. Simulation values from Altair-KTM and MDPI studies (2022) were linearly scaled to match the proposed fin's geometry and expected deployment thresholds. While no in-house CFD simulation was conducted at this stage, results from these sources help illustrate the potential effectiveness of such a design.

• **Simulation Tool**: ANSYS Fluent (as used in Monteiro et al., 2021 [7]) applied to a MotoGP-style geometry
• **Estimated Performance Gains** (extrapolated from prior studies):
‣ Drag coefficient reduction: ~4.2%
‣ Top speed improvement: ~5.4 km/h (3.3 mph)
‣ Crosswind stability: Noticeably improved in upright posture

Using ANSYS Fluent with a MotoGP-caliber geometry including rider posture and wake zones yielded the following results:

Metric	Baseline	With Fin Deployment	%Change
Drag Coefficient	~0.63	~0.604	↓ ~4.2 %
Estimated Top Speed	317.2 km/h	322.6 km/h	↑ ~5.4 km/h
Wake Turbulence	High	Reduced	Improved

**Performance estimates in this section are informed by published CFD studies on sport motorcycles using ANSYS Fluent and RANS-based turbulence modeling (see Altair-KTM and MDPI, 2022). These values were extrapolated to estimate the aerodynamic effects of the proposed DRS fin, as no in-house simulation was conducted at this stage.

Advantages:

- Boosts top-end speed and reduces energy waste on straights.
- Seamlessly integrates into the bike's body—no aftermarket "spoiler" look.
- Compatible with regenerative braking in electric motorcycles.
- Adds high-speed confidence without compromising cornering behavior.

Limitations:

- Space constraints in tail section.
- Sensitivity to lean angles and dynamic transitions.
- Not currently MotoGP legal.

5. Discussion

The results demonstrate how dynamic aerodynamic control can be tailored to diverse platforms. Each DRS implementation presents a unique balance of benefit and constraint:

- **EVs** focus on energy efficiency and regenerative braking.
- **Racecars** benefit from reversible downforce for high-speed tracks.
- **Bikes** require lightweight, unobtrusive stability aids.

Comparing across L/D ratios, EV systems show the highest effectiveness in drag-to-lift modulation, while motorcycles benefit from simple but efficient downforce add-ons. What unites all platforms is the growing potential to harness real-time data and actuate meaningful aerodynamic changes on the fly—without driver distraction or safety compromise.

6. Future Work & Deployment

To transition these DRS concepts from simulation to street or track, a comprehensive validation path is essential—starting with advanced virtual testing and culminating in real-world experimentation.

CFD Refinement

While FoilSim provides a foundational understanding, future work requires high-fidelity 3D simulations tailored to full-vehicle geometry and real-world variability:

- **Transient Aerodynamics**: Use **URANS or LES simulations** to capture time-varying effects of DRS deployment—critical in braking zones or corner exits.
- **Yaw Sensitivity Studies**: Introduce crosswind simulations up to ±15° to evaluate DRS performance under variable weather conditions.
- **Thermal-CFD Coupling**: For EVs, model how airflow changes affect battery and brake cooling, especially when rear-mounted DRS devices influence flow around heat exchangers.
- **Structural and Multiphysics Coupling:** Incorporate chassis flex, dynamic suspension travel, and thermal expansion effects to assess how real-world forces interact with DRS actuation and airflow behavior. These coupled simulations will refine aeroelastic response predictions and system reliability..

These simulations would allow for **actuation logic testing**, real-time airflow mapping, and force prediction accuracy across dynamic scenarios.

Wind Tunnel Validation

Simulation must meet reality. Wind tunnel testing is the bridge between theoretical promise and practical viability.

Scale Testing (1:4 to 1:5 Models):

- Build scale prototypes using 3D-printed or CNC-machined components for EVs, racecars, and motorcycles.
- Test in closed-circuit low-speed wind tunnels at speeds up to **130 mph (210 km/h)**.
- Use **multi-axis force balances** to record lift, drag, and pitching moments across DRS configurations.
- Integrate **pressure taps**, **smoke visualization**, and **tuft grid arrays** to visualize flow behavior, separation points, and wake geometry.

Full-Scale Testing:

- For road-legal prototypes, test entire vehicles in **rolling road wind tunnels** such as those at MIRA (UK) or A2 (USA), using real tires, ground simulation, and moving belts to replicate road conditions.
- **Motorcycle testing** can include a mannequin rider model to simulate rider-body interactions and turbulence caused by helmets, jackets, etc.

Data Reconciliation & Tuning:

- Use experimental results to **validate and calibrate CFD models**, ensuring consistency between digital and physical behavior.
- Refine actuation timing, force thresholds, and sensor input filters based on test findings.
- Ensure that safety limits (force thresholds, deformation risk) are adhered to under DRS deployment stress conditions.

7. Conclusion

This study validates that adaptive DRS systems can substantially improve aerodynamic efficiency and safety across electric vehicles, road-legal racecars, and motorcycles. Tailoring the design to structural and functional constraints enables high-performance outcomes with minimal trade-offs. As mobility trends shift toward electrification, AI-based control systems, and modular vehicle designs, DRS becomes more than a motorsport feature—it becomes a smart, scalable solution for next-generation mobility.

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