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Rear Spoilers and Wings in Automotive Aerodynamics: A Comparative Review of Drag, Downforce, and Flow-Control Effects

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ABSTRACT

Rear aerodynamic devices influence vehicle stability, efficiency, and high-speed performance, but rear spoilers and rear wings operate through different aerodynamic mechanisms and should not be evaluated using the same performance criteria. Spoilers primarily modify flow separation, rear pressure distribution, and wake development, whereas rear wings act as dedicated aerodynamic lifting surfaces that generate negative lift or downforce. This review compares published experimental and computational studies of spoilers, rear wings, and other rear-flow-control devices, focusing on baseline-relative changes in drag coefficient, lift coefficient, and downforce. According to the evidence reviewed, spoiler performance is primarily dominated by wake control, with baseline vehicle geometry and separation behaviour having a significant impact on aerodynamic response. Rear-wing performance is primarily driven by force generation, with increased aerodynamic loading typically resulting in increased drag. Representative studies reported a 16% increase in spoiler drag along with a significant lift reduction, while selected Ahmed-body rear-flow-control configurations achieved pressure-drag reductions of more than 20%. A Formula Student multi-element rear wing produced a transition from positive lift to substantial downforce while increasing drag by approximately 70%. These findings suggest that spoiler optimization is primarily a vehicle-specific wake-control problem, whereas rear-wing optimization is primarily a downforce–drag optimization problem. Neither device is universally superior; the preferred rear aerodynamic strategy depends on the performance requirements and operating environment of the vehicle.

Keywords: automotive aerodynamics, rear spoiler, rear wing, drag coefficient, lift coefficient, downforce, flow separation, vehicle wake

INTRODUCTION

Aerodynamic performance has a significant impact on vehicle efficiency, stability, handling, and performance at high speeds. As the vehicle's speed increases, aerodynamic drag increases the power required to maintain motion, whereas aerodynamic lift changes the vertical load acting on the tyre. These effects result in differing design priorities for road and racing vehicles. Road vehicles prefer low drag and stable high-speed behaviour, whereas racing vehicles may tolerate significantly higher drag if it improves braking and cornering performance.

Rear aerodynamic devices are frequently used to control these forces. Two of the most well-known are rear spoilers and rear wings, but their aerodynamic functions are fundamentally different. A spoiler is typically integrated into or close to the vehicle body, and it primarily affects flow separation, rear pressure distribution, and wake development. In contrast, a rear wing functions as a dedicated aerodynamic lifting surface, producing negative lift, or downforce, via the pressure difference established across its surfaces.

The aerodynamic behaviour of spoilers is therefore closely related to the vehicle's baseline flow field. Changes in rear geometry can affect wake structure and aerodynamic resistance, as shown in studies involving simplified vehicle geometries like the Ahmed body (Ahmed & Ramm, 1984; Meile, 2011). Rear flaps and spoiler-type modifications have also been shown to affect separated flow and, depending on their configuration, reduce or increase aerodynamic drag (Tian, 2017; Hamut, 2014).

Rear wings use a different dominant aerodynamic mechanism. Their primary function is to generate direct force through an airfoil-type surface, with increased aerodynamic loading typically resulting in increased drag. Rather than focusing solely on minimising drag, racing-wing studies consider the balance of vertical force generated and associated aerodynamic resistance. This distinction is important because a large drag penalty may be unacceptable for a road vehicle but beneficial for a racing vehicle if it results in a significant improvement in cornering or braking capability.

Direct comparison across published studies remains difficult because vehicle geometry, device dimensions, velocity, Reynolds number, angle of incidence, and experimental or computational methods vary considerably. Absolute drag and lift coefficients from unrelated studies should therefore not be treated as directly equivalent. A more useful approach is to examine the change between the baseline and modified configurations within each individual study and then identify broader patterns across the literature.

Research Question and Review Scope

This review looks at how rear spoilers and rear wings differ in terms of aerodynamic mechanisms and drag-downforce trade-offs, as reported in previous research. The study focuses on baseline-relative changes in drag coefficient, lift coefficient, and downforce, as well as the impact of rear-device geometry on vehicle wake behaviour.

The central research question is the following:

What are the differences between rear spoilers and rear wings in terms of aerodynamics, drag-downforce trade-offs, and suitability for road and racing vehicles?

The review begins with the aerodynamic principles needed to interpret rear-device performance, then evaluates published spoiler and rear-wing studies, and finally synthesises their quantitative and qualitative findings. The goal is not to identify a universally superior device, but to determine how the appropriate rear aerodynamic strategy varies with the vehicle's performance requirements.

METHODS

This narrative comparative review looked at published studies on rear spoilers, rear wings, simplified vehicle wake control, and reported changes in drag, lift, and downforce. Experimental and computational studies included a baseline vehicle or reference geometry and a modified configuration, allowing the aerodynamic effect of the rear device to be evaluated relative to the original case. Because the reviewed studies used different vehicle geometries, operating conditions, reference areas, and numerical or experimental methods, absolute aerodynamic coefficients were not treated as directly equivalent across studies. The review therefore emphasised within-study changes and recurring trends in the reported drag–downforce response.

The literature for this narrative review was identified through targeted searches of Google Scholar and publisher or journal websites using combinations of terms such as “rear spoiler aerodynamics,” “rear wing aerodynamics,” “drag coefficient,” “lift coefficient,” “downforce,” “Ahmed body,” and “vehicle wake control.” Studies published from approximately 1984 to 2024 were considered to capture both foundational and recent work. Priority was given to experimental, computational, and analytical studies that reported measurable aerodynamic outcomes, particularly changes in drag, lift, downforce, or wake behaviour relative to a baseline configuration. Studies were excluded when they did not provide sufficient aerodynamic detail, did not allow comparison with a baseline or reference case, or were not directly relevant to rear aerodynamic devices or wake-control mechanisms.

Because terminology for rear aerodynamic devices is not fully consistent across the literature, the devices in this review were classified based on their dominant aerodynamic function rather than the original authors' terminology. Body-integrated or near-body trailing-edge devices that primarily modify separation and wake development were classified as spoiler-type devices, whereas freestanding aerofoil-type control surfaces designed primarily to generate aerodynamic loading were classified as rear wings. Ahmed-body flaps and other passive rear devices were included as mechanistic evidence of wake control rather than as direct representations of standard production-car spoilers.

AERODYNAMIC BASIS FOR REAR DEVICES

Drag, Lift, and Downforce

Drag and lift coefficients are common terms for describing the aerodynamic forces acting on a vehicle. Drag acts in the opposite direction of motion and can be expressed as:

$$F_D = \frac{1}{2}\rho V^2 A C_D$$

(F_D) is drag force, (ρ) is air density, (V) is relative airflow velocity, (A) is reference area, and (C_D) is the drag coefficient. Because drag increases with the square of velocity, aerodynamic resistance becomes

more important at higher road and race speeds. Lift operates perpendicular to the direction of motion and can be expressed as

$$F_L = \frac{1}{2}\rho V^2 A C_L$$

where (F_L) denotes lift force and (C_L) represents lift coefficient. Positive lift reduces the effective vertical load acting on the tyres, while negative lift produces downforce. In racing applications, more downforce can improve tyre forces available for braking and cornering, but this is usually accompanied by increased drag. For literature comparisons, the most useful quantities are frequently the changes produced by adding a rear aerodynamic device to a baseline configuration.

$$\Delta C_D = C_{D,\text{device}} - C_{D,\text{baseline}}$$

$$\Delta C_L = C_{L,\text{device}} - C_{L,\text{baseline}}$$

This baseline-relative approach is preferable to directly comparing absolute coefficients from unrelated studies because published work may employ different vehicle geometries, reference areas, velocities, and experimental or computational methods. Throughout this review, positive (C_L) indicates upward aerodynamic lift and negative (C_L) indicates downforce. Where an original study described downforce as a positive magnitude acting in the negative vertical direction, the value was expressed using the negative-(C_L) convention used in this paper. The reference area and coefficient definitions are consistent with those used in each original study, so total drag coefficient, pressure-drag coefficient, and other reported coefficient changes were treated as distinct quantities rather than directly equivalent values.

Flow Separation and Vehicle Wake

Rear aerodynamic performance is strongly influenced by flow separation and wake formation. As air moves over a vehicle, the boundary layer may remain attached to the surface or separate when the local pressure gradient becomes sufficiently adverse. Once separated, the flow forms shear layers and a wake containing recirculating and vortical structures behind the vehicle.

The rear body's geometry has a significant impact on this behaviour. The Ahmed body is commonly used as a simplified reference model because it isolates important aspects of bluff-body vehicle aerodynamics. According to studies using the Ahmed body, changes in rear-slant geometry can significantly alter wake topology, drag, and lift (Ahmed & Ramm, 1984; Meile, 2011; Tunay, 2014), as shown schematically in Figure 1.

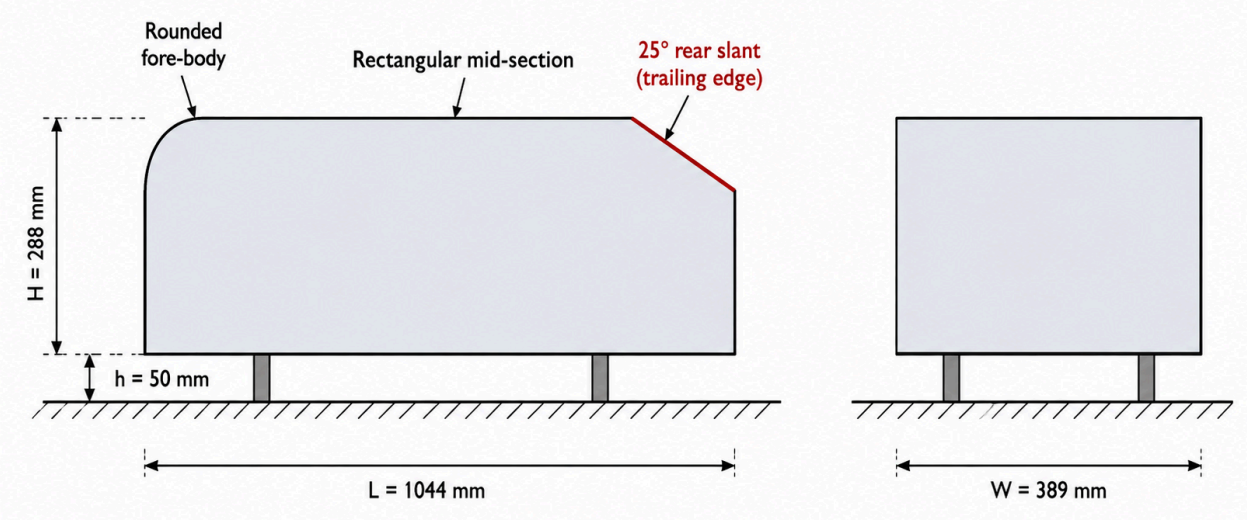

Figure 1. Simplified geometry of the Ahmed reference body, showing the principal dimensions and 25° rear-slant configuration commonly used in automotive aerodynamic studies.

Spoiler-type devices have a direct impact on this separation process. They can change the rear geometry to change the trajectory of the separated shear layer, wake size, and pressure recovery. Tian (2017), for example, demonstrated that rear-flap configurations on the Ahmed body can significantly alter pressure drag, demonstrating how much rear-device performance is dependent on interaction with the existing wake. Thacker (2012) conducted experimental research with suppression of separation on 25° Ahmed-body rear slant to examine the resulting wake structures and drag-reduction mechanism.

The rear wings interact with the flow differently. Their primary function is to generate aerodynamic loading, but their performance is still dependent on the upstream flow field generated by the vehicle. Wing position, height, angle of attack, and exposure to separated or cleaner airflow can all influence downforce and drag.

Drag–Downforce Trade-off

The aerodynamic value of a rear device depends on the purpose of the vehicle. Road vehicles generally benefit from reduced drag, controlled lift, and stable wake behavior. A rear spoiler can therefore be useful even when it does not generate substantial downforce, provided it reduces undesirable lift or improves separation without creating an excessive drag penalty.

Racing vehicles operate under a different objective. Rear wings are deliberately used to generate large aerodynamic loads, and increased drag may be acceptable when the corresponding downforce improves overall dynamic performance. As a result, maximum downforce and minimum drag cannot be considered separately.

The primary aerodynamic function of spoilers distinguishes them from wings. Spoilers primarily alter the existing vehicle flow field, whereas rear wings primarily generate aerodynamic force via a specialised lifting surface. The following sections look at how these two approaches are reflected in published experimental and computational results.

RESULTS

Rear Spoilers: Mechanism and Reported Effects

Rear spoilers primarily influence the existing airflow over the vehicle body. Their aerodynamic effect is thus highly dependent on the baseline rear geometry, separation location, and wake structure. A spoiler's trailing-edge geometry can change the direction of the separated shear layer, the size of the recirculating wake, and the distribution of pressure over the vehicle's rear surfaces. This sets spoilers apart from rear wings, which serve more directly as aerodynamic force-generating surfaces.

The sensitivity of rear-flow behaviour to geometry has been extensively demonstrated using simplified vehicle models. Ahmed and Ramm (1984) discovered that rear-body geometry has a significant impact on the wake and aerodynamic coefficients of bluff-body vehicles, and subsequent research confirmed that even minor changes in rear geometry can significantly alter the separated flow field (Meile, 2011; Tunay, 2014). Tian (2017) extended this principle by investigating rear-flap configurations on Ahmed bodies and demonstrating that flap size, location, and angle can all have a significant impact on wake development and pressure drag.

Because spoiler performance is so dependent on the baseline wake, geometry alone cannot be used to generalise it. A spoiler that improves the flow field on one vehicle may produce a different aerodynamic response on another vehicle with a different roofline or rear-window angle, trunk profile, or underbody flow. The effectiveness of a spoiler should therefore be evaluated relative to the unmodified vehicle rather than by assuming that any rear spoiler will automatically reduce drag or increase downforce.

According to published research, rear spoilers can cause either positive or negative drag changes depending on how they interact with the vehicle's wake. According to Hamut (2014), adding a rear spoiler to a sports car geometry increased the drag coefficient by approximately 16%. At the same time, the lift coefficient decreased from approximately $C_L = 0.26$ to $C_L = 0.05$, representing an 81% reduction in positive lift. This result demonstrates an important road-vehicle trade-off: significant lift reduction can be achieved even as drag increases.

Other rear-flow-control studies demonstrate that the opposite drag response is also possible. Tian (2017) reported that selected flap configurations on a 25° Ahmed body reduced pressure drag coefficient by more than 20%, with the most effective side-flap arrangement producing a reduction of approximately 21.2% and another top-flap configuration producing a reduction of approximately 17.9%. For the 35° Ahmed-body configuration, the best-performing flap arrangement produced a much smaller reduction of

approximately 6%, emphasizing the strong dependence of the aerodynamic response on the baseline rear geometry.

These contrasting results are important for the interpretation of spoiler studies. Hamut (2014) demonstrates a case in which the aerodynamic benefit was primarily a reduction in lift, accompanied by a drag penalty, whereas Tian (2017) demonstrates configurations in which rear-flow modification reduced drag. The literature therefore does not support a universal statement indicating that spoilers either increase or decrease drag. Their performance is determined by how the device geometry interacts with the underlying separated flow.

Additional research confirms this geometry-dependent behaviour. Cakir (2012) numerically evaluated various rear-device geometries and mounting positions on a passenger vehicle model, demonstrating that aerodynamic performance is affected by both device geometry and placement. Sharma and Bansal (2014) investigated a spoiler combined with vortex generators and found changes in drag and lift, demonstrating the sensitivity of rear-flow control to device configuration. Deressa and Sureddy (2016) reported similar changes in pressure distribution and aerodynamic forces after redesigning an SUV's rear spoiler. Daniel (2018) investigated the effects of a rear spoiler using computational fluid dynamics and found changes in both drag and lift, providing additional evidence that spoiler performance is affected by rear-device configuration.

For road vehicles, shifting from a positive-lift to a more neutral state can reduce aerodynamic unloading at higher speeds, especially when done without significantly increasing drag. The effect on overall vehicle stability is also determined by the distribution of aerodynamic loading between the front and rear axles.

Rear spoilers are particularly suited to road vehicles because they can provide moderate aerodynamic intervention without requiring a large independent lifting surface. Their integration with the vehicle body allows them to influence separation and rear pressure distribution while maintaining packaging, visibility, and styling requirements that would render large racing-style wings impractical for most production vehicles.

In general, the goal for road vehicles is to strike a balance between lift control and aerodynamic efficiency. A spoiler that significantly reduces positive lift may be beneficial even when drag rises modestly, whereas a configuration that reduces both lift and drag is especially appealing. The reviewed cases demonstrate that spoiler performance must be evaluated in relation to the baseline vehicle geometry and operating conditions, as similar rear-flow-control concepts can have significantly different effects on drag and lift.

This trade-off is increasingly important for vehicles in which energy efficiency is a major design priority. Additional aerodynamic resistance increases the power required to maintain speed, so a rear device intended for road use must provide a meaningful stability or wake-control benefit without imposing an excessive continuous drag penalty. For this reason, compact lip spoilers and similar integrated rear devices are more consistent with road-vehicle requirements than highly loaded racing wings.

The literature thus characterises rear spoilers primarily as wake- and lift-control devices with a highly geometry-dependent aerodynamic effect. Their reported performance ranges from substantial drag reduction in favourable wake-control configurations to increased drag with significant lift reduction. This variability contrasts with the more direct force-generation and drag trade-off observed in the reviewed rear-wing studies, which are discussed further in the following section.

Rear Wings: Mechanism and Reported Effects

Rear wings differ from spoilers in that they serve primarily as aerodynamic lifting surfaces, rather than as vehicle body extensions used to control separation. When configured for automotive applications, the pressure distribution around the wing generates negative lift, or downforce, increasing the normal load on the tyres. This makes rear wings especially useful in racing applications, where increased tyre loading can enhance braking and cornering performance.

The aerodynamic loading generated by a rear wing is determined by several factors, including aerofoil profile, angle of attack, span, chord, camber, endplate geometry, and position relative to the vehicle. Increasing the effective angle of attack generally increases the pressure difference across the wing, resulting in more downforce until extensive flow separation reduces aerodynamic performance. Rear-wing downforce varies significantly with incidence angle, demonstrating that wing performance is influenced not only by geometry but also by the operating configuration (Tarulescu, 2017; Katz, 2006).

Wing position also affects performance because the incoming flow behind a vehicle is rarely equivalent to an undisturbed freestream. A wing positioned within a separated wake can experience reduced and non-uniform local velocity, while a higher-mounted wing may interact with cleaner airflow. As a result, a rear wing's aerodynamic performance is determined not only by its geometry but also by how it interacts with the entire vehicle flow field (Toet, 2013).

This principle is taken further by multi-element rear wings, which share the aerodynamic load between a main element and one or more flaps. Element spacing, overlap, flap angle, and overall incidence all have an impact on pressure distribution and flow attachment under high loading. These configurations are common in motorsport because they allow for greater aerodynamic force to be generated within smaller geometric dimensions (Katz, 2006; Zhang, 2006).

The main aerodynamic advantage of a rear wing is its ability to generate significant downforce via a dedicated aerodynamic surface. This benefit is typically accompanied by increased drag. Wing drag is caused by profile drag, induced drag from finite-span aerodynamic loading, and interference effects between endplates, supports, and surrounding vehicle surfaces (Katz, 2006; Katz, 1995).

The relationship between downforce and drag is therefore critical in wing design. Increased wing loading can improve cornering and braking performance while decreasing straight-line efficiency. As a result, the optimal configuration is not the one that generates the most downforce under all conditions, but rather the one that provides the best aerodynamic balance for the intended vehicle and operating environment.

Jackson (2018) provides a quantitative example of this relationship with a Formula Student vehicle. The baseline configuration had approximately (C_L = +0.21 and C_D = 0.71). Following the addition of a multi-element rear wing, the reported lift coefficient changed to approximately (C_L = -1.15), representing a transition from positive lift to substantial downforce, while the drag coefficient increased to approximately (C_D = 1.21). The increase in drag coefficient was therefore approximately 70%, illustrating the aerodynamic cost associated with a much larger change in vertical loading.

The study also investigated a drag-reduction configuration in which the drag coefficient decreased from approximately C_D = 1.21 in the loaded-wing configuration to C_D = 0.79 when the wing geometry was changed. The high-downforce wing's drag penalty was significantly reduced, but the drag coefficient remained slightly higher than the baseline value of C_D = 0.71. This shows how adjustable rear-wing geometry can balance downforce and drag based on operating conditions.

Cakir (2012) also evaluated alternative rear-device geometries and mounting positions on a passenger-vehicle model. The results indicate that aerodynamic performance depends on device geometry and placement, reinforcing the need to evaluate rear devices relative to the specific vehicle configuration.

Rear wings are particularly suited to racing vehicles because aerodynamic performance is evaluated according to overall dynamic benefit rather than drag minimization alone. A race car must repeatedly accelerate, brake, and corner, and additional aerodynamic loading can improve tire-force capability during these phases. As a result, a configuration with greater drag may still be advantageous when the additional downforce increases the aerodynamic loading available while braking and cornering (Dominy, 1992). The overall vehicle-performance benefit, however, is determined by the circuit, speed range, tyre characteristics, and aerodynamic balance of the entire vehicle.

The preferred rear-wing configuration varies with circuit characteristics. Lower-drag settings may be advantageous on circuits with long straights, whereas higher-downforce settings may be more valuable where medium- and high-speed corners play a significant role in lap times. Because rear-wing geometry is adjustable, this balance can be altered by varying incidence, flap position, or multi-element configuration (Tarulescu, 2017; Jackson, 2018).

Rear-wing performance must be considered as part of the overall aerodynamic package, not as an isolated component. The distribution of aerodynamic loading between the front and rear axles affects vehicle balance, whereas the upstream flow field can change the effective incidence and loading of the wing. Rear-wing optimisation should take into account both local wing performance and its interaction with the overall vehicle aerodynamics.

The reviewed wing studies exhibit a more consistent aerodynamic pattern than the spoiler literature. Rear wings are intended to generate significant negative lift, and increased aerodynamic loading is usually associated with increased drag. Their effectiveness is thus determined by whether the additional downforce provides a sufficient vehicle-performance benefit to justify the aerodynamic resistance required to produce it.

Comparative Review of Rear Spoilers and Rear Wings

According to the reviewed literature, spoilers and rear wings should not be considered interchangeable aerodynamic devices. Although both are located near the rear of a vehicle and can influence drag and vertical aerodynamic force, they achieve these effects via distinct mechanisms. Spoilers primarily modify an existing flow field, whereas rear wings generate aerodynamic loading via pressure distribution around a specific lifting surface.

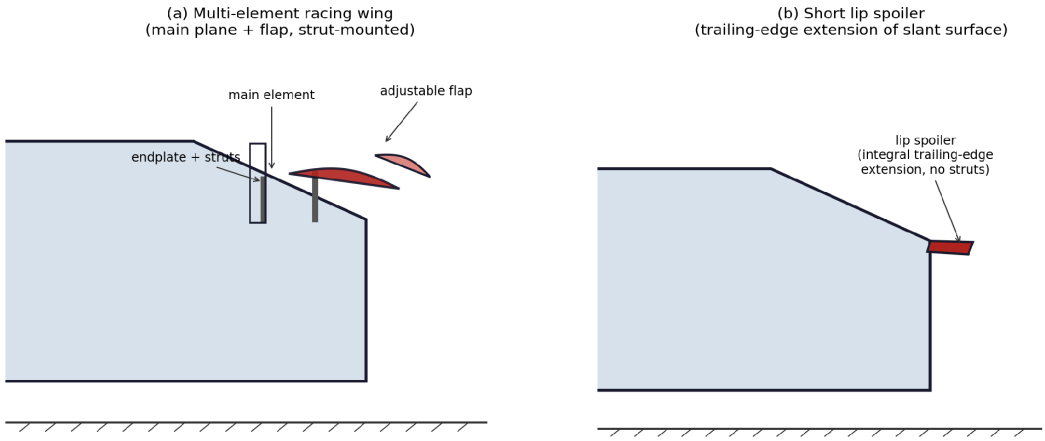

Figure 2. Conceptual comparison between two rear aerodynamic-device configurations: (a) a multi-element rear wing consisting of a main element, adjustable flap, and supporting endplates; and (b) an integrated short lip spoiler positioned at the vehicle trailing edge.

A spoiler changes the geometry encountered by the boundary layer and separated flow near the rear of the vehicle. Its effect therefore depends strongly on the baseline wake. Ahmed-body studies demonstrate that changes to rear geometry can significantly alter separation, pressure recovery, and wake structure (Ahmed & Ramm, 1984; Meile, 2011). Rear-flap investigations show that appropriately configured wake-control devices can reduce pressure drag, while other spoiler configurations may increase drag while reducing positive lift (Tian, 2017; Hamut, 2014).

Rear wings show a more direct correlation between aerodynamic loading and performance. Changes in incidence and wing configuration alter the pressure differential across the wing, affecting downforce and drag (Tarulescu, 2017). Multi-element configurations can generate significantly more vertical loading, but the aerodynamic benefit is typically accompanied by increased resistance (Jackson, 2018).

The numerical findings reported in the literature demonstrate why neither device can be evaluated solely on the basis of drag or downforce. Because the reviewed studies employ various geometries, reference areas, operating conditions, and numerical or experimental methods, absolute aerodynamic coefficients should not be directly compared. The baseline-relative changes within each investigation provide a more meaningful foundation for synthesis.

According to Hamut (2014), adding a rear spoiler increased the drag coefficient by about 16% while decreasing the lift coefficient from C_L = 0.26 to C_L = 0.05. The aerodynamic benefit was primarily lift reduction rather than drag reduction. In contrast, Tian (2017) demonstrated that spoiler-like rear flaps could reduce pressure drag when positioned favorably relative to the baseline wake. For the 25° Ahmed body, the best-performing side-flap configuration produced a reported pressure-drag-coefficient reduction of approximately 21.2%, while another top-flap configuration produced a reduction of approximately 17.9%. For the 35° geometry, the maximum reported reduction was considerably smaller, at around 6%. These findings show that the effectiveness of rear flow-control devices varies significantly with baseline rear geometry.

The wing literature shows a different aerodynamic operating regime. Jackson (2018) reported that fitting a multi-element rear wing to a Formula Student vehicle changed the lift coefficient from approximately (C_L=+0.21) to (C_L=-1.15), while the drag coefficient increased from approximately (C_D=0.71) to (C_D=1.21). This case demonstrates the substantial downforce that can be generated by a dedicated rear wing, together with the associated drag penalty, without implying direct quantitative equivalence with the road-vehicle spoiler studies.

Study	**Vehicle / Geometry - Device**	**Method**	**Reported Aerodynamic Result**	**Interpretation**
Hamut (2014)	Sports-car model — rear spoiler	CFD and experiment	C_D increased from 0.31 to 0.36 (~16%); C_L decreased from 0.26 to 0.05	Significant lift reduction with a drag penalty.
Tian (2017)	Ahmed body (25° and 35°) — rear flaps	CFD	Pressure-drag reduction was ~21.2% at 25° and ~6% at 35°.	Strong reliance on baseline rear geometry.
Cakir (2012)	Passenger vehicle — alternative rear devices and mounting positions	CFD	Various rear-device geometries and mounting positions were tested for their effects on lift and drag.	Aerodynamic performance depended on device geometry and placement.
Jackson (2018)	Formula Student vehicle — multi-element rear wing	CFD	(C_L) decreased from +0.21 to −1.15; (C_D) increased from 0.71 to 1.21 (~70%); and DRS reduced (C_D) to ~0.79.	Large downforce gain with substantial drag; adjustment decreased the penalty.

Tarulescu (2017)	High-speed vehicle — adjustable rear wing	Analytical study	Downforce increased with the wing incidence angle.	Wing loading increased with the incidence angle.
Koca & Özden (2024)	Ahmed body — passive rear flow-control devices	CFD	Selected rear devices reduced drag by approximately 6-7%.	Provides analogous evidence that passive rear-wake modification can reduce drag.
Kim (2022)	Fastback DrivAer vehicle — rear wing	CFD	(C_D) increased by about 14 counts, while (C_L) decreased by around 72 counts (1 count = 0.001 coefficient change).	Significant lift reduction with a modest drag increase
Yudianto (2024)	Generic road vehicle — optimized rear spoiler	Adjoint-based CFD optimization	Multi-objective optimisation resulted in alternative spoiler geometries with varying drag-downforce compromises.	Optimization balanced drag reduction and downforce gain

Table 1. Representative studies have reported comparative aerodynamic effects of rear spoilers and rear wings.

Table 1 summarises studies that do not use a single standardised aerodynamic metric. Hamut and Jackson report overall vehicle lift and drag coefficients, Tian reports changes in pressure-drag coefficients, and Kim reports coefficient changes in aerodynamic counts, with each count representing a 0.001 coefficient change. The values are thus interpreted as within-study effects rather than directly comparable cross-study results.

The comparative evidence reveals an important distinction between the two device classes. The reviewed spoiler studies include both a drag increase of approximately 16% accompanied by substantial lift reduction (Hamut, 2014) and pressure-drag reductions exceeding 20% for selected Ahmed-body flap configurations (Tian, 2017). A spoiler therefore cannot be classified simply as either a drag-reduction or downforce-generating device.

Within the reviewed configurations, rear wings have a more direct relationship with aerodynamic loading and drag. Their primary function is to generate negative lift, and increased loading is typically associated with increased aerodynamic resistance. The Jackson (2018) results provide an extreme example: the rear wing converted the vehicle from positive lift to significant downforce while increasing the drag

coefficient by about 70%. Tarulescu (2017) reported that wing loading is sensitive to incidence. This behaviour is consistent with the relationship between wing incidence, aerodynamic loading, and drag identified across the reviewed studies.

These distinctions help to explain the contrasting applications of the two device categories. Road vehicles require lift control and aerodynamic efficiency without incurring a significant continuous drag penalty, making body-integrated spoilers appealing when they interact well with the baseline wake. Racing vehicles can tolerate higher aerodynamic resistance if it contributes to the required handling balance and high-speed performance. In both cases, the device's effectiveness is determined by its interaction with the entire vehicle, including the baseline wake, aerodynamic balance, and operating conditions.

The reviewed evidence suggests that the primary difference between spoilers and rear wings is their dominant aerodynamic mechanism. Spoilers are primarily wake-control devices, with performance heavily influenced by baseline vehicle geometry and separation behaviour. Rear wings are primarily used for force generation, with increased aerodynamic loading typically accompanied by increased drag. Device selection should thus be based on the required balance of wake control, lift reduction, downforce, and aerodynamic resistance, rather than a single coefficient.

DISCUSSION

According to the reviewed literature, the aerodynamic distinction between rear spoilers and rear wings is best understood through their dominant mechanisms: wake control for spoilers and direct aerodynamic force generation for rear wings. Spoiler performance is strongly correlated with the vehicle's baseline flow field. The contrasting results reported by Hamut (2014) and Tian (2017) demonstrate this dependence: one configuration significantly reduced positive lift while increasing drag, whereas specific rear-flap configurations reduced pressure drag by modifying the separated wake. As a result, the aerodynamic effect of a spoiler cannot be predicted solely based on its presence; its effectiveness is determined by how its geometry interacts with the specific vehicle's separation characteristics. The wake-control and force-generation categories describe the dominant aerodynamic mechanism rather than a strict separation. Spoilers can still generate direct aerodynamic force, but rear wings are still sensitive to the upstream wake, local velocity distribution, and vehicle-body flow field.

Rear wings exhibit a more direct relationship between aerodynamic loading and resistance. Their primary function is to generate negative lift, and changes in wing incidence, geometry, or configuration allow this loading to be deliberately controlled. Jackson (2018) demonstrated the magnitude of this trade-off, with the addition of a multi-element rear wing changing the vehicle from (C_L = +0.21) to (C_L = -1.15), while (C_D) increased from 0.71 to 1.21. The dependence of downforce on wing incidence reported by Tarulescu (2017) further supports the interpretation of rear-wing design as a force-generation problem governed by the trade-off between aerodynamic loading and drag.

These mechanisms also explain why road and racing vehicles have distinct rear-device strategies. Road vehicles prioritise low aerodynamic resistance and controlled lift, whereas racing vehicles may accept a

higher drag penalty if additional aerodynamic loading contributes to the required handling balance and high-speed performance. Rather than focusing solely on maximum downforce or minimum drag, the benefit of either device is determined by operating conditions, aerodynamic balance, and how the rear device interacts with the entire vehicle.

The quantitative results should nevertheless be interpreted cautiously because the reviewed studies differ in vehicle geometry, reference area, operating condition, device dimensions, and computational or experimental methodology. Absolute aerodynamic coefficients from different investigations therefore cannot be treated as directly comparable. The stronger cross-study conclusion is qualitative rather than numerical: spoiler-type devices are generally dominated by their interaction with the existing wake, whereas rear wings are generally dominated by the balance between aerodynamic loading and the drag required to generate it.

LIMITATIONS AND FUTURE WORK

The main limitation of this review is the heterogeneity of the available studies. The published investigations use different vehicle geometries, device dimensions, flow velocities, Reynolds numbers, reference areas, and numerical or experimental methods. Some report total vehicle drag and lift coefficients, while others report pressure-drag changes or device-specific aerodynamic effects. As a result, the reported values cannot be treated as a single standardized dataset, and the review therefore emphasizes within-study changes and recurring aerodynamic trends rather than direct numerical comparison across studies.

A second limitation is the unequal distribution of evidence between simplified reference bodies, passenger vehicles, and racing vehicles. Ahmed-body studies provide controlled information about wake behaviour, but they do not replicate the full aerodynamic complexity of production or racing vehicles. These differences make direct comparison difficult, but they do allow for the identification of broader aerodynamic trends.

Most reviewed studies report total vehicle (C_L), which does not fully describe front-to-rear aerodynamic load distribution or pitching moment. A reduction in total lift should therefore be interpreted as reduced aerodynamic unloading rather than definitive evidence of improved vehicle balance.

Further research should compare spoilers and rear wings on the same baseline vehicle under identical operating conditions. Consistent reference areas, velocities, and aerodynamic measurement methods would enable a more direct assessment of the drag-downforce trade-off between the two device classes.

CONCLUSION

This review shows that rear spoilers and rear wings serve different dominant aerodynamic functions. Spoilers are generally wake-control-dominated, while rear wings are generally force-generation-dominated. Representative literature cases showed that spoiler configurations could

reduce positive lift by approximately 81% while increasing drag by about 16%, while favorable rear-flow-control configurations achieved pressure-drag reductions of up to approximately 21%.

Rear-wing studies revealed significant aerodynamic loading, including a shift from positive lift to downforce, although one high-downforce configuration increased drag by around 70%. Overall, spoiler performance is heavily influenced by baseline wake behaviour, whereas rear-wing performance is more directly determined by the trade-off between downforce generation and aerodynamic resistance. Neither device is universally superior; the appropriate choice is determined by the vehicle's aerodynamic priorities and operating conditions.

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