



# Study on Aerodynamic Optimisation of Medium-Duty Trucks: Drag Control and Fuel Efficiency Improvement

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**Abstract.** Medium-duty trucks play a critical role in regional and urban transportation, but their aerodynamic inefficiency leads to high drag and fuel consumption. This paper investigates strategies to reduce aerodynamic drag and improve fuel efficiency for medium-duty trucks. We first review the fundamental aerodynamic principles governing truck drag, including the importance of drag coefficient, flow separation and wake formation, and the influence of factors such as vehicle shape and crosswinds. Next, we discuss modern aerodynamic optimisation approaches, encompassing computational fluid dynamics (CFD) simulations, wind tunnel experiments, on-road testing, and the incorporation of artificial intelligence (AI) for design optimisation. Several case studies are analysed, highlighting practical improvements such as streamlined cab designs, roof-mounted air deflectors, side skirts, rear drag-reduction devices, and modifications to wheels and underbody. These measures demonstrate significant drag reduction and corresponding fuel savings. Finally, we conclude with an outlook on future trends, including real-time adaptive aerodynamic control systems and AI-driven aerodynamic design, aiming for further drag reduction and fuel economy gains in medium-duty trucks.

**Keywords:** Medium-Duty Trucks, Aerodynamics, Drag Reduction, Fuel Efficiency, Computational Fluid Dynamics

## 1 Introduction

Medium-duty trucks (e.g., Class 4–6 commercial vehicles) serve as essential carriers in urban logistics and regional freight transportation. However, their operational efficiency is significantly impacted by aerodynamic drag, especially at highway speeds. At typical cruising velocities, aerodynamic drag can account for up to 65% of the total resistive force acting on a truck. A reduction in the aerodynamic drag coefficient ( $C_d$ ) directly translates into better fuel economy and lower carbon emissions, which are critical in the context of rising fuel prices, regulatory pressures, and sustainability goals. For instance, a decrease of 0.01 in  $C_d$  can yield a fuel economy improvement of up to 0.5%, indicating even small aerodynamic refinements can lead to substantial cumulative savings over a vehicle's service life [1].

Despite the clear benefits, improving the aerodynamic performance of medium-duty trucks remains a complex engineering challenge. These vehicles are characterised by blunt front profiles, boxy cargo areas, and large exposed underbodies—all of which promote early airflow separation and the formation of turbulent wake regions [2]. Moreover, crosswinds and vehicle yaw exacerbate drag and instability. Traditional solutions such as reshaping the cab or adding passive drag-reduction devices (e.g., side skirts and rear fairings) can be effective, but they must balance cost, maintainability, and regulatory constraints.

In recent years, technological advances have enabled more sophisticated aerodynamic optimisation. Computational Fluid Dynamics (CFD) simulations provide insight into airflow patterns and allow engineers to test design iterations without physical prototypes. Wind tunnel and on-road testing validate these models and help fine-tune real-world performance. Additionally, artificial intelligence (AI) techniques—especially machine learning—are now being applied to accelerate the optimisation process, allowing rapid evaluation of new designs via surrogate modelling and predictive analytics.

This paper aims to provide a comprehensive investigation of aerodynamic strategies for medium-duty trucks. It first reviews the aerodynamic fundamentals that govern drag generation, then discusses contemporary optimisation methods, including CFD, wind tunnel testing, and AI-assisted design. Several case studies are presented to demonstrate how various techniques and devices, such as streamlined cabs, roof deflectors, side skirts, rear tail fairings, wheel covers, and underbody modifications, contribute to drag reduction and fuel efficiency. Finally, the paper outlines future research directions, including real-time adaptive aerodynamic systems and connected-vehicle coordination. Through a multidisciplinary lens, this study offers practical guidance for both truck manufacturers and fleet operators in enhancing performance and sustainability.

## 2 Aerodynamic Fundamentals for Medium-Duty Trucks

### 2.1 Vehicle Aerodynamics

Aerodynamic drag on a vehicle is quantified by the drag coefficient  $C_d$ , a dimensionless parameter that relates drag force to the dynamic pressure and reference area. For bluff-bodied trucks, pressure drag (due to flow separation and wake formation) is the dominant component of aerodynamic resistance, contributing around 90% of the total drag, whereas friction drag along the surface is relatively minor [3]. A large wake of low-pressure turbulent flow forms behind a truck at high speeds, increasing pressure drag. The drag coefficient of typical heavy trucks is around 0.6 in smooth airflow [2], and it increases significantly when the vehicle is subjected to crosswinds (yaw angles) [3]. Aerodynamic lift on the vehicle (from airflow under and over the body) can also occur; excessive lift negatively affects vehicle stability, particularly when the truck is lightly loaded or encountering strong side winds.

Reducing the drag coefficient yields direct benefits for fuel economy: a decrease in  $C_d$  of just 0.01 (about 1.5–2% of a typical truck's drag coefficient) can improve fuel

efficiency on the order of 0.3–0.5% [1]. Therefore, even modest aerodynamic improvements can translate into noticeable fuel savings over the vehicle's operational life.

## 2.2 Key Factors Affecting Drag

The shape of the truck, especially the cab (front-end) design, greatly influences aerodynamic drag. A streamlined, rounded front profile allows air to flow more smoothly around the vehicle, significantly reducing frontal pressure drag compared to a flat-faced design. In contrast, a blunt cab or protruding elements cause early flow separation and large vortices. The cargo box or trailer of a truck is another major source of drag: the abrupt rear end of a box-shaped truck creates a sizable wake region of recirculating flow behind the vehicle, which increases pressure drag. Controlling the flow in this rear area (for example, by managing how the air converges or detaches at the back) is critical to reducing the overall drag.

Crosswind conditions are also an important factor. Strong side winds effectively increase the aerodynamic yaw angle, which can increase the drag coefficient and alter the distribution of pressure on the truck's surfaces. Crosswinds not only raise drag but can also impact handling and stability, as the aerodynamic side forces and rolling moments on the vehicle become more pronounced. In summary, key contributors to a truck's aerodynamic drag include the cab shape, the behaviour of airflow around the cargo box (particularly at the rear), and the effects of wind from various directions.

## 3 Aerodynamic Optimisation Methods

### 3.1 CFD Simulation Techniques

Modern aerodynamic development heavily relies on CFD simulation. Reynolds-averaged Navier–Stokes (RANS) methods are commonly used in the initial design phase to obtain steady-state flow solutions and overall drag predictions. RANS simulations are computationally efficient and can provide quick estimates of how design changes affect the drag coefficient. However, RANS models often struggle to capture complex unsteady flow phenomena in the wake, such as large-scale vortices and time-dependent turbulence.

For deeper insight into transient flow structures, Large Eddy Simulation (LES) and related scale-resolving approaches are employed. LES can resolve the larger turbulent eddies in the wake of the truck, providing more detailed information about vortex shedding and unsteady pressures that contribute to drag and noise. Such high-fidelity simulations are valuable for local optimisation (for instance, refining the shape of a fairing or spoiler) where transient flow details matter [3]. In practice, a hybrid approach is sometimes taken, RANS for quick analysis and design iterations, followed by LES on selected designs or critical regions to validate and fine-tune the aerodynamic performance.

CFD results are often used in conjunction with experimental data. For example, a CFD simulation might identify a promising design modification, which is then tested

in a wind tunnel for validation. Conversely, detailed flow measurements from wind tunnel experiments can be used to calibrate or improve CFD models. This combined use of CFD and physical testing allows engineers to cross-verify results and increases confidence in the predictions [2].

### 3.2 Wind Tunnel and On-Road Testing

Physical testing remains an essential part of aerodynamic optimisation. Full-scale wind tunnel tests of trucks provide realistic data on aerodynamic forces and flow patterns, though such tests are expensive and require specialised facilities. Wind tunnel testing can replicate various wind speeds and yaw angles in a controlled environment, enabling measurement of drag, lift, and side forces on the vehicle. Where full-scale testing is impractical, scale models of trucks are often tested in wind tunnels to guide design decisions.

An alternative and complement to wind tunnel tests is on-road testing, such as coast-down tests or controlled track tests. In on-road aerodynamic tests, the vehicle is instrumented with sensors (for example, pressure taps or velocity sensors) to gather real-time data on drag forces while the truck is driven under actual conditions. A common method is to perform coast-down experiments, where the truck coasts in neutral from a high speed, and the deceleration rate (along with other environmental data) is used to back-calculate the drag coefficient. On-road tests, especially when combined with standardised procedures and corrections, can capture the effects of true operational conditions (including turbulence from the ground and surrounding environment, and the influence of vehicle motion and chassis dynamics on airflow) that might not be fully replicated in a wind tunnel. Overall, using both wind tunnel (or “laboratory”) tests and road tests in tandem provides a more comprehensive evaluation of a truck’s aerodynamic behaviour.

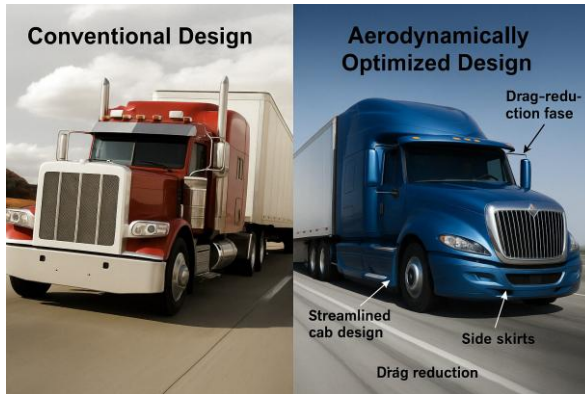
### 3.3 AI-Assisted Optimisation

Artificial intelligence techniques, particularly machine learning (ML), have recently been introduced to the aero-dynamic optimisation process. ML can be used to model the complex relationship between design parameters (such as shape dimensions or add-on device configurations) and the resulting aerodynamic drag [6]. As shown in Figure 1, by training on data from CFD simulations or experiments, ML models (for instance, neural networks or surrogate models) can quickly predict aerodynamic performance for new design variants. This capability enables a rapid exploration of the design space without needing to run a full high-fidelity simulation for every iteration.

One approach is to integrate ML into the design loop: a surrogate model is created based on initial CFD results, and then an optimisation algorithm searches this model for designs that minimise drag. Promising candidates identified by the AI are then verified with CFD or wind tunnel tests, and the results can further refine the model. In this way, AI assists in guiding the design towards an optimal solution much faster than a brute-force search. Researchers have demonstrated that such data-driven

optimisation can reliably find aerodynamic improvements while significantly reducing the number of expensive simulation runs required [6]. Recent studies have successfully applied surrogate modelling for multi-objective aerodynamic optimisation, balancing drag reduction with vehicle stability. As computational power and data availability grow, AI-assisted aerodynamic design is expected.

To become even more prevalent, allowing real-time or near-real-time aerodynamic shape tuning and multi-objective optimisation (considering not just drag but also stability, noise, and other factors).



**Fig. 1.** Comparison of a conventional flat-front truck cab (left), a streamlined cab with a roof deflector (right).

## 4 Case Studies of Aerodynamic Improvement

To illustrate the practical impact of various aerodynamic optimisations, this section presents several case studies focusing on different parts of a medium-duty truck.

### 4.1 Cab Design Optimisation

The truck's front-end design has a major influence on overall drag. We compare a traditional, flat-front cab with a modern streamlined cab. The conventional truck cab, having a blunt face, tends to cause early airflow separation, resulting in a large wake immediately behind the cab and increased drag. In contrast, a streamlined cab design with smooth curves and a sloped windshield guides airflow more gradually over the tractor, thereby reducing the size and intensity of separated flow regions. This difference improves not only the drag coefficient but also the vehicle's stability in crosswinds, as the airflow attachment is improved.

One simple yet effective device for the cab is a roof-mounted air deflector (also known as a roof fairing) installed on top of the cab to guide airflow over the front of the cargo box. Figure 1 illustrates a truck with a roof deflector. Such a deflector can reduce the pressure buildup on the front face of the trailer or cargo box by smoothly channelling air upward. Studies indicate that adding a well-designed cab roof

deflector can achieve an overall drag reduction on the order of 5–10% for a cab-over-engine truck configuration [4]. This translates into meaningful fuel savings, especially during high-speed highway operation where aerodynamic drag dominates. Many modern medium and heavy-duty trucks now come equipped with integrated roof fairings as part of their aerodynamic package.

## 4.2 Cargo Body and Trailer Optimisation

The cargo box (for a straight truck) or the trailer (for a tractor-trailer combination) is typically a bluff rectangular shape that generates considerable aerodynamic drag at the rear. Two common add-on modifications to address this are side skirts and rear tail fairings (also known as trailing-edge flaps or boat tails).

Side skirts are panels mounted along the lower sides of the truck or trailer, extending toward the ground. Their purpose is to reduce the amount of air flowing underneath the truck and to minimise the turbulence and vortices generated by the underbody and wheels. By blocking crossflow under the trailer, side skirts can lower the drag on the vehicle's underside. On medium-duty trucks or trailers, side skirts have been found to reduce overall drag by a few per cent and yield fuel savings of a similar order in highway conditions [5].

Rear fairings or boat tails are tapered panels added to the back of the truck to gradually constrict the airflow leaving the vehicle. Figure 2 shows a schematic of a truck equipped with side skirts and a rear fairing. Instead of the air separating abruptly at the sharp rear edges of the box (which creates a large wake), the rear fairing guides the flow inward, reducing the size of the wake and increasing the pressure at the rear surface. Even a relatively short rear fairing (on the order of 0.5–1 meter long) can significantly cut drag. For instance, combined deployment of side skirts and a rear tail device on a truck can result in drag reductions of 10% or more, translating to fuel consumption improvements of around 5–8% in steady highway driving [5]. These devices are most effective at higher speeds where drag is the dominant resistive force.

Another approach is the use of active aerodynamic devices at the rear. An “active tail” might deploy a movable flap or extendable fairing when the vehicle exceeds a certain speed, optimising the balance between practicality and aerodynamics. Active flow control technologies have also been explored, such as using air jets or suction at the trailer's rear edges to delay flow separation. Research demonstrations of active flow control on large trucks have shown additional drag reduction beyond what passive fairings can achieve [7]. However, such systems are more complex and are still largely experimental. The current trend in industry is to use passive add-on devices (due to their robustness and low cost), although as control technologies mature, more adaptive systems may emerge.

### 4.3 Wheels and Underbody



**Fig. 2.** Aerodynamic add-on devices for a truck: side skirts (along the lower sides) help streamline the underbody flow, and a rear tail fairing (boat tail) reduces the low-pressure wake behind the vehicle.

As shown in Figure 2, exposed wheels and a complex underbody flow are additional contributors to drag on trucks. The rotating wheels and their wells create local areas of turbulence and vorticity. For example, the gap around an exposed truck wheel can act as a cavity that traps and disturbs airflow, resulting in energy losses. Placing aerodynamic fenders or wheel covers can help streamline the airflow around the wheels, thereby lowering drag. In one implementation, simple wheel covers on the rear wheels of a truck were shown to provide a small but measurable drag reduction by smoothing the wheel profile [5]. Ensuring that the wheel arches are designed to minimise air recirculation (for instance, with deflectors that guide air past the wheel well) is another important aspect of wheel aerodynamics [6].

The undercarriage of a truck, with its axles, drivetrain components, and structural elements, also causes airflow disturbances. A flatter, smoother underbody allows air to flow with less separation under the vehicle. Some trucks employ partial underbody fairings or belly pans to cover sections of the chassis. Although installing a completely smooth undertray on a heavy truck can be challenging due to ground clearance and maintenance access, even partial coverage can reduce underbody drag. By decreasing the turbulence generated beneath the vehicle, underbody streamlining contributes to a reduction in overall  $C_d$  and can enhance the effectiveness of other devices like rear diffusers or side skirts. Figure 3 illustrates a medium-duty truck with wheel covers and an underbody fairing added [7-10].

In summary, attention to wheels and underbody aerodynamics — through wheel well design, covers, side skirts, and bottom fairings — yields incremental improvements that complement the larger gains from cab and trailer optimisations. Each element of drag reduction adds up to better fuel efficiency for the truck.

## 5 Conclusion

This study focused on the key technologies and strategies for aerodynamic drag reduction in medium-duty trucks, emphasising the potential for improving fuel efficiency. A multi-faceted approach combining CFD simulation, wind tunnel testing, and AI-based optimisation is emerging as a mainstream trend for enhancing vehicle aerodynamic performance. In practical engineering, it is important to consider the truck's operational conditions and cost constraints to choose an appropriate mix of aerodynamic improvements. For instance, a fleet operator may prioritise low-cost add-ons like side skirts and roof fairings, whereas a truck manufacturer might invest in advanced cab redesign and extensive CFD analysis for a new model.

Looking forward, several development directions hold promise for further drag reduction and efficiency gains. One is the implementation of real-time aerodynamic control systems—for example, active grille shutters or deployable aerodynamic surfaces that adjust to driving conditions on the fly. Another is the integration of vehicle connectivity (telematics) and AI to create adaptive aerodynamics; trucks in a network could coordinate and automatically optimise their aero settings based on data (such as when platooning, where trucks drive closely together to reduce drag) to achieve collective fuel savings [8]. Additionally, the synergy of lightweight materials and aerodynamic design will be important: as trucks incorporate lighter components (to improve payload and efficiency), their designs can be further refined to maintain stability while minimising drag.

In conclusion, aerodynamic optimisation of medium-duty trucks offers a significant opportunity to reduce drag and improve fuel economy. By leveraging a combination of improved vehicle shapes, add-on drag-reduction devices, advanced simulation and testing methods, and intelligent control systems, future trucks can achieve substantially better performance in terms of both fuel efficiency and operational stability on the road.

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