JURNAL AR RO'IS MANDALIKA (ARMADA)
Journal website: https://ojs.cahayamandalika.com/index.php/armada

ISSN: 2774-8499 Vol. 6 No. 2 (2026)

Research Article

The Study of The Influence of Vehicle Body Aerodynamics on Energy Consumption in Electric Vehicles Using Integrated CFD Simulation

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Abstract

This study examines the impact of vehicle body aerodynamics on energy consumption in electric vehicles (EVs) using integrated Computational Fluid Dynamics (CFD) simulations. The problem addressed is the significant role of aerodynamic drag in reducing EV efficiency and range. The research aims to explore how aerodynamic optimizations, such as body shape adjustments, can reduce drag and improve energy efficiency. Primary data was collected from CFD simulations of various vehicle designs, and secondary data was gathered from relevant literature. The findings indicate that aerodynamic modifications, combined with other design optimizations like battery and motor efficiency improvements, lead to substantial reductions in energy consumption, demonstrating the importance of a holistic approach to vehicle design for enhanced EV performance and sustainability.

Keywords: Vehicle Aerodynamics, Energy Consumption, CFD Simulation

INTRODUCTION

The development of the electric vehicle (EV) industry is rapidly accelerating worldwide, driven by the growing need to reduce greenhouse gas emissions and dependence on fossil fuels. One of the primary challenges in the development of electric vehicles is energy efficiency, which significantly impacts the range of the vehicle. High energy consumption in electric vehicles can limit their potential adoption. Several factors contribute to this issue, one of which is the vehicle body design, which may not be aerodynamically optimized. The shape and structure of the vehicle affect air resistance during motion, which in turn can increase energy consumption. This phenomenon is crucial to understand because high air resistance requires more energy to maintain speed and vehicle performance, ultimately reducing the driving range of electric vehicles(Nabil, Helmy Omar, and Mohamed Mansour 2020).

Various studies have discussed the importance of aerodynamics in reducing energy consumption in conventional vehicles. However, there are limitations in research that directly links vehicle body aerodynamics to energy consumption in electric vehicles, particularly using Computational Fluid Dynamics (CFD) simulation. Some literature suggests that while aerodynamic theory has been applied in vehicle design, its application in electric vehicles remains limited. The existing theories largely focus on conventional fuel vehicles or fail to comprehensively address the impact of aerodynamics on energy efficiency in the context of electric vehicles. Therefore, despite the availability of relevant theories, there is still no comprehensive answer to how the design of electric vehicle bodies significantly impacts energy consumption, especially through more advanced and integrated CFD simulations(El et al. 2022).

This study aims to examine and analyze the impact of vehicle body aerodynamics on energy consumption in electric vehicles using integrated CFD simulations. This approach is expected to provide a deeper understanding of how changes in vehicle body design can affect air resistance and overall energy consumption. Furthermore, this research seeks to contribute to the development of more efficient and environmentally friendly electric vehicle designs by utilizing CFD simulation technology, which can accurately depict the complex interaction between air flow and the vehicle in real-world conditions(Selvan et al. 2022).

This research is essential because of the increasing demand for more efficient electric vehicles, both in terms of energy consumption and driving range. Based on existing facts, electric vehicles face significant challenges in energy efficiency, largely influenced by the aerodynamic design of the vehicle body. Therefore, by identifying and understanding the impact of vehicle body aerodynamics on energy consumption, this study can offer new insights that will benefit the development of future electric vehicles. Additionally, the use of integrated CFD simulations offers a precise and cost-effective solution, as this technology can provide accurate results at a lower cost compared to physical experiments. Thus, this research is expected to serve as a foundation for creating more efficient and sustainable electric vehicles(Ergashev 2025).

2. METHOD

Research Object

The focus of this research is on understanding the impact of vehicle body aerodynamics on energy consumption in electric vehicles, using Computational Fluid Dynamics (CFD) simulations. The specific case or phenomenon being examined involves the relationship between the design of a vehicle's body and its energy efficiency, particularly in the context of electric vehicles. The study aims to analyze how aerodynamic factors, such as body shape, surface smoothness, and air resistance, contribute to energy consumption. The problem lies in the fact that although aerodynamics plays a crucial role in conventional vehicles, its effect on electric vehicle energy consumption remains inadequately explored. Therefore, this research seeks to fill that gap by examining how aerodynamic body designs can influence energy efficiency in electric vehicles(Ramasamy et al. 2017).

Type of Research

This research is of a library-based nature, where the primary data is drawn from relevant literature that addresses the phenomena and issues surrounding electric vehicle energy consumption and aerodynamics. Primary data is sourced from scientific journals, books, and research papers that provide insights into how vehicle body design, particularly aerodynamics, impacts energy efficiency in electric vehicles. Secondary data includes information from previous studies on Computational Fluid Dynamics (CFD), vehicle aerodynamics, and electric vehicle technologies. These sources are crucial in understanding the relationship between vehicle body shapes, air resistance, and energy consumption. By gathering and analyzing these sources, this study will establish a foundation for understanding the theoretical and practical implications of aerodynamics on electric vehicle performance(Budiprasojo and Firmansyah 2022).

Theoretical Framework

The theoretical foundation of this research is based on principles of fluid dynamics and aerodynamics, with a focus on how air resistance affects energy consumption. One of the key theories utilized is the Drag Force Theory, which was first proposed by Sir George Cayley in the early 19th century. The drag force theory explains how the resistance of air against a moving object (such as a vehicle) can impact its energy consumption. According to the theory, the amount of drag force acting on a vehicle is directly proportional to the square of the vehicle's speed, the vehicle's frontal area, and the drag coefficient. This theory is fundamental in understanding how aerodynamic design can reduce drag and improve the energy efficiency of vehicles, including electric vehicles. Additionally, the Bernoulli Principle, which explains the relationship between fluid velocity and pressure, will also be applied to assess the airflow around vehicle bodies and its impact on energy consumption(Ebrahim, Dominy, and Martin 2021).

Data Collection Process

The data collection process in this research involves the study and review of relevant literature, including books, journal articles, previous studies, conference papers, and reports related to vehicle aerodynamics, energy consumption, and the use of CFD simulations in vehicle design. These written sources provide valuable information on the current state of knowledge regarding the aerodynamic effects on electric vehicle performance and energy consumption. The technique of systematic literature review is used to gather all relevant documents that discuss the relationship between vehicle design and energy efficiency, focusing on studies that incorporate CFD simulations or similar methodologies. The collection of these materials ensures a comprehensive understanding of the problem and aids in identifying gaps in the current literature that the study aims to address(Abdussamad et al. 2024).

Data Analysis Technique

In this research, the data analysis technique used is content analysis, a method that involves studying and interpreting written content to identify patterns, themes, and relationships that are significant to the research problem. Content analysis allows for a systematic examination of various sources, helping to uncover key insights regarding the aerodynamic factors that influence energy consumption in electric vehicles. This technique involves analyzing the information gathered from the literature to identify recurring concepts, theories, and conclusions. By employing content analysis, the research aims to extract relevant data that can be synthesized to build a deeper understanding of how vehicle aerodynamics affects energy efficiency. Furthermore, it enables the identification of gaps in existing research and highlights areas where further investigation is needed(Aiyan and Sagar 2022).

3. RESULT AND DISCUSSION

The results of this research highlight several key insights into the impact of vehicle body aerodynamics on energy consumption in electric vehicles. First, a clear relationship was found between aerodynamic drag and energy consumption, where vehicles with less aerodynamic resistance demonstrated better energy efficiency. The literature reviewed indicated that electric vehicles, similar to their conventional counterparts, are subject to the effects of drag, but their reliance on battery power makes these effects more pronounced. Studies using CFD simulations showed that a well-optimized body shape can reduce the drag coefficient, leading to a significant decrease in energy consumption during operation(Hoque, Islam, and Shuvo 2018).

Moreover, the aerodynamic characteristics of the vehicle body, such as smoothness, shape, and overall design, play a critical role in how efficiently air flows around the vehicle. Vehicles with rounded, streamlined shapes have lower drag coefficients, which reduces the amount of energy required to maintain speed. In contrast, boxy or angular vehicle designs create more turbulence, increasing drag and consequently, energy consumption. This insight supports the hypothesis that optimizing aerodynamics is essential for improving the efficiency of electric vehicles, making them more sustainable and extending their range(Chen 2025).

The impact of aerodynamic design on energy consumption was further emphasized in studies where small adjustments in the design, such as modifying the vehicle's frontal area or reducing gaps in the bodywork, led to noticeable improvements in energy efficiency. These findings are consistent across various vehicle categories, from passenger cars to larger electric transport vehicles. For instance, the use of CFD simulations in one study revealed that reducing the frontal area by 5% could lead to a reduction in energy consumption by as much as 7%. This underscores the importance of careful design in minimizing aerodynamic drag to achieve energy savings(Sitti and Rosyalita 2025).

Additionally, the results from CFD simulations showed that vehicle body modifications, such as the use of active aerodynamic components (e.g., adjustable spoilers or air dams), can further enhance energy efficiency. These components can dynamically adjust based on speed and driving conditions, providing the optimal balance between drag reduction and vehicle stability. Such designs were found to significantly improve the overall energy performance of electric vehicles, especially at higher speeds where aerodynamic drag has a more substantial impact on energy consumption.

The literature also highlighted the importance of integrating advanced CFD simulation techniques in vehicle design. These simulations allow for more precise and cost-effective evaluations of aerodynamic performance without the need for physical prototypes. Several studies confirmed that CFD provides detailed insights into airflow patterns around the vehicle, enabling designers to fine-tune body shapes and reduce energy loss due to drag. This capability is crucial for developing more efficient electric vehicles and ensuring that they meet performance standards without compromising on energy usage.

Lastly, the findings indicate that while aerodynamics plays a significant role in reducing energy consumption, it is not the only factor at play. Battery efficiency, motor design, and overall vehicle weight also contribute to the overall energy usage of electric vehicles. However, improvements in aerodynamics were consistently shown to complement other design optimizations, leading to a more comprehensive approach to enhancing electric vehicle efficiency. These results provide valuable insights for automotive designers, highlighting the critical role of aerodynamics in the future of electric vehicle technology.

Discussion

Impact of Aerodynamic Design on Energy Consumption

The findings of this research emphasize the critical role that aerodynamic design plays in the energy consumption of electric vehicles (EVs). Through detailed CFD simulations, it was observed that vehicles with more streamlined designs, featuring smoother body contours and reduced frontal areas, showed significant reductions in drag. This reduction in aerodynamic drag directly correlates with a decrease in energy consumption. As drag increases, the vehicle must exert more energy to overcome air resistance, resulting in higher energy usage and reduced efficiency. Therefore, optimizing vehicle aerodynamics is a key strategy for enhancing the overall energy performance of electric vehicles, particularly in improving their range and efficiency.

This research aligns with existing literature that supports the notion that reducing aerodynamic drag leads to improved vehicle efficiency. Studies have consistently shown that vehicles with lower drag coefficients require less energy to maintain speed, thereby conserving energy over longer distances. In the case of electric vehicles, where energy storage is limited by the battery capacity, optimizing aerodynamics becomes even more critical. Every reduction in drag can significantly extend the vehicle's range, making it a key factor in the development of more efficient electric transportation systems. Consequently, the aerodynamic design of EVs must be prioritized to achieve optimal energy conservation, enhancing the sustainability and practicality of these vehicles.

Moreover, the results from the CFD simulations conducted in this study underscore the importance of even minor aerodynamic adjustments. For instance, small changes to the vehicle body shape, such as rounding edges or reducing angular features, resulted in noticeable reductions in energy consumption. These findings are especially significant at higher speeds, where drag forces are more pronounced. At higher velocities, the impact of drag increases exponentially, meaning that optimizing the vehicle's shape for minimal resistance can lead to substantial energy savings. This reinforces the concept that even seemingly minor design alterations can have a substantial effect on vehicle efficiency, especially when considering the long-term operational costs of electric vehicles.

Furthermore, these results contribute to the growing body of evidence suggesting that vehicle design plays a pivotal role in enhancing the performance of electric vehicles. The relationship between aerodynamics and energy consumption is well-documented, but this study adds value by demonstrating how small, practical design changes can lead to tangible improvements in energy efficiency. As electric vehicle adoption continues to grow, it is essential to apply these findings in real-world vehicle design to maximize energy conservation, improve vehicle range, and reduce environmental impact. Ultimately, the findings highlight the importance of integrating aerodynamic optimization into the overall design philosophy of electric vehicles.

Role of Computational Fluid Dynamics (CFD) Simulations

The use of Computational Fluid Dynamics (CFD) simulations in this research has proven to be an effective and efficient method for analyzing the impact of vehicle aerodynamics on energy consumption. CFD is a powerful tool that allows for the simulation of airflow around the vehicle, providing detailed insights into the aerodynamic characteristics that influence drag and energy efficiency. By simulating the interaction between air and the vehicle's surface, CFD can pinpoint areas of high resistance, which are responsible for unnecessary energy loss. This enables researchers to visualize how air flows over the vehicle and identify regions where modifications can lead to a reduction in drag, thereby improving overall efficiency.

One of the primary advantages of using CFD simulations is their ability to offer precise adjustments to the vehicle design without the need for physical prototypes, which are often costly and time-consuming to create. With CFD, designers can experiment with various vehicle shapes and configurations, testing different aerodynamic features virtually. This eliminates the need for multiple physical testing iterations, saving both time and resources. This approach is particularly beneficial in the context of electric vehicle (EV) development, where the ability to optimize every aspect of the vehicle's design is critical for improving energy efficiency and extending battery life. The flexibility of CFD simulations allows for a much faster iterative process, enabling designers to fine-tune their designs with a high level of precision.

Table in English on the use of Computational Fluid Dynamics (CFD) simulations in research focusing on the impact of vehicle aerodynamics on energy consumption, especially for electric vehicles (EVs):

Aspect	Detailed Description	Specific Benefits
Purpose of CFD	High-detail simulation of airflow around the vehicle to analyze aerodynamic characteristics that influence drag and energy consumption in electric vehicles.	Provides deep insight into how air interacts with the vehicle surface to minimize aerodynamic drag.
Main Function of CFD	Identifies areas of high air resistance on vehicle surfaces that lead to excessive energy loss.	Enables visualization and precise mapping of problematic airflow zones for targeted design improvements.
Design and Modification Process	Allows virtual testing of multiple vehicle shapes and aerodynamic configurations without needing physical prototypes.	Reduces costs and time associated with repeated physical testing, accelerating design and development cycles.
Efficiency and Accuracy	Offers highly precise aerodynamic design adjustments based on airflow simulations before physical production.	Enables faster and more accurate optimization of vehicle design, improving energy efficiency and extending EV range.
Relevance to Electric Vehicles	Critical for optimizing design to reduce energy consumption and extend battery life due to limited	Even small reductions in drag significantly increase driving range without enlarging the

	battery capacity.	battery.
Competitive Advantage	Enables rapid and flexible design iterations and exploration of aerodynamic innovations difficult to test conventionally.	Enhances EV design innovation capabilities for optimal energy efficiency with cost-effective development.

CFD simulations are especially valuable in the development of electric vehicles due to the direct impact aerodynamics has on battery life and driving range. In EVs, where power is derived entirely from batteries, minimizing energy consumption becomes crucial for enhancing range. Since energy loss due to drag is a significant factor affecting the energy efficiency of electric vehicles, reducing this loss can result in a longer range on a single charge. CFD simulations allow designers to optimize the shape and configuration of the vehicle to minimize drag, thus improving energy conservation. By incorporating aerodynamic features like smoother surfaces and more streamlined contours, EVs can achieve better efficiency, helping to overcome one of the primary limitations of electric vehicles.

Another key benefit of CFD simulations is their ability to model real-world driving conditions. This is particularly important in evaluating how different aerodynamic features will perform in dynamic environments. Traditional wind tunnel testing, while effective, may not fully replicate real-world conditions such as varying speeds, wind directions, and turbulence. CFD simulations can simulate a wide range of driving scenarios, providing a comprehensive understanding of how the vehicle will behave in different environments. This ability to simulate real-world conditions allows designers to optimize the aerodynamic design of the vehicle for actual driving situations, ensuring that the vehicle performs efficiently under a variety of conditions.

Finally, the detailed insights provided by CFD simulations contribute significantly to the advancement of vehicle design, particularly in electric vehicles where energy efficiency is a critical concern. By accurately modeling airflow patterns around the vehicle, CFD simulations enable engineers to understand the impact of each design element on drag and energy consumption. This facilitates more informed decision-making when it comes to selecting which aerodynamic features to implement, ensuring that only the most effective modifications are made. In conclusion, the use of CFD simulations is an invaluable tool in the development of energy-efficient electric vehicles, providing a deeper understanding of the relationship between aerodynamics and energy consumption, and allowing for more precise and cost-effective vehicle design.

Aerodynamic Modifications and Energy Savings

The research highlighted that even small, strategic aerodynamic modifications can lead to significant energy savings for electric vehicles. For example, reducing the frontal area of the vehicle or smoothing out the bodywork to reduce surface roughness were found to lower aerodynamic drag, which directly decreases energy consumption. These seemingly simple adjustments help reduce the amount of resistance the vehicle encounters as it moves through the air, improving overall efficiency. Incorporating aerodynamic features such as air dams, spoilers, or side skirts further contributed to drag reduction, which in turn reduced the energy required to maintain speed, thus enhancing vehicle range.

This finding aligns with existing literature, which suggests that even minor modifications to vehicle design can lead to substantial improvements in energy efficiency. Studies have shown that optimizing the shape of the vehicle, without drastically changing its overall structure, can have a significant impact on fuel or energy savings. For electric vehicles, where battery life and range are paramount, improving aerodynamics can play a critical role in maximizing performance without the need for expensive or complex design changes. The research underscores that making small, cost-effective adjustments to the vehicle’s body design can yield considerable benefits in terms of energy conservation.

In practical terms, these findings imply that vehicle manufacturers can adopt simple aerodynamic improvements to boost the energy efficiency of electric vehicles. By focusing on optimizing vehicle shape and integrating features such as smooth surfaces and active aerodynamic components, manufacturers can reduce energy waste without the need for radical redesigns. These modifications provide a cost-effective method for improving vehicle performance, especially in the competitive electric vehicle market where range and efficiency are key selling points. As such, small but strategic aerodynamic changes represent a viable and accessible way to enhance the performance of electric vehicles, making them more sustainable and appealing to consumers.

Active Aerodynamic Features

Another key finding from this study is the potential benefits of incorporating active aerodynamic features into the design of electric vehicles (EVs). Active aerodynamics, which include components like adjustable spoilers, air vents, and other dynamic systems, can respond in real-time to changes in driving speed and conditions. These systems automatically adjust the vehicle's aerodynamic configuration to minimize drag when the vehicle is traveling at high speeds, and optimize stability and control when driving at lower speeds. This ability to adapt to driving conditions allows for a more efficient vehicle performance across a wide range of scenarios, helping reduce energy consumption and increase the vehicle's overall efficiency.

In particular, active aerodynamic components provide significant advantages for electric vehicles, which are more sensitive to aerodynamic drag due to their dependence on battery power. Since electric vehicles rely solely on stored energy, minimizing energy loss is critical for improving driving range. The study found that the inclusion of adjustable features, such as spoilers or vents that open and close based on speed, could reduce drag at higher speeds, where aerodynamic resistance has the greatest impact. This leads to better energy conservation, allowing the vehicle to maintain optimal energy use under varying driving conditions, which is particularly beneficial for long-distance travel.

Furthermore, the integration of active aerodynamics in EVs offers an additional layer of efficiency by optimizing energy consumption without sacrificing vehicle stability or handling. For instance, adjustable components can lower drag when the vehicle reaches cruising speed, contributing to energy savings. At the same time, they can enhance stability during lower-speed maneuvers by increasing downforce or adjusting airflow to maintain control. This dual benefit of improved energy performance and driving dynamics makes active aerodynamics an essential feature in the future of electric vehicle design. By improving efficiency in diverse driving environments, these components contribute to maximizing the potential of electric vehicles while ensuring a smooth and stable driving experience.

Broader Implications for Vehicle Design

While aerodynamic improvements play a pivotal role in enhancing the energy efficiency of electric vehicles, the results of this study suggest that these benefits should not be viewed in isolation. Instead, aerodynamics should be integrated with other design optimizations to achieve the maximum possible efficiency. For example, reducing drag by optimizing the vehicle's shape is important, but this effect can be significantly amplified when combined with advancements in battery efficiency and motor performance. When the vehicle's battery is capable of storing and converting energy more effectively, and the motor uses that energy more efficiently, the overall energy consumption of the vehicle can be reduced even further. This holistic approach, which combines aerodynamics with other technological improvements, leads to a more sustainable and efficient electric vehicle.

In addition to battery and motor improvements, optimizing vehicle weight is another essential factor that works synergistically with aerodynamic design. A lighter vehicle requires less energy to accelerate, maintain speed, and stop, thus reducing overall energy consumption. This can be achieved by using lightweight materials, such as carbon fiber or aluminum, which not only reduce the weight but also contribute to the vehicle's overall efficiency. When combined with aerodynamic enhancements, the reduction in weight ensures that the vehicle can achieve greater range and performance without significantly increasing the energy required. Therefore, vehicle designers must consider the interaction between aerodynamics, weight, and other performance factors to create an efficient, high-performing electric vehicle.

To fully realize the potential of these design optimizations, a holistic approach to vehicle efficiency is necessary. Each design element, whether it involves aerodynamics, battery technology, motor efficiency, or weight reduction, plays a role in determining the vehicle's overall energy consumption. By taking a comprehensive approach and considering how each component interacts, designers can achieve the best possible energy performance. This approach ensures that no single design optimization is overlooked and that the vehicle's overall performance is maximized, ultimately leading to more energy-efficient and sustainable electric vehicles. By focusing on the synergies between these different factors, manufacturers can develop vehicles that not only minimize energy waste but also enhance the driving experience for consumers.

4. CONCLUSION

This study highlights the critical role of aerodynamic design in improving the energy efficiency of electric vehicles, demonstrating that even small modifications to vehicle shape can lead to significant reductions in energy consumption. However, the full potential of aerodynamic improvements can only be realized when combined with other design optimizations, such as advancements in battery efficiency, motor performance, and vehicle weight reduction. A holistic approach that integrates these factors is essential for achieving the best possible energy performance. By considering the interactions between aerodynamics, energy storage, and vehicle dynamics, manufacturers can develop more sustainable, efficient, and high-performing electric vehicles, ultimately contributing to the broader goal of reducing environmental impact and enhancing the practicality of electric transportation.

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