Automotive Experiences
Vol. 8 No. 3 (2025) pp. 599-611
p-ISSN: 2615-6202 e-ISSN: 2615-6636

Research Paper

Aerodynamics Performance of Pickup Trucks with and without Covering Cargo Using CFD Analysis

Ruhendran S. Mahendran[1], **Izuan Amin Ishak**[1], **Mohammad Arafat**[1], **Nurshafinaz Mohd Maruai**[2], **Nur Haziqah Shaharuddin**[3], **Shaiful Fadzil Zainal Abidin**[1], **Nurizzatul Atikha Rahmat**[4]

[1]Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), 84600 Pagoh, Johor, Malaysia
[2]Department of Mechanical Precision Engineering, Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia (UTM), Jalan Sultan Yahya Petra, 54100, Kuala Lumpur, Malaysia
[3]Department of Mechanical Engineering, Keio University, Kanagawa 223-0061, Yokohama, Japan
[4]Faculty of Mechanical and Automotive Engineering Technology Pekan Campus, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, Malaysia

izuan@uthm.edum.my

https://doi.org/10.31603/ae.14620

Published by Automotive Laboratory of Universitas Muhammadiyah Magelang

Article Info
Submitted: 25/108/2025
Revised: 19/12/2025
Accepted: 24/12/2025
Online first: 25/12/2025

Abstract

This study evaluates the aerodynamic performance of pickup trucks equipped with different cargo cover configurations with the aim of improving fuel efficiency through drag reduction. Previous studies have shown that cargo cover geometry significantly influences vehicle aerodynamics; however, systematic comparisons across multiple cover types and operating speeds remain limited. In this work, Computational Fluid Dynamics (CFD) simulations were performed using ANSYS Fluent with the standard k–ε turbulence model and a structured mesh to analyse five cargo configurations: open compartment (Case A), bed cover (Case B), canvas cover (Case C), canopy cover (Case D), and camper cover (Case E). Simulations were conducted at vehicle speeds of 70, 90, and 110 km/h. The results indicate that cargo cover geometry has a strong influence on aerodynamic behavior. The canvas cover (Case C) consistently produced the lowest drag coefficient (C_d), ranging from 0.28 to 0.7 across the investigated speeds, due to its streamlined shape and reduced wake turbulence. In contrast, the camper cover (Case E) generated the highest C_d values, ranging from 0.49 to 1.2, as a result of its bulky geometry and pronounced flow separation. For all configurations, C_d increased with vehicle speed, with the camper cover exhibiting the largest rate of increase. Flow visualizations further confirmed that the camper cover produced large vortical structures and an extended wake region, whereas the canvas cover effectively reduced wake size and turbulence intensity. The novelty of this study lies in the systematic comparison of five commonly used pickup truck cargo cover configurations across multiple speeds, with combined analysis of drag and wake characteristics. The findings provide practical understanding of cargo cover selection by highlighting the aerodynamic trade-offs that influence fuel efficiency and vehicle performance in real-world pickup truck operation.

Keywords: Aerodynamics, Cargo covers, Computational Fluid Dynamic (CFD), Flow structures, Pickup trucks

1. Introduction

Covers for cargo have been discovered as one possible way to lower pickup truck aerodynamic drag. This research evaluates the aerodynamic performance of pickup trucks with various cargo cover configurations in order to improve fuel efficiency and drag coefficient (C_d)[1]. Since aerodynamics has a major impact on aspects like speed, stability, fuel economy, and overall performance, it has become an essential field of study in vehicle design. It involves analysing the airflow patterns surrounding automobiles and how they affect handling and energy usage. Compared to other vehicles, pickup trucks provide special aerodynamic issues because of their open cargo areas and bluff-shaped construction [2], which result in large flow separation and increased C_d and turbulence [3]. These aerodynamic inefficiencies are particularly important because pickup trucks are frequently used for heavy-duty, off-road, and transporting tasks in both personal and work settings.

The potential of cargo covers that protect the truck bed, to improve aerodynamic performance is becoming more widely acknowledged [3]. Numerous studies have shown that the presence and design of these covers can improve fuel efficiency, lower drag coefficients, and drastically change airflow behaviour. Mulyawan *et al.* [4] emphasised how roof deflectors and tarpaulin cover can optimise airflow patterns, lowering wake turbulence and improving aerodynamic performance. Similar to this, Alshqirate *et al.* [3] highlighted the influence of slanted cargo covers on vehicle stability and fuel efficiency by using CFD simulations to demonstrate that they might reduce drag coefficients by up to 13%. Vehicle efficiency is mostly determined by the coefficient of drag (C_d), a dimensionless indicator of aerodynamic resistance [5], [6], [7]. Because of flow separation and wake generation at the back, bluff-bodied vehicles, such as pickup trucks, have been found to have increased drag. According to studies by Prachya Mukda [2] and Gamil *et al*. [8], adding streamlined cargo covers to the truck bed can greatly reduce drag and improve vehicle performance [9], [10], [11]. Because it enables precise simulations of intricate flow behaviours and directs design changes without the need for costly prototypes, CFD [12], [13], has shown itself to be a useful tool in analysing these effects.

One of the key metrics used to assess aerodynamic efficiency is the C_d. It is affected by vehicle geometry, speed, and flow separation and measures the resistance an object encounters when travelling through the air [14], [15], [16]. Because of their open cargo areas and bluff bodywork, pickup trucks have higher C_d than streamlined vehicles [1], [17]. Covering the cargo area can dramatically lower C_d values, improving fuel efficiency and reducing pollutants, as demonstrated by several experimental and CFD investigations [18], [19]. Because it allows for the thorough simulation of airflow patterns, drag forces, and turbulence around vehicles CFD, has become a crucial tool in the analysis of these issues [6], [20], [21]. According to studies, knowing how airflow behaves around pickup trucks is essential for enhancing performance and design [22].

Although previous experimental and computational studies have demonstrated that cargo covers can significantly influence the aerodynamic performance of pickup trucks, several important gaps remain in the existing literature. Most prior investigations focus on a limited number of cargo cover geometries or consider a single operating speed, which restricts the generality of their conclusions. Furthermore, many studies primarily emphasize drag reduction without jointly analysing lift characteristics, despite their importance for vehicle stability and handling. A systematic comparison of commonly used cargo cover types under identical simulation conditions, covering a representative range of driving speeds, is therefore still lacking. These limitations reduce the practical applicability of existing findings for real-world pickup truck operation.

To address these gaps, the present study provides a comprehensive CFD-based assessment of five widely used pickup truck cargo cover configurations across three vehicle speeds. The novelty of this work lies in the systematic evaluation of drag and lift coefficients alongside detailed flow visualization, enabling direct comparison of aerodynamic efficiency and stability-related trade-offs among different cargo cover designs. The outcomes of this study offer practical insight for cargo cover selection and contribute to improved understanding of how cargo cover geometry affects pickup truck aerodynamic performance.

2. Methods

This section outlines the methodology employed to analyze the aerodynamic performance of a simplified pickup truck model using CFD simulations in ANSYS Fluent. It details the model configurations, enclosure setup, boundary conditions, mesh refinement, simulation settings, and grid independence study to ensure accurate and reliable results.

2.1. *Model Description*

The pickup truck geometry employed in this study is a simplified model based on the ref. [23], which has been widely used in automotive aerodynamics research to investigate bluff-body flow behaviour. A 1:12 scale model was adopted to reduce computational cost while preserving the dominant aerodynamic features, particularly flow separation and wake formation behind the vehicle. There are five different types of pickup truck designs which are pickup truck models covered with four different types of cargo covers and one pickup truck model without covered with cargo covers (open compartment). **Figure 1** shows Case A (cargo not covered), Case B (bed cover), Case C (canvas cover), Case D (canopy cover), and Case E (camper cover). **Table 1** shows the dimension of the simplified pickup vehicle model.

2.2. *Enclosure and Boundary Conditions*

An essential parameter in numerical simulations including computational fluid dynamics (CFD) and finite element analysis is the enclosure size, referred to as the computational domain. The size of the enclosure affects how accurate and effective the simulation results are. Where boundary conditions are used is determined by the boundaries of the enclosure. **Figure 2** shows the enclosure size when setting up the pickup truck model. The computational domain dimensions were selected following commonly used automotive CFD guidelines to minimize blockage effects and ensure fully developed flow around the vehicle.

Appropriate boundary conditions must be given for dependable findings. The boundary condition utilized in the simulation is depicted in **Figure 3**, which constructs the ground, the outlet, the symmetry side, the velocity inlet, and the vehicle body. The velocity inlet boundary

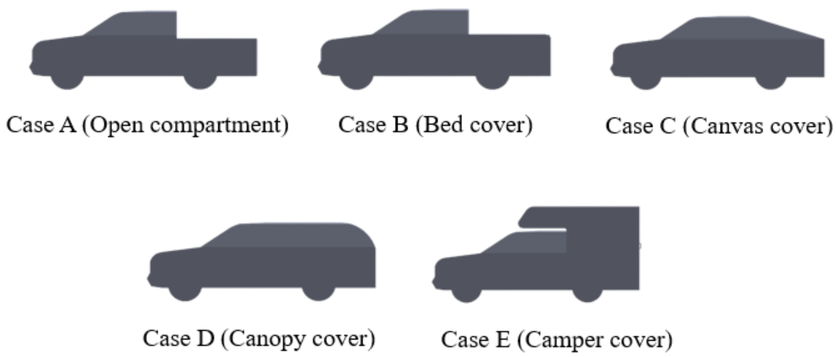

Figure 1. Pickup truck models

Table 1. Dimensions of pickup truck model (open compartment)

Configuration of a basic model	Dimension (mm)
Length	433.12
Width	130
Height	150.03

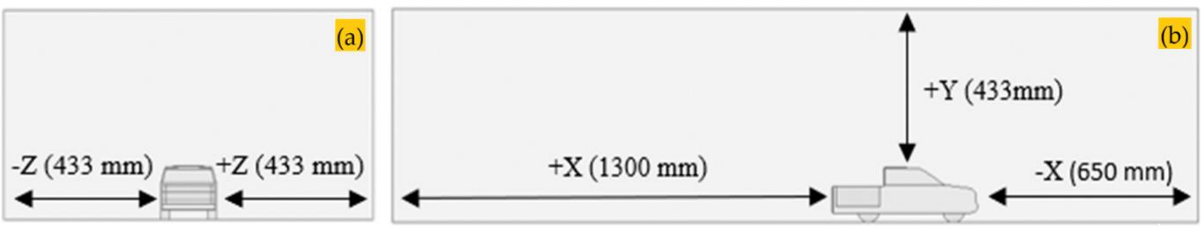

Figure 2. Enclosure for the pickup truck model (a) Front view (b) Side view

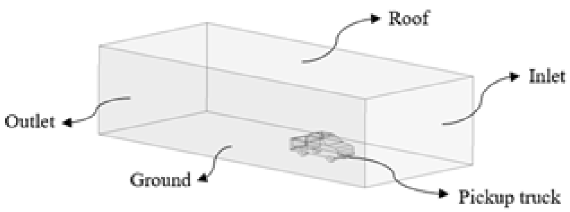

Figure 3. Boundary condition for the pickup truck model

condition is applied at the fluid's entry point into the computational domain. To obtain the freestream conditions, modify the pickup trucks simulation's input velocity. The velocity outlet boundary condition occurs when the fluid leaves the computational domain. Often, a static pressure profile or fixed velocity is used as this boundary condition. All cargo covers were modelled as rigid, non-deformable surfaces; the effects of material flexibility, such as canvas deformation under aerodynamic loading, were not considered in this study.

2.3. *Mesh Refinement*

Unstructured meshing was employed to discretize the computational domain in this study. Based on preliminary mesh sensitivity analysis, a mesh with a nominal element size of 22.5 mm was selected for all simulations. This mesh resolution was applied consistently across all cargo cover configurations to ensure comparable aerodynamic predictions while maintaining reasonable computational cost. Further details regarding mesh convergence and validation are presented in Section 2.5. **Figure 4** illustrates the mesh distribution on the pickup truck model.

2.4. *Simulation Setup*

The Reynolds-Averaged Navier–Stokes (RANS) approach with the standard k–ε turbulence model was adopted due to its robustness, numerical stability, and widespread use in external vehicle aerodynamics studies. Although more advanced turbulence models such as the k–ω SST model may provide improved accuracy in regions of strong flow separation, the k–ε model offers an efficient balance between computational cost and accuracy for comparative analysis of multiple configurations. To determine the aerodynamic performance of pickup trucks across different cargo cover designs and speeds, the study essentially used a steady-state simulation with a fine unstructured mesh (element size 22.5 mm), and the SIMPLE algorithm with suitable boundary conditions. Comprehensive details regarding the solver configuration are presented in **Table 2**. Air was modelled as an incompressible fluid under standard ambient conditions. A uniform inlet velocity corresponding to each test speed was prescribed, with turbulence quantities defined according to typical external aerodynamic flow standard ambient conditions. A uniform inlet velocity corresponding to each test speed was prescribed, with turbulence quantities defined according to typical external aerodynamic flow conditions. Convergence was monitored through residual reduction and stabilisation of aerodynamic force coefficients to ensure solution reliability. In addition, All simulations assumed straight-line vehicle motion with a yaw angle of 0°, representing idealised on-road driving conditions. Crosswind and yaw effects were not considered in the present study and are acknowledged as a limitation.

2.5. *Grid Independent Study*

A grid independence study was conducted to ensure that the predicted aerodynamic coefficients were not influenced by mesh resolution. The open cargo configuration (Case A) was selected as the reference case and simulated at a vehicle speed of 90 km/h using four mesh resolutions: coarse (90 mm), medium (45 mm), fine (22.5 mm), and finer (11.5 mm).

The drag coefficient (C_d) was used as the primary quantitative parameter for evaluating mesh convergence. As the mesh resolution increased, the predicted C_d values exhibited a converging trend, indicating reduced numerical discretization error with finer meshes. While the finest mesh (Mesh 4) produced the lowest

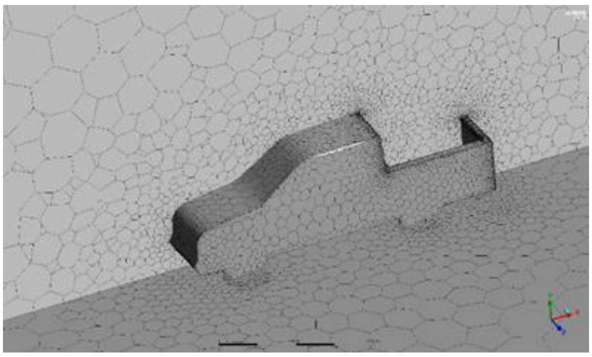

Figure 4. Mesh operation generated for the pickup truck model

Table 2. Parameters for RANS approach use in simulation

Parameters	RANS
Model	k - ε
Type	Standard
Wall treatment	Standard wall functions
Solver type	Steady
Number of iterations	500
Pressure velocity coupling	SIMPLE
Spatial discretization (Gradient)	Green-Gauss cell based
Pressure	Second order
Momentum	Second order upwind
Turbulent kinetic energy	First order upwind
Turbulent dissipation rate	First order upwind

numerical error, the improvement relative to the fine mesh (Mesh 3) was marginal. In contrast, Mesh 3 achieved C_d values within 2.53% of the reference experimental value while requiring significantly lower computational resources than Mesh 4.

Based on this trade-off between numerical accuracy and computational cost, Mesh 3 (element size 22.5 mm) was selected for all subsequent simulations. This mesh resolution was deemed sufficient to capture the essential aerodynamic characteristics of the pickup truck configurations while maintaining computational efficiency. The mesh parameters and corresponding C_d values used in the grid independence study are summarized in Table 3.

3. Results and Discussion

The results were categorized into two main groups for analysis. The quantitative group included drag force coefficient, lift force coefficient and pressure distribution. The qualitative group included velocity streamline and vortex core region caused by changes in velocity acting on the pickup truck.

3.1. *Quantitative Results*

This section presents the quantitative outcomes of the CFD simulation, focusing on how different cargo cover configurations affect key aerodynamic parameters. The analysis includes drag force coefficient, lift force coefficient, and pressure distribution at vehicle speeds of 70 km/h, 90 km/h, and 110 km/h. These results provide insights into the aerodynamic efficiency and stability of each pickup truck configuration.

3.2. *Drag Force Coefficient*

The impact of various cargo cover configurations on a vehicle's drag force coefficient (C_d), which measures aerodynamic efficiency, is shown in Figure 5 (a) – (c). Despite some turbulence, Case A's open cargo arrangement results in a low C_d (0.288) because there is little airflow obstruction. Case B, which has a bed cover, promotes separation at the edges but changes airflow, which slightly raises C_d (0.3105). Case C is the most aerodynamically efficient since it uses a canvas cover to reduce turbulence and flow separation, resulting in the lowest C_d (0.285). On the other hand, because of its less streamlined

Table 3. Parameters used for grid independence study

Mesh Type	Coarse (Mesh 1)	Medium (Mesh 2)	Fine (Mesh 3)	Finer (Mesh 4)
Element Size (mm)	90	45	22.5	11.5
Face Sizing (mm)	50	25	12.5	6.25
Element Number (Cell)	613,581	689,330	1,003,854	2,807,068
Nodes	112,135	126,679	186,351	517,360
Drag Coefficient (C_d)	0.4923	0.4819	0.4700	0.4683
Number of iterations	500	500	500	500
Percentage Error (%)	1	2.16	2.53	0.36

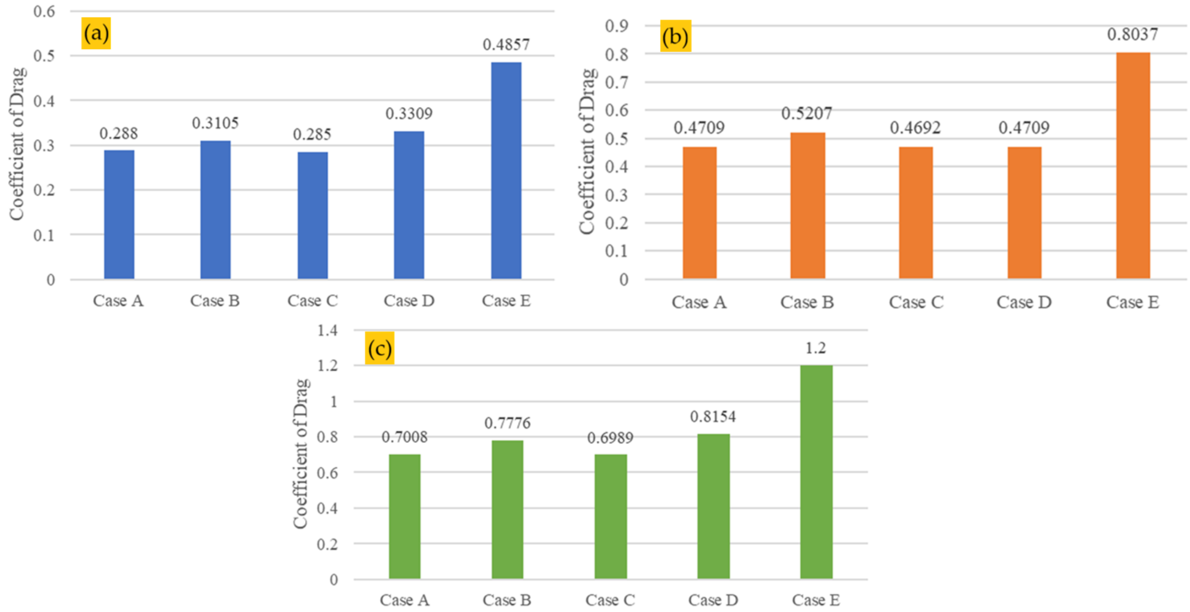

Figure 5. Coefficient of drag (C_d) at (a) 70km/hr, (b) 90km/hr and (c) 110km/hr for open compartment (Case A), bed cover (Case B), canvas cover (Case C), canopy cover (Case D) and camper cover (Case E)

form and bigger frontal surface, Case D, which has a canopy cover, has higher resistance (C_d = 0.3309). The boxy design of Case E, which uses a camper cover, causes significant turbulence and flow separation, giving it the highest C_d (0.4857). With the canvas cover being the most effective and the camper cover the least, the results highlight the significance of aerodynamic design overall.

The drag force coefficients (C_d) for different cargo cover designs at 90 km/h are shown in Figure 5(b). The open cargo configuration (Case A) has a C_d = 0.4709, which is explained by the low turbulence that makes it easy for air to escape. Due to extra turbulence caused on by flow separation at the back corners of the cover, the bed cover configuration (Case B) significantly raises the C_d to 0.5207. By lowering turbulence and flow separation, the canvas cover (Case C) exhibits superior aerodynamic efficiency and obtains the lowest C_d (0.4692). The C_d of the canopy cover (Case D) is the same as that of the open cargo setup (0.4709), indicating that its design has minimal effect on enhancing airflow dynamics. On the other hand, because of its huge, non-streamlined design, which severely impacts airflow and causes huge areas of turbulence, the camper cover (Case E) generates the greatest C_d (0.8037). These results demonstrate the importance of aerodynamic design in reducing drag, with the camper cover producing the most resistance and the canvas cover providing the best performance.

The drag force coefficients (C_d) for different cargo cover designs at 110 km/h are displayed in Figure 5(c). Because of its streamlined shape, which reduces turbulence and flow separation, the canvas cover (Case C) has the lowest C_d (0.6989) and is therefore the most aerodynamically efficient. Due to turbulence from the exposed bed, the open cargo arrangement (Case A) has a little higher C_d (0.7008). Due to airflow disruption at its rear borders, the bed cover (Case B) increases drag a little more, with a C_d of 0.7776. Because of its greater surface area and less streamlined form, the canopy cover (Case D) has a higher C_d (0.8154). Due to its massive and boxy design, the camper cover (Case E) generates the highest C_d (1.2), which causes significant flow separation and turbulence, making it the least efficient at high speeds.

It should be noted that small differences in C_d (below approximately 1%) may fall within the typical numerical uncertainty of RANS-based CFD simulations and should therefore be interpreted cautiously. Nevertheless, the observed trends between configurations are consistent and physically meaningful. Even modest reductions in C_d can translate into measurable fuel savings during highway driving, where aerodynamic drag dominates the total resistance.

3.3. *Lift Force Coefficient*

The coefficient of lift (C_l) for various cargo combinations at 70 km/h is shown in **Figure 6(a)**. Because of the low-pressure zones formed over the open bed, the open cargo configuration (Case A) produces a moderate amount of lift (C_l = 0.146), which causes upward force. By partially enclosing the cargo area, decreasing turbulence, and changing the distribution of pressure, the bed cover (Case B) modestly increases lift (C_l = 0.1574) while maintaining aerodynamic stability. By optimising pressure differentials, the canvas cover (Case C) generates the most lift (C_l = 0.1903); nevertheless, excessive lift may impair vehicle stability even though it increases fuel efficiency. Since its wider structure lessens pressure differentials, the canopy cover (Case D) has a lower lift (C_l = 0.1324), which may improve stability by lowering lift forces. The only configuration with negative lift (C_l = -0.0762), which indicates a downward force, is the camper cover (Case E). Although its boxy shape improves grip and stability by applying more pressure to the top surface, it may also increase rolling resistance and decrease fuel efficiency. These results demonstrate how cargo cover design has a major impact on lift. The necessity to customise designs for certain aerodynamic aims is highlighted by the fact that, although the canvas cover maximises lift, configurations like the canopy and camper coverings may better balance stability and traction.

The coefficient of lift (C_l) at 90 km/h for different cargo cover configurations is displayed in **Figure 6(b)**. Due to turbulence and pressure distribution over the exposed bed, the open cargo configuration (Case A) produces moderate lift (C_l = 0.2512), which marginally lowers downward tyre pressure and could have an impact on stability. By lowering turbulence and promoting smoother airflow, the bed cover (Case B) marginally enhances lift (C_l = 0.2637); nevertheless, the increased lift may affect stability at higher speeds. The streamlined design of the canvas cover (Case C) enhances pressure differentials and generates the largest lift (C_l = 0.3112). Because there is less effective weight on the wheels, stability may be reduced even while fuel efficiency is increased. Because of its bigger structure, which lowers pressure differentials and improves stability by lowering upward lift forces, the canopy cover (Case D) has a lower lift (C_l = 0.2342). The only configuration with negative lift (C_l = -0.1244) is the camper cover (Case E), which disrupts airflow with its boxy form and produces a downward push. This marginally increases rolling resistance but enhances traction and stability, especially in windy or fast-moving situations. While negative lift generated by the camper cover increases drag and reduces fuel efficiency, it can enhance vehicle stability by increasing tire–road contact, particularly at high speeds. This shows an important trade-off

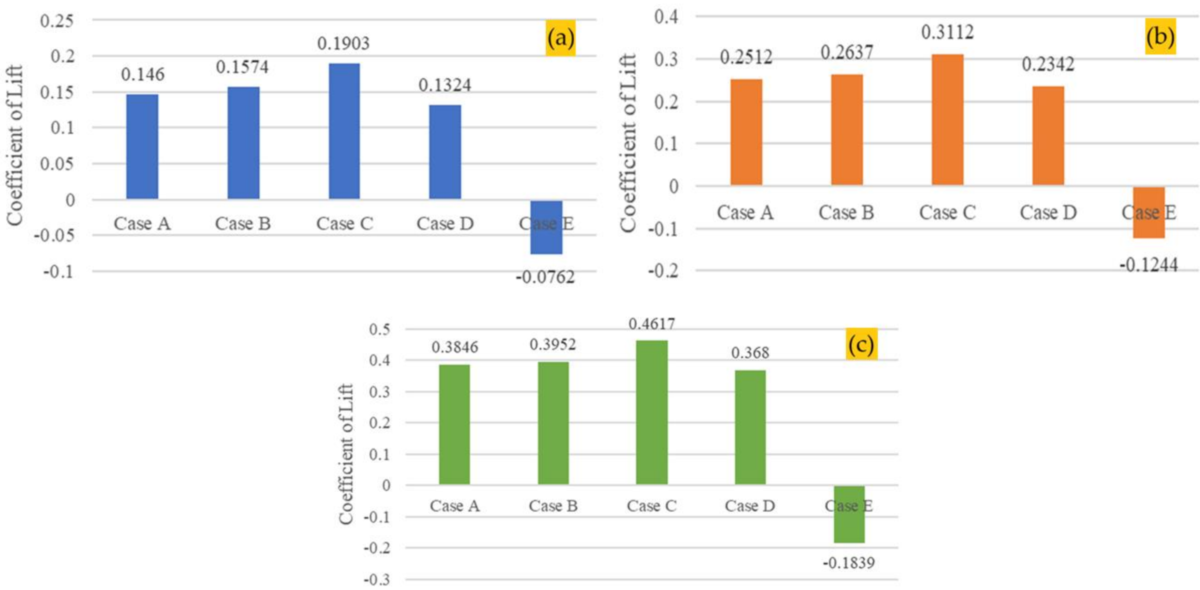

Figure 6. Coefficient of lift (C_l) at (a) 70km/hr, (b) 90km/hr and (c) 110km/hr for open compartment (Case A), bed cover (Case B), canvas cover (Case C), canopy cover (Case D) and camper cover (Case E)

between aerodynamic efficiency and handling stability.

The coefficient of lift (C_l) at 110 km/h for different cargo cover configurations is shown in **Figure 6(c)**. Due to turbulence and partial airflow limitations, the open cargo design (Case A) produces moderate lift (C_l = 0.3846), providing a balance between aerodynamic efficiency and simplicity. By increasing the pressure differential and smoothing airflow, the bed cover (Case B) slightly increases lift (C_l = 0.3952). Of all the configurations, the canvas cover (Case C) has the maximum lift (C_l = 0.4617), mostly because of its streamlined shape, which maximises airflow efficiency while minimising drag and turbulence. The shape of the canopy cover (Case D) limits aerodynamic performance by separating airflow and increasing drag, which results in a reduced lift (C_l = 0.368). The boxy form of the camper cover (Case E) disrupts airflow, resulting in a downward force and a negative lift (C_l = -0.1839). Although this improves stability, aerodynamic efficiency is decreased. The best lift efficiency is provided by the canvas cover, although stability is given priority by the camper cover, which produces a downward force appropriate for particular driving situations.

3.4. Pressure Distribution

Figure 7(a)–(c) present the pressure distribution around the pickup truck for all configurations at the three speeds. The open cargo configuration exhibits low-pressure regions and strong suction at the rear of the vehicle due to flow separation and wake formation, contributing to higher pressure drag.

The canvas cover demonstrates improved pressure recovery near the rear of the vehicle, which is consistent with its lower drag coefficient. By reducing flow separation, the canvas cover minimizes adverse pressure gradients and limits wake growth. The bed and canopy covers show

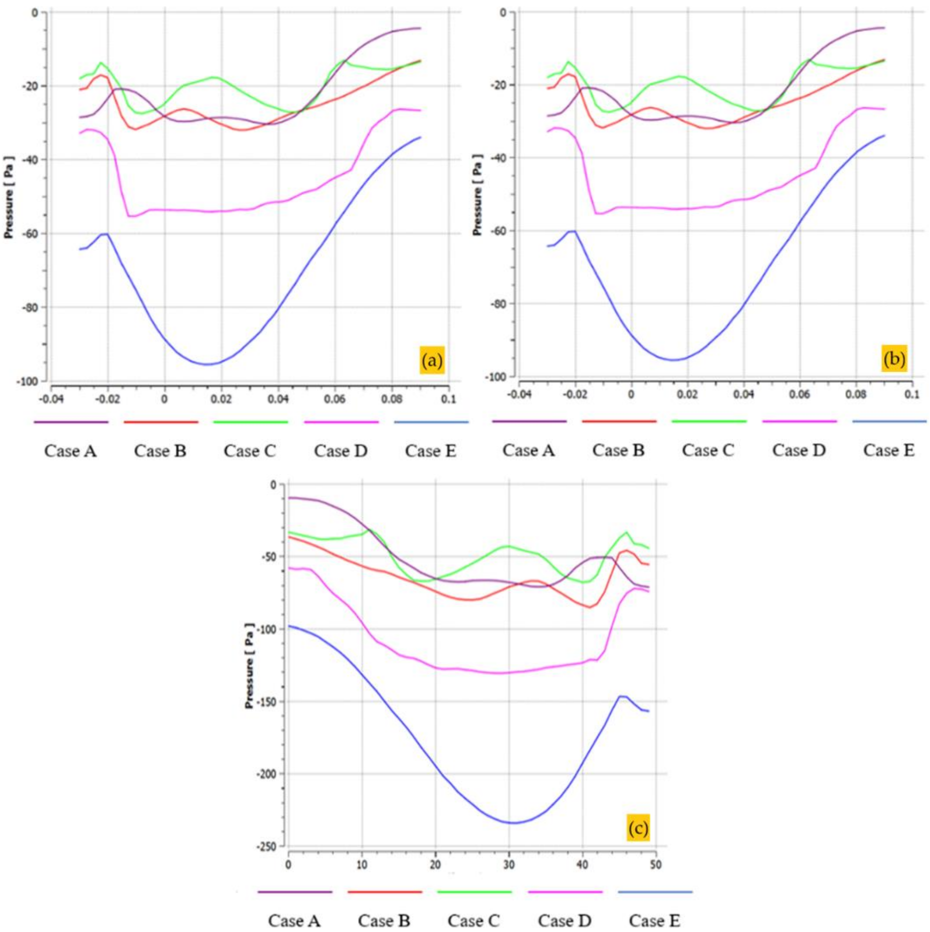

Figure 7. Pressure distribution of (a) 70km/hr, (b) 90km/hr and (c) 110km/hr speed for open compartment (Case A), bed cover (Case B), canvas cover (Case C), canopy cover (Case D) and camper cover (Case E)

moderate pressure recovery, improving upon the open cargo configuration but remaining less effective than the canvas cover. The camper cover displays relatively high pressure on the rear surface due to its enclosed geometry; however, this does not result in drag reduction. Instead, the abrupt geometric transition promotes large-scale flow separation, increasing overall pressure drag. These results indicate that effective pressure recovery must be accompanied by smooth flow attachment to achieve drag reduction.

3.5. *Velocity Streamline*

Figure 8(a)-(e) illustrates the velocity streamlines around a vehicle traveling at 70 km/h under five configurations: open cargo (Case A), bed cover (Case B), canvas cover (Case C), canopy cover (Case D), and camper cover (Case E). Aerodynamic performance is negatively impacted in Case A by the airflow dropping off abruptly into the cargo area, which causes a lot of turbulence, a big wake, and high drag. By using a bed cover, Case B enhances aerodynamics, resulting in a smaller wake, a smoother transition of airflow, and less drag and turbulence. The best results are obtained by Case C, which has a canvas cover and little turbulence, a tiny wake zone, and smooth airflow, guaranteeing the lowest drag and maximum efficiency. In Case D, the canopy cover performs better than open cargo but less efficiently than the canvas and bed cover since it causes considerable turbulence and a noticeable wake as a result of flow separation. Lastly, Case E, which has a camper cover, produces the most drag and the biggest turbulent wake, which drastically lowers aerodynamic efficiency because of the sudden flow separation. The significance of streamlined rear-end designs, like the canvas cover, in reducing turbulence and improving vehicle performance is demonstrated by these findings.

Five different vehicle configurations are shown in Figure 9(a)–(e), which shows the velocity streamline patterns at 90 km/h: open cargo (Case A), bed cover (Case B), canvas cover (Case C), canopy cover (Case D), and camper cover (Case E). Due to airflow entering the cargo area, Case A creates a big wake and severe turbulence, which leads to poor aerodynamic performance and high drag. By keeping the flow linked for a longer period of time, Case B's bed cover increases airflow and lowers wake and drag. With a streamlined canvas cover that reduces turbulence and produces a small, controlled wake, Case C exhibits the highest aerodynamic efficiency and the lowest drag. In comparison to the bed and canvas covers, Case D's sloped canopy causes a moderate disruption in airflow, resulting in a greater wake and mediocre performance. With a camper cover, Case E creates the most turbulence and the biggest wake, which results in the most drag and the lowest aerodynamic efficiency. While open cargo (Case A) and camper covers (Case E) perform poorly because of large wake zones and turbulence, these results demonstrate the advantages of streamlined designs like the canvas cover (Case C) in lowering drag and enhancing overall performance.

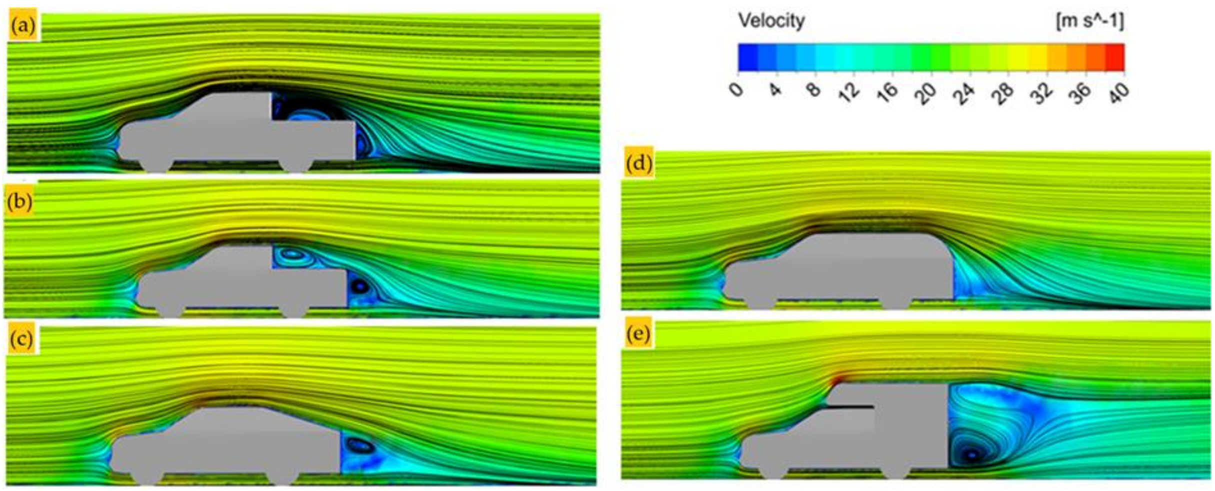

Figure 8. Velocity Streamlines 70km/hr speed for (a) open compartment (Case A), (b) bed cover (Case B), (c) canvas cover (Case C), (d) canopy cover (Case D) and (e) camper cover (Case E)

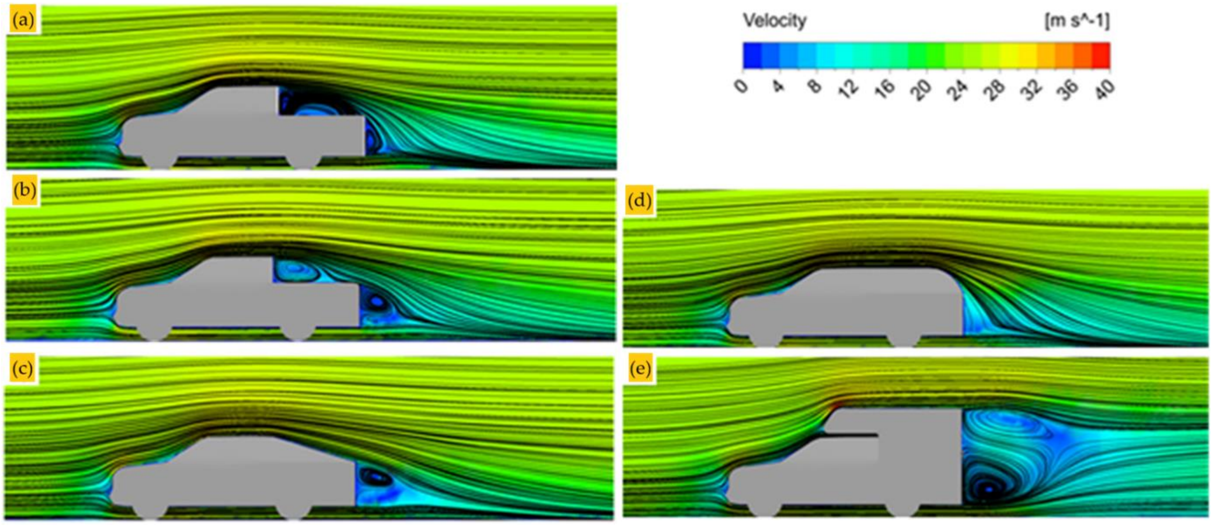

Figure 9. Velocity Streamlines 90km/hr speed for (a) open compartment (Case A), (b) bed cover (Case B), (c) canvas cover (Case C), (d) canopy cover (Case D) and (e) camper cover (Case E)

The velocity streamline's aerodynamic effectiveness is demonstrated in **Figure 10(a)-(e)**,which shows them for a vehicle moving at 110 km/h with different cargo arrangements. Airflow penetrates the cargo compartment in Case A (open cargo), creating wide, turbulent wakes and huge recirculation zones that lead to the highest drag and the lowest aerodynamic efficiency. By enclosing the cargo space, Case B (bed cover) greatly increases efficiency by lowering wake size and turbulence. With its curved surface that maximizes aerodynamic efficiency, reduces recirculation zones, and streamlines airflow, Case C (canvas cover) significantly improves performance. Because of its elevated design, Case D (canopy cover) retains some turbulence and wake but provides a moderate improvement with smoother airflow. Aside from the open cargo, Case E (camper cover) completely encloses the cargo, causing a significant wake and the maximum drag due to its bulky design that obstructs airflow and creates pressure differences. The most efficient designs are generally streamlined ones, such as the canvas cover (Case C), but the camper cover (Case E) and open cargo (Case A) have the worst aerodynamic performance.

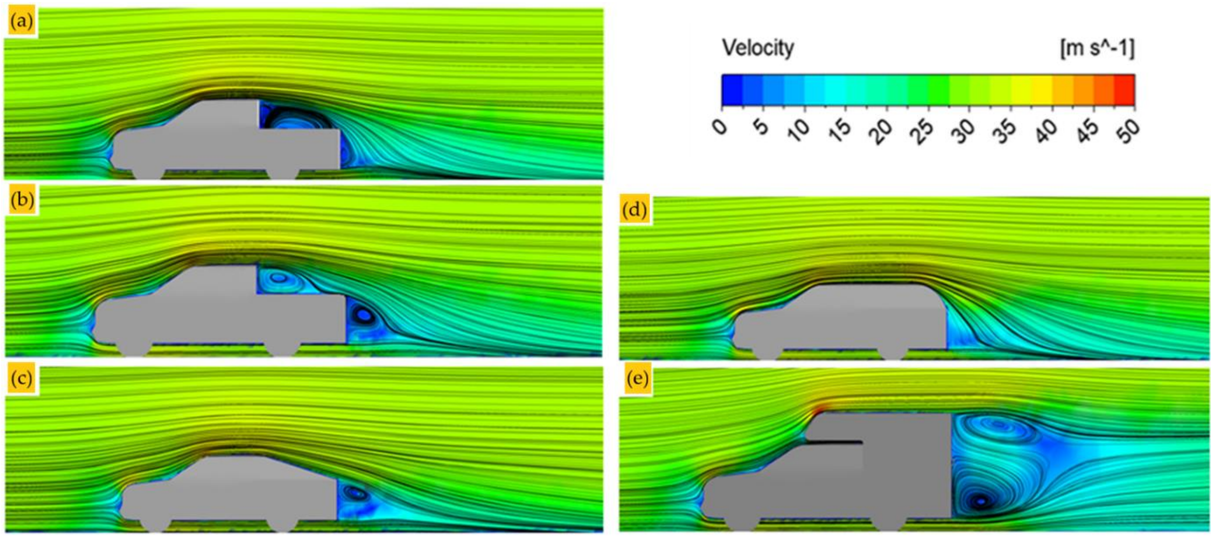

Figure 10. Velocity Streamlines 110km/hr speed for (a) open compartment (Case A), (b) bed cover (Case B), (c) canvas cover (Case C), (d) canopy cover (Case D) and (e) camper cover (Case E)

4. Conclusion

This study numerically investigated the aerodynamic performance of a pickup truck with five different cargo cover configurations using steady-state CFD simulations at vehicle speeds of 70, 90, and 110 km/h. The analysis combined drag and lift coefficients with flow-field visualisation to evaluate the influence of cargo cover geometry on aerodynamic efficiency and wake behaviour.

The results demonstrate that cargo cover design has a substantial impact on pickup truck aerodynamics. Among the configurations examined, the canvas cover (Case C) consistently achieved the lowest drag coefficient across all speeds due to its streamlined geometry, which delayed flow separation and reduced wake size. In contrast, the camper cover (Case E) produced the highest drag coefficients as a result of its bulky and non-streamlined shape, leading to extensive flow separation and a large turbulent wake. The bed cover (Case B) and canopy cover (Case D) exhibited intermediate aerodynamic performance, indicating that partial enclosure alone is insufficient to achieve significant drag reduction without appropriate geometric streamlining. Significant variations in lift behaviour were also observed. The canvas cover generated the highest positive lift, which may enhance aerodynamic efficiency but could potentially affect vehicle stability at high speeds. Conversely, the camper cover produced negative lift at all tested speeds, increasing aerodynamic drag while simultaneously providing a stabilizing downward force on the vehicle. These findings highlight an important trade-off between drag reduction for fuel efficiency and lift-related stability, which should be considered in cargo cover design and selection.

Overall, this study provides clear evidence that streamlined cargo cover geometries can substantially improve aerodynamic efficiency and potentially reduce fuel consumption in pickup trucks, while non-streamlined designs may compromise efficiency despite offering stability benefits. The results offer practical guidance for cargo cover selection and underline the importance of aerodynamic considerations in the design of pickup truck accessories.

Acknowledgements

Communication of this research is made possible through monetary assistance by Universiti Tun Hussein Onn Malaysia.

Author's Declaration

Authors' contributions and responsibilities

The authors confirm contribution to the paper as follows: study conception and design: Ruhendran S.Mahendran, Izuan Amin Ishak, Mohammad Arafat; data collection: Ruhendran S.Mahendran; analysis and interpretation of results: Ruhendran S.Mahendran, Izuan Amin Ishak, Mohammad Arafat; draft manuscript preparation: Ruhendran S.Mahendran, Izuan Amin Ishak, Nurshafinaz Mohd Maruai, Nur Haziqah Shaharuddin, Shaiful Fadzil Zainal Abidin, Nurizzatul Atikha Rahmat. All authors reviewed the results and approved the final version of the manuscript.

Funding

No funding was received for this research

Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

References

[1] A. M. Al-Garni and L. P. Bernal, "Experimental study of a pickup truck near wake," *J. Wind Eng. Ind. Aerodyn.*, vol. 98, no. 2, pp. 100–112, Feb. 2010, doi: 10.1016/j.jweia.2009.10.001.

[2] P. Mukda, "Effect from Accessories on Pickup Aerodynamics by Computational Fluid Dynamics," in *6th International Conference on Advances in Engineering Sciences and Applied Mathematics (ICAESAM-2016) Dec. 21-22, 2016 Kuala Lumpur (Malaysia)*, International Institute of Engineers, Dec. 2016. doi: 10.15242/IIE.E1216022.

[3] Abed Alrzaq Alshqirate, Dastan Zrar Ghafoor, and Sachin L. Borse, "CFD Analysis of Flow Over Pickup Truck with And Without Covering Cargo Area Using OpenFOAM," *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 90, no. 1, pp. 40–51, Dec. 2021, doi: 10.37934/arfmts.90.1.4051.

[4] A. Mulyawan, Anak Agung Adhi Suryawan, and Ainul Ghurri, "Analysis of Variations in Tub Cover Tarpaulin Shape Against Airflow

Patterns and Pressure Distribution Characteristics on Pickup Trucks with the Addition of Roof Deflector," *Nat. Sci. Eng. Technol. J.*, vol. 2, no. 2, pp. 103–109, Mar. 2022, doi: 10.37275/nasetjournal.v2i2.19.

[5] M. H. Dasar and D. J. Patil, "CFD Simulation of Pickup Van," *Int. J. Eng. Res. Technol.*, vol. 2, no. 12, pp. 1995–2004, 2013.

[6] L. s/o Ramachandra, I. Amin Ishak, M. Arafat, N. A. Zolpakar, S. F. Zainal Abidin, and D. Mohd Harun, "Numerical Analysis on the Performance of Aerodynamic Devices on a Car Using CFD," *Int. J. Integr. Eng.*, vol. 16, no. 6, pp. 154–163, Oct. 2024, doi: 10.30880/ijie.2024.16.06.015.

[7] Ainul Ghurri *et al.*, "CFD Simulation of Aerodynamics Truck Using Cylinder as Drag Reduction Device," *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 105, no. 2, pp. 166–181, Jun. 2023, doi: 10.37934/arfmts.105.2.166181.

[8] A. I. Gamil, T. Syam, M. A. Arab, and S. Ghani, "Areadynamic Analysis of GMC Sierra Pickup Truck," in *2021 12th International Conference on Mechanical and Aerospace Engineering (ICMAE)*, IEEE, Jul. 2021, pp. 535–545. doi: 10.1109/ICMAE52228.2021.9522367.

[9] J. Kim, J. Pattermann, V. Menon, and W. Mokhtar, "A CFD Study of Pickup Truck Aerodynamics," *Am. Soc. Eng. Educ.*, pp. 1–9, 2011.

[10] N. Ashgriz and J. Mostaghimi, "An Introduction to Computational Fluid Dynamics Chapter 20 in Fluid Flow Handbook," *Convergence*, p. 1, 2002.

[11] A. Sharma, "Front Matter," in *Introduction to Computational Fluid Dynamics*, Wiley, 2016. doi: 10.1002/9781119369189.fmatter.

[12] W. J. G. S. Pinto and O. Almeida, "Numerical and Experimental Analysis of the Flow Over a Commercial Vehicle - Pickup," *Rev. Eng. Térmica*, vol. 17, no. 2, p. 92, Dec. 2018, doi: 10.5380/reterm.v17i2.64136.

[13] T. Hanlon and D. Risk, "Using computational fluid dynamics and field experiments to improve vehicle-based wind measurements for environmental monitoring," *Atmos. Meas. Tech.*, vol. 13, no. 1, pp. 191–203, Jan. 2020, doi: 10.5194/amt-13-191-2020.

[14] J. Srebric, V. Vukovic, G. He, and X. Yang, "CFD boundary conditions for contaminant dispersion, heat transfer and airflow simulations around human occupants in indoor environments," *Build. Environ.*, vol. 43, no. 3, pp. 294–303, Mar. 2008, doi: 10.1016/j.buildenv.2006.03.023.

[15] J. Xu and S. Zhou, "Flow field analysis of trucks and a design of an additional drag reduction device," *Eng. Rev.*, vol. 38, no. 1, pp. 70–78, 2018.

[16] J. Ha, S. Jeong, and S. Obayashi, "Drag reduction of a pickup truck by a rear downward flap," *Int. J. Automot. Technol.*, vol. 12, no. 3, pp. 369–374, Jun. 2011, doi: 10.1007/s12239-011-0043-7.

[17] V. Atatug and S. Bayraktar, "Numerical investigation of aerodynamic characteristics of generic pickup trucks," *Pamukkale Univ. J. Eng. Sci.*, vol. 26, no. 1, pp. 21–29, 2020, doi: 10.5505/pajes.2019.43778.

[18] S. Holloway, J. H. Leylek, W. D. York, and B. Khalighi, "Aerodynamics of a Pickup Truck: Combined CFD and Experimental Study," *SAE Int. J. Commer. Veh.*, vol. 02, no. 1, pp. 2009-01–1167, Apr. 2009, doi: 10.4271/2009-01-1167.

[19] Mohamed B. Farghaly, H. H. Sarhan, and E. S. Abdelghany, "Aerodynamic Performance Enhancement of a Heavy Trucks using Experimental and Computational Investigation," *CFD Lett.*, vol. 15, no. 8, pp. 73–94, Jun. 2023, doi: 10.37934/cfdl.15.8.7394.

[20] P. Jurusan, "an Experimental Study of the Aerodynamics Forces Acting on a Truck," vol. 5, no. mm, p. 5, 2012.

[21] M. Arafat, I. A. Ishak, and N. Mohd Maruai, "Assessment of computational fluid dynamics simulation approach for the aerodynamic performance of small unmanned aerial vehicle propeller," *Eng. Res. Express*, vol. 6, no. 4, p. 045578, Dec. 2024, doi: 10.1088/2631-8695/ad9e6c.

[22] P. K. Varadarajoo, I. A. Ishak, D. S. B. Maji, N. M. Maruai, A. Khalid, and N. Mohamed, "Aerodynamic Analysis on the Effects of Frontal Deflector on a Truck by using Ansys Software," *Int. J. Integr. Eng.*, vol. 14, no. 6, pp. 77–87, 2022, doi: 10.30880/ijie.2022.14.06.008.

[23] E. Guilmineau, "Numerical Simulation of Flow Around a Generic Pickup With ISIS-CFD," in *ASME 2010 3rd Joint US-European Fluids Engineering Summer Meeting: Volume 1, Symposia – Parts A, B, and C*, ASMEDC, Jan. 2010, pp. 2669–2680. doi: 10.1115/FEDSM-ICNMM2010-30680.