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Design and Fabrication of an Aerodynamic Body Kit for Formula Student Electric Vehicle (FSEV)

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Abstract

Aerodynamic performance is an important factor to improve the efficiency, stability and handling characteristics of Formula Student electric vehicles (FSEV). However, most of the aerodynamics packages used in the Formula Student competitions relies on costly composite materials and sophisticated manufacturing processes, which are hard to implement in projects at the student level with limited financial and manufacturing resources. Therefore, this study is to design and evaluate a low-cost aerodynamic body kit for a Formula Student electric vehicle using Computational Fluid Dynamics (CFD) analysis and conventional manufacturing methods. The proposed aerodynamic package includes a streamlined nose cone, side panels, airflow channels, underbody diffuser and rear aerodynamic elements all made predominantly from aluminum material. The CFD simulations were carried out using ANSYS Fluent 2024 R1 in steady state conditions at the inlet velocities of 20 m/s, 28 m/s, 33.33 m/s and 40 m/s with the SST k-ω turbulence model. The aerodynamic performance was assessed by streamline distribution, pressure contour characteristics, drag force and lift coefficient behavior. The simulation results showed that the proposed body kit reduced the drag force from 980 N to 865 N at 33.33 m/s which is approximately 11.73 % drag reduction. Also, the lift coefficient increased from −0.74 to −0.88, which means an increase in downforce generation and an improvement of the vehicle stability at high speeds. The optimized body geometry also avoided the separation of the air flow and minimized the formation of a wake behind the vehicle. The results indicate that a practical and cost-effective aerodynamic body kit can significantly enhance the aerodynamic performance of Formula Student electric cars without advanced manufacturing technologies.

1. Introduction

Formula Student is a competition in which engineering students learn automotive engineering by designing fabricating and testing race vehicles. In recent years, Formula Student electric vehicle (FSEV) has attracted more attention due to the increasing demand for sustainable transportation systems and energy-efficient vehicle technologies [1], [2]. Aerodynamics is one of the crucial engineering challenges of Formula Student vehicle development, which defines vehicle efficiency, acceleration capability, energy consumption and high-speed stability [3], [4]. Aerodynamic drag is directly related to the energy needed to propel the vehicle at high speeds and aerodynamic lift affects tire grip, braking performance and stability while cornering [5]. Too much drag leads to power losses and reduces the efficiency of acceleration, but too little downforce can make the car unstable during high-speed maneuvers. Therefore, many Formula Student teams use aero parts like front wings, diffusers, sidepods and rear wings to improve the flow management around the vehicle body [6], [7].

Previous studies have shown that optimized aerodynamic geometries can improve the air flow attachment, decrease the wake generation and minimize the pressure drag [8-12]. Computational Fluid Dynamics (CFD) analysis is one of the most widely employed tools in the development of aerodynamics, since it allows a detailed evaluation of streamline behavior, pressure distribution and vortex formation during the design phase [3], [4]. In advanced Formula Student applications, aerodynamic packages are frequently made from carbon fiber composites and validated in wind tunnel testing. These designs exhibit high aerodynamic efficiency, but require expensive materials, specialized fabrication techniques and advanced manufacturing facilities not always available to student level engineering projects. Thus, there is still a need for an aerodynamic solution which is both practical and cost-effective for the improvement of aerodynamic performance, whilst retaining manufacturability and accessibility with conventional workshop equipment. Aluminum material is a good alternative due to its low weight, corrosion resistance, structural rigidity and ease of fabrication by common manufacturing processes [13]. Moreover, proper airflow management assists in cooling the components of electric vehicles, such as batteries and motor controllers [14].

Considering these factors, the objective of this study is to design, manufacture and evaluate a low-cost aerodynamic body kit for a Formula Student electric vehicle using CFD analysis and conventional manufacturing methods. The study aims to improve aerodynamic efficiency, reduce drag force and enhance vehicle stability while maintaining practical manufacturability of the case for student level applications.

2. Methodology

2.1 Vehicle Specification

The Formula Student electric vehicle was built on a tubular steel chassis with an aluminum aerodynamic body structure. Table 1 summarizes the vehicle specifications.

Table 1 *Vehicle specifications*

Parameter	Value
Total vehicle weight	230 kg
Battery weight	45 kg
Motor power	25 kW
Maximum speed	120 km/h
Reference area	1.20 m^2
Vehicle height	1.00 m
Vehicle width	1.20 m
Wheelbase length	1.55 m

2.2 Aerodynamic Body Kit Design

The aerodynamic body kit was designed with the aim of aerodynamic efficiency, manufacturability, structural integration and airflow management around the vehicle body. A range of conceptual designs were examined before settling on the final configuration. The final version of the body kit included a pointy nose cone, side panels, airflow channels, underbody diffuser and rear aero bits.

The nose cone was designed to minimize front stagnation pressure and increase airflow attachment to the upper vehicle surface. Side panels were added to direct the airflow around the exposed chassis structure and reduce turbulent flow interaction near the wheels and cockpit area. An underbody diffuser was employed to stabilize the airflow beneath the car and enhance pressure recovery at the rear. Additional rear aero elements

J. Adv. Mech. Eng. Appl. Vol. 7 No. 1 (2026) p. 72-80

were added to increase downforce and reduce the intensity of the wake behind the car. Fig. 1 Final aerodynamic body kit for the Formula Student electric vehicle.

2.3 Material Selection and Fabrication

Aluminum material was chosen as the main body kit material because of its light weight, corrosion resistance, low fabrication cost and compatibility with standard workshop manufacturing processes. The body panels and aerodynamic structures were made of aluminum sheets with a thickness of 1.5 mm to 2.0 mm.

Conventional workshop equipment was used for cutting, bending, drilling and assembly operations during the fabrication process. The body panels were attached to the tubular chassis by aluminum brackets, rivets and bolted connections to achieve structural rigidity and ease of maintenance. The fabrication sequence started with measurement of the chassis and the development of templates for the panels, and continued with material cutting, panel forming and structural assembly. Additional reinforcement brackets were added at mounting locations to improve vibration resistance and structural stability during vehicle operation. The exploded view of the fabricated aerodynamic body kit assembly is shown in Fig. 2.

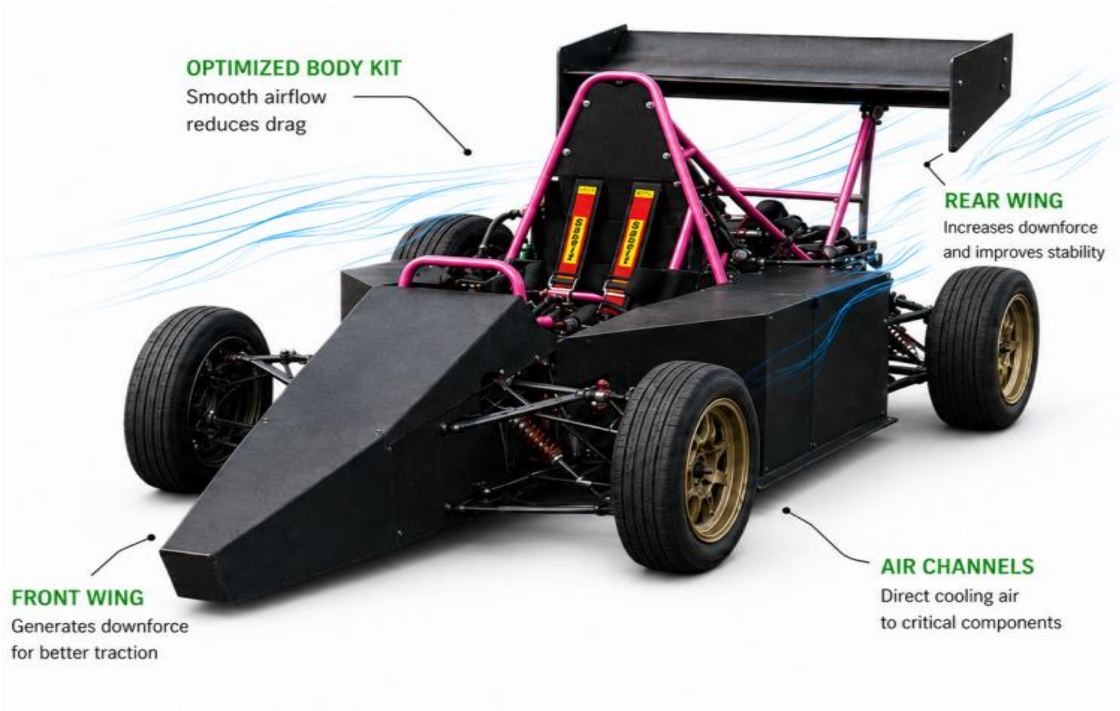


Fig. 1 *Final aerodynamic body kit of the formula student electric vehicle*

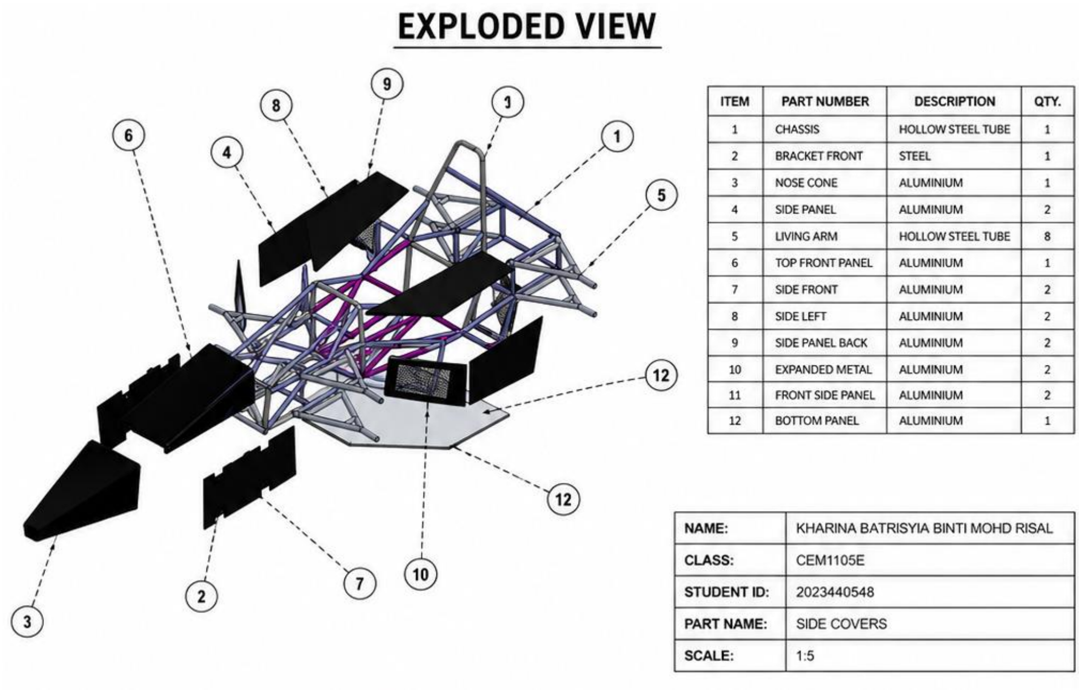


Fig. 2 *The exploded view of the fabricated aerodynamic body kit assembly*

2.4 CFD Analysis

The aerodynamic performances of the vehicle configurations with and without the aerodynamic body kit were estimated by means of Computational Fluid Dynamics (CFD) analysis using ANSYS Fluent 2024 R1. Steady-state conditions were chosen for the simulations with the SST k-ω turbulence model because it can predict external aerodynamic flow separation and wake behavior around bluff-body vehicle geometries. The air was assumed to be incompressible fluid at normal atmospheric conditions with density of 1.225 kg/m 3 and dynamic viscosity of 1.789 × 10 −5 kg/m·s. The working fluid temperature was assumed to be 25 °C.

A 3-D computational domain was established around the vehicle model to decrease the blockage effect and to ensure the stable development of the airflow during the simulation. The inlet boundary was positioned upstream of the vehicle, and the outlet boundary was extended downstream to capture the behavior of the wake formation. The velocity inlet boundary conditions were given 20 m/s, 28 m/s, 33.33 m/s and 40 m/s to the inlet region. The outlet boundary was assigned to zero-gauge pressure outlet conditions. The side and upper domain surfaces were modeled as symmetry boundaries, and the vehicle body and ground surfaces as stationary no-slip wall boundaries. Fig. 3 shows the configuration of the computational domain and the boundary condition used in the CFD simulation.

A fine polyhedral mesh configuration was generated, with local mesh refinement in the vicinity of the vehicle surface, diffuser section and wake regions to improve the flow resolution accuracy and to capture the vortex structures more effectively. The final computational mesh was composed of approximately 2.1 × 10 6 elements. The quality of the mesh was evaluated using the skewness and orthogonal quality parameters. The average value of skewness was maintained below 0.32 and orthogonal quality greater than 0.81 indicating acceptable mesh quality for external aerodynamic analysis. Mesh independence study was performed using different mesh densities and the variation of drag force between medium and fine mesh configurations was less than 2% and it confirmed the numerical solution stability with reasonable computational cost. The convergence criterion for all residuals was taken as 10^{-5}.

The aerodynamic drag force was determined using:

$$F_D = \frac{1}{2} \rho v^2 \pi C_d A \tag{1}$$

J. Adv. Mech. Eng. Appl. Vol. 7 No. 1 (2026) p. 72-80

where:

F_D	drag force (N)
ρ	air density (kg/m^3)
v	inlet velocity (m/s)
C_D	drag coefficient
A	reference frontal area (m^2)

The CFD evaluation was concentrated on the characteristics of streamline distribution, pressure contours, wake formation, drag force and lift coefficient behavior.

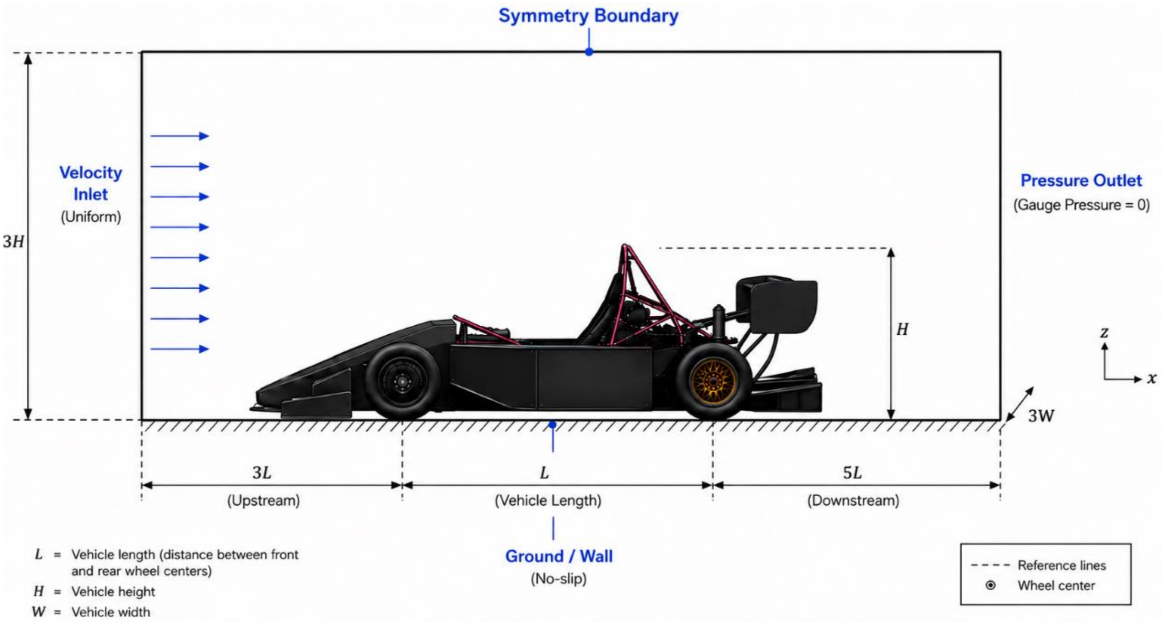


Fig. 3 *The computational domain and boundary condition configuration used in the CFD simulation*

3. Results and Discussion

3.1 CFD Analysis Without Body Kit

Fig. 4 and 5 shows the CFD velocity streamline and pressure contour distribution for the vehicle configuration without aerodynamic body package at the input velocity of 33.33 m/s. The CFD simulation of the baseline vehicle design without the aerodynamic body kit showed a large amount of airflow separation in the cockpit and rear chassis areas. The exposed tubular construction disturbed the flow route and caused unstable recirculation vortices behind the car. At the back part a big wake region was created showing a substantial pressure drag generated.

The pressure contour distribution indicated a high stagnation pressure area in the front nose portion due to the direct airflow effect, whereas a low-pressure area was observed behind the vehicle due to flow separation and vortex generation. The considerable pressure difference between the front and back was a big cause of aerodynamic drag. Moreover, the turbulent airflow under the exposed underbody decreased the flow stability and increased the aerodynamic resistance. The baseline vehicle at an inlet velocity of 33.33 m/s produced a drag force of 980 N and a lift coefficient of −0.74.

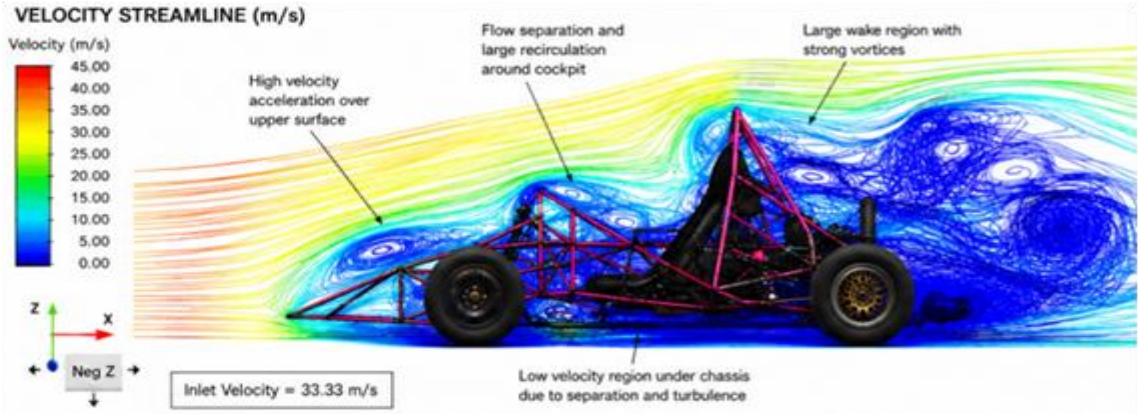


Fig. 4 *CFD velocity streamline without aerodynamic body kit*

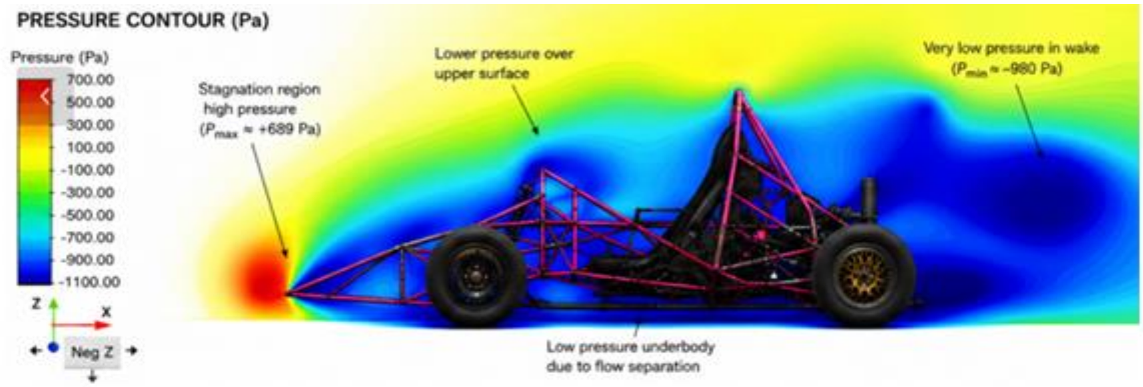


Fig. 5 *Pressure contour distribution without aerodynamic body kit*

3.2 CFD Analysis with Body Kit

Fig. 6 and 7 shows the CFD velocity streamline and pressure contour distribution for the vehicle configuration with the aerodynamic body package. The introduction of the aerodynamic body kit could greatly improve the airflow behavior around the vehicle body. The teardrop nose cone allowed the airflow to more smoothly attach to the upper surface of the vehicle and decreased the stagnation effect at the forward portion. The side panels directed the flow around the chassis and reduced the turbulence interaction at the cockpit region.

The diffuser increased the underbody airflow stability by accelerating the flow under the vehicle and boosting the pressure recovery at the rear portion. Thus, the wake region behind the car was diminished and the vortex intensity was greatly lowered. This reduction in wake generation immediately contributed to less pressure drag and better aerodynamic efficiency.

At input velocity of 33.33 m/s, the drag force fell from 980 N to 865 N and about 11.73% drag reduction was achieved. The lift coefficient also increased from −0.74 to −0.88, which indicated a more effective downforce generation and enhanced vehicle stability during high-speed operation.

J. Adv. Mech. Eng. Appl. Vol. 7 No. 1 (2026) p. 72-80

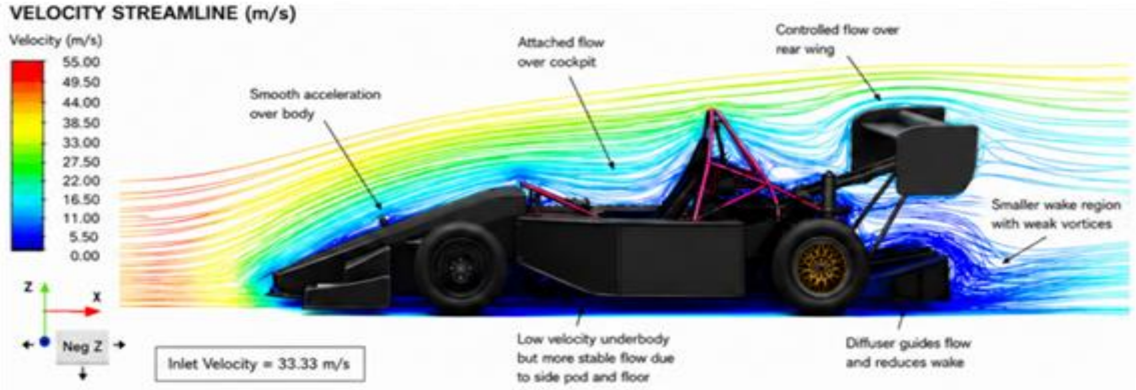


Fig. 6 *CFD velocity streamline with aerodynamic body kit*

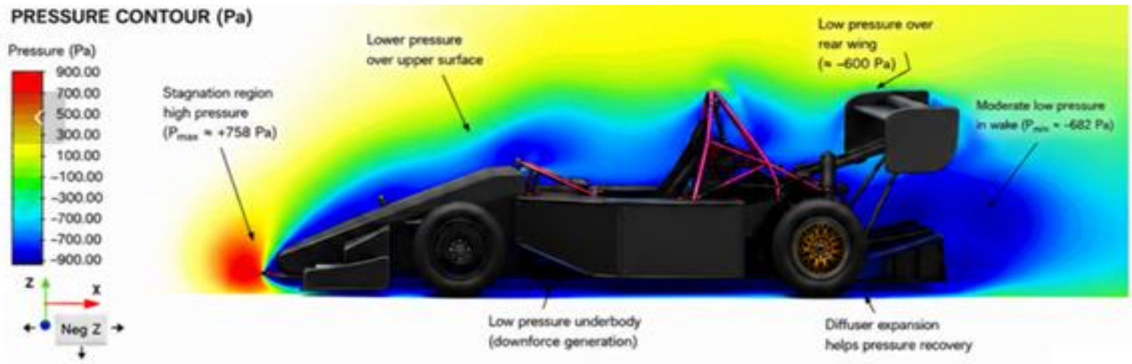


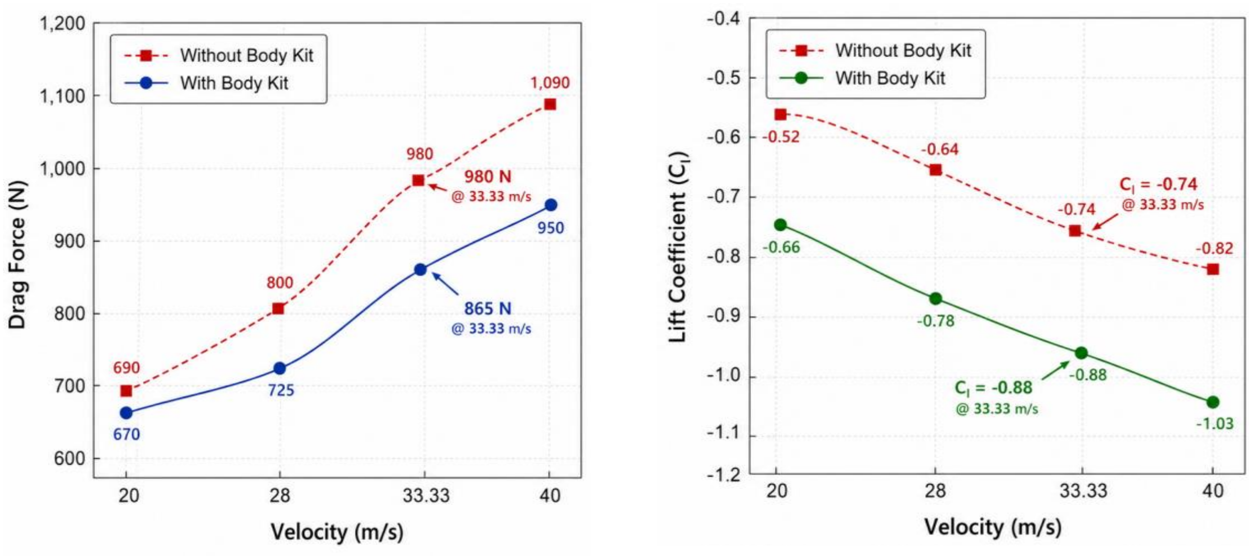
Fig. 7 *Pressure contour distribution with aerodynamic body kit*

3.3 Drag and Lift Performance Comparison

Table 2 summarizes the aerodynamic performance comparison between vehicle configurations with and without the body kit and the comparison graph of drag force and lift coefficient between vehicle configurations with and without the body kit depicted in Fig. 8.

Table 2 Aerodynamic *performance comparison*

Velocity (m/s)	Drag force without body kit (N)	Drag force with body kit (N)	Lift coefficient without body kit	Lift coefficient with body kit
20	690	670	-0.52	-0.66
28	800	725	-0.64	-0.78
33.33	980	865	-0.74	-0.88
40	1090	950	-0.82	-1.03



(a) **(b)**

Fig. 8 *Comparison graph with and without the body kit (a) Drag force; (b) Lift coefficient*

The results show that the aerodynamic drag increased with the increase of inlet velocity due to the increase of dynamic pressure acting on vehicle body. But the aerodynamic body kit always decreases the drag force in all operating conditions. At higher velocities the drag reduction effect became more important because aerodynamic forces increase in proportion to the airflow velocity.

Similarly, the lift coefficient became more negative after applying the body kit, indicating a higher downforce generation. The diffuser and the rear aero parts helped accelerate the flow of air under the car, producing a low-pressure area under the chassis. This pressure difference increased the downward aerodynamic force and improved high-speed stability.

3.4 Fabrication Outcome

The fabrication process resulted in a complete aerodynamic body kit that is integrated with the Formula Student electric vehicle chassis. The aluminum structure showed good rigidity and dimensional accuracy and, at the same time, lightweight characteristics suitable for Formula Student application. The use of bolted and riveted mounting systems simplified assembly operations and allowed for future maintenance and aerodynamic modifications.

Also, the fabrication approach showed that conventional workshop facilities can be used to make practical aerodynamic structures without the need for expensive composite manufacturing technologies. The final assembly had a stable structural integration with the chassis and acceptable aerodynamic geometry alignment.

4. Conclusion

This study presented the design, fabrication and CFD evaluation of a low-cost aerodynamic body kit for a Formula Student electric vehicle using available manufacturing methods and aluminum-based structures. CFD analysis indicated that the suggested body kit resulted in better aerodynamic performance by lowering the drag force to 865 N from 980 N at 33.33 m/s, which accounts for about 11.73% drag reduction. The lift coefficients also improved from −0.74 to − 0.88, indicating improved downforce generation and improved vehicle stability.

The optimized aerodynamic geometry reduced air flow separation minimized wake formation and improved airflow attachment around the vehicle body. The fabrication process also demonstrated that effective aerodynamic structures can be fabricated with conventional workshop equipment without advanced composite technologies. In general, the proposed aerodynamic body kit is a cost effective and practical solution to enhance the performance of Formula Student electric vehicle for student level engineering applications. Future work will focus on experimental verification by wind tunnel testing and on-track aerodynamic performance evaluation.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contribution

*The Authors' contributions: s**tudy conception and design:** Khairina Batrisyia Mohd Fisal and Haszeme Abu Kasim; **CFD analysis, data collection and interpretation of results:** Khairina Batrisyia Mohd Fisal and Haszeme Abu Kasim; **fabrication and experimental work:** Hazim Sharudin, Nairul Akmar Akashah and Jason Lim Wuh Terng; **draft manuscript preparation:** Khairina Batrisyia Mohd Fisal and Mohd Fahmi Md Salleh. All authors took part in the review of the results and approved the final manuscript.*

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