Engineering and Technology Journal e-ISSN: 2456-3358

Volume 09 Issue 08 August-2024, Page No.- 4972-4977

DOI: 10.47191/etj/v9i08.49, I.F. – 8.227

Evaluation of Spoiler Design on the Aerodynamic Performance of an Energy-Efficient Car Prototype Body

Joko Waluyo[1], Satriawan Dini Hariyanto[2*], Nidia Lestari[3]

[1,2,3] Department of Mechanical Engineering, Universitas AKPRIND Indonesia, Indonesia

ABSTRACT: The aerodynamic performance of the prototype body shape of an energy-efficient car can be analyzed from the coefficient of drag (Cd) and coefficient of lift (Cl) values arising from the airflow profile on the vehicle body. The aerodynamic car body affects the fuel consumption and mileage of the vehicle. The spoiler component functions to regulate the shape of the airflow on the car body when driving so that the Cd and Cl values can be varied which aims to improve the aerodynamic characteristics of the vehicle body. In this study, a spoiler design study was conducted using CFD simulation on Solidworks software, the simulation parameters were varied by setting the air speed on the inlet side to 40 km/h, 60 km/h, and 80 km/h. The simulation results show that the use of a spoiler with dimensions of 200 mm x 137.662 mm x 46.1 mm with an Angle of Attack (AoA) of 40.44° can reduce Cd by 6.96% - 14.01% and Cl by 21.35% - 25.93%. The use of a spoiler also changes the wake region at the rear of the prototype body, indicating a reduction in drag at the rear of the prototype body design.

KEYWORDS: CFD, spoiler, Cl, Cd, prototype

1. INTRODUCTION

The Energy Efficient Car Prototype Product (PMHE) owned by Universitas AKPRIND Indonesia is a diesel engine prototype vehicle with a fuel consumption achievement of up to 400 km/l. The sustainability of research that has been carried out to increase PMHE fuel consumption can be done from several aspects, namely: reducing the total weight of the vehicle, modifying the ICE (internal combustion engine) engine, and increasing the aerodynamic performance of the vehicle body. Reducing the total weight of the vehicle can be done by replacing or modifying old components with new components that have a lighter weight (1), ICE engine modifications used can be done by modifying the bore and stroke sizes, while aspects of improving the aerodynamic performance of the vehicle body can be done by adding additional features to the PMHE body. Research conducted by other researchers using the CFD (computational fluid dynamic) simulation method (2) shows the effect of adding a spoiler component to the front of the Arrinera Hussarya Polish supercar model can reduce the Coefficient of Drag (Cd) value by up to 20% (3), However, the addition of this spoiler triggers instability of the vehicle when driving which results in the emergence of the oversteer phenomenon. Research related to the spoiler components designed using Solidworks software while CFD analysis (4) conducted using ANSYS Workbench software using air speed parameters that are varied with values of 120 km/h, 140 km/h, 160 km/h, 180 km/h, and 200 km/h. In this study, there are four different types of spoiler designs that are simulated using the CFD method, from each spoiler design, the Coefficient of lift (Cl) and Cd values are then observed (5). Research on the effect of hatchback design variations on the tailgate of a Skoda Fabia car using CFD simulation analysis resulted in a decrease in Cd value of 0.0062, fuel consumption savings of 0.4 l/100 km and a decrease in exhaust emissions of 1.6 g/km, in addition, the wake region pattern that occurred was also obtained through CFD simulation using ANSYS Fluent (6). Other research on the influence of airfoil design on Cd, Cl, and downforce values has also been conducted by (7), In this study, angle of attack (AoA) variations were made for several variations of airspeed simulation parameter conditions. Highest downforce value was obtained at 1377.112 N at a speed of 70 m/s. Based on previous studies, it can be seen that the aerodynamic characteristics of the airfoil and vehicle body components can be characterized by observing the velocity contour, pressure contour, Cd, Cl, and downforce, but studies on spoiler design evaluation involving numerical simulation using CFD for energy-efficient vehicle body design prototypes still need to be carried out to understand the effect of spoiler design on the aerodynamic performance that appears. In this study, a comparison of CFD simulations was carried out using Solidworks Flow Simulation software (8) for PMHE conditions without spoilers to then be compared with PMHE using spoilers for speeds of 40 km/h, 60 km/h, and 80 km/h. This speed range was chosen due to empirical and technical factors.

2. METHODOLOGY

2.1 Formula

The equations used for CFD analysis on the PMHE body are shown in equation (1) and equation (2).

$$C_d = \frac{2\,F_d}{\rho\,u^2\,A} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(eq. 1)}$$

$$C_l = \frac{2\,F_l}{\rho\,u^2\,A} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(eq. 2)}$$

F_d = drag force
F_l = lift force
ρ = mass density of air at 300 K
u = flow speed at the inlet
A = surface area of body

F_d and F_l values in this study were obtained from the results of CFD simulations run in Solidworks 2022 software. The Cd and Cl variables were calculated by inputting the equations into the calculation before the CFD simulation was run. The value of the surface area of body variable was obtained by plotting the surface of the PMHE body model as shown in Figure 1 which is indicated by the green part.

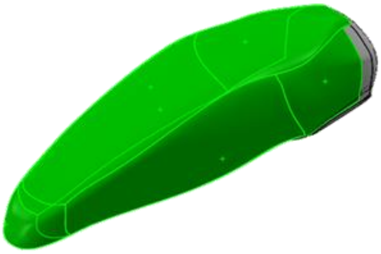


Figure 1. PMHE surface area plotting

The value of ρ in this study uses air conditions at a temperature of 300 K which is 1,177 kg/m3. The air velocity or inlet velocity in the CFD simulation (u) is selected by considering the ability of the PMHE vehicle to drive, using speeds of 40 km/h, 60 km/h, and 80 km/h based on empirical considerations.

2.2 Design of PMHE Body

The PMHE body design is made streamlined with dimensions of length 2806.76 mm, width 731.50 mm, height 635.80 mm as shown in Figure 2. In this study, the body was designed using ABS material with a surface roughness value of 0.01652 µm..

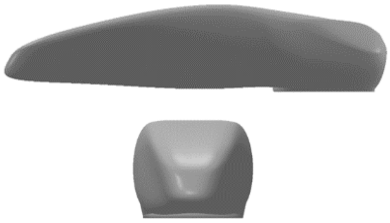


Figure 2. PMHE body design

2.3 Boundary Condition

The boundary conditions used in the CFD simulation in this study include several setting parameters, as shown in Table 1. Figure 3 shows the shape of the boundary conditions and the location of the inlets, outlets, and walls used

Table 1. Boundary value

No.	Boundary	Value
1	Length	4 m
2	Width	2 m
3	Height	1 m
4	Velocity	40 km/h, 60 km/h, 80 km/h
5	Body material	ABS
6	Roughness	0.01652 µm
7	Body surface area	4.05 m
8	Spoiler surface area	$0.02\ m^2$
9	ρ air at 300 K and 1 atm	$1.177\ kg/m^3$

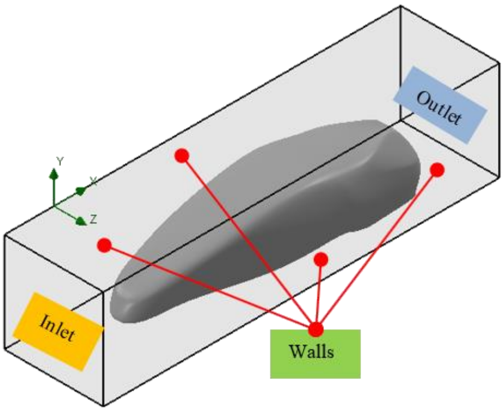
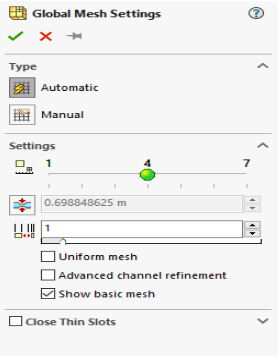


Figure 3. Boundary condition for inlet, outlet, and walls placement

2.4 Meshing

The mesh settings used are using the level 4 mesh type with the automatic type set in the Solidworks software. The mesh settings are shown in Figure 4, the mesh shape is shown in Figure 5.



Global Mesh Settings

Type
Automatic
Manual

Settings
1 4 7
0.698848625 m
1
☐ Uniform mesh
☐ Advanced channel refinement
☑ Show basic mesh

☐ Close Thin Slots

Figure 4. Mesh setting

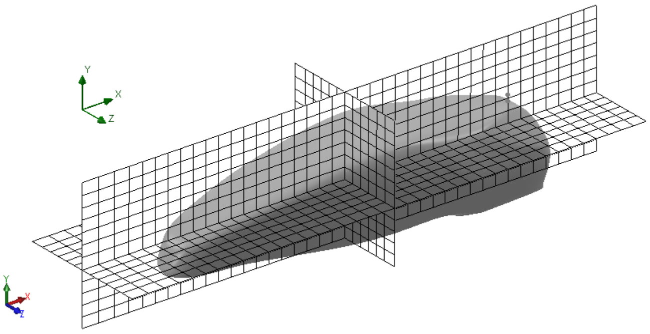


Figure 5. Mesh shape of the model

2.5 Spoiler Design

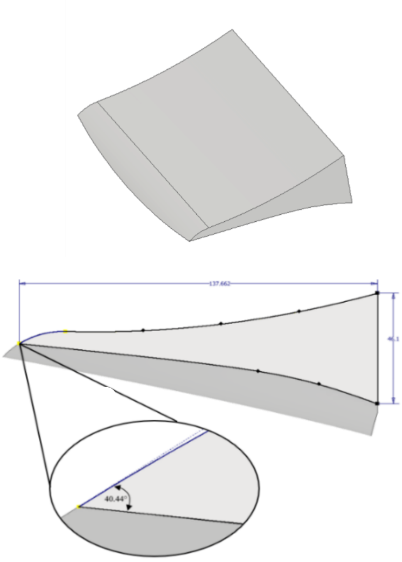


Figure 6. Spoiler geometry dimension

The spoiler design and dimensions are shown in Figure 6. The spoiler has dimensions of 200 mm x 137.662 mm x 46.1 mm with an AoA (Angle of Attack) of 40.44°.

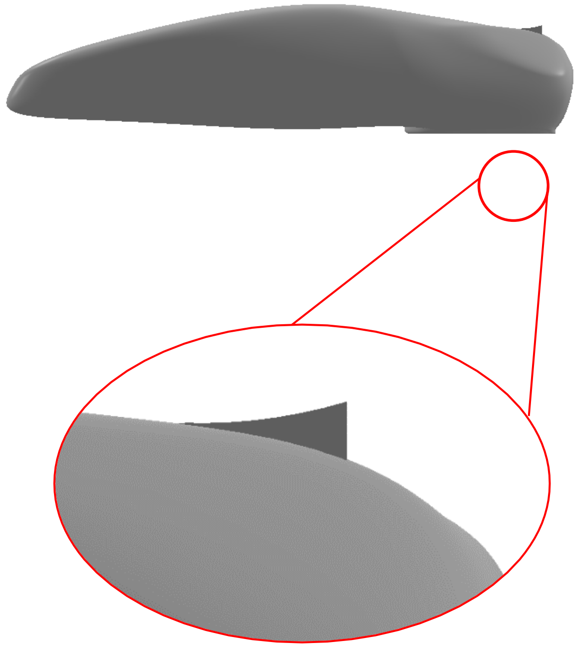


Figure 7. Spoiler placement on the PMHE body

The spoiler is placed on the PMHE body surface in the position as shown in Figure 7.

3. RESULTS AND DISCUSSION

The study of spoiler design on the aerodynamic performance of the PMHE body shows aerodynamic parameter data for two types of simulation models. The first simulation model is a PMHE body without using a spoiler whose aerodynamic characteristic results can be seen in Table 2. Based on the data in Table 2, all parameter values including drag force, lift force, Cd, Cl, and down force increase along with the increase in air flow velocity at the inlet. The same pattern is also found in the second simulation model, namely the PMHE body with a spoiler added to its upper surface. The data in Table 2 also show the same pattern, namely the increase in aerodynamic parameter values is directly proportional to the air velocity value at the inlet. Comparison of aerodynamic characteristics for models 1 and 2 shows a decrease in drag force values at each speed level. Compared to the PMHE body without a spoiler, the PMHE body with a spoiler feature at a speed of 40 km/h has a drag force reduction of 6.5% from the original 7,275 N to 6,802 N. At a speed of 60 km/h, the drag force reduction is 5.58%, while at 80 km/h, a drag force reduction of 13.41% is obtained. The spoiler geometry designed in Figure 6 can also reduce the lift force value of the PMHE body (Table 3). Based on the results of the CFD simulation, the percentage of the decrease in lift force value occurs for speeds of 40 km/h, 60 km/h, and 80 km/h, respectively, the decrease in value is 25.56%, 24.31%, and 21.13%. The down force value also experiences a downward trend body with spoiler. The down force reduction value due to the addition of a spoiler is 25.56%, 24.431%, and 21.13%. Research conducted by (3) also shows a decrease in down force value on the addition of a spoiler. This decrease in down force value can be caused by the influence of spoiler geometry, AoA value, and spoiler placement location.

Table 2. aerodynamic characteristic of PMHE body

No	**Parameters**	**PMHE Body**		
		Inlet air velocity		
		40 km/h	60 km/h	80 km/h
1	Drag Force (N)	7.275	16.121	31.133
2	Lift Force (N)	8.835	19.938	34.794
3	Cd	0.0061	0.0136	0.0260
4	Cl	0.0075	0.0168	0.0300
5	Down Force (N)	8.835	19.938	34.794

Table 3. aerodynamic characteristic of PMHE body with spoiler

No	Parameters	PMHE Body with Spoiler		
		Inlet air velocity		
		40 km/h	60 km/h	80 km/h
1	Drag Force (N)	6.802	15.221	26,956
2	Lift Force (N)	6.576	15.091	27,442
3	Cd	0.0057	0.0128	0.0227
4	Cl	0.0055	0.0127	0.0232
5	Down Force (N)	6.576	15.091	27,442

The changes in F_l and F_d values affect the Cl and Cd values obtained. Based on the equations in (eq 1) and (eq 2), the pattern of changes in Cl and Cd can be seen in Figures 8 and 9.

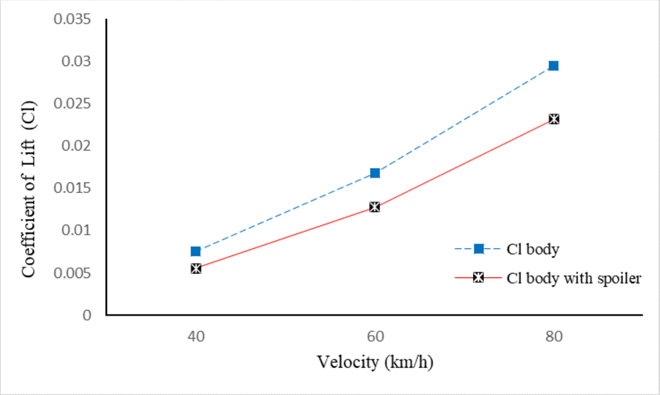


Figure 8. Velocity-Coefficient of lift graphic comparison for body PMHE with spoiler and without spoiler

The addition of a spoiler causes a decrease in the Cl value at each speed range. For air speeds of 40 km/h, 60 km/h, and 80 km/h, the decrease in the Cl value is 25.93%, 24.31%, and 21.35% respectively. This decrease in the Cl value indicates that the addition of a spoiler can reduce vehicle instability caused by lift force when the PMHE is traveling at a certain speed. The change in the Cd value for the PMHE body with the addition of a spoiler is shown in Figure 9.

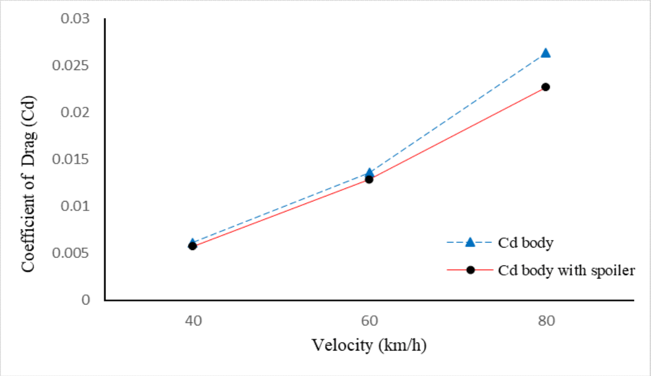


Figure 9. Velocity-Coefficient of drag graphic comparison for body PMHE with spoiler and without spoiler

Based on Figure 9, the addition of a spoiler to the PMHE body shows better aerodynamic performance compared to the PMHE body without a spoiler. This can be observed from the decrease in the Cd value, which can be interpreted that the addition of a spoiler reduces the drag force caused by the body when the PMHE is moving at a certain speed. This decrease in the Cd value is in line with research conducted by (9). Visualization of the velocity contour for the PMHE body without spoiler can be observed in Figure 10.

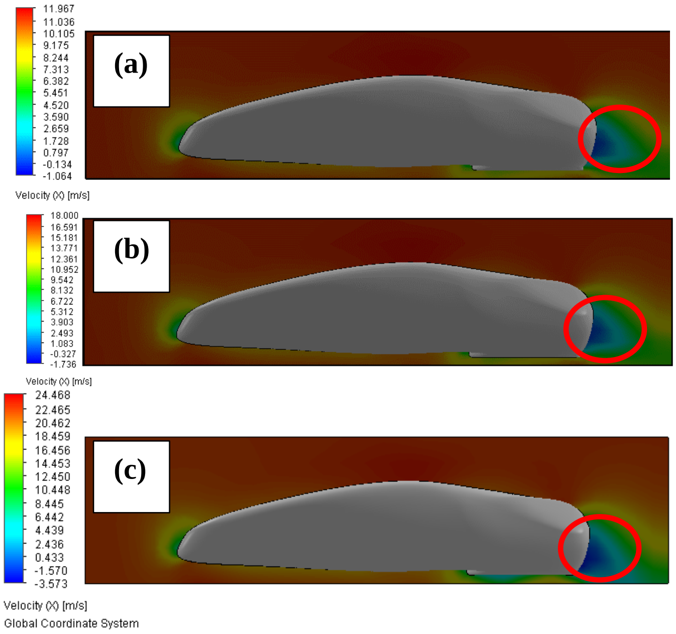


Figure 10. PMHE body velocity countour for different air inlet speed : (a) 40 km/h, (b) 60 km/h, (c) 80 km/h

Gambar xxx Kontur kecepatan pada bodi PMHE untuk parameter kecepatan udara 40 km/h, 60 km/h, dan 80 km/hThe velocity contour visualization for the PMHE body with the addition of a spoiler is shown in Figure 11. Based on the visualization shown in Figure 10 and Figure 11, the position of the wake region can be observed to change when the spoiler is added to the PMHE body. In Figure 10, the circled part shows the shape of the wake region that occurs for each variation of inlet speed. It can be compared that the wake region pattern changes to be more elongated in the PMHE body with the addition of a spoiler, this indicates that the air rotation (vortex) at the rear of the PMHE body has been successfully reduced in intensity with the addition of a spoiler. The wake region resulting from the addition of this spoiler has the potential to reduce the drag that appears when the PMHE vehicle is moving, thereby supporting vehicle efficiency, the same trend was also found in research conducted by (10).

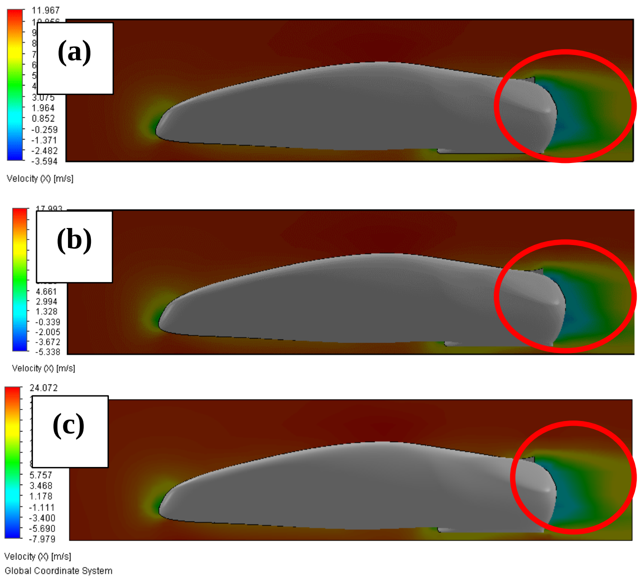


Figure 10. PMHE body velocity countour with spoiler for different air inlet speed : (a) 40 km/h, (b) 60 km/h, (c) 80 km/h

4. CONCLUSIONS

Spoiler design analysis using CFD on the PMHE body using Solidworks software on the PMHE body model shows that the spoiler design with dimensions of 200 mm x 137.662 mm x 46.1 mm with AoA 40.44° at air speed variations of 40 km/h, 60 km/h, and 80 km/h successfully reduces the Cd and Cl values. The decrease in Cd values was 6.96%, 5.58%, and 14.01%, respectively. The decrease in Cl values for air speeds of 40 km/h, 60 km/h, and 80 km/h was 25.93%, 24.31%, and 21.35%. The decrease in Cd and Cl values indicates an increase in aerodynamic characteristics of the PMHE body. The decrease in Cd indicates the potential for decreasing drag on the air when the PMHE is traveling at a speed of 40-80 km/h while the decrease in Cl indicates a decrease in lift on the PMHE which has the potential to increase the stability of the PMHE when traveling at a speed range of 40-80 km/h. The airflow contour profile shows that the use of a spoiler can reduce the occurrence of vortices behind the vehicle body. The decrease in vortex can be seen from the change in the shape of the wake region which changes further away from the prototype design of the vehicle body. The decrease in vortex intensity can potentially reduce the drag that appears at the rear of the PMHE body. From the analysis of CFD data in general, it can be concluded that the use of a spoiler with a design and dimensions as in Figure 7 can improve the aerodynamic characteristics of the PMHE body.

REFERENCES

1. Roslan MH, Hasbullah H, Ramesh T, Hissein Didane D, Manshoor B, Kabrein HA. Journal of Design for Sustainable and Environment Effect of a Spoiler on the Aerodynamic Performance of a Race Car on Track Using Two Different Turbulence Models. JDSE Journal of Sustainable Environment. 2023;5(2):28–37. Available from: http://www.fazpublishing.com/jdse
2. Akpan KE, Okon AA, Akpan WA, Nyaudo II. Optimization of Thermo-Flow in a Solar Food Dehydrator Using Computational Techniques. Eng Technol J [Internet]. 2023;08(11):3061–83. Available from: https://www.researchgate.net/publication/376168375_Optimization_of_Thermo-Flow_in_a_Solar_Food_Dehydrator_Using_Computational_Techniques
3. Szudarek M, Piechna J. Cfd analysis of the influence of the front wing setup on a time attack sports car’s aerodynamics. Energies [Internet]. 2021;14(23). Available from: https://www.mdpi.com/1996-1073/14/23/7907
4. Prabhu L, Krishnamoorthi S, Gokul P, Sushan N, Hisham Harshed PH, Jose A. Aerodynamics analysis of the car using solidworks flow simulation with rear spoiler using CFD. IOP Conf Ser Mater Sci Eng [Internet]. 2020;993(1). Available from: https://iopscience.iop.org/article/10.1088/1757-899X/993/1/012002
5. Mohd Zin MZ, Wan Abdul Rahman WMW. Simulation The Effect of Spoiler on Aerodynamic for Sedan Car. J Automot Powertrain Transp Technol [Internet]. 2022;2(1):1–8. Available from: https://publisher.uthm.edu.my/ojs/index.php/japtt/article/view/11847
6. Fabian M, Huňady R, Kupec F, Mlaka T. Effect of the Aerodynamic Elements of the Hatchback Tailgate on the Aerodynamic Drag of the Vehicle. Adv Sci Technol Res J [Internet]. 2022;16(6):73–87. Available from: https://www.researchgate.net/publication/365923164_Effect_of_the_Aerodynamic_Elements_of_the_Hatchback_Tailgate_on_the_Aerodynamic_Drag_of_the_Vehicle
7. Oztemel MA, Aktas F, Yucell N. Aerodynamic analysis of car rear spoiler with computational fluid dynamics for different angles and profiles. Int J Energy Stud [Internet]. 2023;8(4):649–65. Available from: https://www.researchgate.net/publication/374764270_Aerodynamic_Analysis_of_Car_Rear_Spoiler_with_Computational_Fluid_Dynamics_for_Different_Angles_and_Profiles
8. Akpan WA, Ogbonna PO, Nyaudo II. Design Modification and Production of a Bicycle Powered By an Internal Combustion Engine. Eng Technol J [Internet]. 2024;9(03):3643–66. Available from: https://www.researchgate.net/publication/379476822_Design_Modification_and_Production_of_a_Bicycle_Powered_By_an_Internal_Combustion_Engine
9. Lin K, Zhang S, Liu C, Yang H, Zhang B. Aerodynamic optimization of NACA 0012 airfoils

with attached Gurney flap in the rarefied gas flow. AIP Adv [Internet]. 2023;13(12):1–15. Available from: https://doi.org/10.1063/5.0169049

10. Suryady S, Zhafran R. Analisa Desain Bodi Kendaraan Tipe Urban Concept Pada Pengaruh Koefisien Drag Dan Koefisien Lift. Presisi [Internet]. 2022;24(1):74–84. Available from: https://ejournal.istn.ac.id/index.php/presisi/article/view/1149