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Drag Analysis of Commercial Passenger Car Using Aerodynamic Devices

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Abstract: The environmental problems related with greenhouse gas emissions force researchers to explore better aerodynamically efficient designs. Aerodynamic efficiency provides for a reduction in drag on aerodynamic structures. This paper observes the drag analysis of commercial passenger car using aerodynamic devices. A numerical study has been carried out to investigate the reduction of drag force using aerodynamic devices such as spoiler, ducktail, and diffuser on Perodua Bezza model. Perodua Bezza model and 3 different aerodynamic devices designs were constructed using the modelling software, SolidWorks 2020 and simulated using 70, 110, and 150 km/h of wind speed using Ansys Fluid Flow (CFX). The use of aerodynamic devices, such as a ducktail and diffuser, on the Perodua Bezza model has been found to have a positive impact on the car's fuel consumption and stability. The analysis of the drag and lift coefficient reduction percentage showed that the combination of a ducktail and diffuser provides the least increase in drag coefficient while also contributing to a significant reduction in lift coefficient. This reduction in drag and increase in stability will help improve the fuel efficiency of the base model car. The installation of these aerodynamic devices, either individually or in combination, can enhance the dynamic stability of the Perodua Bezza or make it a more efficient vehicle, thanks to the reduction in aerodynamic drag.

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1. Introduction

Aerodynamics is the study of how moving things interact with air. The environmental problems related with greenhouse gas emissions force researchers to explore better aerodynamically efficient designs. Aerodynamic efficiency provides for a reduction in drag on aerodynamic structures. It is one of the most critical aspects impacting a vehicle's performance. Driving a car is like surfing in a limitless ocean of air. Over the last few years, the degradation of air quality and the depletion of natural resources, specifically oil, have put a lot of pressure on vehicle manufacturers. Aerodynamic drag absorbs around half of the vehicle's energy. One of the key tactics taken by vehicle makers is to reduce drag. Drag is a force in fluid dynamics that acts in the opposite direction of any object moving with respect to a surrounding fluid [1]. Drag forces are velocity dependent, unlike other resistive forces that are largely independent of velocity [2]. The net aerodynamic force on vehicles, planes, and boat hulls are examples of drag.

This research is to identify the correlation of aerodynamic analysis for a car model with the performance towards the car model. Every vehicle has different aerodynamic drag based on their design and their performance basis [3]. There are several types of additional devices that will affect the vehicle aerodynamic. The shortage of natural resources primarily oil urge car manufacturers to apply this concept of aerodynamics.

The difference in pressure generated above and below a vehicle's body as it drives through viscous air is measured by the aerodynamic lift coefficient C_L. A subsequent upthrust or downthrust may be created, depending on body form; however, an uplift, known as positive lift, is undesirable since it diminishes tyre to ground grip, whereas a downforce, known as negative lift, improves tyre road holding [4].

Drag coefficient, in fluid mechanics, is a dimensionless quantity used in a fluid system to calculate an object's drag or pressure, such as air or water. It can be found in the drag equation where a lower drag coefficient means that the object is dragged less aerodynamically or hydrodynamically. The drag factor is often correlated with a certain airfield [5].

The effect of the additional devices towards the aerodynamic performance which is the drag and lift force of Perodua Bezza analyse using Computational Fluid Dynamics. The simulations will be using wind velocity of 70, 110, and 150 km/h for every study.

The Perodua Bezza's top speed is 172 km/h for the low-spec Bezza 1.0G variant. The normal speed is established according to the National Speed Limit Order of 1989, which states that the maximum permitted speed on highways is 110 km/h [6]. By averaging the range speed limits within the town, the simulation's speed has been set at 70 kilometers per hour. Top speed is calculated as the average of the posted highway speed limit and the top speed of the Perodua Bezza model. The Perodua Bezza's top speed, according to the manufacturer, is 172 km/h for the low-spec Bezza 1.0G variant [7].

2. Materials and Methods

To ensure that the research is carried out in a systematic and efficient manner, a flowchart was constructed to serve as a guide for the study. The flowchart, represented in Figure 1, serves as a visual representation of the entire workflow for the research.

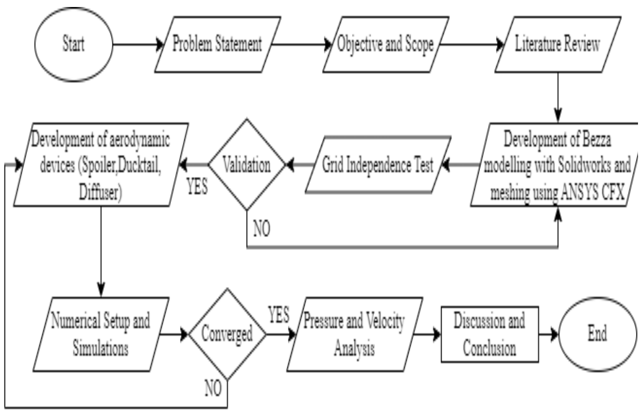

Fig. 1 - Project flowchart

2.1 Geometrical Modelling

Analysis of a car based on the geometry of a Perodua Bezza. This simplified model design and additional aerodynamic devices are created with SOLIDWORKS software, and the dimensions shown in Figure 2 [7]. As a basis for this work, the flow pattern around this model, its drag coefficient, and lift coefficient when the car moves are studied.

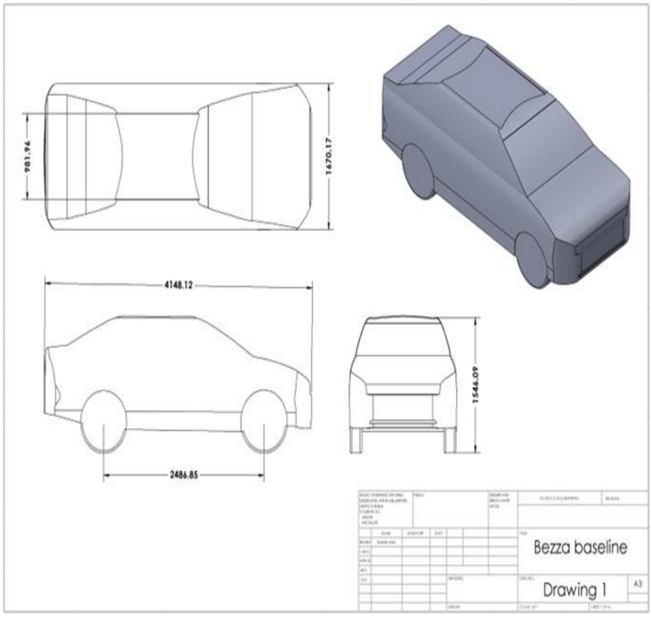

Fig. 2 - Detail drawing of Perodua Bezza model

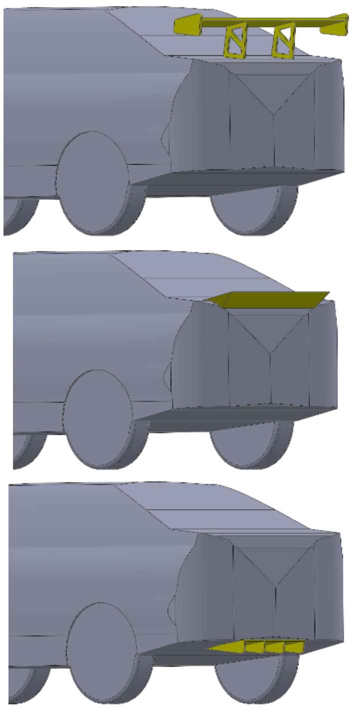

Fig. 3 - Assembly of spoiler, ducktail, and diffuser on Perodua Bezza model

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2.2 Simulation

Meshing is the most important step in a flow simulation analysis. An enclosure which represents as wind tunnel will be designed in dimension of 8000 x 12000 x 4000 mm [8]. The fluid domain then setup-up in CFX Solver. The meshing of the model is done in ANSYS software shown in Figure 4.

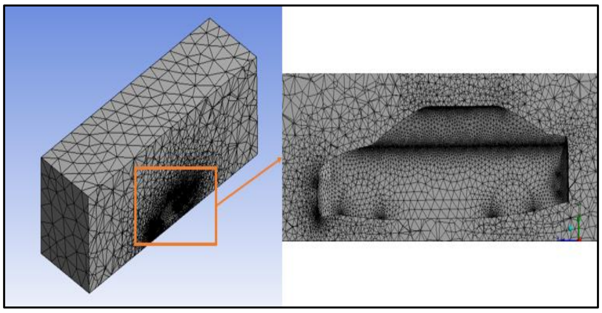


Fig. 4 - Mesh of Perodua Bezza model

Type of boundary which needed to be initialized are the inlet, outlet and walls which already named in Meshing (ANSYS AUTODYN PrepPost). Table 1 shows the boundary condition used in this pre-processing step [8].

Table 1 - Boundary conditions

Type of Boundary	Flow Characteristic	Parameter
Inlet	Normal Speed	7.0000e+01 [km/h]
Outlet	Relative Pressure	0.0000e+00 [Pa]
Wall	Mass And Momentum	No Slip Wall
Car	Mass And Momentum	No Slip Wall
Ground	Mass And Momentum	No Slip Wall
	Wall W	-7.0000e+01 [km/h]

2.3 Equations

The simulation results of the drag force and lift force experienced by the Perodua Bezza model will be used to determine the coefficient values that describe the aerodynamic performance of the car. The coefficient values are calculated using the following equation: the drag coefficient (Cd) is equal to the drag force divided by the dynamic pressure times the reference area; while the lift coefficient (Cl) is equal to the lift force divided by the dynamic pressure times the reference area.

$$C_L = \frac{L}{qS} = \frac{L}{\frac{1}{2}\rho u^2 S} = \frac{2L}{\rho u^2 S} \qquad Eq. 1$$

$$C_D = \frac{2F_D}{\rho\mu^2 A} \qquad Eq. 2$$

To determine the reduction in drag and lift coefficient, the calculated drag and lift coefficient will be compared to the baseline model's drag and lift coefficient.

3. Results and Discussion

The presentation of the data that has been gathered and the simulation results will be the focus of this chapter.

3.1 Grid Independence Test

Figure 5 shows the velocity distributions for baseline Bezza model with the velocity of 70 km/h with different number of nodes. This model was chosen for the benchmark as this model comes with stable low velocity and normal pressure. Based on the grid independence test, there are no significant changes of the velocity distribution from the number of nodes 140K to 146K.

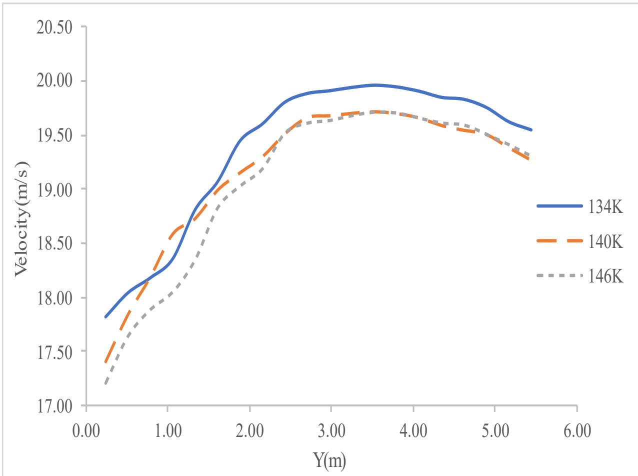
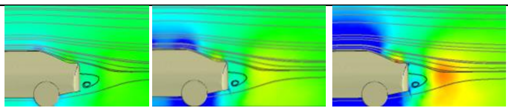
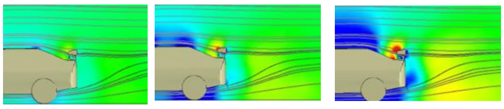
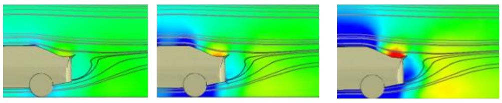
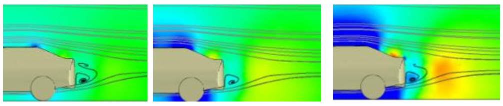
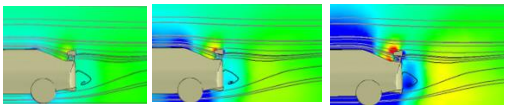
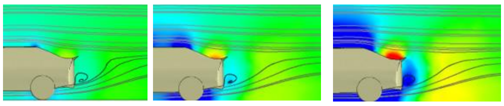


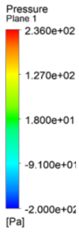
Fig. 5 - Velocity distribution at outlet boundary

3.2 Velocity and Pressure Distribution

The amount of turbulence created behind the rear region of the car determines the magnitude of the drag force shown in Table 2. In the case of Bezza with spoiler, maximum flow separation is observed, which has led to maximum turbulence, thus maximum drag forces [9]. On the other hand, the application of the Ducktail on the baseline model has a lower turbulence at the back than the Bezza equipped with Spoiler, thus drag force is reduced. Moreover, the addition of Diffuser to the baseline model accounted for streamlined flow, which reduced the drag force.

Table 2 - Streamlines superimposed with pressure contour for different add-on devices

Model	70km/h	110km/h	150km/h
Bezza baseline			
Bezza with spoiler			
Bezza with ducktail			
Bezza with diffuser			
Bezza with spoiler and diffuser			
Bezza with ducktail and diffuser			



3.3 **Drag and Lift Force at Different Speed**

Table 3 and Figure 6 present the trend in drag force for different speeds. To consider various scenarios, three different speeds were selected: 70 km/h, 110 km/h, and 150 km/h. The graph in Figure 6 clearly demonstrates that the drag force increases exponentially as the speed of the car increases. This finding is in line with the well-established theory that the drag force experienced by a moving object is proportional to the square of its velocity [2]. The results shown in Table 3 and Figure 6 highlight the importance of reducing drag force, especially at high speeds where the drag force has a significant impact on the performance and fuel efficiency of the car. By reducing the drag force, the car will consume less fuel and be able to maintain its stability even at high speeds, improving overall driving performance and safety.

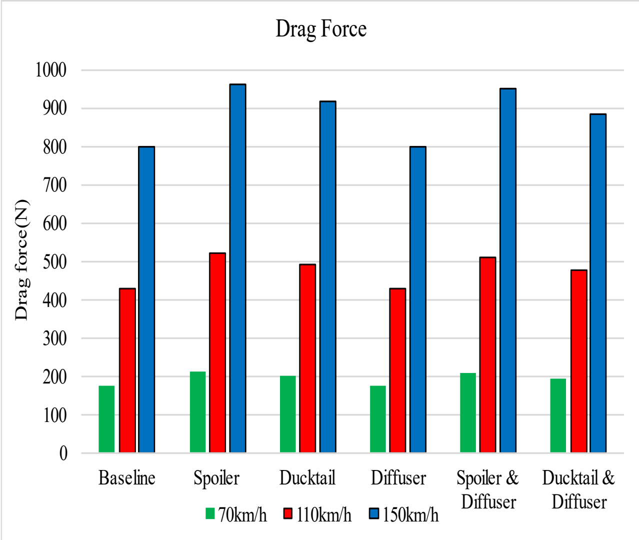


Fig. 6 - Drag Force Distribution for Different Speed

Table 3 - Drag force at different speed

Model	**Drag Force at 70km/h (N)**	**Drag Force at 110km/h (N)**	**Drag Force at 150km/h (N)**
Baseline	175.987	431.587	799.495
Spoiler	212.125	520.966	964.003
Ducktail	201.112	494.568	917.700
Diffuser	175.948	430.383	800.234
Spoiler & Diffuser	208.903	512.909	951.986
Ducktail & Diffuser	193.787	477.649	886.643

In the similar context, Table 4 and Figure 7 shows the trend in lift force for different speeds. Three different speeds are set to 70 km/h, 110 km/h and 150 km/h for considering multiple scenarios. The trend in graph shows that the lift force increases exponentially with the increase in speed. It is observed that negative lift or downforce are created in all cases. In case Bezza with Ducktail and Bezza with Spoiler, highest downforce obtained. This huge amount of downforce is useful for having increased traction with road, which subsequently leads to increased cornering speed. But this will increase the drag and hinder achieving the potential top speed.

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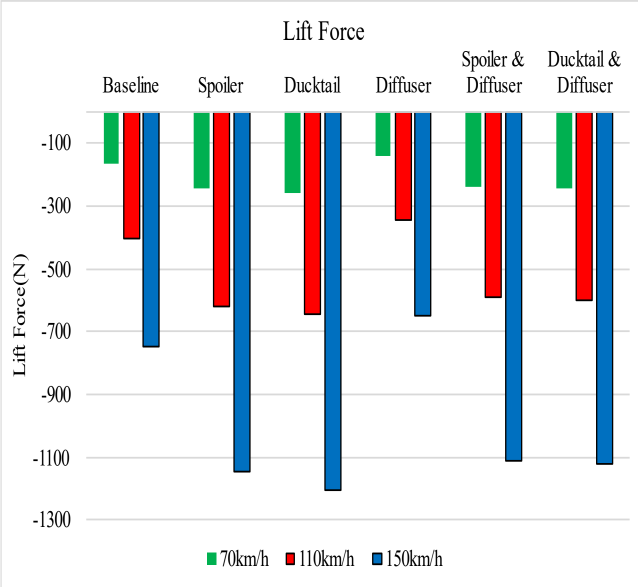

Fig. 7 - Lift force distribution for different speed

Table 4 - Lift force at different speed

Model	Lift Force at 70km/h (N)	Lift Force at 110km/h (N)	Lift Force at 150km/h (N)
Baseline	-164.616	-404.296	-746.335
Spoiler	-245.013	-622.456	-1148.560
Ducktail	-257.545	-645.286	-1205.370
Diffuser	-143.025	-346.172	-651.710
Spoiler & Diffuser	-240.859	-591.211	-1111.130
Ducktail & Diffuser	-243.341	-600.305	-1123.510

3.4 Drag and Lift Coefficient Reduction

Table 5 presents the results of the drag and lift coefficient reduction for the Perodua Bezza model. The table shows that the use of a diffuser on the baseline model results in the greatest reduction in drag coefficient, with a reduction of 0.28%. This reduction in drag coefficient demonstrates the effectiveness of the diffuser in reducing aerodynamic drag and improving fuel efficiency. On the other hand, devices such as spoilers and ducktails can be used to produce downforce, which is an important factor in maintaining stability and handling at high speeds. The data in Table 5 also shows that the lift coefficient of the Perodua Bezza with a diffuser increased by 14.38% when compared to the baseline model. Overall, the results in Table 5 highlight the importance of aerodynamic devices in optimizing the performance and efficiency of vehicles.

Table 5 - Drag and lift coefficient reduction based on Bezza baseline model

Model	Drag Coefficient	Lift Coefficient	Drag Coefficient Reduction (%)	Lift Coefficient Reduction (%)
Baseline	0.3719	-0.3484	-	-
Spoiler	0.4489	-0.5364	+20.71	-53.96
Ducktail	0.4262	-0.5560	+14.59	-59.61
Diffuser	0.3709	-0.2983	-0.28	+14.38
Spoiler & Diffuser	0.4420	-0.5094	+18.84	-46.23
Ducktail & Diffuser	0.4116	-0.5173	+10.67	-48.48

3.5 Discussions

The simulation for all eighteen cases of the Perodua Bezza model was performed using the k-epsilon turbulence model, with the aim of obtaining the drag force, lift force, lift coefficient, and drag coefficient. The baseline model of the Bezza was first simulated to obtain the downforce and drag force, and then various add-ons were added to the model to analyze their impact on the aerodynamic performance of the car. The results of the simulation were presented in the form of contours and graphs, which showed the pressure, streamlines, and forces experienced by the car in each case. The contours and graphs provided a clear visualization of the aerodynamic behavior of the car, and allowed the research team to identify areas where improvements could be made to reduce drag and increase stability. These results are crucial in determining the optimal configuration for the Perodua Bezza model, which will enhance its performance and fuel efficiency.

The results shown in Table 2 indicate that the use of a spoiler on the Perodua Bezza model leads to an increase in the size of the wake at the rear of the car, causing a low-pressure area to form. This, in turn, leads to an increase in the drag force experienced by the car. On the other hand, the use of a ducktail on the Perodua Bezza model results in the greatest negative lift force or downforce. This downforce is generated by the high-pressure region on the model's trunk, which acts to push the car downwards. When compared to the other cases of spoilers and diffusers, the combination of a ducktail and diffuser provides the least increase in drag coefficient while also contributing to a significant reduction in lift coefficient. These results suggest that the installation of a ducktail and diffuser on the Perodua Bezza model will provide an optimal balance between drag reductions and lift reduction, thus improving the fuel efficiency and stability of the car.

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4. Conclusion

From the results presented in this study, it shows that the turbulent models did give its own prediction for the airflow around the various case using the Bezza model. The results that have been obtained through the simulations have achieved all the objectives within the scopes of simulation for the add-on devices on Bezza model.

Add-on devices such as spoiler, ducktail and diffuser can influence the model's downforce, drag force, lift coefficient, drag coefficient, and flow streamlines. Installation of such devices individually or in combination would help improve fuel consumption and dynamic stability of base model car by reducing aerodynamic drag. Furthermore, in this research the help of CFD analysis, the flow streamlines over Bezza model included with aerodynamic devices can be discussed and the best combination of aerodynamic devices are ducktail and diffuser as proved in case Bezza with ducktail and diffuser.

A few changes and improvements should be made to the current study to improve it and produce more accurate results. To get more accurate results, future studies should simulate with a greater number of elements and nodes. Future work can involve adding new, untested aerodynamic concepts to the current geometric analysis or experimentally validating the numerical results that were previously provided.

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