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Roof Box Shape Streamline Adaptation and the Impact towards Fuel Consumption

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Abstract. The fuel price hike is currently a sensational national issue in Malaysia. Since the rationalization of fuel subsidies many were affected especially the middle income family. Vehicle aerodynamic were directly related to the fuel consumption, were extra frontal area result a higher drag force hence higher fuel consumption. Roof box were among the largest contributor to the extra drag, thus the roof box shape rationalization were prominent to reduce the extra drag. The idea of adopting water drop shape to the roof box design shows prominent result. The roof box has been simulated using MIRA virtual wind tunnel modelling via commercial computational fluid dynamic (CFD) package. This streamline shape drastically reduce the drag force by 34% resulting to a 1.7% fuel saving compare to the conventional boxy roof box. This is an effort to reduce the carbon foot print for a sustainable green world.

1 Introduction

The effort of drag reduction mainly focused on the design of the vehicle where designer added an aerodynamic flavour to their car design right after the First World War [1]. However the aerodynamic flavour to the car design were never a successful story due to the design limitation and the sole purpose of the vehicle design itself as a transportation device for human where space were a big issue [2]. For a bluff body vehicle segment having a streamline body were just a non-desirable idea. Most of them were boxy and bulky. The main issue of the bluff body vehicle like MPV was the lag of storage space and many end up having an extra boxy storage box on top of their vehicle.

The box definitely add up extra surface area that face the wind direction and directly affected the total drag of the vehicle which likely contribute to an extra fuel consumption [3]. Recently, designer have shown an increased interest in drag reduction effort to the box design. Somehow an idea of adopting streamlined shape like water drop shape to the roof box design were less explored. The streamlined shape to a car design has been adopted during the post war era. During that era most German aeronautical engineer were forbidden designing an airplane so most end up being a car designer [4]. As their passion on aeronautic most designer like Paul Jarray add up the aeronautical flavor to his car design

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where the main focus was to have the lowest air drag as possible [5]. During that era fuel consumption was a big issue due to the gloomy postwar economy. The most famous Jarray design was the zeppelin airship.

The design was simply based on the most aerodynamic basic shape of an air foil where the drag coefficient were about 0.04. The design was a success in the perspective of aerodynamic but in the perspective of consumer Jarray design has several set back. Base on the fact that the water drop shape was the most aerodynamic shape this research were carried out to explore the potential of such concepts [6].Recent developments in the field of aerodynamic have led to a renewed interest in automotive drag reduction design. Most studies in roof box aerodynamic have only been carried out in a small number of focus areas. Several studies have produced estimates of roof box contribution to the total aerodynamic drag but there is still insufficient data for roof box shape optimization [7]. A. Howell has depicted the automotive accessory contribution to the total drag of the vehicle where the roof box add up around 0.15 to 0.175 [3]. A typical multi-purpose vehicle has a drag coefficient around 0.45, installation of roof box increase the total drag from 25% to 28%. These figure contribute to 2.27% of total fuel consumption calculated using the formula adapted by Zambri Harun [8]. Elaborating the 2.27% increase of total fuel consumption by taking the average fuel price in Malaysia between year 2013 to 2016 which is about Malaysian Ringgit (RM) 2.00 per litter of fuel; A 2.0 litter engine MPV consume about 50 L of fuel a week for average daily drive of 20 km. The MPV consume about 2400 L per year. Installing the roof box add up about RM 109 to the total of one year of fuel cost. There are variety choices of roof box design available in the market depending on the storage requirement. This paper focused on the commonly used roof box design in Malaysia which is for luggage storage.

2 Roof box modelling

The commonly used roof box model in Malaysia were selected as the reference model in this study. In this case model Thule 667ES Excursion were referred. The 3D model were modelled using CATIA V5 software based on the measurement made on the actual model as displayed in Fig. 1 below. This model has the capacity of 350 L. This 3D model were built in single piece where upper cover and the lower tray were merge to simplify the CAD data. It is assumed to be fully solid with no wall thickness as this study only focus on the external aerodynamic.

Fig. 1. Common roof box 3D model developed using CATIA V5.

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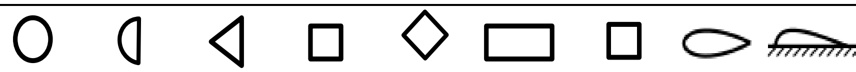
Table 1. Measured Drag Coefficient.



Wind direction									
Shape	Sphere	Half-sphere	Cone	Cube	Angled Cube	Long Cylinder	Short Cylinder	Streamlined Body	Streamlined Half-body
Drag Coefficient	0.47	0.42	0.5	1.05	0.8	0.82	1.15	0.04	0.09

This paper focus on the idea of streamlined shape adaptation and its impact to the total aerodynamic drag. Table 1 exhibit the drag coefficient of various shape. It is easy to identify that the streamlined body has the lowest drag coefficient. Based on this fact the author has adapted the shape onto the roof box design. The details of the design adaptation as illustrated in Fig. 2.

Fig. 2. Streamline roof box 3D model developed using CATIA V5.

3 Pre-processing Configuration

MIRA wind tunnel model of an open back with a rectangular sectional dimension of the test chamber as displayed in Fig. 3 were use in this study as it produce excellence result with optimum calculation time [9]. The meshing setting was set as proposed by Gmbh [10]. The details of the meshing configuration as exhibit in Table 2. The setup chosen is Pressure-Based to monitor pressure. The time chosen is steady state which the iteration will be captured after the flow of air is steady. The details of setup configuration as exhibit in Table 3.

Table 2. Meshing Configuration.

Criteria	Setup
Tunnel Mesh size	Course
Smoothing	Medium
Mesh Extreme size	250mm
Base size	1mm
Growth rate	1.2
Surface mesh size	10mm
Refinement zone size	15mm
Inflation	1.2

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Table 3. Setup Configuration.

Criteria	Setup
Velocity formulation	absolute
Turbulence model	Realizable k-epsilon
Wall function	non-equilibrium [11]
Backflow turbulent intensity	5%
Backflow viscosity ratio	10% [12]
Air density	1.225
Temperature	302.15 K
pressure-velocity coupling	COUPLE

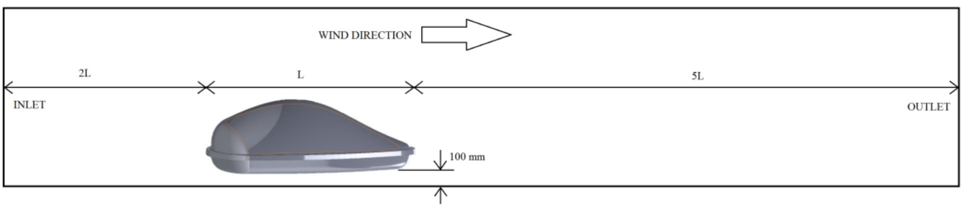

Fig. 3. MIRA Wind tunnel configuration.

4 Result and discussion

Based on the result acquire from CFD analysis, the drag coefficient Cd value for both roof boxes can be obtain after the iteration value has converged. Converging means the iteration value has not changed after ten iterations. Common roof box converging after 800 iterations and 700 for optimise roof box. The velocity contour plot of both common design and optimize design roof box as shown in Fig. 4. Strong evidence of boundary layer separation size reduction was found at the rear region of the optimize design. There was a significant difference between the two designs and there was a significant positive correlation between reduction of boundary layer separation size and the drag coefficient. The different in value as reflected in Table 1.

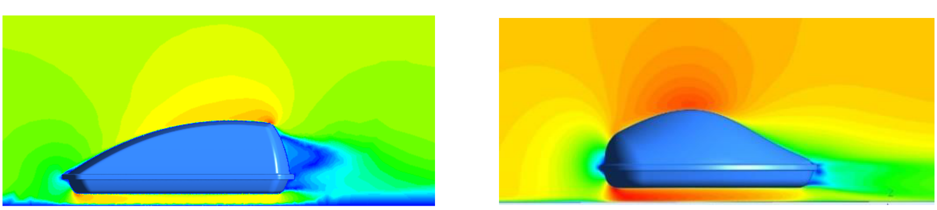

Fig. 4. Velocity contour of common and optimized roof box.

The most striking result to emerge from the data is that by streamlining the box shape resulted a significant drag reduction by 34%. This contribute to a total of 1.7% fuel

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consumption reduction when calculated using fuel consumption formula adapted from Zambri et all [8] as illustrated on Table 4.

Table 4. Fuel consumption contribution of both design.

	Common roof box	Optimise roof box
Total energy	8834.25 w	8297.463 w
Percentage of fuel consumption	3.616 %	1.9088 %

Fig. 5 exhibit that back area of common roof box has a bigger flow layer separation compare to optimize roof box. According to Tsubokura [13] this phenomena contribute the value of drag coefficient. This separation contribute to a pressure difference over the roof box body where the larger pressure difference the higher the drag will be.

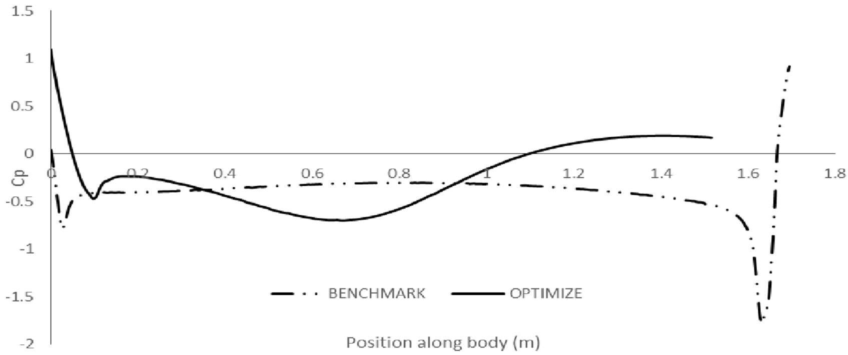

Fig. 5. Cp along upper body of both roof box

This phenomenon was clearly shown in the graph of pressure coefficient (Cp) versus the distance along the upper body in Fig. 5. As can be observed the curve of the common model shows sudden change pressure at the front where a large boundary layer as expected at frontal area where there is the first contact of air flow to the body and it is normal to has such patent. This trend were also experience by the optimize roof box. Then the curve of common roof box again shows significantly sudden change in pressure when it reach at the rear end. This trend were not observe in the optimize roof box curve.

5 Conclusion

In conclusion the improvement of drag coefficient directly affected the fuel consumption. The total saving by installing optimize roof box is 1.7% reduction compare to common roof box. Incorporating this value onto the assumption made in the introduction the optimize roof box contribute a total of RM 70 of saving annually. This data may appear relatively small but by looking at the big picture of global carbon foot print this data has significant contribution toward efforts of greener world.

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