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Research paper

Experimental Investigation on the Aerodynamic Performance of Optimised Pedestrian Crash Friendly Sedan Front End Profiles

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Abstract

Aerodynamic characteristic is an important feature in the manufacturing of a vehicle regardless of its shape. Drag coefficient (C_d) values and vehicle profile shapes have been known to contribute in improving the aerodynamic characteristics. However, vehicles with good aerodynamic performance may not necessarily ensure the safety among pedestrians in the event of a frontal collision with the later. Thus, this research carries out an experimental work to determine the drag coefficient values for three different speeds, 50, 80 and 108 km/h. Three sedan vehicle models, which are optimized in the frontal profile for pedestrian crash are selected, based on previous research output and are modelled in CATIA V52016. These models are then fabricated with the scale of 1:20 through 3D printing method. The models are then set up separately in a wind tunnel having an open circuit suction with a 320mm × 320mm × 420 mm test section. Drag force and coefficient values are generated in the computer connected to the wind tunnel apparatus. Simulation is also simultaneously performed in ANSYS to compare against the experimental results. The drag coefficient values from the experiment fall in the range of 0.305-0.344, for the air velocity of 13.89 m/s, 0.332-0.353 for the velocity of 22.22 m/s and 0.310-0.394 for the velocity of 30 m/s. All the C_d values are very much within the permissible range for drag coefficient values ensuring that fuel efficiency and travel comfort are not compromised thus endorsing its aerodynamic performance.

Keywords: *Drag force; drag coefficient (Cd); aerodynamic performance; pedestrian optimized model; wind tunnel*.

1. Introduction

Pedestrians are one of the common victims in road accidents. In Malaysia, they are the third highest fatality group after motorcyclist and car drivers (MRASR, 2013). Previous researches have shown that the injury outcome in a pedestrian in the event of a crash can be reduced by optimizing the vehicle's front-end profile (Kausalyah et al., 2014; Mizuno Y., 2003; Yang 2003). The vehicle front geometry has an influence to cause 84% pedestrian fatality in the event of a frontal collision (Crandall et al., 2002; Liu et al., 2003). The vehicle front geometry also plays a crucial role in determining an optimum aerodynamic performance (Selvakumar, 2013). This is specifically achieved through the optimization of drag coefficient (C_d) values that ideally should range between 0.2-0.5 (Selvakumar, 2013) for optimum vehicle performance both in fuel efficiency and dynamic stability.

Aerodynamic performance of a vehicle can be experimentally evaluated using the wind tunnel method which is useful in determining flow parameters such as fluctuation of models. Wind tunnel is said to be the most reliable and conventional approach in investigating car profiles experimentally (Hamer,2005). Drag and lift coefficient can be obtained from the experiments. The main concerns of aerodynamics in automobiles are to reduce drag, lower the noise emission and enhance fuel efficiency. The drag forces are determined by the airflow over the vehicle. Measurement of both the vertical and horizontal components of air resistance on a vehicle model can be ascertained through the wind tunnel apparatus. The weight of the vehicle changes due to air resistance when it increases in speed in motion. Drag is the amount of force that the air is pushing on the vehicle at a certain speed thus, it is the amount of resistance the air imposes on the car in a horizontal direction. A vehicle's speed is seen to be stable when it successfully overcomes friction. The most important source of friction at high speeds is air resistance. Therefore, minimizing air resistance will increase the performance efficiency of the vehicle as there will be less energy loss.

This research aims to investigate the drag coefficient values on selected vehicle models which have been optimized for pedestrian frontal collision at the speed of 50km/h. The optimized pedestrian models have been selected based on safe ranges of Head Injury Criteria (HIC) values which were obtained in previous research works (Kausalyah et al.,2014). HIC value is the likelihood of head and brain injury arising from the impact of the head to an object. These models are to be tested at three different common travel speeds (50,80 and 108 km/h) to study the drag coefficient values. A wind tunnel experiment is carried out on these models to evaluate the results and to ensure that the drag coefficient values are stable at the three different velocities tested. A computer simulation is also performed to compare the experimental result obtained.

2. Methodology

2.1 Simulation Models

Three full scale models of the selected vehicles were modelled in CATIA V52016, Figure 1 displays the image of the CATIA model.

Computational simulation to study the fluid flow was performed using the ANSYS FLUENT software and Figure 2 shows the mesh generation of the model. The simulation was performed with three different speeds on each car models. The speed of 50 km/hr which is equivalent to 13.89 m/s was selected to simulate the maximum non fatalistic crash speed for a car to pedestrian impact, 80 km/hr equivalent to 22.22 m/s as the common city highway speed and 108 km/hr equivalent 30 m/s to represent the interstate highway speed. The computational simulation and wind tunnel experiments were done using the m/s units.

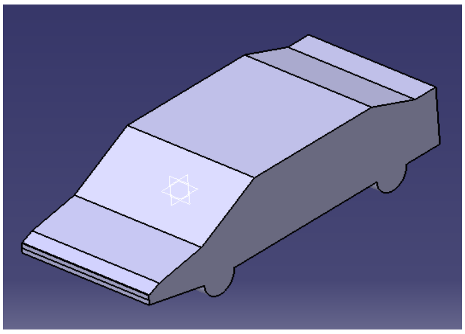

Fig. 1: Geometrical model in CATIA

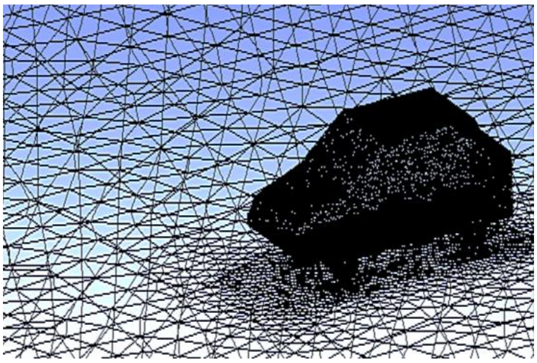

Fig. 2: Mesh generation

2.2 Model Fabrication

Three models of the sedan type of car were chosen in this experiment. The selection was made on the basis that these models contribute to low Head Injury Criteria (HIC) values of less than 500 based on previous research done (Kausalyah, 2014; Mizuno, 2003; Kausalyah et.al, 2015) as shown in Table 1. A HIC of less than 500 is deemed safe in the event of a crash for a pedestrian. The models were scaled down to 1:20 from actual size and modelled in CATIA V52016. The chosen models of cars have different frontal profiles while rear profiles were kept constant to achieve logical appearance of a car.

There were seven parameters (windshield angle, bumper lead, bumper centre height, bumper leading edge, hood length, hood angle, and hood edge height) in fabricating the models as shown in Figure 3 below (Kausalyah et al.,2014). However, wheels and side mirror were neglected and kept to basic geometry of car to avoid any other aerodynamic influences (Gauravkumar et al.,2014).

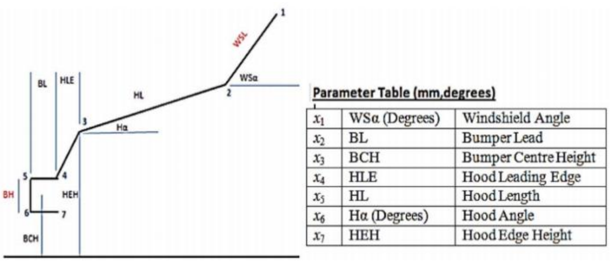

Fig. 3: Vehicle Front-end profile parameters

Table 1: Head Injury Criteria values

Model	HIC
49	340.10
55	181.60
79	211.80

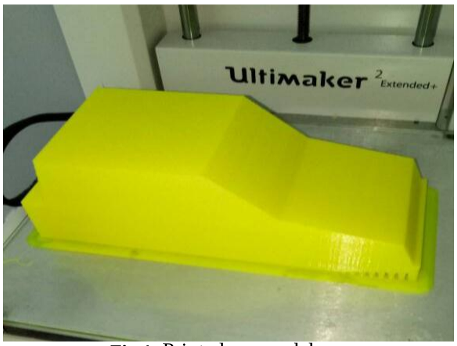

Fig 4: Printed car model

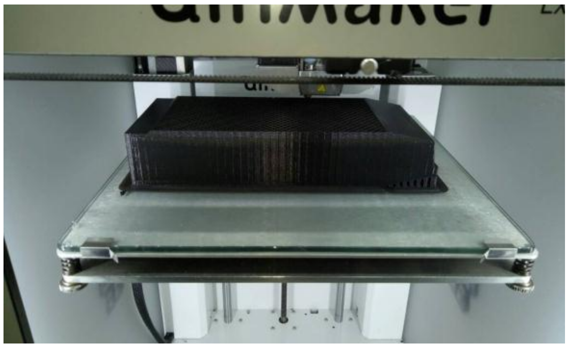

Fig 5: Printing process of car model

The models were then fabricated through 3D printing using the premium Ultimaker 3Dprinter using PLA (Poly Latic Acid) type of plastic as the material as shown in Figure 4 and Figure 5. The printing time was approximately 10 hours per model. The printing time was approximately 10 hours per model. In order to reduce the weight of the car models, only 10% of partition was equipped in the car models. Table 2. below shows the weight and fabrication time for car models.

Table 2: Weight and Fabrication time of car models

Models	Weight (g)	Fabrication time (hr)
49	212	9
55	204	10
79	184	8

2.3. Wind Tunnel Experimental Set Up

The experimental work was carried out in an open circuit suction subsonic type wind tunnel with 320 mm × 320 mm × 420 mm test section at Fluid Mechanics Laboratory, UiTM Shah Alam. The test section was equipped with Plexiglas window for visual observation. The layout of the experimental setup is displayed in Figure 6 and Figure 7. The speed of DC motor ranges from 0-30 m/s.

Tests were conducted on a geometrically similar, reduced scale (1:20) model which only differs in size from actual size. The scaled car model was attached with a rod then connected with the sensor. The model was fixed in the centre of the test section and parallel to the wind flow. Air was blown at low speed to get uniform flow inside the tunnel. Then, the wind tunnel speed is adjusted to the required velocity and data is recorded manually.

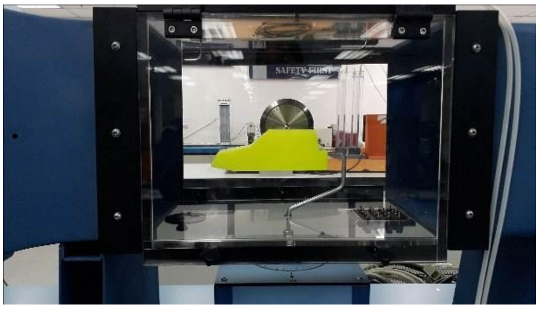

Fig 6: Test Section

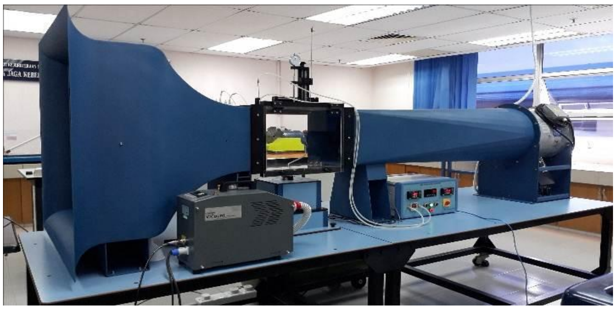

Fig 7: Experimental setup

Air was blown in three different velocities (13.89 m/s, 22.22 m/s and 30 m/s) and the drag force was obtained computationally on the monitor that is linked to wind tunnel test section. The drag coefficient and drag force was obtained. The formulation for the outputs is generated through the equations below (Ansari,2014):

$$C_D = \frac{2\,F_D}{\rho\,V^2\,A} \quad (1)$$

$$F_D = 0.5 \times C_D \times \rho \times V^2 \times A \quad (2)$$

Where, C_D = Drag coefficient
F_D = Drag force
V = Velocity
A = Frontal area
ρ = Air Density

3. Result and Discussion

3.1 Computer Simulation

Table 3 below shows the drag coefficient and drag force on the car models using ANSYS FLUENT. The drag forces values are seen to be stable when tested upon the three speeds in the computational simulation.

Table 3: Drag force and coefficient values on ANSYS

Veloc-ity m/s	Model 49		Model 55		Model 79	
	C_D	F_D (N)	C_D	F_D (N)	C_D	F_D (N)
13.89	0.527	138.876	0.463	151.555	0.461	132.161
22.22	0.526	354.719	0.461	386.167	0.422	309.598
30.00	0.524	646.605	0.460	702.403	0.423	564.692

3.2 Wind Tunnel Experiment

Experimental results of drag force and coefficient of car models were obtained and tabulated in the Table 4. below.

Table 4: Experimental data of car models

Velocity m/s	Model 49		Model 55		Model 79	
	C_D	F_D(N)	C_D	F_D(N)	C_D	F_D(N)
13.89	0.344	0.150	0.310	0.187	0.305	0.164
22.22	0.353	0.471	0.352	0.544	0.332	0.458
30.00	0.394	0.935	0.329	0.926	0.310	0.780

For the velocity 13.89 m/s, the drag force obtained was 0.150N for model 49, 0.187 N for model 55 and 0.164 N for model 79 and the values vary respectively for each model and speed tested. The drag coefficient values for the similar speed are 0.344 for model 49, 0.310 for model 55 and 0.305 for model 79. Figures 8, 9 and 10 below displays the images of the vehicle models after 3D printing.

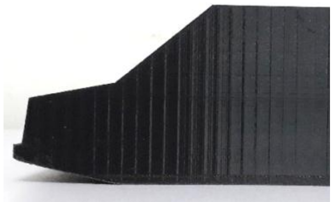

Fig. 8: Model 49

Fig. 9: Model 55

Fig. 10: Model 79

The drag coefficient (C_d) values for model 49 increases from 0.344 to 0.394 as the speed increases. However for models 55 and 79, a different trend is noticed where the C_d increases and then decreases with the increment of speed. The C_d values obtained from the wind tunnel experiments are also showing consistency across the three different speeds tested which indicates that the vehicle profiles present aerodynamic stability. The drag force however shows a steady increase as the speed increases for all three models. This is better illustrated in the graphs below displayed in Figures 11, 12, 13 and 14.

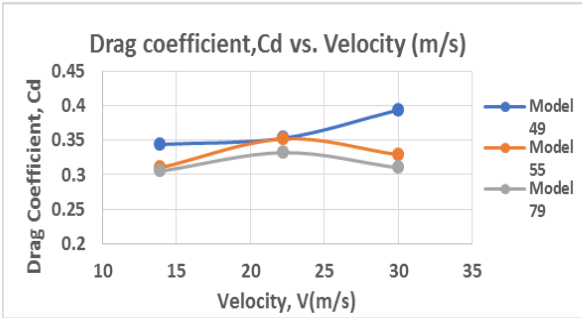

Fig. 11. Variation of C_D with velocity (Experimental)

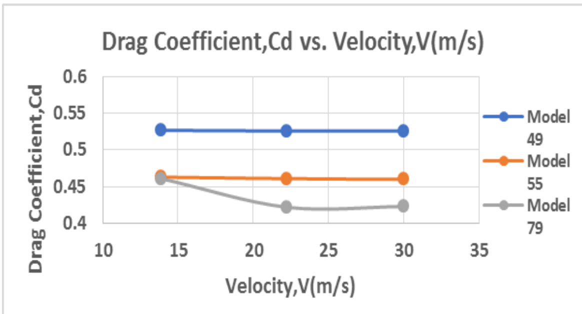

Fig. 12. Variation of C_D with velocity (Simulation)

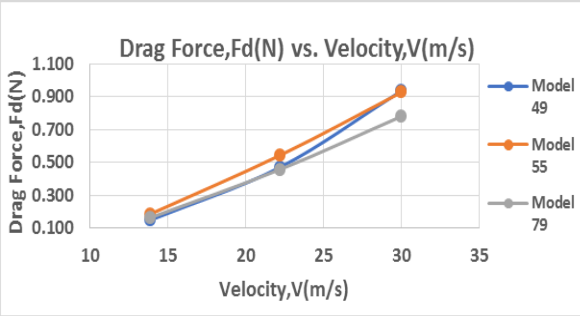

Fig. 13. Variation of F_D with velocity (Experimental)

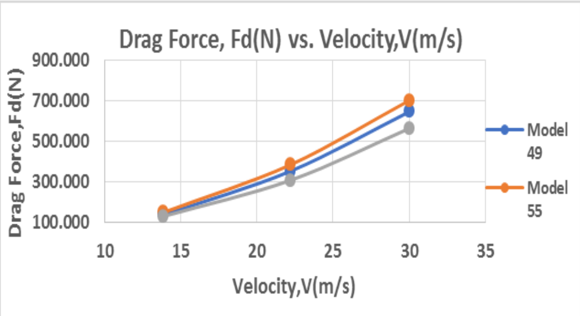

Fig. 14. Variation of F_D with velocity (Simulation)

Tables 5, 6 and 7 below show the comparison between experimental and simulation works for each model and the error differences. The C_d values obtained from the simulations and experiment has an average error of 28.2% for model 49, 28.4% for model 55 and 27.3% for model 79. There are some possible reasons for this occurrence. The air density values in the wind tunnel experiment and computer simulation were not exactly similar as the default values given in the wind tunnel set up were used which were 1.15 and 1.225 each respectively. Other than that, the size of enclosure of the simulation test section is not the exact size fitted in the wind tunnel experiment. These factors may have resulted in the difference.

Table 5: Comparison data for model 49

Velocity	Experimental		Simulation		C_d
m/s	F_D(N)	C_D	F_D(N)	C_D	Difference (%)
13.89	0.150	0.344	138.876	0.527	34.7
22.22	0.471	0.353	354.719	0.526	25.1
30.00	0.935	0.394	646.605	0.524	24.8

Table 6: Comparison data for model 55

Velocity	Experimental		Simulation		C_d
m/s	F_D(N)	C_D	F_D(N)	C_D	Difference (%)
13.89	0.187	0.310	151.555	0.463	33
22.22	0.544	0.352	386.167	0.461	23.6
30.00	0.926	0.329	702.403	0.460	28.5

Table 7: Comparison data for model 79

Velocity m/s	Experimental		Simulation		C_d Difference (%)
	F_D(N)	C_D	F_D(N)	C_D	
13.89	0.164	0.305	132.161	0.461	33.8
22.22	0.458	0.332	309.598	0.422	21.3
30.00	0.780	0.310	564.692	0.423	26.7

4. Conclusion and recommendation

In this study, some of the optimized pedestrian crash friendly sedan front end profiles are investigated experimentally and computationally to determine its aerodynamic performance. From this research, the objective which is to investigate the optimized sedan is fully achieved as the model selected is low in drag coefficient and falls within range of minimum HIC value. The comparison of drag forces between experimental and simulation shows an agreement for the entire range of velocities. The drag coefficient values are falling within the permissible range which is 0.3 - 0.45 as obtained from the wind tunnel experiments, thus proving that the vehicle front end profiles which are pedestrian friendly do have a compliant drag coefficient values for enhanced aerodynamic performance.

However, this study is limited to only the adult population when accessing the head injury and the aerodynamic criteria were evaluated based on that. Future works can look into vehicle profiles which are optimized for children impact and multiple objective optimization can be performed.

Acknowledgement

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