CHAPTER 1

INTRODUCTION

1.1 Background of Study

There are several methods that can be done in order to achieve minimum fuel consumption for a vehicle. Other than the driver's habit, weight reduction, engine optimization and aerodynamics improvement can also reduce the fuel consumption. My project is to perform a study and of the aerodynamics profile of a Perodua VIVA to improve its coefficient of drag. First, the vehicle will undergo several aerodynamic modifications. After the modifications are completed, the vehicle will be taken for a fuel consumption test where 1 liter of fuel will be used to see the distance it can travel.

The proposed modifications in the aerodynamics area are:

1. Hard damper
2. Adjust length of suspensions
3. Replacement of Tires
4. Covering of rear wheel wells
5. Covering of openings/gaps

After performing the fuel consumption test, the vehicle will undergo a coast down test as well as tuft test to see the effects of said modifications above on its coefficient of drag, Cd. The tuft test is conducted to monitor the effects of the modifications on the type of airflow the car experiences, as well as to keep in track the areas required for improvement.

1.2 Problem Statement

There are many factors that can contribute to fuel economy in vehicles. Apart from driving styles, load carried by the vehicle, aerodynamic drag also plays an important role in achieving fuel economy. Increasing the drag force, F_d will result in higher fuel consumption as the vehicle will require more power to overcome the drag. It is well known that at highway and cruising speeds, nearly 50% of the power output from the engine is needed to overcome the drag. To produce more power, the engine will burn more fuel; therefore fuel consumption will increase.

Hence, reducing the drag experienced by a vehicle becomes a common practice to reduce fuel consumption. In general, vehicles nowadays have a coefficient of drag, Cd between 0.25 to 0.36 (regular sedan and hatchbacks). Bigger, bulkier vehicles like trucks and lorries tend to have higher Cd values.

1.3 Objective of Report

The objective of the report is as follows:

1. To perform an aerodynamics study on the Perodua Viva vehicle.
2. To modify the Perodua Viva to achieve as little coefficient of drag as possible to reduce its fuel consumption.
3. To perform fuel consumption tests to verify the results from the study.
4. To provide data for easy comparison.

1.4 Scope of Study

The aim of this project is to provide a study on the aerodynamics profile of a vehicle (Perodua Viva) and ways to reduce drag to improve its fuel consumption. The fuel consumption between the standard and the modified vehicle will be monitored for comparison. Modifications to be made must comply with the rules and regulations of the Perodua Eco- Challenge Tournament.

The scope of my project is to perform experiments (trial runs) as the modifications are completed to see whether the modifications have any effects on the fuel consumption or not.

The trial runs included performing a fuel consumption test after each modification, as well as a coast down test to find out the value of the coefficient of drag of the vehicle after the modifications are completed.

The coast down test is an integral part of the project as it is used to determine the Cd of the vehicle after the modifications. Though the frontal area of the vehicle has little or no change at all, the modifications are hoped to have a positive effect to the reduction of the Cd of the vehicle.

In order to find out about the Cd, it is important for me to conduct the coast down test.

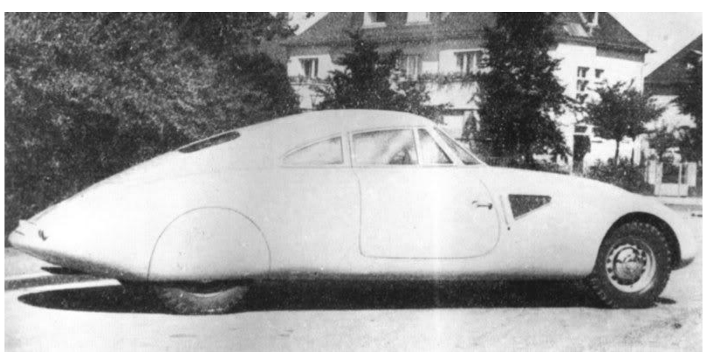
CHAPTER 2

LITERATURE REVIEW

Aerodynamics is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a moving object. (Wikipedia, 2010).

In the mid to late 30's in Germany, there was a lot of work done in creating vehicles with a low Cd. The impetuous for this was the building of the Autobahn, which provided a roadway that was capable of handling much higher speeds than the typical car/engine combinations available at the time could produce. They soon found that by reducing a car's drag, the existing engines could propel a car much faster down the Autobahn than it could do in a traditionally shaped car body. Unfortunately this bout of automotive experimentation was shut down with the the start of WWII and most of the vehicles lost in the ensuing conflict.

As we know, the best design to achieve the lowest Cd as possible is a streamlined design. In the late 30's, the Germans had produced vehicles with peculiar design in order to reduce the aerodynamic drag. Some of the designs were:



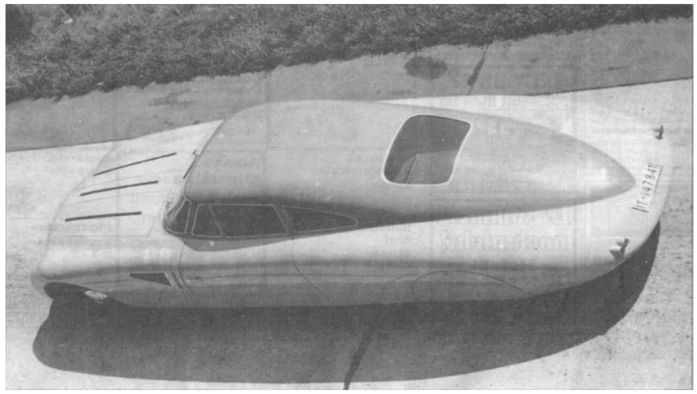


Figure 1: streamlined Maybaches in the 1930's

The above design had longer tailgates to channel air from the roof, so that the size of vertices formed behind the vehicle was reduced. Less vortices formed, less wake was created therefore the drag was reduced.

In the US, some hypermilers (people who are concerned about their vehicle's fuel consumption) are known to modify their vehicle and make them more streamlined. In addition, some of them also go the extent of verifying the result by performing test runs. This is to ensure that the modifications done do not add unnecessary weight to the vehicle, causing the fuel consumption to drop.

For example, a hypermiler from New Orleans, USA had modified his Honda Civic CX to resemble the above design. At first, he used aluminum, Coroplast (corrugated plastic sheet) to form the modified parts, using techniques similar to making a homebuilt aircraft. After that, he used aluminum monocoque and polycarbonate resin thermoplastic to produce stronger parts. (Aerocivic.com, 2005)

The end result is a car with such low aerodynamic drag that it is down in concept car territory and well below the 0.25 Cd (coefficient of drag) of a Toyota Prius (3rd generation). The looks also changed greatly compared to the standard Honda Civic CX.

Figure 2: standard Honda Civic CX

a) Front

b) Back

Figure 2: aerodynamic Civic (Aerocivic)

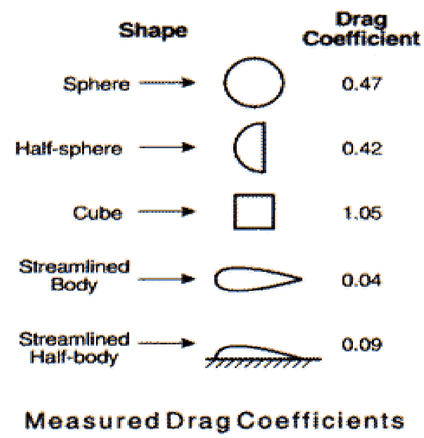
Modification performed by another hypermiler, Phil Knox on his Toyota Tacoma:

Figure: standard Toyota Tacoma (Open Access Article Originally Published: June 29, 2005)

Figure: Phil Knox's Toyota Tacoma

The modifications done on the Aerocivic and Toyota Tacoma above had inspired me to perform similar modifications to a Perodua Viva to reduce its coefficient of drag. To verify the effectiveness of the modifications, several tests will be conducted. In this report I'll explain in detail about the modifications done and the test conducted to verify the result.

Here is a comparison between several shapes and their Cd:



Vehicles are often designed in such a way that it resembles a streamlined half body. This as close as a vehicle can get to a shape that has the lowest Cd, due to several limitations. Such limitations are the need of a boot space, attractiveness, customer preferences, passenger comfort, and ergonomic design of the interior, passenger safety as well as the need to place a huge engine and other equipments.

However, if the above limitations are not taken into consideration, the design can be pushed such that it resembles a streamlined body. Some of the extreme designs are:

Figure 4: a concept car by Bentley

Figure 5: a Pagani Zonda undergoing a wind tunnel test

In both designs, there is no or little boot space at all, as well as only one passenger can get into the car at a time. Therefore the designers can push the design to be more radical.

Other famous studies conducted to improve the drag of a vehicle include the studies performed by Nascar. However, in the studies, their major concern is to induce downforce so that the vehicle can travel at high speed during cornering without rolling over.

Figure 6: a scaled wind tunnel used by nascar

Most of the studies are done by performing a scaled wind tunnel test. A scaled wind tunnel test may not be the test that provides an accurate result, but due to a full scale wind tunnel being costly, a scale wind tunnel test may suffice.

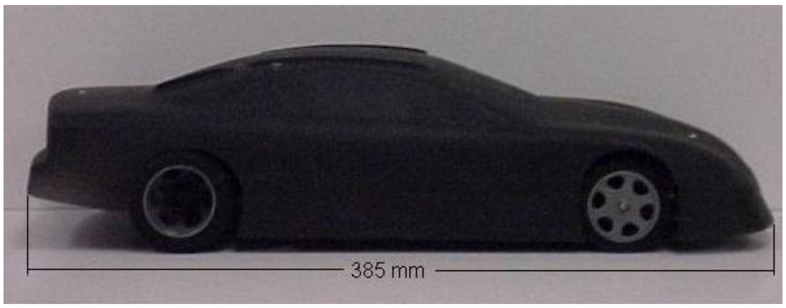


Figure 7: a scale model of a Nascar race vehicle

The purpose of the of test mainly is to figure out the aerodynamic profile that gives better traction, as well less air resistance.

The model is fitted with pressure sensors to take the pressure measurement at different point. Using the pressure measurements, the pressure coefficients at different points are calculated. Some of the results are:

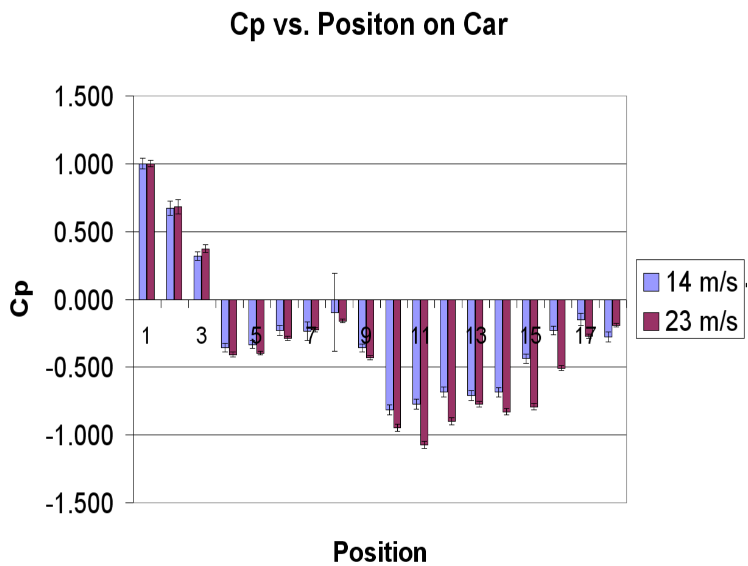


Figure 8: sample result of a Nascar's wind tunnel experiment

The results show the frontal area of a vehicle is the stagnation point, where it experiences highest resistance and highest pressure. The roof of the car is where it experiences the lowest pressure, because of the low air flow velocity.

However, my project is not aimed at achieving higher cornering speeds. Instead, my project is aimed at achieving the lowest fuel consumption possible by reducing drag.

CHAPTER 3

METHODOLOGY

The coefficient of drag, C_d is a measure of the effectiveness of an object at creating a drag force. A higher C_d value indicates that the object creates higher drag force than an object with lower C_d. from the formulas above, we can see that the drag force increases as the frontal (reference) area increases. Therefore, to minimize drag, designers often opt for a more streamlined design.

Reducing drag is also a factor in sports car design, where fuel efficiency is less of a concern, but where low drag helps a car achieve a high top speed. However, for a low to moderate speed application, the difference in drag can cause a significant change in fuel consumption. To further understand and prove this, some modifications are proposed to correlate the drag with the fuel consumption of the vehicle.

At highway speeds, 54% of energy is spent on overcoming aerodynamic drag.

Therefore, reducing the drag force experienced by a vehicle has become common practice to improve fuel consumption.

The coefficient of drag of the Perodua Viva is 0.37. The drag is proportional with the coefficient of drag and if the C_d is reduced, the drag force is reduced, thus less fuel is consumed.

To measure the fuel consumption, the car will be driven at a constant speed along the same tracks. This is to ensure consistency between different drives. The fuel level before and after the car is driven will be noted down, and divided with the distance traveled to obtain an estimation of the vehicle's fuel consumption:

$$F_c = (F_{l,f} - F_{l,i})/s \text{ , where}$$

F_c : fuel consumption in liters per meter

$F_{l,f}$ = Fuel level after driving (liters)

$F_{l,I}$ = Fuel level before driving (liters)

S = distance traveled

The details of the modifications are as follows:

Vehicle Dynamics/ Aerodynamics Improvement

1. Hard damper

By using a hard damper, it will reduce vehicle roll during cornering. With less roll, vehicle will consume less fuel and energy. A reduced vehicle roll enables the driver to drive the vehicle at constant speed even during cornering. A constant speed driving uses less fuel since constant fuel supply for combustion is needed.

2. Adjust length of suspensions

The car suspensions will be lowered. By lowering the suspension, the center of gravity of the car will be lowered and this reduces vehicle tendency to roll. As explained in part (1), a reduced vehicle roll enables the driver to drive the vehicle at constant speed even during cornering. The other advantage of lowering the suspensions is that the aerodynamics profile improves and the coefficient of drag is reduced. The lower the coefficient of drag, the better the vehicle's fuel consumption is. This is because the vehicle does not have to do more work to overcome the drag force. Less work needed to overcome drag means that less fuel is burned.

3. Replacement of Tires

All of the existing tires will be replaced with four sets of spare tires which are smaller in diameters. This reduces rolling resistance of the car. Rolling resistance causes unnecessary frictional loss that increases the vehicle’s fuel consumption.

4. Covering of rear wheel wells

The rear wheel wells will be covered to reduce drag resistance. This is done to improve the aerodynamics profile and reduce the drag.

5. Covering of openings/gaps

Any openings will be covered to avoid unnecessary drag resistance. The openings will be sealed completely to prevent air from flowing into the gap, thus increasing the vehicle’s drag.

To achieve the objective of this report, the Perodua Viva will undergo the mentioned modifications, and a 3D drawing of the vehicle will be made using CATIA software. After modifying all the necessary aspects of the car, an analysis using ANSYS software will be performed to see whether or not the coefficient of drag decreases. To confirm the effects of reducing the coefficient of drag on its fuel consumption, the car will be test driven at a constant speed, and the fuel consumption will be monitored closely and compared.

The analysis will involve the standard vehicle and the modified version model. A CFD analysis will then be conducted to see the effects of the modification on the vehicle’s (both standard and modified) coefficient of drag.

Progress:

A benchmark test was completed (with the seats, air conditioning unit, airbag and spare tire taken out) to monitor the fuel consumption of the vehicle. The seats, air conditioning unit, airbag and spare tire were taken out as part of the weight reduction process (heavier vehicle consumes more fuel). After the mentioned parts were removed, the vehicle was taken for a ride to monitor the fuel consumption. Fuel consumption is measured in kilometers per liters, or simply the distance a vehicle can travel with a liter of gasoline.

In order to obtain the vehicle's fuel consumption, a benchmark test was conducted. The benchmark test was performed while driving the vehicle at a constant speed. In order to simulate the race condition, the speed of which the vehicle was operated was set to be about 50km/h. This was to ensure that the vehicle was operated at a speed higher than the minimum speed (28km/h).

The minimum speed was obtained by calculating:

Track length, s= 1.6km

Minimum lap time (1 lap) 3 minutes 30 seconds i.e: t=3.5m

Average speed for race compliance; $V_{avg} = s/t = (1.6/3.5)*60 = 28km/hr$

However, driving a vehicle at too low a speed will not result in an optimum fuel usage. This due to the optimum fuel consumption occurs at which the maximum torque is achieved. In this case, the vehicle achieves its highest torque at about 3600rpm (80km/h). If the vehicle is driven at the peak torque, maximum power is produced, resulting in an optimum fuel usage. However, for safety reasons, the vehicle cannot be driven at 80km/h, so a constant speed of 50km/h would suffice.

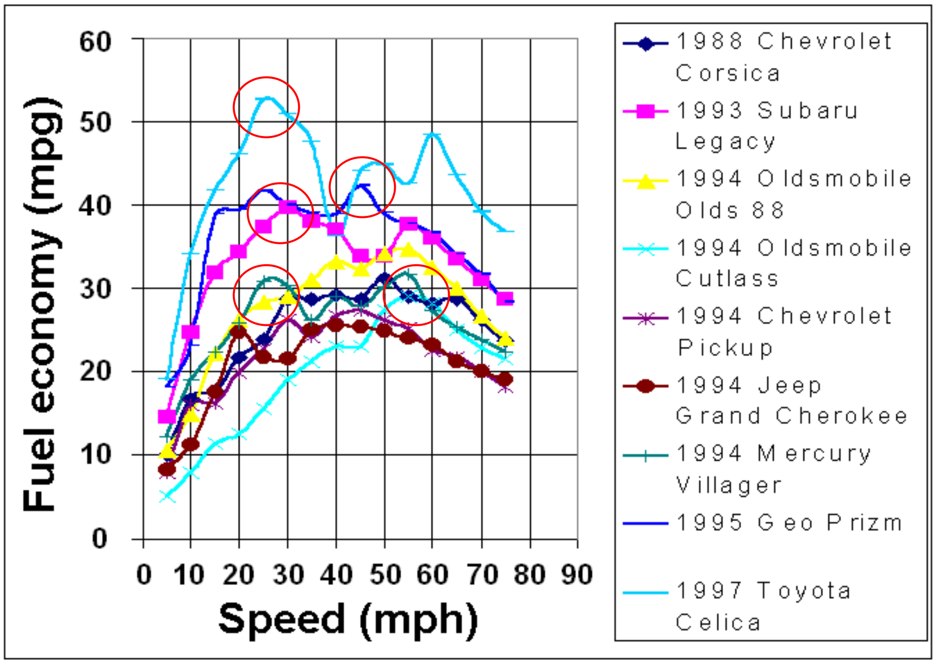


Figure 9: Fuel economy for some cars. Notice the optimum fuel economy occurs at different speeds. (Wikipedia, 2010)

In truth, the fuel consumption obtained from the test was not accurate enough. This was due to the track having junctions that required braking. Fuel economy is maximized if the acceleration and braking are minimized. Braking causes kinetic energy to be lost, and consequently resulted in higher fuel consumption.

After the team decided on a speed of which the vehicle should be driven, a global positioning unit (GPS) was used measure the distance traveled, as well as the average speed of the vehicle.

In the fuel benchmark test, the factors that could affect the engine efficiency (air density, humidity and ambient temperature and ambient pressure) were assumed constant.

The result of the benchmarking test was 18.9km/l. This result will be used as reference in the future to compare the fuel consumption after the modifications are performed.

A diffuser is a shaped section of the car underbody which improves the car's aerodynamic properties by enhancing the transition between the high-velocity airflow underneath the car and the much slower freestream airflow of the ambient atmosphere. It works by providing a space for the underbody airflow to decelerate and expand so that it does not cause excessive flow separation and drag, by providing a degree of "wake infill". The diffuser itself accelerates the flow in front of it, which helps generate downforce.

Adding diffuser and front splitters improve the aerodynamics characteristics of the vehicle. The plan is to modify the rear and front bumper by adding diffuser.

Other planned modifications include mounting a custom hood scoop to allow air to enter the engine bay. This would help to reduce the heat loss and improve the engine efficiency. However, some hood scoops allow too much air coming in, and as result it increases drag. To allow the air to escape thus reduce the drag force while cooling down the engine at the same time, side ventilation (shark fins) will be fitted. This helps the hot air to escape the engine bay.

Adding splitters also helps improving the aerodynamics characteristics of a vehicle. A splitter improves the air flow underneath the vehicle. The air flow is channeled out to reduce drag. A lightweight, heat resistant and strong material is to be used. The cheapest material of choice is aluminum sheet. The aluminum sheet will be shaped and cut in such a way that it is possible for the team to be attached it to the underside of the vehicle.

Other proposed method of reducing the drag is by reducing the wake area. Wider wake area increases drag. This can be achieved by allowing air to go through the roof all the way to the rear. The roof will be partially cut and a Perspex glass will be put in place.

The most important factor that affects the aerodynamic drag is the geometry and shape of an object. For example, square shape experiences the highest aerodynamic drag because it has high coefficient of drag. A sphere however experiences less aerodynamic drag because it has smaller coefficient of drag than a square. In general, a smooth and streamlined object has lower coefficient of drag.

The second part of my project involves changing the geometry and shape of the vehicle to obtain smaller coefficient of drag to reduce the aerodynamic drag. The areas of interest are the side mirrors, wheel wells, underside and the rear part of the vehicle. In order to achieve the goal, few modifications had to be performed on the vehicle. All modifications performed were intended to improve the air flow and lowering the coefficient of drag so that the vehicle experienced less drag and in turn consumed less fuel.

First, a diffuser was put in place underneath the vehicle. This will improve the air flow at the underside of the vehicle, preventing air from entering the crevices and openings underneath the vehicle. This technique is widely used in the automotive industry to improve the aerodynamics profile of a vehicle.

Secondly, the vehicle's rear and side are modified such that it helps in channeling air from the front to the rear. This modification reduces the wake behind the vehicle, and as the wake is reduced, the vehicle experiences less drag. However, to ensure that the modification does not cause the vehicle to experience turbulent air flow (turbulent air flow has higher drag as opposed to laminar flow) a tuff test is conducted. In the tuff test, strings are attached to the vehicle. The strings will give a good indication whether the air flow is laminar or turbulent.

Figure 10: taping strings for tuft test.

Figure 11: vehicle undergoing tuft test

Tufts are applied to the vehicle and remain attached during testing. Tufts can be used to gauge air flow patterns and flow separation.

After all modifications are completed, the vehicle is taken for a coast down test. The coast down test is aimed at obtaining sets of data that can help in determining the aerodynamics drag experienced by the vehicle. In the coast down test, another important parameter that influences the result is the rolling resistance of the tires. This is because the force, F of a moving vehicle is:

$$F = ma = -Fr - Fd$$

Where Fr is the resistance force from the tires, which is

$$F_r = -C_r k_r Mg$$

Cr is the coefficient of rolling resistance; Mg is the weight of the vehicle.

And the aerodynamics drag, Fd can be computed from:

$$F_d = \frac{1}{2} C_d A \rho V^2$$

The data from the coast down test can be used to calculate the coefficient of drag of the modified vehicle, and later to estimate the drag force the vehicle will experience at various speeds.

The details of the modifications:

a) Adding diffuser underneath the vehicle. The objective of adding a diffuser to the vehicle is to improve its aerodynamics profile. The diffuser helps channeling air from the front straight to back without entering any crevices or openings.

b) Lowering the vehicle – the standard springs used in a stock Perodua Viva is replaced with sport springs. The sport springs reduce the overall ground clearance of the vehicle. The ground clearance now becomes 11cm (previous: 14.5cm).

Reducing the ground clearance reduces the coefficient of lift, C_L up to a certain point, before it increases. From the study performed by Lotus, the optimum ground clearance of a vehicle should be 5cm. Lower ground clearance reduces the stagnation point of the vehicle. Less ground clearance minimizes the airflow underneath a vehicle.

Figure 12: installing diffuser

c) Side air ducts – the windows were removed and Perspex glass was used instead. The Perspex glass was mounted in such a way that it would help channeling air from the front to the rear.

d) Placing the side-mirrors inside the vehicle. This is done to minimize the obstructions faced by the airflow. Less obstruction, better airflow is obtained, and less drag is experienced by the vehicle.

The design helped reducing the wake area that in turn will reduce the aerodynamic drag.

Figure 13: side air ducts to channel air from front

Figure 14: A standard (stock) Perodua Viva

Figure 15: UTP PEC's Modified Perodua Viva

Figure 16: UTP PEC's Perodua Viva (rear view). Notice the side air ducts of the car

To fully understand the effects of the modification on the coefficient of drag of the vehicle, a coast down test was performed. The coast down test was conducted by driving the vehicle at a constant speed, and changing the gear to “neutral”, allowing the vehicle to coast down to a certain speed. From the test, the vehicle speed and other important data were obtained using the DL2 Data Logger. The beacon was mounted on top of the vehicle. The data were then exported to Microsoft Excel format for easier reference.

Figure 17: a DL2 data logger used in the coast down test.

The DL2 data logger gives an accurate data measurement for the coast down test. However there is another method of performing the coast down test without using the DL2 data logger. The downloaded data from the DL2 data logger contained the vehicle speed, time, acceleration, distance traveled and other useful information. The beacon must be mounted such that it faces the direction of travel of the vehicle before it can collect any data. The data are then recorded in a memory card and can be downloaded from a laptop.

Another way of conducting the coast down test is by using a stopwatch, pen and paper (to record the data) and an excel spreadsheet. The steps are:

a. Drive on a flat road with little traffic or wind.
b. Have the passenger ready with stopwatch and paper to record data.
c. Have the driver accelerate up to above 70 km/h or so, and shift into neutral.

d. Record data as follows. The driver should indicate when the speed drops to exactly 70 km/h. At this time (t=0) the passenger should start the clock. The passenger should indicate every 10 seconds after that and the driver should call out the current speed to the nearest whole km. The passenger should record this value next to each time.
e. Repeat the test in the opposite direction.
f. Plot a graph of velocity against time. This plot is a reference plot. Using an excel spreadsheet, estimate the Cd and Crr. Plot another graph (model) using the estimated values of Cd and Crr. If the model graph matches the actual graph, the estimated value of Cd is correct.

The coast down test is a useful and simple method to compute the coefficient of drag of a vehicle.

In the world of automotive, the study of aerodynamics is aimed at designing a vehicle that has an aerodynamics profile such that it reduces the power requires to overcome the drag. This branch of study is essential as it helps designers to come up with the best vehicle design that helps reducing fuel consumption.

In comparison, a hatchback car (Perodua Viva, Chevrolet Aveo, Perodua Myi, Proton Savvy etc) generates more vortices at the back than a regular sedan (BMW 3 Series, Proton Persona, Toyota Vios etc). This is because the rear of a hatchback lacks a large boot space that gives a regular sedan an elongated body at the rear. A hatchback's design generates a lot of vortices at the rear as the momentum of the wind flowing over the top of a hatchback changes abruptly, unlike a regular sedan. The abrupt change of momentum generates more vortices, resulting in higher wake at the rear. Higher wake is the reason for higher trailing drag experienced by a vehicle. In some hatchbacks, a spoiler is mounted on top of the vehicle to channel air in such a way that it resembles the air flow on a regular sedan. If the rate of change of momentum of air decreases, the formation of vortices also decreases, and the wake will be reduced.

CHAPTER 4

RESULT AND DISCUSSION

For each and every modifications performed on the vehicle, a test run was conducted. The test runs were performed to confirm the effects of such modifications and to conclude that the modifications actually improved the fuel consumption of the vehicle.

4.1 Test Runs

4.1.1 Coast down Test (Side Air Ducts/Diffusers)

Figure 19: vehicle undergoing coast down test

After the side air ducts were finished, the vehicle was taken for a simple test drive. The test drive was performed to compare the fuel consumption of the vehicle before and after the modifications.

The vehicle was taken for a test run to verify the effects of adding diffuser and side air ducts to the vehicle. The test run was conducted by taking the vehicle for a ride with only a liter of test fuel (Petronas Primax95). After draining all the fuel from the fuel tank, a liter of the test fuel was added to the tank. Then, the vehicle was driven until it stopped. The vehicle was driven at a constant test speed (60km/h), with the same test conditions (ambient Temperature 32^{o}C +-5^{o}C, ambient Pressure 1atm).

4.1.2 Tuff Test

The tuff test was conducted to obtain a basic understanding of the type of air flow on the surfaces of the vehicle. The most affected area is the wheel wells and the side air ducts. A laminar flow is desired because it has less drag compared to a turbulent flow. This due to laminar flow exerts more resistance on the surface of the vehicle, and as the air resistance increases, the drag for exerted on the surface is also increased. While the vehicle was driven, a camcorder was used to record the motion of the strings in order to monitor the air flow type. The video was then inspected. The motion of the strings gave an indication that the flow is laminar.

The area where the air flow is mainly turbulent is the wheel wells. Further improvement can be achieved by covering the wheel wells to ensure laminar flow along the side of the vehicle.

4.1.3 Fuel Consumption Test

After the modifications are completed, the vehicle is taken for a fuel consumption test. The objective of the fuel consumption test is to see the effects of the modifications on the fuel consumption of the vehicle. There are 4 major modifications done on the vehicle, and 4 tests are conducted in total.

The most significant modifications done are the installation of the sport springs to reduce the ground clearance of the car, the installation of the underbody cover and the installation of the side air duct.

The test is performed along the same track for consistency:

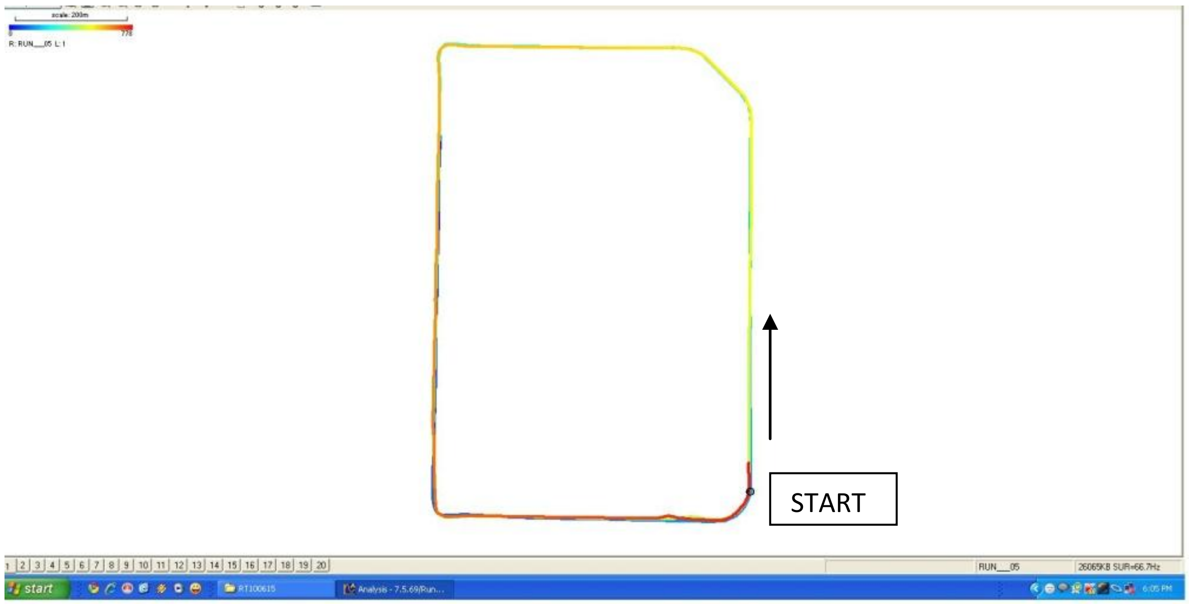


Figure 20: Track visualization generated from DL2 Data Logger

In order to eliminate or minimizes the effect of wind on the drag force of the car, the tests are conducted under a windless, clear weather day. This is important as windy days will increase or reduce the drag, and the result may not be as accurate.

The procedure of the tests is as follows:

1. Drive the vehicle until the engine stalls.
2. Crank the engine and see whether the engine starts or not. If the engine doesn't start, this indicates that there is no fuel left in the fuel lines and fuel tank.
3. Remove the fuel line connections and drain all fuel leftovers from the fuel line.
4. Reconnect the fuel line.
5. Using a measuring cylinder, measure exactly 1 liter of fuel on a level surface.
6. Cover the measuring cylinder while transferring the fuel to minimize fuel evaporation.
7. Reset the odometer until the value shows '0'.
8. Pour the fuel from the measuring cylinder into the fuel tank.
9. Push the vehicle to the starting position.

10. Start the engine, and quickly jump to gear D. this is done to avoid any wastage of fuel during idling.
11. Drive along the track until the engine stalls and die (fuel has run out).
12. Repeat three times and get the average fuel consumption.

From the fuel consumption tests conducted, the result can be summarized as:

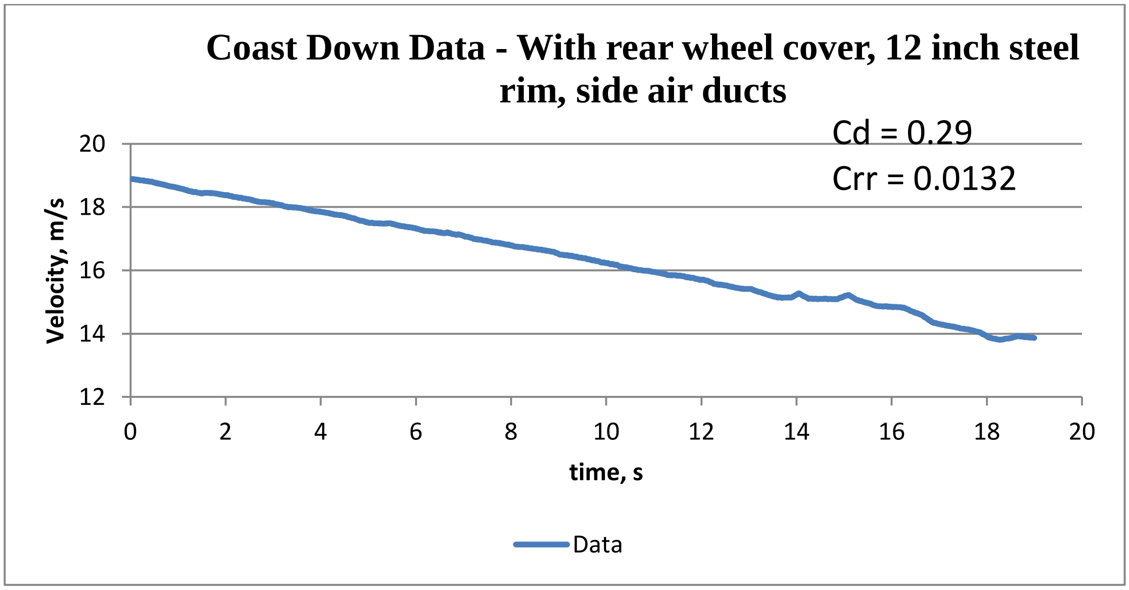
Modifications	Details	Fuel Consumption
Baseline Test	Continued from previous tests, vehicle with weight reduced, use low resistance tires, compressed air fuel system, aircond removed, electrical devices removed	22.1 km/l
Sport springs installed	Reduced ground clearance from 18 to 14cm (front), rear 19 to 17 cm. Rear is not lowered much due to weight is mainly from the engine, weight distribution to the front.	23.4km/l
Underbody Cover installed	From rear all the way to the mid section of the vehicle, used aluminum sheet for lightweight, mounted with bolts and cable ties.	24km/l
Side air ducts installed	Use Perspex glass; mount using aluminum bars for lightweight, covered with	25.2km/l

	aluminum sheets, gaps covered with smooth masking tape.	
Miscellaneous	Replacement of side mirrors (smaller side mirrors), openings at the bonnet for engine cooling, cover of rear wheel wells	25.7km/l

Table 1: Summary of Test Results

4.1.4 Calculations & Discussions

From the data obtained in the coast down test, a plot of velocity against time is computed.



Graph 1: Plot of Speed vs Time for coast down test

The actual plot is a plot of the velocity against time obtained from the test.

To calculate the Cd and Crr, use any value from the data, for example:

DATASET		
Set 1		
t	V	a
		-
0.12	18.87	0.27327
5.17	17.49	
Set 2		
t	V	a
		-
10.92	15.98	0.31203
13.58	15.15	

Table 2: sample data from coast down test

From equation, we know that:

$F = ma = -Fr - Fd,$

Where $F_d = \frac{1}{2}C_d A\rho V^2$, and $F_r = C_{rr}k_r Mg$. Rearranging (i) the equation yields

$$-C_d = \frac{Ma + C_{rr}K_r Mg}{A * 0.5 * \rho * V^2}$$

The estimated mass, M of the vehicle is 760kg, $\rho = 1.23$kg/m^3, A =2.21m^2.

1st, the acceleration of the vehicle can be calculated from the data above:

$$a = \frac{V_2 - V_1}{T_2 - T_1}$$

Inserting the values from set 1 yields:

$$a = \frac{17.49 - 18.87}{5.17 - 0.12}$$

a = -0.2733 m/s^2.

$$A * 0.5 * \rho * V^2 = 2.21 * o.5 * 1.23 * 18.87^2 = 483.96$$

And the force experienced by the vehicle, F:

$$Ma = 760 * (-0.2733) = -207.7N$$

Substituting the values into (i) yields

$$-C_d = \frac{-207.7 + C_{rr}K_r Mg}{483.96}$$

$$-C_d = -0.428 + \frac{C_{rr}K_r Mg}{483.96}$$

$$-C_d = -0.428 + \frac{C_{rr}K_r * 760(9.81)}{483.96}$$

$$-C_d = -0.428 + 15.405 C_{rr}K_r \quad \ldots (ii)$$

Now, using the data from set 2:

$$A * 0.5 * \rho * V^2 = 2.21 * o.5 * 1.23 * 15.98^2 = 347.07$$

$$a = \frac{15.15 - 15.98}{13.58 - 10.92}$$

$$a = -0.3120$$

$$Ma = 760 * (-0.312) = -273.143N$$

$$\frac{Ma}{A * 0.5 * \rho * V^2} = \frac{760(-0.312)}{347.07}$$

$$= -0.683$$

$$\frac{C_{rr}K_rMg}{347.07} = \frac{760(9.81)}{347.07}C_{rr}K_r$$

$$= 21.48C_{rr}K_r$$

Therefore,

$$-C_d = -0.683 + 21.48C_{rr}K_r \qquad \ldots(iii)$$

To find $C_{rr}K_r$, substract iii and ii :

$$-C_d = -0.428 + \ 15.405C_{rr}K_r \quad \ldots(ii)$$

$$\underline{-[-C_d = -0.683 + 21.48C_{rr}K_r \qquad \ldots(iii)\ ]}$$

$$0 = 0.255 - 6.075C_{rr}K_r$$

$$C_{rr}K_r = \frac{0.255}{6.075}$$

$$= 0.042$$

$$-C_d = -0.428 + \ 15.405(0.042)$$

$$-C_d = 0.22$$

Therefore, from the coast down test conducted, the coefficient of drag of the vehicle (after modification) is 0.22. Note that Crr*kr is the combined term for rolling resistance and rotational inertia.

Drag and Power Calculations

It is known that the formula for drag force, F_d is:

$$F_d = \frac{1}{2}C_dA\rho V^2$$

Since the fuel consumption tests were conducted at a constant speed of 60km/h, given the values of Cd of a standard vehicle is 0.36, air density is 1.23kg.m^3 and the frontal area, A of the standard vehicle is estimated as:

$$A = height * width$$

$$A = 1.475 * 1.53$$

$$A = 2.26m$$

Converting speed, V to m/s:

$$V = \frac{60km}{hr} * \frac{1hr}{3600s} * \frac{1000m}{1km}$$

Which gives V= 16.67m/s.

From the formula, the drag force experienced by a standard vehicle can be calculated as follows:

$$F_d = \frac{1}{2} 0.36 * 2.26 * 1.23 * (16.67^2)$$

The drag force experienced by a standard vehicle is 139.05N.

From the coast down test performed on the modified vehicle, the coefficient of drag of the vehicle now is 0.22.

Substituting the necessary values into the drag equation:

$$F_d = \frac{1}{2} 0.21 * 2.26 * 1.23 * (16.67^2)$$

The drag force now becomes 109.5N.

The drag reduction is;

$$\%\ improvement = \frac{139.05 - 109.5}{139.05} * 100\%$$

This gives a reduction of drag of about 22%.

After obtaining the drag value experienced by the vehicle (both standard and modified), the power required to overcome the drag can now be calculated.

$$P = Fv$$

$$P = \frac{1}{2} C_d A \rho V^3$$

Thus, by substituting the values obtained above, the power required to overcome the drag is:

$$P = 139.05 * 16.67$$

The power required to overcome the drag for the standard vehicle is 2317.96 watt.

For the modified vehicle, the power required is

$$P = 109.5 * 16.67$$

The power required to overcome the drag for the modified vehicle is 1825.37 watt.

Power is reduced by 492.6watt.

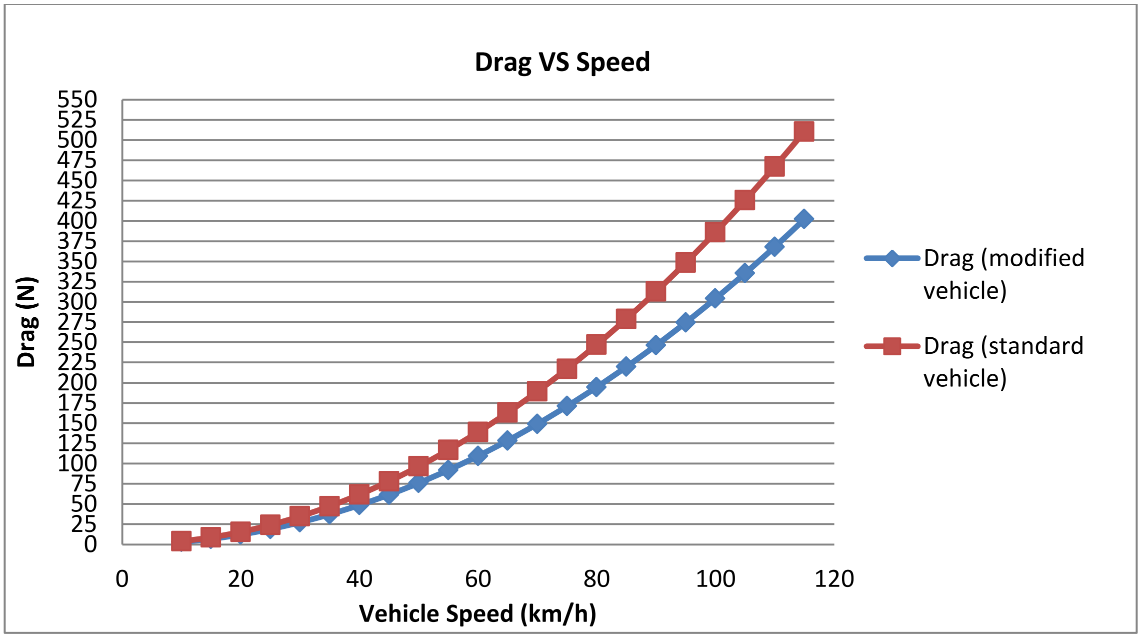
In percentage, power reduced is

$$\%\ improvement = \frac{2317.96 - 1825.37}{2317.96} * 100\%$$

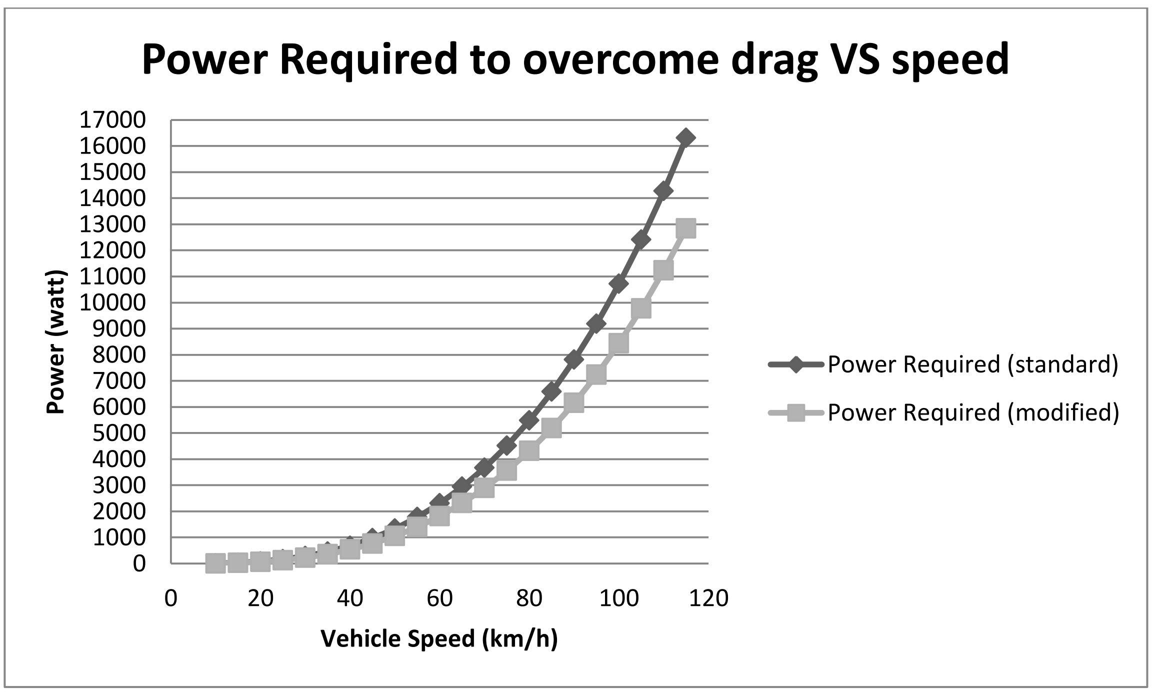
A 21% improvement.

*note that in the calculations above a test speed of 60km/h is used, due to safety precautions.

Therefore, the vehicle requires less power to overcome the drag after the modifications are completed.



Graph 2: Drag vs Speed



Graph 3: Power vs Speed

From the plots of drag vs speed as well as power vs speed, we can see that the drag increases quadratically as the speed increases. At lower speeds, the drag experienced is small, and the effects are considered negligible. However, to obtain optimum fuel consumption the vehicle has to be driven at a speed of which the engine produces the highest amount of torque, which is between 70 to 80km/h. However, due to safety reasons, the vehicle speed has to be set at 60km/h.

From the plots, we can see significant reductions of the drag experienced by the vehicle. After modifying the vehicle, it has lower coefficient of drag, and in turn reduces the overall drag. As the drag is reduced, the power required to overcome the drag is also reduced, and the fuel consumption is reduced. This is also shown from the result of the fuel test.

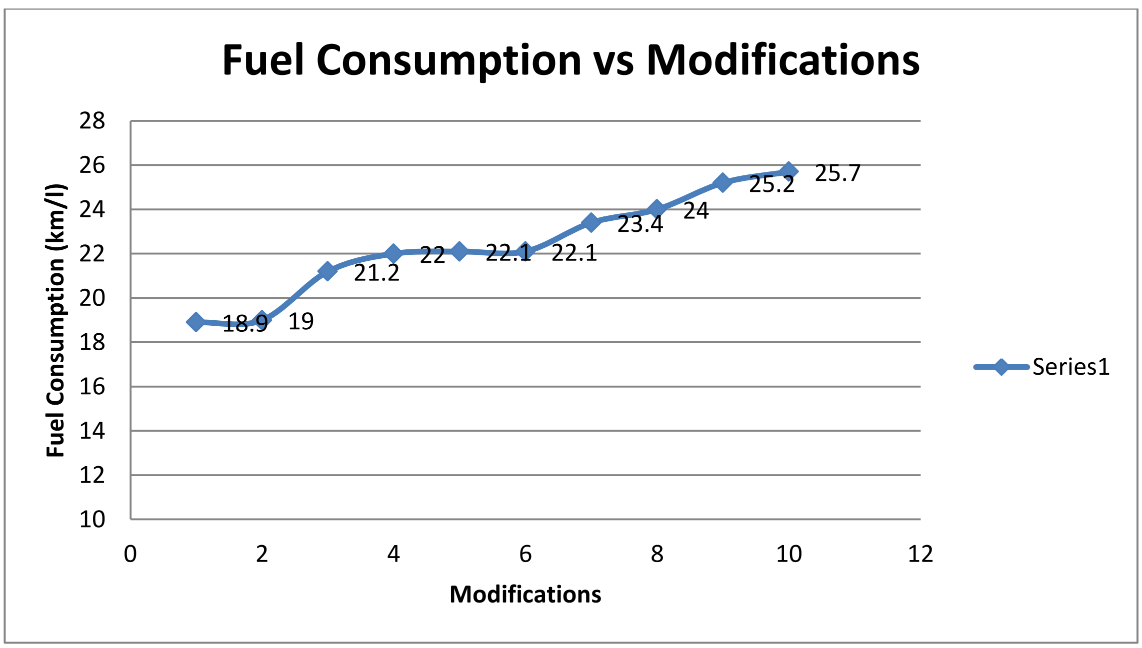
Furthermore, as we travel faster, the drag will increase. The result from the fuel consumption test is also concurrent with the result from the coast down test, because as the drag is reduced, the vehicle now travels further using 1 liter of fuel.

Result:

Modifications	Fuel Consumption
Baseline Test	22.1 km/l
Sport springs installed	23.4km/l
Underbody Cover installed	24km/l
Side air ducts installed	25.2km/l
Miscellaneous	25.7km/l

Table 2: Fuel Consumption Test Results

Run/Configuration	Modifications/Details	Fuel Consumption (km/l)
1	Stock Car	18.9
2	Electrical devices removed	19
3	Weight reduction	21.2
4	No aircond	22
5	Low Resistance Tires	22.1
6	Baseline Test	22.1
7	Sport springs installed	23.4
8	Underbody Cover installed	24
9	Side air ducts installed	25.2
10	Miscellaneous	25.7



Graph 4: plot of fuel consumption for different vehicle configurations

The result shows that the fuel consumption improves as the drag force is reduced. The calculations from the coast down test also confirm that the Cd of the vehicle is reduced from 0.36 to 0.22 that results in about 20% drag reduction. Overall, the reduction of the Cd of the vehicle improves the fuel consumption from 22.1km/l to 25.7km/l. thus, it is evident that lowering the Cd helps reducing the drag and fuel consumption while travelling at highway speed.

CHAPTER 5

CONCLUSION

From the results above, we can conclude that improving the aerodynamics profile of a vehicle improves the fuel consumption greatly. The modifications done on the vehicle improve the coefficient of drag of the vehicle from 0.36 to 0.29. Less coefficient of drag means that the vehicle will experience less drag force when moving, and in turn will reduce its fuel consumption.

Based on the calculations perform from the raw data obtained in the coast down test, the vehicle experiences about 22% less drag than a stock car. The 22% reduction translates into a reduction of power required of about 20%. Since during highway speed, about 50% of the energy produced is wasted to overcome the drag, the amount of energy wasted has been reduced.

The reduction of drag also means that the reduction of power required. In order to produce more power, the engine will burn more fuel. If more fuel is burnt, the fuel consumption will increase, and less distance traveled.

In the project, the main aim is to relate the reduction of the drag force to a vehicle's fuel consumption. However, it is difficult to record fuel consumption of a vehicle by using means other than distance traveled per liter fuel. Raw fuel consumption (brake specific fuel consumption, BSFC) can only be recorded by operating the engine with an engine dynamometer.

The tuft test also indicates that the modifications have little effect to the nature of the air flow of the vehicle. The air flow through the air ducts is laminar, therefore less drag.

The result shows that the fuel consumption improves as the drag force is reduced. From the tuft test conducted, an improvement to the wheel wells is done. The wheel wells experience turbulent air flow that has higher air resistance. A wheel well cover is mounted to the rear to improve the airflow.

Overall, the project has succeeded in meeting its objectives. The drag force experienced by the vehicle is reduced, and subsequently the fuel consumption is also reduced. The total reduction of the fuel consumption is 6.8km/l, and in a competition like PEC, every kilometer counts.

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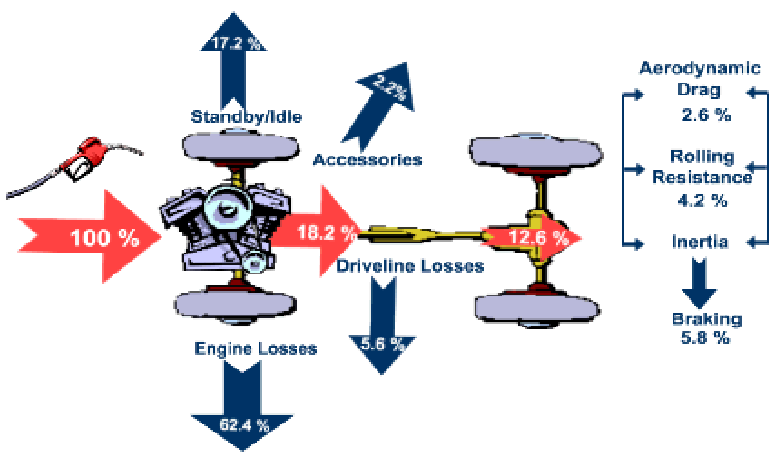
APPENDIX A

No. of Experiment	Experiment Condition	Total Distance Travelled (km)
1	Stock car (no modification)	18.9
2	Car without the air-conditioning system	22
3	Car without alternator	-
4	Car without electrical devices	19
5	Car without power steering system	-
6	Car with weight reduction (more than 10% of original weight)	21.2
7	Car with Low Rolling Resistance Tires (LRR)	22.1

*Previous test results. Experiments on aerodynamics are performed after experiment no 7.



Energy losses of a vehicle coasting down a highway.

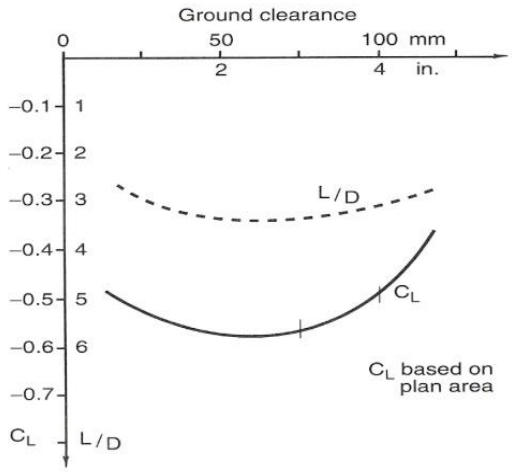


Figure 15.29 *Lotus ground-effects wind tunnel results (Ref. 168).*

Lotus study: ground clearance effects. L/D is the ratio of the lift to the drag force.