DESIGN AND ANALYIS OF VORTEX GENERATOR
FOR A HEV MODEL

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DESIGN AND ANALYSIS OF VORTEX GENERATOR FOR A HEV MODEL

JOHARI BIN ISMAIL

A report is submitted in partial fulfillment
of the requirements for the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
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NOVEMBER 2008

SUPERVISOR DECLARATION

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive.

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Date : 7 November 2008

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Name of Panel : Mr Yusof Bin Taib
Position : Lecturer
Date : 7 November 2008

STUDENT DECLARATION

I declare that this thesis entitled "Design and Analysis of Vortex Generator for a HEV Model" is the result of my own research except as cited in the reference. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:
Name	: Johari Bin Ismail
Date	: 7 November 2008

DEDICATION

I would like to show my expression and gratitude to Allah Subhanahu wa Ta'aalaa whose guidance, help and grace was instrumental in making this humble work become a reality. Thanks to my beloved parent, Mr Ismail Bin Che Samad and Pn. Rohani Bte Mat Adam and to all by sibling and friends. Thanks also to all staff in Faculty of Mechanical Engineering from University Malaysia Pahang especially to my supervisor.

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Also, I want to dedicated my thankful for my friends that always be on my side and help me from simulation study to preparing the final report. Also my precious thankful goes to my family that always support me in whatever situation I’m in.

Lastly, for all the people whether direct or indirectly involved in my project, I want to dedicated my thankful for you all that willing to help me finishing the project. Thank you very much to all of you.

ABSTRACT

Design and analysis of vortex generator by using Computational Fluid Dynamic (CFD) on Hybrid Electrical Vehicle (HEV) model was carried out on this project. One of the main causes of aerodynamic drag for vehicle is the separation of flow near the vehicle's rear end. To control the flow separation, delta wing shaped vortex generator is test for application to the roof end of vehicle. A vortex generator (VG) is an aerodynamic surface, consisting of a small vane that creates a vortex. The model of vehicle that can be used to conduct this project is HEV model for Proton Iswara. The objective of the project is to determine the percentage of drag reduction by using VG, ranging from 60 km/h to 120 km/h that designed by Computational Aided Design (CAD) in SolidWorks software. Vortex generator themselves create drag, but they also reduce drag by preventing flow separation at downstream. The overall effect of vortex generators can be calculated by totaling the positive and negative effects. Drag coefficient can be obtained by using output of CFD then export into FEM analysis to find the value of drag force to be applied into aerodynamic drag coefficient equation. Besides that, CFD simulation results such as contour plot also used to analyze the characteristic of streamline flow at the rear end of HEV model. Comparison of drag coefficient between the model of HEV vehicle with and without vortex generator must be done to achieve the project objectives. The application of VG had shown that 6.61 percent reduction in aerodynamic drag coefficient.

ABSTRAK

Mencipta dan menganalisis “vortex generator” menggunakan “Computational Fluid Dynamic” (CFD) terhadap model Kenderaan Hibrik Elektrik (HEV) menjadi keutamaan dalam projek ini. Salah satu penyebab rintangan aerodinamik sesebuah kenderaan adalah pemisahan aliran udara pada bahagian belakang kenderaan iaitu di atas permukaan cermin belakang. Untuk mengawal pemisahan aliran udara ini “vortex generator” berbentuk “delta wing” diaplikasi pada hujung bumbung kenderaan dimana aliran udara mula terpisah. “Vortex Generator” (VG) merupakan satu alat aerodinamik yang terdiri daripada bilah-bilah yang akan melajukan aliran udara. Model kenderaan yang digunakan untuk menjalankan projek ini ialah model HEV untuk Proton Iswara. Objektif projek ini adalah untuk menentukan peratusan penurunan nilai rintangan aerodinamik dengan aplikasi VG, dianalisis pada kelajuan 60 km/j sehingga 120 km/j yang dicipta menggunakan “Computational Aided Design” (CAD) dalam perisian kejuruteraan “SolidWorks”. VG juga menyebabkan rintangan aerodinamik bertambah tetapi ianya juga mengurangkan aerodinamik dengan mencegah pemisahan aliran udara supaya tempat di mana aliran udara mula terpisah diganjakkan ke hujung cermin belakang. Kesan keseluruhan VG boleh dihitung dengan memerhatikan perbezaan kesan negetif dan positif. Nilai rintangan aerodinamik boleh didapati daripada CFD dan dihantar ke dalam analisis FEM. Simulasi CFD juga akan digunakan untuk menganalisis ciri-ciri aerodinamik yang berlaku di bahagian atas cermin belakang kenderaan. Perbezaan nilai aerodinamik antara model HEV dengan VG dan model HEV tanpa VG dikira untuk menentukan objektif projek tercapai. Penggunaan VG menunjukkan penurunan nilai rintangan aerodinamik sebanyak 6.61 peratus.

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LIST OF SYMBOL

C_D	Drag Coefficient
ρ	Air Density
A	Frontal Area
V	Speed
F_D	Drag Force
P	Aero power
V_o	wind velocity

LIST OF ABBREVIATION

HEV	Hybrid Electrical Vehicle
CFD	Computational Fluid Dynamic
VG	Vortex Generator

CHAPTER 1

INTRODUCTION

1.1 Introduction to Vortex Generator

A vortex generator (VG) is an aerodynamic surface, consisting of a small vane that creates a vortex. Some surfaces on an airplane can result in air flow separation from the surface or skin. A vortex generator creates a tip vortex which draws energetic, rapidly-moving air from outside the slow-moving boundary layer into contact with the aircraft skin. This keeps the flow close to the aircraft surfaces. Vortex generators can be found on many devices, but the term is most often used in aircraft design. Vortex generators are also being used in automotive vehicles. In one form they are used as in aircraft to influence the boundary layer of air flow primarily for drag reduction. Vortex generators are likely to be found the external surfaces of vehicles where flow separation is a potential problem because VGs delay flow separation. The vortex is oriented by appropriate placement of the vortex generator in order to redirect airflow in the flow field so that adverse interactions are prevented or delayed. With this mechanism, the generators act as a flow deflector.

1.2 Project Objectives:

1) Design a vortex generator of HEV model.
2) To determine the percentage of drag coefficient reduction by Vortex Generator.

1.3 Project Background

Purpose of this project is to make vortex generator (VG) to develop HEV Model for Proton Iswara in UMP Mechanical Lab. This project involves designing and simulating a model of VG based on boundary layer theory. To select the appropriate shape and size of the VG which generate streamwise vortex, the most efficient shape is important to achieve the objectives. The thickness of the boundary layer is measured based on the assumption that the optimum height of VG would be nearly equal to the boundary layer thickness. Overall this project will acquire the skill of design and analysis using simulation software.

1.4 Problem Statement

There are two types of flow that occur on all vehicles, attached flow and separated flow. Separated airflow at the rear end of sedan vehicle is turbulent air and turbulent air increase drag. When separated flow is created it effectively expands the size of the hole and vehicle needs to punch a larger hole through the air as moving. This requires more energy and increase the drag. Now, this project must be continued to reduce the drag by adding the vortex generator at the rear end of vehicle in order to control flow separation.

1.5 Project Scopes

1) Study on aerodynamic drag reduction by Vortex Generator.
2) Design the model of VG with SolidWorks.
3) Model analysis using CFD in COSMOSFloWorks software.
4) Interpret result of drag force in FEM analysis by using COSMOSWork software.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will provide detail description of literature review done regarding the project title of design and develop HEV model vortex generator based on boundary layer theory. In this literature review, it starts with the introduction to the vortex generator, external flow, boundary layer theory, drag coefficient, flow separation, optimum height vortex generator for vehicle and function of the vortex generators have been analyze and shown. These information are been used and been referring when develop the Vortex Generators (VG). This information is being got from the books, journals, websites and market survey.

2.2 Introduction to Vortex Generator

A vortex generator is an aerodynamic surface, consisting of a small vane that creates a vortex. Vortex generators can be found on many devices, but the term is most often used in aircraft design. Vortex generators are likely to be found the external surfaces of vehicles where flow separation is a potential problem because VGs delay flow separation [4]. On aircraft they are installed on the leading edge of a wing in order to maintain steady airflow over the control surfaces at the rear of the wing. They are typically rectangular or triangular, tall enough to protrude above the boundary layer, and run in span wise lines near the thickest part of the wing. They can be seen on the wings and vertical tails of many airliners.

Figure 2.1 Vortex Generator at rear end of vehicle

Vortex generators are positioned in such a way that they have an angle of attack with respect to the local airflow. A vortex generator creates a tip vortex which draws energetic, rapidly-moving air from outside the slow-moving boundary layer into contact with the aircraft skin. The boundary layer normally thickens as it moves along the aircraft surface, reducing the effectiveness of trailing-edge control surfaces; vortex generators can be used to remedy this problem, among others, by re-energizing the boundary layer. Vortex generators delay flow separation and aerodynamic stalling; they improve the effectiveness of control surfaces.

2.3 External Flow

External flows involving air are often termed aerodynamics in response to the important external flows produced when an object such as an airplane flies through the atmosphere. Figure below show the external flow around sedan vehicle for passenger car [1].

Figure 2.2 External Flows over the Car

A streamline is a line that is parallel to the direction of flow of a fluid at a given instant or the path a given particle follows in a flowing fluid. A streamlined shape, therefore, is one that is constructed with a shape that offers a minimum resistance to fluid flow. Prime examples of streamlining are modern aircraft and just about any fish or sea mammal.

There are two types of airflow that occur on all vehicles; Attached Flow and Separated Flow. As far as is practical, vehicle designers strive to keep the flow of air as close to the vehicle skin as possible. This is attached flow, and from an aerodynamic streamlining viewpoint, it is much more preferable than separated flow [10].

2.4 Boundary Layer Theory

A boundary layer is that layer of fluid in the immediate vicinity of a bounding surface. In the Earth's atmosphere, the planetary boundary layer is the air layer near the ground affected by diurnal heat, moisture or momentum transfer to or from the surface. On an aircraft wing the boundary layer is the part of the flow close to the wing. The boundary layer effects occur at the field region in which all changes occur in the flow pattern. The boundary layer distorts surrounding nonviscous flow. It is a phenomenon of viscous forces. This effect is related to the Reynolds number. The character of the viscous flow around a body depends only on the body shape and the Reynolds number [2].

There are two types of viscous flow, laminar flow and turbulent flow. Laminar flow sometimes known as streamline flow occurs when a fluid flows in parallel layers, with no disruption between the layers. Turbulent flow is a fluid regime characterized by chaotic, stochastic property changes and unstable boundary layer [3].

2.5 Drag Coefficient

In a moving common car there are constantly forces acting to the car in which causes drag to overcome the resistance. It is dependent on the geometry of the body, motion of the body and the fluid in which it is traveling. Aerodynamic drag depends on the size of the vehicle (which characterized by its frontal area), the drag coefficient c_D (which is a measure of the flow quality around the vehicle), and the square of the road speed V [3].

$$F_D = C_D \frac{1}{2} \rho V^2 A \tag{2.1}$$

$$C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A} \tag{2.2}$$

C_D = Drag Coefficient

ρ = Air Density

A = Frontal Area

V = Speed

F_D = Drag Force

Aerodynamic drag on vehicles can be reduced by streamline the body or by controlling boundary layer separation [12].

2.6 Flow Separation

Flow separation is one of the major problems in external flow [1]. Separated Airflow is turbulent air and turbulent air increases drag. When Separated Flow is created it effectively expands the size of the hole the vehicle makes as it passes through the air by adding to the dimensions of the sides, the top and the undercarriage so that aerodynamically, it is larger than it physically is. The vehicle punches a larger hole through the air.

Attached Flow occurs when air naturally flows quite smoothly over the surface contours of a moving body. However, if that Attached Flow encounters an excessively sharp corner, bend radius or blunt object in the body shape, it breaks free of the surface and becomes wildly chaotic and turbulent. Once that happens, the airflow no longer follows the contours of the body shape. This chaotic, turbulent flow is called Separated Flow [10].

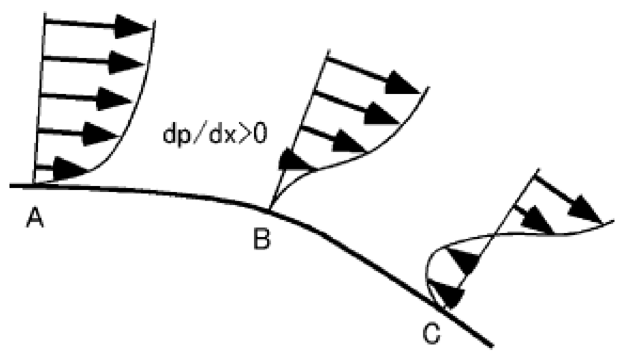


Figure 2.3 Schematics of velocity profile around rear end

Figure above shows a schematic of flow velocity profile on the vehicle’s centerline plane near the roof end. Since the vehicle height in this section becomes progressively lower as the flow moves downstream, an expanded airflow is formed there. This causes the downstream pressure to rise, which in turn creates reverse force acting against the main flow and generates reverse flow at downstream Point C. No reverse flow occurs at Point A located further upstream of Point C because the momentum of the boundary layer is prevailing over the pressure gradient (dp/dx). Between Points A and C, there is separation Point B, where the pressure gradient and the momentum of the boundary layer are balanced [4].

Flow separation is mostly an undesirable phenomenon because it entails large energy losses and boundary layer control is an important technique for flow separation problem on airfoils and in diffusers [8]. This energy loss is due to the increasing drag force developing by the car to overcome the resistance as moving. Therefore more fuel to move it through the air than if the airflow was attached [9].

2.7 Optimum Height Vortex Generator

There are two main types of vortex generator, bump-shaped and delta wing shaped. But the most common used to optimize the rear end of the vehicle is delta-wing shape vortex generator because it has small frontal projection area compared to bump-shaped [4]. This will allow the vortex generator to create smaller drag by them to reduce drag coefficient.

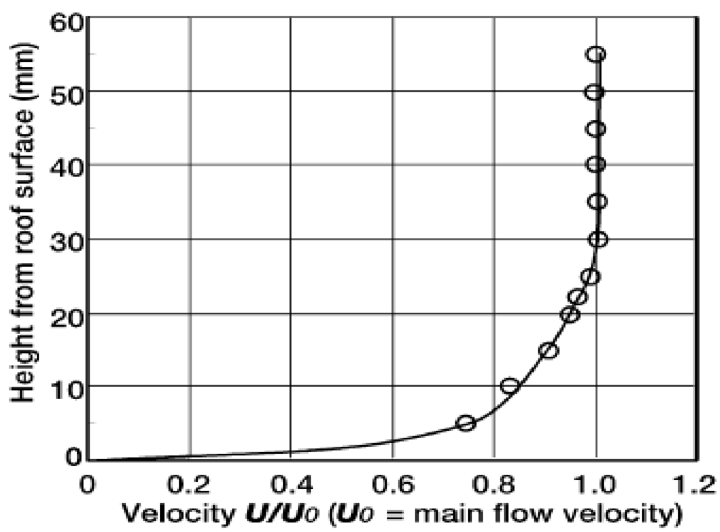


Figure 2.4 Velocity profile on roof [4].

To select appropriate shape and size of the VG which generates streamwise vortex the most efficiently (with the least drag by itself) is important to achieve objectives. In connection with the size, the thickness of the boundary layer is measured based on the assumption that the optimum height of the VG would be nearly equal to the boundary layer thickness [4, 6 and 12]. Figure 2.4 show the boundary layer thickness at the roof end immediately in front of the separation point is about 30 mm. Consequently, the optimum height for the VG is estimated to be up to approximately 30 mm. The VG are not highly sensitive to these parameters and their optimum value ranges are wide [4].

An increase in height of the VG simultaneously causes two effects: one is reduced drag resulting from delayed flow separation and the other is increased drag by the VG itself. These two effects are balanced when the VG's height is approximately 30mm [4]. The actual effectiveness of installing VG is therefore deduced by subtracting the amount of drag by them from the amount of drag reduction that is yielded by shifting the separation point at downstream [7].

2.8 Function of Vortex Generator

To control or delaying flow separation at the roof end of a vehicle, Vortex Generator (VG) are installed to optimize the rear end. The VG helps smooth the flow of air onto surfaces or into the void behind a bluff trailing edge of the vehicle [5]. VGs also cause the airflow above the rear window to attach to the surfaces of the body [11]. The streamwise vortices that accelerate by the VG will reduce or eliminate the reverse flow that acting against the main flow develop at point C as shown is Figure 2.3. The reverse flow will tend to separate the laminar boundary layer and flow separation takes place. This point is known as boundary layer transition. After the flow pass through this point, the boundary layer become unstable and inevitable thicken and the main function of VG is to re-energized the boundary layer so that the flow is remain attach to the surface of the body.

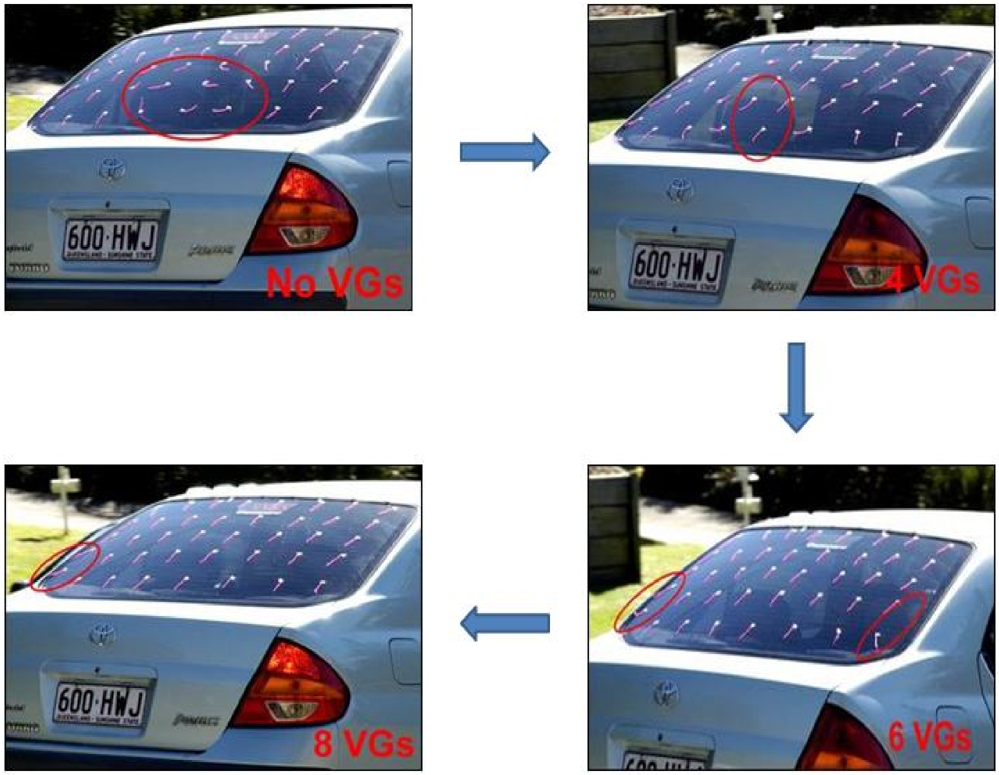


Figure 2.5 Experimental Investigation of VG [10]

Figure above show the airflow pattern over the rear window of the Prius at about 50 km/h. As can be seen, there is attached flow across the transition from roof to rear window (ie the wool tufts all nicely line up).

The attached flow continues down the window at both ends of the rear glass, however, in the lower middle area (circled) there is turbulence. In other words, a separation bubble forms at the middle/base of the rear window which would adversely affect the flow onto the boot-lid. (NO VG).

With the four vortex generators in place, the difference in airflow was immediately apparent. This time, the airflow down the middle of the rear window remained attached to the glass (circled). This change in flow pattern is directly downstream of the vortex generators. However, either side of this path of influence, the turbulence remained. (4 VGs)

The airflow pattern is completely transformed, with no separation bubble forming at all. However, with such good airflow, any turbulence becomes more visible and some can be seen at the base of the window at each extreme end. (6 VGs)

With eight vortex generators placed on the roof, the separation at the lower edges of the rear glass remains caused by airflow wrapping around the C-pillars. This may be able to be addressed by fitting a pair of vortex generators part way down the rear glass, one each side. (8 VGs)

CHAPTER 3

PROJECT METHODOLOGY

3.1 Introduction

This chapter will provide detail explanation on the methodology of carrying out this project from the beginning to the end. Title was given by the supervisor in the beginning of this semester with the title is “Design and Develop Vortex Generator for a HEV Model”. A detail related literature review was done and important information were acquired and explained in the previous chapter. Since the title given was about design and develop vortex generator, the research on optimum shape and size of vortex generator to optimize the rear end of sedan vehicle was done as a guide in VG sketching and designing. The software that will be used to fulfill last target objectives was FEM Analysis in CFD software in order to analyze the drag coefficient reduction by vortex generator.

3.2 Project Methodology

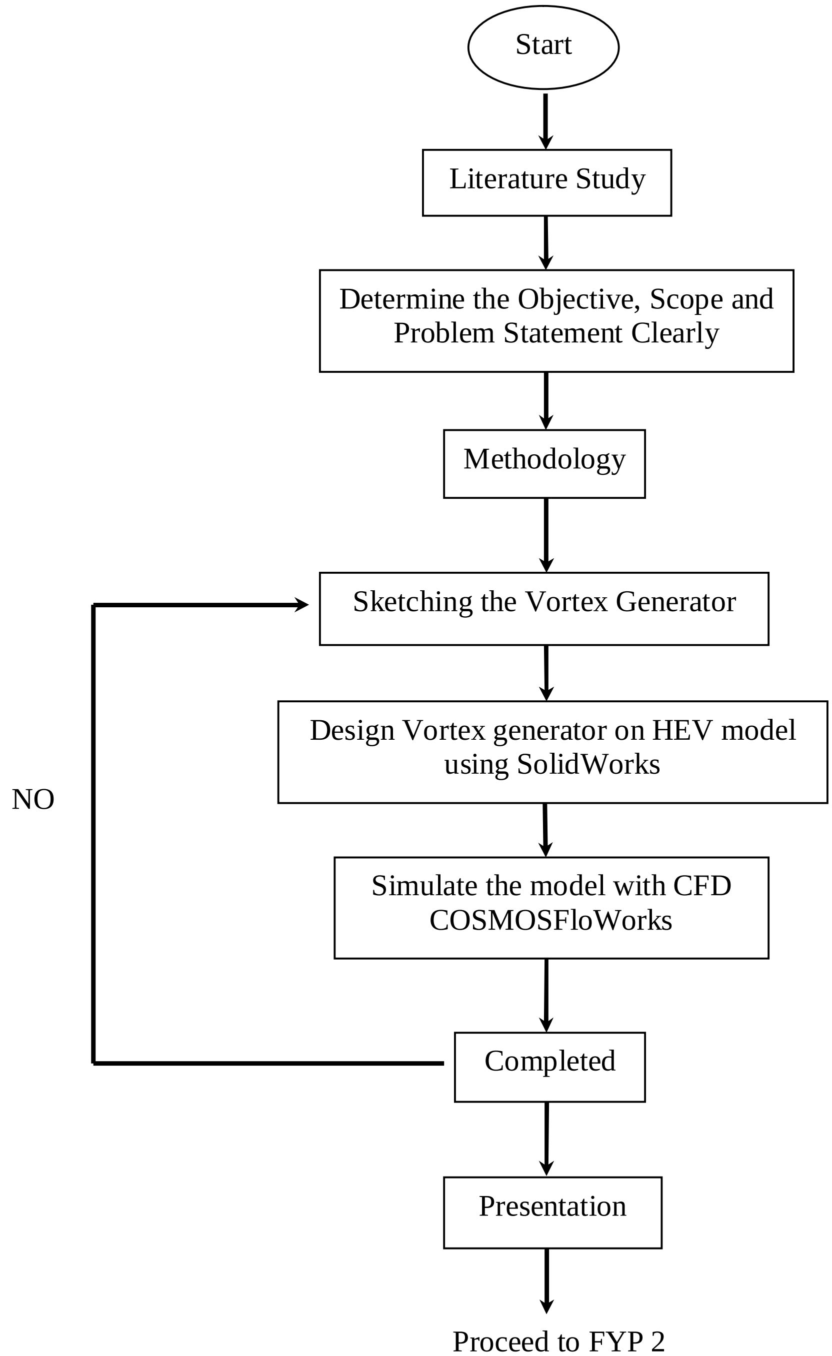


Figure 3.1: Methodology flow chart for FYP 1

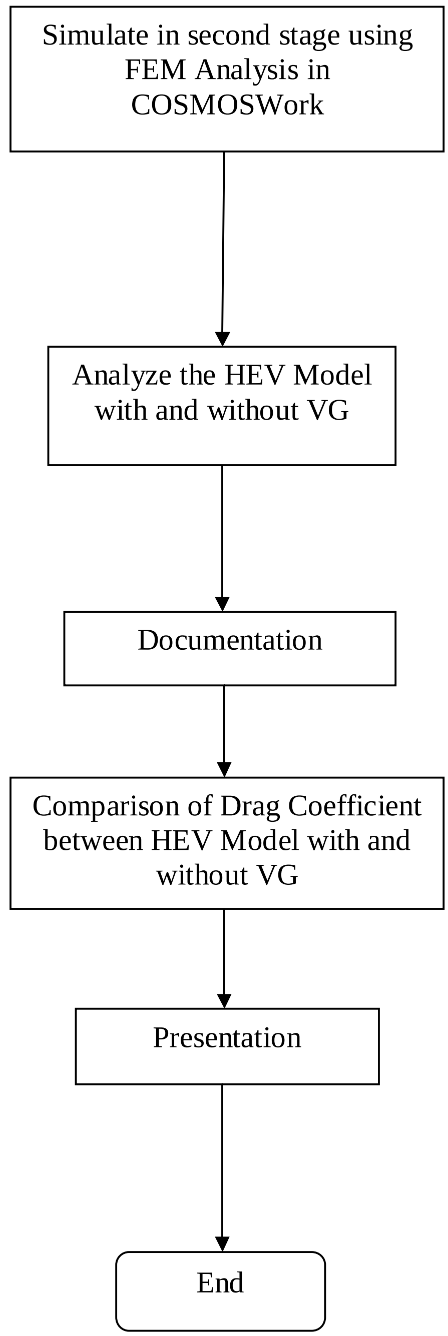


Figure 3.2: Methodology flow chart for PSM 2

3.2.1 Literature Study

This project is start with literature review and research about the title. The source for literature study is being got from books, published journals, company websites and market survey. This stage is very important to make the researchers or individual can perform and implement the tasks with correct way and can understand what the important things needed before proceed to the next stage.

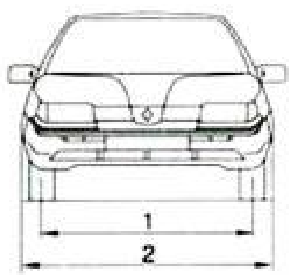
3.2.2 Identify Project Objectives

The main important of the project is determination the objectives. Before that, it is important to analyze the problem occur at the rear end of the vehicle so that the target objectives set up will reduce or eliminate the potential problem. After determine the project objectives, scopes of this project must be done so that the project progress will run smoothly.

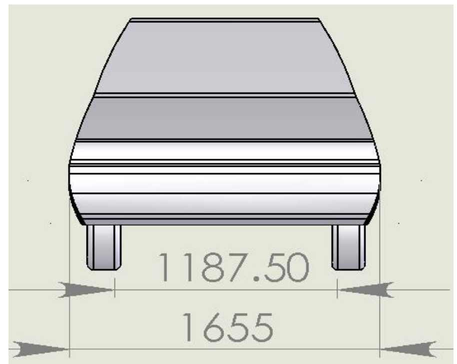
3.2.3 3-D Car Modeling

HEV model was modeling and transferred into a 3-D modeling using the 3-D modeling simulation (SolidWorks). The model is modeling by referring the true dimension from the Proton Manuals Book. The model of vortex generator is added to this 3-D model at the rear end of vehicle. The model dimension and actual vehicle dimension is not quite match. This is because some detailing such as a fender, underbody, front and rear bumper of the vehicle were made by using the assumption that will only fits the model. This is the important things to carry out for the simulation result.

All the part that has been mention at above, the part is modeled together with the body because the project is focusing on the external flow only. The dimension is not accurate from the real measurement from the Proton Manual Book.

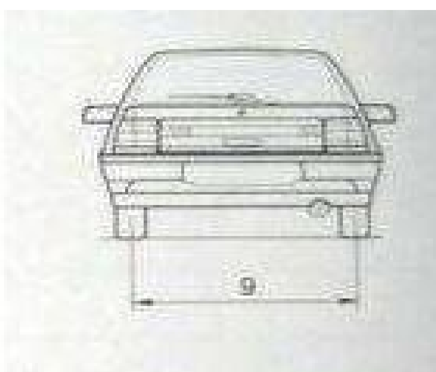


(a) Front View

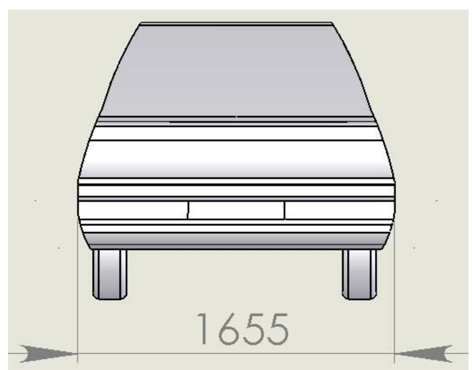


(b) Front View

Figure 3.3: (a) manual drawing from the data sheet, (b) 3-Dimensional drawing

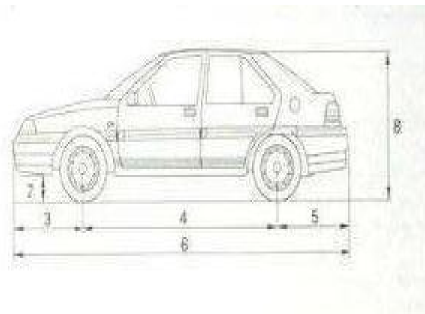


(a) Rear View

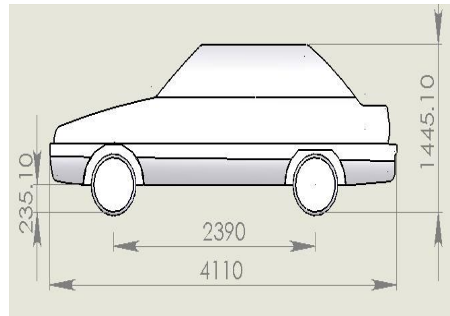


(b) Rear View

Figure 3.4: (a) manual drawing from the data sheet, (b) 3-Dimensional drawing



(a) Side View



(b) Side View

Figure 3.5: (a) manual drawing from the data sheet, (b) 3-Dimensional drawing

3.2.4 Design Criteria of Vortex Generator

Before start the model sketching, the appropriate shape and size of VG must be known first. From literature study, the most efficient shape of VG was delta-wing shape because it has small frontal projection area and can give smaller drag by itself. Delta wing-shaped VGs were found to be less sensitive to change in height than bump-shaped VGs [4]. Moreover, the vortex generated at the edge of a delta-wing-shaped VG keeps its strength in the flow downstream of the edge since it barely interferes with the VG itself because of the VG’s platy form. Figure 1 and figure 2 below show the dimension of vortex generator for Proton Iswara model.

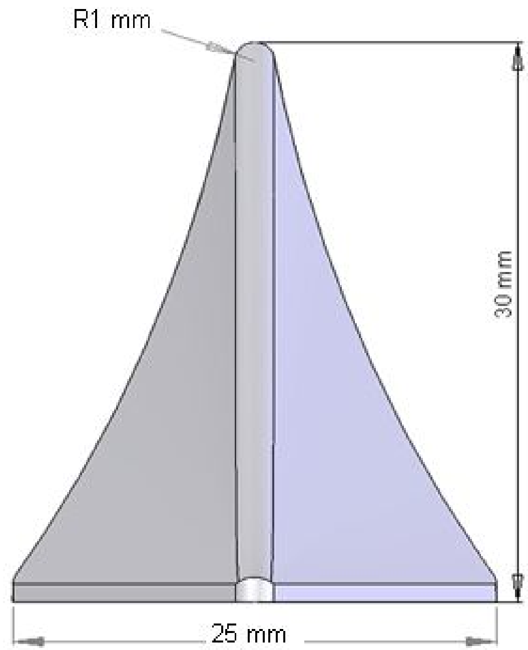


Figure 3.6 Front View of VG

In connection with the size, the thickness of the boundary layer is measured based on the assumption that the optimum height of the VG would be nearly equal to the boundary layer thickness. The boundary layer thickness at the roof end immediately in front of the separation point is about 30 mm. Consequently, the optimum height for the VG is estimated to be up to approximately 30 mm.

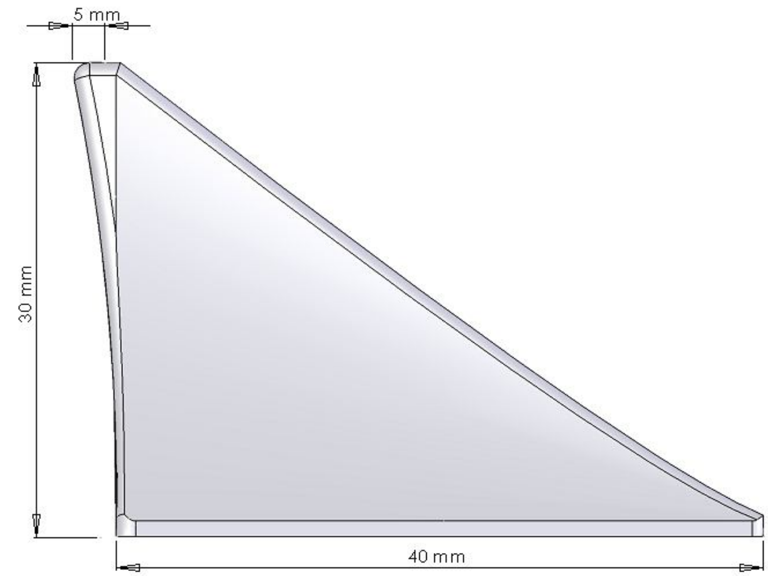


Figure 3.7 Side View of VG

The VG are arranged in a row in the lateral direction at interval of 77.5 mm which consist of 9 fins based on aftermarket vortex generator. Figure 3 below show the VGs arrangement in lateral direction for Proton Iswara model.

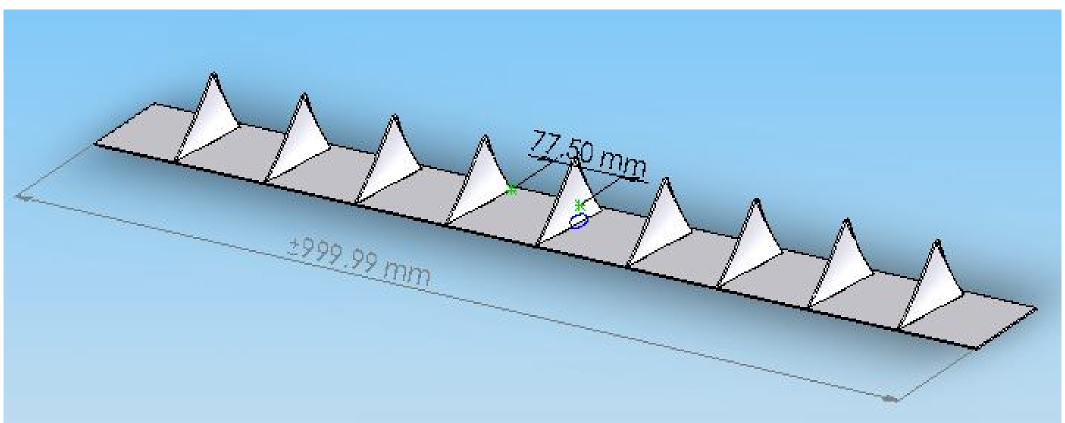


Figure 3.8 VGs Arrangement in Lateral Direction at 77.5 mm intervals with 9 fins of VGs

3.2.5 Vortex Generator Applying for Model Improvement

The delta wing-shaped VGs should be installed at a yaw angle of 15° to the airflow direction [4]. This angle is seen as the best angle for reduced drag coefficient at the rear end of vehicle model before the separation point. Vortex generators are positioned in such a way that they have an angle of attack with respect to the local airflow.

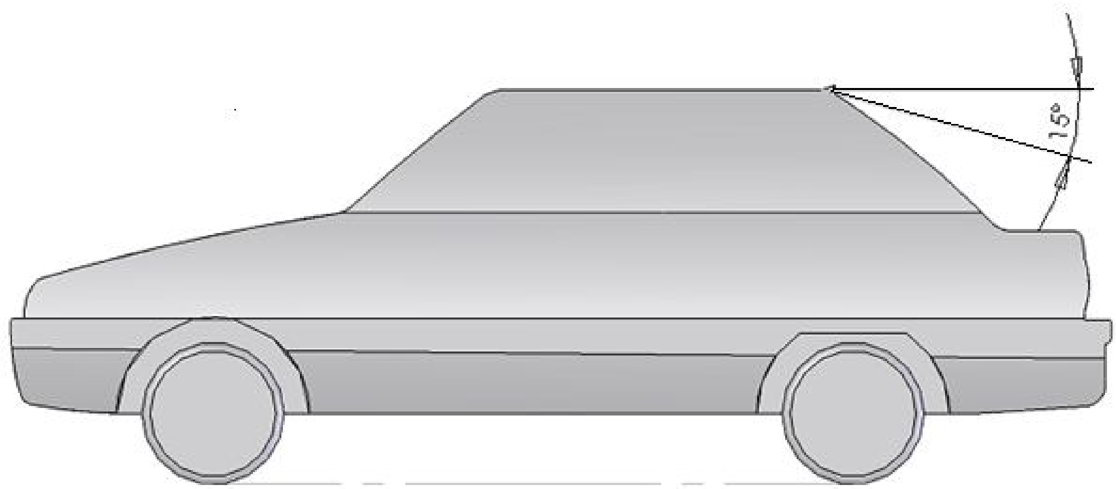


Figure 3.9 Complete Assemble of Vortex Generator with HEV Model

3.2.6 Design Simulation Analysis

After the model parameter were finalized, the complete assemblies of the HEV model with VG model will be used to analyze the drag force develop by the car in CFD analysis by using COSMOSFloWorks software. In this analysis, the model was laid a boundary condition setting for external flow. The flow is considered both as laminar and turbulent air with a CFD model. The analysis works same as the wind tunnel analysis test for actual car. Figure below show the boundary condition in CFD.

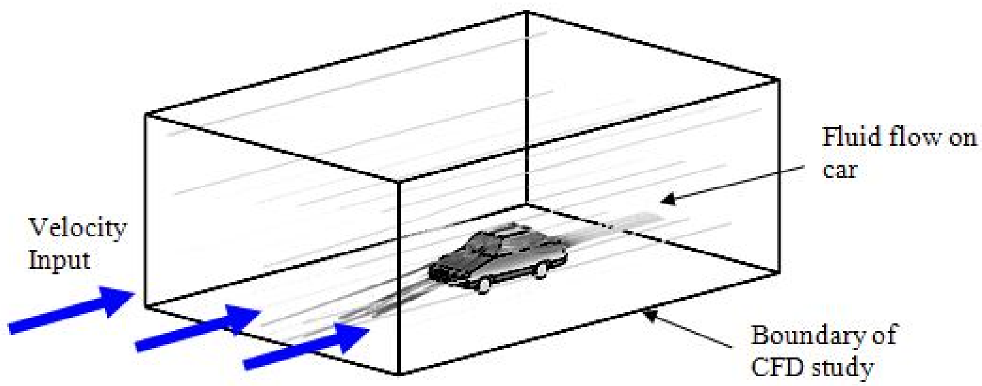


Figure 3.10 CFD Boundary Condition

This CFD simulation will be used for determine the flow over the car before and after adding the vortex generator to see the difference. This method of CFD simulation is depending on the model, every little aspect will affect the result. The analysis type is the external flow of vehicles and the effect of the velocity distribution at speed analysis.

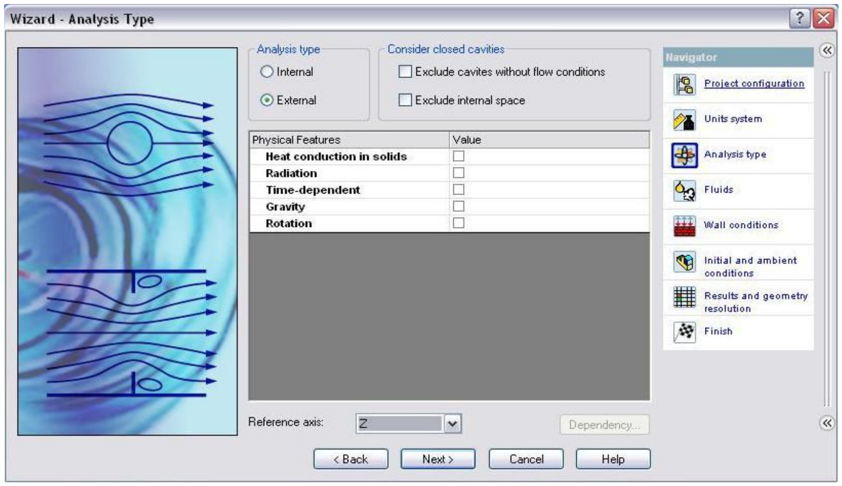
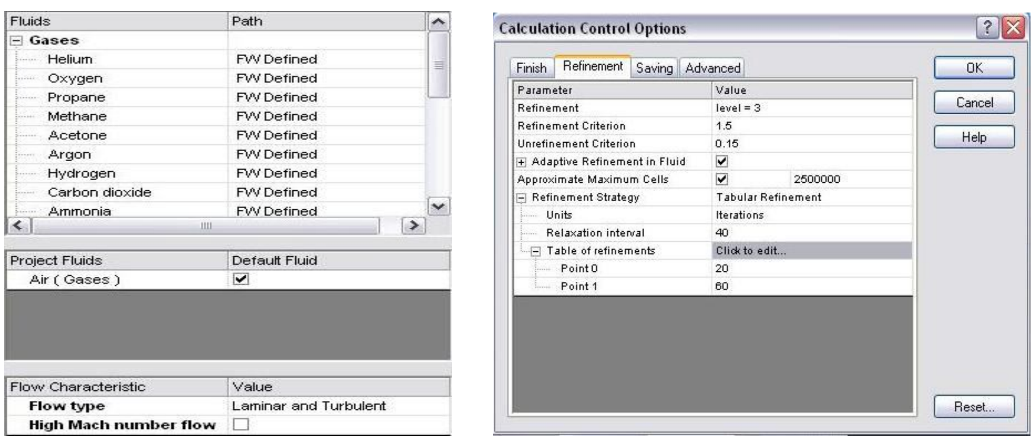


Figure 3.11 Simulation analysis type

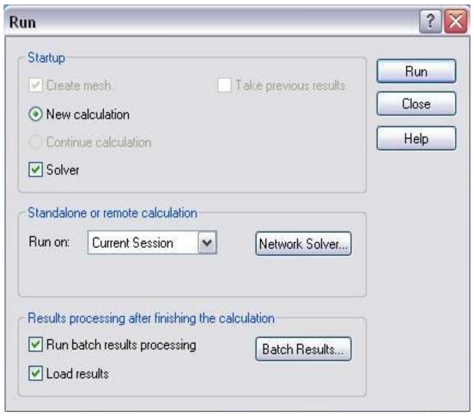
The setting velocities are set 60 km/h to 120 km/h at the 10 km/h intervals. During this simulation also, all the data will be recorded and the graph of the analysis will be compared after all the simulation is archive.



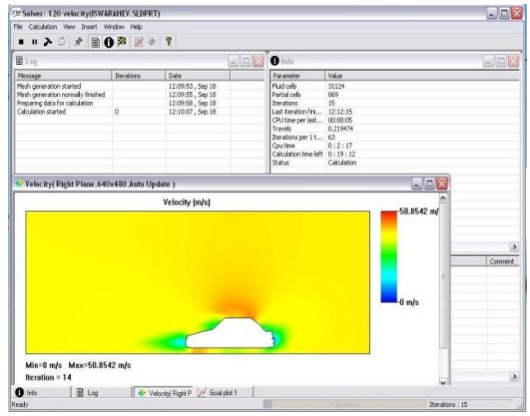
(a) Analysis Fluids (b) Refinement

Figure 3.12: (a) Project wizard, (b) FloWork input data for the project analysis

Air is taking as a fluid for project analysis that surrounding the whole car model in the simulation. The flow characteristic value is a laminar and turbulent and these types of flow will be considered for the simulation. For the refinement, the level taking is level 3 and the two points that taking for the table of refinement is 20 and 60. The unit in refinement is iterations.



(a) Run Simulation



(b) Analysis Solver

Figure 3.13: (a) Run startup for simulation, (b) Velocity analysis solver

The analysis will be done on two different models at velocity range (60 km/h to 120 km/hr). The first model is the model without VG and another model is with VG. The result from COSMOSFloWorks analysis will be export to COSMOSWork software for FEM analysis to obtain drag force, $F_{D.}$

In Finite Element Model (FEM) analysis, the whole model will be assumed as rigid body. The tires are restrict from moving to vertical and lateral direction but it can move backward. This analysis concept is similar to wind tunnel test for actual car. The rear part is fixed support so that the car body is support by longitudinal force only and the force value is obtained from the rear support as the CFD analysis take place. The value obtained is the drag force of the car at fixed velocity and drag coefficient, C_D can be calculated using the formula in chapter 2.

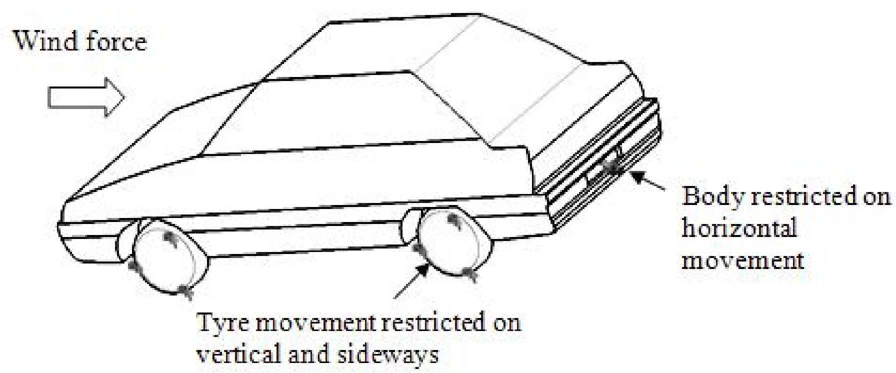


Figure 3.14 FEM Analyses in COSMOSWork

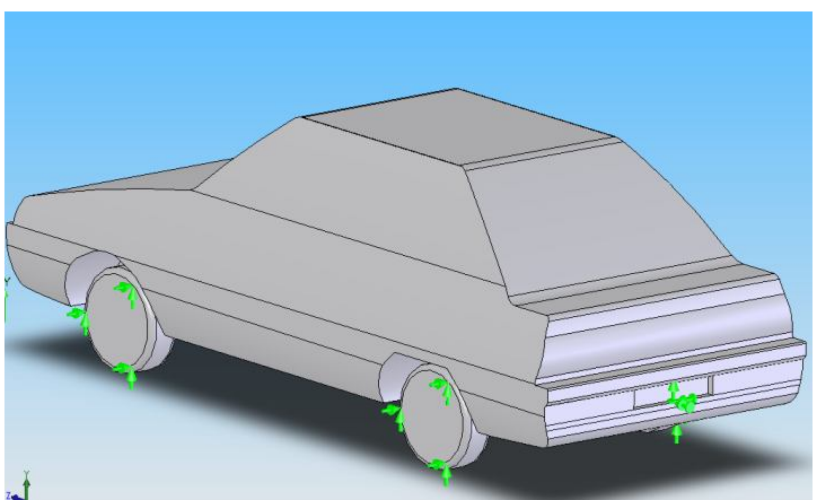


Figure 3.15 Load and Restraint for HEV Model Without VG

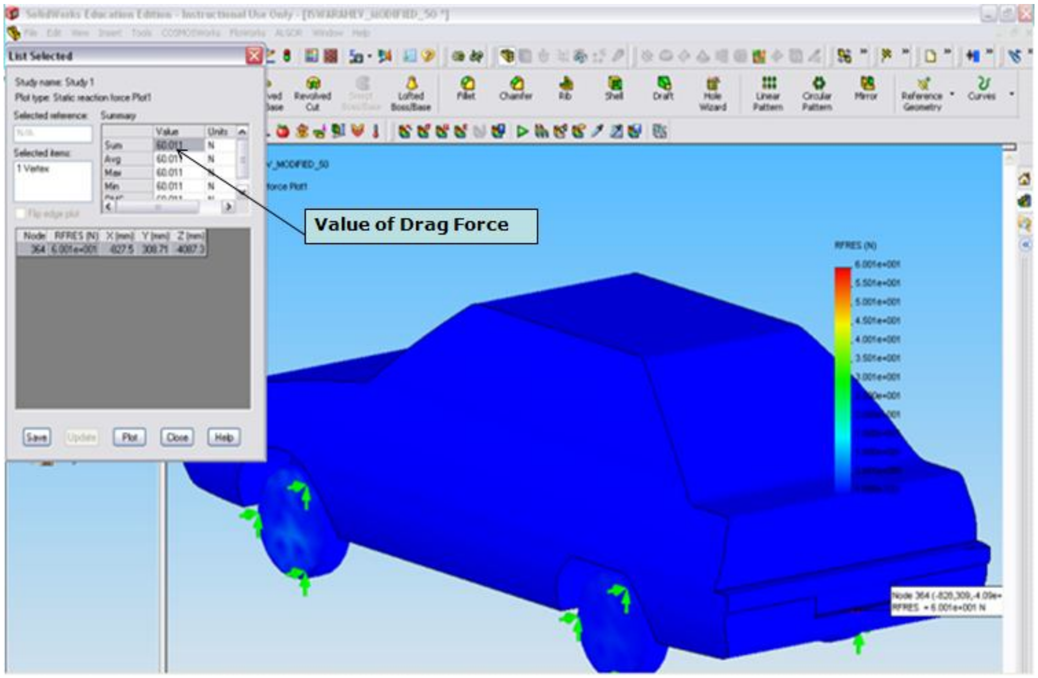


Figure 3.16 Drag Force Analyses in FEM Analysis

Figure above show the drag force value that obtain from FEM Analysis and this value of drag force will be used to calculate drag coefficient based on the equation 2.2.

3.2.8 Comparison of Drag Coefficient

To achieve the last project objective, the comparison in term of drag coefficient between the model without VG and model with VG must be done. If the C_D is reduce by VG installation, the project is complete before proceed to documentation. If not, the new design of VG must be done and run the simulation analysis again until the C_D is decrease.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The main objective of this project is about to analyze the effect of vortex generator installed on model of HEV based on drag coefficient reduction. The comparison will be done between the model with and without vortex generators in order to analyze and observed the drag reduction by using CFD simulation in COSMOSWork software. To improve the efficiency of the vehicle, reducing the coefficient of drag (C_D) should be the main concern.

The vortex generators can be used to improve fuel economy by reducing drag and used to make a car more aerodynamically stable. This CFD simulation analysis will determine there is any changing and improvement before and after the rear diffuser device are install at the vehicle model.

4.2 Data of Various Velocities and Drag Forces

The drag forces data collections that were getting from FEM analysis for various velocities was listed in the Table 4.1 below

Table 4.1 Table of various velocities and drag forces

Velocity (Km/h)	Drag Force (N)	
	Without VG	With VG
60	101.8	94.56
70	140.5	130.5
80	187.4	174.3
90	240.7	225.4
100	301.3	283.2
110	368.5	347.7
120	441.1	420.1

4.2.1 Value of Projected Area

The projected area means as frontal area of the HEV's body that has overall height and width is 1.36 m and 1.655 m. While, the value of projected area were measured is about 1.84 m^2 directly from the CAD's Software for model without and 1.847 m^2 for model with VGs.

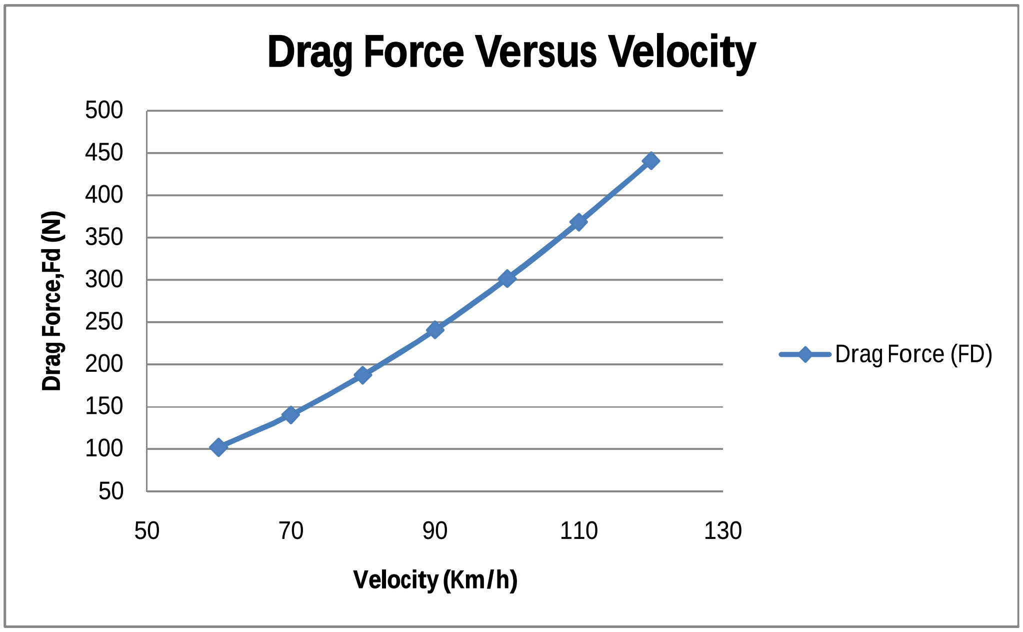
So, $A = 1.84\ m^2$ (Without VG)

$A = 1.847\ m^2$ (With VG)

4.3 Data Analysis

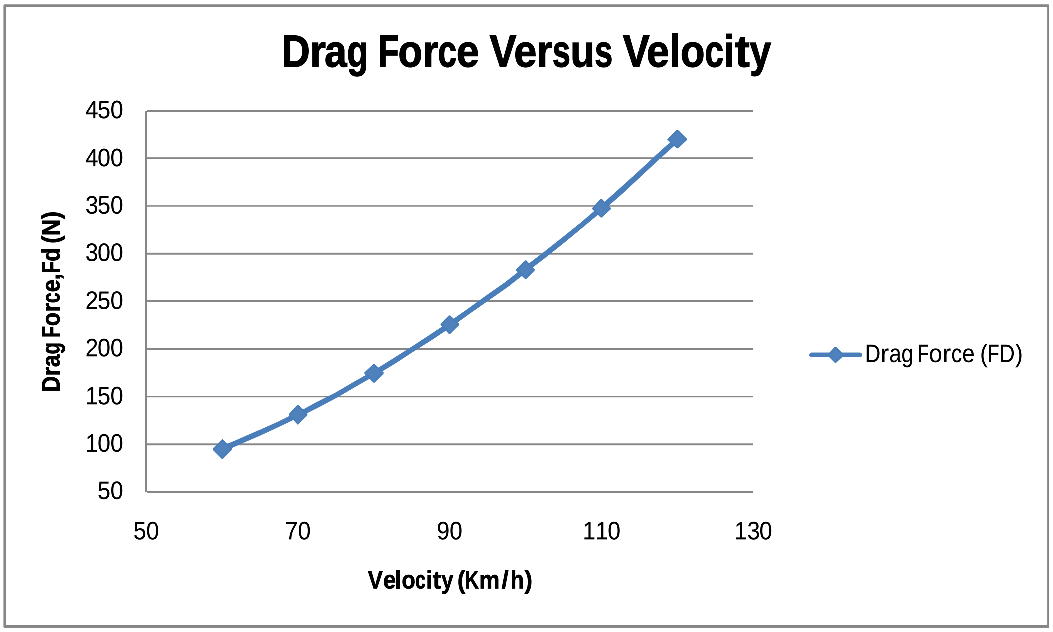
4.3.1 Graph Drag Force, F_D against Velocity, V

The data from Table 4.1 was plotted into the graph of forces, *Fd* against the velocity for both HEV models with and without Vortex Generators (VGs). Then, the graph series of F_D Vs Velocity was shown in Graph 4.1 and Graph 4.2.



Graph 4.1 Graph Drag Forces against Velocity for HEV model without VG

Graph 4.1 above shown the curve of positive quadratic form graph or exponential graph. It shows clearly the drag forces, F_D was function to the square of velocity from 60 km/h up to 120km/h for every 10km/h of velocity analysis for model analysis without VG. The minimum drag force can be obtain from 60 km/h is about 101.8 N and the maximum drag force were observed from 120 km/h is about 441.1 N. Thus, it means the increasing of velocity would affected to the increasing of drag forces.



Graph 4.2 Graph Drag Force against Velocity for HEV model with VG

Graph 4.2 above also shown the curve of positive quadratic form graph or exponential graph. It shows clearly the drag forces, F_D was function to the square of velocity from 60 km/h up to 120km/h for every 10km/h of velocity analysis for model analysis with VGs. The minimum drag force can be obtain from 60 km/h is about 94.56 N and the maximum drag force were observed from 120 km/h is about 420.1 N. Thus, it means the increasing of velocity would affected to the increasing of drag forces.

4.3.2 Calculation of Drag Coefficient

From the all data collections of Table 4.1, Graph 4.1 and Graph 4.2, reference point measurement, and projected area of the car. The drag coefficient, C_D was calculated base on the equation (2.2). The calculation were including for every speed of analysis where is between 60 km/h to 120km/h for every 10km/h interval then plotted into a graph.

4.3.2.1 Sample of Drag Coefficient Calculation

The drag coefficient can be calculated by using the drag force equation given. From the value of drag force that obtains in COSMOSWork analysis, the drag coefficient, C_D can be determined. The drag coefficient will be calculate with the equation at the below.

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

F_D = drag force [N]

ρ = density of the air [kg/m^3]

A = area of the body [m^2]

V = velocity of the vehicle model (60 km/h until 120 km/h)

Calculation of C_D for model without vortex generators at velocity 60 km/h based on data given,

F_D = 101.8 N

ρ = 1.225 kg/m^3

A = 1.84 m^2

V = 16.67 m/s

Solution,

$$C_D \quad = \frac{101.8\,N}{{}^1\!/_2\left(1.225\frac{kg}{m^3}\right)(16.67\frac{m}{s})^2\,(1.84m^2)} = 0.32505$$

Calculation of C_D for model with vortex generators at velocity 60 km/h based on data given,

F_D = 94.56 N

ρ = 1.225 kg/m^3

A = 1.847 m^2

V = 16.67 m/s

Solution,

$$C_D \quad = \frac{94.56\,N}{{}^1\!/_2\left(1.225\frac{kg}{m^3}\right)(16.67\frac{m}{s})^2\,(1.847\,m^2)} = 0.30079$$

4.3.2.2 Data of Drag Coeffiecient, C_D for Various of Velocity, V

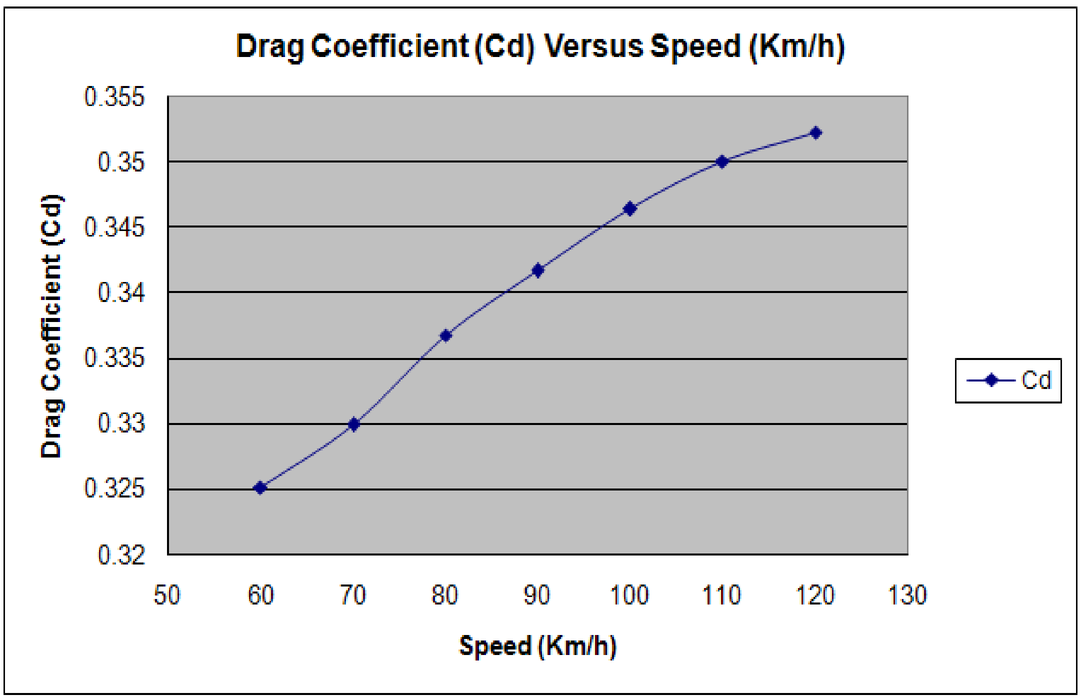
Since the drag coefficient has been calculated for every velocity, the drag coefficient and velocity was listed in Table 4.2 and plotted in Graph 4.3 and Graph 4.4.

Table 4.2 Table drag coefficients for both model with and without VGs at various velocity.

Velocity (km/h)	**Drag Coefficient, C_D**	
	Without VG	With VG
60	0.3251	0.3008
70	0.3299	0.3052
80	0.3368	0.3121
90	0.3417	0.3188
100	0.3464	0.3244
110	0.3501	0.3291
120	0.3523	0.3343
Average of C_D	**0.3403**	**0.3178**

Table 4.2 shown the Drag Coefficeint, C_D that calculated from the equation 1 that can be observed for the model of HEV with and without VG. The average drag coefficient obtained are 0.3403 for model without VGs and 0.3178 for model with VG.

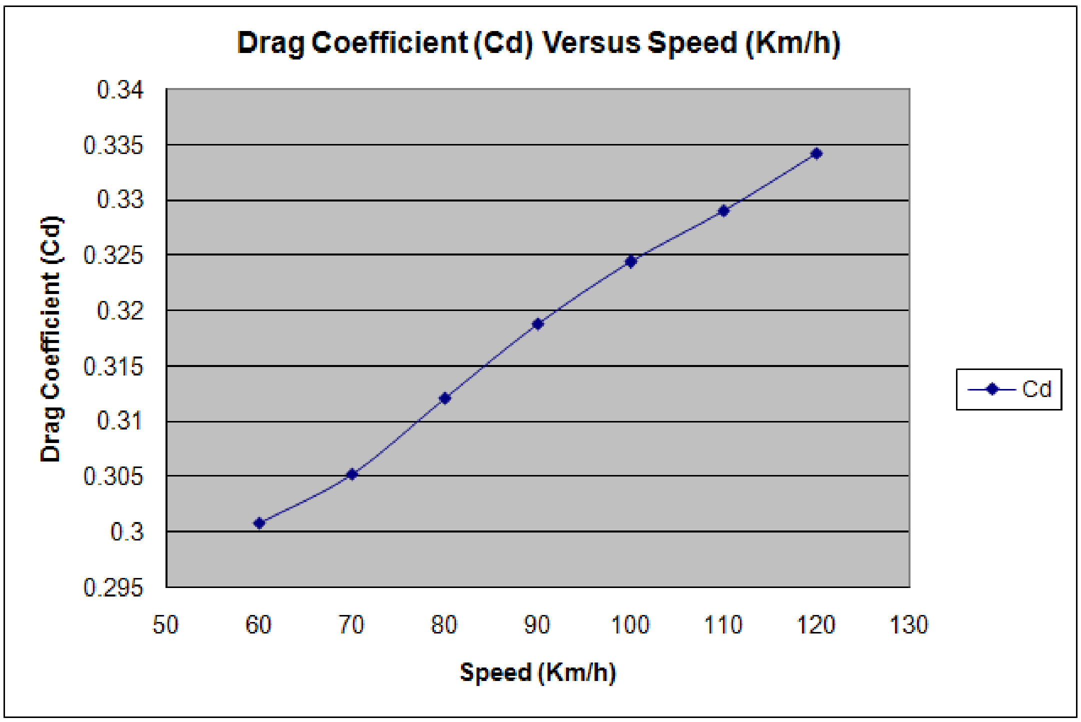
The drag coefficient data from table 4.2 are plotted in graph 4.3 below for the model without VGs ranging from 60 km/h to 120 km/h.



Graph 4.3 Drag Coefficient Analysis for HEV model without VG

From the graph of drag coefficient versus speed above, the increasing of C_D is slightly proportionally with the increasing of speed. The higher speed of test vehicle will give higher drag coefficient due to higher drag force to overcome as the vehicle moving. The minimum C_D obtained at the speed of 60 km/h with 0.3251 and the maximum value of C_D obtained at the speed of 120 km/h with 0.3523. The average C_D for model without VG is 0.3403.

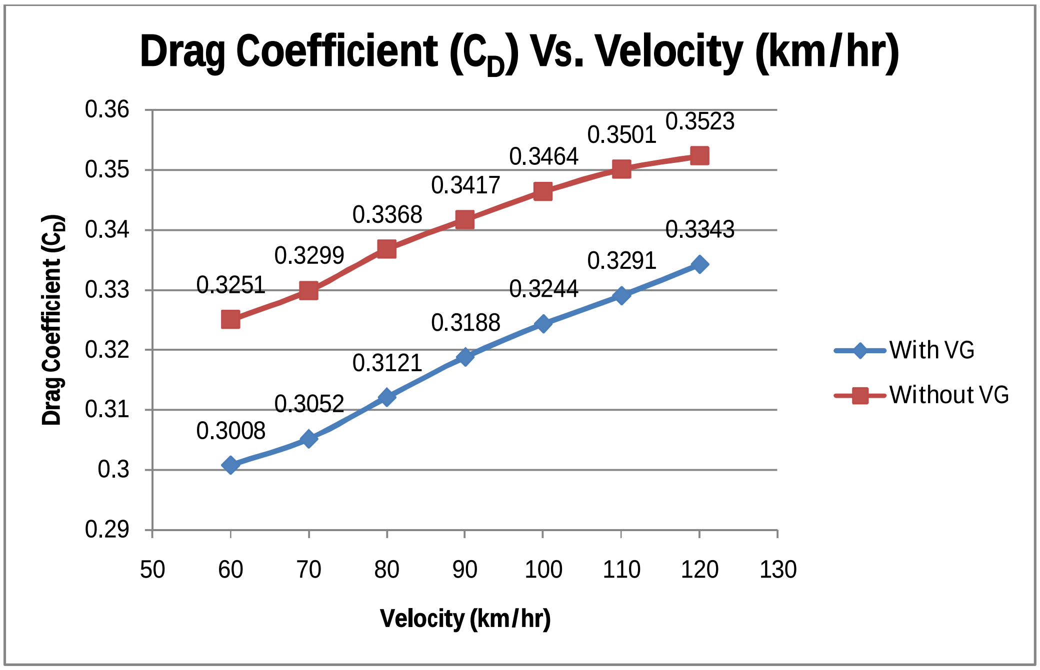
The drag coefficient data from table 4.2 are plotted in graph 4.4 below for the model with VGs ranging from 60 km/h to 120 km/h.



Graph 4.4 Drag Coefficient Analysis for model with VG

From the graph of drag coefficient versus speed above, the increasing of C_D is slightly proportionally with the increasing of speed. The higher speed of test vehicle will give higher drag coefficient due to higher drag force to overcome as the vehicle moving. The minimum C_D obtained at the speed of 60 km/h with 0.3008 and the maximum value of C_D obtained at the speed of 120 km/h with 0.3343. The average C_D for model without VG is 0.3178.

The comparison of drag coefficient against vehicle speed between both models with and without can be obsecred from the Graph 4.5 below. The different lines of the drag coefficient with and without vortex generators are plotted.



Graph 4.5 Comparison of Drag Coefficient Vs Velocity with and without VG

Graph 4.5 clearly show the drag coefficient reduction by using vortex generators that indicated in blue line compared to vehicle without vortex generators for all speed analysis. Total reduction in drag coefficient is about -0.0225, calculated from average drag coefficient deduction for both model. The drag coefficient decrease because the effect of VG is strong enough to reduce the wake region slightly after the separation point to make the airflow more streamline so that the moving vehicle less force required overcoming the air flow resistance.

4.3.3 Calculation of Aero Power

The aero power can be calculated by using the aero power equation from the previous study. From the result value of drag coefficient that obtains in drag coefficient equation, aero power, P can be determined. The aero power will be calculate with the equation at the below.

$$P = \frac{\rho}{2} C_D A V (V + V_o)^2 \qquad (2)$$

P = Aero power [W]

ρ = air density [kg/m^3]

C_D = drag coefficient

A = vehicle section area [m^2]

V = velocity [m/s]

V_o = wind velocity [m/s]

4.3.3.1 Sample of Aero Power Calculation

Calculation of Aero Power for model without vortex generators at velocity 60 km/h based on data given,

ρ = 1.225 kg/m^3

C_D = 0.3251

A = 1.84 m^2

V = 16.67 m/s

V_o = 0 m/s

Solution,

$$P = \frac{1.225\ kg/m^3}{2}\ (0.3251)\ (1.84\ \mathrm{m}^2)\ (16.67\ \mathrm{m/s})\ (16.67\ \mathrm{m/s} + 0\ \mathrm{m/s})^2$$

$$= 1.697\ \mathrm{kW}$$

Calculation of Aero Power for model with vortex generators at velocity 60 km/h based on data given,

ρ = 1.225 kg/m^3

C_D = 0.3008

A = 1.847 m^2

V = 16.67 m/s

V_o = 0 m/s

Solution,

$$P = \frac{1.225\ kg/m^3}{2}\ (0.3008)\ (1.847\ \text{m}^2)\ (16.67\ \text{m/s})\ (16.67\ \text{m/s} + 0\ \text{m/s})^2$$

$$= 1.576\ \text{kW}$$

4.3.3.2 Data of Aero Power,*P* for Various of Velocity, *V*

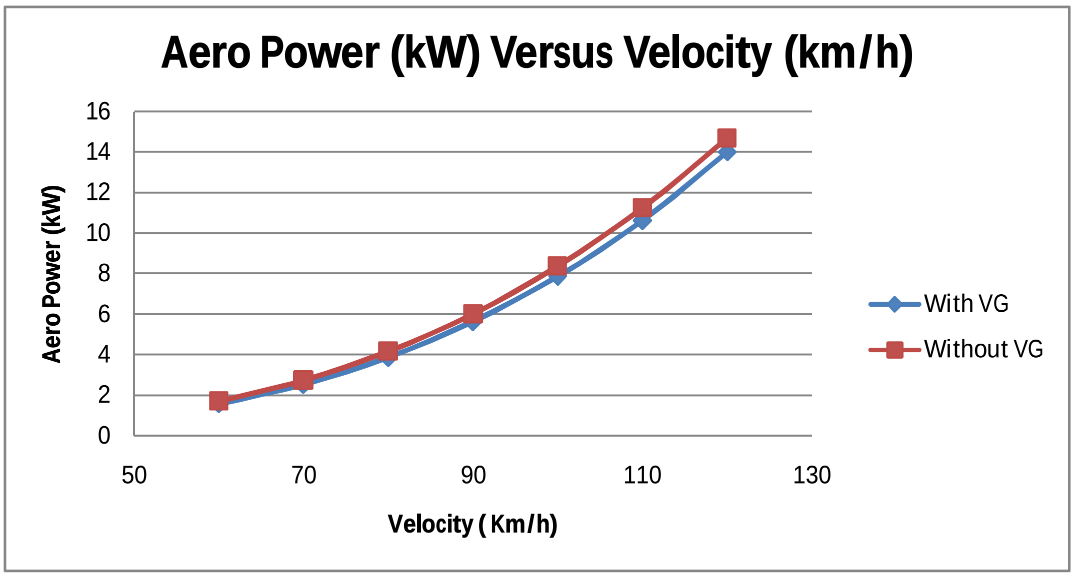
Since the aero power has been calculated for every velocity, the drag coefficient and velocity was listed in Table 4.3 and plotted in Graph 4.6.

Table 4.3 Table of aero power for both model with and without VG at various velocity

Velocity (km/h)	**Aero Power, kW**	
	Without VG	With VG
60	1.697	1.576
70	2.731	2.536
80	4.164	3.873
90	6.017	5.635
100	8.369	7.868
110	11.261	10.626
120	14.701	14.003
Average of Aero Power	**6.991**	**6.588**

Table 4.3 shown the Aero Power that calculated from the equation 2 that can be observed for the model of Proton Iswara with and without VG. The average aero power obtained are 6.991 kW for model without VG and 6.588 kW for model with VG.

The comparison of Aero Power against vehicle speed between both models with and without can be obserced from the Graph 4.6 below. The different lines of the drag coefficient with and without vortex generators are plotted that indicated in red and blue line.



Graph 4.6 Comparison of Aero Power Vs Velocity with and without VG

Graph above show the aero power reduction by using vortex generators that indicated in blue line compared to vehicle without vortex generators. At the first three speed analysis, 60 km/h to 80 km/h, the reduction of aero power do not decrease much but after the speed of 90 km/h to 120 km/h, the reduction of aero power can be seen clearly. Total reduction in aero power is about -0.403 kW, calculated from average aero power deduction for both model. The aero power decreases because less power required moving the vehicle by VG installation.

4.4 Percentage Reduction

Percentage reduction is very important to determined the project objective achived by vortex generator installed at the separation point of HEV model. The percentage reduction calculated can be devided by two categories, reduction of drag coefficient and redution of aero power for various velocities. The value of average C_D and Aero Power will be used to be apply in equation 3 below:

$$\% \text{ reduction} = \frac{Average\ without - Average\ with}{Average\ without} \times 100\% \tag{3}$$

Table 4.4 Average Value of C_D and Aero Power

Type of Reduction	Average Value	
	Without VG	With VG
Drag Coefficient, C_D	0.3403	0.3178
Aero Power, kW	6.991	6.588

4.4.1 Percentage of Drag Coefficient Reduction

$$\% \ C_D \text{ reduction} = \frac{0.3403 - 0.3178}{0.3403} \times 100\%$$

$$= 6.61 \ \%$$

4.4.2 Percentage of Aero power Reduction

$$\% \text{ P reduction } = \frac{6.991\ kW - 6.588\ kW}{6.991\ kW} \text{ x } 100\%$$

$$= 6.19\ \%$$

The perventage reduction are 6.61 % for drag reduction and 6.19 % for aero power that will contribute to better aerodynomic characteristic of the car.

4.5 Contour Plot

4.5.1 Velocity Plot on the Vehicle Center Line at Various Speeds

The process of results collection started from CFD. The car body was subjected to vehicle speed ranging from 60 km/h to 120 km/h. The plot was seen from the center line of the car as the results are clearer. The plots in Figure 1 show changes in the flow stream that indicates a velocity profile of flow separation condition at the vehicle rear end by using vortex generator. The blue color regions are the separation regions where the velocity of the flow is reversed and this is also known as the wake area.

There is a huge difference of flow separation profile at all speed analysis between vehicle without vortex generator and with vortex generator. This may be due to the effect of vortex generators installed are strong enough to shift the flow separation further downstream so that the flow will attach to the surface of vehicle rear end. As the speed increased the rear flow separation of the model without vortex generator is curved upwards compared to flow velocity obtained from the vortex generator of 15° angle. Clearly this is seen on the 120 km/h model. The reduction of the separation angle is a good indication that the vehicle can move more efficiently in the wind at the same velocity with the model vortex generator applied. This will reduce the drag of the car.

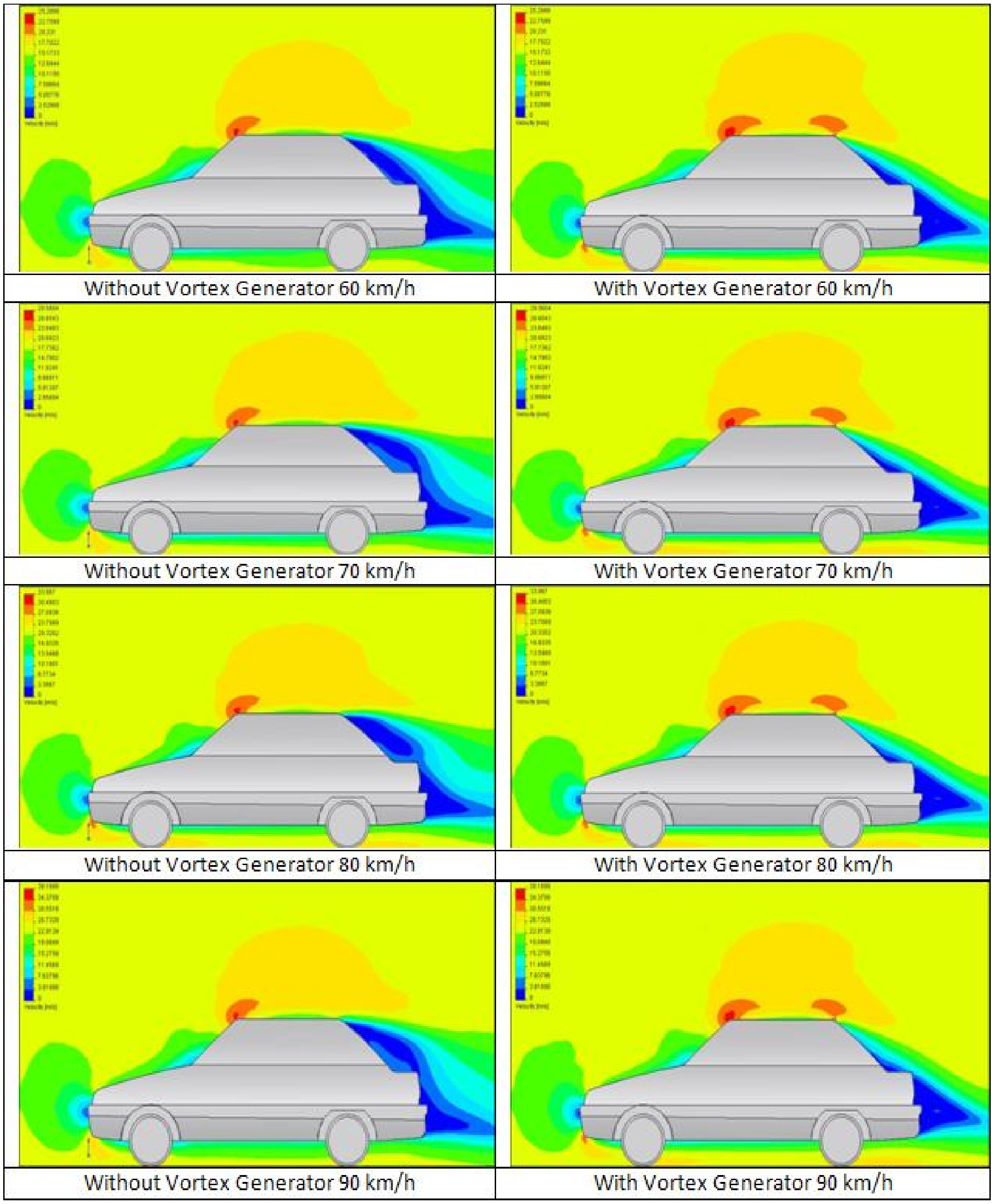


Figure 4.1 Velocity Plot on the Vehicle Center Line at Various Speeds

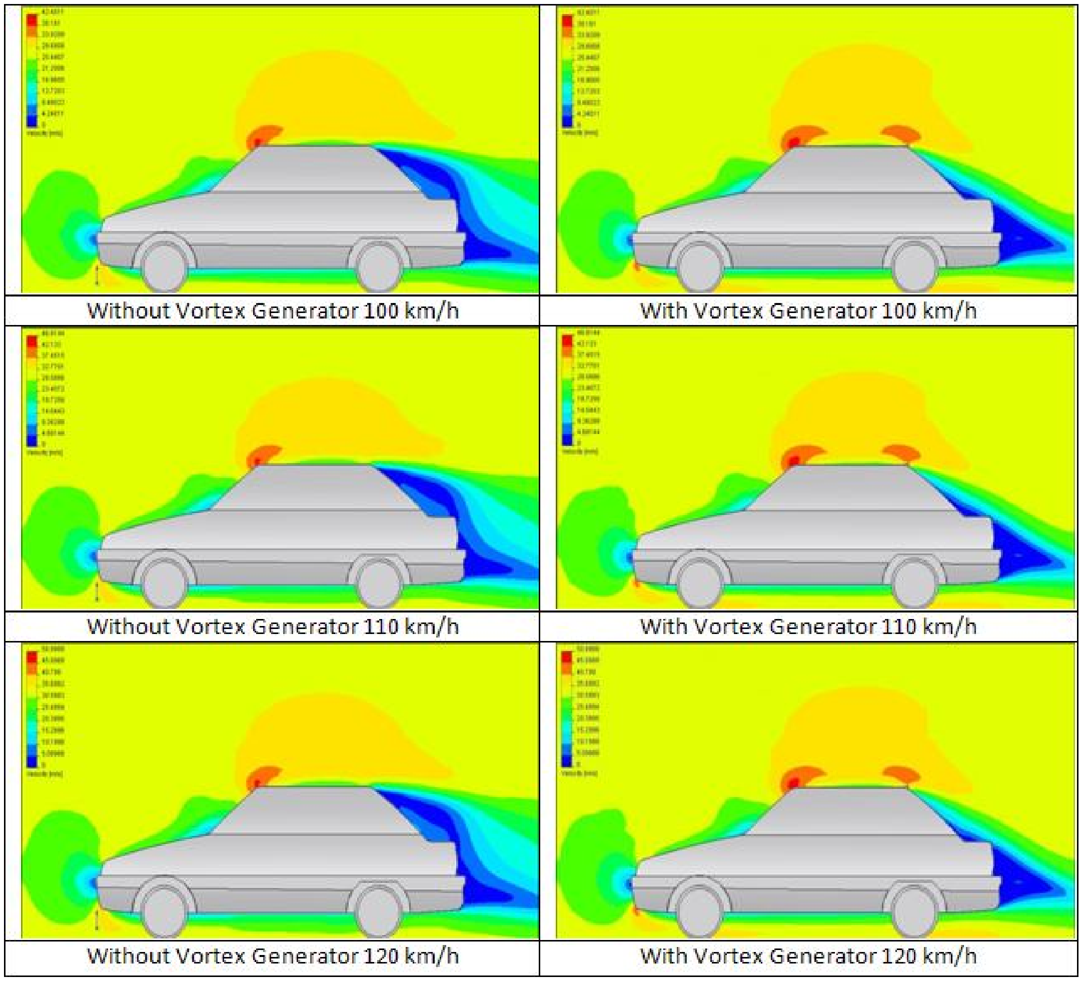


Figure 4.1 Velocity Plot on the Vehicle Center Line at Various Speeds

The red region above VG show that air flow velocity around the separation point flowing with high speed compared to model without that there is no red region exist around the separation point. This due to the effect of VG by delaying or prevent the separation point in order to maintain steady airflow over the control surface at the rear window of the car.

4.5.2 Velocity Plot on the Top Rear End of Vehicle at Various Speeds

The velocity plot is also seen for the vehicle model from the top rear end of the car. Figure 2 below shows how the region is affected. There is more separation at the rear end in the vortex generator model without as compared to the model with vortex generator. There are huge differences between the both models at all speed analysis. The higher wake region occur at the rear end surface on model without vortex generator and this will give higher drag because the vehicle need to punch a larger hole through the air.

An expand airflow occur slightly after the separation point and less airflow attached above the rear window to the surfaces of the body. While the model with vortex generator shown the different condition that the airflow remain attach to the surface of the body because the main function of vortex generators themselves is to re-energized the boundary layer so that the flow is remain attach.

From Figure 2, the model without VG shown the attached flow continues down the window at both ends of the rear surface, however, in the lower middle area there is turbulence. In other words, a separation bubble forms at the middle or base of the rear window. This is seen from the blue contour above the rear window. The model with VG shown the difference in airflow was immediately apparent. The airflow down the middle of the rear window remained attached to the surface of the body. The airflow pattern is completely transformed, with no separation bubble forming at all. However, with such good airflow, any turbulence becomes more visible and some can be seen at the base of the window at each extreme end. This is because the location of VG is slightly in front of separation point.

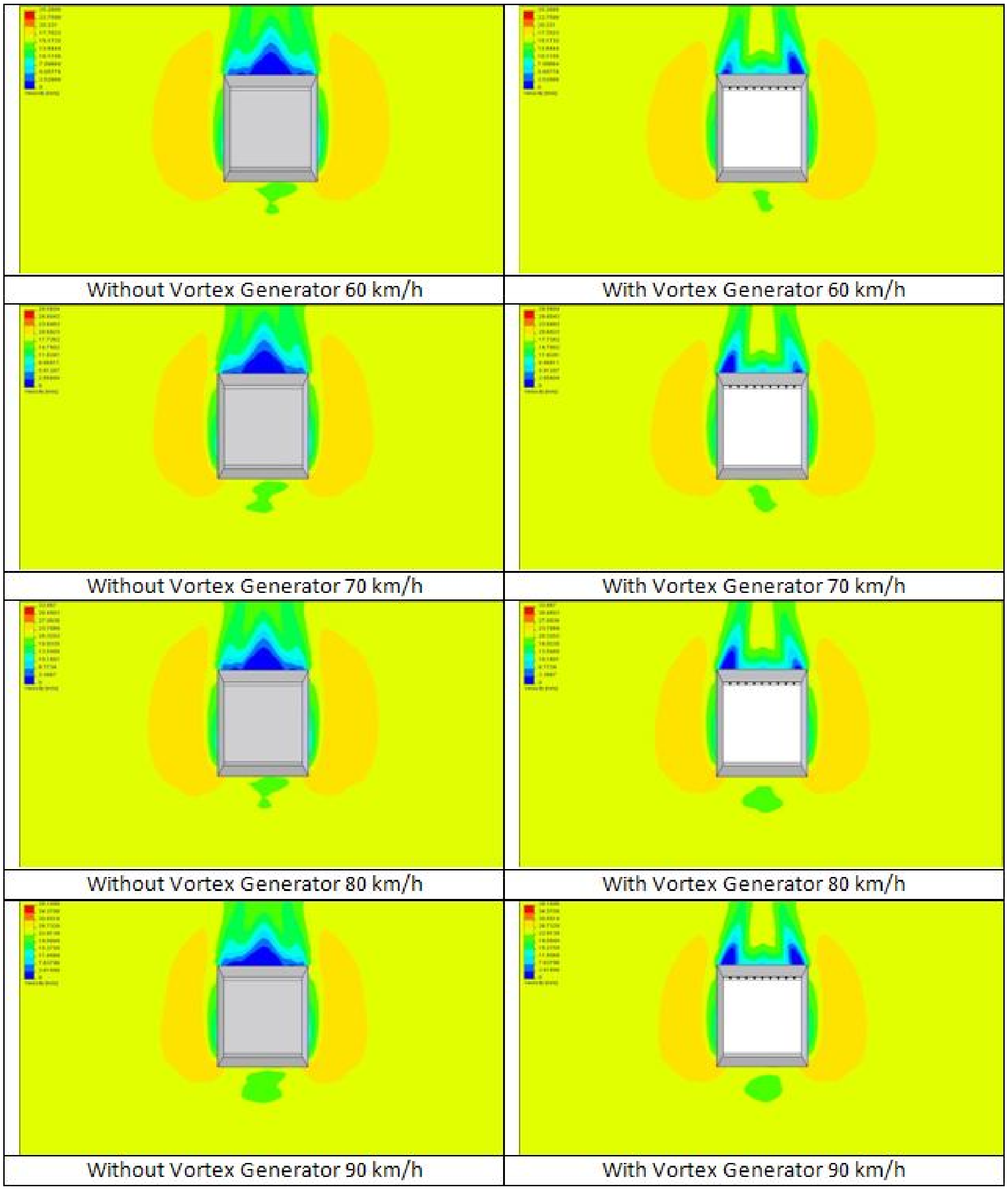


Figure 4.2 Velocity Plot on the Top Rear End of Vehicle at Various Speeds

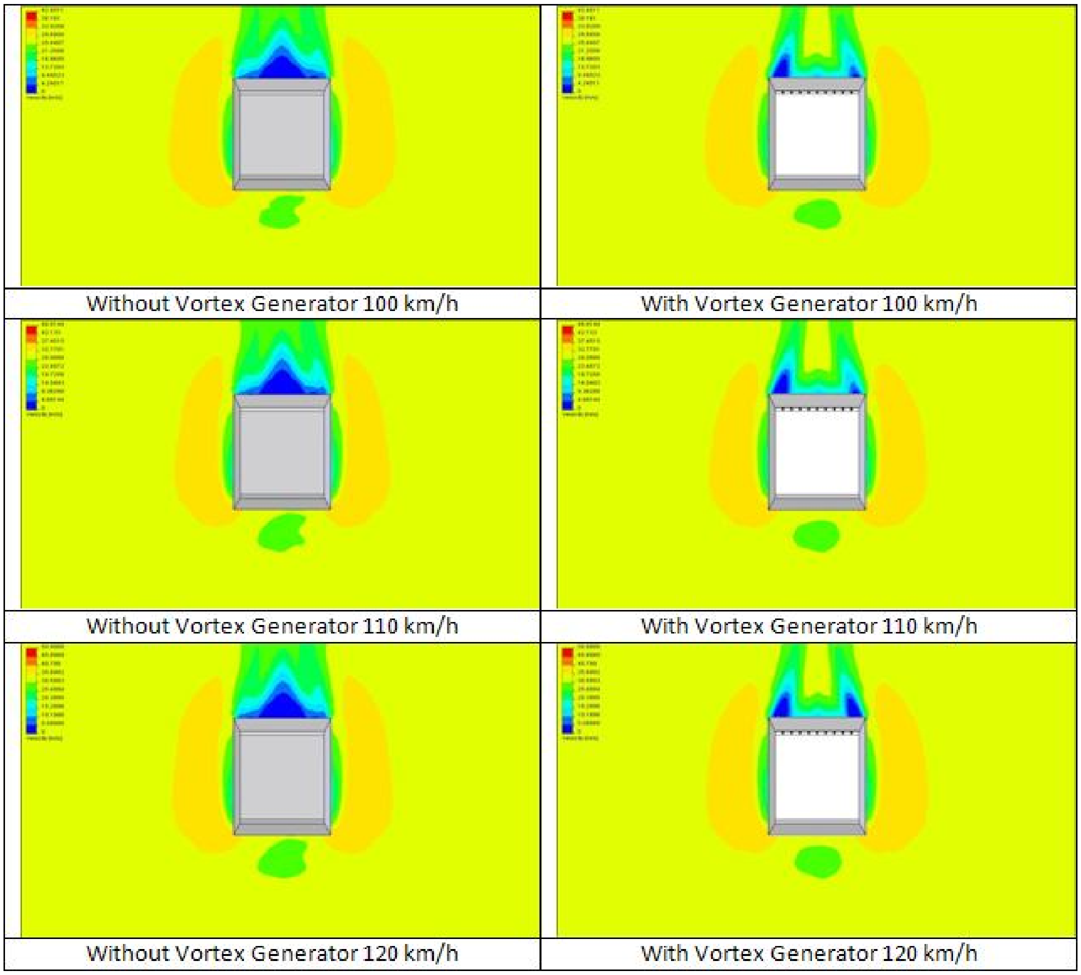


Figure 4.2 Velocity Plot on the Top Rear End of Vehicle at Various Speeds

The streamline does not stick to the body in the rear window transition but instead tends to leave at this point as can seen on model without vortex generator. The result is a larger wake of disturbed air produced that indicated with blue region.

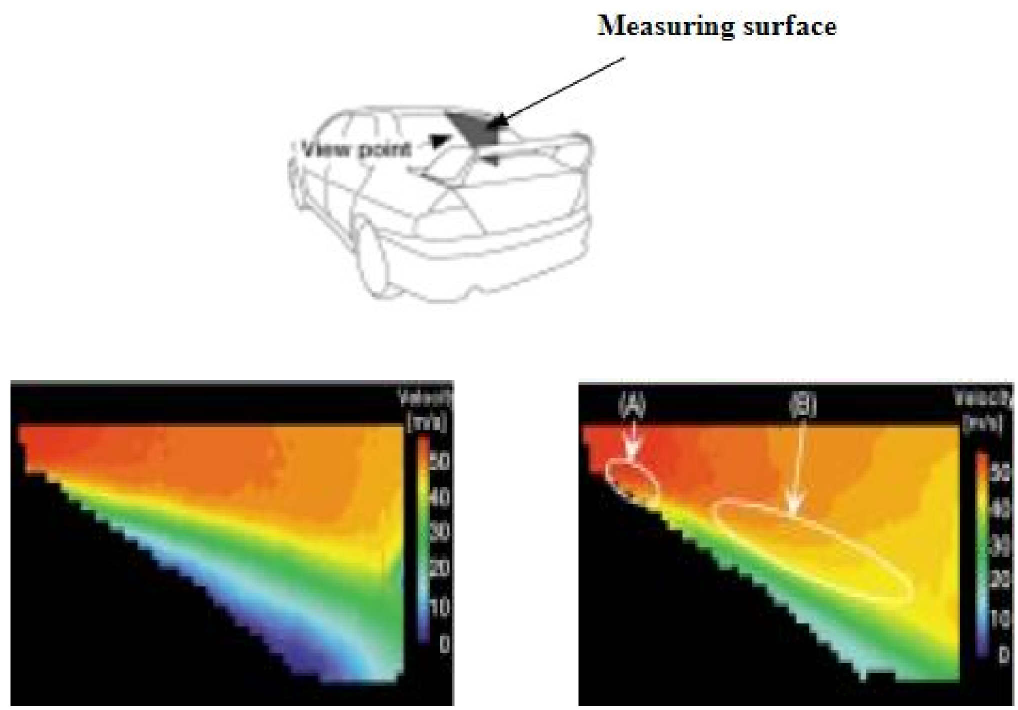
4.6 Result Discussion

The result obtain from both model analysis show the reduction of drag coefficient and aero power by using vortex generators as an aerodynamically device had been proved and the project objective achieved. The drag reduction effect for VG of 30 mm height and installed at yaw angle of 15º slightly before separation point were all equivalent to -0.0225. The effect of VG is estimated that the separation point is shifted to downstream, which in turn narrows the flow separation region. This can be seen from the velocity plot on the vehicle center line at various speeds.

The high velocity region is expanded downward by addition of VG, signifying that the flow separation region is narrowed. As evident from the figure, the case with VG shows an increase in velocity on the surface of the body (rear window) just behind the VG and extension of the high velocity zone downward. This supports the estimation that VG cause airflows above the rear window to attach to the surfaces of the body. The estimation that the streamwise vortex causes the separation point to shift downstream is confirmed by CFD results in COSMOSWork software in Figure 1 that shows close-up views of the flow field near the separation point. The case with VG shows flow separation occurring further downstream than in the case without VG.

4.6.1 Result Validation

Result validation can be done by comparing the velocity distribution above surface of rear window of vehicle with previous researcher. The analysis of VGs had been done by Masaru KOIKE, Tsunehisa NAGAYOSHI and Naoki HAMAMOTO with the paper of "*Research on Aerodynamic Drag Reduction by Vortex Generators*". Figure 4.3 below show the velocity distribution for model with and without VG.



a) Without VGs b) With VG

Figure 4.3 Velocity distributions for model with and without VG at 60 km/h by Mitsubishi motor technical paper.

It is confirm that application of VG will cause the airflow above rear window travel at high speed compared to model without VG that airflow travel almost 0 m/s that indicated with blue region. The simulation result and analysis result by previous researcher of VG in term of velocity distribution above rear window is almost have the same pattern.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

Starting from the process of literature review to process of design vortex generators, simulation in CFD software and finally calculation data of drag reduction had been done in order to complete the project objectives. The analysis done is to measure the effectiveness of vortex generators in term of drag and aero power reduction for improvement of vehicle aerodynamic characteristic.

5.2 Conclusion

The conclusion of this project can be summarized as the Vortex Generators (VGs) were studied to install immediately upstream of the flow separation point in order to control separation of airflow above the rear window and improve the aerodynamic characteristics. Application of the VG of the optimum shape and height determined through the literature review to the Proton Iswara model showed a 0.0225 reduction in drag and 0.403 kW reductions in aero power. Factors contributing to the effect of VGs were verified by conducting measurement of velocity distribution at vehicle center line (Figure 1) and velocity distribution at top rear end (Figure 2) of vehicle in COSMOSWork simulation.

As a result of the verifications, it is confirmed that VG create streamwise vortices, the vortices mix higher and lower layers of boundary layer and the mixture causes the flow separation point to shift downstream, consequently separation region is narrowed. From this, the prediction can be done that VG cause smaller wake region produce at the trailing end of the roof and less energy required to move the vehicle compared to model without VG. The result shown that the project objectives are achieved completely that to determine the percentage of drag coefficient reduction by vortex generators that contribute to 6.61 % reduction.

5.3 Recommendation

To improve the efficiency of the vehicle, vortex generators are one of the aerodynamic devices to be concern in order to improved car stability at high speed. The recommendation for future work is, the next student should used better software analysis such Fluent software for more accurate result. This type of software normally used for industrial application to test their vehicle produced. Another recommendation is the project can be done by analyze the VG with various height and shape to study the effectiveness of VG to height changes so that the most optimum height and size of VG can be determined clearly.

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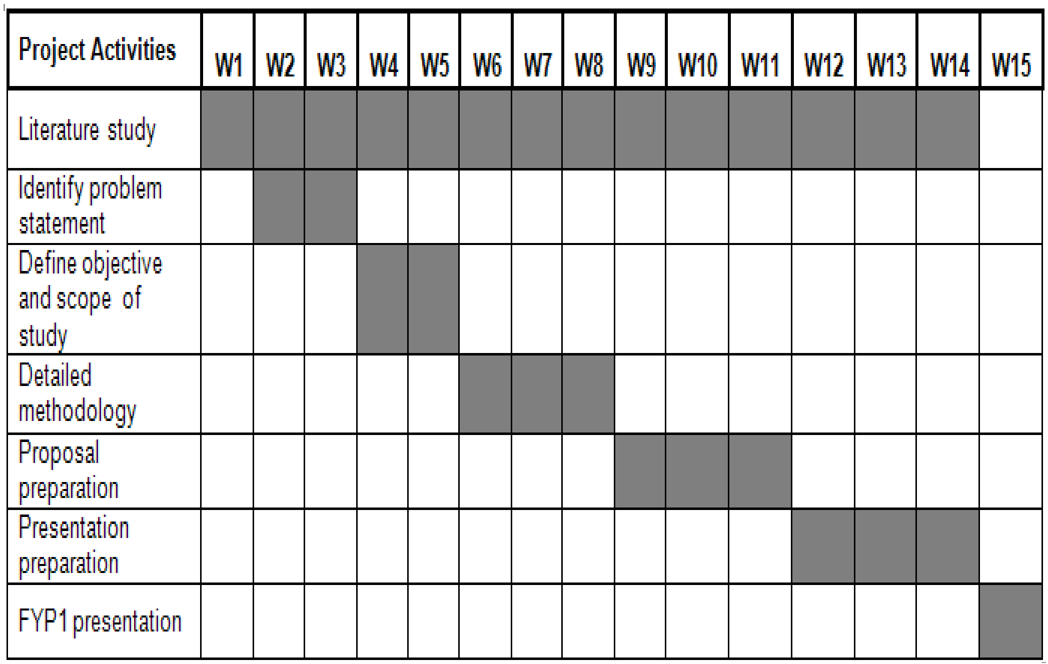
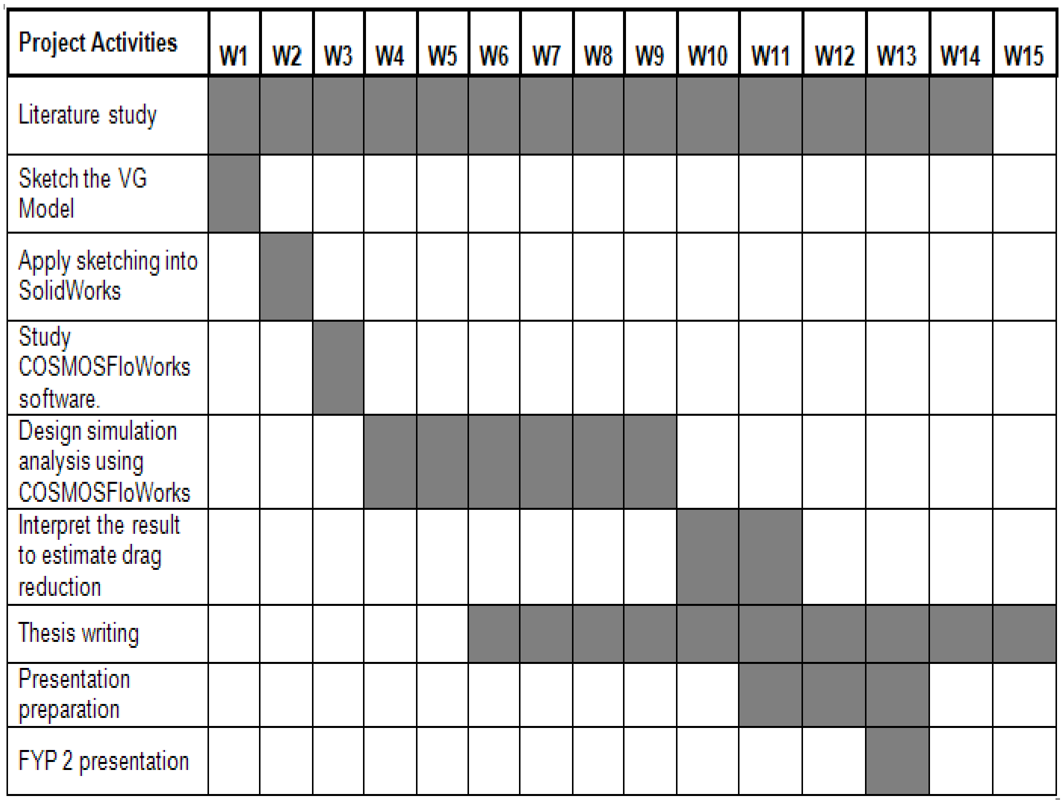
Appendix A

Project Timeline



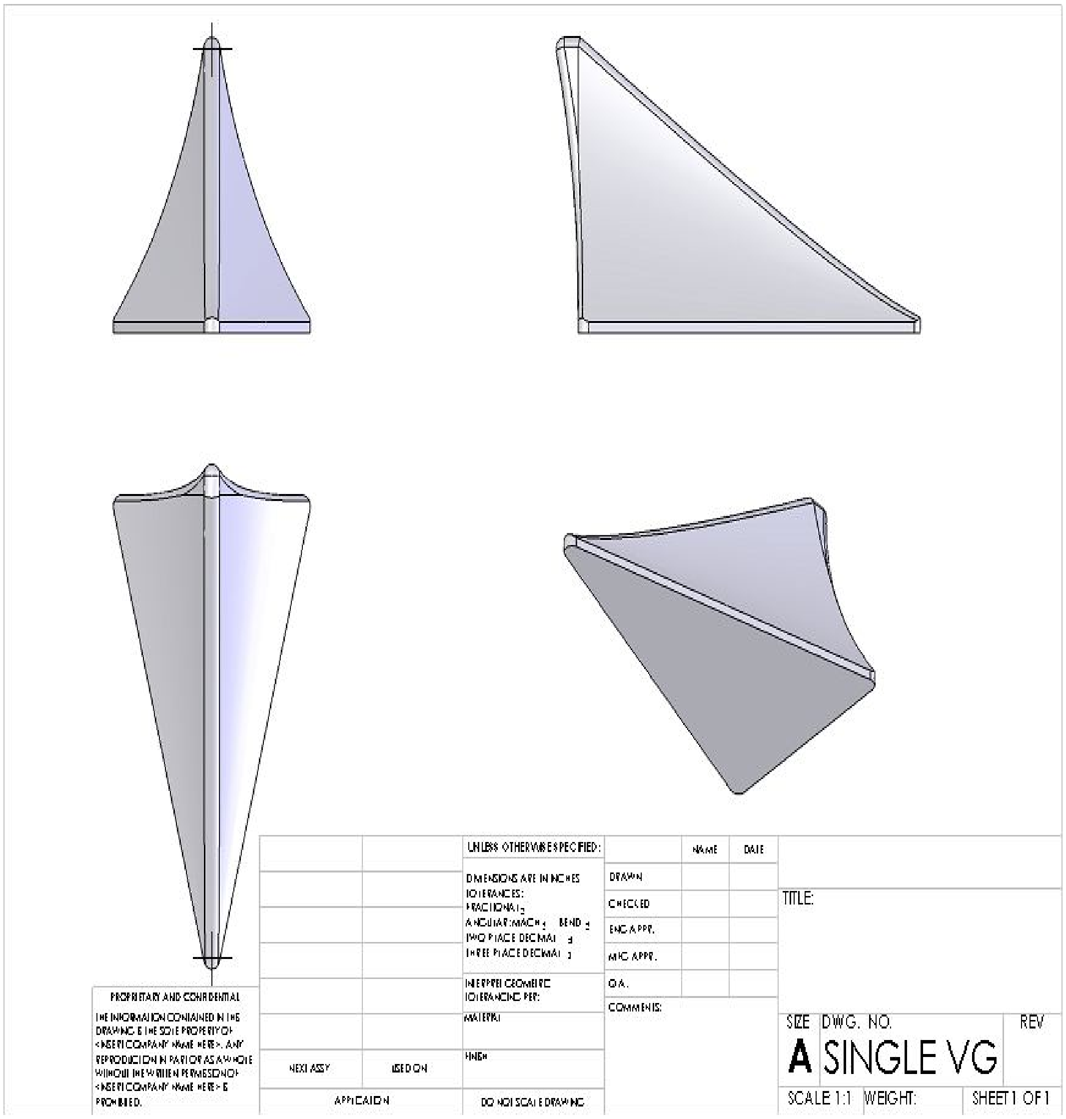
Final Year Project 1 Gantt Chart



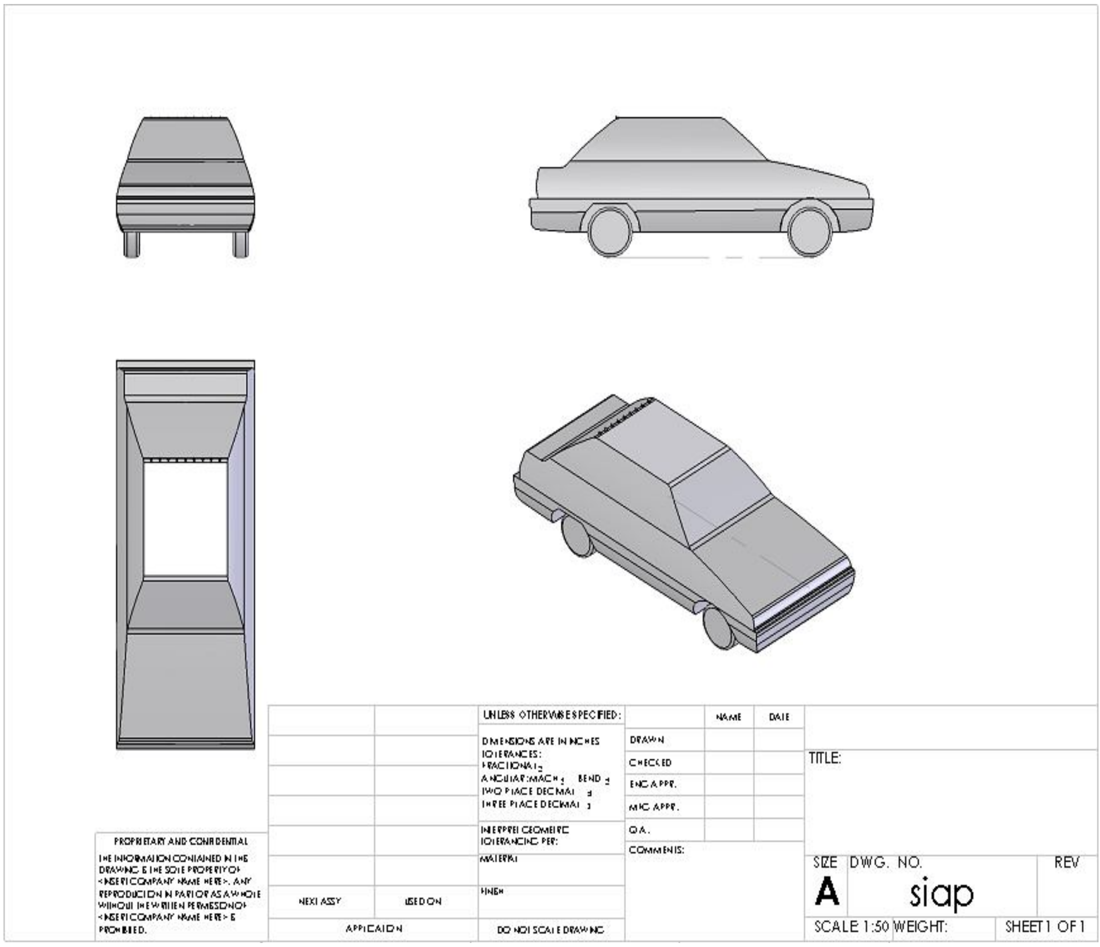
Final Year Project 2 Gantt Chart

Appendix B

Drawing in Solid Works



Single Vortex Generator



HEV Model with VG