AERODYNAMICS OF AFTERMARKET REAR SPOILER

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AERODYNAMICS OF AFTERMARKET REAR SPOILER

RIDHWAN BIN CHE ZAKE

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
University Malaysia Pahang

NOVEMBER 2008

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive

Signature:
Name of Supervisor: En. Zamri Bin Mohamed
Position: Lecturer
Date: 10 November 2008

Signature:
Name of Panel:
Position:
Date:

STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature: …………………………

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Int the Name of Allah, The Most Beneficent,, The Most Merciful

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ABSTRACT

Performance, handling, safety, and comfort of a car are significantly affected by its aerodynamic properties. Getting high power under the hood is not enough to judge the performance of the car. Aerodynamic properties must be considered for the purpose of studying the drag and stability performance of a car. In order to improve car aerodynamic drag and its stability, an aerodynamic device is needed such as rear spoiler. Rear spoiler is an aerodynamic device that functions to slow down and collect air, causing it to stagnate. This rear placing device creates an area of high pressure to replace the usual low pressure over the trunk resulting increasing stability. The objective of this study is to investigate the effects of aftermarket rear spoiler to car aerodynamics drag and stability. Several rear spoilers design is attached at rear part of base line model. Both BLM model and rear spoiler models are built in CAD software. The CAD data then, either with or without rear spoiler are analyze in CFD software to estimate the drag and lift force which is acting on the car. Force, drag and lift coefficient values will be determined in order to study their effect to drag and stability. Some limitations occurred due to the complexity of the design. From the result, rear spoiler can help to reduce drag, by creating high pressure at the back.

ABSTRAK

Prestasi, kawalan, keselamatan dan keselesaan sesebuah kenderaan banyak dipengaruhi oleh ciri-ciri aerodinamik kendereaan tersebut. Prestasi sesebuah kereta tidak dapat dinilai melalui keupayaan enjin kereta sahaja. Ciri-ciri aerodinamik pada kereta amat penting sebagai keperluan untuk kajian prestasi kereta dari segi daya tujah dan kestabilan kereta. Bagi meningkatkan keupayaan tujahan aerodinamik kereta dan keseimbangannya, radas aerodinamik diperlukan sebagai contoh 'spoiler' belakang. 'Spoiler' belakang adalah satu radas aerodinamik yang mana berfungsi sebagai memperlahankan aliran udara menyebabkan ia tidak mengalir. Radas yang dipasang pada bahagian belakang kereta ini akan menyebabkan terbentuknya satu kawasan yang bertekanan tinggi, menggantikan kawasan tersebut yang kebiasaannya bertekanan rendah, seterusnya meningkatkan kestabilan kereta. Objektif projek ini ialah untuk mengkaji kesan penggunaan 'spoiler' belakang terhadap daya tujah aerodinamik kereta dan keseimbangannya. Beberapa reka bentuk 'spoiler' belakang akan dipasang pada bahagian belakang model asas kereta. Model-model ini akan dibina terlebih dahulu dalam perisian CAD. Model-model ini kemudiannya, sama ada dengan atau tanpa 'spoiler' belakang akan dianalisis dalam perisian CFD untuk menafsirkan daya tujah dan daya angkat yang bertindak pada badan kereta tersebut. Daripada daya-daya tersebut, pemalar daya tujah dan pemalar daya angkat akan ditentukan kerana melalui pemalar-pemalar ini, kesan daya tujah dan daya angkat dapat terhadap kereta dapat diketahui. Dari keputusan, satu kesimpulan boleh dibuat mengenai 'spoiler' belakang boleh membantu dalam mengurangkan daya tujah pada kereta dengan menghasilkan kawasan yang bertekanan tinggi pada belakang kereta.

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LIST OF SYMBOLS

p	Pressure
ρ	Air density
v	Vehicle's speed
dF_x	Net x-component of force
dF_y	Net y-component of force
dA	Small element of surface area
τ_w	Wall shear stress
D	Drag
L	Lift
D_A	Aerodynamic drag force
C_D	Drag coefficient
A	Frontal area
L_A	Aerodynamic lift force
C_L	Lift coefficient
T_r	Air temperature
P_r	Ambient pressure
z_s	Height of spoiler

LIST OF ABBREVIATIONS

CAD	Computer-aided design
CFD	Computational fluid dynamic
3-D	Three dimensional
Re	Reynolds number
Ma	Mach number
Fr	Froude number
ε/l	Relative roughness
BLM	Base-line model

CHAPTER 1

INTRODUCTION

1.1 PROJECT INTRODUCTION

Nowadays the everyday cars are changed by their owners to make the look sportier. Having more power under the hood leads to higher speeds for which the aerodynamic properties of the car given by the designer are not enough to offer the required down force and handling. The performance, handling, safety, and comfort of an automobile are significantly affected by its aerodynamic properties. Extra parts are added to the body like rear spoilers, lower front and rear bumpers, air dams and many more aerodynamics aids as to direct the airflow in different way and offer greater drag reduction to the car and at the same time enhance the stability. In case of that, many aerodynamics aids are sold in market mostly rear spoiler. Rear spoiler is a component to increase down force for vehicle especially passenger car. It is an aerodynamic device that design to ‘spoil’ unfavorable air movement across a car body. Main fixing location is at rear portion, depends on shape of the rear portion either the car is square back, notchback or fastback because not all rear spoiler can be fix at any type of rear portion of a car. However spoiler also can be attached to front/rear bumper as air dam. Rear spoiler contributed some major aerodynamics factor which is lift and drag. The reduction of drag force can save fuel; moreover spoiler also can be used to control stability at cornering. Besides can reduce drag and reduce rear-axle lift, rear spoiler also can reduce dirt on the rear surface.

1.2 PROBLEM STATEMENT

When a driver drives his or her car in high speed condition, especially at highway which is speed limit 110 km/h, the car has high tendency to lift over. This is possible to happen because as the higher pressure air in front of the windshield travels over the windshield; it accelerates, causing the pressure to drop. This lower pressure literally lifts on the car's roof as the air passes over it. Worse still, once the air makes its way to rear window, the notch created by the window dropping down to the trunk leaves a vacuum or lower pressure space that the air is not able to fill properly. The flow is said to detach and the resulting lower pressure creates lift that then acts upon the surface area of the trunk. To reduce lift that acted on the rear trunk, a rear spoiler can attach on it to create more high pressure. Spoilers are used primarily on sedan-type cars. They act like barriers to air flow, in order to build up higher air pressure in front of the spoiler. This is useful, because as mentioned previously, a sedan car tends to become "Light" in the rear end as the low pressure area above the trunk lifts the rear end of the car.

1.3 PROJECT OBJECTIVE

The objective of the project is to investigate the effects of aftermarket rear spoiler to the car aerodynamic drag and lift. The effects of rear spoiler can be determine by estimate the value of C_D (coefficient of drag) and C_L (coefficient of lift) especially when the car in high speed which above highway speed limit. Besides, the objective of this project also to ascertain advantages and disadvantages of a passenger car having rear spoiler. The differences between car with and without spoiler can be determined by compare the value of C_D and C_L of each. Several number of rear aftermarket spoiler are selected. Five models of rear spoilers will be chosen and the 3-D models will be built in CAD software according the actual dimension. The models will be analyzed in CFD software to estimate the value of C_D and C_L. From the value of C_D and C_L, which rear spoiler either reduce drag or reduce lift force, or reduce both or not can be determine.

1.4 PROJECT DESCRIPTION

An investigation on effects of rear spoiler to car aerodynamic drag and its stability will be done by estimate the value of C_D by doing some CFD analysis. Estimation of the C_D results the effects of rear spoiler to the passenger car. Since title is 'Aerodynamics of Aftermarket Rear Spoiler', so this project is more focused on rear spoilers that are already sold in market. This is because not all design of rear spoiler is suitable and fulfills car owner's need. Some design of rear spoiler will be observed and several designs will be selected to build up model in CAD software. The models will built up according its actual dimension to make sure any errors during analyzing can be avoided. After both models of spoilers and car model completed, models then will be analyzed in CFD to estimate value of drag force and lift force. From the value of both forces, the value of C_D and C_L can be estimate and the data then interpret into graph or scatter plot and also into bar chart. Analysis for base line model will done first before proceeds to next analysis. Each model is run analysis for five times, to ensure its accuracy of the results.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL AERODYNAMICS CONCEPT

2.1.1 Bernoulli's Equation

Daniel Bernoulli's equation defines the physical law upon which most aerodynamic concept exists. This equation is absolutely fundamentals to the study of airflows, and any attempt to improve the flow field around a vehicle is governed by the natural relationship between the fluid (air), speed and pressure. The Bernoulli's equation, which is can be obtained by integrating $F = ma$ (Munson, Young, Okiishi, 2006), is derived using the assumptions that (1) the air density does not change with pressure, (2) viscous effects are assumed negligible, (3) the flow is assumed to be steady, (4) the flow is assumed to be compressible and (4) the equation is applicable along a streamline (Munson, Young, Okiishi, 2006). Therefore, the formula can be applied along any point on a streamline where the relation between the local static pressure (p), density (ρ), and the velocity (v) is:

$p + \frac{1}{2} \rho v^2 + \gamma z =$ constant along streamline (Munson, 2006) [Eq. 1]

or $(p / \rho) + \frac{1}{2} v^2 =$ constant (Katz, 1995) [Eq. 2]

if it does not take into account any height term

From the equation, this indicates that an increase in pressure will cause a decrease in velocity and vice versa.

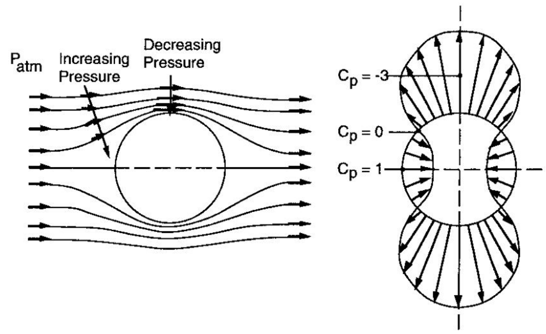


Figure 2.1: Pressure and velocity gradient in the air flow over body (Gillespie, 1992)

This moment of the air flow near the body creates a velocity distribution which in turn creates the aerodynamics loads acting on the vehicle. These loads, in general, can be divided into two (2) major contributions. The first is the shear (skin friction) force, resulting from the viscous boundary layer, which acts tangentially to the surface and contributes to drag. The second force is pressure, which acts normally (perpendicular) to the surface and contributes to both lift and drag meaning that "the vehicle downforce is really the added effect of the pressure distribution". (Katz, 1995)

2.1.2 Drag and Lift concept

There are two basics categories of aerodynamic forces acting on the vehicle. (1) Shear stress, which an act parallel to the body surface and contributes only to drag. (2) Pressure, which acts normally (perpendicular) to the surface and is responsible for a vehicle' lift and part of drag.

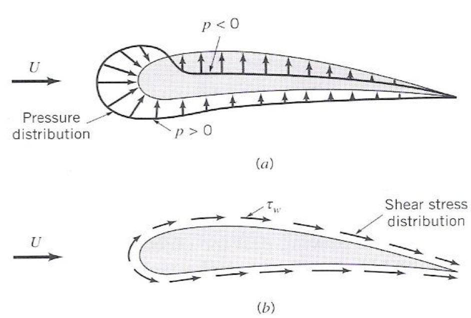


Figure 2.2: Forces from the surrounding fluid on a two-dimensional object

The resultant of the shear stress and pressure distribution can be obtained by integrating the effects of these two quantities on the body surface.

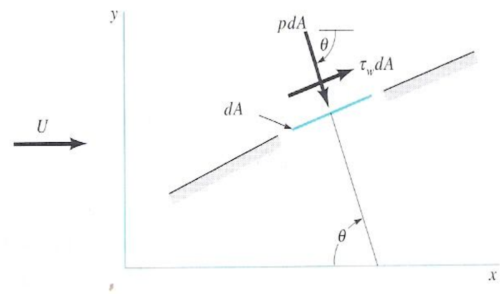


Figure 2.3: Pressure and shear forces on a small element of the surface body (Munson, 2006)

$$dF_x = (p\, dA) \cos\theta + (\tau_w\, dA) \sin\theta \qquad \text{[Eq. 3]}$$

$$dF_y = -(p\, dA) \sin\theta + (\tau_w\, dA) \cos\theta \qquad \text{[Eq. 4]}$$

Thus, the net x and y component of the force on the object are:

$$D = \int dF_x = \int p \cos\theta\, dA + \int \tau_w \sin\theta\, dA \qquad \text{[Eq. 5]}$$

$$L = \int dF_y = -\int p \sin\theta\, dA + \int \tau_w \cos\theta\, dA \text{ (Munson, 2006)} \qquad \text{[Eq. 6]}$$

The resultant force in the direction of the upstream velocity is termed the drag, D and the resultant force normal to the upstream velocity is termed of lift, L.

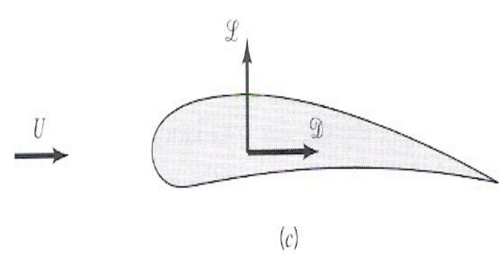


Figure 2.4: Resultant force (lift and drag) (Munson, 2006)

For some three dimensional (3-D) bodies there may also be side force that is perpendicular to the plane containing D and L. the resultant forces due to these contributions can be divided into 3 components: moment, drag and lift coefficients but here is only important in cases of strong cross winds. For this study, the cross winds is assumed negligible and only drag and lift are to be considered.

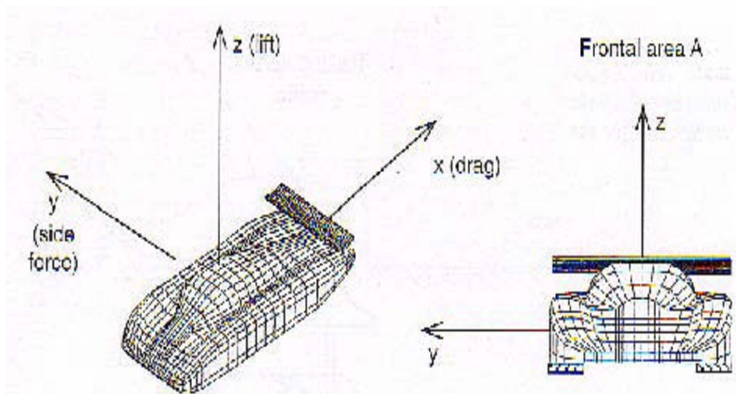


Figure 2.5: Illustrations of Lift, Drag and Moment Force Components (Katz, 1995)

2.2 AERODYNAMICS FORCES

2.2.1 Drag Force

Aerodynamics drag force is the force which opposes the forward motion of the vehicle when the vehicle is traveling. The aerodynamics drag force acts externally on the body of a vehicle. The aerodynamics drag affects the performance of a car in both speed and fuel economy as it is the power required to over come the opposing force. Because air flow over a vehicle is so complex, it is necessary to develop semi-empirical models to represent the effect. Therefore, aerodynamic drag force is characterized by:

$$D_A = \tfrac{1}{2}\, \rho\, v^2\, C_D\, A \qquad \text{[Eq. 8]}$$

Where C_D = coefficient drag [dimensionless]

A = frontal area [m^2]

ρ = density of air [kg/m^3]

v = velocity of vehicle [m/s]

Coefficient of drag, C_D, is defined as how the aerodynamic the shape is to the incoming air. C_D is determined empirically for the car (Gillespie, 1992). It is possible to have an aerodynamic drag coefficient greater than 1 if the air is pushed outward such that the effective area of the air movement is greater than the area of object facing the air.

C_D is a function of other dimensionless parameters such as Reynold number (Re), Mach number (Ma), Froude number (Fr) and relative roughness, ε / l. That is

$$C_D = \text{Ø}\,(shape, Re, Ma, Fr, \varepsilon/l) \quad \text{(Munson, 2006)}$$

The frontal area, A, is the scale factor taking into account the size of the car. Because the size of a vehicle has a direct influence on drag, the drag properties of a car are sometimes characterized by the value of 'C_DA' [1]. The frontal area is slightly less than the total width of the car multiplied by its height and its measured in square meters (m^2).

The air density, ρ, is related to humidity, altitude, pressure and temperature. At standard condition, the density of air is considered 1.23 kg / m^3. Density at other conditions can be estimated for the prevailing pressure, P_r and temperature, T_r, conditions by equation:

$$\rho = 1.225\ [(Pr / 101.325)\ (288.16 / (273.16 + T_r))] \quad \text{(Gillespie, 1992) [Eq. 9]}$$

Where P_r = atmospheric pressure in kPa

T_r = air temperature in °C

The final parameter is velocity of car, v. The speed of the vehicle is in meter per second (m/s). The term $½\, \rho\, v^2$ in the equation is the dynamic pressure of the air.

2.2.2 Lift force

The aerodynamic drag force is acted horizontally to the vehicle and there is another component, directed vertically, called aerodynamic lift. It reduces the frictional forces between the tires and the road, thus changing dramatically the handling characteristics of the vehicle. This will affect the handling and stability of the vehicle.

The pressure differential from the top to the bottom of vehicle causes a lift force. These forces are significant concerns in aerodynamic optimization of a vehicle because of their influence on driving stability. The force, L_A is quantified by the equation

$$L_A = \tfrac{1}{2} \rho v^2 C_L A \qquad \text{[Eq. 10]}$$

where L_A = lift force

C_L = coefficient of lift

A = frontal area

The lift force dependent on the overall shape of the vehicle. At zero wind angle, lift coefficient normally fall in the range of 0.3 to 0.5 for modern passengers car (Huco, 1998), but under crosswinds conditions the coefficient may increase dramatically reaching value of 1 or more. (Hogue, 1980)

2.2.3 Pressure distribution

Most of the lift comes from the surface pressure distribution. A typical pressure distribution on a moving car is shown in figure.

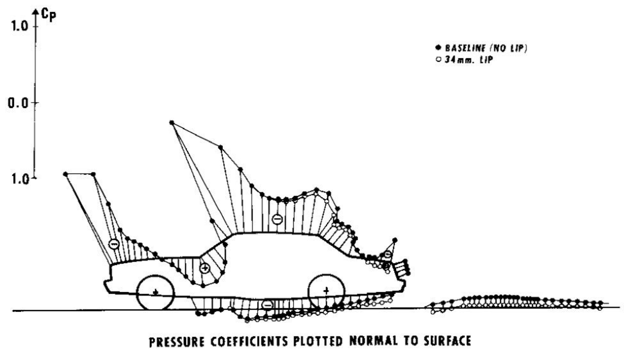


Figure 2.6: Pressure distribution along the center line of a car (Gillespie, 1992)

The distribution for the most part with simple Bernoulli equation analysis. Location with high speed flow (i.e. over the roof and hood) has low pressure while location with low speed flow (i.e. on the grill and windshield) has high pressure. It is easy to believe that the integrated effect of this pressure distribution would provide a net upward force (Munson, Young, Okiishi, 2006). This force is negative force, meaning that the force that no need to enhance the stability of a vehicle. The opposite force of upward force is downforce.

2.2.4 Downforce

Downforce is created when air moves through and over parts of the car. For example, a car wings are set at angles which force the air up and through them. For every force there is an opposite force. Therefore as the air is the air is forced upwards, it also creates a force pushing downwards. This is achieved without making the car heavier that it already is.

Downforce pushes the car into the road harder increasing the friction between the tires and the road allowing the car take corners at high speed and the driver to have more control during corner.

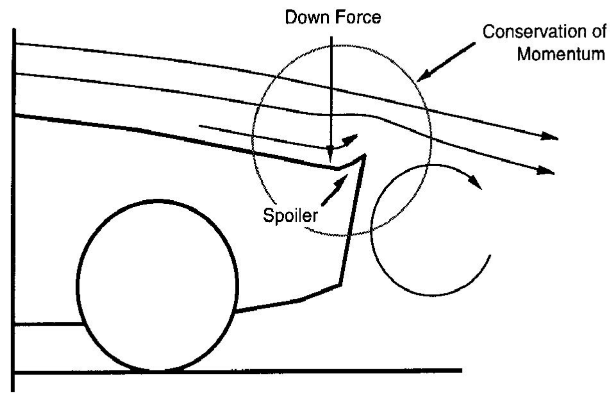


Figure 2.7: Influence of a spoiler on flow over the rear (Gillespie, 1992)

2.2.5 Drag and Lift coefficient

Drag and lift coefficient are dimensionless forms of lift and drag (Munson, Young, Okiishi, 2006). The reason for defining the drag and lift as non-dimensional coefficient is that the value of the coefficient is “independent of speed and will be related to the vehicle’s shape only”. (Katz, 1995)

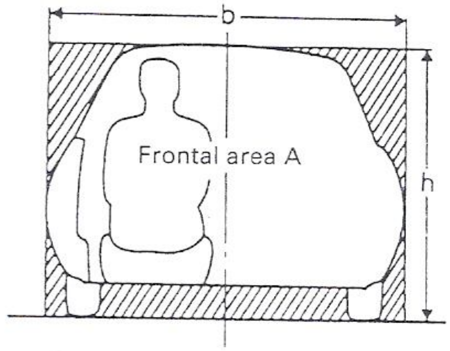
The lift coefficient, C_L and drag coefficient, C_D are defined as

$$C_L = L_A / (1/2\ \rho\ v^2 A) \qquad \text{[Eq. 11]}$$

and $$C_D = D_A / (½\ \rho\ v^2 A) \quad [2] \qquad \text{[Eq. 12]}$$

where D_A is the drag force and L_A is the lift force.

A is a characteristic area of the object. Typically, *A* is taken to be frontal are – “the projected area seen by a person looking toward the object from a direction parallel to upstream velocity, *v* (Munson, Young, Okiishi, 2006).



$A \approx 0.81 \cdot (b \cdot h)$

Car Class	Frontal area A m^2
mini	1.8
medium size	1.9
upper medium size	2.0
full size	2.1

Table/Figure 2.8: Frontal Area of cars (Hucho, 1998)

2.3 AERODYNAMIC DEVICE - REAR SPOILER

A spoiler is an aerodynamic device attached to an automobile rear boot whose intended design function is to ‘spoil’ unfavorable air movement across a body of a vehicle of some kind in motion. Spoilers are widely used on sedan type cars such as NASCAR stock cars. These aerodynamic aids produce down force by creating a "dam" at the rear lip of the trunk. This can result in improved vehicle stability by decreasing lift or decreasing drag that may cause unpredictable handling in a car at high speed. Spoilers are often fitted to race and high performance sports car, although they have become common on passenger vehicles as well.

Rear spoiler located on the rear deck may serve several purposes. By deflecting the air upward, the pressure on the rear deck is increase, hence creating a down force at the most advantageous point on the vehicle to reduce lift. If this modified pressure distribution is integrated in the x and y direction, the result is lower drag and lift.

A rear spoiler can have three effects. It can reduce drag, reduce rear-axle lift and reduce dirt on the rear surface. With rear spoiler also, attention first focused on drag, but increasing emphasis is now placed on negative lift.

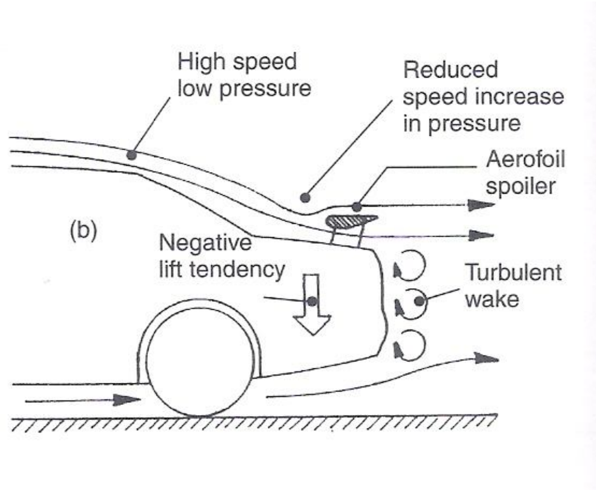


Figure 2.9: Effect of rear spoiler on lift (Heisler, 2002)

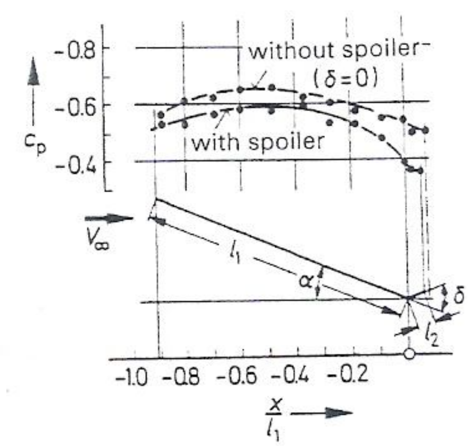


Figure 2.10: Two-dimensional flap as simulation model for a rear spoiler (Ohtani, 1972)

From the figure above, it explain about the function of a rear spoiler in terms of a flat plate under an angle of attack. By deflecting the flap, the pressure on the flat plate is increased. If this modified pressure distribution is integrated in the x and y direction, the result is lower drag and lift. Figure next shows the isobars measured for a fastback.

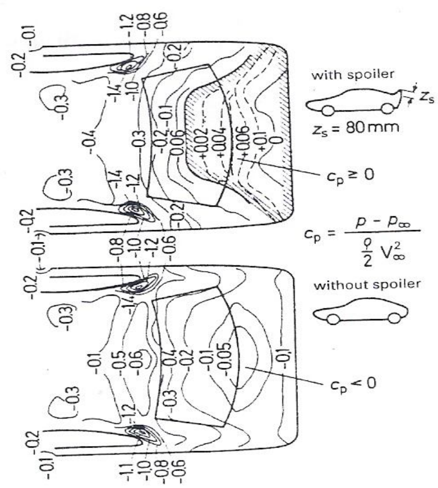


Figure 2.11: Isobars on a fastback, with and without spoiler (Ohtani, 1972)

The spoiler causes a clear rise in pressure on the rear slope in front of it. If the pressure is plotted versus the vehicle's z/h for the center cross section, the reduction in drag is obvious

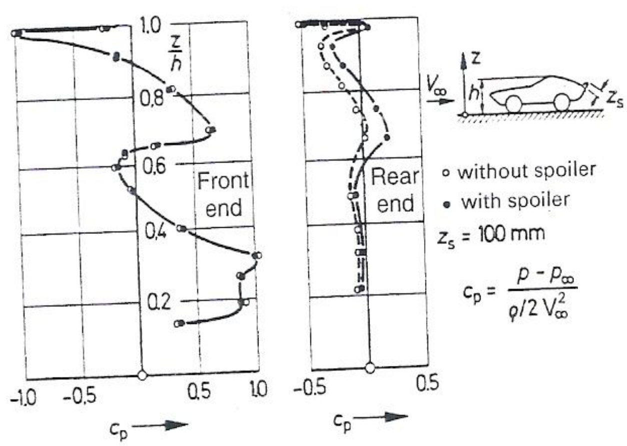


Figure 2.12: Pressure spoiler increase at the rear of a vehicle due to a rear spoiler (Ohtani, 1972)

The way in which drag and lift happened is depend on the height z_s of the spoiler. The influence on the pressure distribution is shown below. The possibility of reducing drag is comparatively low. In fact on sporty cars, and even more so on racing cars, even an increase in drag is accepted in order to ensure that the rear-axle lift gets low.

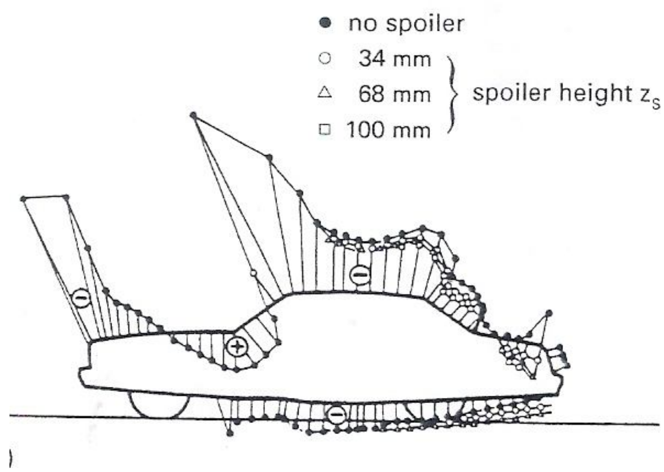


Figure 2.13: Influence of the height of a rear spoiler on pressure distribution (Schenkel, 1977)

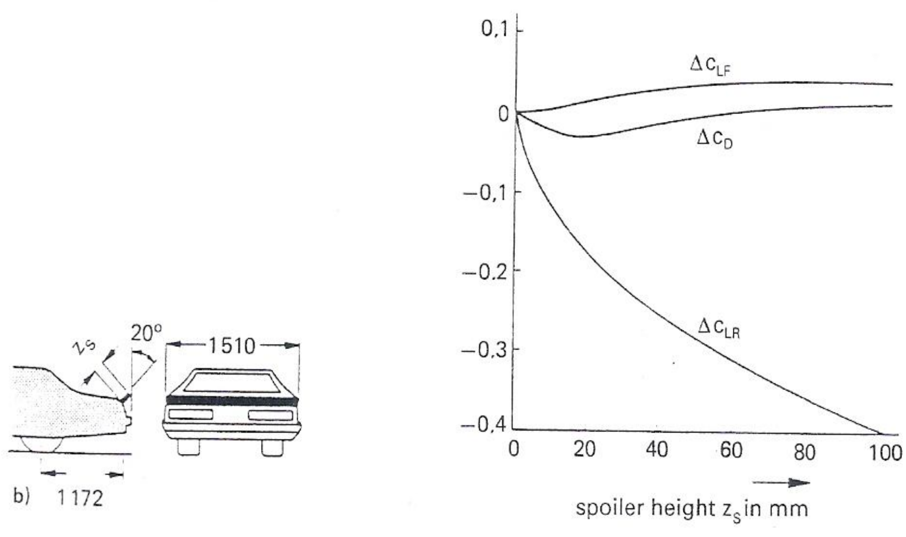


Figure 2.14: Influence of the height of a rear spoiler on lift and drag for a notchback (Schenkel, 1977)

The extended rear spoiler can increase the pressure on hatch; as a result, rear-axle lift is reduced about a third. Figure below is shows how a rear spoiler influences in reducing lift force at rear.

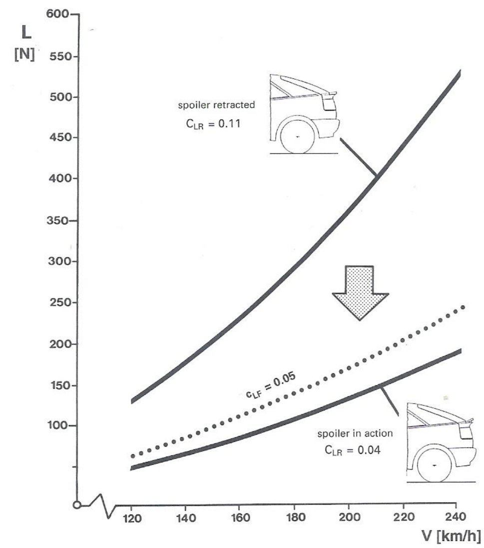


Figure 2.15: Reduction in rear-axle lift on the Volkswagen Corrado by means of a retractable rear spoiler (Schuster and Horn, 1989)

Figure 2.16 also is intended to demonstrate how a given pair of values can be achieved with quite different shapes, thereby allowing considerable freedom to design.

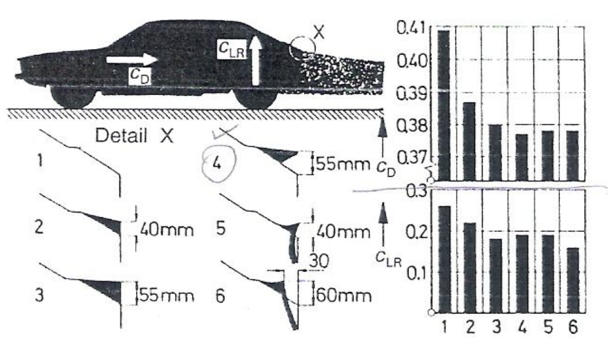


Figure 2.16: Design alternatives for a rear spoiler (Jansen, 1975)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Since this project titled “Aerodynamics of Aftermarket Rear Spoiler”, a detail related literature review was done and important information was explained in details in previous chapter. Then, methods proceeding to next step will be done. This part is important to make sure that all the progresses are done step by step. Besides, it is also to ensure the project is finish by the schedule (project timeline) and the objective of the project is achieved. A survey on design of the aftermarket rear spoiler was done by surveying several spoiler designs in market that currently most used. Because there several type of rear spoiler in market, so this step to ensure that the rear spoiler that will be used is most used by car’s owner. The designs then build up in CAD software and analyze in CFD software. The result of analysis will be either use or refine if needed. The result of analysis will be analyze and discuss for the next step and summary will be done to conclude the project.

3.2 SURVEYING AND OBSERVING THE DESIGN

Several design of aftermarket spoiler was surveyed and observed in market. The survey was done by searching in market and also looks out in the internet. Besides, by searching in car magazines and also by observed on-road car with rear spoiler can be done. There are many type of spoiler out there and the design must be capable and suitable with car model. This is because to minimize any errors during analyzing. May be some designs are not suit with the model. The test car model is sedan type. So, rear spoiler to attach at the rear boot must suit and fix with that kind of car design. Spoiler like deck lid or free-standing airfoil must be used, which is suitable with sedan type car. Sedan cars rear boot is known as notchback. Therefore, the spoilers that are use for squareback car and hatchback car can be ignored.

Figure 3.1: Deck lid spoiler

Figure 3.2: Several type of rear wing

3.3 MODELLING IN CAD SOFTWARE

CAE tools will be use for modeling and analyzing the models. First, the models will build up in CAD (Computer-Aided Design) software. Mostly people use CAD software to design and build up the model. For this project, SolidWorks will be use to build up the model and the model will be design according the actual dimension to make sure it can produce an approximately accurate. The design of the spoiler not just accurate in dimension, but it also must fix with the base line model that will be use. This precaution step can avoid any errors during analysis and also to make the model of spoiler is easily mate with the base line model. The base line model that will be use in this project also must build up according the actual design. The base line model used is Proton Saga 2008 and rear spoiler models that used is airfoils spoiler, touring wing, GTR wing, deck-lid spoiler, and V-man wing.

3.3.1 Base Line Model

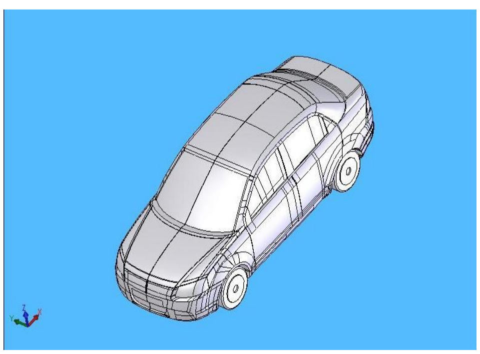


Figure 3.3: Isometric view of BLM

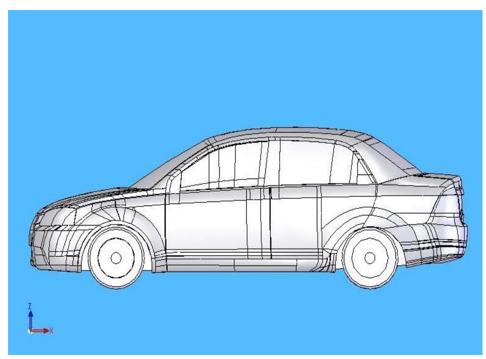


Figure 3.4: Side view of BLM

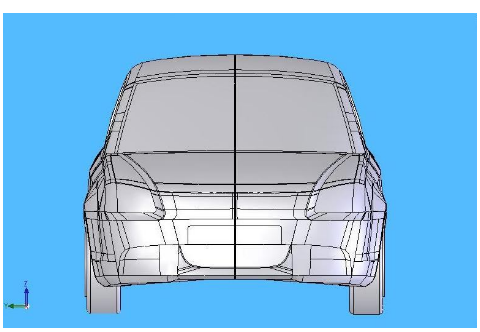


Figure 3.5: Frontal view of BLM

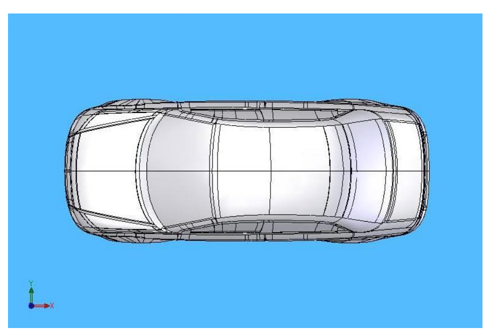


Figure 3.6: Top view of BLM

3.3.2 Rear Spoiler Model

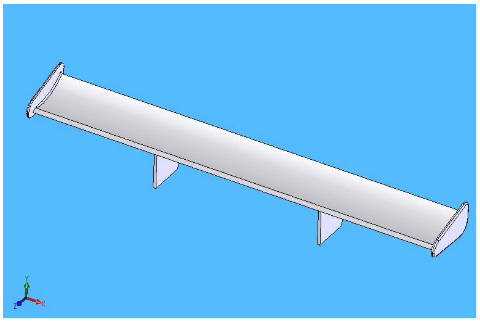


Figure 3.7: Airfoils spoiler (Spoiler 1)

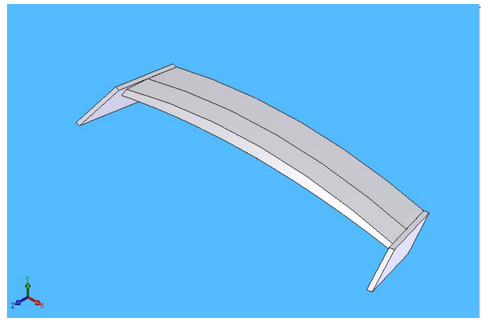


Figure 3.8: Touring wing (Spoiler 2)

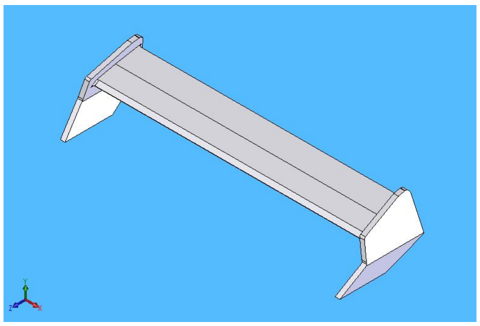


Figure 3.9: GTR wing (Spoiler 3)

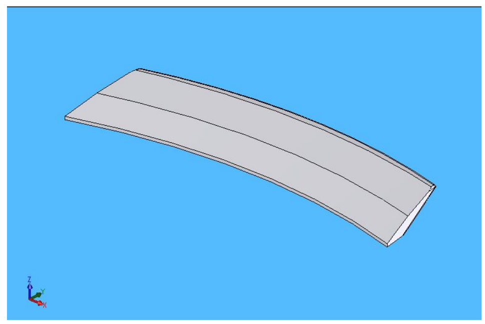


Figure 3.10: Deck lid spoiler (Spoiler 4)

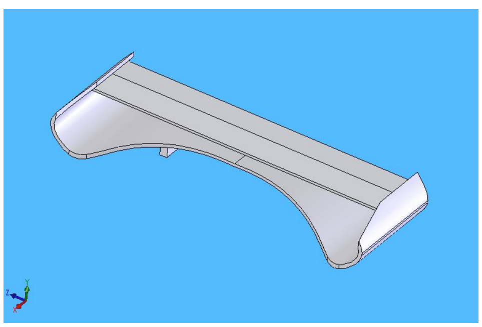


Figure 3.11: V-man wing (Spoiler 5)

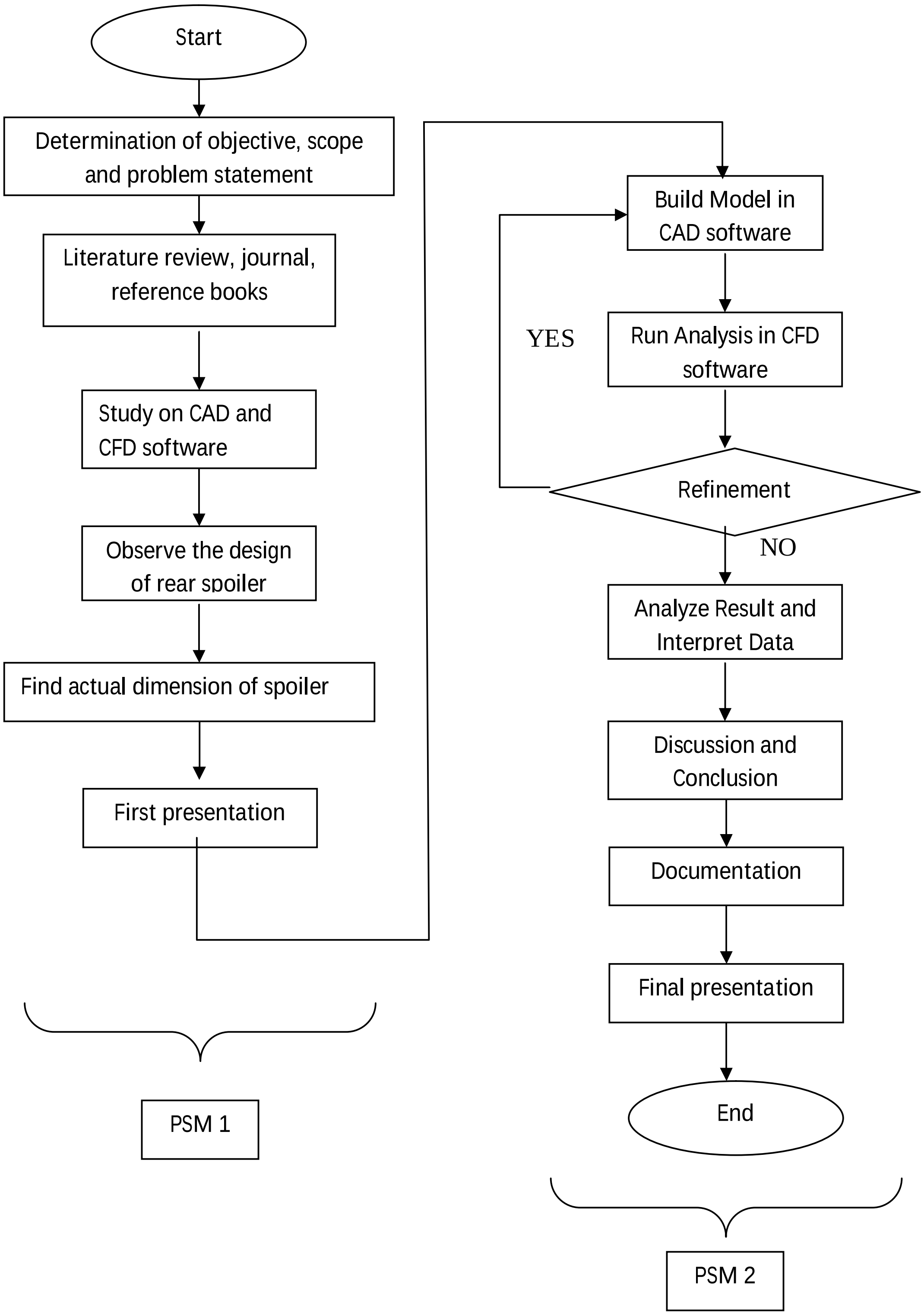
3.4 ANALYZING IN CFD SOFTWARE

During this project, COSMOSFloWorks will be use to analyze the car model with its attachment, which is the spoiler. COSMOSFloWorks is the only fluid flow analysis tool for designers fully embedded inside SolidWorks. With this software, it can analyze the solid model directly. The model that has been built up in SolidWorks then will be export into COSMOSFloWorks to analyze the model. Through this software, it can analyze parts, assemblies, subassemblies, and multibodies. Detail steps for use this software is include in its tutorial. The design will analyze, the data will interpret, the result will produce and analysis will summarize and present in form of table, graph, chart or etc.

During the analysis, some errors may be come. Some precaution steps must be notice before analyzing the model, such as the model is must properly build in SolidWorks. Besides, the result that will be got also is not follow as need. Let say that the result get from analysis is differ from the aspect result, known that the value of C_D is between 0.3 – 0.5 for passenger car, but result shown the C_D from analysis is larger than range. So, refinement is needed by modify the model and analyze again in COSMOSFloWorks.

Besides that, some limitations must be considered during analyzing the model to make sure that the results are acceptable. Ground line must be 160mm. Ground line is a distance between road surface and bottom part of the car. This distance is important to keep in constant so that the C_D and C_L are acceptable for standard sedan car. Another part that is important is the location of installment of rear spoiler. The location of base of rear spoiler must be same for all type of rear spoiler, so that the pressure acting at the back is in same region. So the location must be located at same point and the origin point (0,0) is acting as reference point.

3.5 OVERALL METHODOLOGY



CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related to car aerodynamic drag & lift and its attachment for aerodynamics aids which is rear spoiler. A review of other relevant research studies is also provided. Substantial literature has been studied on aerodynamic drag, aerodynamic lift and influences from both and purpose of rear spoiler as one of the aerodynamic aids. The review is organized chronologically to offer insight to how past research efforts have laid the groundwork for subsequent studies, including the present research effort. The review is detailed so that the present research effort can be properly tailored to add to the present body of literature as well as to justly the scope and direction of the present research effort.

4.2 DATA PRESENTATION

4.2.1 Table of Result

Table 4.1: BLM car without Rear Spoiler

Velocity (km/h)	**Drag Force (N)**	**Lift Force (N)**	C_D	C_L
70	153.86	51.109	0.329	0.1183
90	255.0	85.771	0.330	0.117
110	383.397	129.588	0.331	0.1153
130	536.83	182.00	0.333	0.108
150	718.946	248.474	0.334	0.096

Table 4.2: BLM car with Rear Spoiler 1 (Airfoils Spoiler)

Velocity (km/h)	**Drag Force (N)**	**Lift Force (N)**	C_D	C_L
70	147.431	49.646	0.3326	0.112
90	244.117	80.6639	0.333	0.110
110	369.157	125.973	0.334	0.115
130	512.359	172.825	0.335	0.113
150	684.323	224.034	0.336	0.110

Table 4.3: BLM car with Rear Spoiler 2 (Touring Wing)

Velocity (km/h)	**Drag Force (N)**	**Lift Force (N)**	C_D	C_L
70	144.062	49.867	0.325	0.1125
90	241.185	82.839	0.329	0.1130
110	364.775	127.397	0.333	0.1163
130	503.183	168.237	0.329	0.1100
150	670.066	216.906	0.329	0.1065

Table 4.4: BLM car with Rear Spoiler 3 (GTR Wing)

Velocity (km/h)	**Drag Force (N)**	**Lift Force (N)**	C_D	C_L
70	144.5	50.089	0.326	0.113
90	239.719	83.571	0.327	0.114
110	359.298	127.069	0.328	0.116
130	501.653	189.649	0.328	0.124
150	670.066	248.474	0.329	0.122

Table 4.5: BLM car with Rear Spoiler 4 (Deck lid Spoiler)

Velocity (km/h)	**Drag Force (N)**	**Lift Force (N)**	C_D	C_L
70	145.966	27.3237	0.329	0.06
90	245.374	38.936	0.335	0.053
110	370.477	54.845	0.338	0.05
130	515.898	74.5878	0.337	0.048
150	681.176	131.847	0.334	0.045

Table 4.6: BLM car with Rear Spoiler 5 (Universal Shogun Spoiler)

Velocity (km/h)	**Drag Force (N)**	**Lift Force (N)**	C_D	C_L
70	149.381	66.993	0.337	0.1511
90	247.783	107.372	0.338	0.1465
110	368.061	143.749	0.336	0.1412
130	518.477	213.591	0.339	0.1396
150	692.47	275.657	0.340	0.1353

Table 4.1 to table 4.6 shows the variation of drag force and lift force against vehicle's speed. These tables are concluded after the simulation is done. It noticed that the variation of drag force and lift force are same for each models. It varies linearly with the vehicle's speed. When the vehicle's speed is increase, the drag force and lift force are also increase. It meaning that, the earlier assumptions that drag and lift force is increase when vehicle's speed increase is correct. Besides is had obeyed the formula [Eq. 8] and [Eq. 10]. From the formula, noticed that the increment of velocity will increase the drag/lift force. Let say that air density, frontal area and drag/lift coefficient are constant, and the velocity is changes, the drag/lift force also will change.

4.3 DATA ANALYSIS

4.3.1 Drag and Lift Coefficient Estimation

After analysis the models, drag force and lift force, which are had been set up before running the analysis, can be determined at the last step of simulation. From drag force and lift force, coefficient of drag (C_D) and coefficient of lift (C_L) can be determined by using a formula. Formula [Eq. 11] and [Eq. 12] has been derived earlier in Chapter 2. From the value of both coefficients, a graph represents C_D and C_L against velocity can be plotted.

4.3.2 Variation of Drag Coefficient Against Velocity

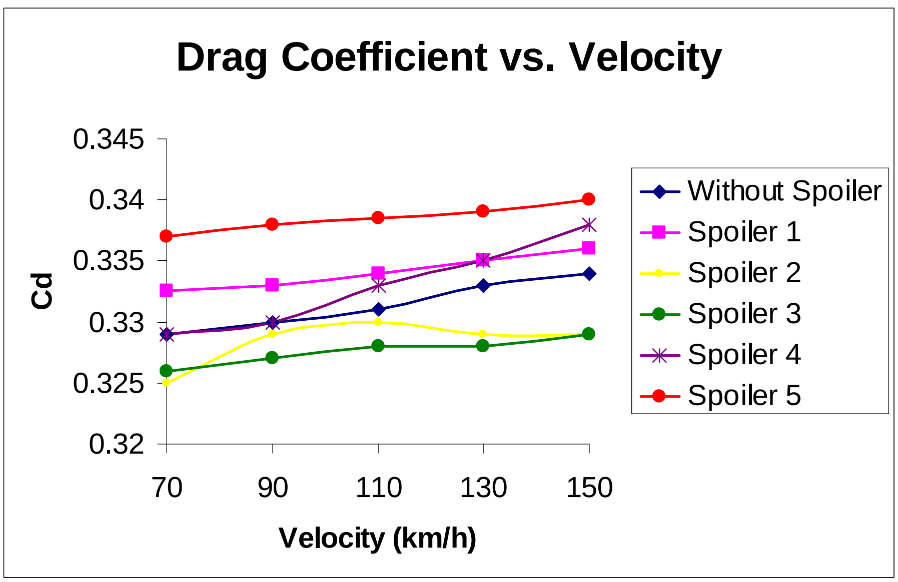


Figure 4.1: Variation of Drag Coefficient against Vehicle's Speed

Graph above shows the variation of C_D against increment of velocity for a base-line model (BLM) with and without a rear spoiler. Except the rear spoiler 2, all of BLM with and without a rear spoiler are increasing in drag. Even the value C_D of each type of rear spoiler is different but the variation of C_D is increase when velocity of car increases. This is because the increment of C_D is related with drag force that acting on the car. When velocity of car is increase, the drag force is increase. From the graph, the increment of C_D is constantly increases with velocity. Which is it increasing about 0.3% when car changing its speed each 20 km/h. Except for BLM with rear spoiler type 4. For first range of velocity, which is from 70-90 km/h, the change of C_D is same like others, which is about 0.3%. But after speed 90 km/h, the C_D is increase about 0.9% when car's moving in 110km/h. As well as 130 and 150 km/h, the changes of C_D are same, which is about 0.9%.

For BLM with rear spoiler type 2, at speed of 70 km/h, the C_D is 0.325. Then it increase about 1.2% in speed of 90 km/h and increase about 0.3% when speed increase to 110 km/h. But the C_D is drop back about 0.3% when reached 130 km/h and C_D is constant until 150 km/h. It means that, this type of spoiler is really good when car moves in very high speed.

4.3.3 Variation of Lift Coefficient against Velocity

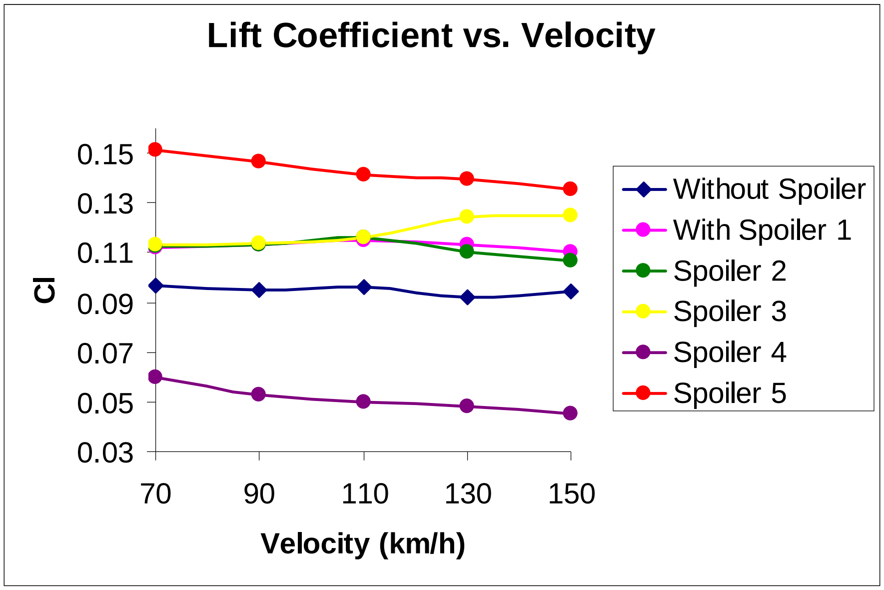


Figure 4.2: Variation of Lift Coefficient against Vehicle's Speed

Graph above shows the variation of lift coefficient against velocity of the car. All graphs, except BLM with spoiler 3, are decreased when the velocity is increased. It means that C_L is decreasing when increasing of velocity. The decreasing of C_L shows that the car is fewer tendencies to lift over when cruise in high speed, but the decreasing is only in small amount for each velocity. So that evens the C_L is decrease, car is has tendency to lift over when in high speed. Except for BLM with rear spoiler 3, C_L is increased when the speed of car is increase. It means that the tendency of that car to lift over is higher. From the graph, shows that only BLM with rear spoiler type 4 is reduced lift force. This is because the value of average C_L is lesser than average C_L of BLM without any rear spoiler. It means that rear spoiler type 4 is good in reducing lift force compared with others one.

4.3.4 Comparison of Average C_D and C_L for Each Model

Table 4.7: Average of C_D and C_L of BLM With and Without Rear Spoiler

	Without spoiler		**Spoiler 1**		**Spoiler 2**	
Velocity (km/h)	C_D	C_L	C_D	C_L	C_D	C_L
70	0.329	0.1183	0.332	0.112	0.325	0.1125
90	0.330	0.1170	0.333	0.110	0.329	0.1130
110	0.331	0.1153	0.334	0.115	0.333	0.1163
130	0.333	0.1080	0.335	0.113	0.329	0.1100
150	0.334	0.0960	0.336	0.110	0.329	0.1065
Average	**0.3314**	**0.1183**	**0.3341**	**0.112**	**0.329**	**0.1117**

	Spoiler 3		**Spoiler 4**		**Spoiler 5**	
Velocity (km/h)	C_D	C_L	C_D	C_L	C_D	C_L
70	0.326	0.113	0.329	0.06	0.337	0.1511
90	0.327	0.114	0.335	0.053	0.338	0.1465
110	0.328	0.116	0.338	0.05	0.336	0.1412
130	0.328	0.124	0.337	0.048	0.339	0.1396
150	0.329	0.122	0.334	0.045	0.340	0.1353
Average	**0.3276**	**0.1178**	**0.3346**	**0.0512**	**0.338**	**0.1427**

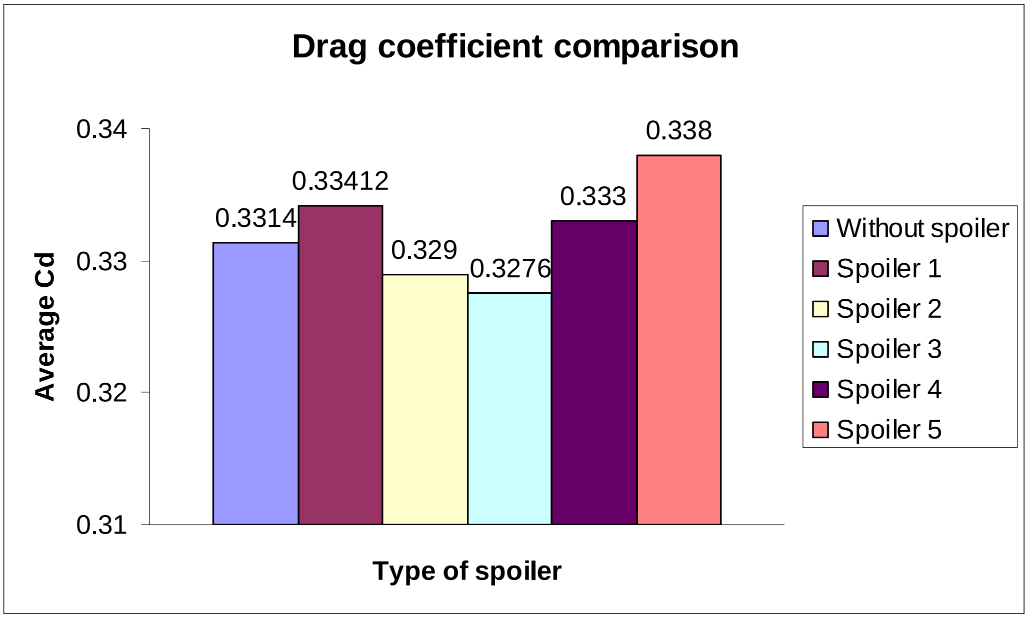


Figure 4.3: Comparison between BLM with and Without Rear Spoiler in Terms of C_D

Bar chart above shows comparison of average C_D among BLM with and without rear spoiler. Comparison had done by compare the C_D of BLM and C_D of BLM with each type of spoiler. C_D of BLM is 0.3314 and higher C_D of BLM with rear spoiler are came from spoiler type 1 which is 0.3341, type 4 (0.333) and type 5 (0.338). Higher C_D means that these types of spoiler are increasing drag. Lower C_D came from spoiler type 2 and 3. C_D for BLM with rear spoiler type 2 is 0.329 (reduce 0.72%) and C_D for BLM with rear spoiler type 3 is 0.3276 (reduce 1.15%). It means that only rear spoiler type 2 and type 3 are reducing drag.

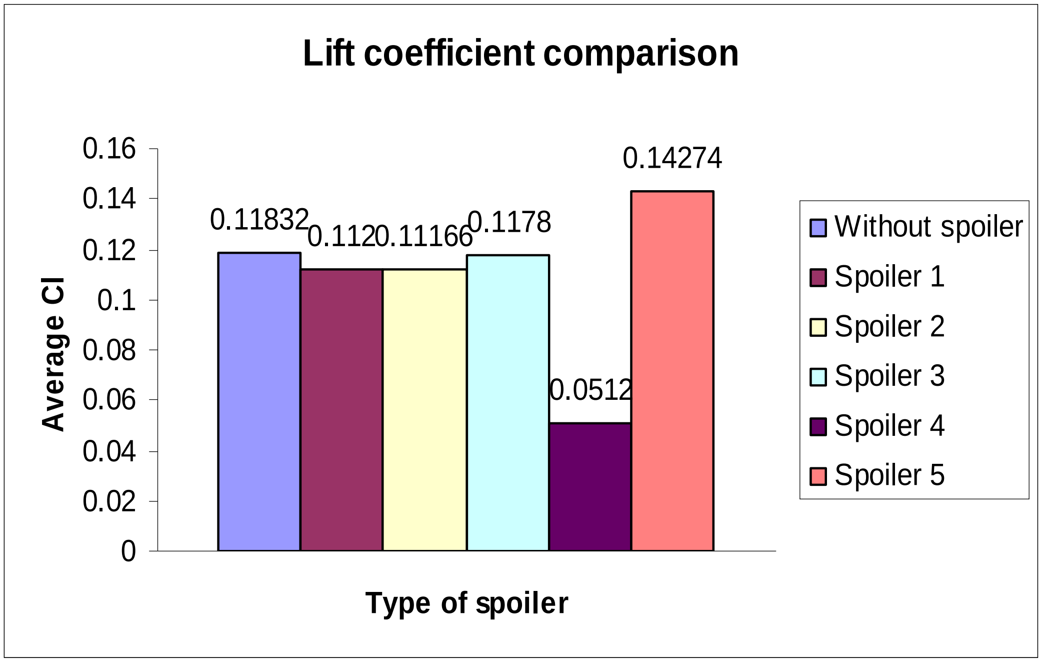


Figure 4.4: Comparison between BLM with and Without Rear Spoiler in Terms of C_L

Bar chart shows the comparison of average C_L between BLM with and without rear spoiler. Comparison had done by comparing the C_D of BLM and C_D of BLM with each type of rear spoiler. This comparison is done to estimate which one of type of rear spoiler is reducing lift or not. The C_L of BLM is 0.11832. Lower value from this value means that reducing lift and higher means it increasing lift. It shows that only one type of rear spoiler is increasing lift which type 5. Its C_D is 0.14274; increase about 17% from C_L of BLM (0.11832). For rear spoiler 1, 2, 3, lift reduced only in small amount which is for rear spoiler type 1 reduced about 5.3% to 0.112, rear spoiler type 2 reduced 5.6% to 0.11166 and for rear spoiler type 3 is reducing about 0.44% to 0.1178. These types of rear spoiler are only reducing small amount of lift force but for rear spoiler type 4, it is reduced in great amount which is about 56% to 0.0512.

4.3.5 Summary

From the data presentation and data analysis above, it can be summarized that not all types of rear spoiler are reduce drag and reduce lift force. Some of them are reduce drag and some of them are reduce lift force. Besides, some is reducing both and some is not reducing either drag or lift.

In term of reducing drag, rear spoiler type 3 is very suitable. This happened because the rear spoiler type is design to stabilize the vortices in the separation flow, thus reducing aerodynamic drag. In general, they tend to increase drag.

In term of reducing lift force or creating downforce, rear spoiler type 4 is very good in creating downforce. By deflecting the air upward, the pressure is increased on the rear deck aerating a downforce at the most advantageous point on the vehicle to reduce rear-axle lift.

For both reductions, only rear spoiler type 2 that reducing drags and lift but only in small amount. For rear spoiler type 5, it is not reducing either one and it can say that this type of rear spoiler is not suitable.

4.4 DISCUSSION ON PRESSURE AND VELOCITY DISTRIBUTION

This part will be discussed about the pressure and velocity distribution along the vehicle. These both distributions are important to show and prove the purpose of rear spoiler actually. Since it has been summarized that rear spoiler type 4 is good in creating downforce and rear spoiler 3 is good in reducing drag, so this further discussion is based on these two types of rear spoiler only. Besides, these two rear spoilers show the high impact to car aerodynamic properties.

4.4.1 Pressure Distribution along BLM without Rear Spoiler

The real effects of rear spoiler are discussed in this part. This study of effects was discussed on rear spoiler type 3 and rear spoiler type 4. These rear spoilers were use in further discussion because these type of spoiler were give a huge effect in reducing drag and reducing lift. Noticed in the early part, rear spoiler type 3 is good in reducing drag and rear spoiler type 4 is good in reducing lift. This study of effects done by interprets the pressure distribution and velocity distribution of BLM with and without the rear spoiler.

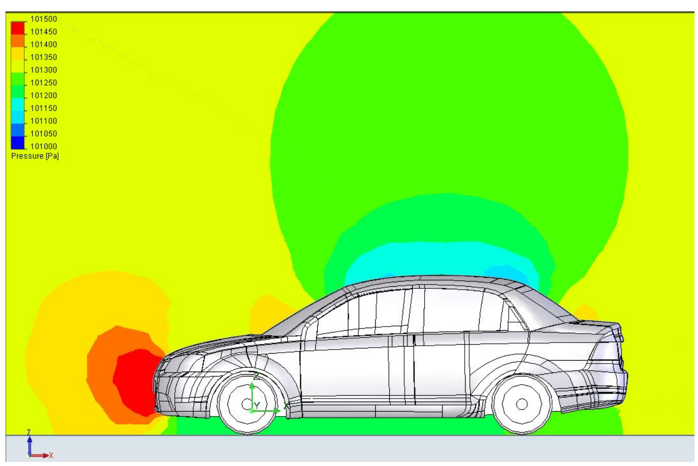


Figure 4.5: Pressure Distribution along BLM without Rear Spoiler

Velocity and pressure characteristic on a car region are related inversely to each other. If velocity is high so the pressure is low and vice versa. Figure 4.5 shows the basic mechanisms account for the static pressure distribution and velocity distribution along the body of a car. The pressures are indicated as being negative or positive with respect to the ambient pressure measured some distance from the vehicle.

High positive pressure was developed in front of the car, which is at front bumper. This happened because at this region a high velocity drop rapidly to approximately zero and this call stagnation point. At this region, a high positive pressure will be developed because of the drop of velocity. The decreasing of velocity results increasing pressure. Note that a negative pressure is developed at the front edge of the hood as the flow rising over the front of the vehicle attempts to turn and follow horizontally along the hood. The adverse pressure gradient in this region has the potential to stall the boundary layer flow creating drag in this area.

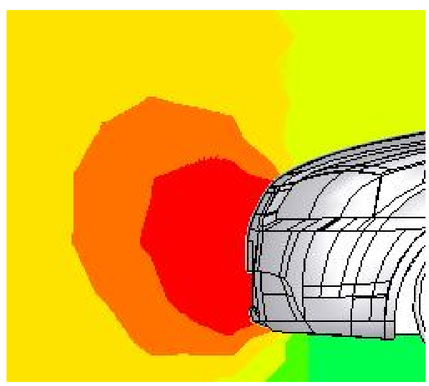


Figure 4.6: Pressure Distribution at Front Bumper

Near the base of the windshield and cowl, the flow must be turned upward, thus high pressure is experienced. The high-pressure region is an ideal location for inducting air for climate control systems, or engine intake, and has been used for this purpose in countless vehicles in the past. The high pressures are accompanied by lower velocity in this region, which is an aid to keep the windshield wipers from being disturbed by aerodynamic forces.

Figure 4.7: Pressure Distribution at Windshield and Cowl

Over the roof line the pressure again goes negative as the air flow tries to follow the roof contour. Evidence of the low pressure in this region is shows in figure 4.2 that high negative pressure acting along the roof.

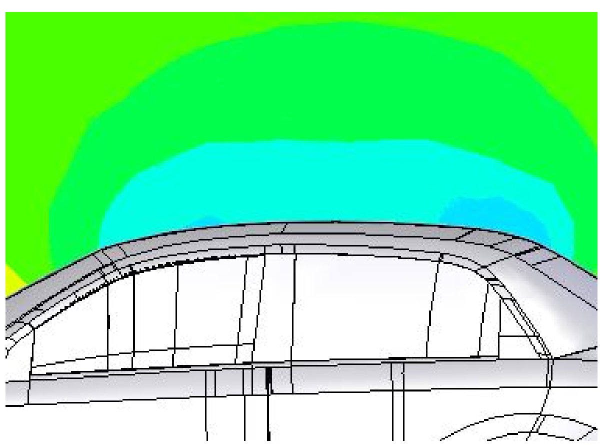


Figure 4.8: Pressure Distribution along Roof Line

After that, the pressure increased but still in low pressure down over the backlite and on to the trunk because of the continuing curvature.

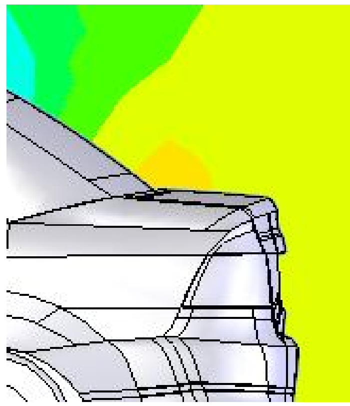


Figure 4.9: Pressure Distribution at Rear Trunk

Since at rear of the vehicle the pressure is low, it means that the lift force is high. So a tendency of a car to lift over is high. To avoid this happen, more downforce must be created at that region. To do that, a rear spoiler must be attached to increase the pressure at back results reduced rear-axle lift force. Figure 4.2 proves that rear spoiler can increase pressure and reduced rear-axle lift. The pressure along the boot with rear spoiler is high than without one. This happen because a high velocity flow along the trunk and when it encroaches upon rear spoiler, the velocity is drop results increasing pressure. The increasing of pressure results more downforce created. High downforce can increase the traction with road and increase the stability of the car.

4.4.2 Pressure Distribution Along BLM with Rear Spoiler

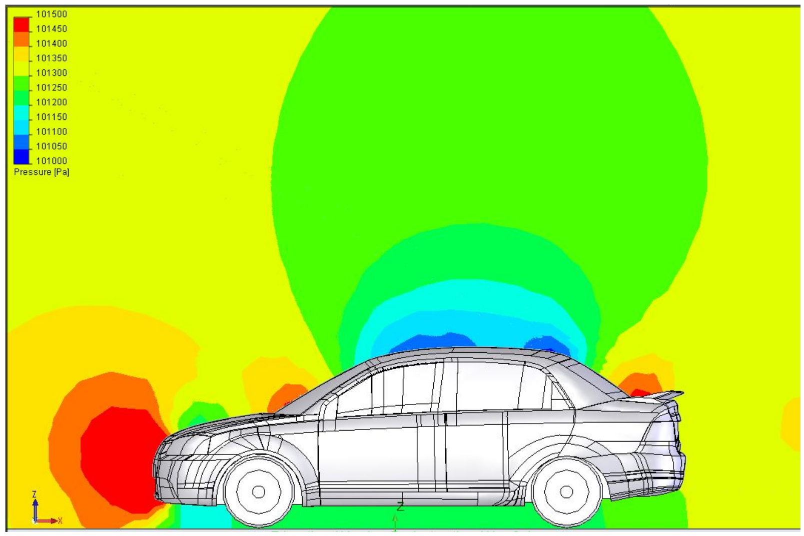


Figure 4.10: Pressure Distribution along BLM with Rear Spoiler Type 4

Figure 4.10 above shows the pressure distribution along BLM with rear spoiler type 4. Noticed that the distribution is difference than BLM without rear spoiler and the major difference is occurred at some point especially at the rear trunk. At the rear trunk, pressure is higher compare with BLM without rear spoiler. At the back region, the pressure here is very high because air flow collide rear spoiler results dropped the velocity. The drop of velocity of flow results increasing pressure at back portion. The increasing of pressure will create more down force and reducing rear lift-axle force.

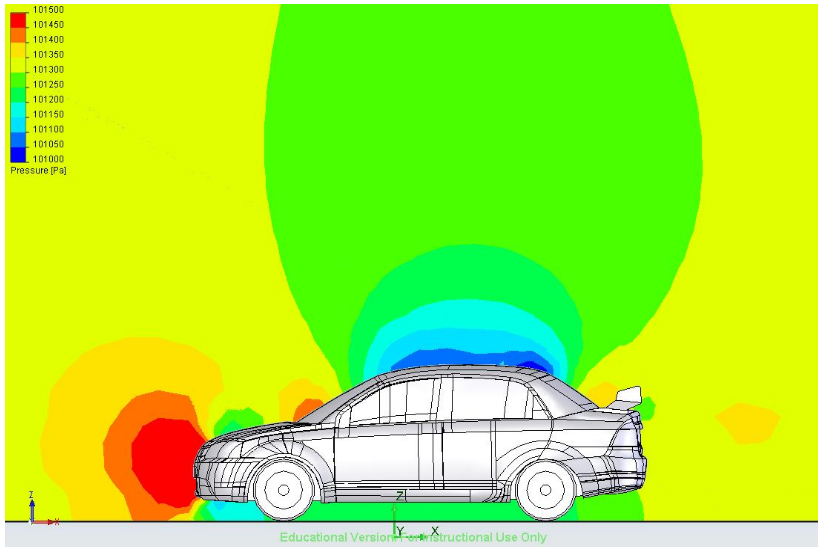


Figure 4.11: Pressure distribution along BLM with rear spoiler type 3

Figure 4.11 above shows the pressure distribution along BLM with rear spoiler type 3. Noticed that the distribution along the car, starting from front hood until roof line is same like pressure distribution of BLM with rear spoiler type 3. But the difference is occurred at rear trunk of the car. The pressure acting at back for BLM with rear spoiler type 3 is less high pressure than pressure for BLM with rear spoiler type 4. Rear spoiler type 4 is not primarily to increase downforce. This spoiler is designed to reduce drag that acting on the car. But even though it not reduce lift force in huge amount, refer to figure 4.4, it reduce about 0.4%. Even it does not reduce lift force in huge value, but its function as reduce rear-axle lift is accepted.

4.4.3 Comparison of Pressure Distribution at the Rear Portion

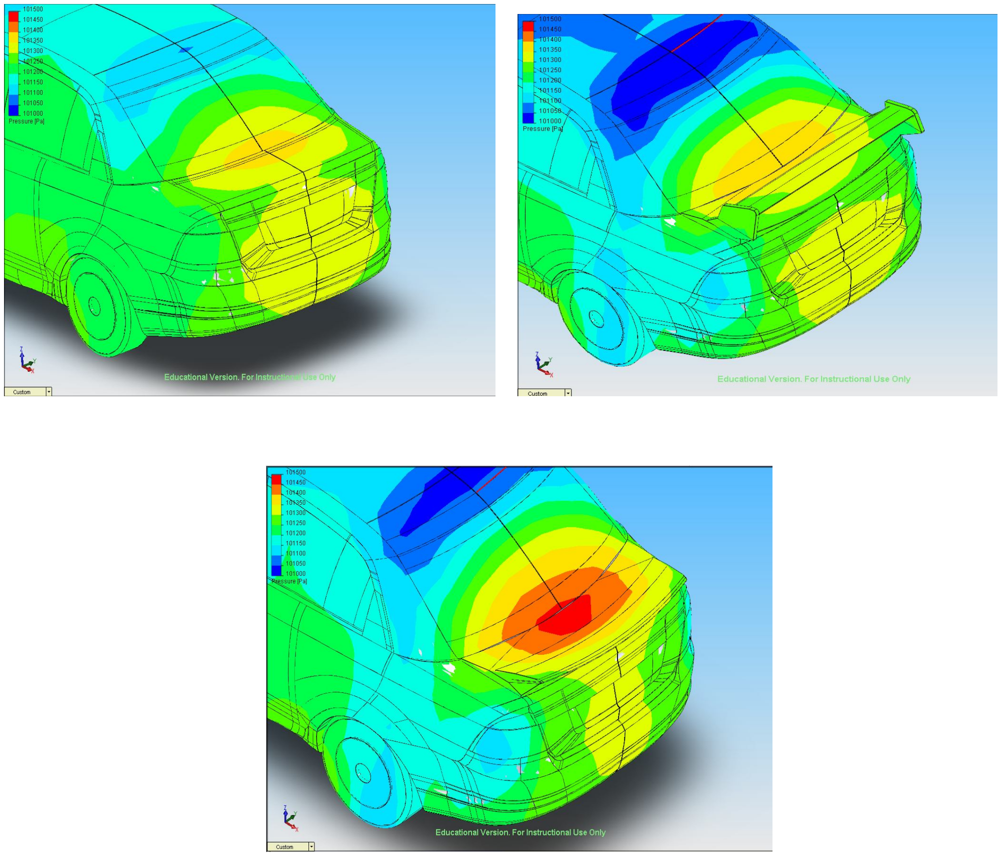


Figure 4.12: Pressure Distribution at the Back for BLM With and Without Rear Spoiler

Figure 4.12 above shows the differences of pressure distribution for BLM without rear spoiler and BLM with rear spoiler type 3 and 4. From earlier discussion, rear spoiler type 4 is very good in creating downforce and figure above proved it. Noticed that pressure distribution for BLM with rear spoiler type 4 is very high pressure, which is about 101.45 kPa and the pressure for BLM with rear spoiler type 3 is about 101.35 kPa. The pressure difference is about 0.1%. This difference meaning that rear spoiler type 3 is better in creating downforce than rear spoiler type 4. From the figure also shows that the pressure acting on the BLM with and without rear spoiler 4 is same.

4.4.4 Velocity Distribution on BLM without Rear Spoiler

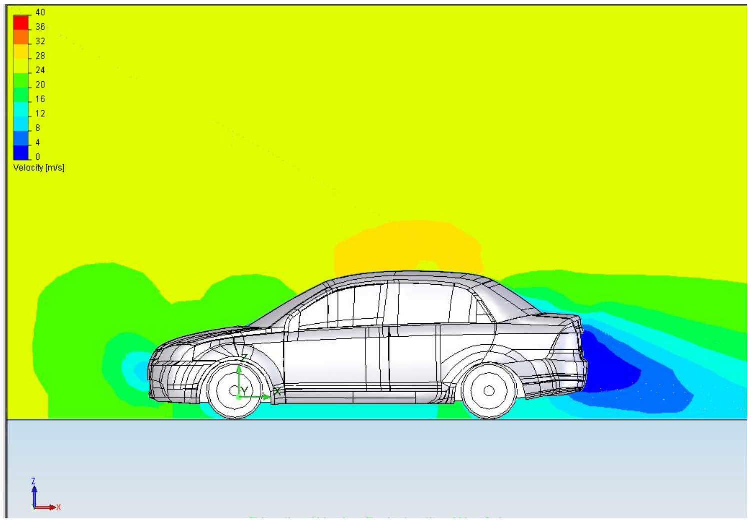


Figure 4.13: Velocity distribution along BLM without rear spoiler

Figure 4.13 above shows the velocity distribution along BLM without spoiler. According to one of the fundamental laws governing the motion of fluids is Daniel Bernoulli's principle, which relates an increase in flow velocity to a decrease in pressure. It has been discussed before that the region with high pressure has a low velocity of flow. Air flow’s speed becomes low when it hits the front bumper. Then when it flows along the front hood, the velocity is started to increase until at windshield. After passed the windshield, the flow is started to flow along the roof line. At this region, the velocity is very high, assisted by flow that did not hit the car. As passed the roofline, flow is started to move downward. As the flow turns again to follow the body, the velocity of flow is started to decrease, results the pressure again increases. The increasing pressure acts to decelerate the flow in the boundary layer, which causes it to grow in thickness. Thus it produces what is known as an adverse pressure gradient. The point where the flow stops is known as the separation point. At this point, the main stream is no longer attached to the body but is able to break free and continue in a more or less straight line. Because it tries to entrain air from the region behind the body, the pressure in this region drops below the ambient. Vortices form and the flow are very irregular in this region.

4.4.5 Velocity Distribution at the Rear Portion of the Car

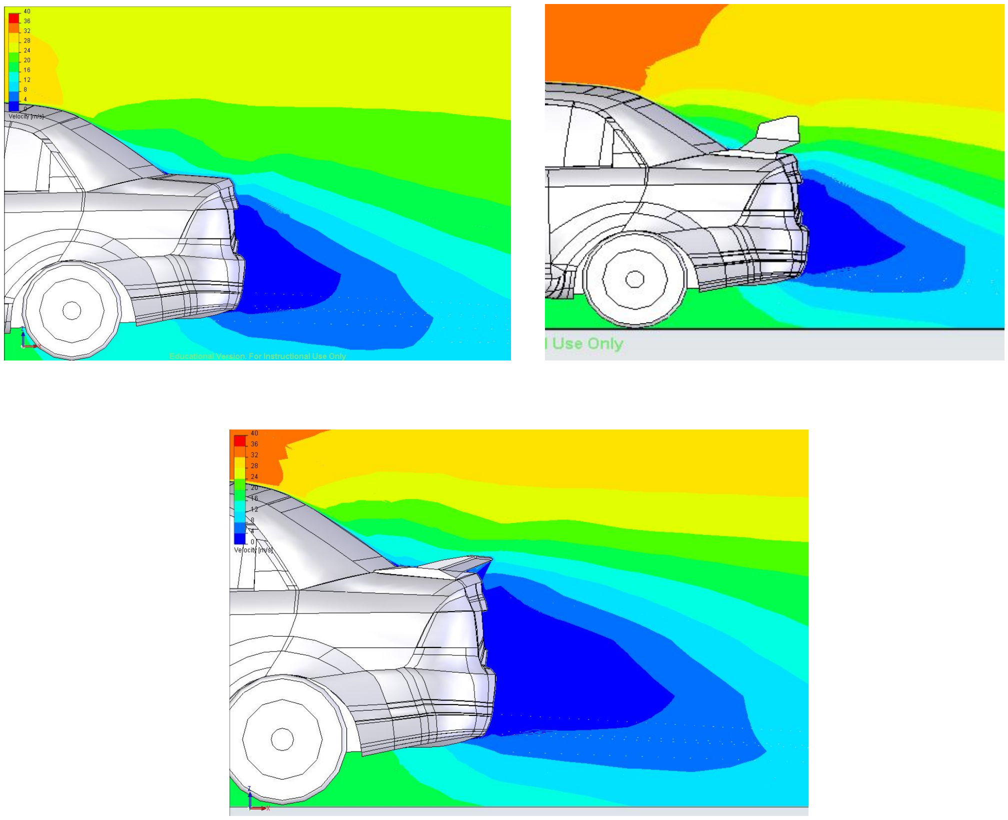


Figure 4.14: Wake region at rear end of the car

Figure 4.14 above shows the comparison of velocity distribution for BLM with and without rear spoiler type 3 and 4. From the figure above, noticed that blue colour represents the wake region. The higher wake region occur at the rear end surface will give higher drag because it can say like a vehicle need to punch a larger hole through the air. It noticed that the wake region for BLM with rear spoiler type 3 is lower than BLM with rear spoiler type 4. That is why C_D for BLM with rear spoiler type 3 is less than the others which is 0.3276 compare to C_D of BLM with rear spoiler type 4 and BLM without rear spoiler. It noticed that the wake region of BLM with rear spoiler type 4 is higher than BLM without rear spoiler. It has proven that C_D of BLM with rear spoiler type 4 is higher than C_D without rear spoiler. The C_D is 0.333, which is higher without rear spoiler (0.3314). This phenomenon happened because the pressure in the separation region is below that imposed on the front of the vehicle, and the difference in these overall pressure forces is responsible for “form drag”. The drag forces arising from the action of viscous friction in the boundary layer on the surface of the car is the friction drag. The back of the car has a direct impact on aerodynamic forces through control of the separation point. Separation must occur at some point, and the smaller the area, generally the lower the drag.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

After further studies and investigation, this project can be concluded that not all rear spoilers are reducing drag and lift force. They are only certain spoilers that can help to reduce drag and lift. Some of them are only reducing drag and others are only reducing lift.

Rear spoiler type 3 is good in reducing drag. The C_D is reducing from 0.3314 to 0.3276 and the reduction is about 1.15%. The reduction of C_D is important in term of fuel economy. Past research proved that the reduction of C_D as much as 0.01 can improve a car's fuel economy by approximately 0.2 mpg. 0.2 mpg is equal to 0.085 km/l. So this type of rear spoiler can improve about 0.08 km for each liter of petrol.

Rear spoiler type 4 is very good in creating downforce. C_L is reducing from 0.11832 to 0.0512 and the reduction about 56%. Reduction of lift force is important to avoid the car get lift over when drive in high speed. Negative lift at rear-axle (positive down force) increases the stability margin and improves vehicles control. Lowering the overall C_L increases the maximum lateral acceleration potential and greatly improves handling.

5.2 Recommendation for Furhter Study

For future studies and research, this project needs several improvements so that this project can carry out better. Recommend that:

1) Use better CFD software for run analysis of the model. For example FLUENT that has been applied to industrial applications.

2) Analysis the effects of rear spoiler for several type of car. For example hatchback car, notchback car and fastback car. Because this different types of car given different effects of drag and lift

REFERENCES

Buchheim, R., Maretzke, J., Piatek, R., 1985, "*The Control of Aerodynamic Parameters Influencing Vehicle Dynamics*," SAE Paper No. 850279

Garry, K. P., Le Good, G. M., 2005, "*An Investigation of the Sensitivity of Rear Wing Orientation for Saloon Race Cars*" 2005-01-1018, Vehicle Aerodynamics 2005. SAE International

Gillespie, T.D. 1992. *Fundamentals of Vehicle Dynamics*. SAE International

Heisler, H.; 2002 "*Advanced Vehicle Technology*"; Elsevier Butterworth-Heinemann.

Hucho, W-H. 1998. "*Aerodynamics of Road Vehicles 4th Edition*". SAE International

Hogue, J. R., 1980, "*Aerodynamics of Six Passenger Vehicles Obtained From Full Scale Wind Tunnel Test*," SAE Paper No. 800142

Janssen, L. J., Hucho, W.-H., 1975 "*Aerodynamische Entwicklung von VW Golf und Scirocco*," ATZ, Vol. 77.

Joseph Katz; 1995 "*Race Car Aerodynamics – Designing for speed*"; Rohert Bentley Inc Auto Publisher.

Munson, Bruce, R.,Young, Donald, F., Okiishi, Theodore, H. ; 2006 " *Fundamentals of Fluid Mechanics*," 5th Edition, John Wiley & Sons (Asia) Pte Ltd.

Ohtani, K., Takei, M., Sakamoto, H., 1972, "*Nissan Full Scale Wind Tunnel – Its Application to Passenger Car Design*," SAE Paper 720100.

Schenkel, F. K., 1977, "*The Origins of Drag and Lift Reductions on Automobiles with Front and Rear Spoiler*," SAE Paper No. 770389

Singh, R., Golsch, K., 2005, "*A Downforce Optimization Study for a Racing Car Shape*," 2005-01-0545, Vehicle Aerodynamics 2005. SAE International

APPENDICES

Appendix A – Project Timeline

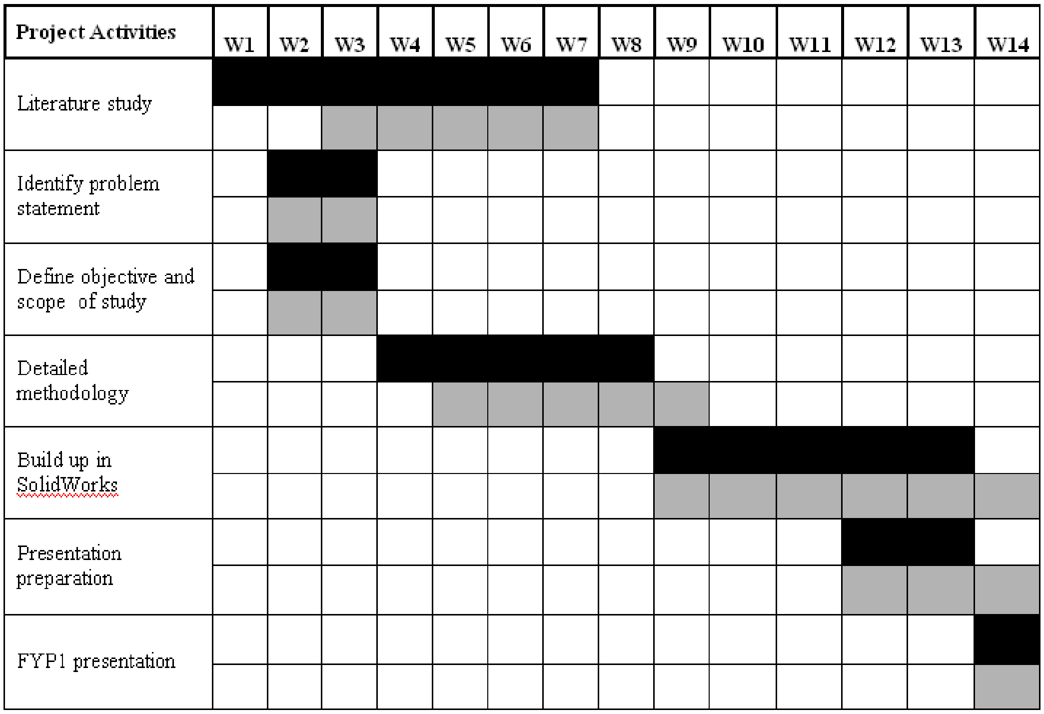
Appendix B - Analyzing Car Using COSMOSFloWorks

Appendix C – CAD Models of BLM Model and Rear Spoiler Model

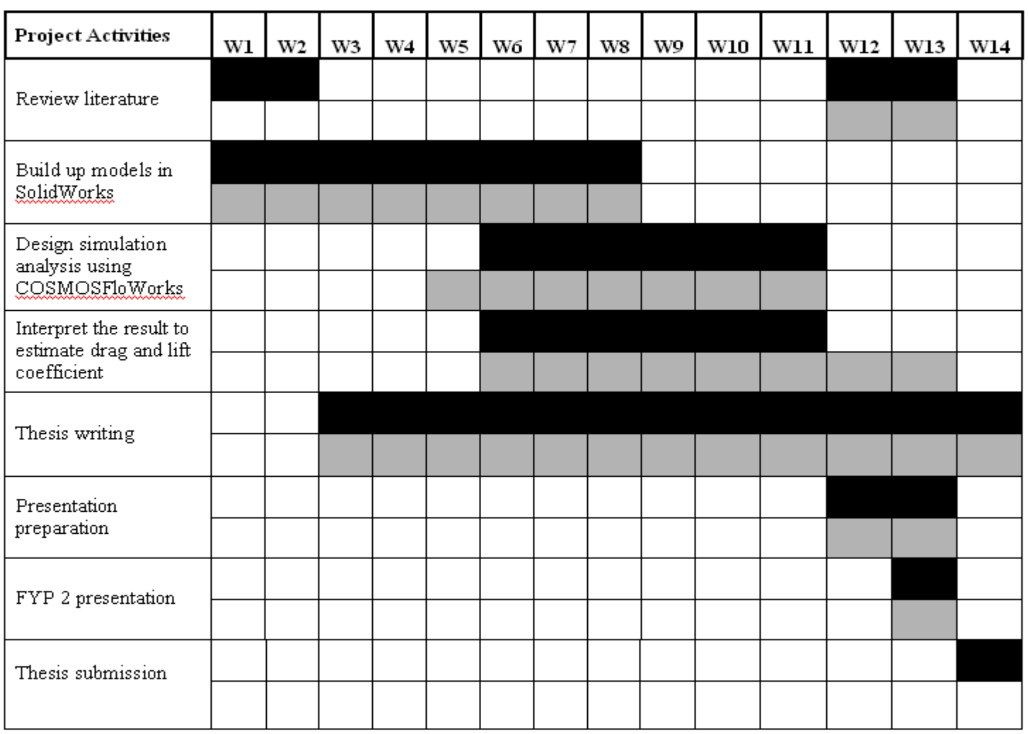
Appendix A

Project Timeline

APPENDIX A - PROJECT TIMELINE



FYP 1 Gantt Chart



FYP 2 Gantt Chart

Appendix B

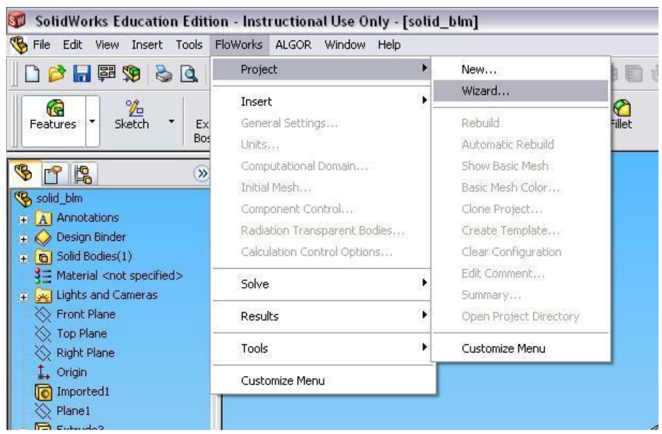
Analyzing Car Using COSMOSFloworks

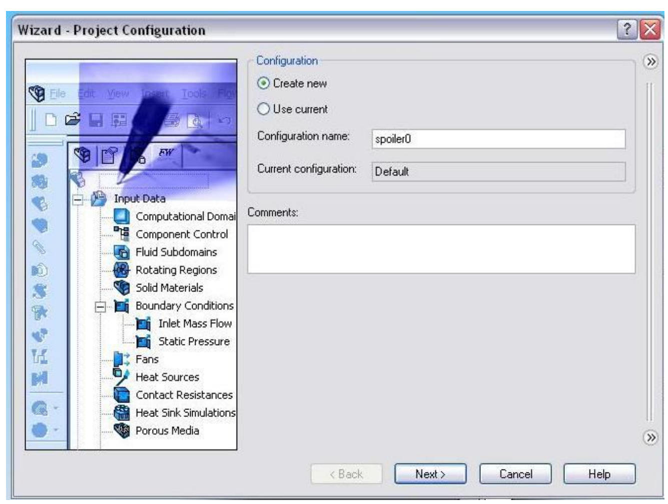
B-1 Opening the File

Open the car assembly file. Click **Open**. From the **Open** window, browse the `Solid BLM Project` directory. Select `solid_blm.sldasm` and click **Open**.

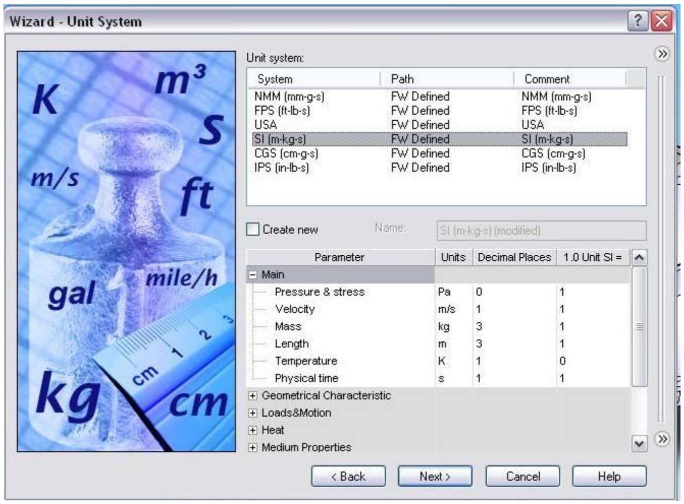
B-2 Create a COSMOSFloWorks Project

Click **FloWorks** > **Project** > **Wizard**. Select **Create new** to create a new configuration and name it. (e.g. ‘`spoiler0`’). Click **Next**.



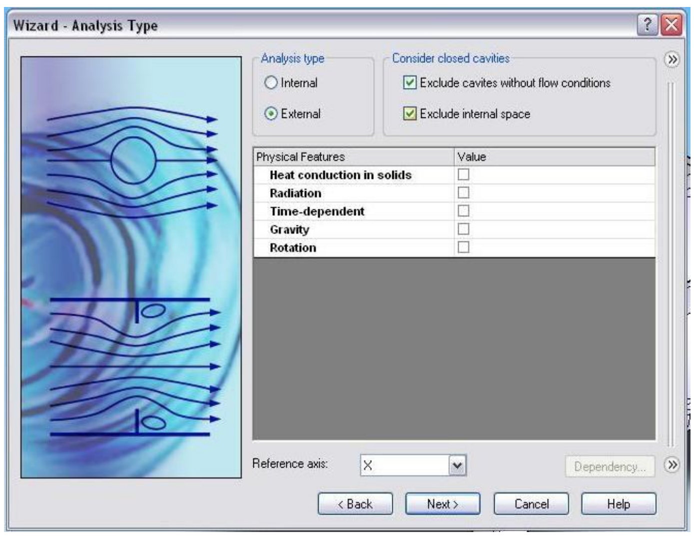


Choose **SI (m-kg-s)** in the **Unit System** area. Click **Next**.



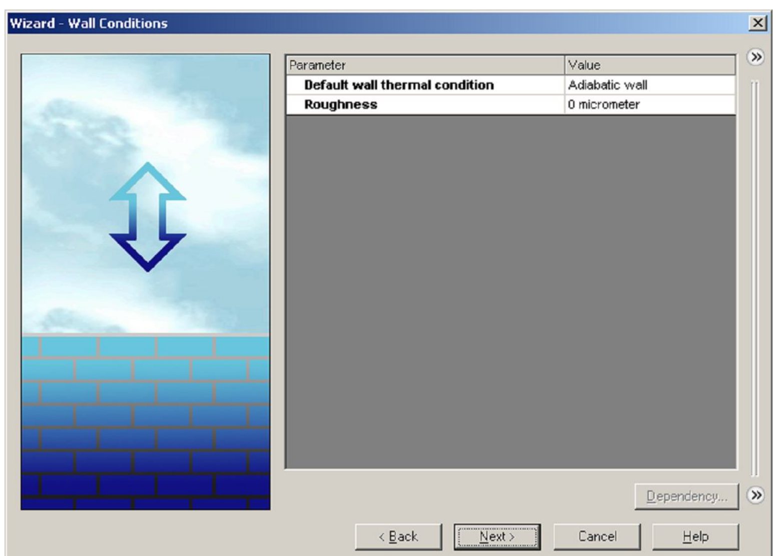
Select **External** as the **Analysis Type**. Select the **Exclude cavities without flow conditions** and the **Exclude internal space** check boxes.

For **Reference** axis, select **X**. Click **Next**.

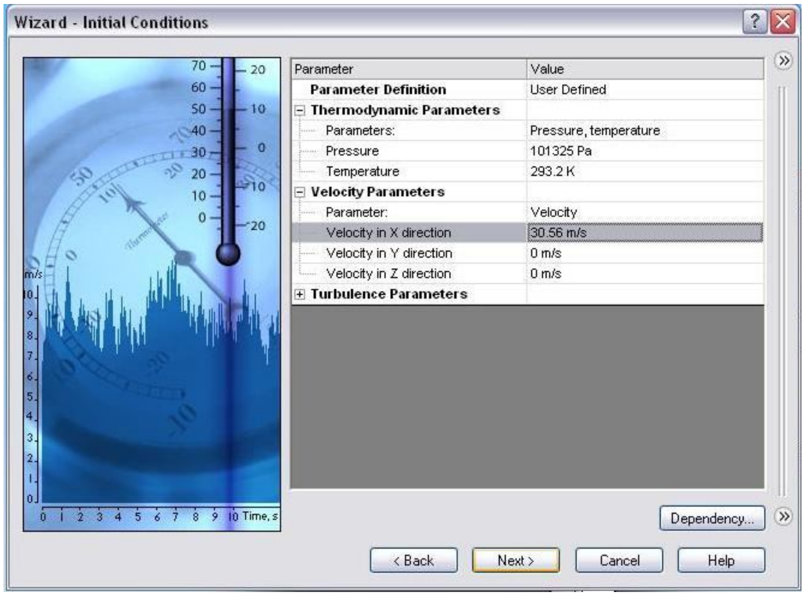


Under **Gases**, Select **Air**, then click **Add**. Click **Next.**

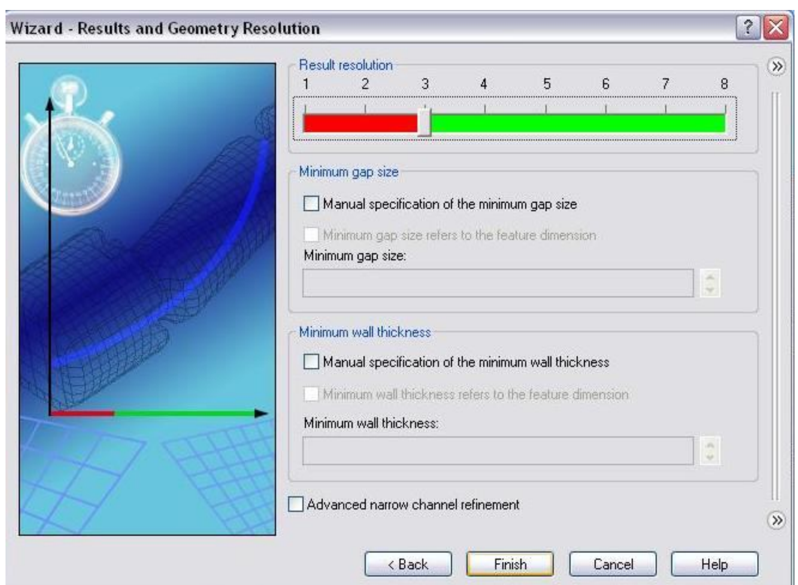
Default **Adiabatic wall** and **Roughness** value of **0 micrometer** are acceptable. Click **Next**.



Under **Velocity Parameters**, Double-click the value of **X-component** and type the velocity (E.g. **30.56 m/s**). Click **Next**

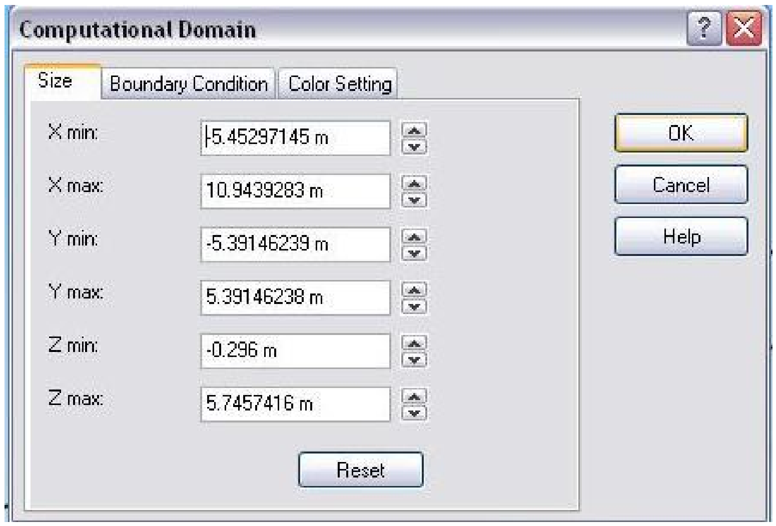


Set the **Result Resolution** to **3** which will yield acceptably accurate results in a reasonable amount of time. Click **Finish**.



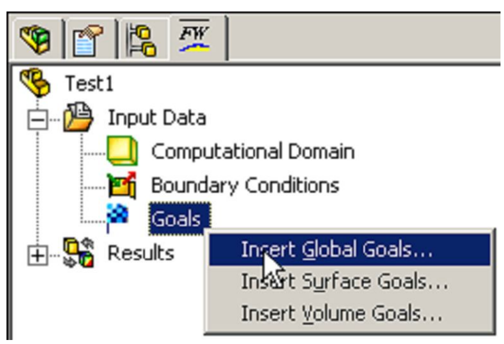
B-3 Modifying the Computational Domain

Click on the COSMOSFloWorks analysis tree tab. Expand the `Input Data` listing. Right click `Computational Domain` and select **Edit Definition**. On the **Size** tab, modify **Z min** to the value which is approximate to the tires of the car. Click **OK**.

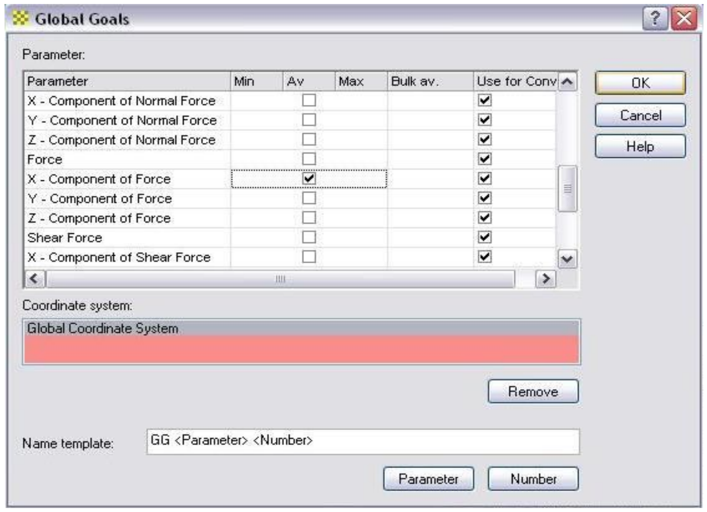


B-4 Setting the Goals.

Right click `Goals` in the COSMOSFloWorks analysis tree and select the **Insert Global Goals**.



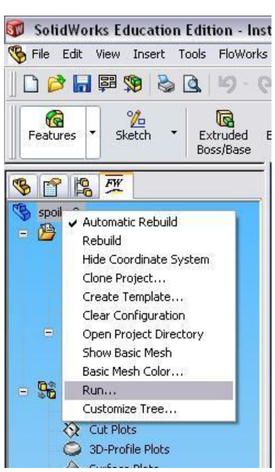
Check the **X-component of Force** in the **Parameter** list and click **OK**.

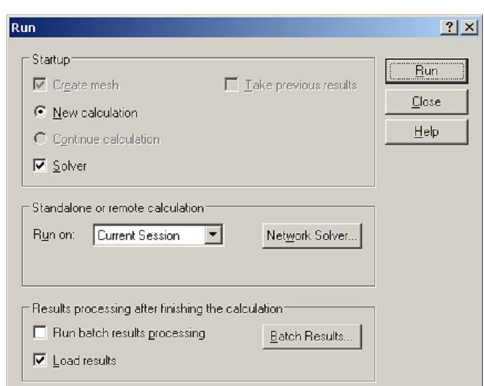


Right click `Goals` again and select **Insert Global Goals**. Check the **Z-component of Force** in the **Parameter** list and click **OK**. Two goals icons appear in the COSMOSFloWorks analysis tree. Change the X component to `Drag` and the Z component to `Lift`.

B-5 Running the Analysis

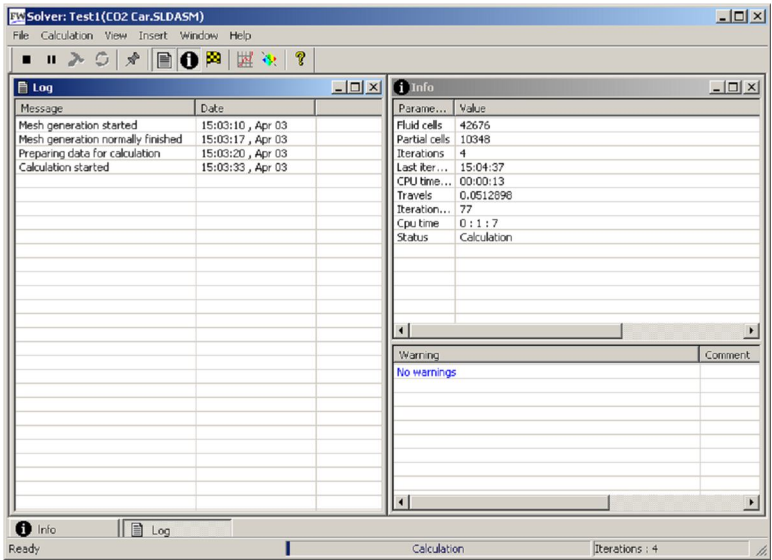
Right click `spoiler0` and click **Run**





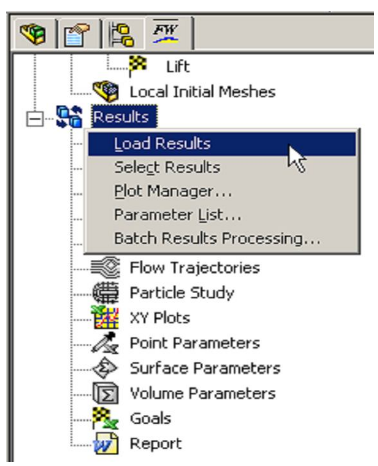
B-6 Solver information

The **Solution Monitor** window appears after a minute or so. On the left of the window is a log of each step taken in the solution process. On the right is an information window with mesh information and any warnings concerning the analysis.

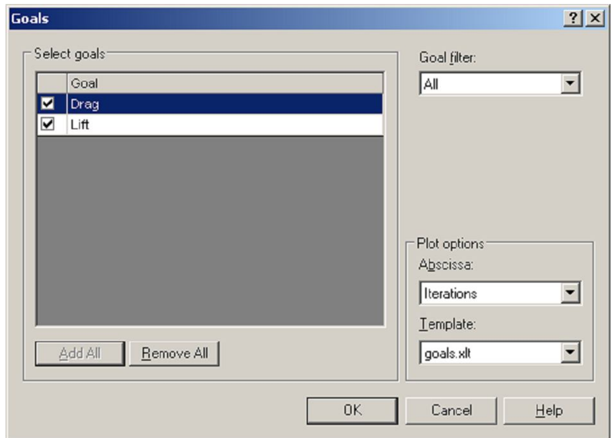


B-7 Accessing the Results

Right click `Results` in the COSMOSFloWorks analysis tree and select **Load Results**. Select `1.fld` and click **Open** to load the results file.



In the COSMOSFloWorks analysis tree, expand the `Results` listing and right-click `Goals`. Select **Insert** from the shortcut menu. Check **Drag** and **Lift**, or click **Add All**. Click **OK**.



Microsoft® Excel is launched and a spreadsheet opens. Pay particular attention to the first three columns. They show the name of the goal, the units (newtons, in this case) and the value.

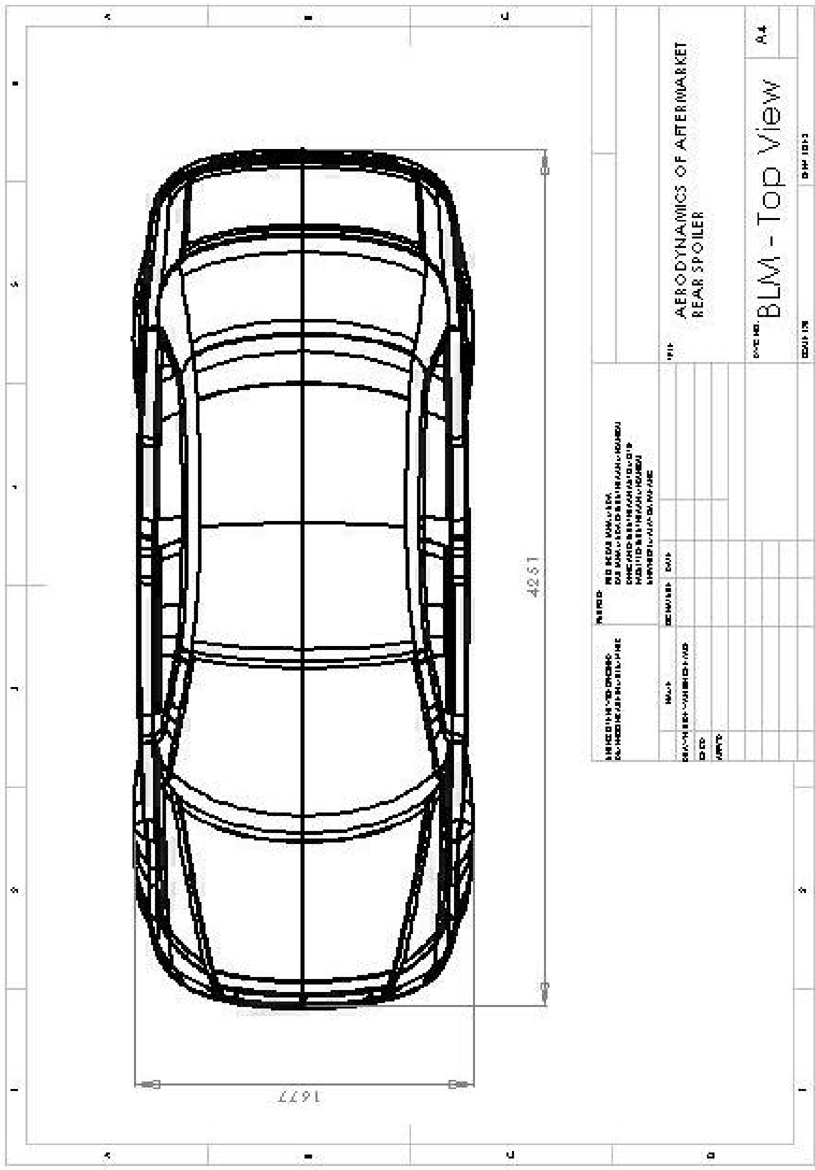
solid_blm.sldprt [test3]

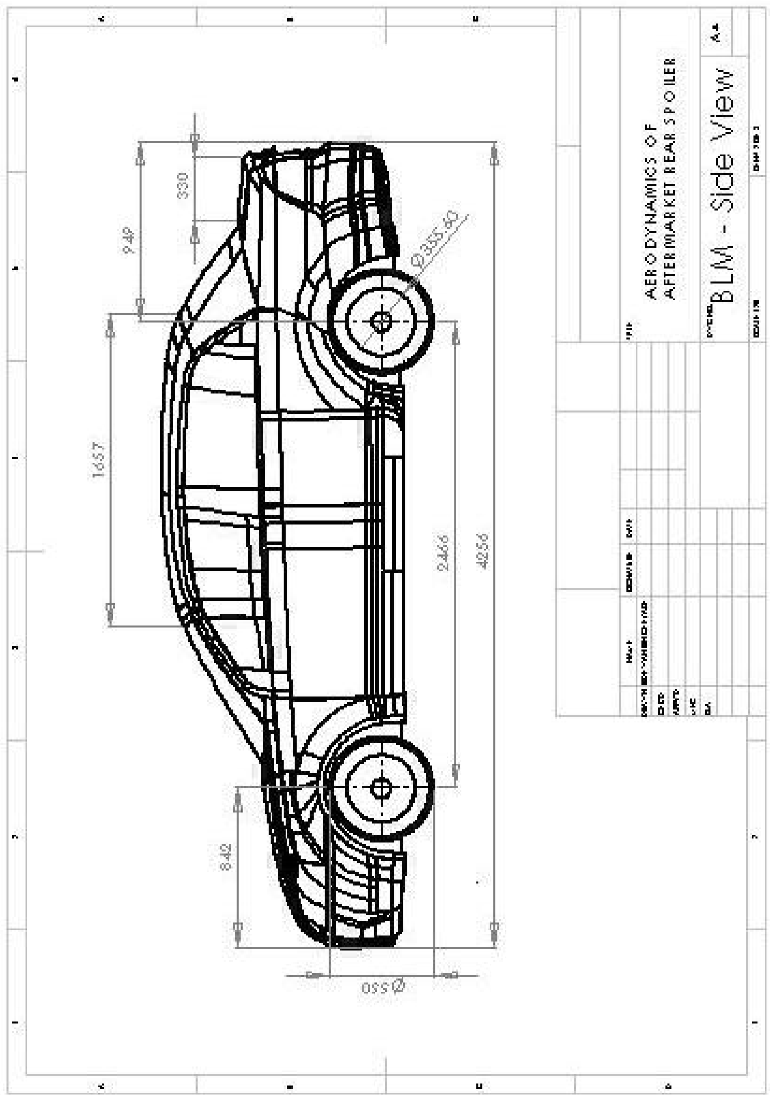
Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Drag	[N]	404.6661382	406.918	402.142	412.341	100	Yes	10.1987338	21.8064201
Lift	[N]	67.69381398	54.8754	10.6035	81.2865	100	Yes	70.6829683	70.8518083

Iterations: 67
Analysis interval: 29

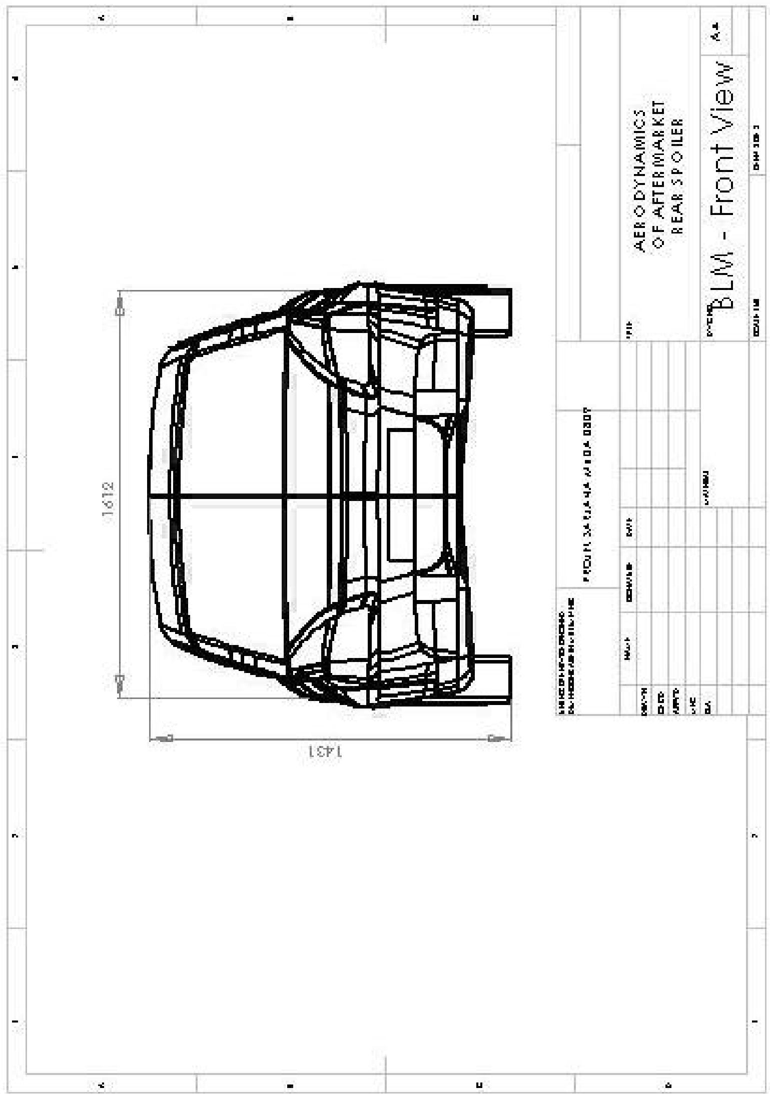
Appendix C

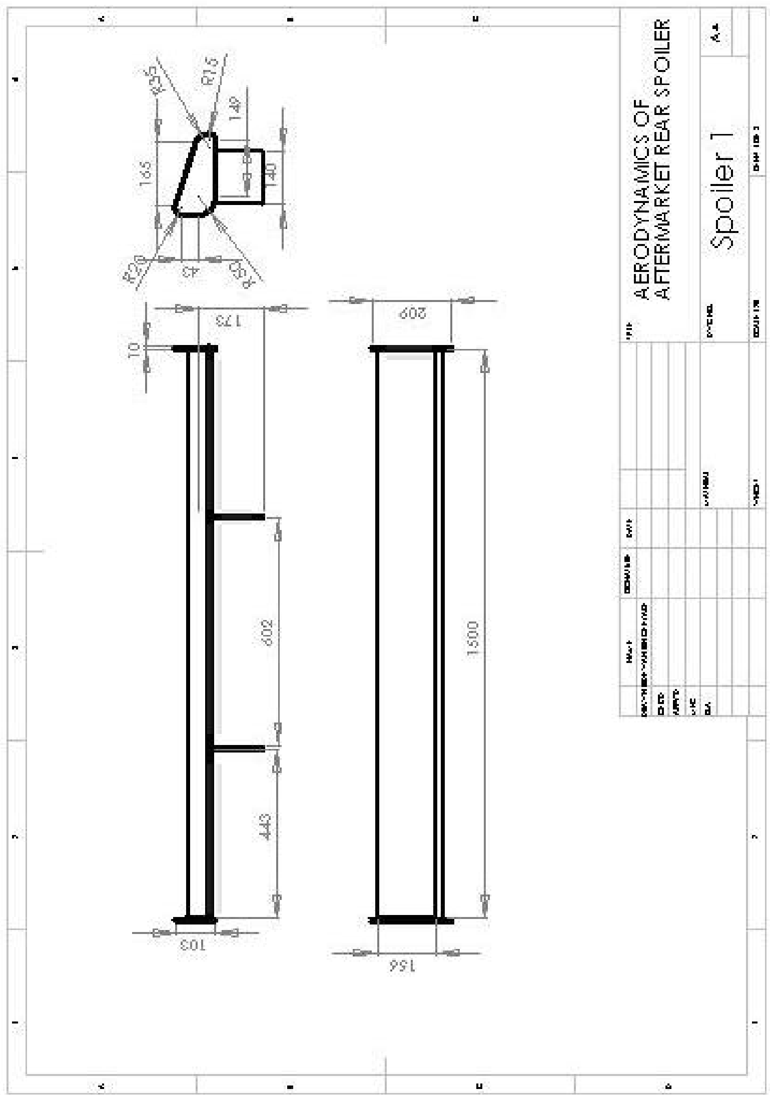
CAD Model in SolidWorks


AERODYNAMICS OF AFTERMARKET
REAR SPOILER
BLM - Top View
A4
4251
1677



AERODYNAMICS OF
AFTERMARKET REAR SPOILER
BLM - Side View
330
949
1657
2466
4256
842
Ø355.60
Ø550


1612
1431
AERODYNAMICS
OF AFTERMARKET
REAR SPOILER
BLM - Front View


AERODYNAMICS OF AFTERMARKET REAR SPOILER
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R15
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165
140
R20
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R50
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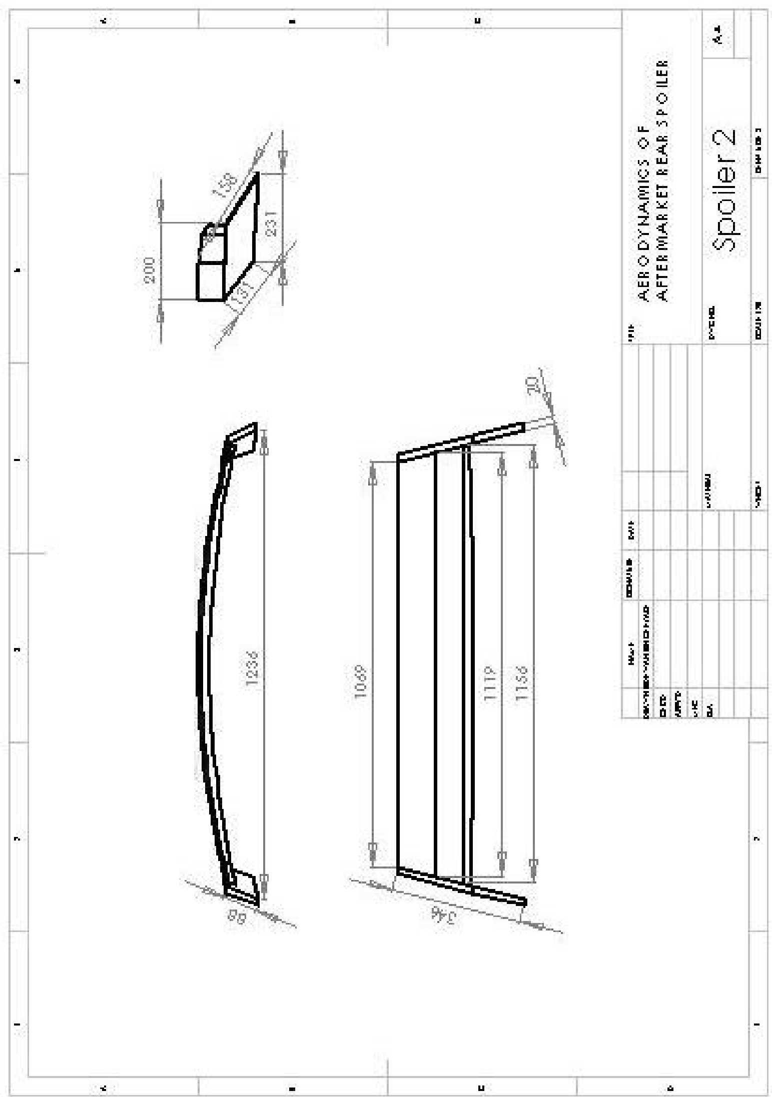
443
103
209
1500
156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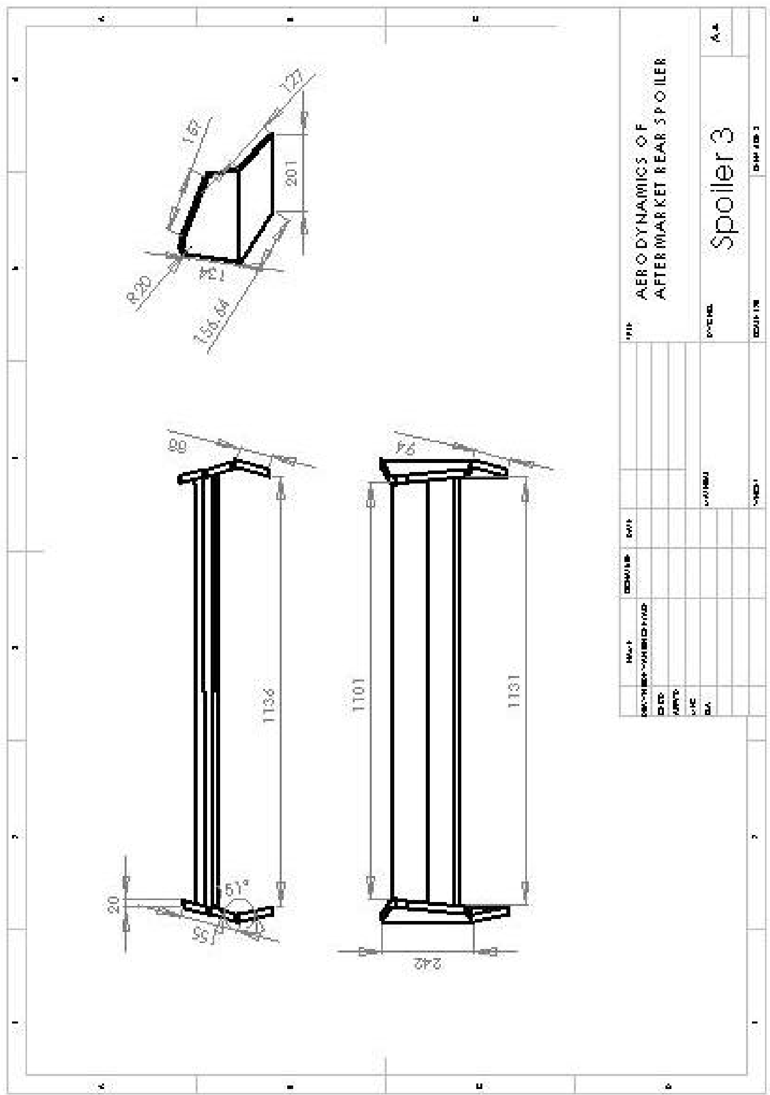
200
231
131
1236
1069
1119
1156
20
88
346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201
R20
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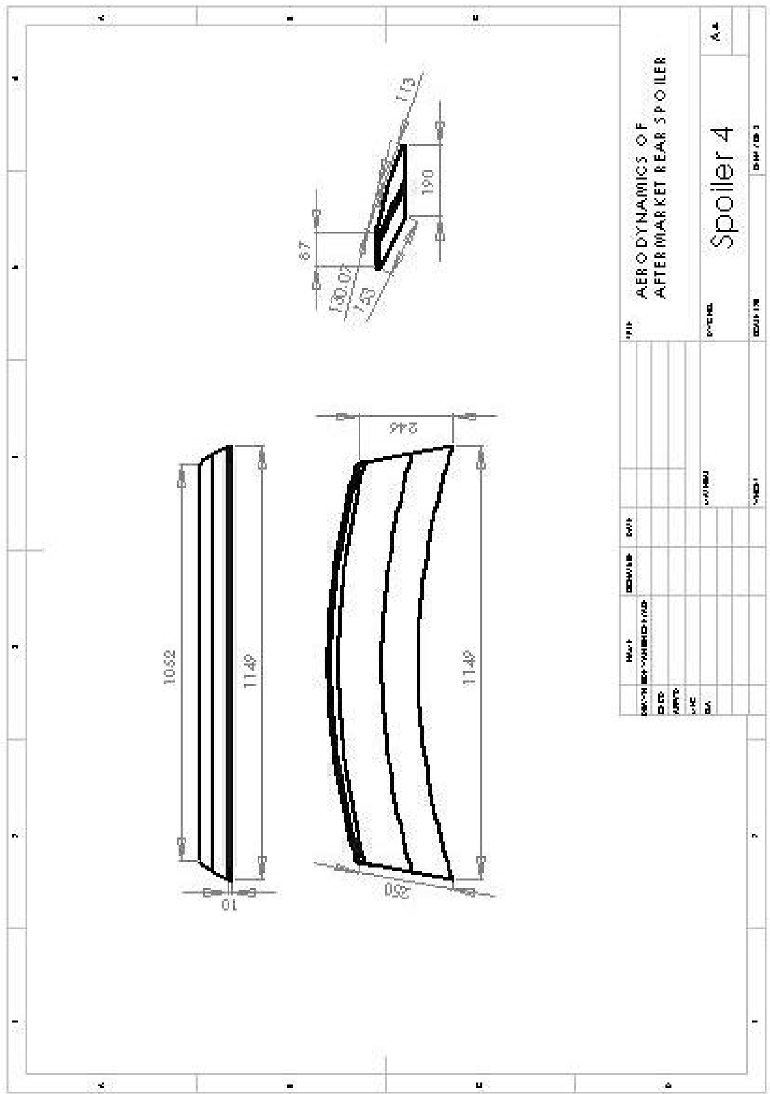
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1149
10
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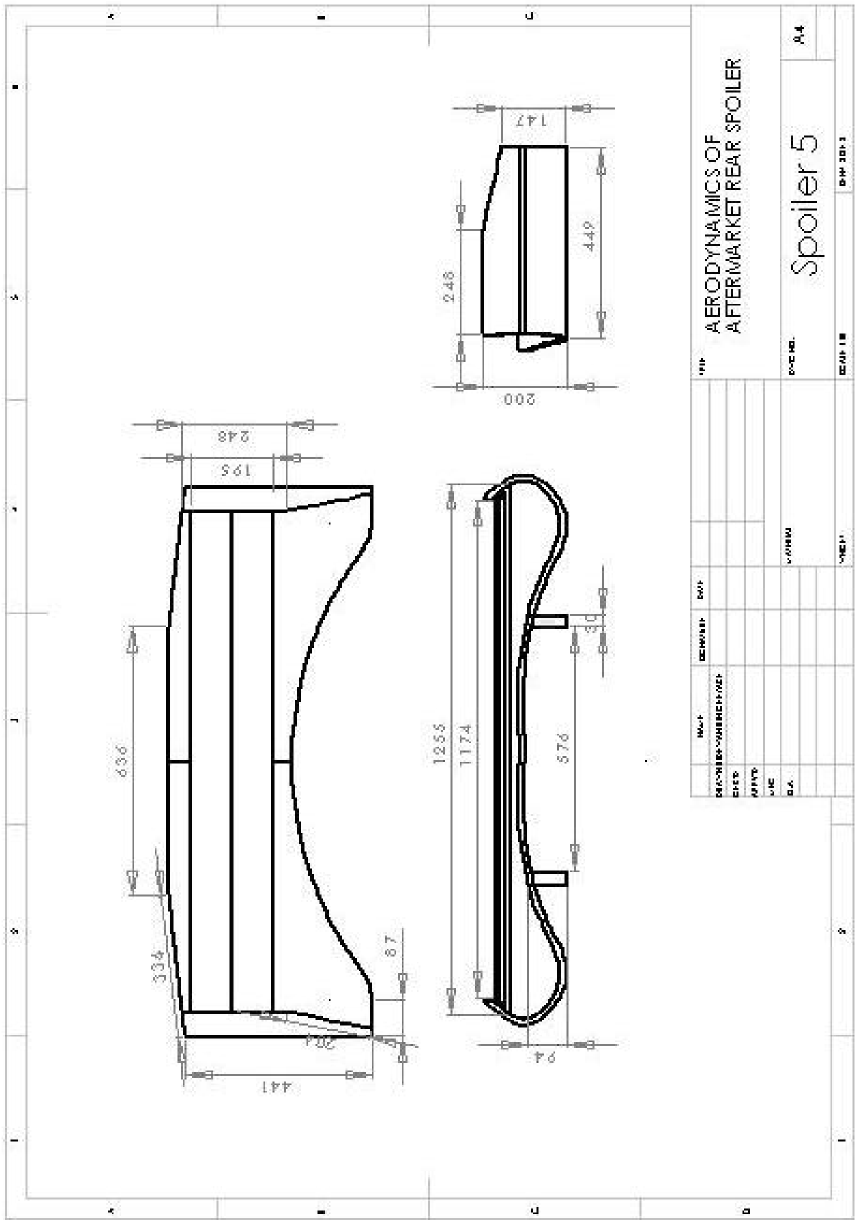
246
87
130.07
153
190
113


AERODYNAMICS OF
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Spoiler 5
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449
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195
636
1255
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334
87
204
441
94