Vehicle Body Design and Analysis of a Practical, Fuel Efficient City Concept Car

By

Mohamad Iskandar Bin Sahar

Dissertation submitted in partial fulfilment of the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme
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Approved by,

____

(Mr. Mui'nudin Bin Maharun)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHAMAD ISKANDAR BIN SAHAR

ABSTRACT

The objective of this project is to model the vehicle body design and do analysis of a practical, fuel efficiency city concept car and from the result obtained, studies will be carried on to increase the fuel efficiency of the base model which is PeroduaMyvi by the means of changing the body design of the carfocusing to reduce the drag coefficient and the coefficient of lift of the vehicle. The PeroduaMyvi is one of the leading local cars in its class due to its fuel efficient and lightweight. However, there are always rooms for improvement forMyvi body design so that the fuel efficiency can be increased. The scope of study of this project will be as follow: · Study about ways to reduce drag coefficient and rolling resistanceby changing the design of the body. This includes the factors like the material used for the body and aerodynamic design. Study and construct the model and simulate it using Catia and ANSYS fluent software to measure drag coefficient and coefficient of lift under different driving condition. Analyze the obtained results and propose some potential improvements that can be implemented to obtained fuel efficiency car. The methodology for this project basically has more emphasis on using the CATIA and Fluent software. Some equation will be used to calculate the relationship between aerodynamic design and fuel consumption to enable the objective of this project to obtain high fuel efficiency based on the vehicle body design.

The modification to be made is the vehicle body design of the basic model of PeroduaMyvi to achieve a practical, fuel efficiency of a city concept car. Based on the Perodua ECO Challenge competition, the first step that need to done is to remove the upper part of the body which is shown in Figure 1. Next step is to install the rib cage or the chassis so that later the upper part can be completed with outer shell of the vehicle.

ACKNOWLEDGEMENT

I would like to express my gratitude to all those who gave me the possibility to complete this project. I want to thank to Allah S.W.T for giving me good health to do the necessary research work. In addition, I would like to thank to my fellow friends who always encouraged me with this project.

I am deeply indebted to my supervisor, Mr. Mui'nudin bin Maharun from Faculty of Mechanical Engineering whose help, stimulating suggestions and encouragement helped me in all the time of the research and writing of this Final Year Project.

Lastly, I would like to give my special thanks to my parents whose patient love enabled me to complete this project, sacrifice their time and money in show of support towards me. I hope that all results obtained in this research can be used as references for the betterment of science and technology.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Recently, fuel price becomes as hot topic and never ending issue especially the demand of fuel is very high. Malaysia Government has stood up in helping citizens by giving certain amount of money per vehicle owner to reduce their burden. However, the solution of reducing the total amount of fuel cost and consumption seems to be more helpful if the design of the car body itself can be manipulated to reduce the cost.

The fuel economy of a vehicle is evaluated by the amount of fuel consumptionper 100 km traveling distance (litres/100 km) or mileage per gallon fuel consumption(miles/gallon).

The operating fuel economy of a vehicle depends on a number of factors, includingfuel consumption characteristics of the engine, gear number and ratios,vehicle resistance, vehicle speed, and traffic conditions.

Maximizing fuel efficiency of a vehicle is one of the prime areas of focus in the highly competitive automotive industry which requires development of efficient and optimized vehicle designs. External aero analysis using Computational Fluid Dynamic (CFD) techniques is widely used in the accurate estimation of an automotive vehicle's drag coefficient, often critical in determining the fuel efficiency of the vehicle and thus drives the design development process. In a typical design process, several design variations are analyzed, their effect on specific parameters such as the drag and lift coefficients is studied, and thereby, an optimum vehicle design is developed. Numerous techniques can be used to develop design variations from an existing design and to perform design development studies. [7]

1.2 Problem Statement

Recently, fuel price becomes as hot topic and never ending issue especially the demand of fuel is very high. Malaysia Government has stood up in helping citizens by giving certain amount of money per vehicle owner to reduce their burden. However, the solution of reducing the total amount of fuel cost and consumption seems to be more helpful if the design of the car body itself can be manipulated to reduce the cost.Although the goal of the PEC race is fuel efficiency, the chassis must still be stiff enough for good handling and has sufficient strength to support all the loads. The chassis must be able to accommodate a 3 cylinder 660 cc engine and averaged size driver. The regulations state that the chassis must be of space frame tube construction only. Any form of monocoque design is not allowed due to safety and cost constraints. Material for the chassis must either be ferrous metal or aluminium alloy. A side bar must be integrated in the design and must be situated about 400 mm of the ground. The chassis must incorporate a structural roll bar which includes a front hoop and a main hoop and must torsional rigidity of at least 2000 Nm/degree. The main hoop must be able to support four times the weight of the car. The car must demonstrate the ability to stop within 20 m from 50 km/h. Finally the bulkhead for the impact attenuator must be at least 350 mm in height and 400 mm in width. The impact attenuator must have a crushing distance of at least 200 mm. To comply with the rules and regulation of the PEC, the chassis will be of space frame type using mild steel. Space frame chassis was chosen for the simplicity of the design, ease of construction and facilitate the integration of the others car components.

1.3 Scope of Study

For this semester for FYP, the project assigned is to model the vehicle body design and do analysis of a practical, fuel efficiency city concept car and the base vehicle or the datum used for car design is PeroduaMyvi. In order to do the project, there is some knowledge that I need to know and understand which are:

1. Element of a city concept car
2. The factors affecting fuel efficiency
3. Types of vehicle chassis

1.4 Objectives

1. To model the vehicle body design,PeroduaMyviin CATIA software.
2. To model the vehicle body design in CATIA software based on the modification of an existing vehicle.
3. To simulate air flow around the vehicle using ANSYS software.
4. To analyse the aerodynamic of the vehicle body design by comparing the coefficient of drag of the vehicle

CHAPTER 2

LITERATURE REVIEW

2.1 City Concept Car

The CityCar concept was designed as an all-electric four-wheel ultra-small vehicle (USV) for two passengers, and drive-by-wire driver interface. Each wheel is independently digitally controlled, with its own wheel motor, which enables them to move in different direction and speed, and allows the wheels to rotate up to 120 degrees, allowing for turning on a dime or 0-degree turn radius, thus giving the vehicle more precise maneuverability. This feature makes the City Car suitable for urban conditions, as it can perform sideways motions for parallel parking, and O-turns instead of the conventional three-point turns. (William J. etc. al, 2010)

This wheel arrangement allows entry and exit at four points around the vehicle's perimeter. The city car was designed for front entry, which is feasible because there is no engine in the way. Baggage and emergency entry and exit are at the rear, and there is no side entry and exit. This configuration allows nose-in parking to the curb, and passenger embarkation from the sidewalk rather than from the road, which allows the elimination of the need for side clearance between parked vehicles. It also simplifies the vehicle, which does not need to accommodate door openings. (William J. etc. al, 2010)

The CityCar was designed with a collapsible frame through a four-bar linkage that enables the vehicle to fold up for more compact parking, making possible to stack three or four CityCars in the length of a traditional parking bay, a particularly efficient feature in crowded urban settings. [4]. Safety systems operate at multiple levels. The car's folding mechanism also provides space for crash-deceleration systems. Its electronic sensing and wireless communications contribute to reduce the likelihood of crashes. And if a crash occurs, the low mass and relatively low speed reduces the energy involved in a crash with a similar vehicle. Seat belts and airbags will still be needed. (William J. etc. al, 2010)

2.2 Vehicle coefficient of drag, Cd

The aerodynamic abilities of a car are measured using the vehicle's coefficient of drag. Essentially, the lower the Cd, the more aerodynamic a car is, and the easier it can move through the wall of air pushing against it. An old Volvo 960 sedan achieves a Cd of .36. The newer Volvos are much more sleek and curvy, and an S80 sedan achieves a Cd of .28. Today, most cars achieve a Cd of about .30. SUVs, which tend to be more boxy than cars because they're larger, accommodate more people, and often need bigger grilles to help cool the engine down, have a Cd of anywhere from .30 to .40 or more. Pickup trucks -- a purposefully boxy design -- typically get around .40 [9]. Toyota Prius is hybrid, but it has an extremely aerodynamic shape for a good reason. Among other efficient characteristics, its Cd of .26 helps it achieve very high mileage. In fact, reducing the Cd of a car by just 0.01 can result in a 0.2 miles per gallon (.09 kilometers per liter) increase in fuel economy [9]. As the 1950s and '60s came about, some of the biggest advancements in automobile aerodynamics came from racing. Originally, engineers experimented with different designs, knowing that streamlined shapes could help their cars go faster and handle better at high speeds. That eventually evolved into a very precise science of crafting the most aerodynamic race car possible. Front and rear spoilers, shovel-shaped noses, and aero kits became more and more common to keep air flowing over the top of the car and to create necessary down force on the front and rear wheels [5].

Components of the drag of a brick shaped bluff body and their reduction

Drag type	**% of the C_D**	**Caused by**	**Way of reduction and measures**
Forebody drag	65	Overpressure on the front face	Reduction of overpressure by accelerating the flow: rounding up of upper horizontal and vertical leading edges, slanting the front face
Base drag	34.9	Depression on the rear end	Increase of pressure: boat-tailing, tapering the rear part of the body, rounding up of trailing edges
Side wall, roof and underbody drag	0.1	Shear stresses over the walls, roof and underbody	Decrease of shear stresses: reduction of roughness, decrease of the velocity in the underbody gap

Table 1 Components of drag

Aerodynamic drag is a function of vehicle speed V, vehicle frontal area, A_f, shape of the vehicle body, and air density, ρ:

$$F_W = \frac{1}{2}\rho A_f C_D (V - V_W)^2,$$

2.3 Coefficient of lift

Lift coefficient may also be used as a characteristic of a particular shape (or cross-section) of an airfoil. In this application it is called the section lift coefficient. It is common to show, for a particular airfoil section, the relationship between section lift coefficient and angle of attack.[5] It is also useful to show the relationship between section lift coefficient and drag coefficient.

The section lift coefficient is based on two-dimensional flow - the concept of a wing with infinite span and non-varying cross-section, the lift of which is bereft of any three-dimensional effects. It is not relevant to define the section lift coefficient in terms of total lift and total area because they are infinitely large. Rather, the lift is defined per unit span of the wing, *l*. In such a situation, the above formula becomes:

$$c_l = \frac{l}{\frac{1}{2}\rho v^2 c}$$

Where c, is the chord length of the airfoil.

The section lift coefficient for a given angle of attack can be approximated using the thin airfoil theory,[6] or determined from wind tunnel tests on a finite-length test piece, with end-plates designed to ameliorate the three-dimensional effects associated with the trailing vortex wake structure.

Note that the lift equation does not include terms for angle of attack — that is because the mathematical relationship between lift and angle of attack varies greatly between airfoils and is, therefore, not constant. (In contrast, there is a straight-line relationship between lift and dynamic pressure; and between lift and area.) The relationship between the lift coefficient and angle of attack is complex and can only be determined by experimentation or complicated analysis. See the accompanying graph. The graph for section lift coefficient vs. angle of attack follows the same general shape for all airfoils, but the particular numbers will vary. The graph shows an almost linear increase in lift coefficient with increasing angle of attack, up to a maximum point, after which the lift coefficient reduces. The angle at which maximum lift coefficient occurs is the stall angle of the airfoil.

2.4 Computation of Vehicle Fuel Economy

Vehicle fuel economy can be calculated by finding the load power and speed, and thus the specific fuel consumption of the engine.

The engine power output, Pe is always equal to the resistance power plus the dynamic power for acceleration of the vehicle

$$P_e = \frac{V}{\eta_t}\left(F_f + F_w + F_g + M_v \delta \frac{dV}{dt}\right)$$

$$P_e = \frac{V}{1000\eta_t}\left(Mgf_r \cos\alpha + \frac{1}{2}\rho_a C_D A_f V^2 + Mg \sin\alpha + M\delta \frac{dV}{dt}\right)(\mathrm{kW})$$

The time rate of fuel consumption can be calculated by:

$$Q_{fr} = \frac{P_e g_e}{1000\gamma_f}(\mathrm{l/h})$$

Where g_e is the specific fuel consumption of the engine in g/kWh and γ_f isthe mass density of the fuel in kg/L.

2.5 Types of vehicle chassis

Ladder frame

This was the first type of chassis to be designed. Almost all car manufacturers used it until the early 60s. Nowadays some SUVs still use it. As its name connotes, ladder chassis resembles a shape of a ladder having two longitudinal rails inter linked by several lateral and cross braces. It uses few, large diameter tubes. Axels pay an important role in sustaining weight. [7]

Advantages: Cheap to hand build. Can cope with heavy loads.

Disadvantages: Few torsional rigidity, that is because it is a 2D chassis.

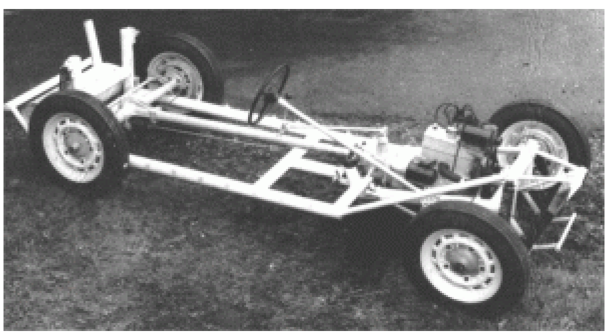

Figure 2.1

Space frame

Useseveral small tubes to create a 3D chassis. Tubes are placed in several directions to cope with the forces they need to withstand. Normally, these chassis are designed for a purpose. These tubes are welded together. To make the welding simpler square-section tubes are also used (however, circular tubes provide the maximum strength). They are normally used in sport applications. Optimizing the design makes hard to put openings (like doors). That is why space frame chassis make acceding to the driving seat difficult (high doors). Take for example the 1950's Mercedes-Benz 300SL Gullwing. [7]

Advantages: Very accurate. High stiffness. Great torsional rigidity.

Disadvantages: Very expensive. Handmade. Tubes need to be cut, shaped, and welded manually.

Who uses it: Some competition cars. Some sporty road cars use space frame design in some parts of the chassis.

Figure 2.2

<u>Monocoque</u>

Monocoque is a one piece structure which defines the final shape of the car. Metal sheets are pressed with big stamping machines. These parts are welded (normally spot welding) or riveted together to conform the chassis. The welding process is mostly robotized. These chassis are produced in a stream production line, so they are fast to make. Tolerances are tiny. Nowadays 99% of the production cars use this type of chassis. They are heavy chassis because they use a lot of metal. However, they have really good impact strength. Normally steel is used; steel has 3 times the modulus of Aluminum but only two times the weight, and is cheaper and easier to weld. [7]

Figure 2.3

Combination

Combination of monocoque and space frame. The safety cell is made through monocoque chassis construction. The rest of the chassis is made through space frame design. It has some of the advantages of each one. Another advantage is that is simpler and cheaper to produce than monocoque alone. [7]

2.6 Lightweight

In developing lightweight car, there are many ways, but it is most effective way to apply light materials. So, aluminum, magnesium, plastic, composites are applied to engine parts, chassis parts, body parts and etc. In these parts, the application of aluminum to body parts are most effective way in weight reduction.(Chung, Y. D., etc al,2000)

The substituting aluminum alloys for some steel in the traditional steel framework structure and optimizing the structural combination will implement the integrated load-supporting with the hybrid structure. It can develop the advantages of aluminum alloy sheets in weight reduction and increased strength and rigidity and result in the whole body structural optimization. (Long, J. Q. etc al, 2008).

2.7 List of assumptions

Wind screen

At average speed (90km/h) and above, as driving speed increased, aerodynamic noise on ground vehicle were becoming relatively effect the comfort of the occupants especially at the area of front windscreen and side mirrors. It is vital for the researcher and engineer to study these phenomena in order to rectify the problem for the future models.

Spoiler

A spoiler is an automotive aerodynamic device whose intended design function is to 'spoil' unfavorable air movement across a body of a vehicle in motion, usually described as turbulence or drag. Spoilers on the front of a vehicle are often called air dams, because in addition to directing air flow they also reduce the amount of air flowing underneath the vehicle which generally reduces aerodynamic lift and drag. Spoilers are often fitted to race and high-performance sports cars, although they have become common on passenger vehicles as well.

Spoilers are usually made of:

ABS plastic: Most original equipment manufacturers create spoilers produced by casting ABS plastic with various admixtures, which bring in plasticity to this inexpensive but fragile material. Frailness is a main disadvantage of plastic, which increases with product age and is caused by the evaporation of volatile phenols.

Fiberglass: Used in car parts production due to the low cost of the materials. Fiberglass spoilers consist of fiberglass cloth in filled with a thermosetting resin. Fiberglass is sufficiently durable and workable, but has become unprofitable for large scale production due to the amount of labour.

Silicon: More recently, many auto accessory manufacturers are using silicon-organic polymers. The main benefit of this material is its phenomenal plasticity. Silicon possesses extra high thermal characteristics and provides a longer product lifetime.
Carbon fibre: Carbon fibre is light weight, durable, but also a very expensive material. Due to the very large amount of manual labour, large scale production cannot widely use carbon fibre in automobile parts production currently.

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

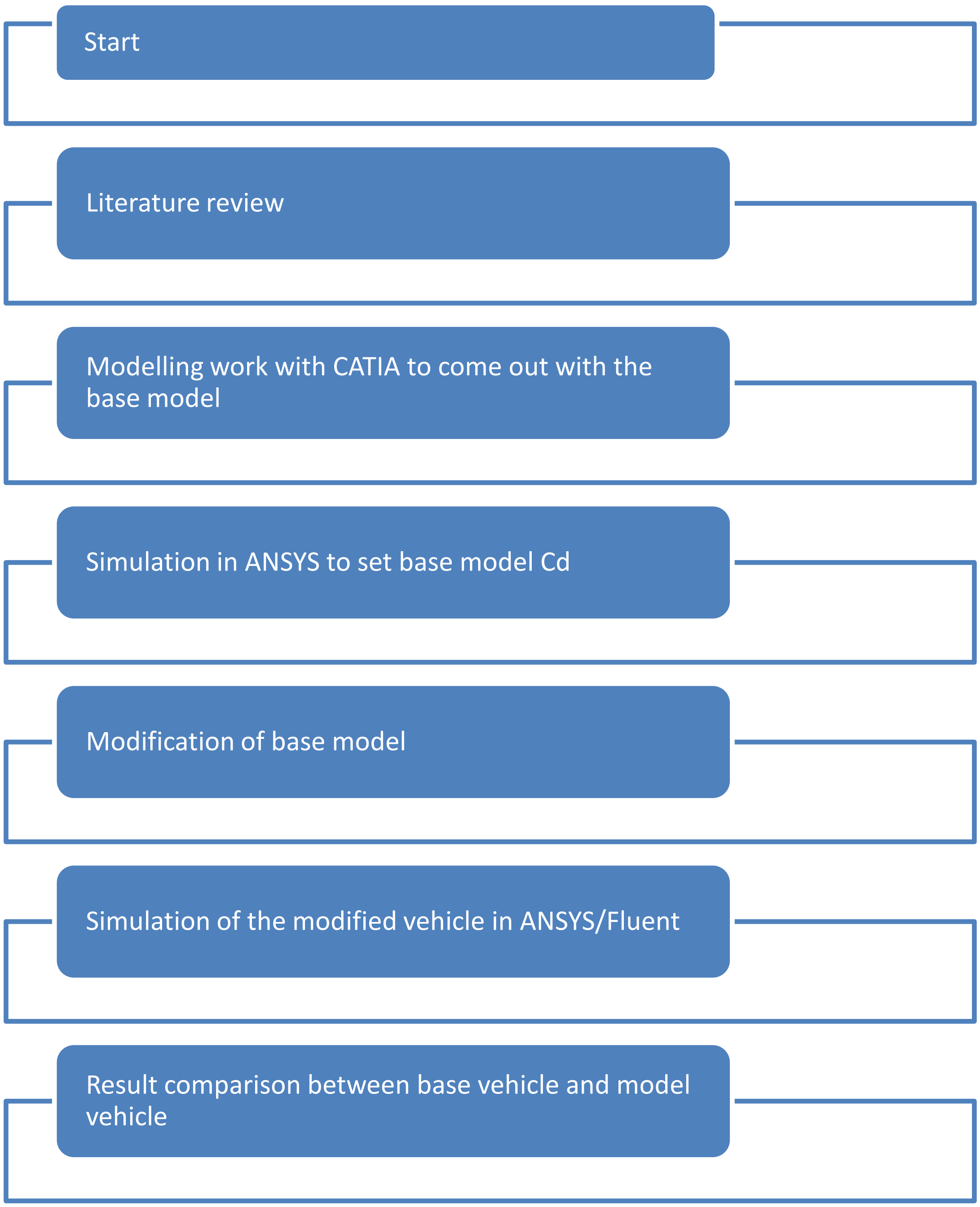

Figure 3.1 Flow chart

3.2 Simulation of air flow around vehicle in Ansys

Assumptions:

Properties

Use PSI system of units

Property type	= AIR-MM
Density	=1.23kg/m^3
Viscosity	= 1.983kg/m s

Conditions

Reference Pressure	= 101kPa
Outlet Pressure	= 0 kPa (relative pressure)
Default Temperature used	=293K
Flow Velocity of	= 9000mm/sec

1. Set Preferences
2. Establish Element Type
3. Import work from CATIA V5
4. Boundary condition

   -Solid Model Boundary Conditions
5. Preparation for Meshing
   - Size Controls, Lines, Set
   - Set the number of divisions and the ratio, OK
6. Meshing Step

   Use the Mesh Tool
   - Choose Areas
   - Line
   - Refine
   - Mesh
7. FLOTRAN Setup
8. Execution Control

9. Choose 50 Global Iterations to start with

   -We are not relying on the automatic termination criterion based on problem convergence

10. Flow Environment
11. FLOTRAN Execution
    - Done in SOLUTION:
    - Run FLOTRAN
    - Execute 50 iterations, look at the results and then run 50 more.
    - Convergence monitors indicate the normalized rate of change of the solution

3.3 Gantt Chart FYP

No.	Detail/ Work	Week														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Research to model vehicle body															
2	Modeling work with CATIA															
3	Analyze vehicle body design in ANSYS Fluent															
4	Submission of Progress Report															
5	Prepare the end result of the project															
6	Preparation for Pre-SEDEX Poster & Presentation															

7	Pre-SEDEX Poster & Presentation
8	Submission of Draft Dissertation to Supervisor
9	Submission of Dissertation and Technical Paper to Supervisor
10	Oral Presentation
11	Submission of Dissertation (hard bound)

Figure 3.2

CHAPTER 4

RESULT AND DISCUSSION

4.1 Modelling base CATIA model using Sketch Tracer

The first activity for CATIA modelling is to obtain sketch of PeroduaMyvi. Using Sketch Tracer tutorial for Sketch Tracer importing car blueprints for
<u>Modelling base CATIA model using Sketch Tracer</u>

Sketch

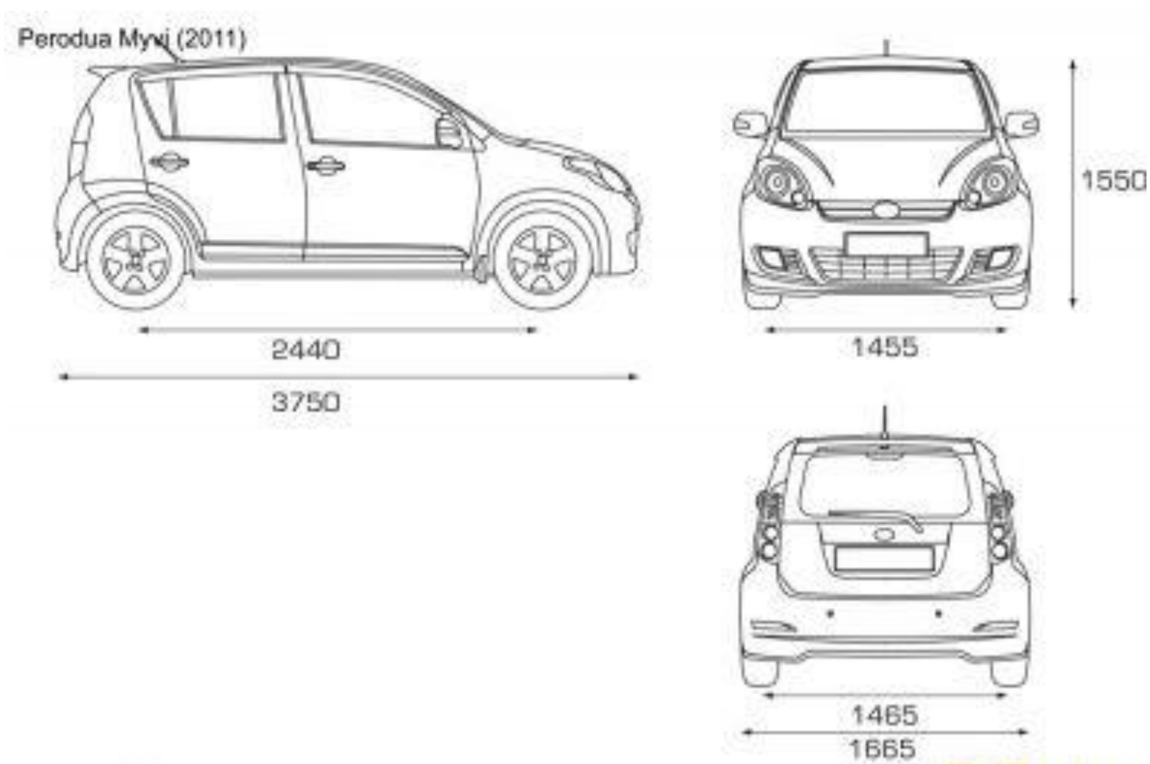

Figure 4.1 Orthographic view of PeroduaMyvi

4.1.1 Using CATIA Sketch Tracer, an immersive sketch of PeroduaMyViwas created.

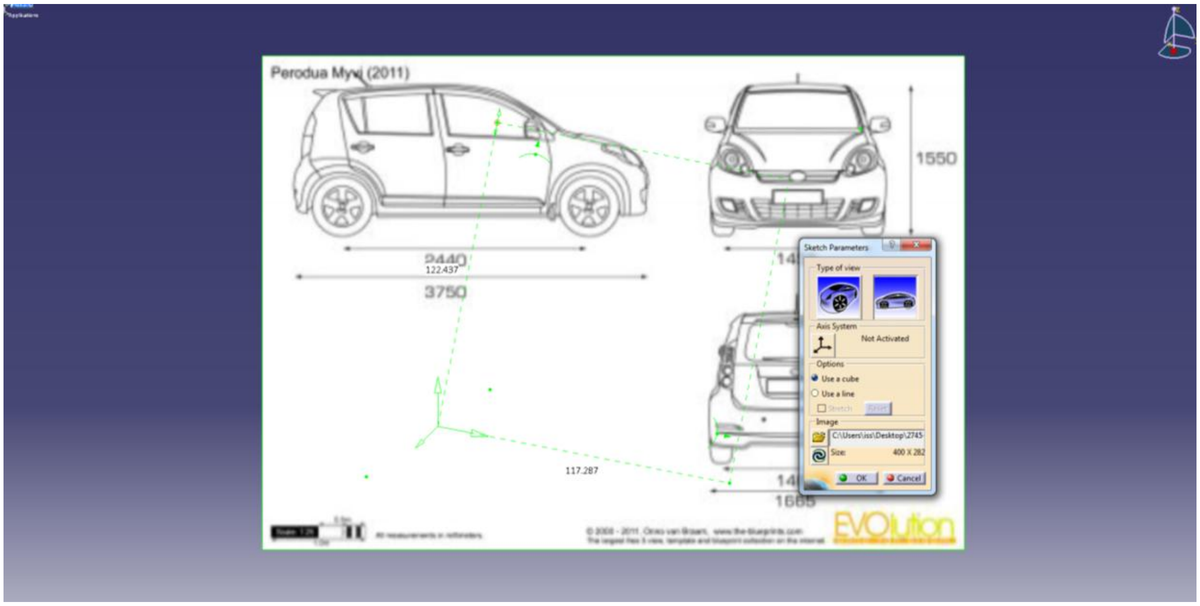

Figure 4.2 Imported orthographic view of PeroduaMyvi

4.1.2 Immersive sketch for the right side of the car

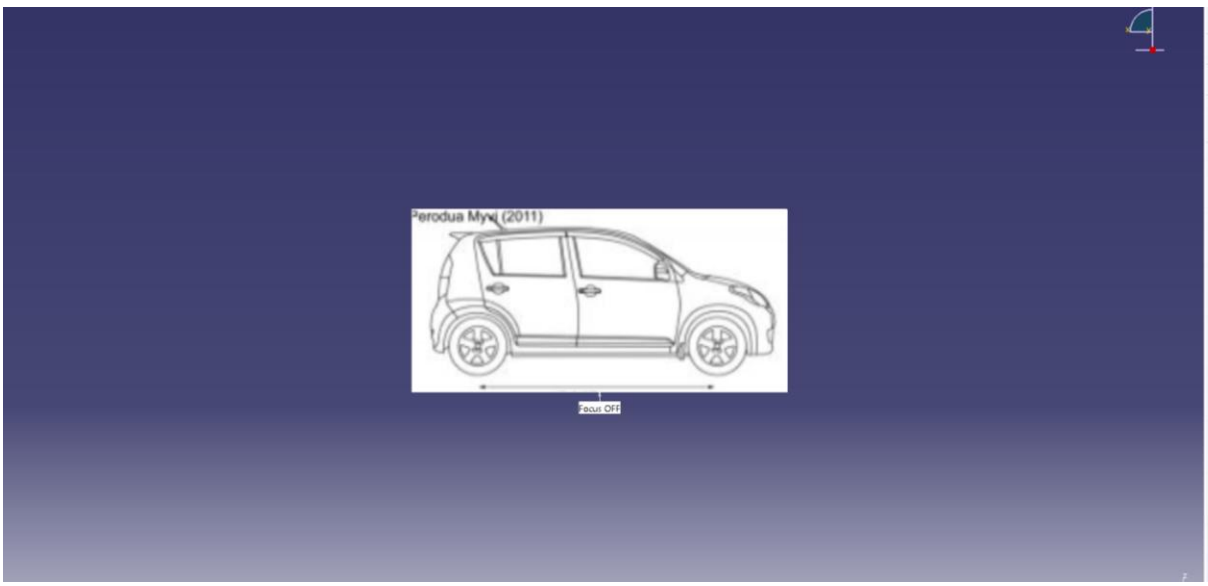

Figure 4.3 Right View of PeroduaMyvi

4.1.3 Create an immersive sketch for front area of car

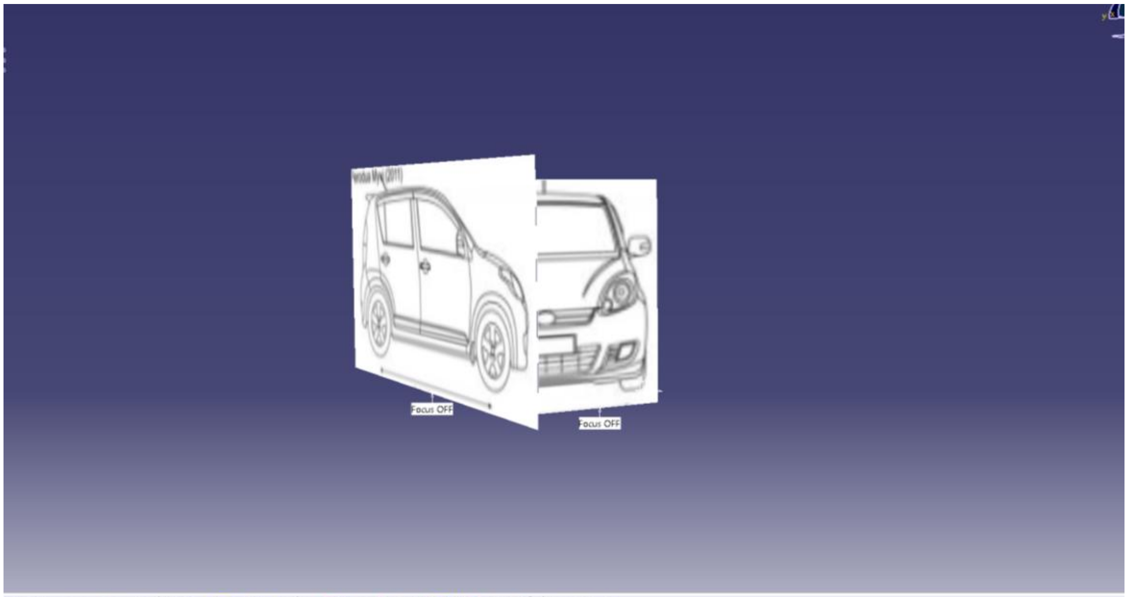

Figure 4.4 Immersive sketch

The figure showed the view of the vehicle from the side and the front is combinedtoform an immersive sketch. This process is very important before the views will be generated into a solid model.

4.2 Part, Wireframe and Surface Design

4.2.1 Start to model vehicle using part design and wireframe and surface option based on the immersive sketch

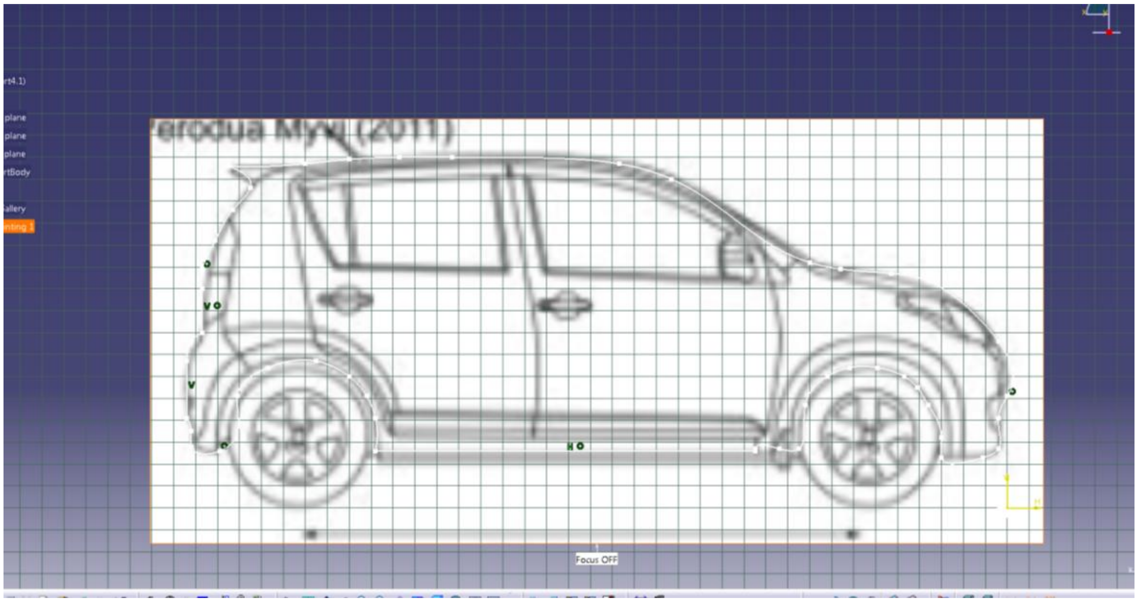

Figure 4.5Part design on immersive sketch

From the view obtained from Sketch Tracer, the process to build a solid model of a car is started by define the important points from sketch before the points was joint to form a 2D sketch. From there, a solid 3D model is formed using the extrusion function.

4.2.2 Produced 3D model

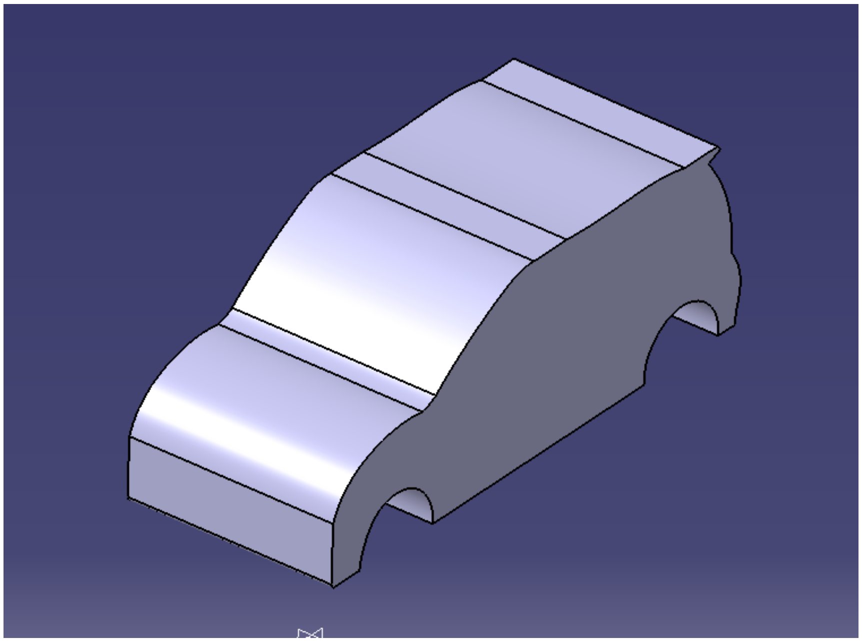

Figure 4.6 3D model of PeroduaMyvi

4.2.3 Base model after using pocket tool

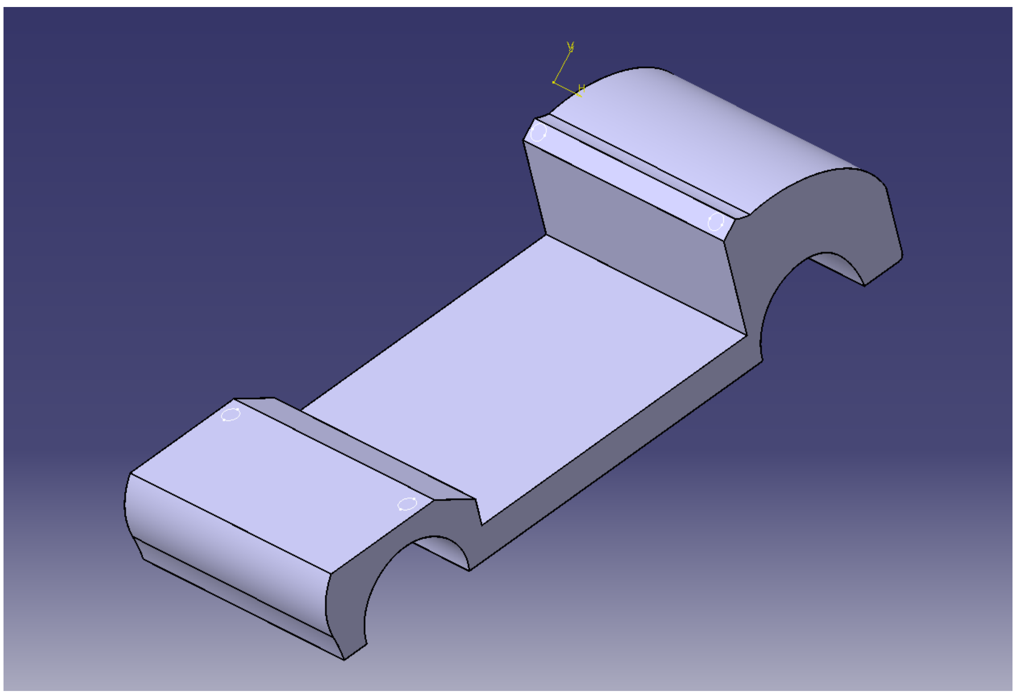

Figure 4.7 Cutline model

Figure 4.7 shows the shape of the vehicle after being cut using pocket tool. After this, space frame chassis will be installed on the top of the monocoque chassis of PeroduaMyvi . From the analysis made earlier, the boot height must be increased besidesrounding up the vertical and upper horizontal leadingedges on the front face to reduce forebody drag significantly.

4.3 Modeling of modified vehicle body design using space frame chassis 3D design

4.3.1 Modified model

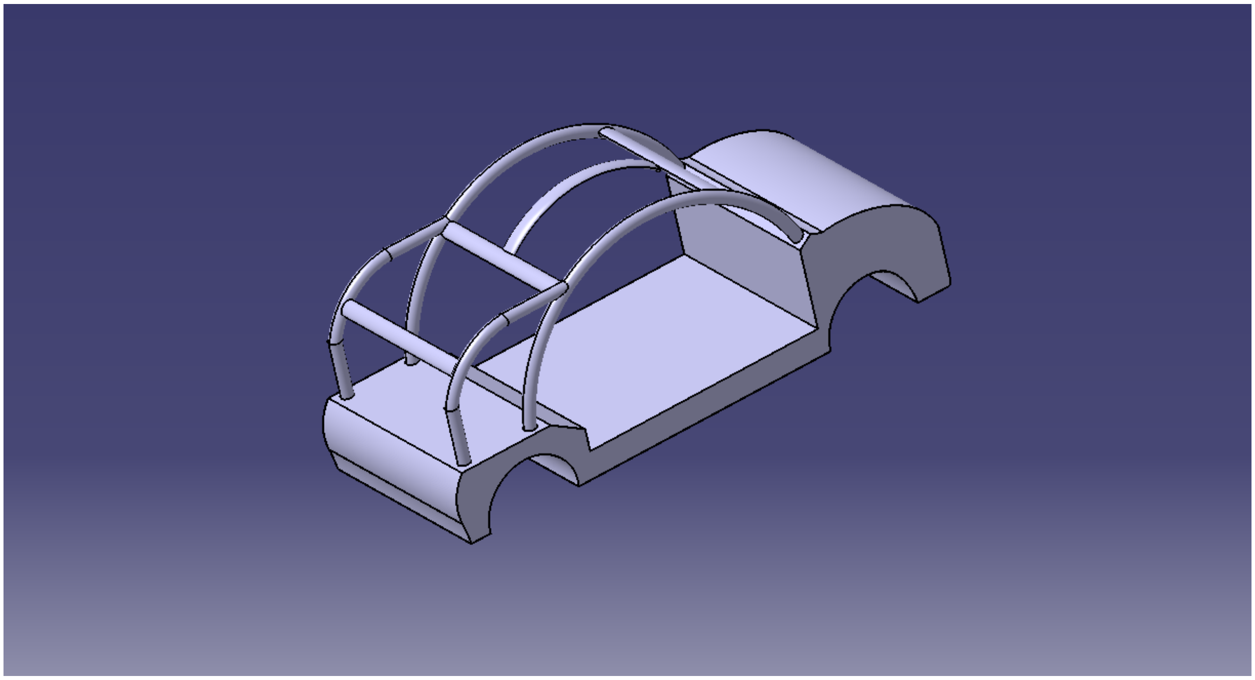

Figure 4.8 Modified model

4.3.2 Top View

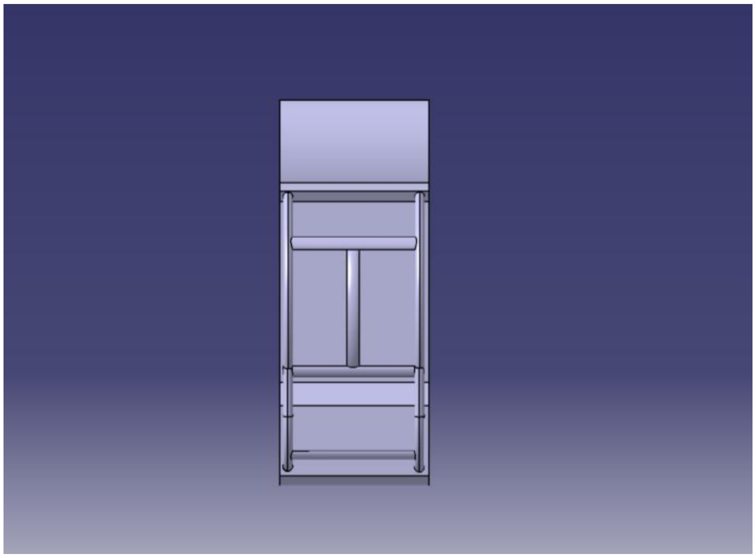

Figure 4.9 Top view of modified model

From the top view, it can be observed that the roof of original car, PeroduaMyvi has been removed and was replaced with 5 bar linkage which has no surface. With this modification the drag acting on the roof has been reduced.

4.3.3 Left View

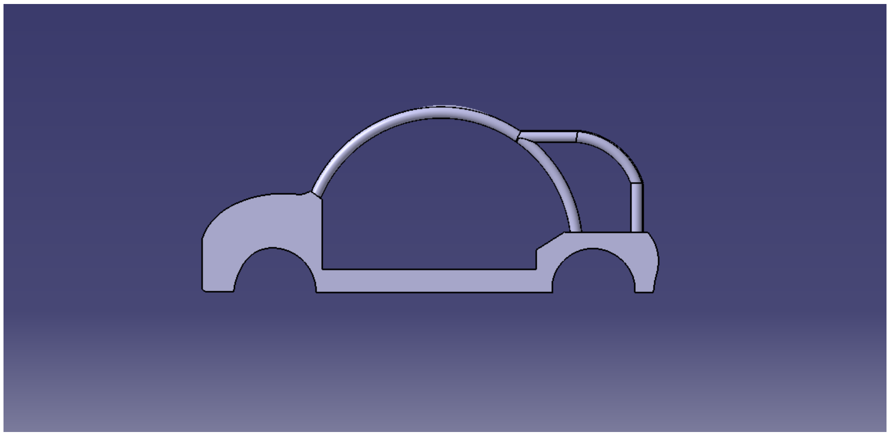

Figure 4.10 Side view of modified model

From the left view, the doors have been removed completely and this modification reduces the drag acting on the side wall of the car.

4.3.4 Front View

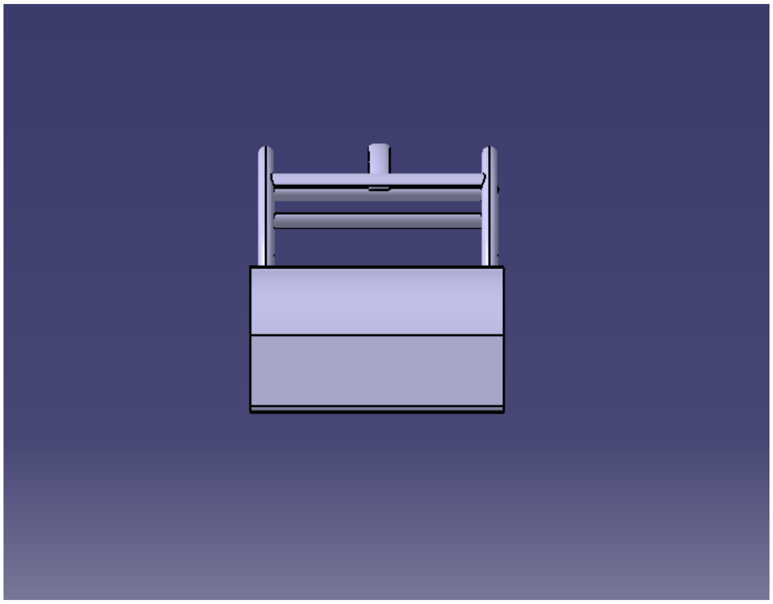

Figure 4.11Front view of modified model

The front view shows that the front part of the chassis has been modified by rounding up the vertical and upper horizontal leading edges on the front face is most significant drag reduction can be achieved.

Based on literature, reduction of forebody drag contributes about 65% of the total drag coefficient of the car.

4.3.5 Rear View

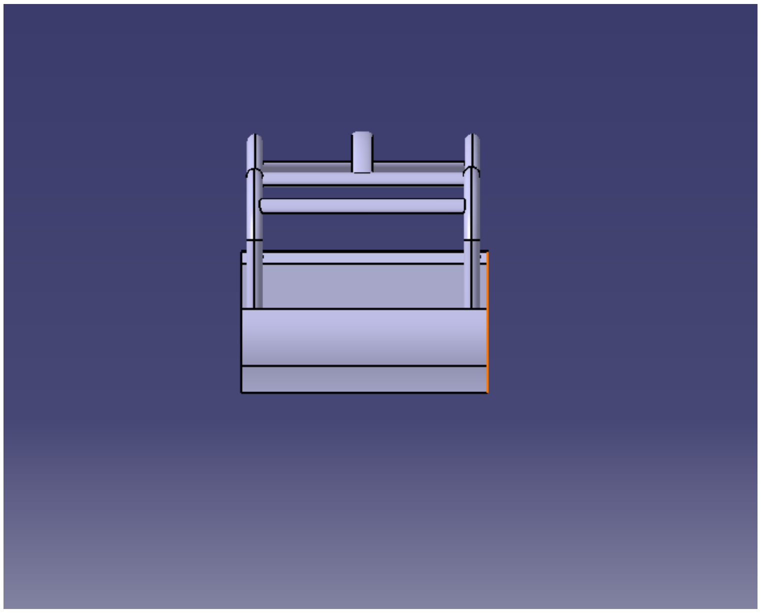

Figure 4.12 Rear view of modified model

To decrease the base drag of the vehicle, the rear part of the vehicle is tapered to increase the pressure at the back hence reduces the coefficient of drag. This contributes about 35% of the drag coefficient.

4.4.1 2Dsimulationson the airflow around the vehicle

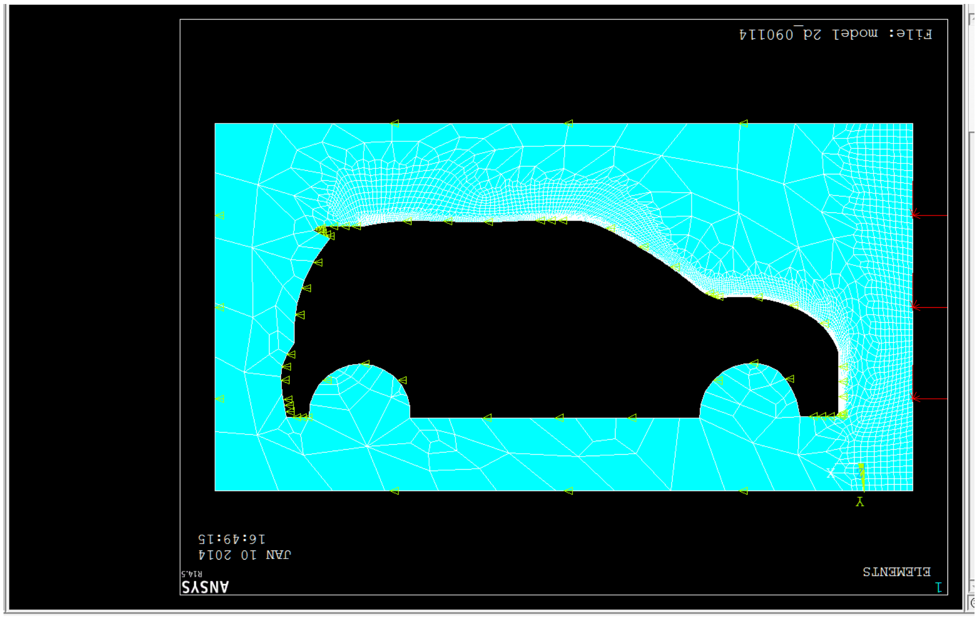

Figure 4.13 Mesh of 2D model

Figure 4 shows that the mesh process of the2D simulation on the airflow around the vehicle. The load is set around the boundary lines. From the figure, it can be observed that velocity of 90000mm/s was applied at the front side of the vehicle. For the pressure load, it was applied around the vehicle body and the other lines at the wall. The pressure applied to those areas is 0.

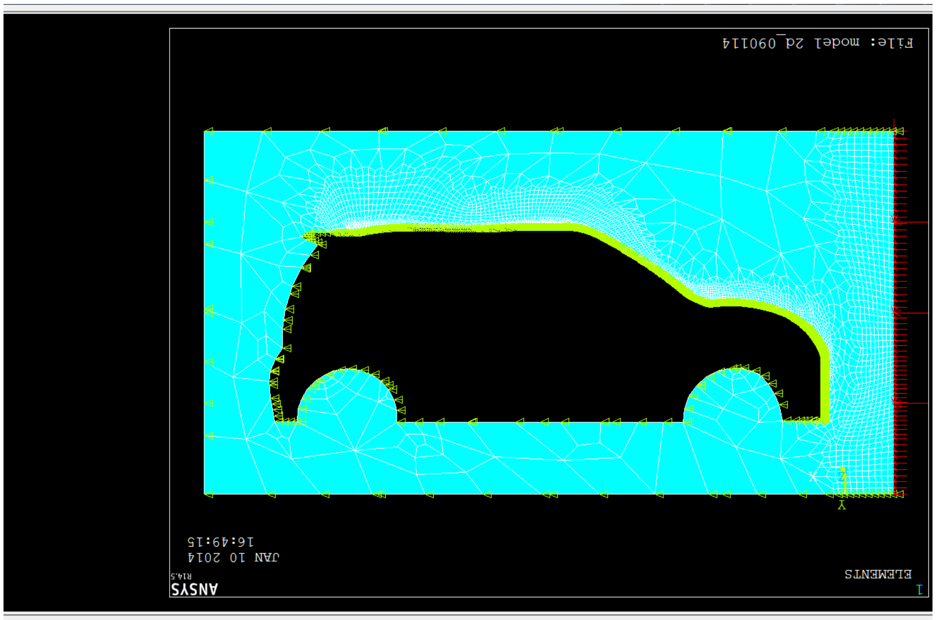

Figure 4.14 Mesh model after the run Flotran

The figure above shows that

Execute 50 iterations

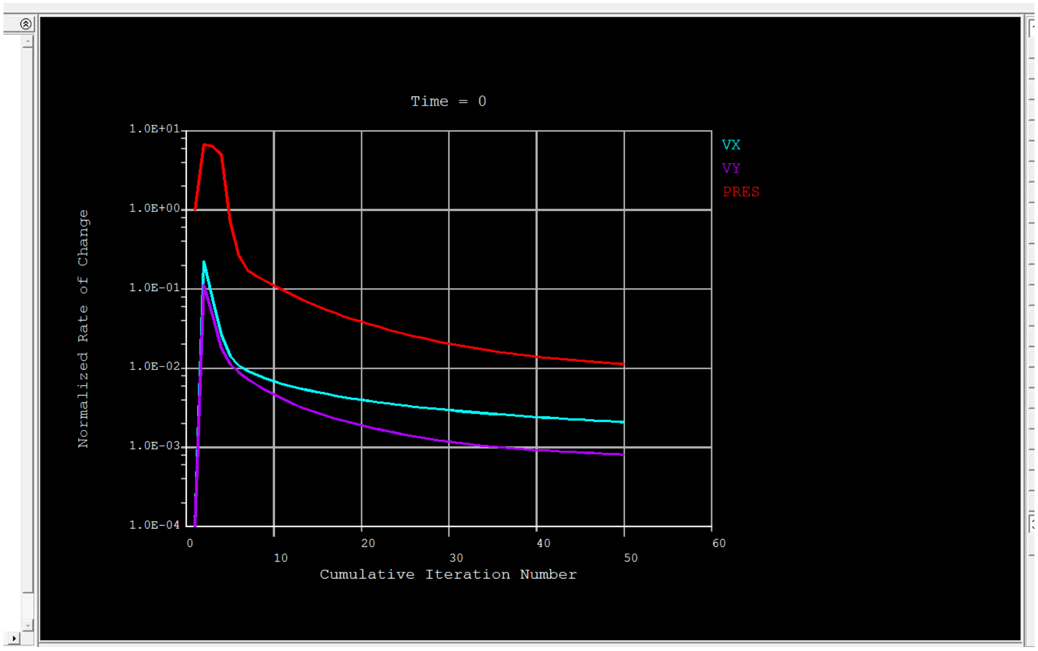

Figure 4.15 Normalized rate of change vs. cumulative iteration number (50 iteration)

Convergence monitors indicate the normalized rate of change of the solution. The figure showsall VX, VY and Pressure increase in the normalized rate of change to maximum at 3 iteration then rate of change decrease exponentially at 10 iteration before continue to drop further as the number of iteration increases.

After 100 iteration

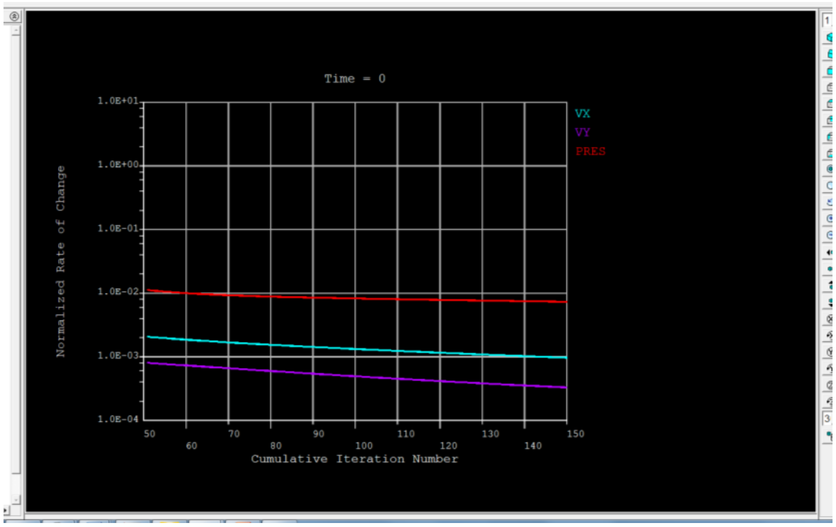

Figure 4.16 Normalized rate of change vs. cumulative iteration number(100 iteration)

The figure showsthat normalized rate of change of the pressure remains constant while the rate of change of velocity VX and VY keep decreasing with the increment of iteration number.

4.5 Discussion

By designing the new chassisfor PeroduaMyvi, the coefficient of drag has been reduced by:

1. Reduction of forebody drag(decrease the overpressure on the front)
   - The most significant drag reduction can be achieved byrounding up the vertical and upper horizontal leadingedges on the front face.
   - Relatively small amendments can result considerabledrag reduction.
   - The drag reduction of front spoiler is large if its use iscombined with rounded leading edges.
2. Reduction of base drag
   - Tapering of rear partresults is reduction of thesize of rear separationbubble and increase ofpressure.
   - Rear spoiler and increase ofboot height reduces dragand lift simultaneously.
   - Slanted trailing edges cancause longitudinal vorticesincreasing the drag and lift
3. Reduction of side wall, roof and underbody drag (decrease of shear stresses)

- Roof and side wall drag can be reduced by reduction of roughness of the wall (no protruding parts, frames)

- Underbody drag can be reduced by reducing the roughness (covering) and reducing the velocity inunderbody gap (tight underbody gap, front spoiler)

4. Reduction of vehicle mass
   - By replacing the most of the monocoque chassis by space fame chassis, most of the car parts has been reduced including removing the doors and the roof, the total mass is reduced.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

For this project, the factor of vehicle body designwhen only considersof aerodynamics factor from a fuel economy standpoint, you're primarily looking at coefficient of drag. Essentially, this is how easily a vehicle moves through the air, though drag isn't the only factor that is considered.

Optimization of vehicle bodies results in considerable reduction of fuel consumption, improvement of comfort characteristics and more favorable driving characteristics ofground vehicles.

In optimization besides wind tunnel investigations numerical simulation of flow field has become more and more important.

5.2 Recommendation

The coefficient of drag is not determined yet as there are few assumptions to be made before it can be tested in ANSYS Fluent.

Problem occurred when trying to simulate the model into ANSYS Fluent to get the coefficient of drag as there are a few assumption and steps need to be done.

Fabrication

In order to obtain a more accurate data, the modified vehicle model must be fabricated. The prototype can undergo simulation to obtain the aerodynamic performance of the vehicle such as example using wind tunnel test or coast down test.

In optimization besides wind tunnel investigations numerical simulation of flow field has become more and more important.

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