DESIGN, ANALYSIS AND FABRICATE SOLAR CAR CHASIS AND BODY (RACE TYPE)

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DESIGN, ANALYSIS AND FABRICATE SOLAR CAR CHASIS AND BODY (RACE TYPE)

MUHAMAD FIKRI BIN ABD RAHMAN

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

Faculty of Mechanical Engineering
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JUNE 2011

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled "*Design,Analysis And Fabricate Solar Car Chassis And Body (Race Type)*" is written by *Muhamad Fikri Bin Abd Rhaman*. We have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

(CHE KU EDDY NIZWAN BIN CHE KU HUSIN ....
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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project report 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.

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STUDENT'S DECLARATION

I declare that the work in this thesis entitled design, analysis and fabricate solar car chassis and body (race type) is the works of my own project accept as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature : ………………………….

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ABSTRACT

This thesis present about design and analysis solar car chassis and body. The objective of this project is to design analysis and fabricate the elements of body and chassis of a race type solar car for the target of the most lightweight and lowest material cost design. The solar car chassis was design using Solid Work 2010. Aluminum alloy AA6063-T6 was used as a material for solar car chassis. Two designs of solar car chassis were analyzed. The finite element modeling and analysis were performed using ALGOR software for analysis the solar car chassis. The maximum displacement magnitude, worst stress and worst strain was compare between solar car chassis Design 1 and Design 2. The solar car body is developing using Solid Work 2010. Fiberglass and alumunium sheet was used as a material for solar car body. Three designs of solar car body were analyzed. The computational fluid dynamic was performed using COSMOSFLOWORK software for analysis the solar car body. The pressure at front, rear and drag force was compare between solar car body Design 1, Design 2 and Design 3. As conclusion the best design for chassis is solar car chassis Design 2 and the best for body is solar car body Design 3.The solar car chassis design 2 have minimum displacement, worst strain and worst stress. The solar car body design 3 have minimum drag force and pressure at front of the body.

ABSTRAK

Tesis ini membentangkan tentang kerangka dan badan kereta solar. Tujuan dari projek ini adalah untuk mereka, membuat analisis dan elemen-elemen badan dan kerangka kerete solar jenis perlumbaan untuk target yang paling ringan dan kos bahan terendah. Kerangka kereta solar ini dibina menggunakan Solid Work 2010. Aluminium aloi AA6063-T6 digunakan sebagai bahan untuk kerangka kereta solar. Dua rekaan kerangka kereta solar dianalisis. Pemodelan unsur terhingga dan analisis dilakukan dengan menggunakan perisian ALGOR untuk menganalisa kerangka kereta solar. Perbezaan sesaran maksimum, tegangan dan regangan kerangka kereta solar Rekaan 1 dan Rekaan 2 di bandingkan. Badan kereta solar dibina menggunakan Solid Work 2010. Gentian kaca dan kepingan alumunim digunakan sebagai bahan untuk badan kereta solar. Tiga rekaan dari badan kereta solar dianalisis. Dinamik bendalir pengkomputeran dilakukan menggunakan perisian COSMOSFLOWORK untuk analisis badan kereta solar. Tekanan di bahagian depan, belakang dan daya rintangan antara badan kereta solar Rekaan 1, Rekaan 2 dan Rekaan 3 dibandingkan. Sebagai kesimpulan rekaan yang terbaik untuk kerangka adalah kerangka kereta solar Rekaan 2 dan yang terbaik untuk badan adalah badan kereta solar Rekaaan 3. Kerangka kereta solar Rekaan 2 mempunyai seseran tegangan dan regangan yang minimu. Badan kereta solar Rekaan 3 mempunyai tekanan dibahagian depan dan daya rintangan yang minimum.

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LIST OF SYMBOLS

ρ	Density
E	Modulus of Elasticity
S_U	Ultimate Tensile Strength
F_D	Drag force
V	Velocity
A	Frontal area
C_D	Drag coefficient
P	Pressure
σ	True Stress, Local Stress
δ	Displacement Magnitude
ε	True Strain, Local Strain
%	Percent

LIST OF ABBREVIATIONS

AA	Aluminium alloy
FEA	Finite Element Analysis
CFD	Computational Fluid Dynamic
FYP	Final Year Project
I.C	Internal Combustion

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Solar energy is referred to as renewable and sustainable energy because it will be available as long as the sun continues to shine. Estimate for the life of the main stage of the sun are another 4-5 billion years. The energy from the sunshine electromagnetic radiation, is referred to as insulation. The emergence of interest in solar energy utilization has taken place since 1970, principally is the worlds most abundant and permanent energy source. The amount of solar energy received by the surface of the earth per minute is greater than the energy utilization by the entire population in one year. (Pimentel et al.,1994)

Solar energy is also uses in commercial buildings. On an office building, atria can be covered with glass/glass PV modules, which can be semi-transparent to provide shaded light. On a factory, large roof areas have been the best location for solar modules. If they are flat, then arrays can be mounted using techniques that do not breach the weather proof roof membrane. Also, skylights can be covered partially with PV. The vertical walls of office buildings provide several opportunities for PV incorporation.

In automotive section, there are some races authorized to some organization to encourage corporate organization like university or college team to create their own solar car and compete each other in term of speed and also the energy efficiency of solar car. The most notable solar car races in present time are the World Solar Challenge and the North American Solar Challenge which been contested by a solar car from variety university and corporate team (Carroll, 2003).

Solar cars combine technology typically used in the aerospace, alternative energy and automotive industries. The design of a solar vehicle is severely limited by the amount of energy input into the car. Most solar cars have been built for the purpose of solar car races. Solar cars depend on PV cells to convert sunlight into electricity. In fact, 51% of sunlight actually enters the Earth's atmosphere. Unlike solar thermal energy which converts solar energy to heat for either household purposes, industrial purposes or to be converted to electricity, PV cells directly convert sunlight into electricity. When sunlight (photons) strike PV cells, they excite electrons and allow them to flow, creating an electrical current. PV cells are made of semiconductor materials such as silicon and alloys of indium, gallium and nitrogen. Silicon is the most common material used and has an efficiency rate of 15-20 %.(Pimentel et. al., 1994)

1.2 PROBLEM STATEMENT

Based on the World Solar Challenge rules and features of car design, the solar car must be designed follows these criteria:

i. Design solar car which not exceed the maximum length is 5000mm, maximum width is 1800mm and minimum height of the driver’s eye is 700mm above the road.
ii. Ordinary design of four wheel solar car is heavy and not very efficient in material usage, hence chassis will be design according three wheels.

1.3 OBJECTIVE OF THE PROJECT

After make a consideration with the project background and problem faced, I decide the objectives of my project such:

i. To design the elements of body and chassis of a race type solar car for the target of the most lightweight and lowest material cost design.
ii. To analyze the elements of body and chassis of a race type solar car.
iii. To fabricate the solar car than can withstand the load from the solar panel body, driver, actuator and also the suspension.

1.4 PROJECT SCOPES

This project is focusing on design and development the integrated chassis of a three wheel solar car which can drive by asian people as well as more aerodynamics and able to travel in long distance. This focus area is done based on the following aspect:

i. Design a chassis of three wheel solar car using aluminum and FRP.
ii. Perform analysis spaceframe chassis characteristic and discover the effects of stress, torsion and deflection on a chassis.
iii. Perform computational fluid dynamic analysis to discover the positive and negative pressure, also drag force
iv. Fabricated solar car where the primary analyzed design.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Basically chassis is considered as a framework to support the body, engine and other parts which make up the vehicle. Chassis lends the whole vehicle support and rigidity. Chassis usually includes a pair of longitudinally extending channels and multiple transverse cross members that intersect the channels. The transverse members have a reduced cross section in order to allow for a longitudinally extending storage space.

The chassis has to contain the various components required for the race car as well as being based around a driver's cockpit. The safety of the chassis is a major aspect in the design, and should be considered through all stages. Generally, the basic chassis types consist of backbone, ladder, spaceframe and monocoque. Different types of chassis design will result the different performance of each chassis.

2.2 TYPES OF CHASSIS

Chassis is considered to be one of the significant structures of an automobile. It is usually made of a steel frame, which holds the body and motor of an automotive vehicle. To be precise, car chassis or automobile chassis is a skeletal frame which bolts various mechanical parts like engine, tires, brakes, steering and axle assemblies. Chassis usually made of light a metal or composite plastic which provides strength needed for supporting vehicle components and load into it. Here I listed several different types of automotive chassis which include ladder chassis, backbone chassis, monocoque chassis and tubular space frame chassis (Wakeham, 2009).

Ladder chassis is considered to be one of the oldest forms of automotive chassis or automobile chassis that is still been used by most of the SUVs till today. It is also resembles a shape of a ladder which having two longitudinal rails inter linked by several lateral and cross braces. The lateral and cross members provide rigidity to the structure (Wakeham, 2009).

The other type of chassis is backbone chassis which has a rectangular tube like backbone and simple in structure. It usually made up of glass fiber that is used for joining front and rear axle together and responsible for most of the mechanical strength of the framework. The space within the structure is used for positioning the drive shaft in case a rear-wheel drive. Furthermore, the drive train, engine and suspensions are all connected to each of the ends of the chassis. This type of chassis is strong enough to provide support smaller sports car besides it is easy to make and cost effective (Wakeham, 2009).

As for monocoque chassis, most modern cars nowadays use this type of chassis. A monocoque chassis is a single piece of framework that gives shape to the car. A one-piece chassis is built by welding several pieces together. It is different from the ladder and backbone chassis as unlike them incorporated with the body in a single piece, where as the former only support the stress members. The demanding of a monocoque chassis highly increased since it is cost effective and suitable for robotized production (Christopher, 2004).

In this study, it is decided that tubular space frame chassis is used for the urban car. Since ladder chassis is not strong enough, motor racing engineers have developed a 3-dimensional design which known as tubular space frame. Tubular space frame chassis employs dozens of circular-section tubes (some may use square-section tubes for easier connection to the body panels though circular section provides the maximum strength), position in different directions to provide mechanical strength against forces from anywhere. These tubes are welded together and form a complex structure. For higher strength required by high performance sports cars, tubular space frame chassis usually incorporate a strong structure under both doors. Tubular space frame chassis also very strong in any direction compared with ladder chassis and monocoque chassis of the same weight. The Figure 2.1 below showed the sample tubular space frame chassis of TVR Tuscan (Christopher, 2004).

Figure 2.1: An example of chassis of TVR Tuscan
Source: (Wan, 2000)

Discussing the current chassis design, there is several existing design of aluminium chassis that had been used by automobile company around the world. Lotus Engineering as the example has been building cars with aluminium chassis for many years. Lotus succeeds to introduce that none of the chassis are welded since the strength of aluminium is decrease once it is welded. They have decided that the chassis are held together only with screws and adhesive. When Lotus first introduced the method on the low-volume Elise in 1996, company leaders were worried about the market acceptance for what is essentially a glued-together car, but the technique proved so successful (over 23,000 cars produced with no reported failures) that it has become the basis of a new higher volume venture that may help to bring aluminium-intensive vehicles more into the mainstream (Whitfield, 2004).

2.3 CHASSIS DESIGN PRINCIPLE

The fundamental principle of a chassis design states that the chassis is to be designed to achieve the torsional rigidity and light weight in order to achieve good handling performance of a race car. By the definition, torsional rigidity (TR) is refers to the ability of chassis to resist twisting force or torque. In the other words, torsional rigidity is the amount of torque required to twist the frame by one degree. These parameters also applied to spaceframe chassis. Generally, the effect of the torsional rigidity on spaceframe is different to the monocoque due to their construction format, but the structure is used to approximate the same results as the difficult to twist monocoque chassis. Figure 2.2 shows the torsional rigidity applies to race car chassis. (Matt, 1999)

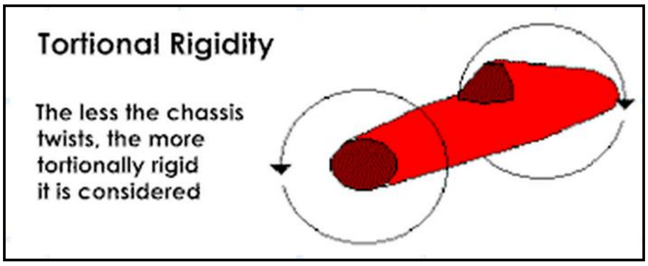


Figure 2.2: Torsional rigidity on race car chassis.

Source: (Matt, 1999)

According to the statement above, chassis designed must have high torsional rigidity in order against the twisting force or torque. In order to increase torsional rigidity on the chassis, the format of tube pipes arrangement must be considered. By strategically positioning a frame member, torsional rigidity increase significantly. The principle is to place the frame members in a triangulated format as shown in Figure 2.3.

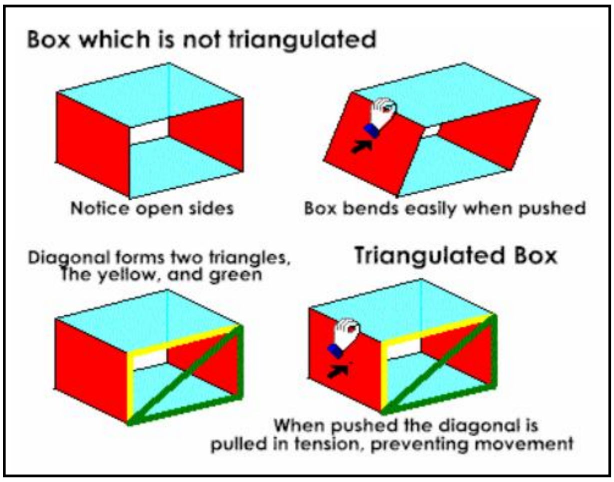


Figure 2.3: The strategy on positioning a spaceframe member.

Source: (Matt, 1999)

The triangulated box imparts strength by stressing the diagonal in tension and compression. As shown, the box will not easily deformed by bending force due to the triangulated format of frame. Hence, most race car chassis today designed in triangulated format as shown in Figure 2.4 below.

Figure 2.4: Juno Racing Ltd. spaceframe

Source: (Sport Race, 2004)

2.4 ADVANTAGES OF SELECTED CHASSIS

Since the spaceframe chassis is the most suitable chassis type used in the prototype car construction in WORLD SOLAR CHALLENGE compared to others chassis types, hence I decide to apply this concept in my project.

The advantages of spaceframe chassis are described below:

i) Since the spaceframe systems are triangulated format, it will provide maximum strength and minimum deflection of the design compare to the other chassis types due to the support from tubular pipes.

ii) Spaceframe chassis systems are lighter than traditional steel. Therefore, it provides significant economy in foundation costs.

iii) Using a spaceframe chassis in a race car, the high torsional rigidity can be achieved as well as its light weight. It means that, spaceframe chassis designs will enchance the rigidity/weight ratio.

2.5 CHASSIS DESCRIPTION

When designing the frame for a solar powered vehicle, many parameters are important to take into account. Since the high importance of low aerodynamic resistance (Roche et al,1997), the design space for the frame is quite complex. Furthermore, the frame has to meet the requirements for strength and stiffness in every load condition. Moreover, mounting points need to be provided to attach different components such as the battery package, electronics, suspension parts, body panels, etc.

Reliability is crucial when developing a solar powered vehicle (Carroll, 2003). Hence, the team chose to work with a conventional space frame structure instead of a monocoque structure. Even though composite monocoques have the potential to be very light but the strength calculation and the manufacturing is rather complex which often leading to a result the body frames with higher total mass (Potter Kevin, 1997). Space frame structures are by nature very efficient. Bending moments are transmitted as tension and pressure loads along the length of each tube. By consequence, strength calculation can be accurate and straight forward. Manufacturing could be done by welding extruded tubes together.

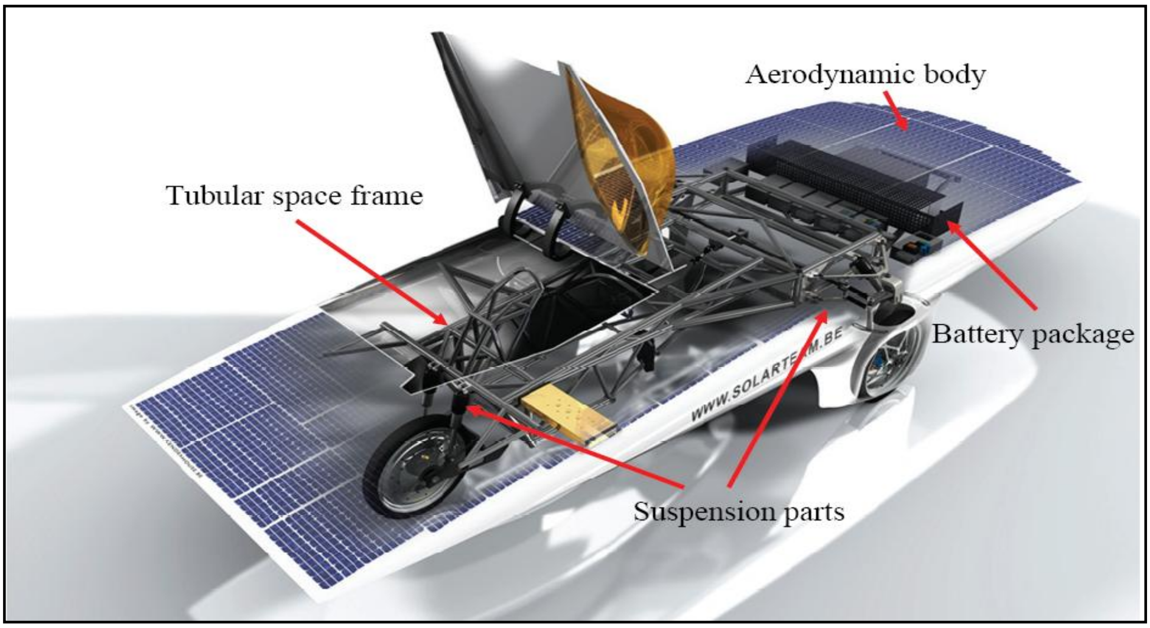


Figure 2.5: Different components in the solar powered vehicle

Source: (Brecht,2008)

2.6 MATERIAL SELECTION

Different chassis materials can reduce the weight of the vehicle, improving the vehicle power to weight ratio. Material selection can also provide advantages by reducing member deflection, increasing chassis strength and can determine the amount of reinforcement required. The materials which used to build the spaceframe chassis in this project are aluminum and fiberglass.

2.6.1 Aluminum

Aluminum is a nonferrous material with very high corrosion resistance and very light material compared to steels. Aluminum cannot match the strength of steel but its strength-to-weight ratio can make it competitive in certain stress application. Aluminum can also be alloyed and heat treated to improve it mechanical properties, which then makes it much more competitive with steels however the cost increases dramatically.

Pure aluminum is also a possible material and is reasonably affordable and very light but it is the weakest and will require extra reinforcement to produce a rigid chassis. Aluminum is very hard to work with as it requires very skilled welding and is an overall softer metal. Basically there are several types of aluminum. For this project, I decide to use Aluminum Alloy 6063-T6. Aluminium alloy 6063 is one of the most extensively used of the 6000 series aluminium alloys. (Aalco. 2005)

Aluminum Alloy 6063 is the least expensive and most versatile of the heat-treatable aluminum alloys. It has most of the good qualities of aluminum. It offers a range of good mechanical properties and good corrosion resistance. It can be fabricated by most of the commonly used techniques. In the annealed condition it has good workability. The typical properties of aluminum alloy 6063 include medium to high strength, good toughness, good surface finishing, excellent corrosion resistance to atmospheric conditions, good workability and widely available. It is welded by all methods and can be furnace brazed. It is available in the clad form ("Alclad") with a thin surface layer of high purity aluminum to improve both appearance and corrosion resistance (Aalco. 2005).

This aluminum type is used for a wide variety of products and applications from truck bodies and frames to screw machine parts and structural components. 6063 is used where appearance and better corrosion resistance with good strength are required.

Table 2.1, Table 2.2 and Table 2.3 below shows the typical composition, the physical properties and the mechanical properties of Aluminum Alloys 6063 respectively.

Table 2.1: Typical Composition of Aluminum Alloys 6063

Element	**6063 (% Present)**	**6063A (% Present)**
Si	0.2 to 0.6	0.3 to 0.6
Fe	0.35 max	0.15 to 0.35
Cu	0.1 max	0.1
Mn	0.1 max	0.15
Mg	0.45 to 0.9	0.6 to 0.9
Zn	0.1 max	0.15
Ti	0.1 max	0.1
Cr	0.1 max	0.05
Al	Balance	Balance

Source: (Aalco. 2005)

Table 2.2: Physical Properties of Aluminum Alloys 6063

Property	**Value**
Density	2.70 g/cm^3
Melting Point	600°C
Modulus of Elasticity	69.5 GPa
Electrical Resistivity	0.035x10^{-6} O.m
Thermal Conductivity	200 W/m.K
Thermal Expansion	23.5 x 10^{-6} /K

Source: (Aalco. 2005)

Table 2.3: Mechanical Properties of Aluminum Alloys 6063

Temper	**O**	**T4**	**T6**
Minimum Proof Stress 0.2% (MPa)	50	65	160
Minimum Tensile Strength (MPa)	100	130	195
Shear Strength (MPa)	70	110	150
Elongation A5 (%)	27	21	14
Hardness Vickers (HV)	25	50	80

Source: (Aalco. 2005)

2.6.2 Fiberglass

Fiberglas is a material which made from extremely fine fibers of glass. It is used as a reinforcing agent for many polymer products and resulting composite material known as fiber-reinforced polymer (FRP) or glass-reinforced plastic (GRP). It’s called as fiberglass due to popular usage. Fiber reinforced polymer (FRP) composites are thin laminates that are externally bonded to structural members using epoxy adhesive. The FRP significantly increases the members' load carrying capacity. These structural strengthening systems are made of high strength fibers (such as glass, kevlar, and carbon) embedded in a resin matrix. The resin protects the fibers, maintains their alignment, and distributes the loads evenly among them (FGS, 2010).

FRP's, which have been extensively used in industries such as aerospace, automotive, and sport equipment, are now becoming a mainstream technology for the structural upgrade of concrete structures. In addition to their high-strength and lightweight properties, important characteristics of FRPs for structural repair and strengthening applications are their non-corrosive properties, speed and ease of installation, lower cost, and aesthetics. FRP fabrics may be adhered to beams and slabs to increase their shear and flexural capacity, and can be wrapped around columns to increase their load carrying capacity and ductility for seismic events (FGS, 2010).

FRP has high degree of design flexibility. The practical uses of FRP are virtually endless. Its unique physical properties allow it to be easily tooled, molded and manufactured to meet almost any specifications. Because there are few constraints on size, shape, color or finish, the styling and appearance can take precedence over manufacturing costs. This design freedom and the easiness to work make FRP an economical alternative for the manufacture of any component or finished product in any quantity (FGS, 2010).

Basically, there are several types of glass fiber. For my project, I decide to use E-glass fiber type. E-Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fiber forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fiberglass. E-Glass is a low alkali glass with a typical nominal composition of SiO_2 54wt%, $Al_2O_3$14wt%, CaO+MgO 22wt%, B_2O_3 10wt% and Na_2O+K_2O less then 2wt%. Some other materials may also be present at impurity levels. The properties that have made E-glass so popular in fiberglass and other glass fiber reinforced composite include low cost, high production rates, high strength, and high stiffness, relatively low density, and non-flammable, resistant to heat, good chemical resistance, relatively insensitive to moisture, able to maintain strength properties over a wide range of conditions and good electrical insulation (Azom. 2001).

Table 2.4 below shows the typical properties and the mechanical properties of some common fiber.

Table 2.4: Comparison of typical properties for some common fibers.

Materials	**Density (g/cm^3)**	**Tensile Strength (MPa)**	**Young modulus (GPa)**
E-Glass	2.55	2000	80
S-Glass	2.49	4750	89
Alumina (Saffil)	3.28	1950	297
Carbon	2.00	2900	525
Kevlar 29	1.44	2860	64
Kevlar 49	1.44	3750	136

Source: (Azom. 2001)

2.7 THE ADVANTAGES OF USING ALUMINIUM FOR A CHASSIS

There were researches made from current aluminium chassis in the industry. In term of corrosion resistances, we all believe that aluminium has excellent corrosion resistances. This is due to our experience with very weak sheet materials used for body or anodized parts. The high strength heat treatable alloys do not like to anodize. Even if we could anodized a complete chassis after fabrication it would not be successful and could not successfully weld after anodizing. Anodizing produces a relatively thick oxide layer on the surface of aluminium and it is the oxide which seals the surface and gives aluminium it excellent corrosion resistance.

Existing urban vehicle currently used aluminium as material for their chassis. To support the details, Jaguar’s Lightweight Vehicle Technology is the most suitable example. Jaguar’s industry leading and riveted aluminium monocoque body structure, introduced their latest model. The aluminium body incorporates the latest thinking in epoxy bonding and riveting techniques to produce a chassis that is very safe, as well as very light. In fact, the new model, XK’s aluminium chassis is significantly lighter and stiffer yet impressive 50 percent stiffer respectively. Jaguar’s Lightweight Vehicle Technology is unique in the industry as a complete aluminium monocoque body structure as distinct from an aluminium spaceframe with separate aluminium panels. Its strength and light weight come from the way the shell is constructed, using new jointing technologies developed by Jaguar and its suppliers (Surrey, 2010).

Besides, safety is another major benefit of this very strong construction method. That is partly inherent in aluminium as a material, which absorbs significantly more energy per kilogram of material weight than steel when it is deformed. But the strength advantage doesn’t only apply to high-speed impacts; it also means lower-speed accident repair costs are kept to a minimum. The reduction in the number of joints in the all-new XK further increases strength, and the front of the body is protected by easily replaced ‘crush cans’ that absorb the energy in impacts up to just over 9mph (15kph).

The new XK’s all-aluminium doors are each over 13 lbs (6 kg) lighter than an equivalent steel door and their mountings are significantly stiffer, which allows smaller gaps. Mounting the window glass rails directly to the aluminium castings at the front and rear of the door gives better sealing from the frameless layout and an impressively solid sound and feel when closed. Figure 2.3 below shows the chassis of the new XK model (Surrey, 2010).

Figure 2.6: The chassis of the new XK model

Source: Surrey (2010)

2.8 FINITE ELEMENT ANALYSIS (FEA) USING ALGOR

Finite Element Analysis (FEA) Finite Element Analysis (FEA) was first developed by R. Courant in 1943, who utilized the Ritz method of numerical analysis and minimization of variation calculus to obtain approximate solutions to vibration systems. FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition (Widas, 1997).

2.9 LIFT FORCE AND DRAG FORCE

Lift or down force is the force generated perpendicular to the direction of travel for an object moving through a fluid (gas or liquid). The same effect occurs when a fluid moves over a stationary object, such as an airfoil in a wind tunnel. Airfoils are the most efficient shapes found so far that can generate lift while at the same time minimizing drag(Freddie Mehta, 2006). Drag is an unavoidable consequence of an object moving through a fluid. Drag is the force generated parallel and in opposition to the direction of travel for an object moving through a fluid. Drag can be broken down into the following two components:

i. Pressure drag - dependent on the shape of an object moving through a fluid.
ii. Friction drag - dependent on the viscous friction between a moving surface and a fluid, derived from the wall shear stress.

The lift and drag force depend on the density ρ of the fluid, the upstream velocity V, the size, shape and orientation of the body(Cimbala & Cengel, 2006). The fluctuation in the local air stream velocity produces a spectrum of pressure on the various faces of the vehicle. This pressure creates a rise in forces acting along the three axis (Wolf-Heinrich Hucho,1987).

The pressure drag force is given by:

$$F_{D,\ pressure} = (\rho \ V^2 A \, C_D) / 2 \qquad (2.1)$$

The friction drag force is given by:

.

$$F_{D,\ friction} = (\rho \ V^2 L \, D \, C_D) / 2 \qquad (2.2)$$

The pressure drag is proportional to the frontal are and to the differences between the pressure acting on the front and back of the front and back of the immersed body. Therefore, the pressure drag is usually dominant for blunt bodies. The pressure drag becomes most significant when the velocity of the fluid is too high for the fluid to be able to follow the curvature of the body. The friction drag can be neglected because in blunt bodies the effect of friction drag is small (Cimbala & Cengel, 2006).

2.10 COMPUTATIONAL FLUID DYNAMIC (CFD) USING COSMOSFLOWORK

CFD is a computational technology that enables researcher to study the dynamics of fluid flow. Using CFD, a computational fluid dynamic model that represents a system or device can be analyzed. Then the physics and chemistry of the flow can be applied to this virtual prototype and the software will predict the flow dynamics and related physical phenomena. Therefore, CFD is a sophisticated computationally-based analysis technique. Besides that, CFD can be used model coupled phenomena of gases and liquids, including heat and mass transfer, moving bodies, multiphase flow, chemical reaction, fluid-structure interaction and acoustics through computer modeling (John, 2008). Using CFD, the product will get to the market faster. This is because CFD can save time that used for building prototype. CFD is commonly used for aerodynamics study of air craft and vehicles (lift and drag), hydrodynamics of ships, combustion (I.C engines and gas turbines), marine engineering (loads on off shore structures), meteorology (weather prediction) and etc (Versteeg & Malalasekera, 1995). A moving car experiences an increase in aerodynamic forces with an increase in its velocity. Just like an airfoil, the body of a car experiences drag and lift forces, the only major difference being that due to the shape of a car it experiences a negative lift or down force (Scibor,1975). The down force generated by its shape gives the car the ability to go around non-banked curves with higher speeds. Hence an aerodynamically superior car design generates a low drag force but a high down force. An aerodynamically superior car design can reduce power uses and increase its efficiency (Scibor,1975).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Mostly the chassis type used in the construction of prototype car is spaceframe. This is because due to the specification of the spaceframe which is more rigid than other chassis. But, certain of the chassis designed in the solar car is not totally look like a spaceframe chassis, instead the design is integrated between monoque and spaceframe. It’s mean that for the driver and engine compartment, the designer use the spaceframe chassis concept in order to support the load and combined with monoque concept to build overall body which made by FRP. The designer uses the combination between spaceframe and monocoque in order to reduce the weight of the car.

Theoretically, the chassis design concept state that the chassis designed must have the triangulated format of tubular pipes in order to increase the torsional rigidity of the chassis. But for the designing of the prototype car using spaceframe chassis for solar car, it is not important to follow this concept because the goals of the design is to have a lightweight car which can cruise further by using less amount of energy. It’s mean that, the car will not go faster and not facing the twisting force or torque. The designer will ignore about the principle which is to place the frame members in a triangulated format as mentioned before.

3.2 THE DESIGN PROCESS

The engineering design process is the steps of chassis and body design construction process. This process applied the basic science, mathematics and fundamental of engineering required in the project. The design process begins when all the analysis related to the project is done. This chapter explains how chassis and body were designed and how the simulations of the chassis and body were performed.

3.3 DESIGNING METHOD

This part will explain about how the chassis and body design is performed. Before get the final chassis and body design, several steps must to be considered in order to get the best design. For this part, SOLIDWORK 2009 is used to create the model of the chassis and body design, ALGOR V 23.1 used to analyze the model of chassis and COSMOSFLOWORK used to analyze the model of body . Flow chart below explains how the chassis and body design is performed.

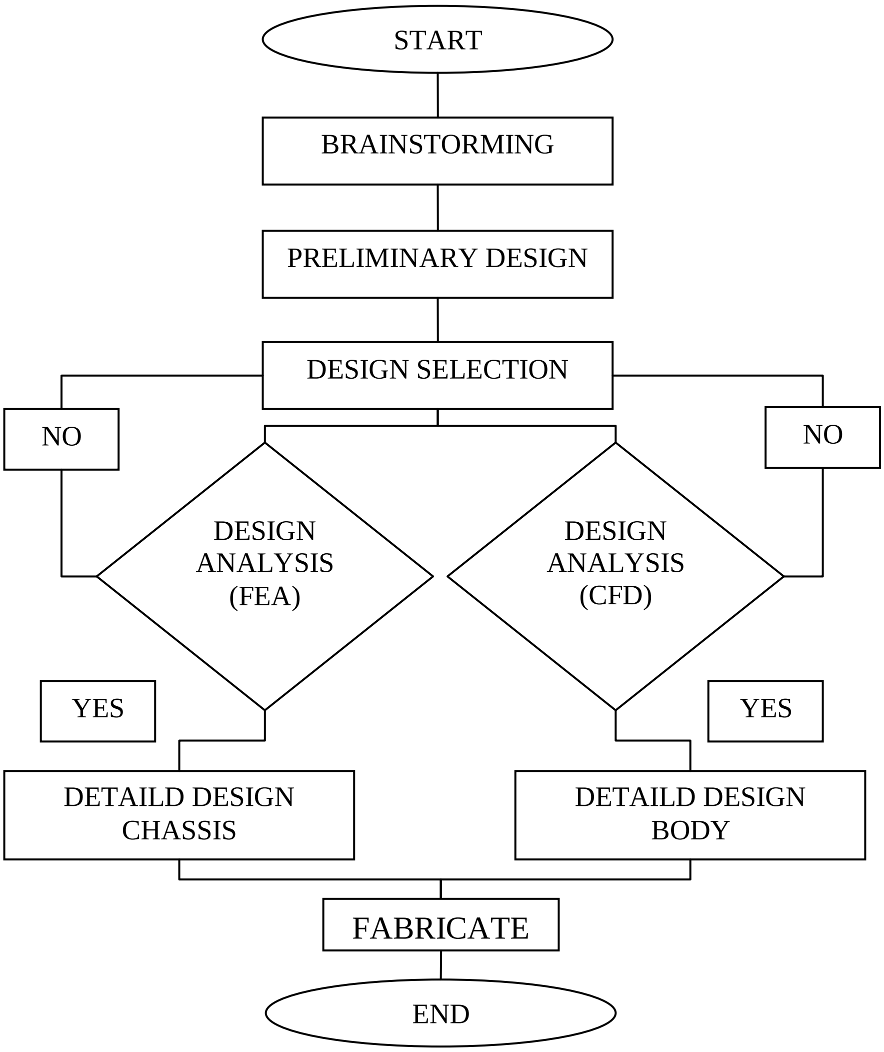


Figure 3.1: Chassis and Body Design Flow

3.3.1 Brainstorming

Before start the project, rough ideas and the steps proposed must be drafted to ensure that the project follows the planned steps. The rough idea about the chassis and body designed is described by sketching the chassis and body.

3.3.2 Preliminary Design

Preliminary design process is the evaluation leading up to the selection of the best overall design. It includes the overall system configuration, basic schematics and layout. In these step, the parameters that must be noticed is the rules of world solar challenge. The basic design must follow the regulations. A decision then must be made on one of the design as the preliminary design. These designs must go through to next step of design process.

3.3.3 Design Selection

The solar car chassis design is refer from Team 17 solar car from FAMU/FSU College of Engineering. This chassis have 3 wheels, which is 2 tires for front and 1 tire for rear. One rear wheel attached using a cantilever suspension, a braking system comprised of two front disc brakes, a parking/emergency brake, and a steering system. The rear wheel is attached to the motor and is used to propel the car.

3.3.4 Chassis Design Analysis Using ALGOR

The three-dimensional (3D) wire frame is developed using FEMPRO which is shown in Figure 3.1. The finite element model is developed using the beam type element as shown in Figure 3.2 The linear static analysis is considered to determine the stress with linear material, element definition is pipe with diameter 25 mm and wall thickness 3 mm. Material properties play an important role in the result of the FE method. The material properties are one of the major inputs. The material information is listed in Table 3.1. The solar car chassis was loaded with forces applied whereas the front arm and rear arm was fixed. The forces are from 6N to 60N due the weight applied to chassis. The loading and constraints of the chassis is shown in Figure 3.3.

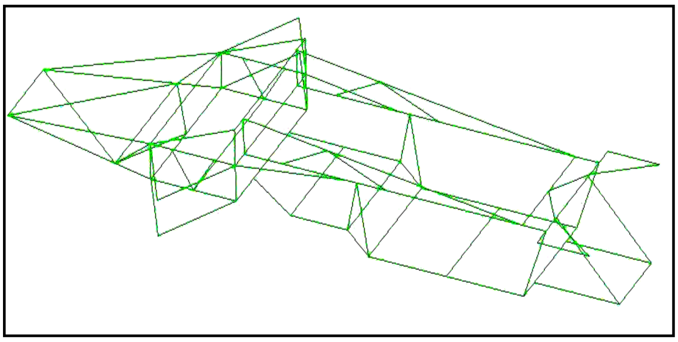


Figure 3.2: 3D wire frame for solar chassis.

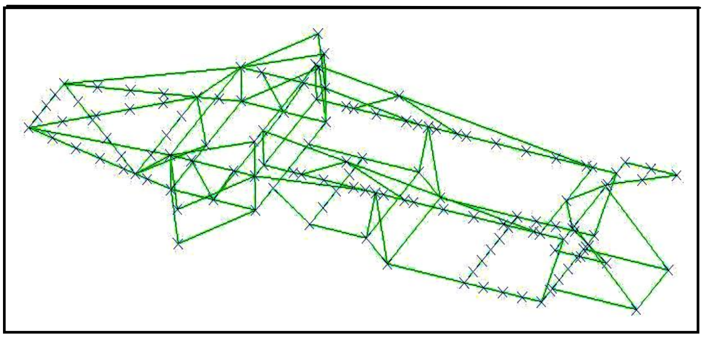


Figure 3.3: Finite element model of solar car chassis

Table 3.1: Mechanical properties of AA6063-T6.

Properties	**Value and unit**
Ultimate tensile strength	241 MPa
Density	2 698.79 kg m^{-3}
Modulus of elasticity	68.9 Mpa
Shear strength	152 Mpa

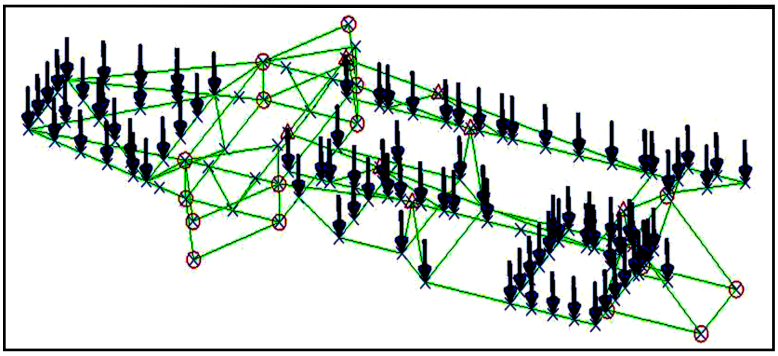


Figure 3.4: The loading and boundary conditions

3.3.5 Body Design Analysis Using COSMOSFLOWORK

The three-dimensional (3D) model is developed using SolidWorks software which is shown in Figure 3.4. Three design of the model has been develop to do this analysis. The computational fluid dynamic simulate by using COSMOSFloWorks simulation. SI unit is taken as unit system it shown in figure 3.5. External flow is choosing as analysis type and the reference axis is X it shown in figure 3.6. Air is used as the fluid in this simulation it shown in figure 3.7. The velocity in x direction of the air is 22.22 m/s (VDM Verlag,2010) it shown in figure 3.8. It is the average of the solar car speed. Take result resolution to 7 it shown in figure 3.9. Figure 3.10 shown the one of the design meshed model in CFD analysis.

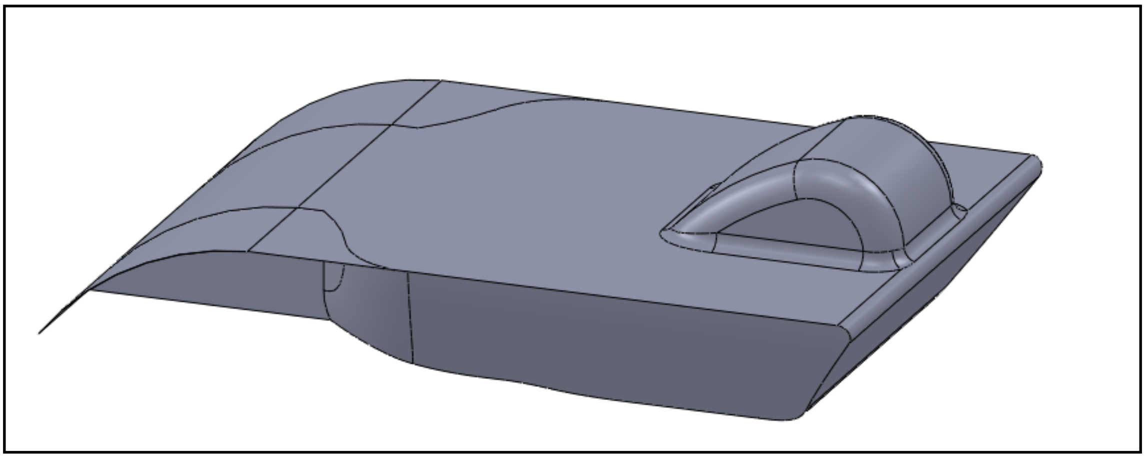
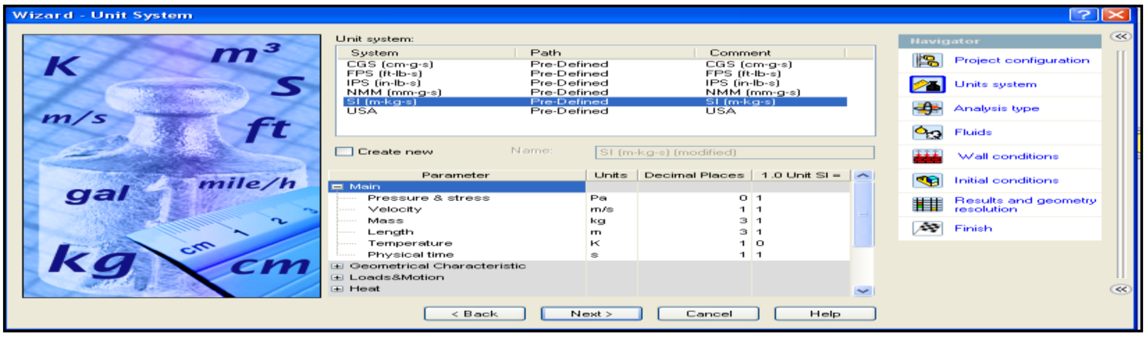


Figure 3.5: 3D model solar car body.



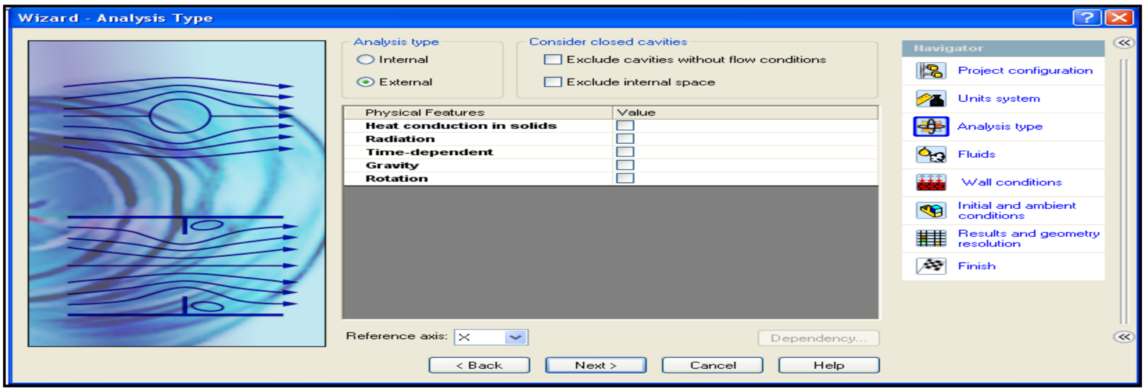
Unit system:

System	Path	Comment
CGS (cm-g-s)	Pre-Defined	CGS (cm-g-s)
FPS (ft-lb-s)	Pre-Defined	FPS (ft-lb-s)
IPS (in-lb-s)	Pre-Defined	IPS (in-lb-s)
NMM (mm-g-s)	Pre-Defined	NMM (mm-g-s)
SI (m-kg-s)	Pre-Defined	SI (m-kg-s)
USA	Pre-Defined	USA

☐ Create new Name: SI (m-kg-s) (modified)

Parameter	Units	Decimal Places	1.0 Unit SI =
Main			
Pressure & stress	Pa	0	1
Velocity	m/s	1	1
Mass	kg	3	1
Length	m	3	1
Temperature	K	1	0
Physical time	s	1	1
Geometrical Characteristic			
Loads&Motion			
Heat			

Figure 3.6: Unit system



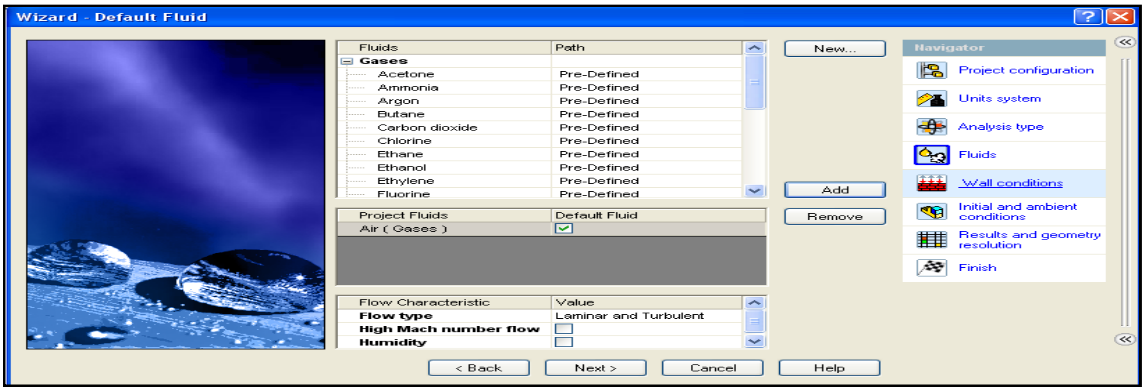
Analysis type
○ Internal
● External

Consider closed cavities
☐ Exclude cavities without flow conditions
☐ Exclude internal space

Physical Features	Value
Heat conduction in solids	☐
Radiation	☐
Time-dependent	☐
Gravity	☐
Rotation	☐

Reference axis: X

Figure 3.7: Analysis type

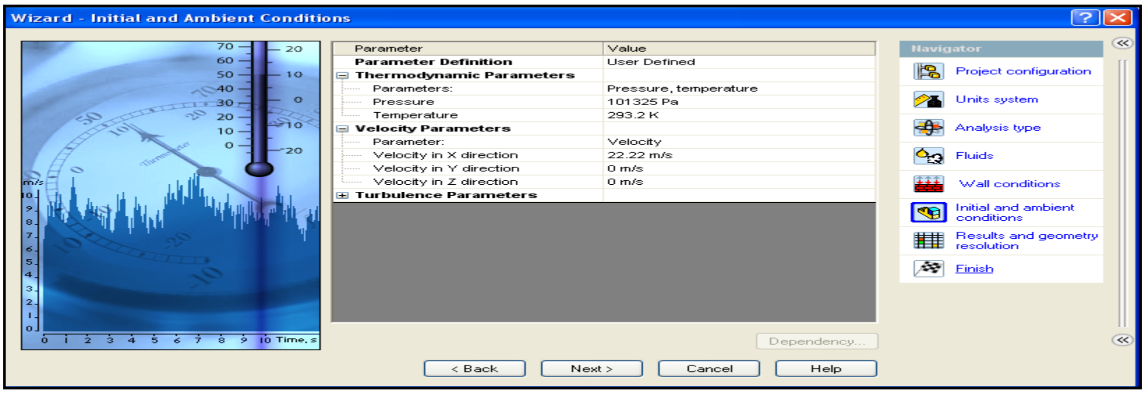


Fluids	Path
Gases	
Acetone	Pre-Defined
Ammonia	Pre-Defined
Argon	Pre-Defined
Butane	Pre-Defined
Carbon dioxide	Pre-Defined
Chlorine	Pre-Defined
Ethane	Pre-Defined
Ethanol	Pre-Defined
Ethylene	Pre-Defined
Fluorine	Pre-Defined

Project Fluids	Default Fluid
Air (Gases)	☑

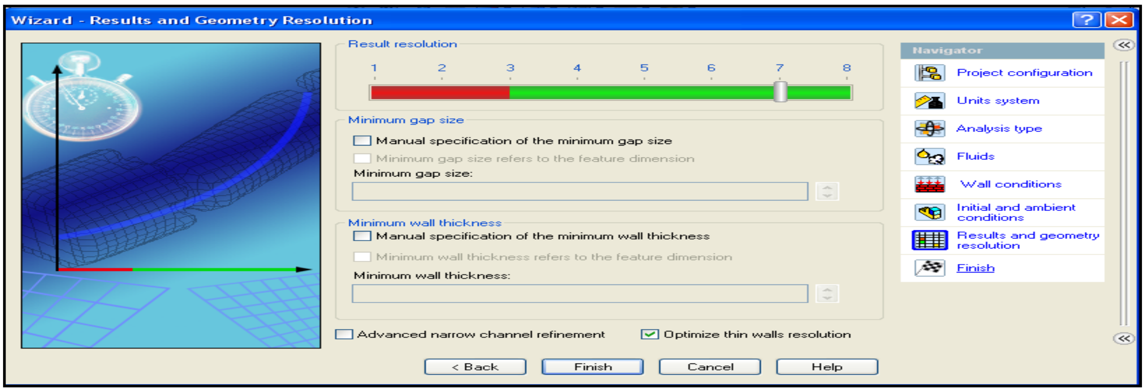
Flow Characteristic	Value
Flow type	Laminar and Turbulent
High Mach number flow	☐
Humidity	☐

Figure 3.8: Default fluid



Parameter	Value
Parameter Definition	User Defined
⊟ **Thermodynamic Parameters**	
Parameters:	Pressure, temperature
Pressure	101325 Pa
Temperature	293.2 K
⊟ **Velocity Parameters**	
Parameter:	Velocity
Velocity in X direction	22.22 m/s
Velocity in Y direction	0 m/s
Velocity in Z direction	0 m/s
⊞ **Turbulence Parameters**	

Figure 3.9: Initial and ambient condition



Result resolution

1 2 3 4 5 6 7 8

Minimum gap size

☐ Manual specification of the minimum gap size

☐ Minimum gap size refers to the feature dimension

Minimum gap size:

Minimum wall thickness

☐ Manual specification of the minimum wall thickness

☐ Minimum wall thickness refers to the feature dimension

Minimum wall thickness:

☐ Advanced narrow channel refinement ☑ Optimize thin walls resolution

Figure 3.10: Results and geometry resolution

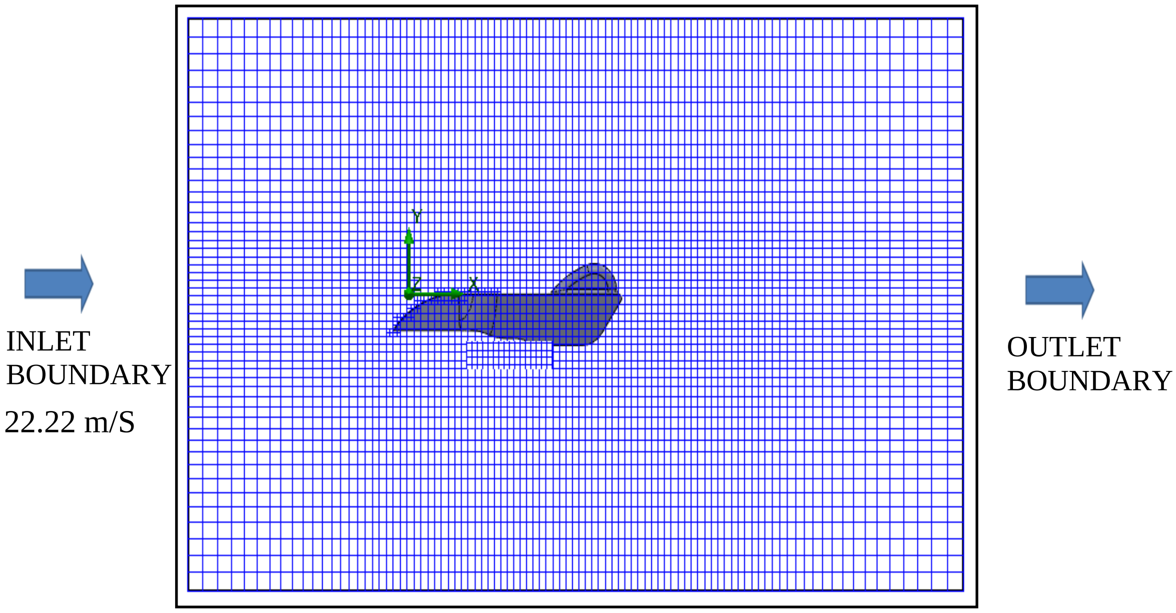


Figure 3.11: Meshed model

3.3.6 Detail Design Chassis

Detail design phase is to develop a system of drawings and specifications that completely describe the final design. During this stage, part of chassis is specified in detail. The detail design of the chassis has been completed with detailed drawings. It has been done by SolidWork 2008 SP0.0. Figure B1 is a 3D design of solar car chassis Design 1in appendix B. Figure B2 is a 3D design of solar car chassis Design 2 in appendix B. Figure C1 is a dimension of solar car chassis Design 1 in appendix C. Figure C2 is a dimension of solar car chassis Design 2 in appendix C.

3.3.7 Detail Design Body

Detail design phase is to develop a system of drawings and specifications that completely describe the final design. During this stage, part of chassis is specified in detail. The detail design of the body has been completed with detailed drawings. It has been done by SolidWork 2008 SP0.0. Figure D1 is a 3D design of solar car body Design 1in appendix D. Figure D2 is a 3D design of solar car body Design 2 in appendix D. Figure D 3 is a 3D design of solar car body Design 3 in appendix D. Figure E1 is a dimension of solar car body Design 1 in appendix E. Figure E2 is a dimension of solar car body Design 2 in appendix E. Figure E3 is a dimension of solar car body Design 3 in appendix E.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter will discuss the result of solar car chassis and body. Finite element analysis of solar car chassis has been performing using FEMPRO ALGOR. Two chassis design was analyzed. Computational fluid dynamic of the solar car body has been performing using Cosmosflowwork. Three design of body was analyzed.

4.2 FINITE ELEMENT ANALYSIS (FEA) ON CHASSIS USING ALGOR

Finite element analysis has been performed to these two designs. The linear static analysis is performed utilizing the ALGOR software. There three major mass that have been uses in this analysis that is 90 kg for driver weight, 150 kg for battery package weight and 30 kg for body weight. The three weights is the major weight in the solar car chassis. The result has been take that are stress contours, strain contours and displacement distribution.

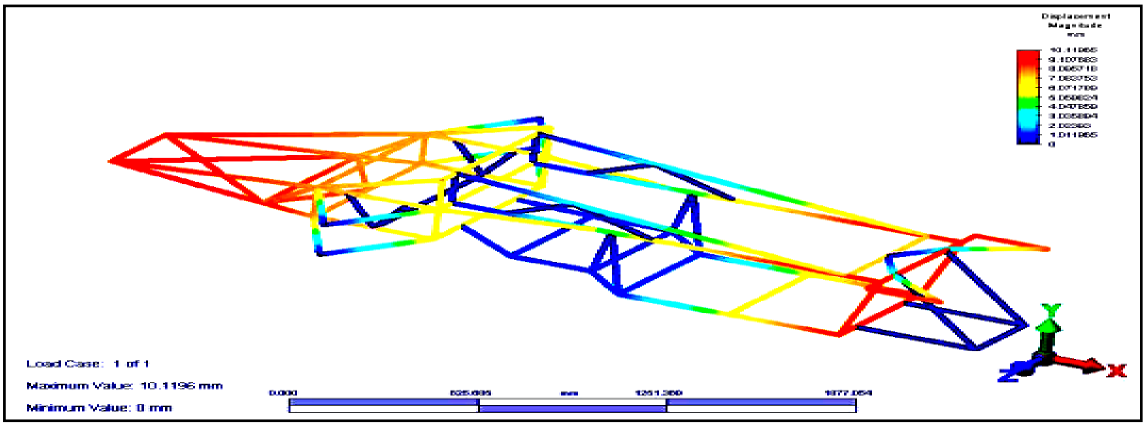


Figure 4.1: Displacement distribution of solar car chassis Design 1

From the analysis that have been perform the result of displacement distribution of solar car chassis design 1 is shown in the figure 4.1. In this analysis it is observed the maximum displacement is 10.12 mm. The result show a high displacement is occur at the tip of the front arm and at the back of solar car chassis design 1.

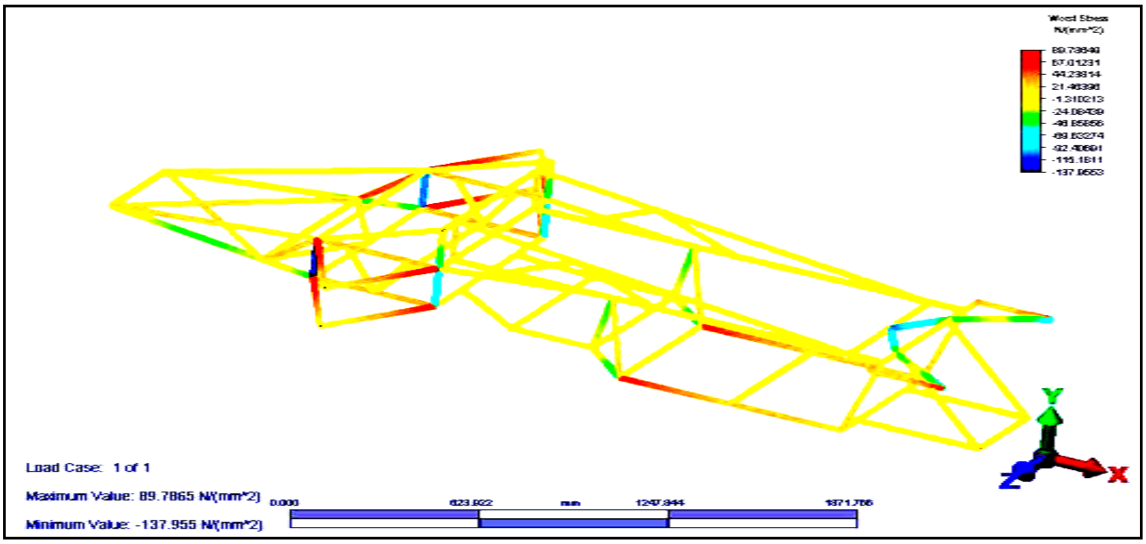


Figure 4.2: The stress contours of solar car chassis Design 1

From the analysis that have been perform the stress contours of solar car chassis design 1 is shown in the figure 4.2. In this analysis it is observed the maximum tensile and compressive stresses are obtained of 89.78 MPa and 137.95 MPa respectively. The result show a high tensile and compressive stresses is occurring at the tip of the front arm of solar car chassis design 1.

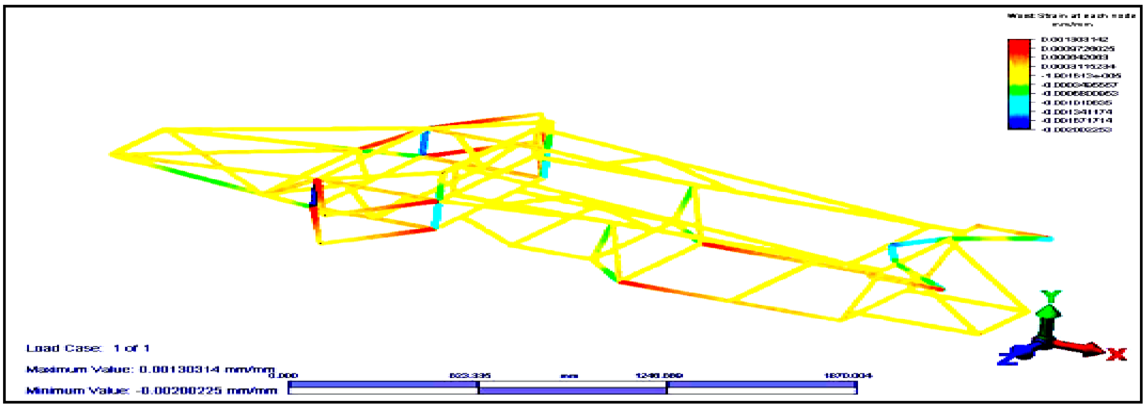


Figure 4.3: The strain contours of solar car chassis Design 1

From the analysis that have been perform the strain contours of solar car chassis design 1 is shown in the figure 4.3. In this analysis it is observed the maximum tensile and compressive strains are obtained of 13×10^{-4} and 20×10^{-4} respectively. The result show a high tensile and compressive stresses is occurring at the tip of the front arm of solar car chassis design 1.

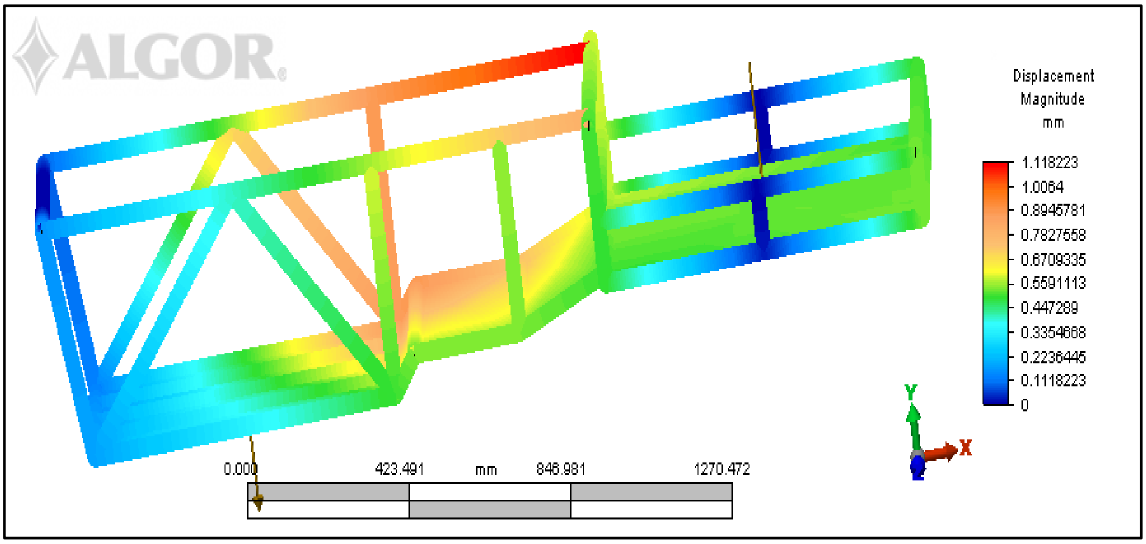


Figure 4.4: Displacement distribution of solar car chassis Design 2

From the analysis that have been perform the result of displacement distribution of solar car chassis design 2 is shown in the figure 4.4. In this analysis it is observed the maximum displacement is 1.12 mm. The result show a high displacement is occurring at the upper chassis and the center of the platform chassis of solar car chassis design 2.

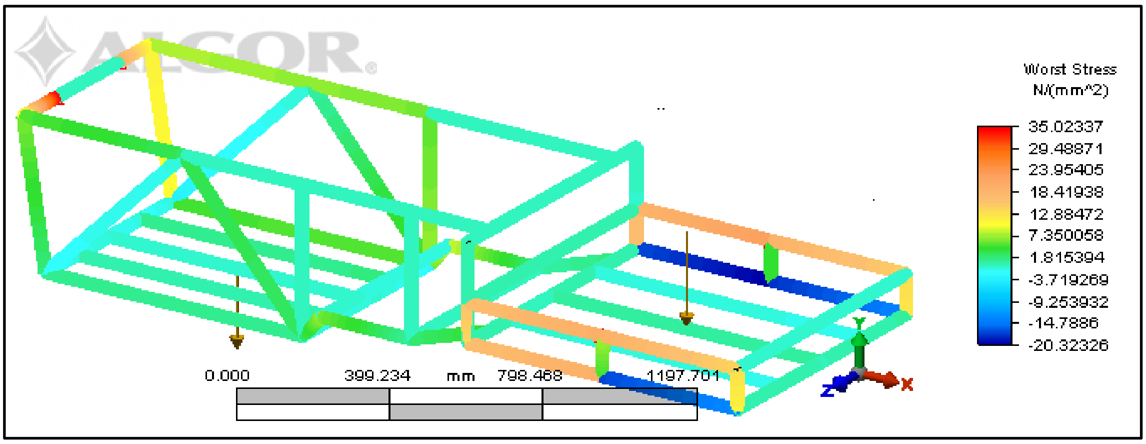


Figure 4.5: The stress contours of solar car chassis Design 2

From the analysis that have been perform the stress contours of solar car chassis design 2 is shown in the figure 4.5. In this analysis it is observed the maximum tensile and compressive stresses are obtained of 35.02 MPa and 20.32 MPa respectively. The result show a high tensile at the back of the chassis and compressive stresses is occurring at the tip of the front arm of solar car chassis design 2.

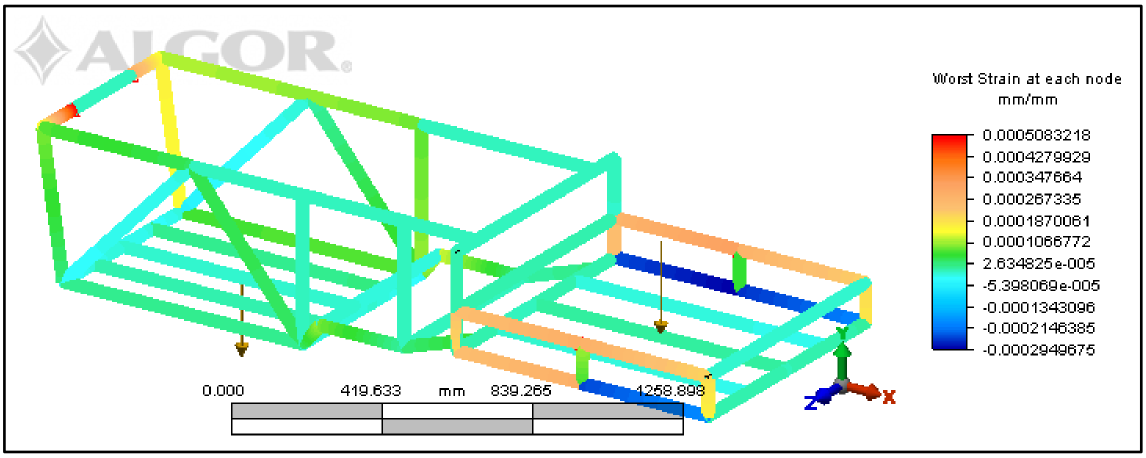


Figure 4.6: The strain contours of solar car chassis Design 1

From the analysis that have been perform the strain contours of solar car chassis design 1 is shown in the figure 4.6. In this analysis it is observed the maximum tensile and compressive strains are obtained of 5×10^{-4} and 3×10^{-4} respectively. The result show a high tensile and compressive stresses is occurring at the tip of the front arm of solar car chassis design 1.

4.3 COMPARISON RESULTS OF CHASSIS.

In this section, overall result comparing the solar car chassis design 1 with the solar car chassis design 2 is discussed. The result is measure with the same force applied but in different truss arrangement and the solar car chassis has a platform alumuniam for increase the strength of the chassis. Compared solar car chassis design 2 with solar car chassis design 1, it is shown that the displacement magnitude and worst stress of the solar car chassis design 2 is smaller than solar car chassis design 1 but the solar car chassis design 2 is slightly increase in weight because the material uses in solar car chassis design 2 is more than solar car chassis design 1.

Comparing both designs, the result shows the solar car chassis design 2 is strength than solar car chassis design 1 due to the lower value of displacement magnitude, worst stress and worst strain. The solar car chassis design 2 will be fabricated as a chassis for this solar car. Here are the comparison results of both designs as stated in the Table 4.1 below.

Table 4.1: The comparison results between the solar car chassis design 1 and the solar car chassis design 2.

Parameters and Unit		**Solar Car Chassis Design 1**	**Solar Car Chassis Design 2**
Weight of material (N)		234.7	356.61
Volume of material (mm^3)		8.8570×10^{6}	1.3457x10^{7}
Center of Gravity solar car chassis (mm)	X_c	1572.9	-1128.9
	Y_c	73.41	7.82
	Z_c	-200	3.98
Displacement magnitude, δ (mm)		10.12	1.12
Worst stress (tensile), σ (MPa)		89.78	35.02
Worst stress (compressive), σ (MPa)		137.95	20.32
Worst strain (tensile), ε		13×10^{-4}	5×10^{-4}
Worst strain (compressive), ε		20×10^{-4}	3×10^{-4}

4.4 COMPUTATIONAL FLUID DYNAMIC ANALYSIS ON SOLAR CAR BODY USING COSMOSFLOWORK

Three model of solar car bodies have been analyze using CFD method. The design is shown in figure 4.7, figure 4.8 and figure 4.9. The pressure contours of the design are shown in this section. The worst design is a Design 1 it shown in figure 4.7 (a) that the pressure distribution occurs at the front of the solar car body with the maximum value of 101.77 kPa. It is because the front of the car is quite concave, because of that shape the air is tendency to trap so it will make high pressure at the front of the car that will increased the pressure drag of the car. Figure 4.7(b) is shown the pressure distribution at the back of the solar car body Design 1, from that figure the maximum negative pressure occurs is 101.11 kPa. The design 1 has not fully achieved the aerodynamic shape. From the CFD analysis using cosmosflow work the drag force of the design 1 is 129.12 N it the highest drag force compare to Design 2 and Design 3. Figure 4.7(c) show the pressure distribution of solar car body Design 1.

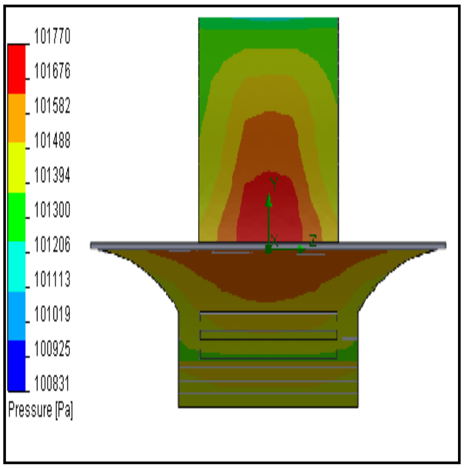


Figure 4.7(a): The pressure contours over solar car body for Design 1(front view)

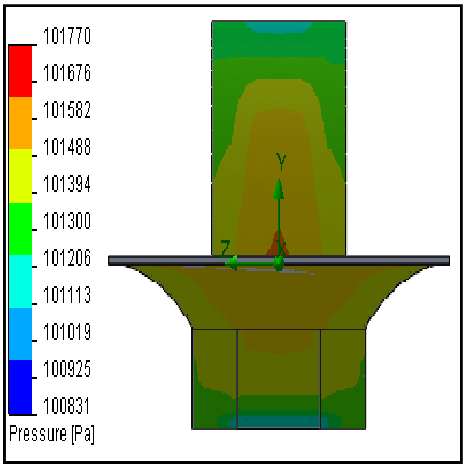


Figure 4.7(b): The pressure contours over solar car body for Design 1(back view)

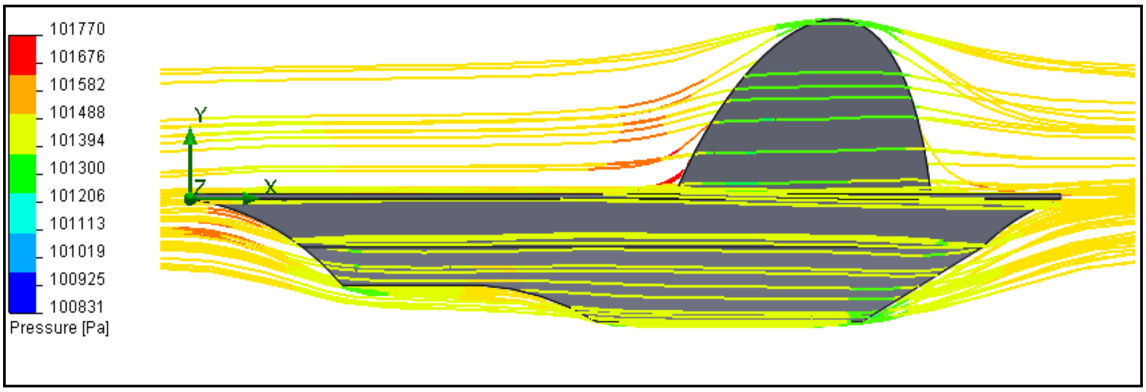


Figure 4.7(c): The pressure distribution around the solar car body for Design 1

Several improvements are done to Design 2. Figure 4.8(a) show the pressure distribution occurs at the front of the solar car body Design 2 with the maximum value 101.61 kPa. The front of design 2 is done by the concept boat. It is improve the travel of the air to become less drag force. Figure 4.8(b) show the pressure distribution at the back of the solar car body Design 2, the maximum negative pressure is 101.24 kPa. From the CFD analysis using cosmosflow work the drag force of the design 2 is 120.75 N. Figure 4.8(c) show the pressure distribution of solar car body Design 2.

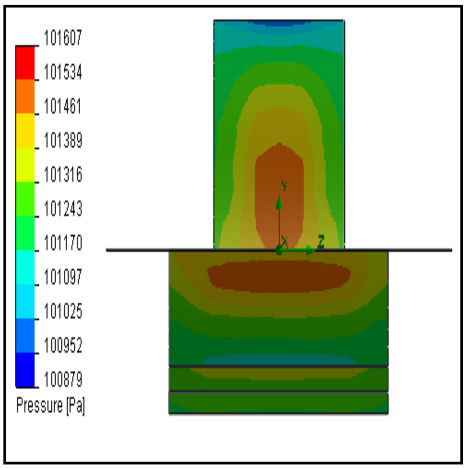


Figure 4.8(a): The pressure contours over solar car body for Design 2(front view)

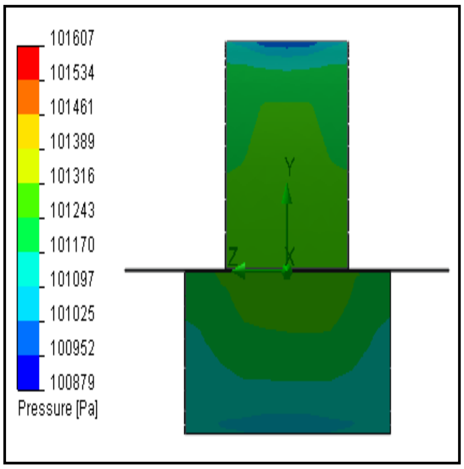


Figure 4.8(b): The pressure contours over solar car body for Design 2(back view)

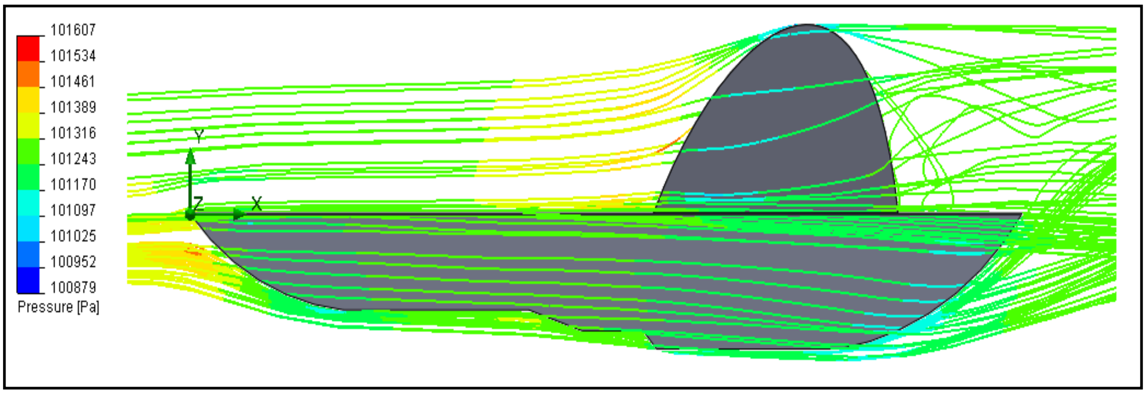
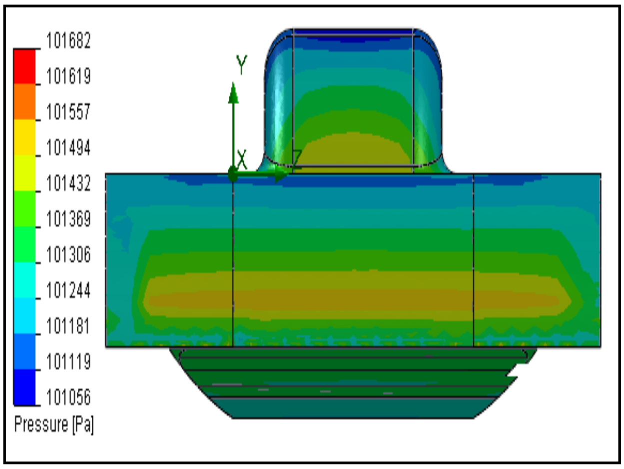


Figure 4.8(c): The pressure distribution around the solar car body for Design 2

The best design is design 3. The design 3 has been improved on the front of the car. The reshaped of the design 3 on the front part by reducing the angel slope of the curve, reduce the pressure at the front of the car. This is demonstrating when comparing figure 4 and figure 5 with figure 6. This reduces the drag forces caused by the small angel of slope at the front of the design 3 therefore contributing to a reduction in the overall C_D value. Figure 4.9(a) show the pressure at front of the car in design 3 is the lowest that is 101.56 kPa. From the CFD analysis using cosmosflow work the correspondent drag force of the design 3 is 109.33 N which is the lowest drag force. The shape of the body has major influence in the effect of the drag force. Figure 4.9(b) show the design 3 has the lowest negative pressure at the back of the car that is 101.31 kPa. The highest negative pressure will increase the drag force of the car it is occur in design1 and design 2. To make the body of car that have low drag force it must done more aerodynamic shape of the body, so the air can travel more smooth. It will lower the usage of power consumption to move the solar car. Figure 4.9(c) show the pressure distribution of solar car body Design 3.Table 4.2 shows the pressure at front of the car and the drag force that occur at the car.



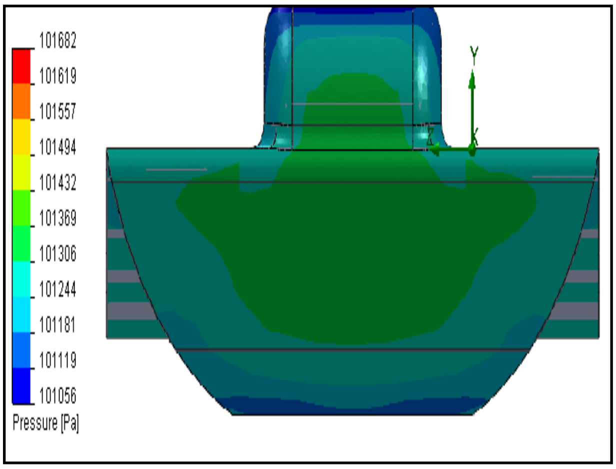


Figure 4.9(a): The pressure contours over solar car body for Design 3 (front view)

Figure 4.9(b): The pressure contours over solar car for body Design 3(back view)

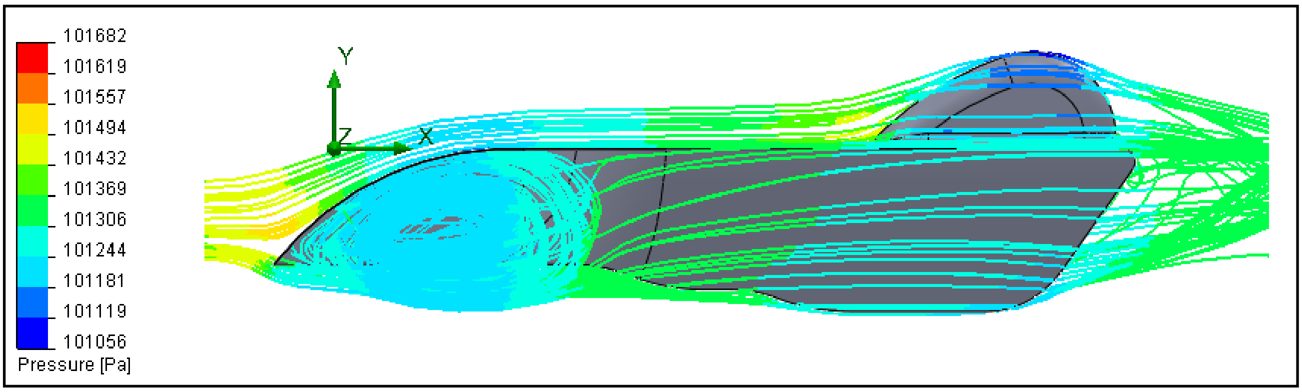


Figure 4.9(c): The pressure distribution around the solar car body for Design 3

Table 4.2: Pressure at front and drag force of solar car body

Parameter and Units	**Solar Car Body Design 1**	**Solar Car Body Design 2**	**Solar Car Body Design 3**
Drag force (N)	129.12	120.75	109.33
Pressure at front (kPa)	101.77	101.61	101.56

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter is the summary of what this whole research is about. It concludes all the outcomes, observation of results and analysis, and discussion throughout the experiment. Recommendations may also be given on improving future work and studies.

5.2 CONCLUSION

In this research, it is successfully achieving the objective with the acceptable result outcome. The design of solar car chassis has been developing referring the other team solar World Solar Challenge. The chassis that have design have 3 wheels, which are 2 wheels for front and 1 wheel for rear. This design has similar appearances from The Brasidius (2005) Michigan State University Solar Car Team.

Two designs of solar car chassis have been develop. These designs are analyze using ALGOR. The Design 2 is choosing for fabricating because the result from the analysis shown this design is better than Design 1. The maximum displacement for Design 2 is 1.12 mm which is decrease as much 88.93%. The worst stress of Design 2 is 35.02 MPa for tensile its decrease 61.00% and 20.32 MPa for compressive its decrease 85.27%. The worst strain of Design 2 is 5×10^{-4} for tensile its decrease 61.54% and 3×10^{-4} for compressive its decrease 85.00%.

Three designs of solar car body have been develop. These designs are analyze using COSMOSFLOWORK. The Design 3 has been choose for fabricating because the result from the analysis shown this design the best design compare to Design 1 and Design 2. It shown the pressure occurs at the front of the Design 1 is 101.56 kPa its decrease 0.2% and the negative pressure at the back of the body is 101.3 kPa its increase 0.19 %. The drag force of the body is 109.33 N its decrease 15.33%.

5.2 RECOMMENDATION

Based on the findings of this study the following recommendation can be made. The suggestions are as follows:

1. The analysis of chassis can be done using other software such as MSC.Nastran.
2. The analysis of body can be done using ANSYS FLUENT.
3. Make the body of the car more aerodynamic to decrease the drag force.

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APPENDIX A

Gantt Chart

PROJECT ACTIVITIES	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**
Receive FYP title	■													
Discuss with supervisor		■	■	■	■	■	■	■	■	■	■	■		
Research about title		■	■	■	■	■								
Collecting data			■	■	■	■	■	■	■					
Prepare report			■	■	■	■	■	■	■	■	■	■		
Submit report to SV											■	■	■	
Presentation preparation												■	■	
FYP1 presentation														■

Figure A1: Gantt chart Final Year Project 1

PROJECT ACTIVITIES	WEEK																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Discuss with supervisor	■																					
Design and run the analysis		■	■	■	■	■	■	■	■	■	■	■										
Collecting data		■	■	■	■	■	■	■	■	■	■	■										
Fabricate					■	■	■	■	■	■	■	■										
Prepare report		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Submit draft 1 to SV													■									
Presentation preparation													■	■								
Submit draft 2 to SV															■							
Submit draft 1 to Second Examiner																	■					
Submit draft 2 to Second Examiner																		■				
Signature from supervisor and Second Examiner																					■	
Submission of hard bounded to faculty																						■

Figure A1: Gantt chart Final Year Project 2