UNIVERSITI TEKNOLOGI PETRONAS

engineering futures

Design and Fabrication of a Fuel Efficient Simple Vehicle Chassis

by

Ian Leong Mun Choong

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

JUNE 2010

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CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme

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Approved by,

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(Dr. Zainal Ambri bin Abdul Karim)

Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JUNE 2010

CERTIFICATION OF ORIGINALITY

This is the 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.

IAN LEONG MUN CHOONG

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ABSTRACT

The goal of the project is to determine the design and the material used to fabricate both the body and the frame of a simple one man vehicle in order to increase the fuel efficiency. The vehicle frame design and configuration was referenced from the literature review based on the number of members and joints to reduce the total material used. The most suitable frame configuration that was used for the project is the ladder frame chassis. The frame material was chosen with the density and yield strength as criteria to reduce weight without sacrificing strength. With the criteria in mind, the selected material to construct the frame with was the 7075 T6 Aluminium alloy. Then a FEA was conducted to measure the design's performance against the loads applied onto the chassis. As for the vehicle body, the shape of the body was inspired by the high speed Japanese Bullet Train called the Shinkansen. The body is also shaped to be like a water droplet as it is the most aerodynamic shape in existence. The vehicle body material was chosen based on the density of the material, the manufacturability, and the cost. Hence the material deemed suitable was the Fibre Glass whose material properties are customisable. After conducting stress analysis, a 2 layer reinforced fibre glass with polyester as matrix was used for the body material. Finally the frame and body were assembled together to form the simple vehicle chassis.

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CHAPTER 1

BACKGROUND OF STUDIES

1.1 Introduction

With the rise of global awareness in reducing fossil fuel emissions, saving costs and the environment as well as obtaining a sustainable energy source for automobiles, there have been many attempts to come up with a solution that can potentially solve this predicament.

Among many examples is the solar car, a simple vehicle that is powered using only solar cells. Another would be the Shell Eco-marathon cars, all which are built with the objective of having the best fuel efficiency in mind. All of these vehicle share some common similarities, in which they are small, can only house one person, have only bare and necessary parts, and very fuel economic. These vehicles are highly specialised and optimised, produced to represent what can be achieved with current technology and offer a glimpse into the future car design based on minimal environmental impact in a world with reduced oil reserves.

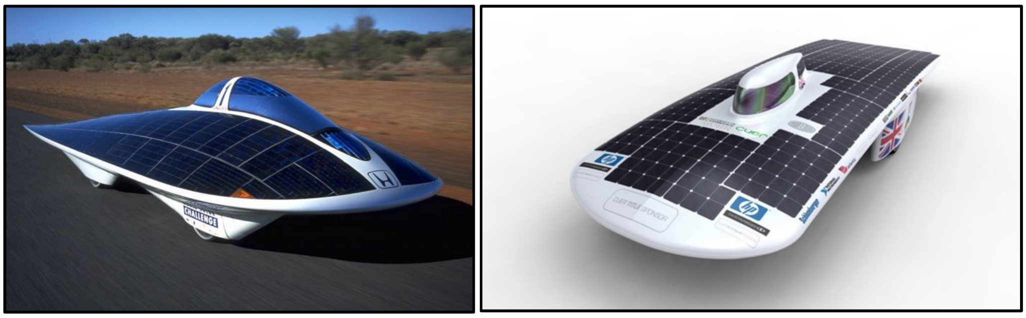


Figure 1: Simple vehicle examples: solar cars

This project attempts to construct the chassis of a simple vehicle body such that it promotes fuel efficiency. The vehicle designed is a simple one-man vehicle, and the chassis must be able to sustain the loads of the driver and the parts of the vehicle. The shape of the vehicle is also important to reduce drag forces. The ultimate goal of the project is to reduce the weight of the vehicle through the chassis design and material selection as the weight of a vehicle will have inverse effect on the fuel economy of the vehicle.

Figure 2 shows the result of a study conducted by the National Research Council of the United States of America which shows the relationship between the weight of the vehicle including passengers and loads (payload) with the fuel efficiency of the vehicle is shown. It can be deduced from the curve that the higher the weight of a vehicle, the lower its fuel efficiency is.

There are also other factors which affect the fuel economy of a vehicle, such as the aerodynamics and rolling resistance of the vehicle. However for the project, the weight factor will be the primary criterion in determining the vehicle design.

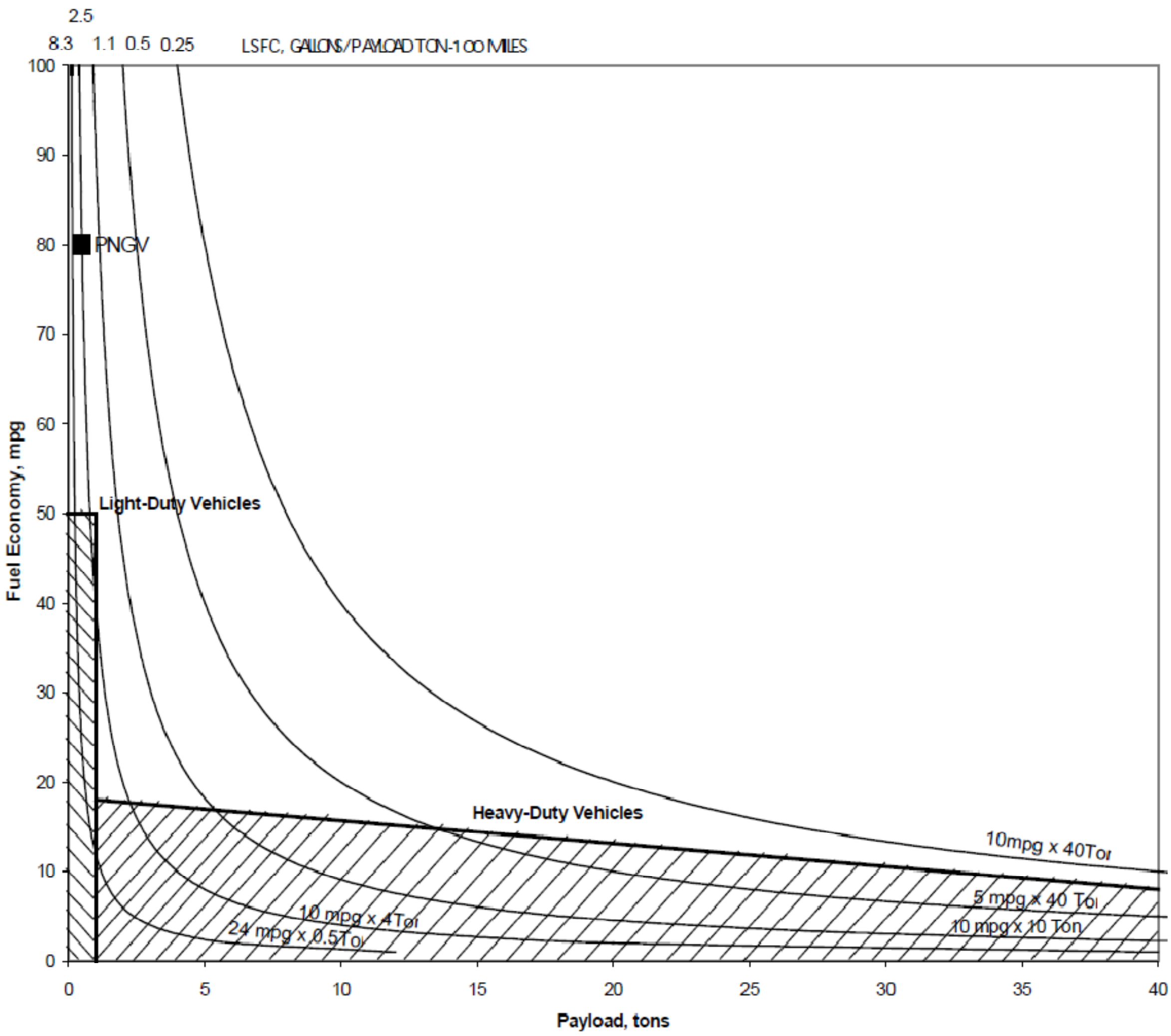


Figure 2: Relation between the fuel efficiency and weight of vehicle.

The study undertaken also includes the research of a body shape which is aerodynamic with a minimal frontal area and a chassis structure that is both lightweight and sturdy. The focus is to create a vehicle body which is made of a lightweight material and yet be able to sustain the stresses without failure. The vehicle shape will also need to be aerodynamically sound to reduce the effects of air drag to reduce the fuel consumption even more. Careful design and material selection will be crucial in achieving the objective of the project.

1.2 Problem Statement

The weight of a vehicle directly affects the fuel consumption of a vehicle, as a heavier vehicle contains more momentum and naturally resists motion when stationary. And so to begin moving the vehicle, the engine must generate a force larger than the momentum of the vehicle which results in more fuel being consumed. This is proven through Newton's laws of motion.

The project focuses on the vehicle body design in order to produce a chassis and body that is both lightweight and sturdy. The secondary objective is to design a vehicle body that is also smooth and streamlined to reduce air drag to allow for the maximum efficiency of the engine. The cost and safety issues are also taken into consideration as it would be one of the main criteria at which the design will be based on.

1.3 Objective

- To design frame chassis of a simple one man vehicle that is light, strong and streamlined.
- To reduce the effects of drag of a moving vehicle body by having an aerodynamic shape.
- To fabricate and assemble the body, chassis and parts from specified material.

1.4 Scope of Study

The vehicle can be classified as a technology demonstrator, and does not contain features of a standard road vehicle. The vehicle only contains parts that are essential to its function and safety of the driver.

The scope of study for the project includes the study and research of the design of other simple vehicles' chassis structure and body. Factors which motivate the designs from other institution are referenced and revised. A vehicle design that is able to house one driver and all the necessary components, being compact, sturdy and aerodynamically shaped is drawn.

CAD software was used to model the vehicle design to generate an accurate dimension of the vehicle. The vehicle design model was then used to conduct Finite Element Analysis to determine the stresses and deflection of the chassis.

The objective of increasing the fuel efficiency of the simple vehicle was achieved by reducing the weight of the vehicle through material selection and chassis design. Materials used to fabricate the chassis and the body was researched in depth to ensure suitability and compliance with the objectives and limitations of the project. All the stresses and loads that the material will handle were determined such that the material selected can be optimised to reduce deflection and prevent failure. Materials must be lightweight but at the same time able to handle all the forces and loads that the vehicle will experience. Frame configuration was properly looked into to have a balance between the amount of materials and strength of the frame.

Drag forces created by the moving vehicle was reduced by having a shape that is aerodynamic. Shapes with small drag coefficients were investigated and implemented into the design of the vehicle body. Effects of air drag were not studied in detail as it is rather insignificant at low speeds. For the project the aerodynamics is considered to be an optimisation option.

The body and chassis were fabricated as designed using the prescribed materials. With the completion of the fabrication process, the body and chassis will be assembled with the other parts to form the complete simple vehicle. With the vehicle at hand, physical tests and trial runs will be conducted to ensure all the equipments and features are working as planned. Final adjustments will be made as well to the prototype to any inadequacies discovered.

1.5 Relevancy of the Project

The ultimate goal of the project is to have the lowest fuel consumption with the most mileage out of the vehicle. The project's relevancy is to increase the efficiency of the vehicle by reducing weight of the frame and body of the vehicle, and also by having a vehicle body shape that is aerodynamic to reduce air drag when the vehicle is in motion.

The project is very much relevant to answering the calls for a greener and more sustainable energy for vehicles. It is hoped that the lightweight design of the chassis frame and body, and also the aerodynamic design of the prototype will inspire a technological breakthrough for automotive industries globally.

The project is also significant as the success of this project as a whole will mark the beginning of UTP's involvement in future Shell Eco-Marathon and also energy efficiency automobile research and studies. This will allow UTP to actively participate in the effort towards an eco-friendly and energy sustainable future.

1.6 Feasibility

The project is deemed feasible within the given time frame as the design is for a simple vehicle. In this sense, existing technologies and materials will be applied and selected for the completion of this project. Also, known knowledge and theories will be applied in the design process of the vehicle so no new research is necessary to complete the project. All the required tools and equipments needed to conduct the project are also readily available within the university grounds.

CHAPTER 2

LITERATURE REVIEW AND THEORIES

2.1 Design Fundamentals

The total mass and aerodynamics of the vehicle are important issues influencing its design. Both mass and aerodynamic resistance must be minimized in order to achieve a maximum distance. An easy way to reduce the aerodynamic resistance of the vehicle is to reduce its speed. Achieving precisely at an average speed of 35*km/h* will improve efficiency, but on a track with various slopes and flats demands an extremely accurate driving strategy. It is also necessary for the driver to increase the speed of the car when approaching the tracks steeper inclines due to the car lacking the power to hold its speed driving up some of these hills. Wind changes affect the aerodynamic impact angles and thus lead to even more variables to be taken into account.

To improve the aerodynamics at a given speed, the following design aspects are important:

- Minimal projected frontal area,
- Minimal Coefficient of Drag (C_d) value.

When attempting to reduce the projected frontal area, many factors need to be considered. The driver, the drive system and the power train must fit inside the vehicle. Furthermore, this design must follow some rules set to limit the design:

- Set minimum ratio between wheelbase and total vehicle height,
- Roll bar to secure the driver,
- Separate driver and power train compartments,
- Reasonable steering radius for turns and overtaking,
- Wheels should not be accessible to the driver,
- Adequate field of vision to the front, side and rear.

2.2 Literature Review of Past Designs

2.2.1 PAC-Car II

The current world record holder is the PAC-Car II which is able to traverse 5385 kilometres with hydrogen equivalent to 1 litre of gasoline (ETH PAC-Car II 2009). The PAC-Car II is the product of the students from the Swiss Federal Institute of Technology Zurich.

The PAC-Car II prototype has a body structure that does not have a chassis as its body is capable of self-supporting. It utilises a rigid carbon fibre monocoque body which is able to support structural load by using the external skin without the use of an internal frame or truss. This configuration can reduce the vehicle's mass without compromising its structural integrity. Using this carbon fibre exoskeleton design, the vehicle weighs at 29 kilograms.

In terms of aerodynamics, the PAC-Car II is equipped with 3 wheels, whereby the single rear wheel is powered and steered whereas the two fixed front wheels have a camber angle of -8°. This solution allows for a reduced frontal surface area by eliminating the room required to steer the wheel. The wheel configuration provides sufficient ground clearance and an optimal weight distribution on each wheel, while allowing for rollovers to be avoided under normal driving conditions, including cornering, passing or obstacle avoidance. Experiments which they conducted show that the camber angle does not provide too much rolling resistance. With this, the PAC-Car II has a drag coefficient of 0.075 and a frontal area of 0.254 meter squared; while it's rolling resistance with Michelin Radial Tires are 0.0008 (ETH PAC-Car II 2009).

Although the monocoque body have the highest potential for increasing vehicle strength by increasing its rigidity, it also has its drawbacks:

- Restricted possibility for modification due to the high level of component integration,
- Poor accessibility of internal parts,
- Narrow opening for the driver to enter the vehicle,
- Expensive and sophisticated fabrication process,

- Limited choice of raw material.

2.2.2 Other Designs

Recent design entries at the Shell Eco-Marathon have seen many different shapes and sizes of vehicle body and structure. Most vehicles however have a narrow and streamlined design with a 3-wheeled configuration.

Emphasizing on the body and aerodynamics of the vehicles, there are commonly two different configurations whereby the front wheels are being internally or externally placed onto the chassis. Having a body which envelopes the wheels provides a lesser air drag, but the trade of is having more materials to construct the body which translate into more mass. On the other hand, having the wheels on the external part of the body will allow for the isolation of the driver from the wheels, and also a lighter body for the vehicle. As for the body shape, aerodynamics and minimal frontal area is the primary design goal. Every entry will have a streamlined or sharp body shape in order to effectively reduce the effects of air drag.

The chassis structures of the entries are also commonly divided into two different categories. One of them is the above mentioned monocoque exoskeletal frames while the other is the internal frame or truss. While the monocoque frames are extremely light weight and rigid, they are very expensive and complicated to fabricate, often requiring advanced expertise and experience. The monocoque design has also a very limited selection of materials that can used in order to achieve the desirable effect. The more common internal frames are easier and more versatile to design and manufacture. These frames often vary from team to team as the possibilities are infinite. They are however much heavier as compared to the monocoque designs, and require many joints and fixtures. The external non-load-bearing body can be made from many different materials while the internal frames itself can also have a wide spectrum of materials to choose from hence the limitations are greatly reduced.

2.3 Air Drag and Aerodynamics

The primary objective when designing the body of the vehicle for the Shell Eco-marathon is the influence of air drag. The vehicle will not be travelling at a speed at which the effects of air drag will be drastic. However, since the objective of the vehicle is to perform optimally and efficiently hence air drag should be reduced as much as possible in order for the vehicle to perform.

Drag is a force which is opposing the movement of vehicles though the air, this force is generated though the differential pressure between at front and rear of the machine. This pressure difference acts on the frontal area of the vehicle to give the drag force. Hence a larger frontal area will constitute to a larger drag force. As the vehicle moves though the air it will move aside the molecules, if this is done at low speed these molecules will follow along the outer shape of the machine and little resistance will be generated. This is only possible with a well streamlined shape, such as the classic teardrop (Tony Foale 1997).

There are many different causes which bring about the existence of aerodynamic drag. First of all there is the frontal area, which is the area of the car exposed to a force coming from directly in front of the car. The frontal area is simply exposed to the winds push in the same way a sail on a boat is exposed, but with the exact opposite effect. Therefore the vehicle will have to be designed with as little a frontal area as possible, by placing all the different components in a long and narrow shape. Everything that goes into the car needs to be as compact as possible so that in the end it will be the size of the driver and the ability to see out of the car that determines its dimensions.

It is also necessary to shield the wheels of the vehicle, because even though the shape of a wheel is pretty aerodynamic, the rolling motion drags air into, and out of the car, and creates a turbulent region all the way down the side of the car (DTU Roadrunners 2009).

2.3.1 Literature Review of Vehicle Bodyworks

Looking at all the designs of the previous Shell Eco-marathon entrees, all of the vehicles are compact with a small width and height while having a long, streamlined body. The drivers are in the lying down position to reduce the height of the vehicle and there is usually little or no space for the drivers to move about freely in the cockpit. Most of the recent vehicles have the teardrop shape which enhances the aerodynamics and thus reducing the air drag. Some of these vehicles also have their wheels covered or contained within the body of the vehicle, which in turn reduces the air turbulence created by the rotation of the wheels.

Taking the PAC-Car II for instance, it stands only at 0.61*m*, a width of 0.57*m* and a length of 2.78*m* (ETH PAC-Car II 2009). The shape of the vehicle is that of a teardrop, with all its wheels covered. The cockpit is accessed by removing the top-rear half of the body. The PAC-Car II was able to travel 5382 kilometres with one litre equivalent of fuel.

Figure 3: PAC-Car II body design

The Remmi 7 of the Tampere University of Technology is 0.6*m* high, 0.6*m* wide and 2.8*m* long (Tampere University of Technology 2009). The shape is very much similar to that of the PAC-Car II, with covered wheels and a teardrop shape. The entire top half of the body is removable to provide access into the car. The Remmi 7's best performace was at 3306 kilometeres per liter of fuel.

Figure 4: Remmi 7 body design

The vehicle of Team Crocodile from Cambridge University, have a dimension of 2.75*m* long, 0.9*m* high and 0.75*m* wide (Cambridge University Team Crocodile 2009). The vehicle has a platform tub shape, which sports many curves on the body. The driver enters the vehicle by removing the entire top half of the body. Team Crocodile's vehicle is able to achieve 1275 kilometres with one litre of fuel.

Figure 5: Team Crocodile body design

Pingu II, a vehicle designed and created by the HAW Hamburg has a rather unique design. It is shaped like the head of a penguin. It is 3*m* long, 0.8*m* wide and 0.75*m* high (HAW Hamburg Pingu II 2009). The entire top half of the vehicle is removed for the driver to enter and exit the vehicle. This vehicle can go 1621.9 kilometres per litre of fuel.

Figure 6: Pingu II body design

As seen from these selected prototypes, it is evident that every one of them is designed to have a minimal frontal area, by having the vehicle as small as possible. This is done by limiting the vehicle's dimensions to the size of the driver. Also, the vehicle is designed such that the top portion of the vehicle is removable such that the driver is able to enter and exit the vehicle.

2.4 Chassis and Frame

Automotive chassis is a skeletal frame on which various mechanical parts like engine, tires, axle assemblies, brakes, steering etc. are bolted. The chassis is considered to be the most significant component of an automobile. It is the most crucial element that gives strength and stability to the vehicle under different conditions. Automobile frames provide strength and flexibility to the automobile. The backbone of any automobile, it is the supporting frame to which the body of an engine, axle assemblies are affixed. Tie bars, that are essential parts of automotive frames, are fasteners that bind different auto parts together.

Automotive frames are basically manufactured from steel. Aluminium is another raw material that has increasingly become popular for manufacturing these auto frames. In an automobile, front frame is a set of metal parts that forms the framework which also supports the front wheels. It provides strength needed for supporting vehicular components and payload placed upon it.

Automotive 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. More precisely, automotive chassis or automobile chassis is a skeletal frame on which various mechanical parts like the engine, tires, axle, brakes, steering etc are bolted. At the time of manufacturing, the body of a vehicle is flexibly moulded according to the structure of chassis. Automobile chassis is usually made of light sheet metal or composite plastics. It provides strength needed for supporting vehicular components and payload placed upon it. Automotive chassis or automobile chassis helps keep an automobile rigid, stiff and unbending. Auto chassis ensures low levels of noise, vibrations and harshness throughout the automobile. The different types of automobile chassis include:

Ladder Chassis: Ladder chassis is considered to be one of the oldest forms of automotive chassis or automobile chassis that is still used by most of the SUVs till today. As its name connotes, ladder chassis resembles a shape of a ladder having two longitudinal rails inter linked by several lateral and cross braces.

Backbone Chassis: Backbone chassis has a rectangular tube like backbone, usually made up of glass fibre that is used for joining front and rear axle together. This type of automotive chassis or automobile chassis is strong and powerful enough to provide support smaller sports car. Backbone chassis is easy to make and cost effective.

Monocoque Chassis: Monocoque Chassis is a one-piece structure that prescribes the overall shape of a vehicle. This type of automotive chassis is manufactured by welding floor pan and other pieces together. Since monocoque chassis is cost effective and suitable for robotised production, most of the vehicles today make use of steel plated monocoque chassis.

Space Frame Chassis: **S**pace Frame Chassis has small tubes that are only in tension or compression - and has no bending or twisting loads in those tubes. That means that each load-bearing point must be supported in three dimensions. The tubes are commonly steel tubes, which are being welded together at the joints.

2.4.1 Literature Review of Vehicle Frames

The Shell Eco-Marathon has seen only few variations of frame types due to the nature of the competition. Most vehicles have simple chassis as to reduce weight and support the internals parts of the vehicle. But over the years, frame designs have improved due to the advancement in manufacturing, materials and engineering technologies.

Although the backbone chassis frame is by far the simplest type of frame to design, but it is very much unfavourable as it leaves the sides of the vehicle vulnerable in the event of a collision, and reinforcing the sides would require additional materials, and thus more weight. Hence the backbone chassis is always neglected in design selection. A team that uses the Backbone chassis is the Isfahan University of Technology of Iran (IUT Supermileage Team 2008). The frame is constructed with 7075 Aluminium and weighs 8 kilograms. It is joined together by TIG welding.

Figure 7: IUT's backbone frame.
Notice the single tube which forms the 'backbone' of the frame.

Space frame chassis is used in the Shell-Eco Marathon vehicle chassis because it provides a stiff frame with minimal materials. The tubes that make up the configuration of the space frame contribute to the ease of the design as well as its strength. Since the only forces experienced by the frame's members are compression and tension, analysis is easier and depends mainly on the configuration. The Penn State University's vehicle utilizes the space frame considering the strength to weight ratio, structural rigidity, driver visibility, and shell mounting points (PSU SEM Project Chassis Group 2007). The material used for this vehicle is 6061 aluminium based upon low cost, weight, and material properties to maximize performance. With the 6061 aluminium, the frame design suggests using 1¼ " diameter tubing that has 1/8" thick walls, for a vehicle frame weight of 49.5 *lbs*.

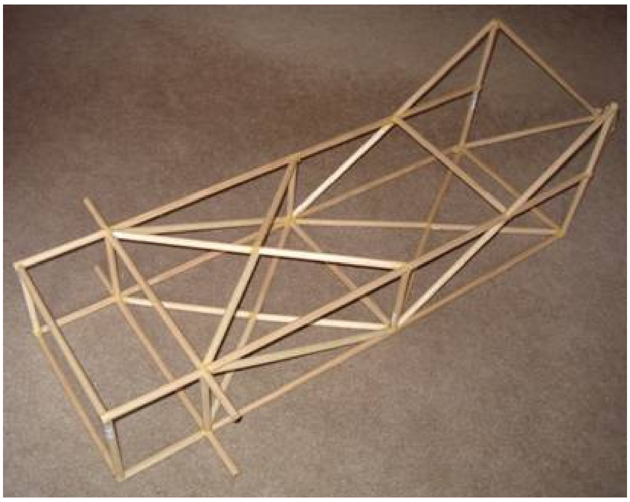


Figure 8: PSU's Space frame mock-up model.

The ladder chassis is by far the more popular frame for young entrants due to its simplicity and ease of fabrication. The parallel bars that are used as the main support for the chassis will have to be stronger and stiffer than the other bars as they are the foundation for load bearing, this thus causes the frame to be heavier. For the ladder chassis, analysis has to be done properly as well to accurately identify the stresses and deformation regions of the frame due to the simplicity of the design. An example of this frame is the vehicle made by the Dalhousie University. Their frame was fabricated from 6061 T6 Aluminium round and square tubing (Liam Jefferey 2008-2009).

Figure 9: Dalhousie University's ladder chassis.

Monocoque frame are also known as unibody frames. Monocoques are exoskeleton frames, whereby the body itself is the load bearing component. Monocoque frames have incredible stiffness-to-weight ratio and has gained much popularity within the competition as well as the automotive industry. The downsides to the monocoques are that they are very difficult to design and fabricate due to the nature of its complexity. It is also very expensive as high strength composite materials such as carbon fibre are required to properly create a light-weight monocoque. The world record car, the Pac-Car II utilizes the carbon fibre monocoque frame.

Figure 10: Monocoque of the Pac-Car II.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

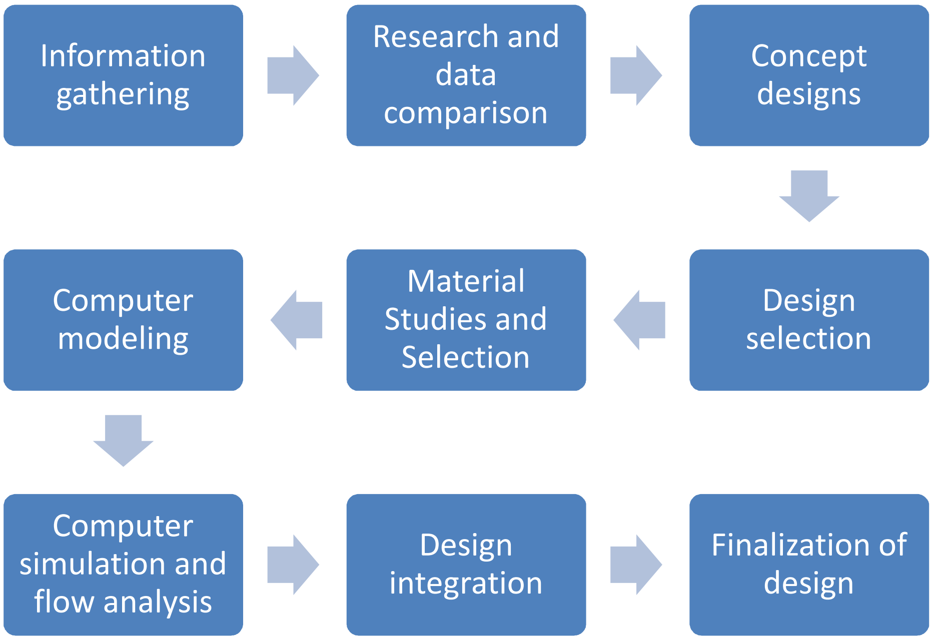


Figure 11: Research execution flow chart

3.1.1 Information Gathering

Information about the project is gathered by looking through relevant materials found on the internet, journals, and texts. Information and knowledge deemed useful is preserved and scrutinised. The purpose is to obtain a general idea on the project, to define the problems and limitations of the project, and to have a better insight regarding the projects' work flow.

3.1.2 Research Data and Comparison

All the compiled information and data is sorted and filtered. Additional and specialised information is studied deeper. Among the studied topics include TIG welding, Carbon Fibre fabrication and processing, aerodynamics, automotive frames and so on. The information and data are also being filtered by the set constraints to eliminate solutions that would be inefficient, costly, and physically impossible to create. Relevant information is used as literature review and reference for the project.

3.1.3 Concept Designs

Sketches and drafts of the projects' designs are made based on the information gathered and deciphered. These will serve as the base plan for the project to be further analysed and improve. Sketches of the body and frame were created. The sketches are attached in the Appendix.

For the project, one of the design concepts is to design a body with the internal wheel configuration with the internal frame. This will allow an optimal aerodynamics while having a sturdy body, but harder to fabricate. The cost for the internal frame is also much less compared to the monocoques. Another concept will be having the front wheel excluded from the body. This design will also provide an aerodynamic shape, but the external wheels will cause slight turbulence, but it will be easier to fabricate and also lighter.

3.1.3.1 Determination of Physical Constraints

The design of the chassis and body depends solely on the objective of the study, which is to be lightweight, compact, rigid, and aerodynamic. The constraints of the project are referenced from Shell Eco-marathon's rules and regulations because the event is relevant towards the construction of simple vehicles.

Body and Vehicle Configuration

The vehicle must have three or four running wheels which are in continuous contact with the road under normal conditions. All aerodynamic appendages which adjust or prone to changing shape due to wind whilst in motion are forbidden. The vehicle must not have any shape or design externally and internally. (Shell Eco-marathon Official Rules 2010, Section 3A Article 25)

The specified dimensional constraints are:

- Maximum height must be less than 100*cm*

- The maximum height measured from the top of the driver's compartment must be less than 1.25 times the maximum track width between the two outermost wheels.
- The track width must be at least 50*cm*, measured between the midpoints where the tyres touch the ground.
- The wheelbase must be at least 100*cm*
- The maximum total vehicle width must be less than 130*cm*.
- The total length must not exceed 350*cm*.
- The maximum vehicle weight excluding driver is 140*kg*.

(Shell Eco-marathon Official Rules 2010, Section 3A Article 26)

Crash Protection

The driver must be protected from vehicle rollover and collisions. The roll bar can be alongside or behind the driver, and must extend 5cm around the driver's helmet when seated in a normal driving position with the safety belts fastened. The roll bar must also extend in width beyond the driver's shoulders while in the normal position. The roll bar must be capable of withstanding a static vertical and horizontal load of 700N without deforming. (Shell Eco-marathon, Official Rules 2010, Section 3A Article 27)

Human Factor and Safety

One of the main purposes of the chassis is to provide a cockpit for the driver. The chassis should provide enough space for the driver to enter and exit without assistance. It must also provide clear vision to the front and sides of the vehicle. A permanent bulkhead must also be installed to completely separate the cockpit from the engine compartment to prevent liquid or flames to reach the driver in the event of a fuel leak or fire.

3.1.4 Design Selection

Looking at each of the concept designs, a list of the possible solutions is made and the pros and cons of each solution are discussed. All possible alternative solutions have to be analyzed to determine their potential. Mathematical and key engineering principles are applied, and the potential performance of the solution is analyzed to determine if the solution is physically possible. The laws of nature are reviewed during this process and whether the product is economically practical is determined by using common sense.

Preliminary calculations that were made are used to determine the stress and deflection acting unto the components. This will then show a simple overview of whether the frame is able to withstand the loads without yielding.

3.1.4.1 Determination of Loads

When designing the chassis, assumptions need to be calculated as to the expected loads that could be experienced by the chassis. These loads include the known static loads of the vehicle components such as the driver and engine, while also including predicted dynamic loads which will occur when the vehicle is in motion. Worst case loads should also be calculated and designed for to prevent the vehicle from failing.

Static Loads

When the car is stationary the loads from the vehicle and its components will be exerted through the frame to the wheels and the ground. Design of the chassis, it is important to be aware of these loads such that the components are supported with minimal deflection and deformation. The main load components that that need to be analyzed are the driver and the engine because these two masses account for most of the vehicle’s mass, other minor components account for the remaining weight.

Dynamic Loads

Dynamic loads are created from the vehicle in motion. This can be proven through Newton’s Law F=ma (Hibbeler 2005). When the vehicle is accelerating, forces are produced by the engine and motion is transferred to the wheels. When analyzing this force, focus will be on the driver and frame.

From the trial runs, the engine is able to accelerate the vehicle from 0 to 35 *km/hr* in around 5 seconds. Assuming that the acceleration is constant the formula (Giancoli 1991):

$$a = \frac{v_f - v_i}{t}$$

Where, a = acceleration
v_f = Final Velocity
v_i = Initial Velocity
t = time

When 35k /hr = 9.72 m/s and the initial velocity = 0

$$a = \frac{9.72 - 0}{5}$$

$$= 1.94\, m/s^2$$

To allow for the fluctuations in acceleration, a value of 2 m/s^2 will be applied to calculations. This will also allow for a slight factor of safety.

<u>Defined Loads</u>

These loads are approximates of the forces that the chassis frame will experience. It should be noted that although these loads are calculated on assumptions, but they are generally similar to the actual forces. The values assumed are taken by neglecting some minor factors and using maximum values to simulate worst case scenarios, and thus allow the chassis frame to withstand all situations.

Static loads:	Mass of engine	= 10kg
	Mass of driver	= 50kg
	Mass of chassis	= 35kg
	Estimated total mass	= 95kg

These loads will be applied in the direction of gravity through the engine mounts and seat. The wheel axle must hold the total mass of chassis as well as all components.

Acceleration forces:

On engine = Mass of engine × acceleration

= 10 × 2

= 20N

The force calculated will be in opposite direction of vehicle motion and will be transferred through the engine mount.

$$\text{On Driver} = \text{Mass of driver} \times \text{acceleration}$$
$$= 50 \times 2$$
$$= 100N$$

The force calculated will be widely spread through the seat while some load will be transferred to the race harness and steering wheel. The force will oppose the direction of vehicle travel.

3.1.4.2 Stresses Criteria

Stresses need to be identified and quantified such that the effects of the forces exerted by these loads onto the frame can be analysed. Excessive stresses on the frame will result in deflection, plastic deformation, and even failure. Hence it is essential that the principles of stresses and how they are formed and transferred through the frame.

<u>Tension Members</u>

Members which are experiencing tensional forces are defined as the member having two pulling forces applied at either end (Hibbeler, 2005). When the load within the member coincides with the longitudinal centripetal axis of the member, the stress distributed through the member can be assumed to be uniform and defined by (Hibbeler, 2005):

$$\text{Stress: } \sigma = {}^{F}\!/_{A}$$

Where, F = Force or load applied
A = Cross sectional area

When the normal stress of a tension member exceeds the yield strength of the material, it will experience a plastic deformation which is permanent and irreversible. So if the chassis frame experiences any plastic deformation, the frame is considered to have failed. This failure will result in a permanently bent or twisted frame. When designing the chassis, the working stresses should be well clear of the yield strength with an appropriate safety factor being taken into consideration to avoid this failure.

If the normal stress of a tension member exceeds the ultimate tensile strength of the material, failure of the member will occur. But usually the tensile strength of the material is much higher than its yield strength, and only the yield strength will be the datum for measurement.

Deflection

Deflection in a vehicle frame is undesirable but inevitable. If a chassis frame was constructed so that no deflection would occur at all, it would be over-designed and require extensive amounts of material amounting in excess weight.

Deflection can be caused by many different stresses, such as axial forces either in tension or compression. The analysis of deflection will become increasingly complicated with the complex arrangements of the supporting members. A deflection can be calculated by using (Hibbeler, 2005):

$$\delta = \frac{PL}{AE}$$

Where, δ = Deflection
P = Load
L = Length
A= Cross sectional area
E= Modulus of Elasticity

Bending

Bending stresses occur when a member is subject to a rotational moment load. This moment causes one side of the member to be in tension while the other is in compression. The bending stress can be calculated using (Hibbeler, 2005):

$$\sigma_b = \frac{My}{I}$$

Where, σ_b = Bending stress
M = Moment
y = Distance from the neutral axis
I= Moment of inertia of the cross section

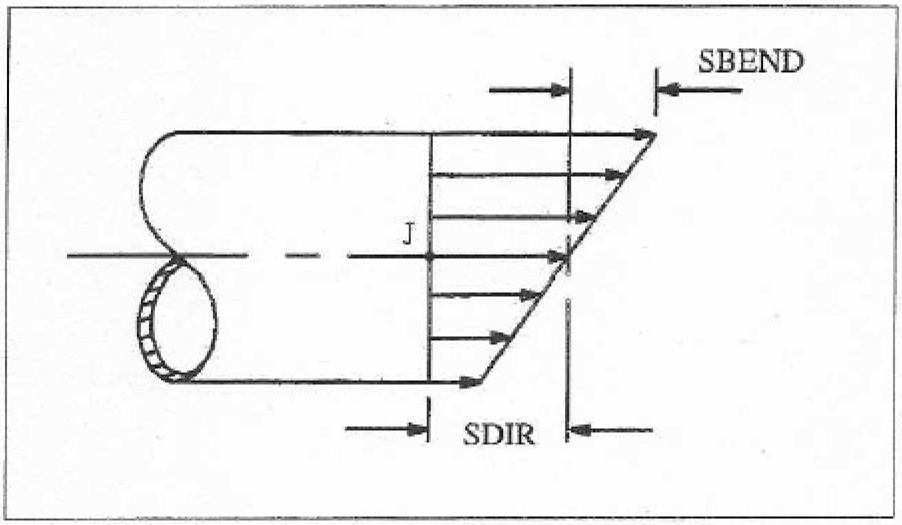


Figure 12: Bending stress

As shown in the figure above, the maximum bending stress occurs at the outer surface. For bending situations, it is only important to have material at the outer most edge of the member, as this is where the maximum stresses occur. So, hollow tubes are one of the best materials for resisting bending stresses.

3.1.4 Material Studies and Selection

Potential materials that will be used in the project are thoroughly studied and analysed. The material properties are used in conjunction with the calculations to determine the stresses and deformations of the frame and body when load is applied.

Simple analysis is also performed to calculate the weight of the vehicle by multiplying the volume of the frame with the density of the material (Budynas & Nisbett, 2007).

Mass: $M = V \times \rho$ Where, V = Volume of the material
ρ = Density of the material

Initial materials that will be considered for the frame are:

- Steel
- Aluminium
- Titanium
- Carbon Fibre

The manufacturability of the material will also be an important factor in the decision aside from the cost and strength-to-weight ratio. The ultimate goal of the material will be selecting a material which has the lowest weight and still provides adequate strength.

3.1.5 Computer Modelling

Once a design has been selected, it is modelled using Computer Aided Design software. The software being used is Catia V5 R14. The computer model will serve as an accurate graphic visualization of the project at this stage, and also to aid in the analysis process.

3.1.5.1 Detailed Stress Analysis

Stresses can be measured and calculated using many different methods. One of the common ways is to physically apply loads to the chassis and measure the deflection by sight or strain gauges. When the deflection is known then the stress can be calculated. Stresses can also be calculated using simple formulae and hand calculations but this normally requires many simplifications and assumptions to be made. When complex structures such as the chassis are analyzed, the formulas become very large and complex, and often require much iteration, therefore computer programs are required to calculate the stresses involved.

When analyzing the chassis frame, physical and numerical tests will be performed to calculate the real stresses that might be experienced in the chassis under race conditions. Using both methods, comparisons can be made to verify the accuracy of the results.

Numerical Testing

Due to the complexity of the chassis frame's geometry, hand numerical calculations would prove lengthy and prone to errors. So, the numerical tests will be completed using finite element analysis (FEA) within CATIA V5 software. The software allows complex numerical calculations to be performed in feasible time. Property settings required to conduct FEA can often be complicated to simulate the real conditions.

Physical Testing

Physical tests conducted on the chassis will only be to verify the results of the FEA. Physical tests are also to ensure that there are no critical faults in the chassis.

3.1.6 Computer Simulation and Flow Analysis

The designed frame will be simulated and tested in Computer Aided Engineering software for Finite Element Analysis and also flow dynamics. This will ascertain the strength and safety of the design, as well as its performance through the detailed analysis of the forces acting on the frame and body.

3.1.7 Design Integration

The frame and the body will be put together and the contact points will be carefully analysed. Joints and fixtures will also be analysed in this stage to ensure the compatibility and strength of the union.

3.1.8 Finalization of Design

The design will be checked and confirmed before finalizing. Minor changes and adjustments can still be made after this accordingly.

3.2 Project Activities

Past activities for project include:

- Understanding the competition requirements
- Research on past competition entry designs and study on suitable frame design
- Understanding theories and applications of stress and loads on a beam for frame design
- Understanding the theories behind aerodynamics for body design
- Research on frames and chassis
- Sketching of frame and selection
- Material studies and selection for frame
- Modelling and analysis of frame
- Finalizing frame design

3.3 Gantt Chart and Key Milestones

Please refer to the appendix for the proposed project Gantt chart.

3.4 Equipment Needed

The equipments that may be necessary to visualize the project are:

- CAD software, CATIA v5 r18
- CAE software such as Matlab and ADAMS
- Properties analysis software such as Ansys, Gambit, and Fluent
- Workshop and tools for fabrication

CHAPTER 4

RESULT

4.1 Frame Chassis

The vehicle frame that will be designed will be contested in the Shell Eco-marathon Asia 2010 in the Prototype category, where the weight and aerodynamics of the vehicle will play the greatest factor in the frame and body design. In this sense, the weight the materials will play a much greater role in deciding the frame design instead of its strength, rigidity or comfort. The frame will usually be very compact and small, allowing space for only one driver to handle the vehicle and all the essential components to run the vehicle. The design of the frame will be mostly based around the size of the driver and the competition parameters.

4.1.1 Physical Constraints

These are the set of dimensional limits that will be set based on essential components and also the organizer's rules. These dimensions will be the fundamental design constraints whereby all the concept designs will be based about. These dimensions include:

- Driver's dimensions and visibility.
- Frame dimensions (length, width and height).
- Ride elevation, wheel base length, track width, wheel hub height.

4.1.1.1 Driver Space Dimensions

The frame design will be mainly based around the driver's position, giving ample room for the driver to manoeuvre in the vehicle and also ability to enter and exit the vehicle without aid. The driver can be in any position except having the head-first whereby the driver is lying on his belly, and the head being at the front of the vehicle (Shell Eco-marathon Official Rules 2010) for apparent safety reasons. The initial dimensioning of the frame is made by estimating the driver's position during normal driving conditions and also the rules set by the organizer. The desired drivers' position is:

- A lie-down position which has minimal height to reduce frontal area
- Eye level must be above any other points on the body as to allow unobstructed vision

As such, a simple drawing showing the driver's position is made using CATIA V5 based on the template available for Asian males, with a weight of 50kg and a corresponding height of 168cm.

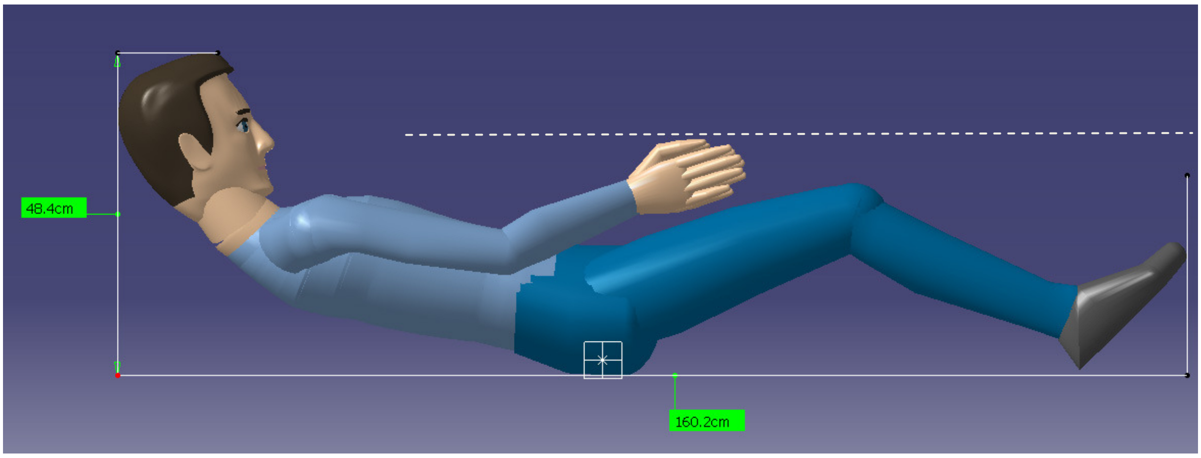


Figure 13: Length and height of driver position

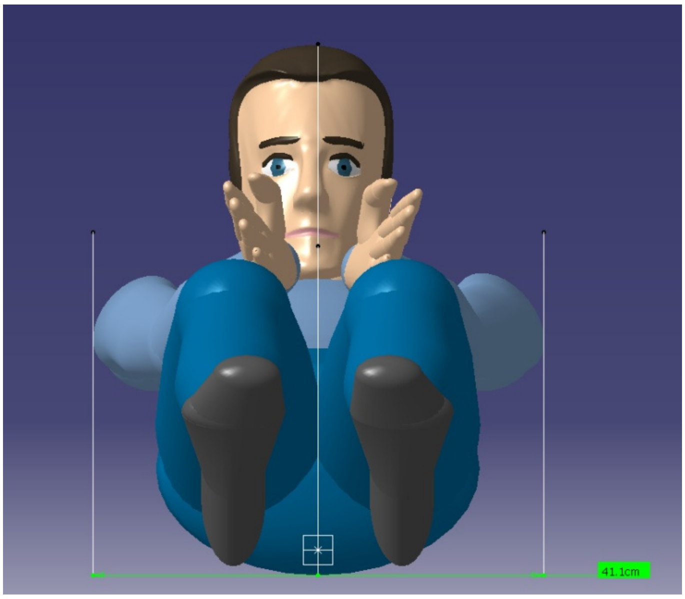


Figure 14: Width of the driver position

As a result, the estimated dimensions required by the driver's position are:

Height: 48.4cm

Length: 160.2cm

Width: 41.1cm

4.1.1.2 Driver Visibility

The Shell Eco-marathon 2010 Official Rules state that the driver must have access to a direct arc of visibility, ahead and to 90° on each side of the longitudinal axis of the vehicle. This field of vision must be achieved without aid of any devices. Movement of the driver's head within the confines of the vehicle body to achieve a complete arc of vision is allowed.

The visibility will be assessed to ensure on track safety. Assessment will be conducted by having seven 60cm high blocks spread out in every 30° in a half circle, with 5m radius arc in front of the vehicle, and visibility of these blocks must be achieved.

With this in mind, the driver's visibility in the position above is created using the CATIA V5 software. The assessment blocks were modelled as mentioned, and the driver's viewpoint is obtained.

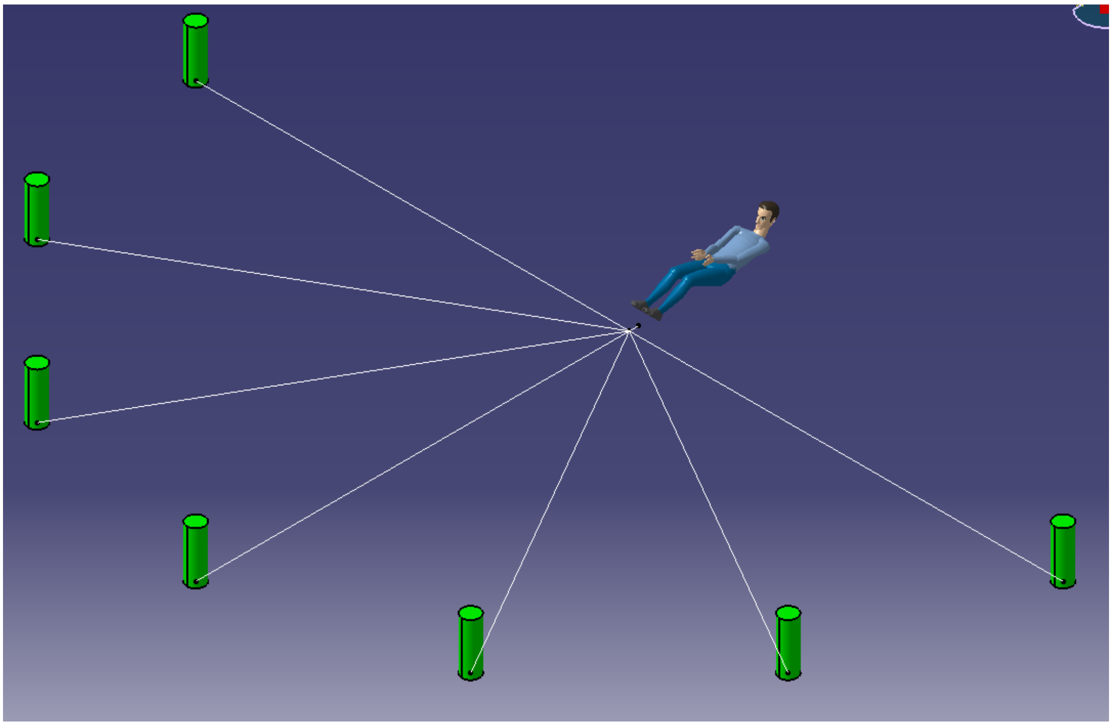


Figure 15: Visibility assessment layout with driver in position

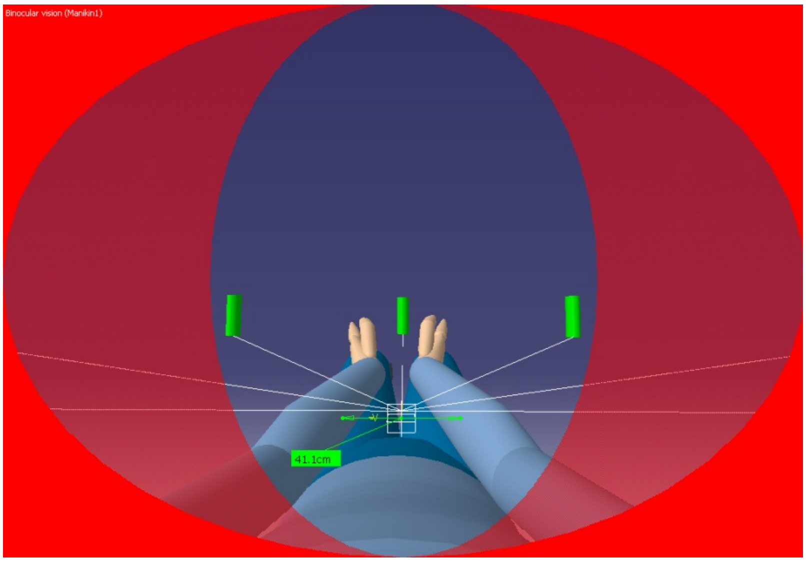


Figure 16: Driver’s front view when in normal position

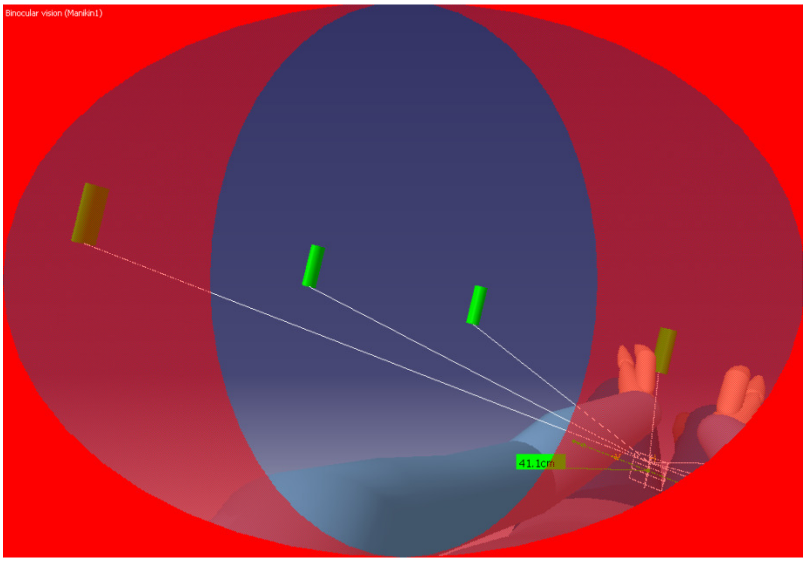


Figure 17: Driver’s left view in normal position with head turned left

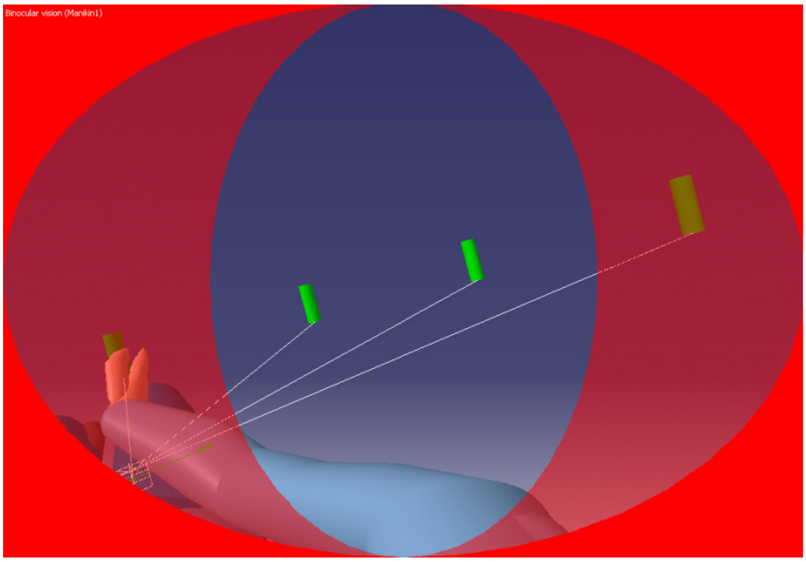


Figure 18: Driver’s right view in normal position with head turned right

As the model result suggests, the driver's assumed position allows for the visibility around the vehicle as per the rules. The visibility is good without any aid, and obstruction. The next visibility test will be conducted when the outer body is in place.

4.1.1.3 Vehicle Frame Dimensions

The vehicle's dimensions should be able to contain space for the driver's cockpit and engine space. It must also adhere to all the regulations set by the organizers. Since the driver is the largest component in the vehicle, it will take precedence in determining the core dimensions of the vehicle.

Table 1: Dimensioning criteria and result

Item	Rules Dimensions	Constraints	Selected Dimension
Height	< 100cm Roll Bar 5cm above driver's helmet	48.4cm (driver) + 5cm clearance < 1.25× track width	55cm
Width	≥ 50cm (track width) < 130cm	41.1cm (driver) 50cm (track)	45cm (frame) 50cm (front wheels)
Length	≤ 350cm ≥ 100cm (wheelbase)	160.2cm (driver) 40cm (engine) 30cm (rear wheel hub)	250cm
Ground clearance	-	-	5cm
Wheel hub height (measured from frame)	-	20" (50.8cm) wheel diameter	20cm

With these numbers, a model is drawn to visualize the dimensions. It is attached in the appendix.

4.2 Frame Design

From the different types of chassis configurations as discussed in Chapter 2, the backbone chassis and the monocoque chassis are excluded from design as they are deemed not feasible for this project.

The backbone chassis as discussed leaves the sides of the vehicle vulnerable without reinforcements. The central load bearing member might be strong in term of bending and stress, but is extremely weak when in torsion. In order to fix these problems, more materials will be required to support the main frame and thus causes the frame to be heavier and costlier. The improved backbone frame's performance can also be easily matched by the other chassis types. Hence, the backbone chassis is thus eliminated.

The monocoque chassis is undoubtedly the best chassis available for a small and light-weight vehicle. However, the difficulty and complexity to design and fabricate a monocoque chassis are far beyond the project's scope. To optimize the monocoque's performance, it is usually made from carbon fibre. This thus creates another issue as carbon fibres are scarce, very expensive, and requires a professional expertise to fabricate. Taking the lack of skills and resources to produce a proper monocoque chassis into account, it is also deemed not feasible.

For the project, chassis that are deemed feasible are the space frame chassis and the ladder chassis. A simple sketch of both the chassis design for the project has been created based on the literature review. The sketches are attached in the appendix. The pros and cons of both the chassis types are shown in the table below:

Table 2: Comparison between space frame chassis and ladder chassis

Space Frame Chassis	Ladder Chassis
<u>Pros</u> • Easy to analyse • Members are in tension and compression only • Members of the frame are the same <u>Cons</u> • Harder to fabricate • Heavier due to more number of members • Harder to fabricate due to the more numbers of members, and structure might exhibit defects because of the many joints	<u>Pros</u> • Easy to design • Light weight due to a lesser number of members • Easier to fabricate <u>Cons</u> • Requires more precise analyses • Different sizes of members for different loads • Members experience torsional forces as well

4.2.1 Concept Designs

Based on the result above, the frame types which are deemed feasible for the project are the space frame and the ladder frame. Both of which have their own pros and cons. A concept model was made for each of the model type to decide between which are more suitable for the project. The concept models are made by referring to the literature reviewed models of other institutions who have participated in similar events.

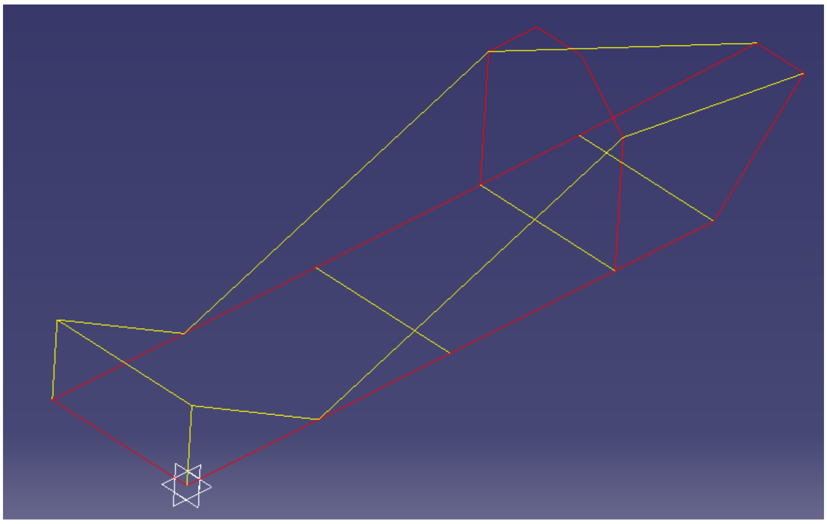


Figure 19: Ladder frame concept design

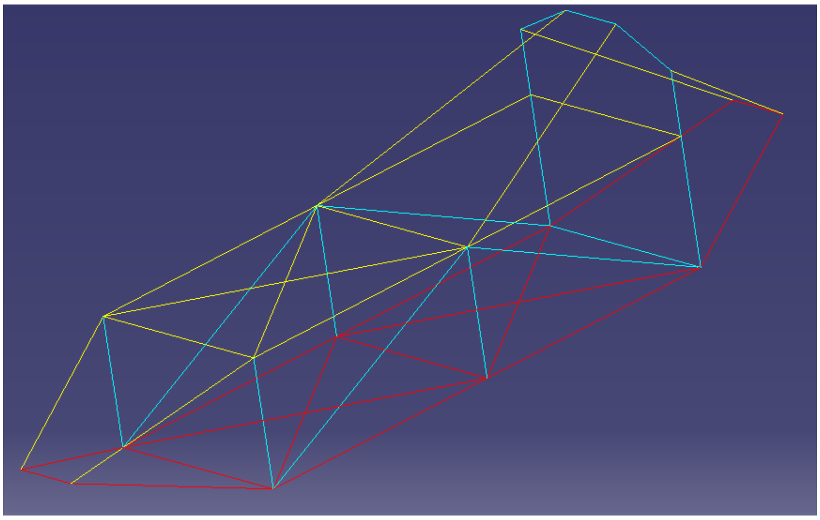


Figure 20: Space frame concept design

Detailed view of the concept models are attached in the appendix.

4.2.2 Concept Selection

With the two concept design in hand, simple decision making can be made to decide which frame is more feasible in terms of meeting the project objectives. The frames will be evaluated based on the number of members, the number of joints, and estimated weight (by assuming each member is homogenous and has an equal length of 0.5*m* and tube outer diameter of 2.5*cm* and thickness of 0.3*cm*, and mild steel as construction material with density of 7.85g/cm^3) for comparison purposes.

Table 3: Selection result between ladder and space frame

Item	Ladder Frame	Space Frame
Number of Joints	16	23
Number of Members	19	36
Estimated Weight	27.8*kg*	52.7*kg*

Based on the table above, the space frame contains more joints, more members and weighs almost 2 times more. It is undeniable that the space frame is much more rigid and sturdy. However, the main goal of the design is to have a lightweight frame while strength and rigidity is only secondary. Hence, the frame type that will be utilised is the ladder frame.

4.2.3 Frame Design with Dimensions

Using the ladder frame type concept and constraining the design to the dimensions specified, a draft design is made. Some major changes have been made to the concept design which was made by referring the frame of the Dalhousie University Supermileage Team.

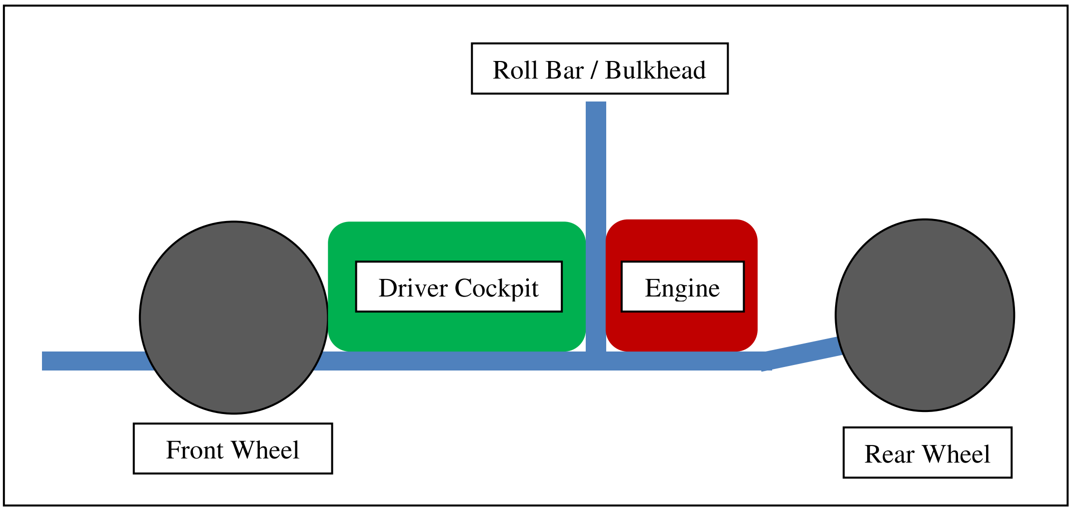


Figure 21: Basic layout of frame design

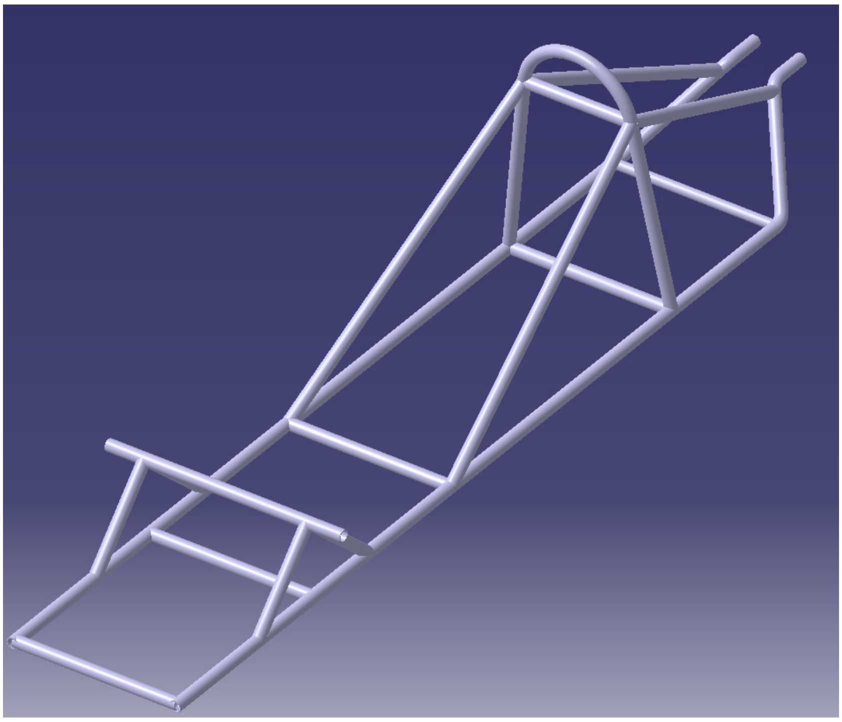


Figure 22: Ladder frame design

The complete dimension of the drawing is attached in the appendix. The table below shows the basic dimension and weight of the frame:

Table 4: Basic dimensions of the ladder frame

Item	Dimension
Length of frame (excluding rear wheel)	250cm 215cm (Wheel base)
Width of frame	25cm (Front) 45cm (Body) 50cm (Front wheel track width)
Height of frame	55cm (roll bar measured from bottom member) 60.4cm (Measured from ground)
Weight	10.382kg

4.2.4 Frame Material

Materials for the frame will be considered based on these factors:

- Weight (density)
- Strength – Ability of the materials to withstand stresses without yielding
- Manufacturability – Ease of fabrication and working of the material

The preliminary material selection includes:

- Steel
- Aluminium
- Titanium
- Carbon Fibre

Carbon Fibre, although its strength and stiffness can be tailored as required due to its anisotropic nature, it is also one of the most expensive and toughest material to work with. With the lack of resources to purchase and handle carbon fibre, hence the material is neglected for the design considerations.

Steel is the oldest frame material ever used. Its alloys contain iron, carbon and other materials to improve its properties. Steels are used extensively due to its various properties that can be applied in almost every application. Steels are also very easy to work with, as it can be brazed, welded and bonded. The most common steel alloy used in frames is the 1010 Carbon Steel.

Aluminium is presently the most popular frame material. It comes in various alloys and hardness which compensates for its weaker and ductile nature. Aluminium is very light, lightest among all the metals used in frames. Aluminium however requires more advanced manufacturing processes to ensure its strength is maintained after machined. It has to be heat-treated to restore its strength after welding. The most common aluminium alloy used in frames is the 6061 T6 Aluminium.

Titanium can be considered as one of the strongest metals on earth with its alloys. Titanium alloys are as strong as steel but are generally 45% lighter. It is also twice as strong as aluminium but only 60% heavier. Titanium also alloys have great corrosion resistance. However, titanium alloys have a very hefty price tag and this thus limits its usage. The most common titanium alloy used in frames is the Grade 9 Titanium.

Each metal have its own specific properties which defines its usage. A materials density shows the weight of the material for a known volume of it. The specific stiffness of a material shows its resistance towards deformation while the specific strength of a material indicates its resistance towards fracture.

Comparing the basic properties of the 3 most commonly used metals for frames:

Table 5: Comparison of Basic Properties of Common Frame Materials

	Modulus of Elasticity, E GPa	Density, ρ G/cm^3	Yield Stress, S Mpa	Specific Stiffness, E/ρ	Specific Strength, S/ρ
1010 Carbon Steel	210	7.8	240	25.6	30
6061 T6 Aluminium	70	2.7	260	25.9	95
ASTM 9 Titanium	110	4.5	550	24.4	122

The manufacturability of the materials also play an important role in selecting a material for the frame, as the frame would have to be manually constructed and joined. Below is the table of comparison for the manufacturing of frames:

Table 6: Comparison of materials manufacturability

	Steels	Aluminium Alloys	Titanium Alloys
Brazing	Yes	No	No
Welding	Yes	Yes	Yes
Bonding	Yes	Yes	Yes

Looking at the tables above, Aluminium seems to be the best choice in terms of stiffness, strength and price. It is also fairly good in terms of manufacturability. Among the three metals, their specific stiffness is more or less equal. The strength of the materials is the ones which differentiate from one another, with Aluminium performing averagely between carbon steel and titanium alloy. Given that aluminium alloys are more easily obtained and much cheaper compared to titanium alloys, and also much lighter, it is thus selected to be the primary material for the frame construction of this project.

Now that aluminium has been chosen as the preferred metal to be used to construct the frame, the different alloys will be looked into to select the optimum material. The two common aluminium alloys used in the construction of frames are the 6061 T6 Aluminium Alloy and the 7075 T6 Aluminium Alloy. Below is the summary and comparison between the basic physical properties of the two alloys.

Table 7: Properties of 6061T6 and 7075 T6 aluminium alloys

Item	**6061 T6 Aluminium Alloy**	**7075 T6 Aluminium Alloy**
Density, ρ $^{kg}/_{m^3}$	2700	2810
Ultimate Tensile Strength MPa	310	572
Yield Strength MPa	276	503
Modulus of Elasticity, E GPa	68.9	71.7
Poisson's Ratio	0.33	0.33

Comparing the properties of the two different alloys, other than the big difference in tensile and yield strengths, most other properties are about the same. Hence, it is apparent that the 7075 T6 Aluminium Alloy is the stronger material and best suited to be used to construct the chassis frame.

Tube Size

The sizes of aluminium tubing available at the metal shop are:

Table 8: Tube Sizes available

Item	Outer Diameter (inch)	Thickness (mm)
1	1 ¼ (3.175cm)	1.59
2	1 (2.54cm)	3.0
3	¾ (1.905cm)	1.5

With these tubing sizes, a simple analysis is made to determine which has the best performance. For the analysis purposes, a tube length of 1 meter for each tube size is used. A tensional force of 500N is applied at one end of the tube at a direction parallel to the tube axis while the other end is fixed. Deflection and bending is also calculated with a force of 500N applied at one end of the tube perpendicular to the tube axis while the other end is fixed.

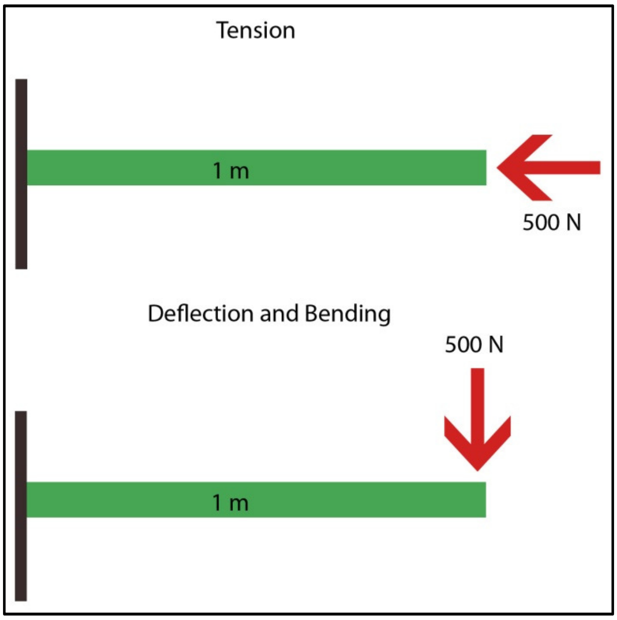


Figure 23: Simple tube analysis diagram

Table 9: Result of simple tube analysis

Item	OD	Thickness	ID	Area	Ix	Mass	Tension	Deflection	Bending
	cm	cm	cm	cm2	cm^4	kg	Pa	cm	Pa
1	3.175	0.159	2.857	1.507	1.718	0.423	331.89	0.0046	29108.11
2	2.540	0.300	1.940	2.111	1.348	0.593	236.84	0.0033	37095.77
3	1.905	0.150	1.605	0.827	0.321	0.232	604.58	0.0084	155893.1

From the simple analysis of each of the tube sizes, it is found that the tube with the 1" OD and 3mm thickness is the strongest, and is tougher in resisting deflection. With these properties in mind, the preferred tube size for construction would be the 1" OD tube.

4.2.5 Frame Assessment

The assessment of the chassis is an integral part of the design phase to ensure that the chassis will perform under the applied loads without unexpected results. The amount of deflection of the members and the stresses experienced by the frame are significant factors that will influence the performance of the frame.

The material properties used in the analysis of the chassis is very critical. A slight mistake can result in severe calculation errors which could then lead to incorrect results showing that the chassis strength to vary greatly from what it actually is. The material properties for the 7075 T6 Aluminium Alloy tubes used in the construction of the chassis are listed in table 8. The material properties were taken from tables and calculated, details is attached in the appendix.

The tube size used for the construction of the frame has an outer diameter of 1" or 2.54*cm* with a thickness of 3*mm*. Analysis of the frame will be based on this size of tubing.

Table 10: Material properties of 7075 T6 Aluminium Alloy for analysis

Young's Modulus	71.7 *GPa*
Density	2810 kg/m^3
Poisson's Ration	0.33
I_{xx} (Moment of inertia of cross sectional area)	1.348 cm^4
Cross sectional area	2.111 cm^2

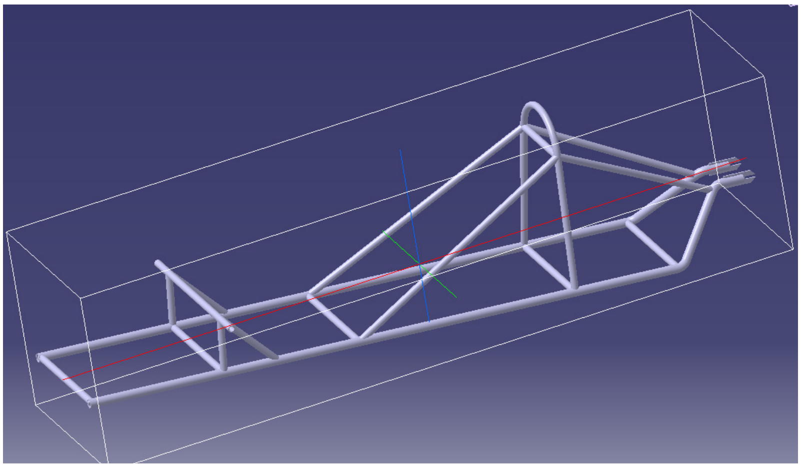


Figure 24: Centre of Gravity of Chassis Frame

Centre of Gravity

The centre of gravity is a simple representation of an objects position of weight. It is a single central point at which force can act on the body as a whole. The centre of gravity is a point where the object can be picked up and will remain in equilibrium.

The centre of gravity of the chassis frame is determined using CATIA V5. The solid model of the frame was created and the centre of gravity was found using mass analysis function. The centre of gravity requires the density of the material to be known such that it can be obtained. The centre of gravity of the frame was located at 132.674*cm* in the X-axis, 0.074*cm* at the Y-axis, and 12.753*cm* in the Z-axis.

4.2.6 Deflection Analysis

Chassis deflection is one of the important criteria that need to be known for it is one of the contributing factors to vehicle failure. Chassis frame deflections are caused by having component mounts or loads in the middle of an unsupported beam.

The project frame was analysed for deflection using CATIA V5 finite element analysis component. The chassis frame was modelled in 3 dimensions and each of the members is meshed into small nodes and elements such that a high accuracy result can be obtained. The meshed nodes and elements of the frame can be seen in the appendix while a close up of the roll bar after meshing is shown below.

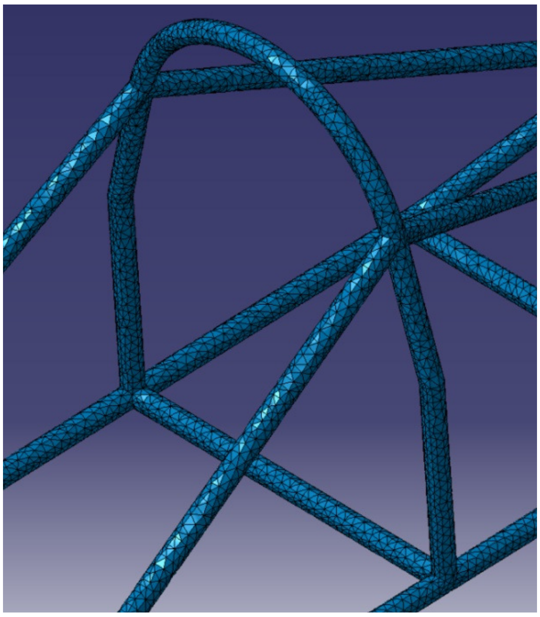


Figure 25: Close –up of meshing of nodes and elements

<u>Static Load Deflection</u>

The model's deflection was analysed by applying loads to simulate the weight of the driver and engine. The acceleration of gravity is taken to be 10m/s^2 and safety factor of 1.5 is also added to the loads to simulate worst case conditions.

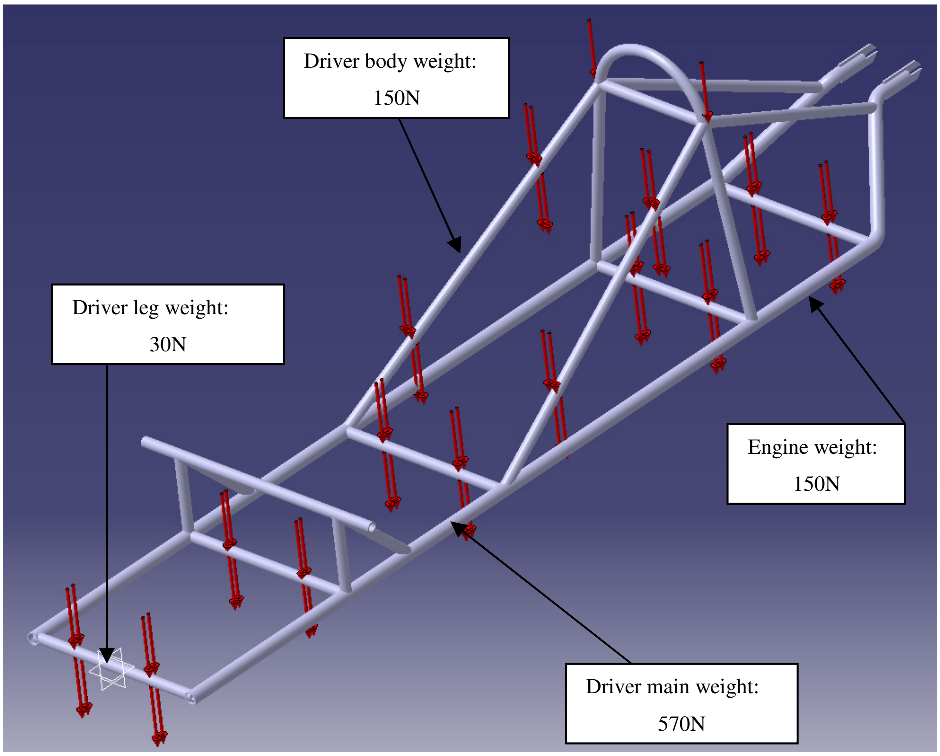


Figure 26: Application of Loads with Safety Factor on the Chassis Frame

With the loads properly applied to simulate real load conditions, the software can then analyse the deflection of the frame accordingly. After the result is produced, the deflection of the frame can be visualised. From the result, maximum displacement is 0.453cm. Location of this maximum deflection is attached in the appendix.

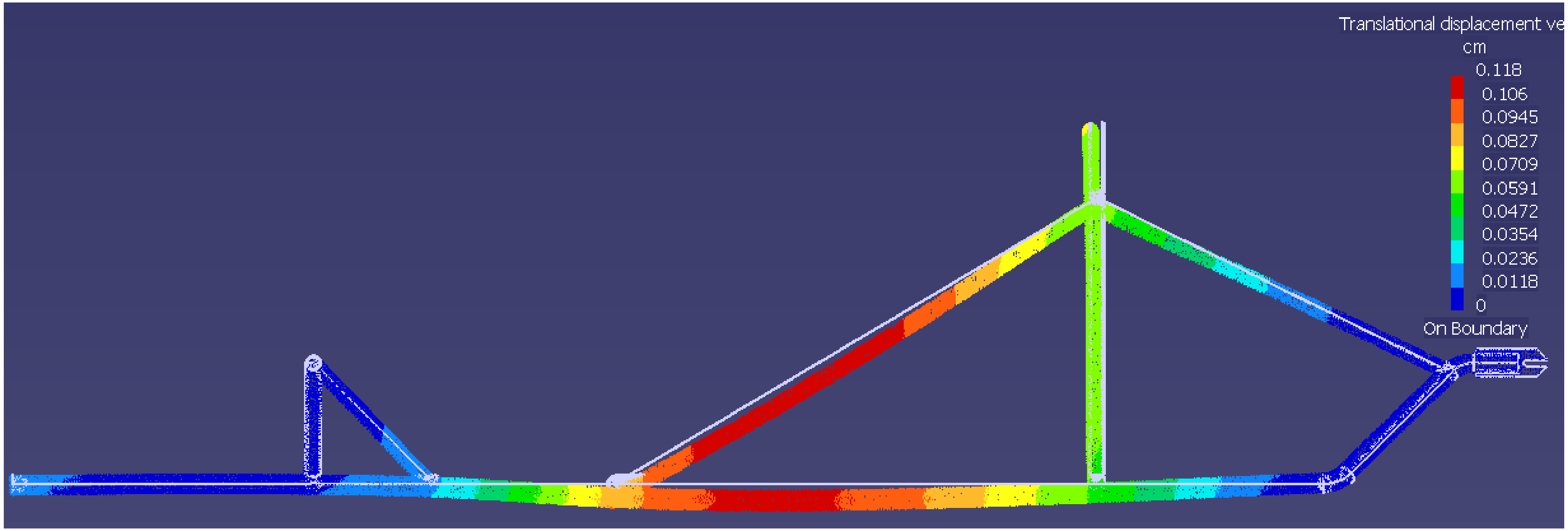


Figure 27: Deflection of the frame with applied static loads with 20 times amplification and comparison to the original shape.

With the maximum deflection of the frame at about 1.18*mm*, this is about 5% of the tube's diameter. The stresses that are exerted onto the frame can be calculated to determine the effect of the deflection.

Roll Bar Load Deflection

As mentioned before in chapter 3, the roll bar must be able to withstand a static load test of 700*N* which will be performed by the organizers as part of their safety requirement. The concept of the roll-bar is that it's meant to protect the driver in the event that the car turns turtle. A slight deformation is acceptable, but the main role of the roll-bar is that it should not impact the driver's helmet if the car turns upside down. This is also the reason why a 5cm clearance is required around the helmet.

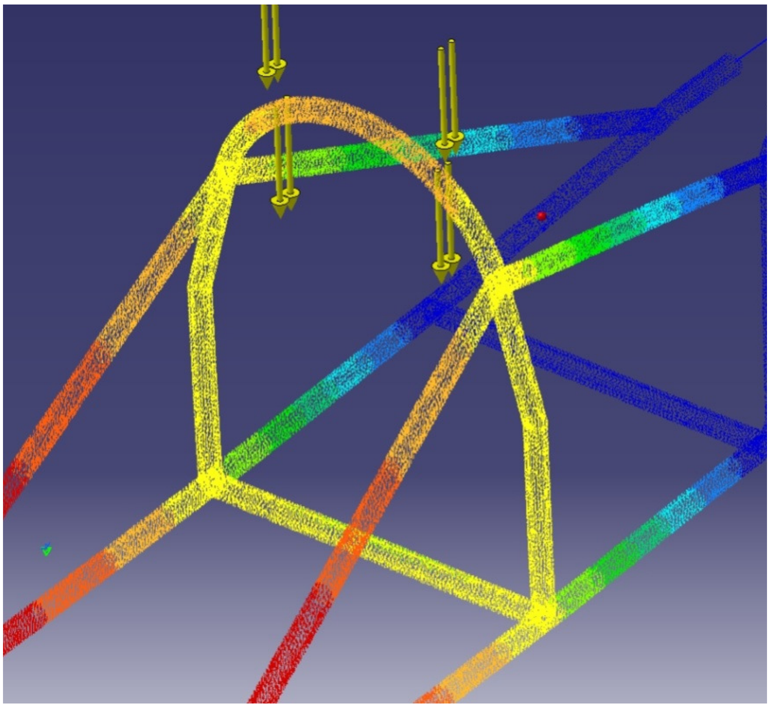


Figure 28: Deflection of roll bar under 700N load

The analysis show that the roll bar will suffer a deflection of at most 0.7mm which is acceptable as a 5cm clearance would be more than enough to cover for this compaction.

Dynamic Load Deflection

When the vehicle is accelerating and braking, forces are exerted on the vehicle, the driver and the components which are relative to the direction of vehicle travel. In addition to the static loads which the vehicle must sustain, the frame must also take this force into account. Hence a horizontal force which is acting towards the back of the vehicle is applied to the model, and the deflection is taken note of. The results are attached in the appendix.

4.2.7 Stresses Analysis

It is important to know the stresses acting on the vehicle because they will determine if whether the frame will perform effectively with the loads in a normal condition. If the stresses exceed the material's yield strength, then the frame will definitely exhibit plastic deformation that is detrimental to the frame's integrity.

The stress that is relevant in deciding whether the material will be experiencing plastic deformation is the Von Mises Stress. Using the FEA model in CATIA V5, the Von Mises Stress is plotted according to magnitude of the stresses. The complete stress visualisation is viewable in the appendix. The figure below shows the maximum stress at the frame when static loads are applied:

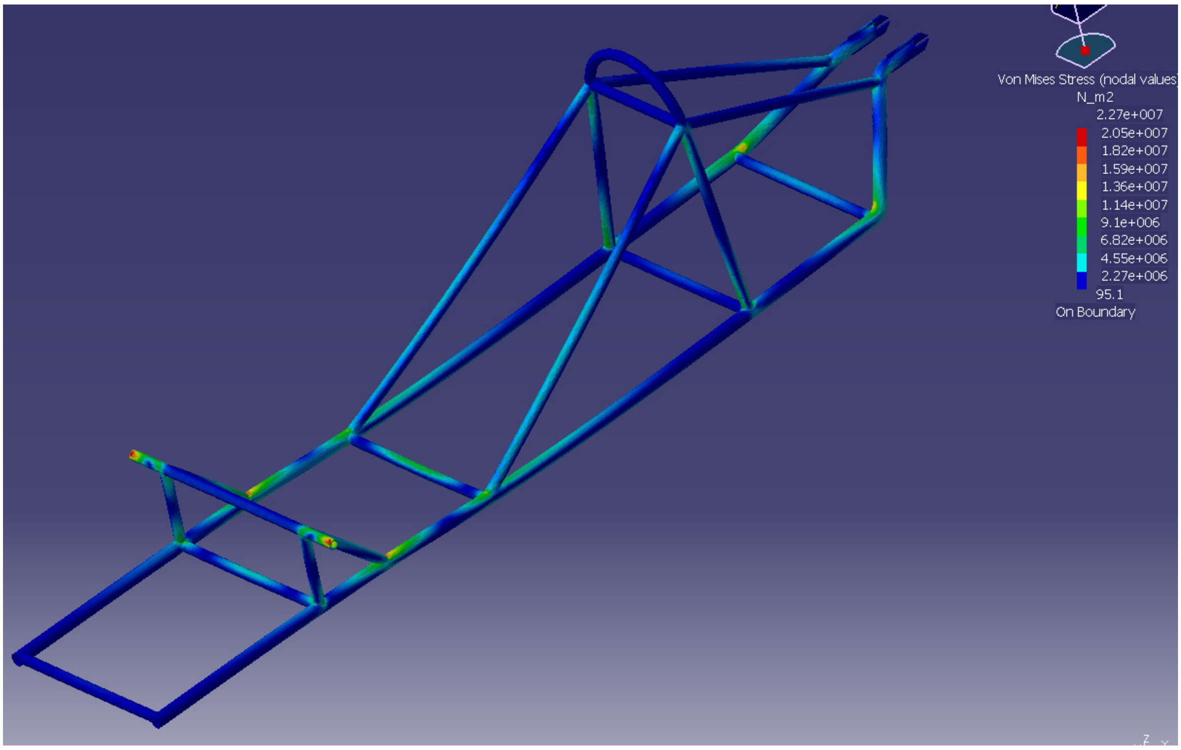


Figure 29: Maximum Von Mises Stress of chassis frame

As mentioned before for the frame to perform efficiently under normal driving conditions without deformation, the stresses experienced by the frame must be less than the yield strength of the frame construction material. Once the yield strength of the material is overcome, the frame will start to exhibit plastic deformation that will cause the frame to twist or bend permanently. Also adequate safety factor must be allocated into the design calculations as to allow for worst case scenarios such as collision.

Adding safety factor for design purposes:

$$\sigma_{vm} < \frac{\sigma_y}{N}$$

Where,
N = factor of safety
σ_{vm} = Von Mises Stress
σ_y = Yield Strength

The maximum stress obtained from the analysis was 26.1MPa. The yield strength of the 7075 T6 Aluminium tube is 503MPa. Comparing the two and computing the added safety factor of 1.5:

$$\sigma_{vm} \times N = \sigma_y$$
$$26.1MPa \times 1.5 = 503MPa$$
$$39.15MPa \ll 503MPa$$
$$\sigma_{vm} \ll \sigma_y$$

From the comparison above, it is shown that the stresses experienced by the frame are far below the yield strength of the material. Hence it is safe to say that the frame will perform as desired without yielding and acceptable deflection.

4.3 Body

4.3.1 Design Basis

Initial design is based on the teardrop shape as it is the most aerodynamic shape for a moving object. The teardrop shape allows the parting air to flow along the body of the vehicle, decreasing the amount of turbulent eddies formed around the vehicle which in turn reduces the air drag forces. Drag forces can be reduced if the vehicle has:

- Small frontal area
- Minimal ground clearance
- Steeply raked windshield
- Converging rear end
- Slightly raked underside
- Cover open wheels

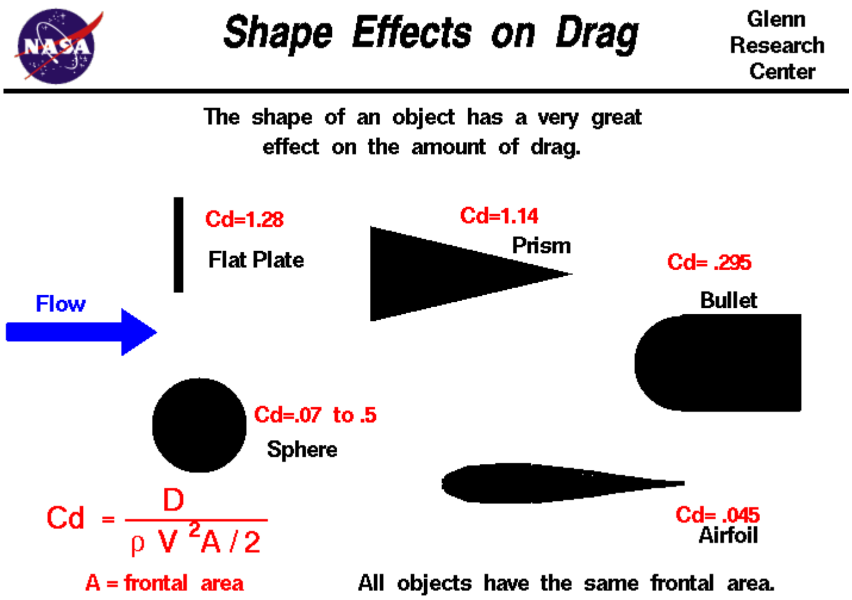


Figure 30: Drag Coefficient of various shapes

Picture source: http://www.grc.nasa.gov/WWW/K-12/airplane/shaped.html

The design will also be as compact as possible, allowing only for sufficient space for the driver to effectively manoeuvre the vehicle. Having a small vehicle will reduce the frontal area of the vehicle, thus reducing the amount of air being parted when the vehicle is motion to reduce the wake produced.

The design will also have to allow for the ease of access in and out of the vehicle by the driver as well as for the technical team to inspect the internal parts of the vehicle. An easier alternative to this is to allow the entire top-half of the body to be detachable from the chassis, which would reveal the internals of the vehicle.

It is also recommended to design the body to envelop the wheels to a certain extent, or create an additional casing to cover the wheels as the rotation of the wheels will create a significant amount of air drag to the vehicle. This however would require more materials to be used and thus creates more weight.

Also the design parameters set by the vehicle frame are:

- Length of frame (including rear wheel) – 275.4cm
- Width of frame – Front 25cm, body 45cm, and track width 50cm
- Height of frame (measured from ground) – 60.4cm

4.3.2 Body Designs

4.3.2.1 Concept Designs

The basic design of the car will be based on the limitations set by the internal parts as shown in Figure 5. The design concepts are based on the design of the Japanese Shinkansen (Bullet Train).

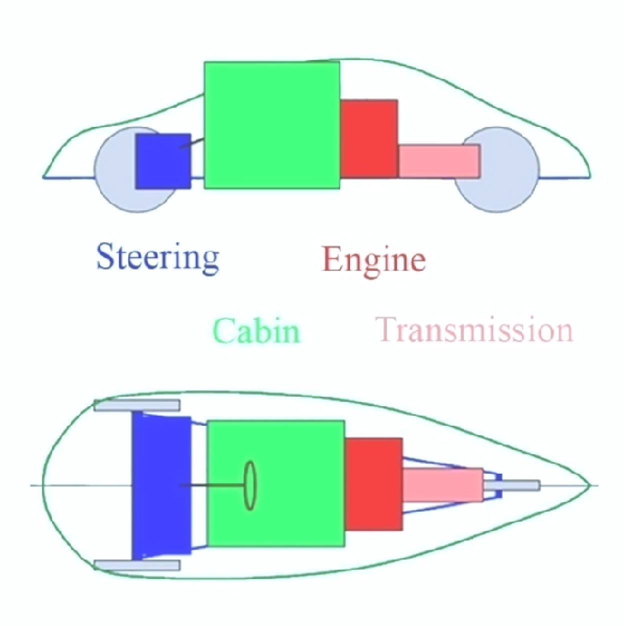


Figure 31: Basic Concept of Body Design

The sketches for the concept designs are attached in the Appendix.

Concept 1 has a smooth and curved body shape which incorporates the aerodynamic shape of a teardrop. The body will envelope the front wheels to reduce the drag caused by them. The top of the cockpit will be transparent to allow the driver visibility of the field. The top half of the body can be removed to allow entry and exit for the driver, and also access to the internal parts of the vehicle.

Concept 2 on the other hand is very much similar to Concept 1, with the exception of the forward wheels which are placed outside of the vehicle in favour of an easier fabrication and also smaller and lighter body.

Concept 3 is geometrically shaped to reduce the frontal area of the vehicle. It is also easier to fabricate as opposed to the other 2 designs due to its geometric shape. However, it has a larger air drag due to the sharp edges and ledges. It also has a transparent cockpit to allow visibility to the driver. The top half of the body is also removable.

4.3.2.2 Body Design Selection

Concept design 2 is selected for the project as it fits the objective of the project the most, having reduced weight while maintaining aerodynamics. The design is referenced from the high speed Japanese bullet train called Shinkansen. The Shinkansen is carefully designed for high speed travel, having an aerodynamic shape and small drag coefficient.

Figure 32: The 500 Series Shinkansen

Picture source: http://currawong.net/2010/03/29/japans-most-famous-shinkansen-bullet-train-removed-from-nozomi-service/

Using the vehicle frame as the base constraint, a body design was produced using CATIA. The frontal are of the design equals to the area of the roll bar. The front portion of the vehicle body resembles that of the Shinkansen, shaped like a bullet. The general shape of the vehicle is that of a teardrop, the shape with the least drag coefficient. Below is the result:

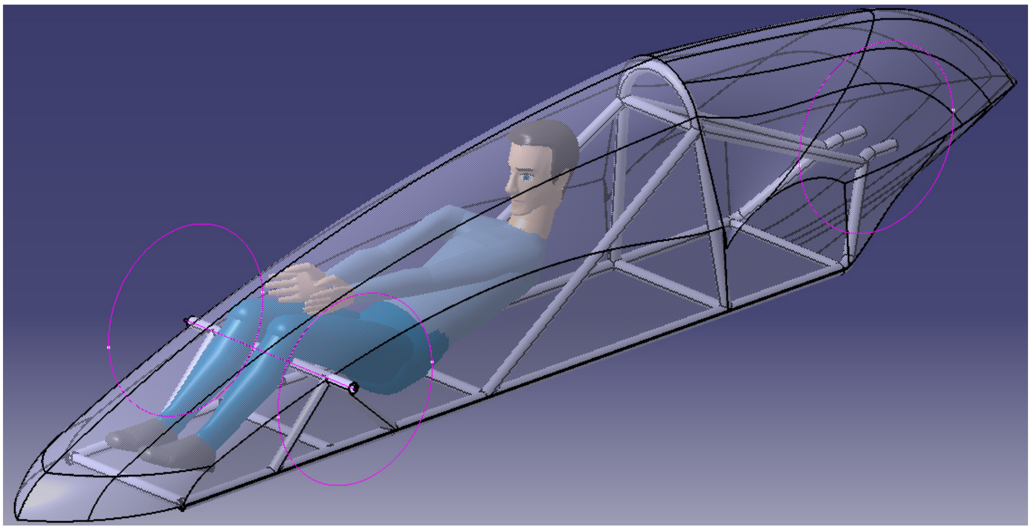


Figure 33: Body design

4.3.3 Material Selection

The design selection will be based on the following criterion:

- Weight and stiffness of body material
- Price of material

The material of the body must be able to withstand the drag forces that will be experienced by the vehicle when going at a maximum speed of 35*km/h* without noticeable deflections. Also the material of the body should be made out of lightweight material to overall reduce the weight of the vehicle which will ultimately increase the vehicle's fuel efficiency.

4.3.3.1 Feasible Materials

The feasible body construction materials that were identified to be lightweight and easily accessible are:

Aluminium

Aluminium has a low density and high strength. However it is hard to form and is easily deformed due to its low elasticity. Aluminium is easily obtained and recycled, and possesses corrosion resistant properties. There are many different alloys available to suit the formability and strength requirements (Davies 2003).

GFRP

Commonly known as fibreglass, GFRP is widely used in the automotive industry. GFRP is advantageous due to its high formability, controllability of material properties, wide scope of applications, and relative ease of production. GFRP has a lower density compared to aluminium but its production must be carefully controlled to achieve the desired properties and effect. It easily formable but not easily repaired and cannot be recycled. GFRP also provides good corrosion resistance as well as good dimensional stability and scratch resistance qualities (Davies 2003).

CFRP

Commonly known as carbon fibre, CFRP is very similar in its advantages and disadvantages to GFRP however is has a lower density and higher strength. These improved material properties lead to a much higher material cost. CFRP is 30% lighter than GFRP, making it a better material albeit it's higher cost (Balfour 2000).

For the project, Aluminium is deemed not feasible due to its inability to be formed easily. This is important because the shape of the body that was decided is heavily contoured and smooth, thus requiring a material that can be shaped easily to acquire the desired result.

Between Fibreglass and Carbon Fibre, both have the properties to be formed easily as they are produced using a liquid mixture of matrix and reinforcement fibres. Once harden it will take the shape of the mould that was used to hold the composite in place. The only major difference between the two composite are their weights. As mentioned above, Carbon Fibre is 30% lighter than Fibreglass and stronger, but causes the material cost to increase tenfold.

Since the price of the material is the secondary criterion, Carbon Fibre, despite its superior properties and advantages is deemed not suitable due to its hefty price. Hence, fibreglass would be used for the construction of the body.

4.3.3.2 Customizing Material Properties

The properties of composites are customisable according to the number of layers of woven reinforcement fibres laid in the production of the composite. The strength and stiffness can be tailored in the directions and locations that are necessary by strategically placing materials and orienting fibre direction (Performance Composites Inc, 2010).

To determine the properties of fibreglass that best suit the need project objectives, the basic properties of 3 different types of fibreglass composites having different layers of reinforcement fibres are compared. The fibreglass composites have each 1, 2 and 3 layers of reinforcement fibre, while the matrix mixture used is the same which is polyester with MEKP catalyst. All the fibreglass composites tested have lengths of 20*cm* and widths of 10*cm*.

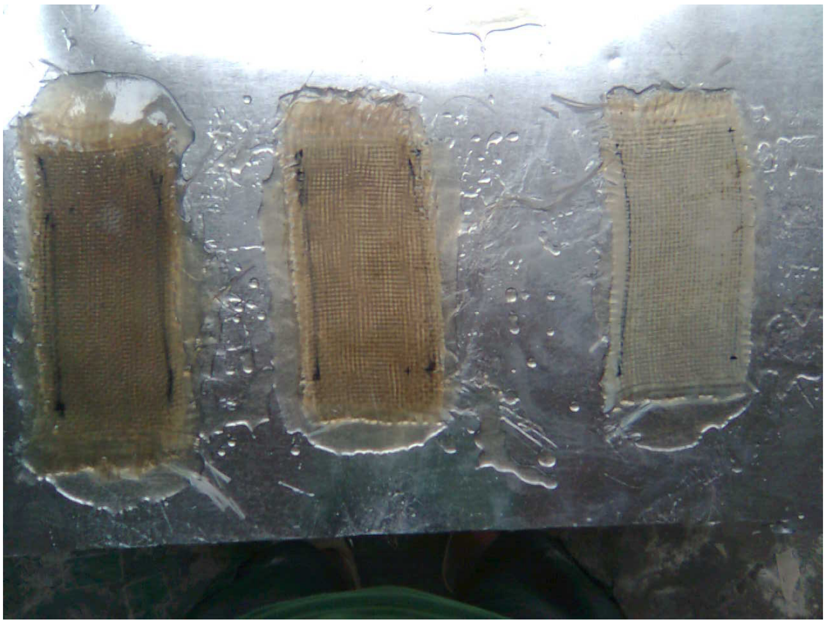


Figure 34: The fibreglass composites that are hardening.
From left: 3 layers of woven glass fibre, 2 layers and 1 layer. Each has an area of 20cm×10cm.

The basic properties of the composites obtained are:

Table 11: Basic Properties of the fibreglass composite

Layers	Thickness (mm)				Weight (kg)	Volume (m^3)	Density (kg/m^3)
	1	2	3	Avg			
1	1.04	1.12	1.08	1.08	0.040	0.0000216	1851.852
2	1.9	1.94	1.88	1.91	0.060	3.813E-05	1573.427
3	2.6	2.5	2.74	2.61	0.085	5.227E-05	1626.276

Also a deflection test was conducted to measure the stiffness of the material. The material is subjected to a force and the deflection caused by the weight is measured. The weight of the object is to simulate the drag force that the composite material will be experiencing when travelling at a speed of 35*km/h*. The drag force is calculated as such:

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

Where:
F_D = Drag Force
ρ = density of air at 40°C = 1.127
v = relative velocity of object
C_D = Drag coefficient (for flat plate = 1.2)
A = Frontal Area

$$F_D = \frac{1}{2}(1.127)(9.722^2)(1.2)(0.02)$$

$$F_D = 1.278N \times 1.5(Safety\ Factor)$$
$$F_D \approx 2N$$

And so a force of 2*N* will be placed onto the composite to measure its deflection. This will be achieved by placing a 200*g* weight onto the middle of the 20*cm*×10*cm* composite material supported on two ends. The configuration of the test is shown in the figure below.

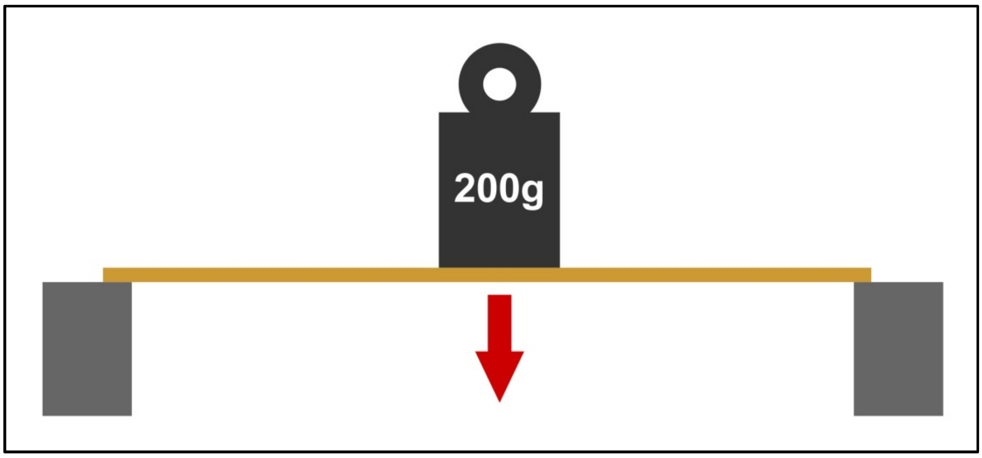


Figure 35: Deflection test configuration

Each of the composite material with different reinforcement fibre layers are subjected to the test and the deflection caused by the load is recorded. The result is shown below:

Table 12: Deflection test result

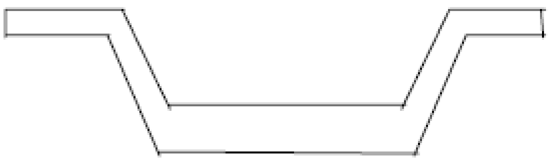
Layers	Deflection without weight (mm)			Deflection with 200g weight (mm)			Net deflection (mm)	Deflection/Thickness %
	1	2	Avg	1	2	Avg		
1	22.1	22.36	22.23	17.46	16.78	17.12	5.11	473.15
2	22.36	22.28	22.32	21.64	22.18	21.91	0.41	21.50
3	23.42	23.44	23.43	23.32	23.32	23.32	0.11	4.21

From the test, Fibreglass with 2 layers of reinforcement fibre will be used for the construction of the vehicle body as it has the lowest density compared to the other two while offering a good stiffness with only a deflection of about 20% of its thickness. This will ensure the vehicle to be lightweight and strong at the same time.

4.3.3.3 Manufacturing Process

The manufacturing process for fibreglass that was adopted by this process would be the wet lay-up process using a mould. The shape of the part is determined by the shape of the mould, and the mould surface is either in contact with the exterior or interior of the part. Mould release agent is first applied to the mould to prevent the fibreglass part from adhering to the mould. Then fibreglass and the resin matrix are deposited on to the mould and the wet composite is compressed by rollers, which evenly distributes the resin and removes air pockets.

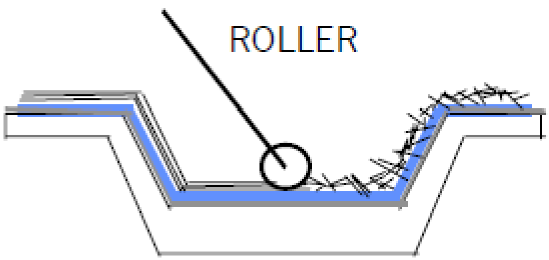
Another layer of fibreglass is deposited and more resin matrixes are deposited onto the new layer. The new wet composite is then rolled and compacted again. When the resin is cured and hardened, the part is removed from the mould. Excess material is trimmed of and any surface defects are fixed using polyester filler. After this, the part is then ready for paint and assembly. The entire process is depicted below:



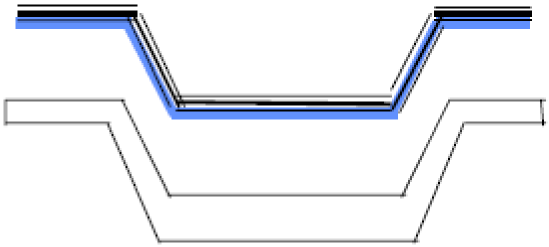
Mould is made from foam, with a layer of plaster to prevent matrix from seeping into the foam. The mould surface is smoothen and filled for a good finish.

Mould release agent such as wax or silicon is applied onto the mould area.

The woven fibreglass is cut according to the mould shape and placed onto the mould. The resin matrix is then poured onto the fibreglass. The composite is evenly applied using a roller.



The previous step is repeated so that another layer is applied to get a two layer reinforced composite.



Once the composite is fully cured, it can be easily removed from the mould.

Figure 36: The fabrication process of fibreglass composite for the prototype

4.4 Prototype Fabrication

With both the design and analysis of the frame and body completed, the next step in the process is to fabricate the design according to specifications. Since the project is a small scale project to produce a prototype, the budget is limited and most of the parts are customised. Hence, the fabrication is mostly hand-made.

Pictures of the prototype fabrication are attached in the appendix.

CHAPTER 5

CONCLUSION

The ladder frame chassis was used as the frame for the simple one man vehicle. The material for the vehicle frame is the 7075 T6 aluminium tube with an outer diameter of 1" and thickness of 3mm. The material was chosen due to its density which weighs lesser than the other materials. Analyses on the frame design show that the frame could withstand all the static and dynamic forces with a maximum deflection of 1.26*mm* which is about 5% of the tube thickness. The frame will also perform without plastic deformation as the maximum stress experienced is 39.15*MPa* which is much less than the material's yield strength.

The shape of the body is an important factor in determining the aerodynamics of the body. With the teardrop shape, the air drag can be minimised and thus improve the performance of the vehicle by reducing the engine output required to overcome air drag. The frontal area should also be as small as possible to reduce the air wake produced from the parting of air flow by the movement of the vehicle. The vehicle body is constructed from fibreglass composite with 2 layers of reinforcement. The composite is tested to be light, stiff, and also economically sound.

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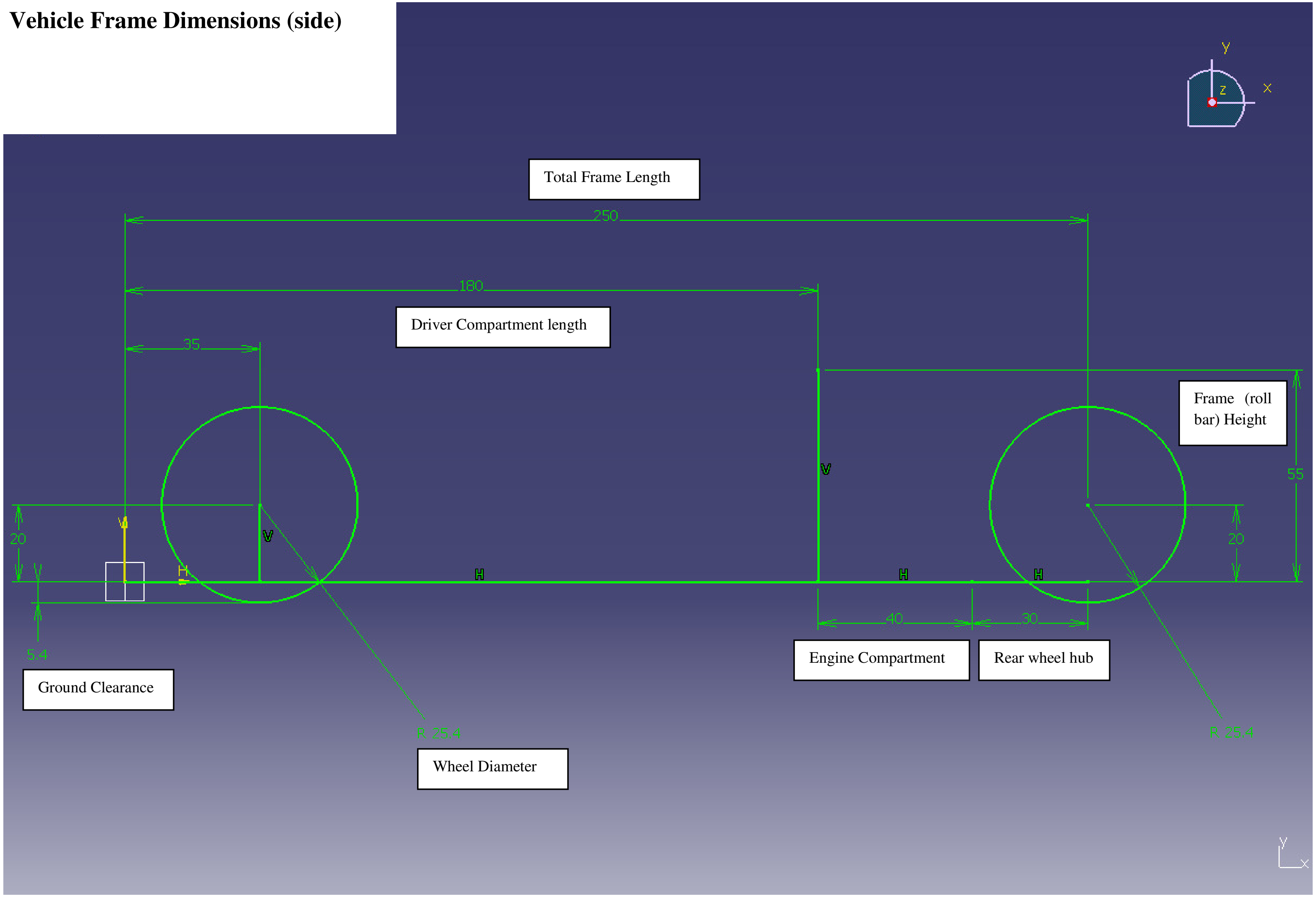
Appendices

Gantt Chart

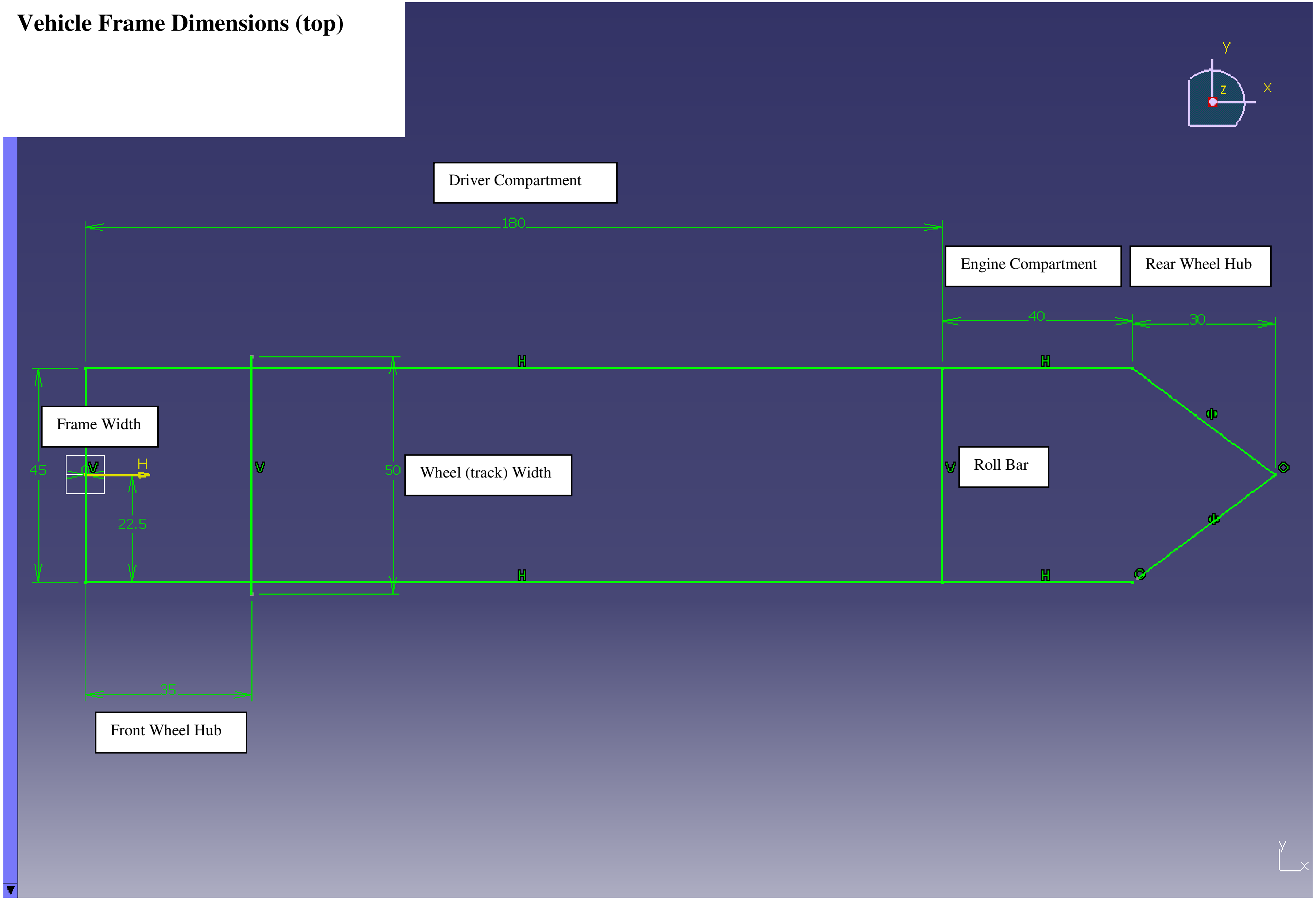
FYP 2

Week Number Activities / Milestone	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Body Design and research														
Concept Design Evaluation														
Concept Design Analysis														
CAD Modelling														
Aerodynamics Analysis														
Adjustments														
Fabrication of Body														
Assembly of Components														
Outdoor Testing and modifications														
Finalization and adjustments														

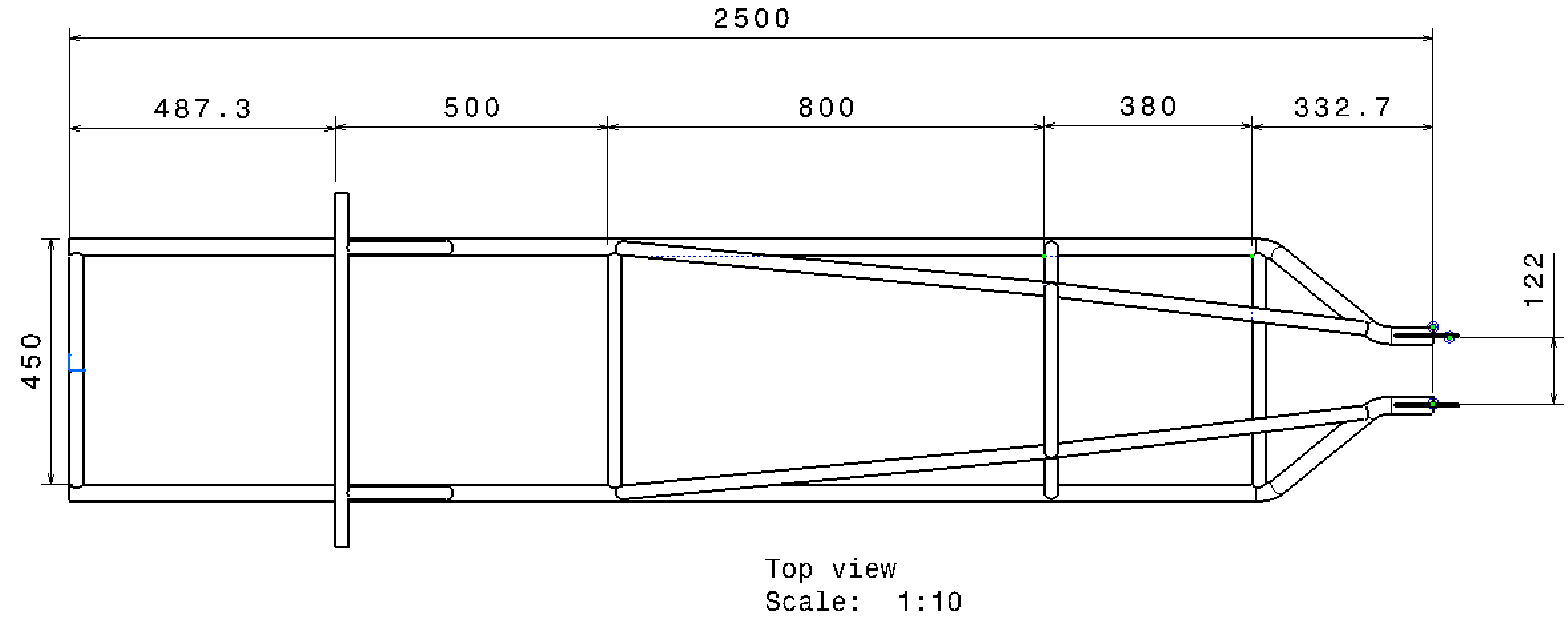
Vehicle Frame Dimensions (side)



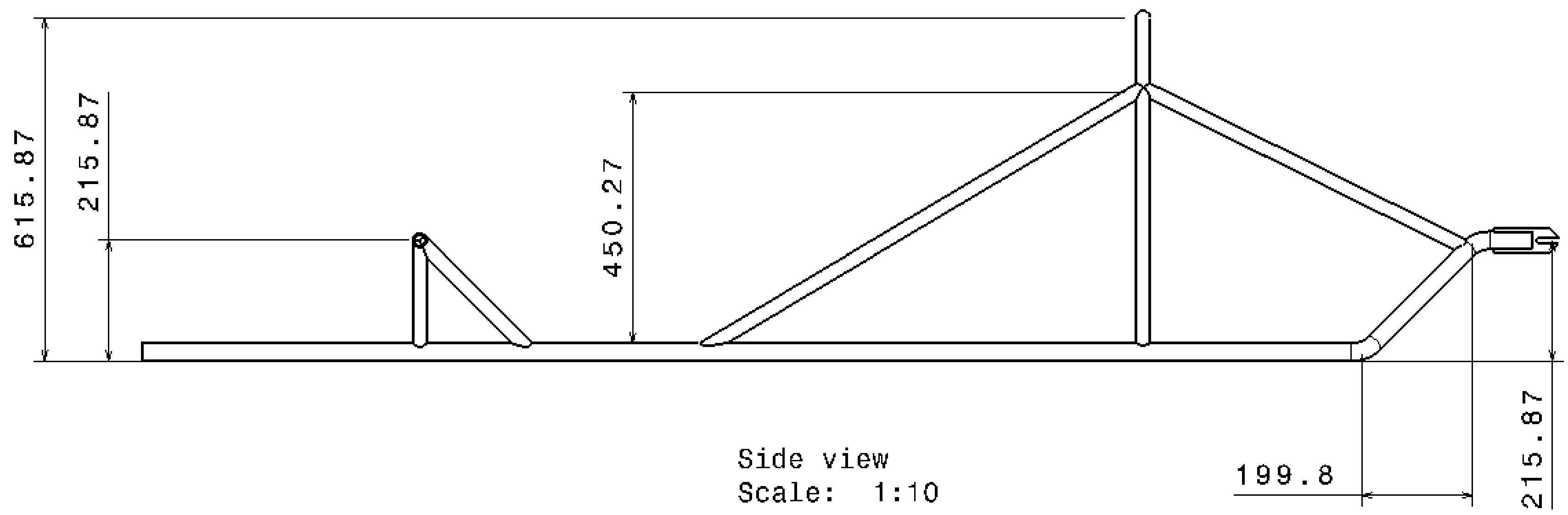
Vehicle Frame Dimensions (top)



Ladder Frame Dimension (Top)

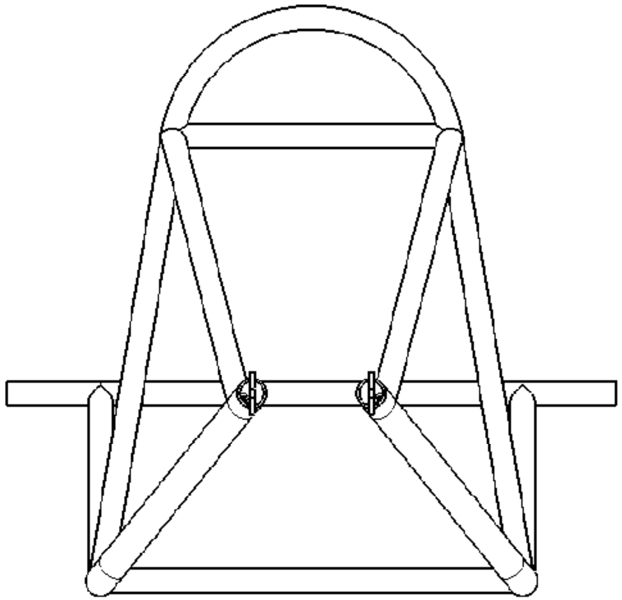


Ladder Frame Dimension (Side)



Ladder Frame Dimension (Front)

Rear view
Scale: 1:10



Calculation of Material Properties

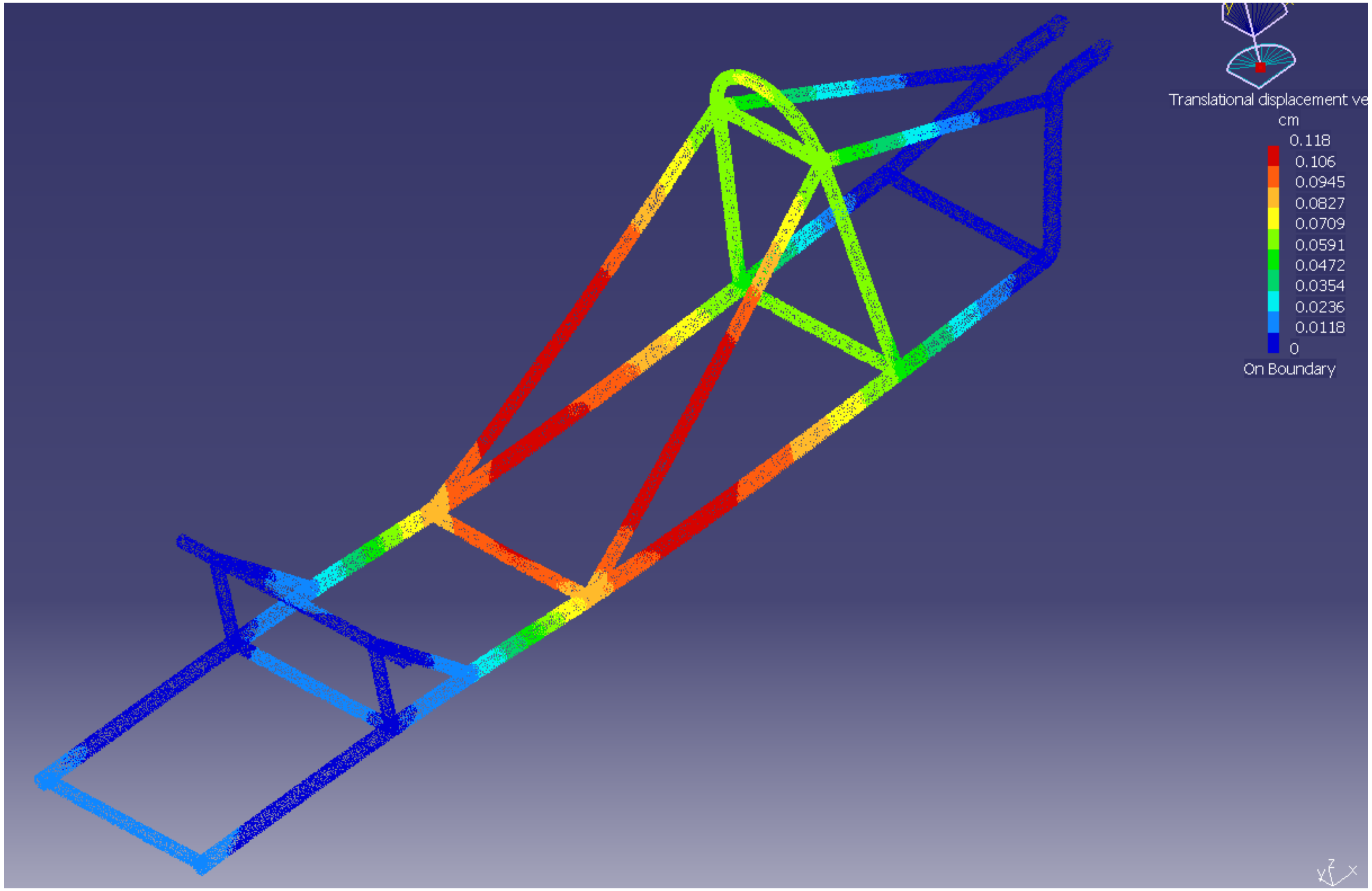
Moment of Inertia of Cross Sectional Area of Tube

$$I_x = \frac{\pi}{64}(d_o^4 - d_i^4)$$
$$= \frac{\pi}{64}(2.54^4 - 1.94^4)$$
$$= 1.34786\ cm^4$$

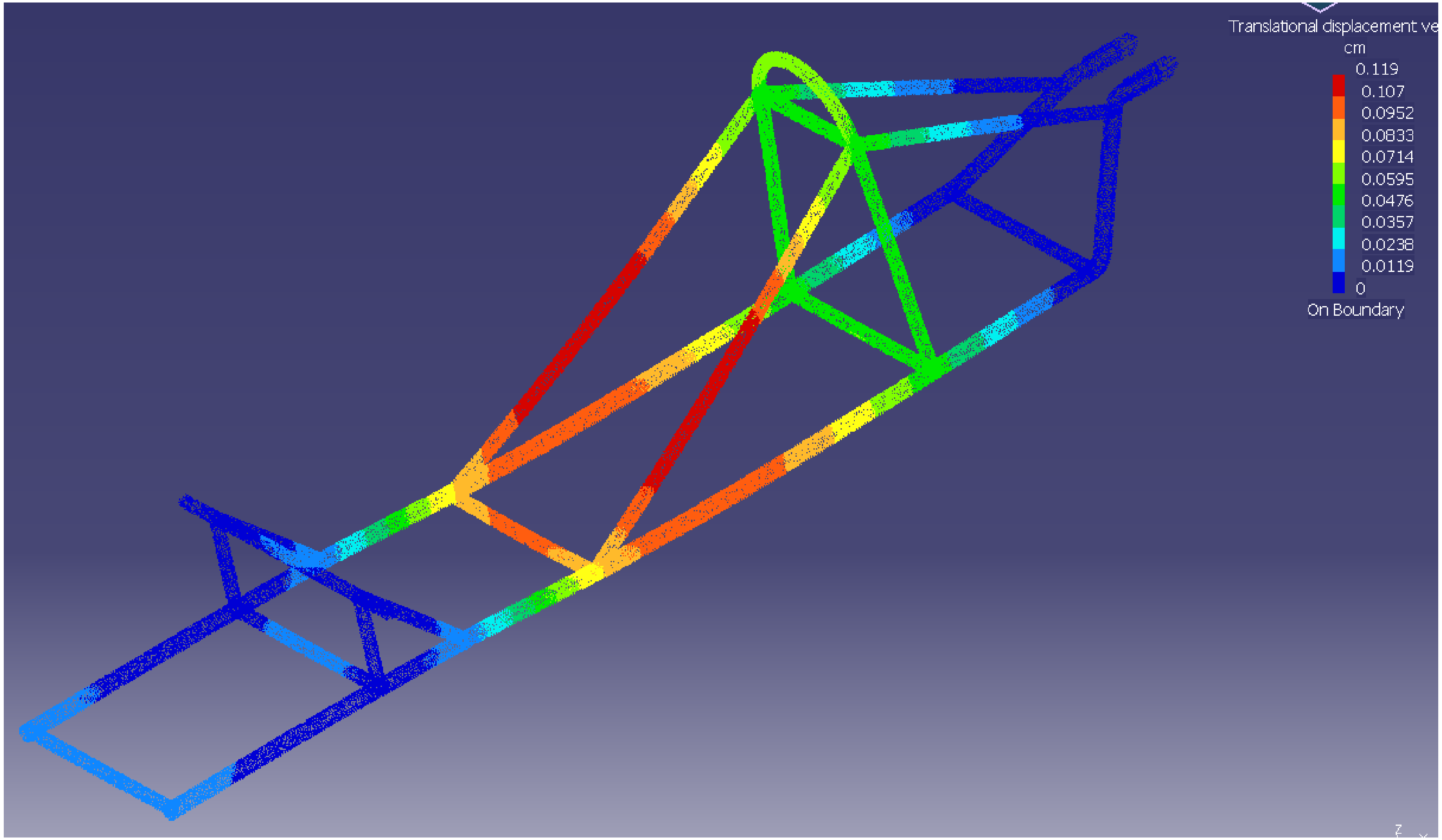
Cross Sectional Area of Tube

$$A = \frac{\pi}{4}(D^2 - d^2)$$
$$= \frac{\pi}{4}(2.54^2 - 1.94^2)$$
$$= 2.1111\ cm^2$$

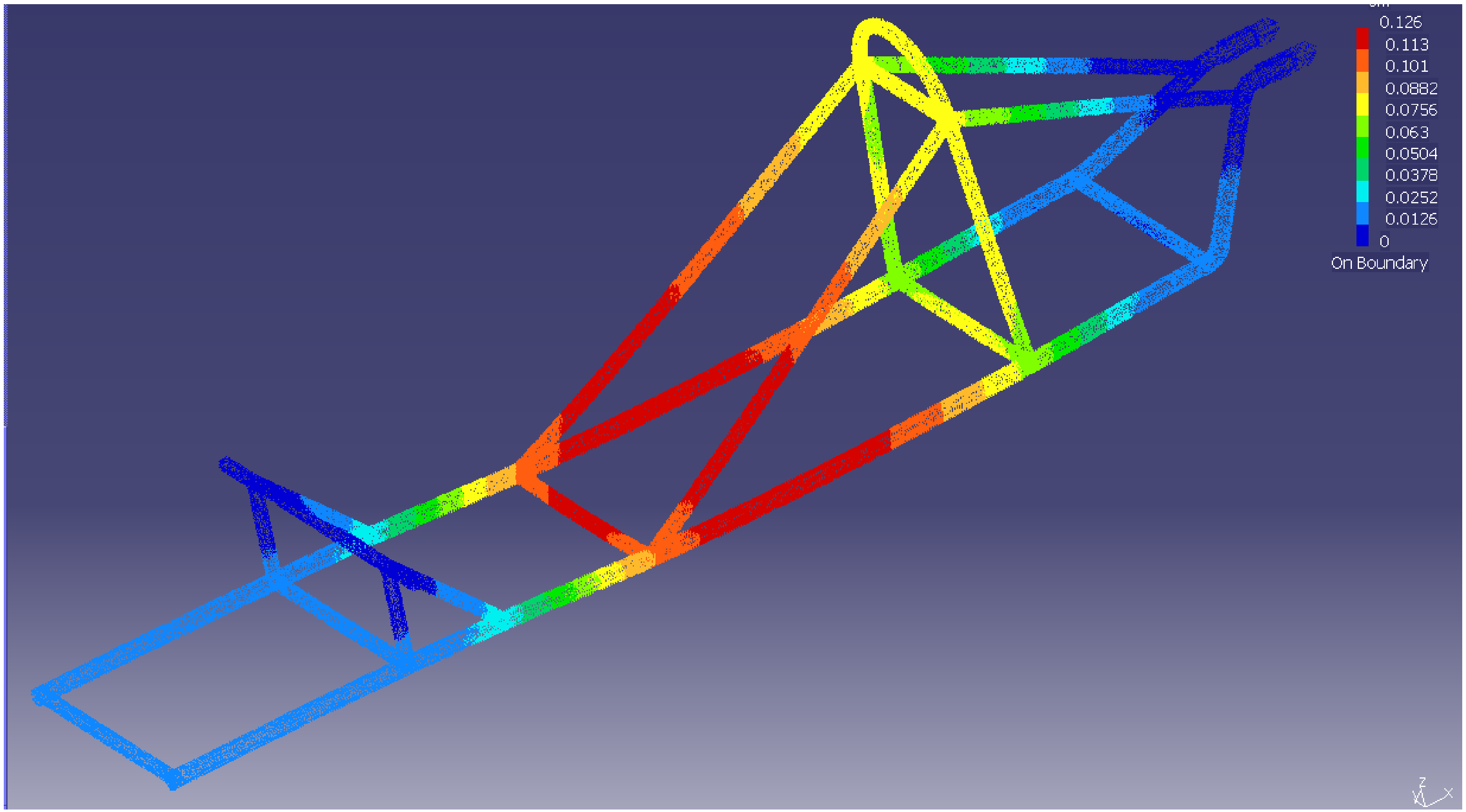
Deflection of Frame with Static Load



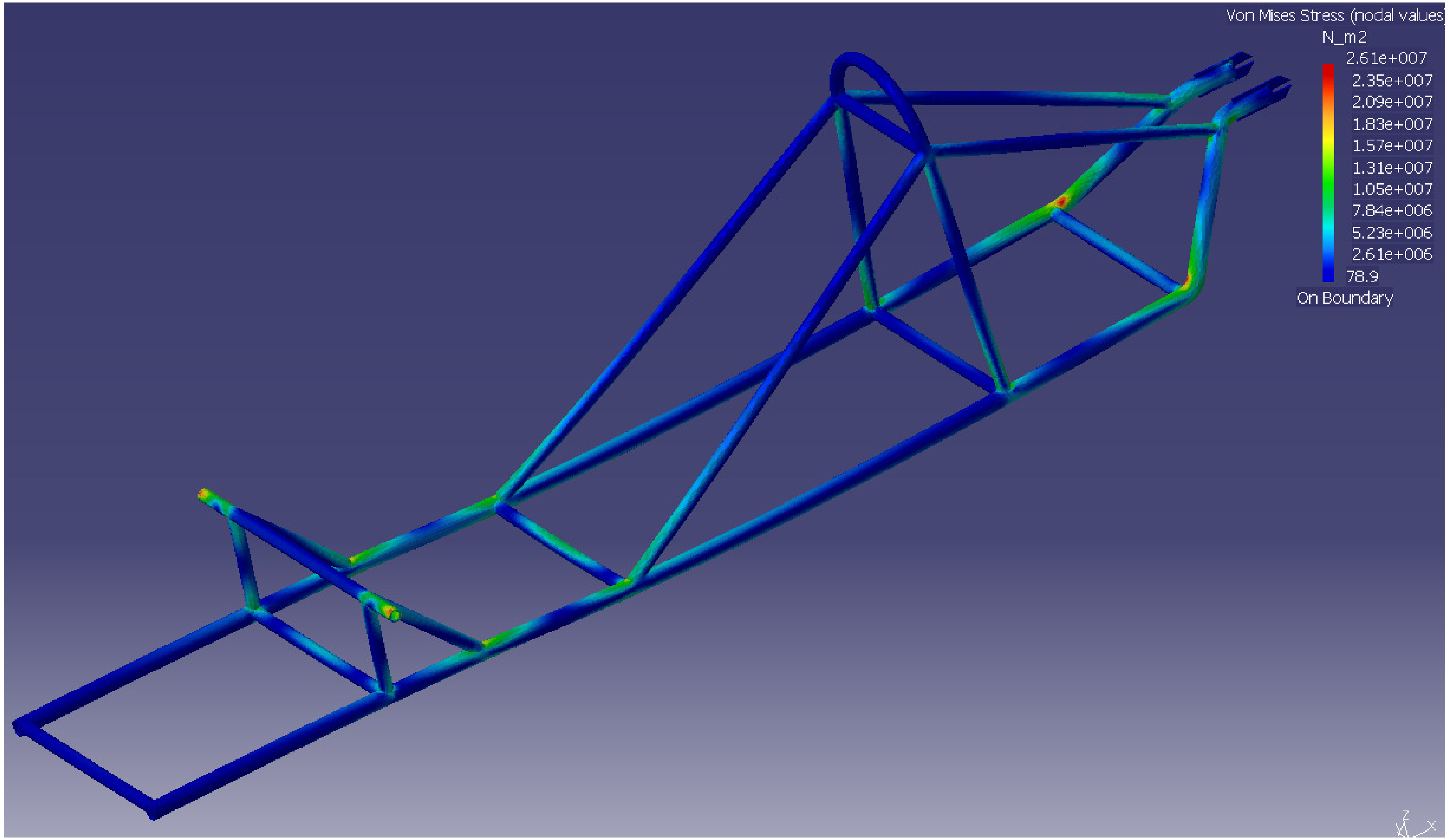
Deflection of Frame with Acceleration Load



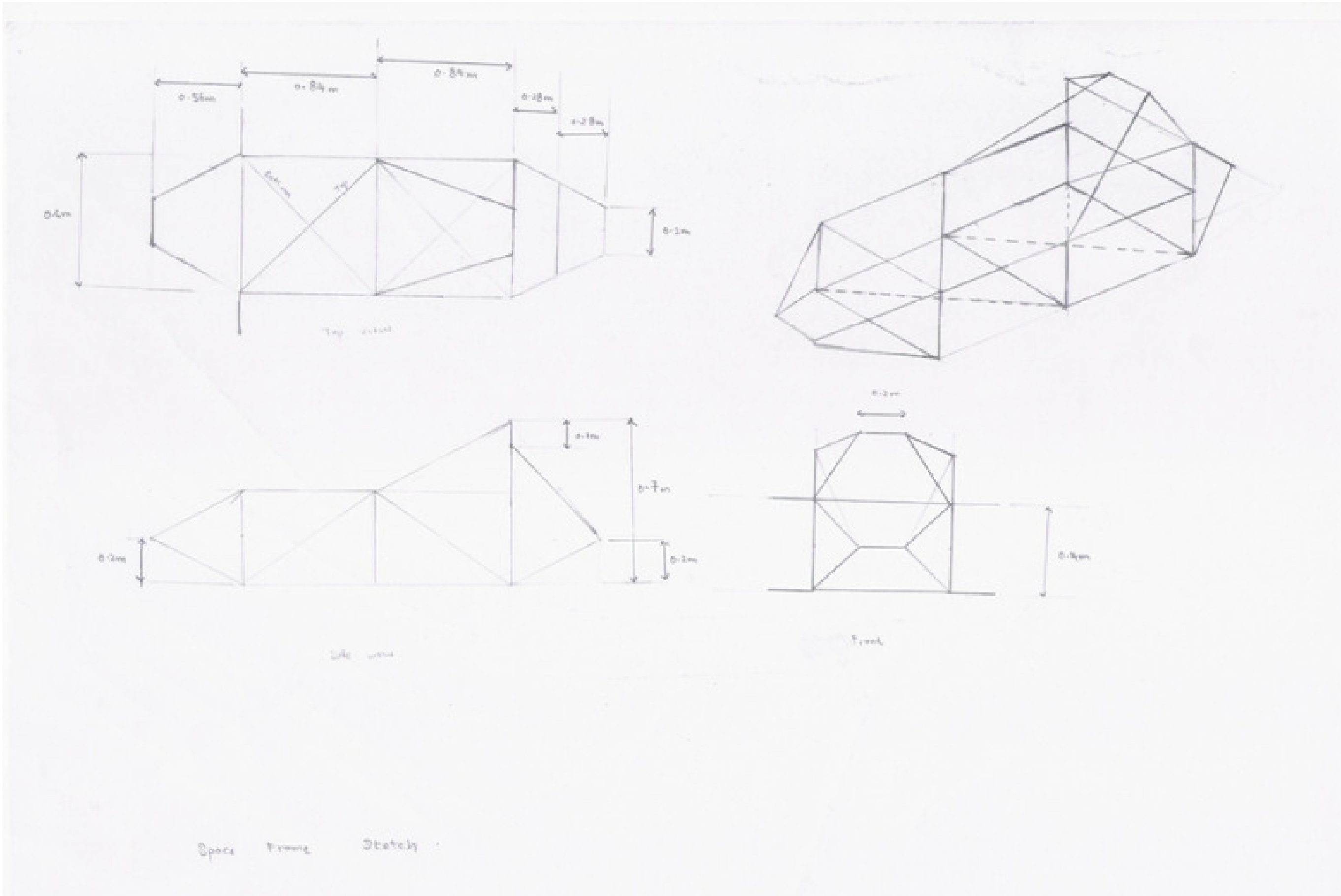
Deflection of Frame with Braking Load



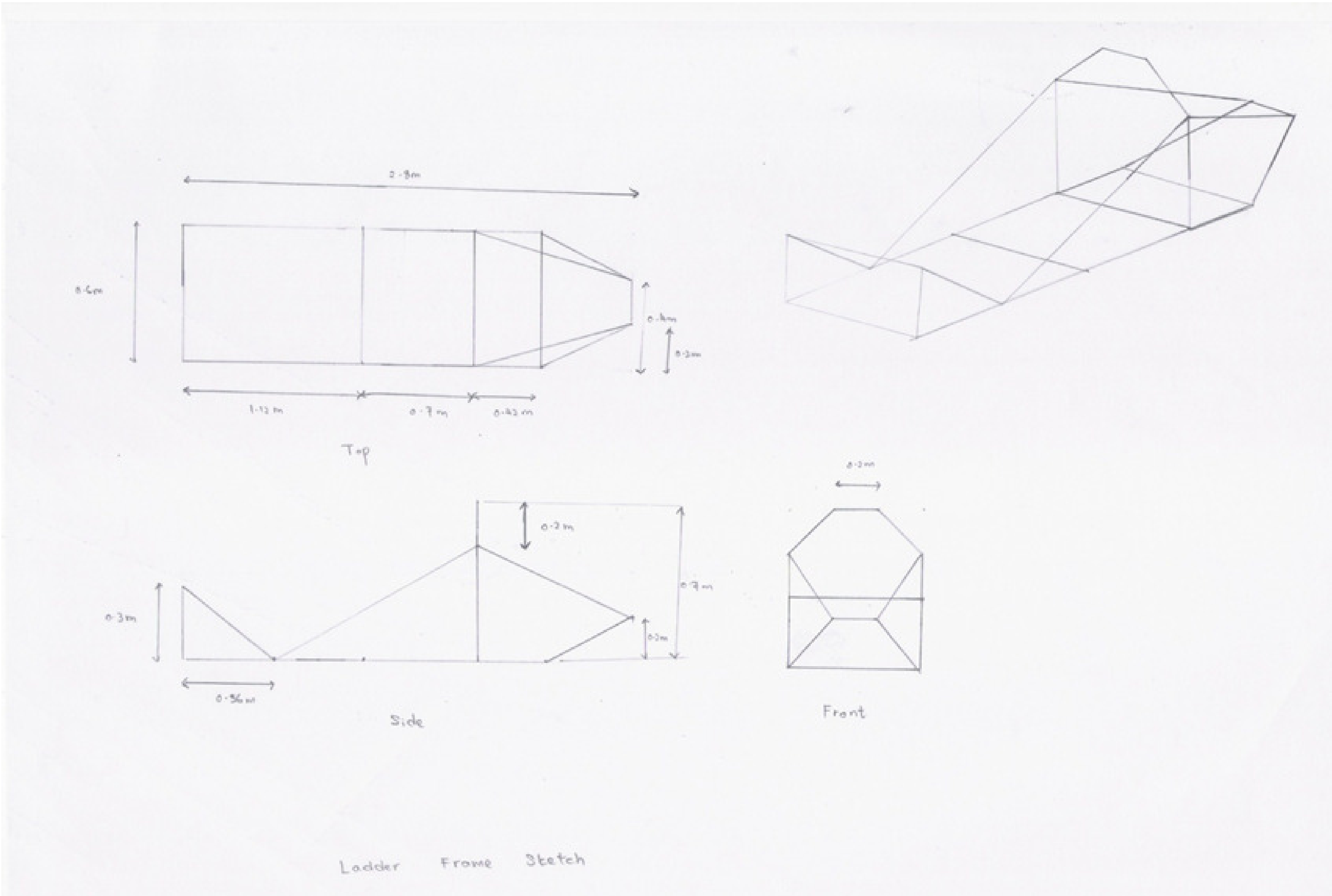
Von Mises Stress Graphic Visualisation



Sketches of Vehicle Frame



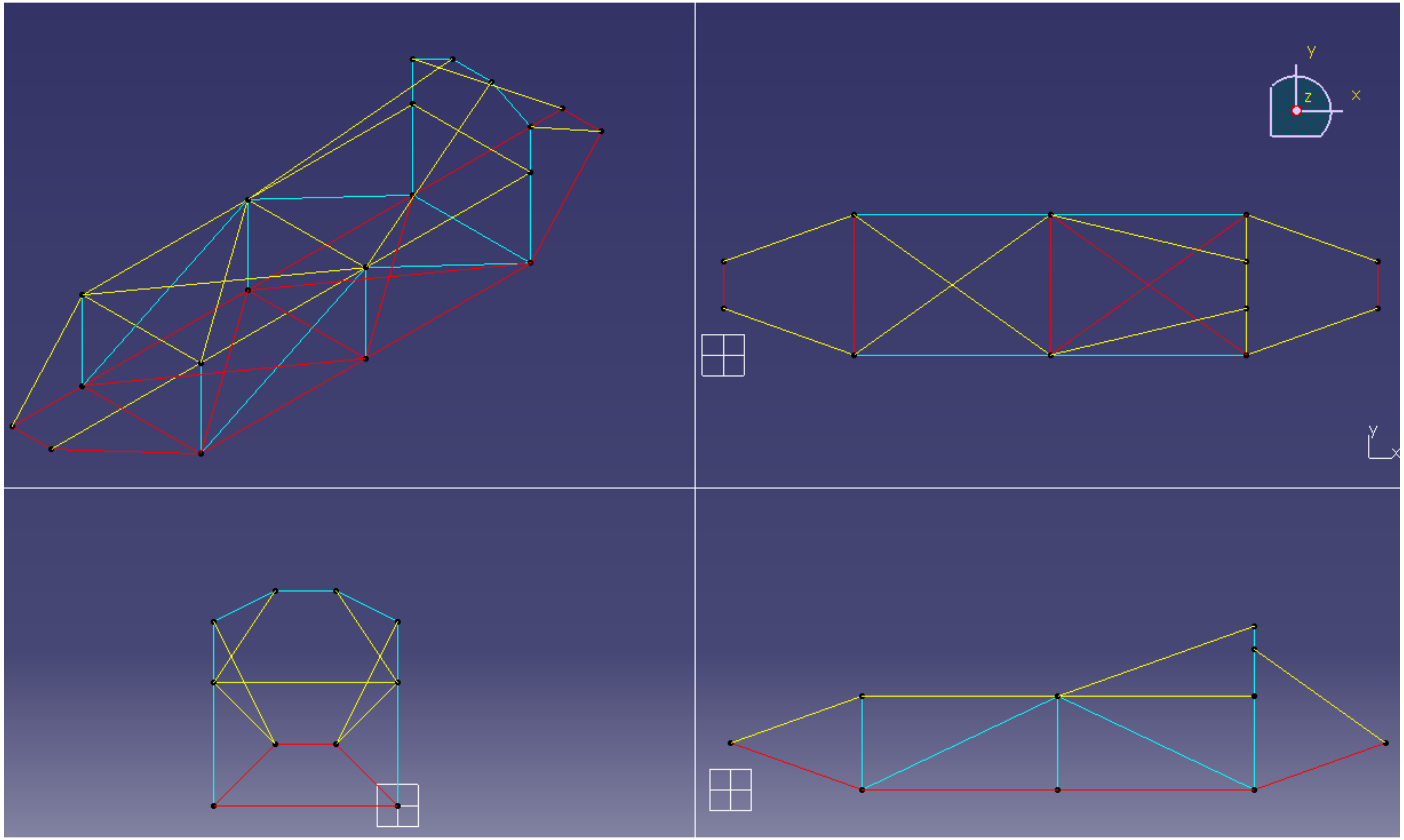
Space Frame Sketch



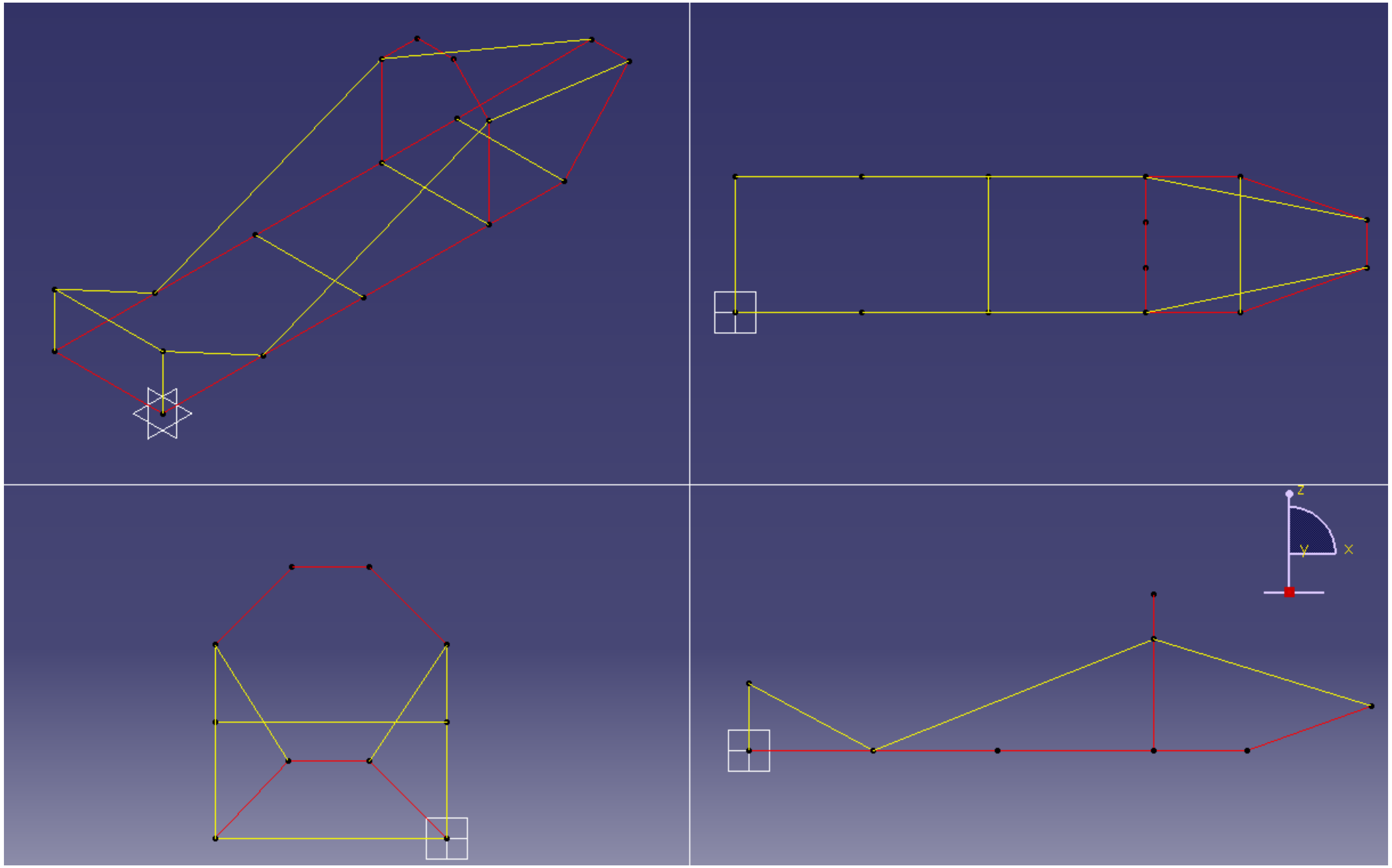
Ladder Frame Sketch

m

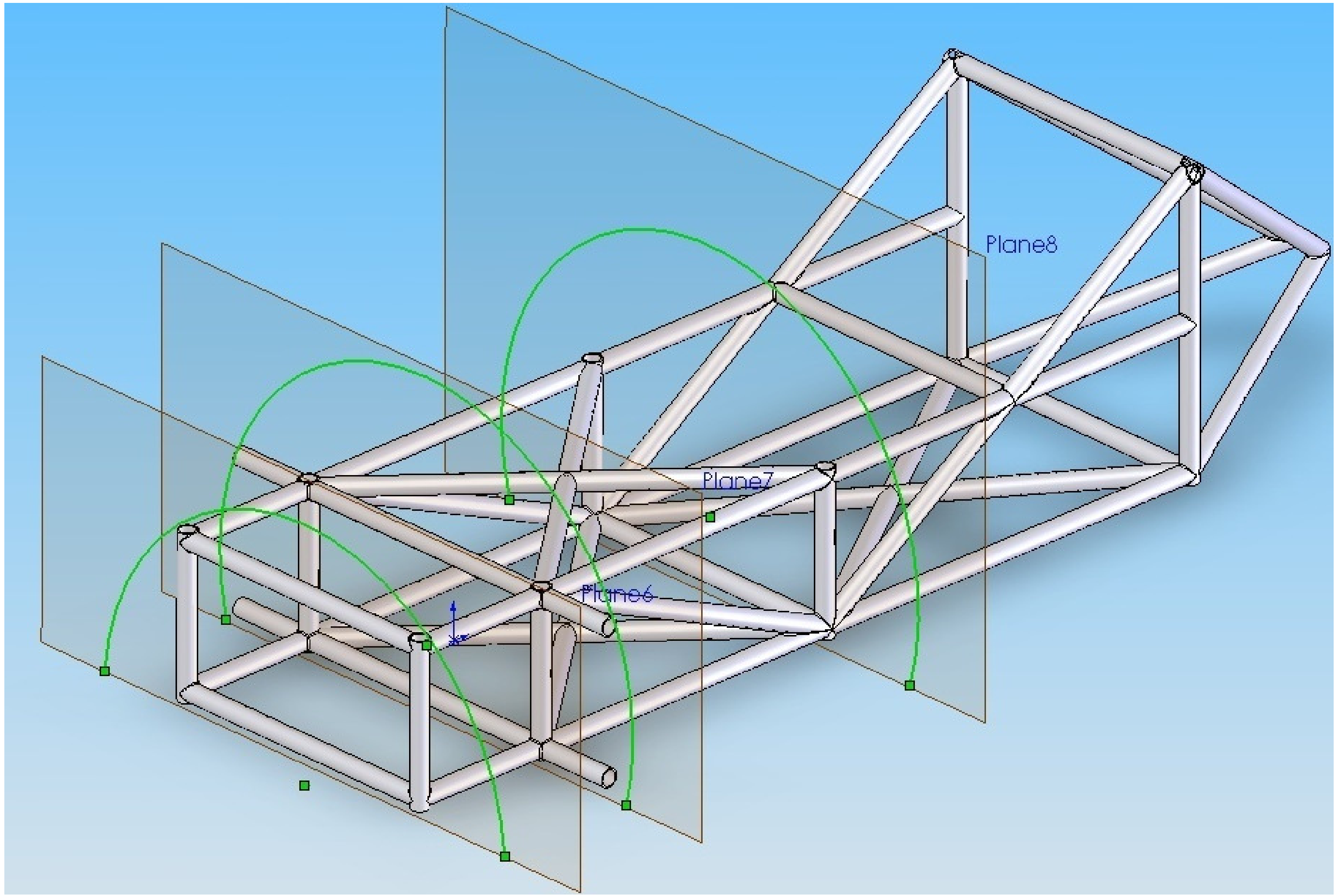
Space Frame Wireframe Model



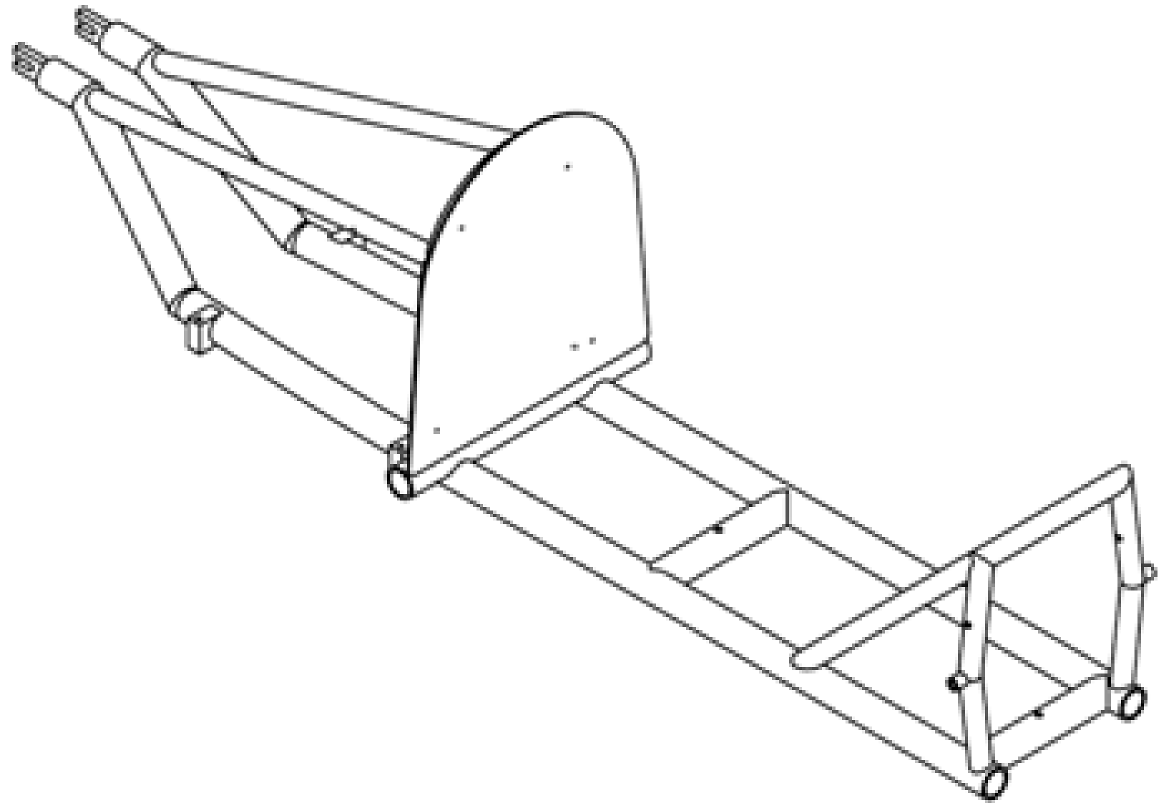
Ladder Frame Wireframe Model



References used for Frame Sketches

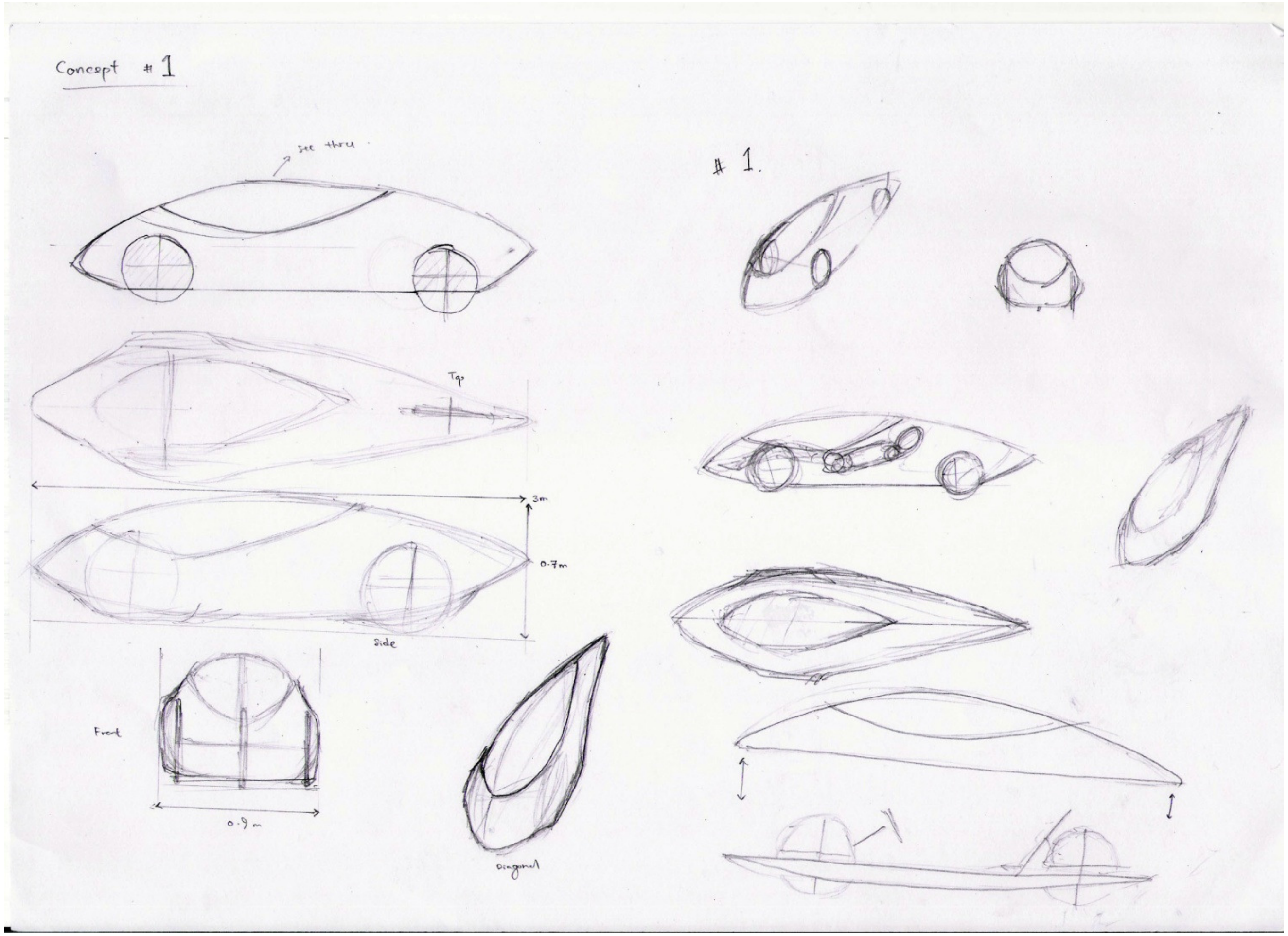


Penn State University Shell Eco Marathon Project Team Space Frame Chassis

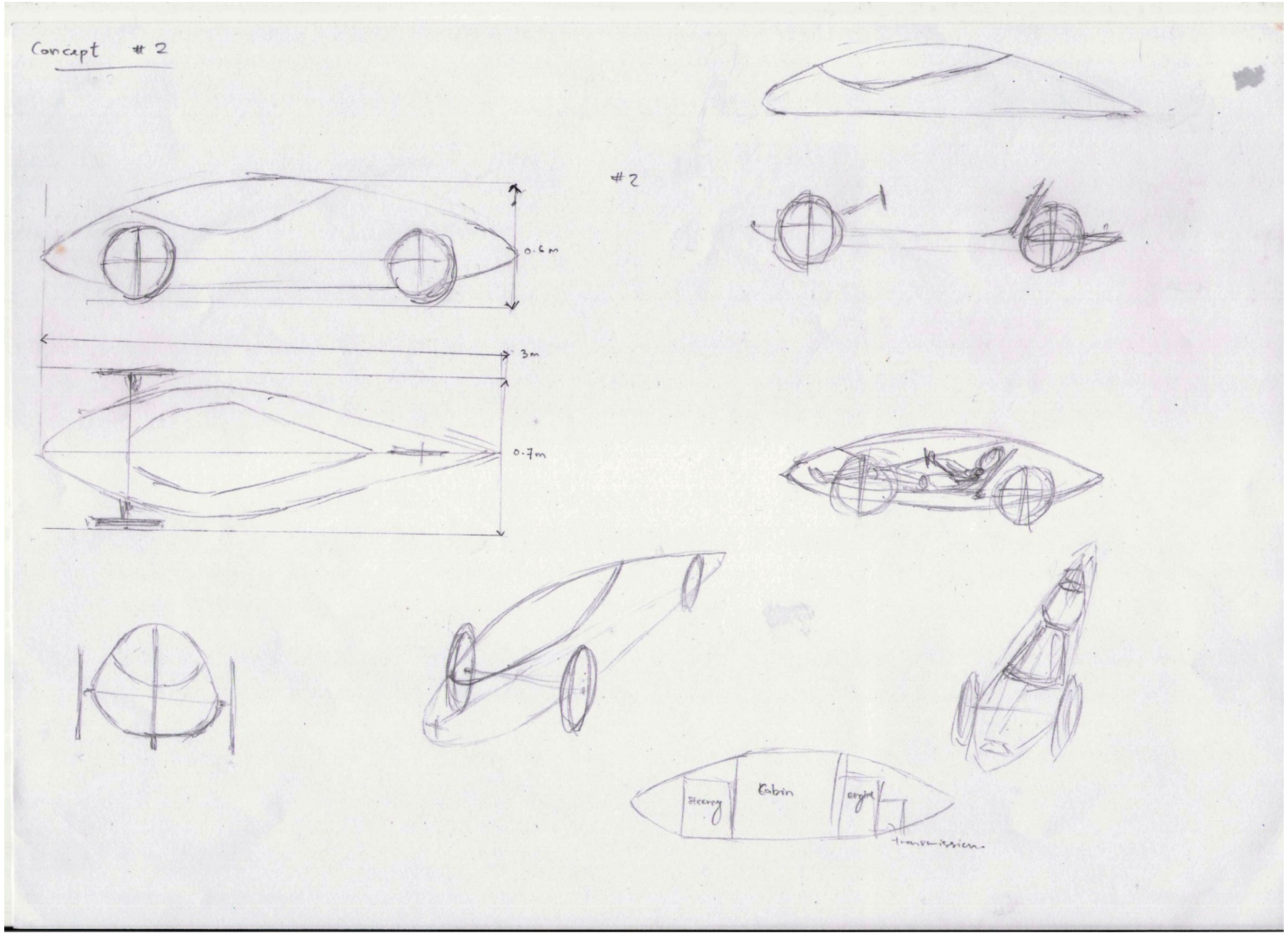


Dalhousie University Supermileage Team Ladder Frame Chassis

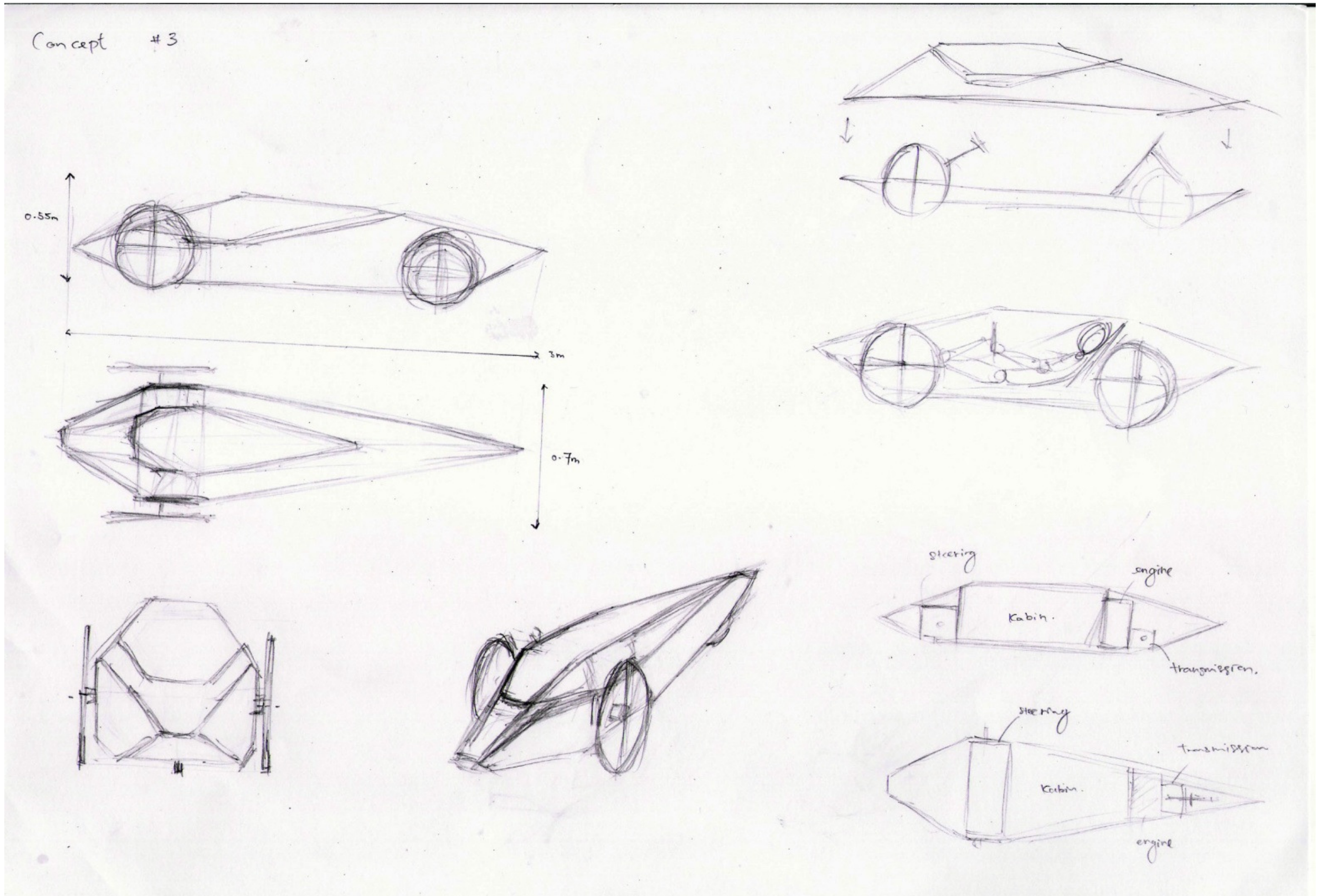
Sketches of Body (Graphical Representation)



Body Concept 1



Body Concept 2



Body Concept 3

Properties of Materials

1010 Carbon Steel

Mechanical Properties

Properties		Conditions	
		T (°C)	Treatment
Density (×1000 kg/m^3)	7.7-8.03	25	
Poisson's Ratio	0.27-0.30	25	
Elastic Modulus (GPa)	190-210	25	
Tensile Strength (Mpa)	365	25	cold drawn (round bar (19-32 mm)) more
Yield Strength (Mpa)	305		
Elongation (%)	20		
Reduction in Area (%)	40		
Hardness (HB)	105	25	cold drawn (round bar (19-32 mm)) more

Source: http://www.efunda.com/materials/alloys/carbon_steels/show_carbon.cfm?ID=AISI_1010&prop=all&Page_Title=AISI%201010

6061 T6 Aluminium

Physical Properties	Metric	English	Comments
Density	2.7 g/cc	0.0975 lb/in³	AA; Typical

Mechanical Properties			
Hardness, Brinell	95	95	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	120	120	Converted from Brinell Hardness Value
Hardness, Rockwell A	40	40	Converted from Brinell Hardness Value
Hardness, Rockwell B	60	60	Converted from Brinell Hardness Value
Hardness, Vickers	107	107	Converted from Brinell Hardness Value
Ultimate Tensile Strength	310 MPa	45000 psi	AA; Typical
Tensile Yield Strength	276 MPa	40000 psi	AA; Typical
Elongation at Break	12 %	12 %	AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break	17 %	17 %	AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity	68.9 GPa	10000 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Notched Tensile Strength	324 MPa	47000 psi	2.5 cm width x 0.16 cm thick side-notched specimen, K_t = 17.
Ultimate Bearing Strength	607 MPa	88000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	386 MPa	56000 psi	Edge distance/pin diameter = 2.0
Poisson's Ratio	0.33	0.33	Estimated from trends in similar Al alloys.
Fatigue Strength	96.5 MPa	14000 psi	AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen
Fracture Toughness	29 MPa-m½	26.4 ksi-in½	K_{IC}; TL orientation.
Machinability	50 %	50 %	0-100 Scale of Aluminum Alloys
Shear Modulus	26 GPa	3770 ksi	Estimated from similar Al alloys.
Shear Strength	207 MPa	30000 psi	AA; Typical

Source: http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061T6

3-2.5 (ASTM Grade 9) Titanium Alloy

Physical Properties	Metric	English	Comments
Density	4.51 g/cc	0.163 lb/in³	Typical

Mechanical Properties	Metric	English	Comments
Tensile Strength, Ultimate	650 MPa	94300 psi	Typical
Tensile Strength, Yield	550 MPa	79800 psi	Typical 0.2% Proof Stress
Elongation at Break	15.0 %	15.0 %	Typical
Modulus of Elasticity	105 - 120 GPa	15200 - 17400 ksi	Typical
Poissons Ratio	0.300	0.300	
Fatigue Strength	325 MPa	47100 psi	Limit; test specifics not reported
Shear Modulus	43.0 - 45.0 GPa	6240 - 6530 ksi	
Bend Radius, Minimum	2.50 t	2.50 t	Typical; on 0.078 in (2 mm) sheet

Source : http://www.matweb.com/search/datasheet.aspx?matguid=3695f9f62f87457db57cb148a93399de&ckck=1

7075 T6 Aluminium Alloy

Physical Properties	Metric	English	Comments
Density	2.81 g/cc	0.102 lb/in³	AA; Typical

Mechanical Properties	Metric	English	Comments
Hardness, Brinell	150	150	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	191	191	Converted from Brinell Hardness Value
Hardness, Rockwell A	53.5	53.5	Converted from Brinell Hardness Value
Hardness, Rockwell B	87	87	Converted from Brinell Hardness Value
Hardness, Vickers	175	175	Converted from Brinell Hardness Value
Tensile Strength, Ultimate	572 MPa	83000 psi	AA; Typical
Tensile Strength, Yield	503 MPa	73000 psi	AA; Typical
Elongation at Break	11.0 % @Thickness 1.59 mm	11.0 % @Thickness 0.0625 in	AA; Typical
	11.0 % @Diameter 12.7 mm	11.0 % @Diameter 0.500 in	AA; Typical
Modulus of Elasticity	71.7 GPa	10400 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Poissons Ratio	0.330	0.330	
Fatigue Strength	159 MPa @# of Cycles 5.00e+8	23000 psi @# of Cycles 5.00e+8	completely reversed stress; RR Moore machine/specimen
Fracture Toughness	20.0 MPa-m½	18.2 ksi-in½	K(IC) in S-L Direction
	25.0 MPa-m½	22.8 ksi-in½	K(IC) in T-L Direction
	29.0 MPa-m½	26.4 ksi-in½	K(IC) in L-T Direction
Machinability	70 %	70 %	0-100 Scale of Aluminum Alloys
Shear Modulus	26.9 GPa	3900 ksi	
Shear Strength	331 MPa	48000 psi	AA; Typical

Source : http://www.matweb.com/search/DataSheet.aspx?MatGUID=4f19a42be94546b686bbf43f79c51b7d&ckck=1

Basic Properties of Fibreglass

Material thickness	Typically range from 1/16" to 1/2". Can use sandwich construction to achieve lighter and stiffer parts.
Corner radius	Recommend 1/8" or larger
Shape	Will duplicate the shape of the mold. Can be heavily contoured
Dimensional tolerance	Tool side can be ± .010" of the tool Non Tool Side ± .030"
Surface finish	Tool side can be class A Non Tool side will be rough, but can be smoothed out Can be gel coated painted, or use any other surface coating
Shrinkage	.002 in/in
Electrical properties	RF Transparent Excellent insulating characteristics Can provide EMI shielding through conductive coating
Fire retarding	Resins available in fire retardant applications meeting various ASTM classes & smoke generation requirements
Corrosion	Resins available for corrosion applications, especially for hot brine, most acids, caustics, & chlorine gases

Source: http://www.performancecomposites.com/fiberglassdesignguide

Prototype Construction