University of Southern Queensland

Faculty of Engineering and Surveying

Control and Instrumentation For the USQ Formula SAE-A Race Car

A dissertation submitted by

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Abstract

Formula SAE is a competition held annually, for student designed and built formula cars. The competition is organised by the Society of Automotive Engineers (SAE), and has been held in the United States of America since the early 1980's. The competition was developed to satisfy a need for engineering students to have 'hands on' experience in the design, development and manufacture in automotive systems. The benefits of the competition have been recognised throughout the world and in the last 10 years the USA competition has grown, with three competitions held throughout the world every year, which includes an Australian event.

The Faculty of engineering and surveying at University of Southern Queensland has recognised the benefits of this competition for student development, and in 2004 plan to compete in the Formula SAE-A (Australia) competition. In order to successfully design and build a USQ entry into this competition the design of the car was divided into seven different research projects for final year mechanical engineering students. This research project relates to the control and instrumentation systems required for a successful USQ Formula SAE-A race car.

The goal is to investigate possible solutions for the control and instrumentation of the USQ Formula SAE-A race car, leading to the design and/or designation of these systems and their implementation within the car. This includes all control mechanism and instrumentation for the safe operation of the car. The research project is broken into sections relating to common ergonomic requirements and research is carried out utilising solid modelling software to produce solid models components, allowing for component analysis prior to component manufacture.

Within this research the cockpit layout is initially outlined before driver seating, and hand and foot controls are designed and/or designated. Safety Issues and instrumentation research concludes this dissertation, which will prove to be an excellent reference material for future Formula SAE-A based research and development.

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ENG4111 & ENG4112 ***Research Project***

Limitations of Use

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Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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For access to the library and engineering computer labs

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Chapter 1

1 Introduction

1.1 Introduction

Within this dissertation, the area of control and instrumentation required for the USQ entry into the 2004 Formula SAE-A competition will be discussed. The research project will be conducted to conform to the rules and regulations of the Formula SAE-A competition. This introductory chapter will outline and discuss the aim, methodology and the general overview of the conducted research, design and construction of the controls systems.

1.2 Project Aim

The aim of this research project is to investigate possible solutions for the control and instrumentation of the USQ Formula SAE-A race car, leading to the design and/or designation of these systems and their implementation within the car. This includes all control mechanism and instrumentation for the safe operation of the car. The core of this research project will investigate and design driver to car interfaces for optimal driving performance within the confines of a limited budget. This project will result in the design of a driver cockpit for use in the 2004 Formula SAE-A race car, including areas such as-

- Driver Seating

- Steering control
- Gearbox and Clutch Control
- Engine Monitoring and Control
- Brake Control

1.3 Methodology

Methodology used in conducting this research project will begin with an initial background investigation into the Formula SAE competition and the associated rules, and an investigation into areas of relevance to the design of driver cockpit for the USQ Formula SAE-A race car, which will be conducted to establish a good knowledge of background material. The design of the driver cockpit will then be broken into seven separate sections, in an order that will allow the design to easily conform to Formula SAE-A rules, i.e. most critical ruled design elements holding greater priority in early design stages. The selected order of design will be as follows-

- General layout
- Driver position
- Hand controls
- Foot controls
- Safety issues
- Instrumentation

In order to design a driver cockpit with a driver to car interface that allows for optimal driving performance, design solutions must create a user friendly environment for the driver by good application of ergonomic principles, and ergonomic data. Therefore each of the section involving a driver to car interface will begin with an initial investigation of applicable ergonomics before possible solutions are brought forward and discussed. The optimal solution for the USQ Formula SAE-A race car will then be selected, analysed and optimised. Finally each separate section of the design is manufactured and evaluated (where possible).

1.4 Overview

The following chapter will discuss the background information relevant to the design of a driver cockpit for the USQ Formula SAE-A race car. Chapter 3 will define the general cockpit sizing and layout; before the driver's seat is selected and seating position is designated in chapter 4. Chapters 5 and 6 will look at design and implementation of hand and foot controls respectively. Safety issues will be discussed and appropriate solutions defined within chapter 7, and instrumentation will be investigated and selected in chapter 8. Chapter 9 will conclude this dissertation and outline the optimal and the actual solutions for the design of the driver cockpit for the USQ Formula SAE-A race car.

1.5 Conclusion

This chapter has introduced the research project which investigates and design the driver cockpit of the USQ Formula SAE-A race car, by breaking the project into small sections and which, investigated in the correct order, will provide for an optimal design. Good knowledge of relevant background material, discussed in the next chapter, will form a good basis for the latter sections of this report.

Chapter 2

2 Background

2.1 Introduction

This chapter reviews the background of the Formula SAE competition; from the beginnings of the concept through to its growth around the world in the current day. The rules of the 2004 Formula SAE-A competition which impact directly on the design of a driver cockpit will then be discussed before an investigation is conducted into driver cockpit design solutions used within other sectors of the motor sport fraternity. A review of previous work conducted relating to this research project will conclude the study of this background material.

2.2 Background of Formula SAE

Early engineering design competitions were simple on-campus events, involving students to design and build a simple machine or structure with limited materials, i.e. bridge building out of ice block sticks and tower building using straws etc. However this offered little interest, for students with interests in cars and motor development. In a measure to fill this void, several universities in the United States of America (USA) began hosting local design competitions in the mid seventies, with a competition for off-road vehicles designed and built by the students. This competition grew over the following years gathering support of the local sector of the SAE, which then was followed by the SAE international involvement. The rapid growth of this off-road competition, lead to the creation of an alternate competition called Formula SAE with annual events beginning in the early 1980's for road designed vehicles. The competitions intent is to allow students to learn first hand about the design of racing cars and other parts of the world saw the benefits of the US competition for the future success of the students involved, which has led to the creation of the Formula Student Competition in the United Kingdom in 1998 and the Formula SAE- Australasia competition in 2001 (Case, 2001). Since the creation of the competition the rules have evolved into the current rules which will be discussed in the following section.

2.3 2004 Formula SAE-A Competition Rules Affecting Design Outcome

The 2004 Formula SAE-A competition has many rules that affect the design of the driver cockpit for the Formula SAE-A race car. The design intent for a Formula SAE race car is to produce a prototype race car designed for a non-professional auto-cross racer that costs under US$25000, for a manufacturing firm planning to produce four cars a day. The car must be designed to be low in cost, easy to maintain, and reliable, the marketability of the car enhanced by factors such as aesthetics, comfort and use of common parts. The following sections will provide a brief description of the judging criteria and a brief overview of the rules affecting the design of the driver cockpit. A complete set of rules and regulations can be found at the SAE Australasia website at 'http://www.sae-a.com.au/fsae/downloads/FSAE_Rules_04.pdf'.

2.3.1 Judging Criteria

Each race car competing in the Formula SAE-A competition will be judged in both Static and Dynamic events (rule 1.3). Static events are conducted on the first day of competition and judging in this event is broken down into the three categories of presentation, engineering design, and cost analysis. This event is particularly important in relation to the design of the driver cockpit as it is reasonably exposed, allowing the presentation and engineering design of the driver cockpit to be easily assessed. The dynamic events are held after the static events and comprise of four separate events of acceleration, skid-pan, autocross, and endurance performance. Dynamic events make up 67.5% of the total allocated marks for the competition so good results in these events make a great difference to the overall mark in the competition, and a cockpit design that allows the driver to maximise the potential of the race car in these events is therefore imperative.

2.3.2 Rules affecting the Cockpit Design

The 2004 Formula SAE rules state that the cockpit must be an open-cockpit style (rule 3.1.1), meaning that there is to be no roof over the drivers head, and for this reason, there are rules regarding the safety issues of protecting the drivers head and other areas exposed from the cockpit. Rule 3.3.4.1 states that the tallest drivers helmet or the 95th percentile male template as described in the rules, must be 50.4mm clear of a line drawn between the front and main roll hoops as shown in figure 2.1.This figure also illustrates the other requirement described within this rule; that the front roll hoop must be no lower than the steering wheel in any angular position.

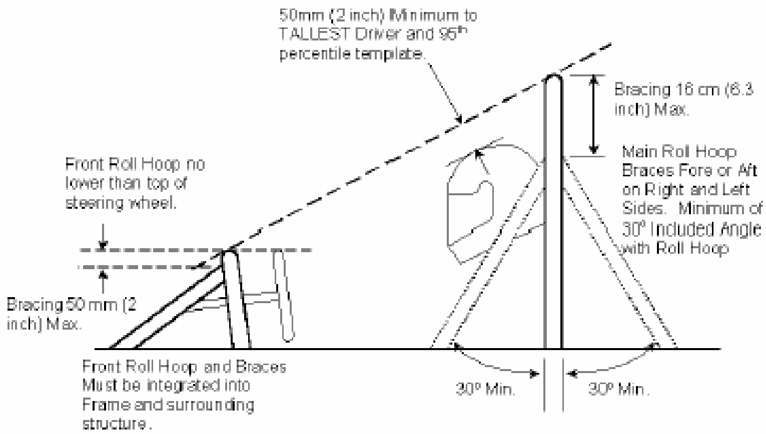

Figure 2.1 – Helmet clearance requirements for compliance with rule 3.3.4.1

The steering wheel must have a near circular shape and be joined to the steering shaft with a quick release mechanism. The fitting of a quick release mechanism also aids compliance to rule 3.4.7, which states that all drivers must be able to exit to the side of the vehicle in no more than 5 seconds. With time beginning when the driver is fully seated and hands in driving position on the connected steering wheel and time stopping when the driver has two feet on the ground at the side of the car (SAE, 2004).

Rule 3.4.12 also affects the design of the cockpit as it states that ‘all the vehicles controls must be accessible from inside the cockpit, without any part of the driver being outside any of the major structural members of the vehicle’(SAE, 2004).

Section 3.4 of the Formula SAE-A rules is concerned with driver safety issues, including the driver restraint system. Stating the type, material, mounting, and positioning of the driver restraint to be used, a summary of key mounting criteria is shown in figure 2.2.

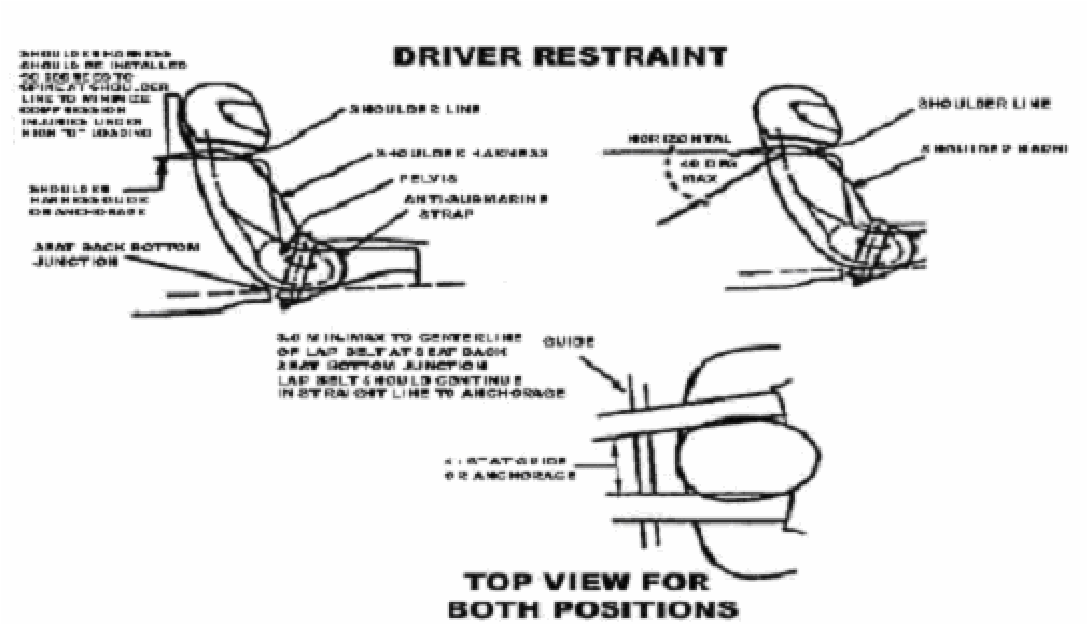

Figure 2.2 – Driver Restraint Criteria as described by rule 3.4.1

Section 3.4 also designates that the driver must wear an approved safety helmet, driving suit, gloves, eye protection, shoes, arm restraints (restricting arm motion to within the cockpit) and hair covering, if hair protrudes from beneath the driver's helmet.

According to this section the driver must have a minimum field of vision of 200° (a minimum of 100° to each side) which can be achieved by placing mirrors on the side of the cockpit.

Head Protection is covered under rule 3.4.4, which states that a head restraint must be provided to limit rearward motion of the head in case of an accident (SAE, 2004). The head restraint is a padded area of non-resilient, and energy absorbing material of a set thickness and placed no more than 25mm behind the drivers head when sitting in the driving position.

Cars must also be fitted with two positive master switches, each of which must disable all electrical circuits and must stop the engine to reduce the risk of fire, in the case of a fuel leakage. Each car must also be able to start without any outside assistance, so a starting switch will also have to be fitted, and placed within the driver cockpit. The use of electronic 'by-wire' control for throttle, braking and steering operation within the car is banned from use in the competition. This is because of safety issues that could be associated with a student designed 'by-wire' control of such systems; therefore most controls will be formed using linkages, shafts and cables.

2.4 Current layout design solutions used for Race Cars in other forms of Motor Sport

The control and instrumentation of race cars has changed dramatically since motor sport began early in the 20th century. A very simple vehicle design in the early years meant that the main control input came from the driver, and this hasn't changed here at the start of the 21st century. However the driver's job is made easier by the greater inclusion of control and instrumentation systems. The use of control and instrumentation systems on modern racing cars is mainly dependent on the cash budget of a competing team. This section of the background investigation will analyse the cockpit design solutions utilised in three vehicles used in different motor-sport categories with differing annual budgets. The vehicles chosen are an Intercontinental C kart, a Champ car, and a Formula 1 car. These vehicles where chosen as they represent the entire scope of motor sport categories while also including a sequential gear shift or similar and require similar characteristics of acceleration, braking and cornering performance, albeit at an elevated level, and the design solutions used could be directly applied to the USQ Formula SAE-A car.

2.4.1 Intercontinental C Kart (125cc Gear Box Karts)

Although not classified as style formula car, this category of motor sport is seen as the lowest budget, competitive circuit racing category using a gearbox. An Intercontinental C kart utilises a purpose made 125cc gearbox engine, mounted on a kart fitted with 4-wheel disc brakes. They have excellent acceleration and braking properties as they can accelerate to 100km/h and come to a stop again in around 5 seconds. Also in one lap of a circuit, which often takes around a minute, drivers may make greater than 20 gear changes. These qualities make the cockpit design important to a kart's performance and the controls are arranged as shown in figure 2.3.

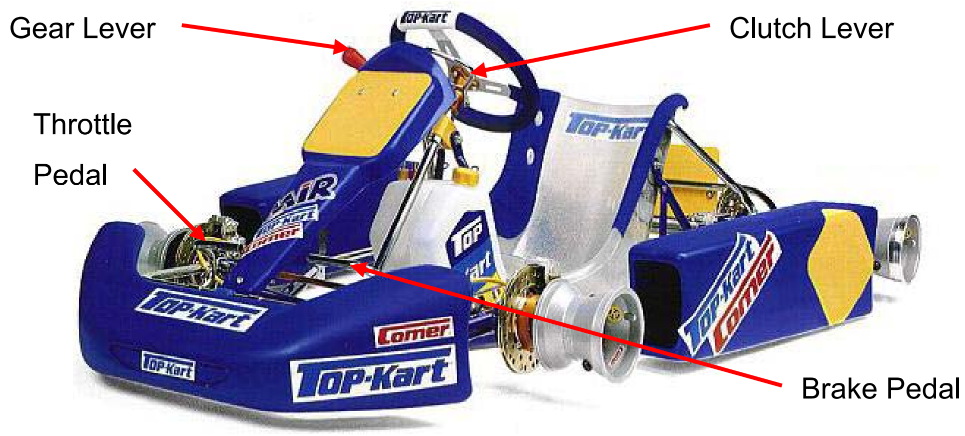

Figure 2.3 - Driver Control Layout of an Intercontinental C Kart (comer-topkart.com, 2004)

The throttle is operated by a pushing motion generated by movement of the driver's right ankle. Brake operation is performed by the same pushing motion generated this time by the driver's left ankle. Steering wheel rotation of a kart is about 180°, and mounted on the steering shaft is a clutch lever which follows the same profile as the steering wheel. Clutch lever operation is performed by pulling the lever towards the steering wheel using the left hand. Gear shifting is conducted by a lever, placed close to the steering wheel on the right side; using the right hand to pull back changes to a higher gear, while pushing forward changes down a gear.

Benefits of this system are its simplicity, as all controls are operated by either rods or cables. However as the Formula SAE-A car has much more body work and therefore is maybe harder to fit rods running backwards to the gearbox as done in this case however it wouldn't be impossible.

2.4.2 Champ-Car

Champ cars are at the high end of commercially available formula cars; however the cockpit layout used is the same as lower budget cars used in Formula Ford, Formula Atlantic, etc. The driver cockpit layout of these cars is design to allow driver's to travel at over 200 mph; therefore the cockpit must provide unrestricted control of the race car. The driver controls are arranged that there are three foot controls and two main hand controls. Throttle and brake control are performed by movement of the right ankle on two separate pedals place beside each other. Clutch operation is performed by left ankle motion on a foot pedal. Steering wheel rotation is just less than 360°; the steering wheel is also used to mount many different electrical buttons and knobs, used for different braking bias and fuel efficiency settings, and communication to crew members etc. Gear changing is performed in a sequential manner by a lever on the right hand side of the car and is operated using the same method as described for an Intercontinental C kart. All controls are placed within close proximity to the drivers hand on the steering wheel as shown in figure 2.4.

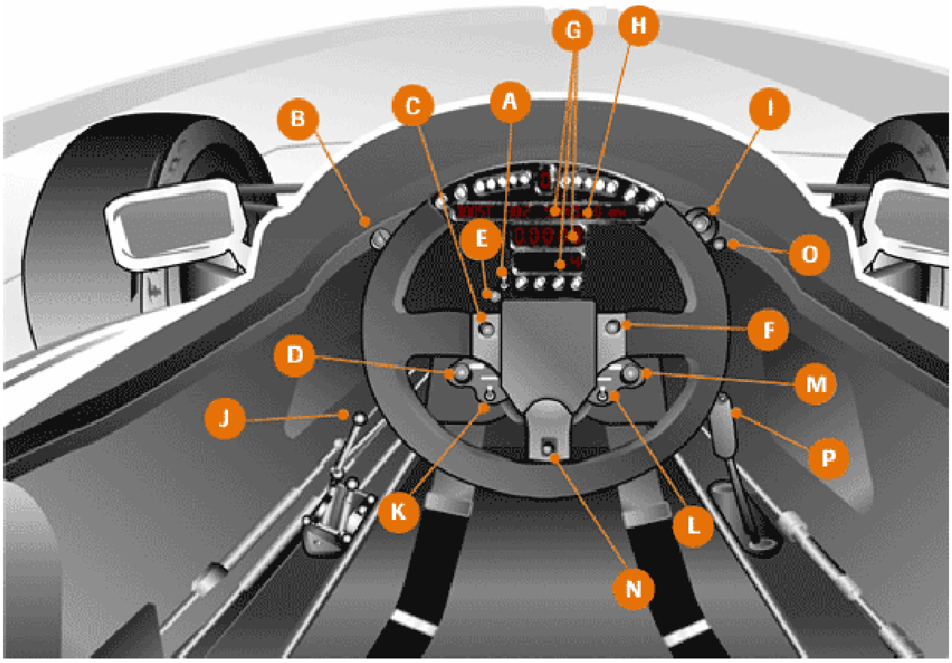

Figure 2.4 - Cockpit view of a Champ Car (Champcarworldseries.com, 2004)

The controls shown above correspond to the following:-

A. Dash Scroll Switch- this switch allows the driver to change between different screens, on the LCD Display to view more than one set of data on one display.

B. Fire Extinguisher- The button allows the driver to activate the on-board fire extinguisher system. The onboard fire extinguisher system is directed throughout the race car by a series of pipes and nozzles at potential areas of fire.

C. Radio Button- This allows the driver to talk to his/her crew in the pits. This allows the driver to relay any problems with the car to the crew. This allows the crew to assess the problem properly before making a decision on the best course of action to rectify the problem.

D. Pit Lane Speed Limiter- Pressing this button limits the speed of the vehicle to the pit lane speed limit as determined by the race formula's rules. This allows the driver to concentrate on perfect placement of the race car in the pit area, so pit stop time is reduced.

E. Fuel Re-set Button- this resets the race car's fuel gauge and fuel monitoring electronics after a pit stop where fuel is added.

F. Overtake Button- This button gives the driver maximum engine power. Drivers in this series are allocated a set number on times they can utilise this function in each race determined by the governing body.

G. Pi Research LCD Information Screen- this allows drivers to see a number of different channels of data and warnings alarms on the one small display. The driver has a button on the steering wheel to change the page on this screen, which would display different data than the previous.

H. RPM Shift Lights- these lights are any easy method showing the driver the engine revolutions per minute, with confusing the driver with the un-required accuracy of a digital display. Lights a configured to show 1 led (usually green) for the bottom engine RPM in the usable range; more light progressively switch on as the engine rpm increase until the shift rpm where a red light comes on and informs the driver that the shift rpm has been reached.

I. Ignition Switch- switches the car electrical systems on, similar to the key ignition on a passenger car.

J. Anti-roll Bar Adjustment Levers- these levers adjust the amount of corner roll that is resisted by the suspension system. The driver has control on both the front and rear anti-roll bars independently.

K. Turbo Boost Switch- this allows the driver to adjust the amount of turbo boost on the engine. This feature allows drivers to either conserve fuel or have high engine power depending on what they deem best.

L. Weight-jacker Switch- this adjust the car's corner handling characteristics. A car which has a tendency to go straight instead of turning or has the rear of the car sliding around corners can has this problem reduced or fixed by proper use of this setting.

M. Drink Button- supplies liquid to the driver's mouth, by a small hose fitted inside the helmet, from the drink reservoir.

N. Fuel Mixture Switch- allows the driver to alter the engines fuel consumption for different race strategies throughout the course of a race.

O. Engine Map Switch- allows the driver to change the engine characteristics, by altering the 'engine map', which changes the power distribution throughout its rev range.

P. Gear Shift Lever- the driver pulls back to go up through the gears and pushes forward to change down gears.

2.4.3 Formula 1

Formula 1 is the ultimate of formula car competition, as the competing cars cannot be purchased, and are built by each team and respective technical partners to maximise the potential of their large annual budgets. For this reason no two team's cars are exactly the same but driver cockpit layouts have been optimised over decades of racing to produce a similar solution throughout the competition. Throttle and brake control is performed respectively by right and left ankle motion. Steering control is performed by using a figure-8 style steering wheel, and all driver hand controls are mounted on the steering wheel for quick access. Gear shifting is performed by electronic paddle switches mounted on the back of the steering wheel. Clutch operation over recent years has moved from a foot control, to a hand control with the development of electronic control 'by-wire' systems. Currently the clutch is mounted on the back of the steering wheel and is also an electronic control. Most control systems used on the formula 1 race car are electronic to reduce weight and driver operation effort. Driver controls constantly being added onto the steering wheel, for easier access, allowing driver concentration to remain focused on the driving task. The Williams Formula 1 Website (www.bmw.williams.com) has good video interviews with their drivers- Juan Pablo Montoya and Ralf Schumacher, talking about their steering wheel layout.

2.5 Literature

The design of a driver cockpit for a racing car or Formula SAE racer is usually kept within the confines of each racing team therefore there has been very little published on the topic.

An article found in ‘Engineer’, volume 292 written by Jon Excell, about the use of the JACK system used for the ergonomics of Jaguar road cars and it’s introduction into the design of the Jaguar Formula 1 race car, has also been helpful as it gave insight into how elite forms of motor sport undertake tasks similar to this project.

Ergonomic literature is relevant to this research project, as it directly relates to the design and use of hand controls and foot pedals. ‘Ergonomics How to Design for Ease and Efficiency’ by Karl Kroemer et. al. is a good source of information for the ergonomic design problems with automobile foot pedals examples; it also details the design of Handwheels. This book also covers the preferred and regular manipulation spaces for both hands and feet, information about fitting humans into restricted places and other human factors such as fatigue etc. ‘Fitting the Task to the Man’ by Etienne Grandjean, covers human factors extensively; this book is mainly concerned with functions of the human body. It covers such relevant topics as muscular work, nervous control movements (including reflexes), improving work efficiency, display equipment, fatigue, and vision. Combining the use of the virtual modelling methods to produce a similar outcome to the JACK system, and ergonomic information given in the above sources provide a good basis to begin the design process for each section covered within this report.

2.6 Conclusion

Now that relevant background knowledge is established an effective solution to the control and instrumentation for the USQ Formula SAE-A race car can be outlined, utilising knowledge of the Formula SAE-A rules and solutions utilised throughout other forms of motor sport. The following chapter will generate a basic outline of the requirements of the cockpit design and generate a solid base for later chapters.

Chapter 3

3 Cockpit Layout

3.1 Introduction

Determining the optimum driver cockpit layout for the USQ Formula SAE-A race car, is critical to the creation of a user friendly environment for the driver. The cockpit must have sufficient room to allow unrestricted movement for the driver when operating controls, while minimising unutilised space to reduce the weight and overall size of the race car, increasing the potential for its acceleration and aerodynamic properties. In order to create the optimal solution, this chapter will first discuss the initial layout criteria, before determining the size requirements of the driver cockpit. The systems implemented throughout the race car requiring driver input will then be discussed before the optimal driver cockpit size is discussed and selected.

3.2 Systems requiring driver control

To generate a correct cockpit layout first the required systems controlled by the driver must be determined. The systems requiring driver control, in our car are the brake, engine, power-train and steering.

Control of the brake system requires a method that operates the brakes on all four wheels via a force to two separate brake master cylinders as required by the Formula SAE-A, rule 3.2.5; it would also be beneficial to be able to adjust the ‘braking bias’ which is the percentage of braking force between the front and rear of the car. This is because the moment created around the centre of mass of the vehicle under a braking condition creates an increase in the forces applied between the front tyres and the consequent equal reactive force applied by the road inturn reducing the tyre to road, force interaction at the rear of the vehicle. The required braking bias varies as track surface conditions and car weight distribution changes; this makes it a beneficial adjustment for application in the USQ Formula SAE-A race car.

The Engine system that was selected by the relevant team member for our vehicle is a 4-cylinder 600cm^3 motor cycle engine from a 1993 Yamaha FZR 600. This system has only one mode of control requiring driver input, which is the percentage of throttle opening in the carburettor, the engine was originally designed so that there was 1 carburettor per cylinder, however due to the intake air restrictor required by the Formula SAE-A rules, only one carburettor will be used on the engine when utilised in the race car. The engine is also fitted with sensors to measure engine revolutions per minute (RPM), coolant temperature and wheel speed. For racing purposes there is no need for the use of a speedometer as the intent of racing is to go as fast as possible at all times, so it will be omitted for this project. Engine RPM can be measured using a few different methods. A Common element of this measurement is the use of a counter, with a set sample rate. The counter can be triggered by a switch (commonly a magnetic on/off switch) mounted on ignition rotor which is mounted directly onto the engine’s crank shaft, using this method is easy because it requires little computation to translate into RPM, as the number crankshaft rotations counted in the set sample rate is multiplied by the number of samples occurring in a minute (a constant), which gives the RPM measurement. Coolant temperature is measured by a thermo-couple mounted in aluminium casing used to mount the thermostat (a thermally opened valve used to keep coolant temperatures constant). The engine is also fitted with an oil pressure warning light which is mounted after the engines oil pump. When engine oil pressure is less than required for adequate lubrication of the engine this light is switched on. Engine RPM, Coolant temperature and engine oil pressure sensors will be utilised within the instrumentation section of this report.

The power-train system has two driver controlled operations, gear selection and clutch control. Gear selection is critical to maintain maximum possible performance of the engine. Due to the engines power characteristics it is beneficial to change the transmission ratios between engine crankshaft and the final drive shaft, to maintain that the engine is always working within its intended engine revolution range. Correct transmission gear selection will maintain maximum possible power transmission to the rear wheels throughout the speed range required for the competition. Another benefit is increased engine life because the time spent under and over revving of the engine is dramatically reduced. The FZR 600 engine used in this project contains a gear-box between the engine crankshaft output, and the output sprocket is located on the left-hand side, at the rear of the engine casting. The gearbox is a 6-speed sequential gearbox (sequential meaning that the gears are all placed in sequential order according to the gear shift), and for the current engine the gear placement according to the gear shift on the bike is as shown in the figure 3.1.

2-6
↑
N
↓
1

Figure 3.1 – Gear selection pattern for Yamaha FZR 600 gearbox.

The N signifies the neutral position meaning that no gears are in mesh, therefore power cannot be transmitted through the gearbox, and there is an output for a neutral position light, indicating when this is selected. First gear in the gearbox is selected by pushing the gear lever down from the neutral position. Second gear and following gears are selected by lifting the lever from its normal position. The design of a sequential gearbox, allows for gear shifting when the drivetrain is in motion, without the use the clutch, due to the gear shift mechanism being used, which is called a 'dog clutch' mechanism (Bosch, 1986). The driver can change up gears by a sudden reduction of throttle when changing up gears, or a sudden increase in throttle when changing down gears, each of these procedures reduce the torque applied to the 'dog clutch' and allow it to slip easily between gears. The clutch incorporated within the gearbox casing is operated via a cable operation, the cable acts on a lever connected to a shaft; activating the release of the clutch, as the clutch is naturally engaged.

The steering system as designed by the relevant team member is a rack and pinion system. This system basically consists of a rack, a shaft that connects to the steering drag link, with gear teeth cut into one side, and a pinion which is a gear that is connected to the steering shaft which moves the rack and consequently the steering (Bosch, 1986). The steering ratio is determined the ratio between the pinion revolutions to the travel of the rack. For this project the steering designer, has specified a steering ratio that results in the steering wheel rotation of 360º to move from lock-to-lock, meaning that it is 180° from straight ahead to the maximum available turn in the corresponding direction i.e. 180° counter clockwise for maximum left turn, and 180° clockwise for maximum right turn.

3.3 Initial Layout criteria

The basic layout criteria of the driver cockpit within the USQ Formula SAE-A race car, can be compared to that of any common work station used in common production industries. A good layout design will reduce driver mental and physical fatigue, as an easy to use layout will reduce the intensity of the mental and physical effort (Grandjean, 1990). The layout should provide an easy, effective, logical interface, so that time is not lost in unnecessary thinking and movement, which leads to increased driver mental and physical fatigue, which will reduce concentration and increase the possibility of a mistake resulting in lower driver performance and an increased probability of an accident causing vehicle damage and possible driver injury.

A correct cockpit layout will also allow the driver to be able to assess the handling characteristics of the vehicle with greater ease leading to faster on-track development, which is of great benefit because even the world's best racing design teams need hours of on-track testing to modify their designs to suit individual drivers and race track ambient conditions.

Before the task of cockpit sizing can be undertaken the driver seating position and appropriate degrees of freedom must be investigated. The driver seating position selected in the USQ Formula SAE-A race car must allow the driver a good view of the track, and any potential danger areas, in the direction of motion for the car, this criteria results in the drivers eye's facing to front of the race car, and viewing of rearward objects which is less of a requirement, but will be possible by the use of mirrors placed on the sides at the front of the driver cockpit. The driving position will also assist in keeping a low centre of gravity for the overall race car as desired in the design of a competitive formula style car, reducing the generation of undesirable chassis roll while cornering. To fulfil these requirements the driver is seated in a position close to the floor of the car, with legs pointing towards the front of the vehicle. The driver will be placed at the rear of the allocated cockpit area facing the front of the vehicle with driver hand controls restricted to the shaded area of the total range of arm motion, as shown in figure 3.2, to reduce the frontal area of the cockpit, thus increasing aerodynamic efficiency.

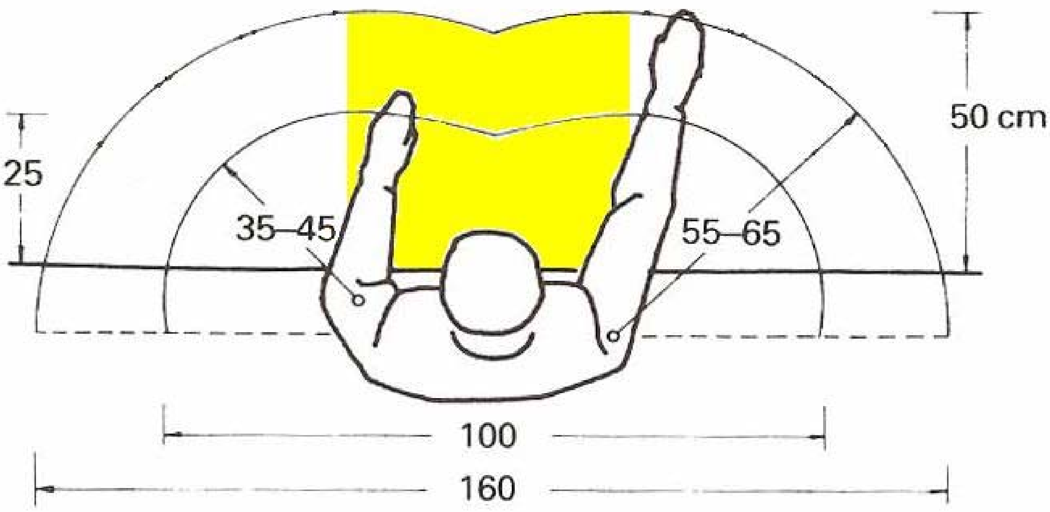

Figure 3.2 – Total range of motion for arms, with shaded section indicating allocated area for driver cockpit hand controls (Grandjean, 1990).

3.4 Cockpit Layout for USQ Formula SAE-A race car

The cockpit layout for implementation into the USQ Formula SAE-A race car, will be selected from the most applicable design solutions used in other forms of motor sport as described in the section 2.4. As the design intent of a Formula SAE-A race car is for a non-professional auto-cross racer, the driver controls should also not differ greatly from that of a normal Australian passenger car, which the non-professional would be more familiar with. The use of a cockpit layout similar to that commonly used in a passenger car is important to the design of a Formula SAE-A race car as testing time can be conducted more effectively as no time is lost with drivers learning a new system, and utilising pre-established driver reflexes.

For this reason the logical positioning of the throttle and brake controls will be at the front of the allocated cockpit area, and will be operated by the right and left feet respectively. The selection a foot pedal for braking control also conforms to the prediction that a large force will be applied to this system and in this case powerful leg muscles can be utilised if required. Steering control will be operated by hand controlled steering wheel located in at the centre of the body at a height just below the front roll hoop in accordance with Formula SAE-A rule 3.3.4.1. Gear selection will be also be designated to hand controlled lever mounted in close vicinity to the steering wheel, on the left hand side, similar to that used in a champ-car, however shifted to the left side of the car to reduce driver confusion, by conforming with Australian passenger cars. The positioning of the gear shift lever to the left also assists linking the lever to the gearbox, as the gearbox selector shaft is also positioned on the left side of the gearbox casing. Clutch control is selected to be of hand control, by a lever mounted right hand side of the steering wheel, as steadier motion can be achieved by hand motion (Grandjean, 1990). The Lever will be mounted on the steering shaft rotating in conjunction with the steering wheel so that the right hand doesn't have to change grip in order to operate the clutch. This method was considered acceptable because the traditional clutch control for motor bike engines is by a hand lever. The decision against normal left foot clutch control as used in manual transmission passenger cars, allows for greater freedom and space reductions for the front cockpit area where foot pedals are placed. With all key driver controlled systems optimal position selected the sizing of the cockpit can now proceed.

3.5 Cockpit Sizing

Initial dimensions for the cockpit size were generated by Chris Baker, the USQ Formula SAE-A chassis designer. These measurements were generated approximately by using a tape measure to measure around the perimeter of a medium-large sized man while he sat on the ground in the driver position outlined in the previous section. However in an effort to ensure the cockpit complied with specific needs of our team members, measurements were taken at a team meeting on the 24th March, 2004 (Appendix B). Measurements were taken in positions that were similar to ergonomic data tabulated in appendix C, which gave a direct correlation between the team gathered data and other data given on this table without more extensive measurement. The two positions in which measurements were taken are shown by figures 3.3 and 3.4.

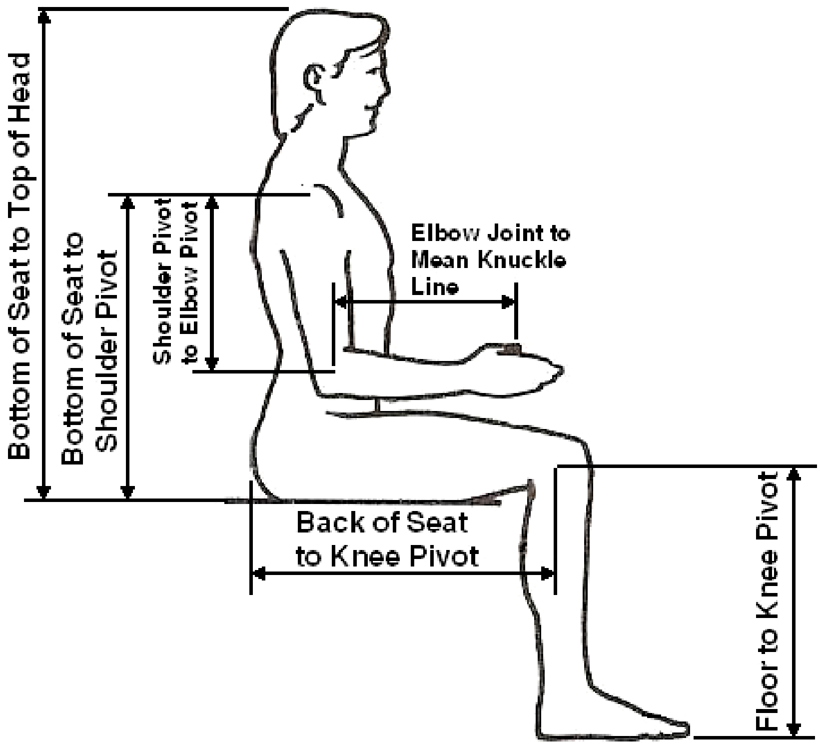

Figure 3.3– Sitting Team Member Measurements

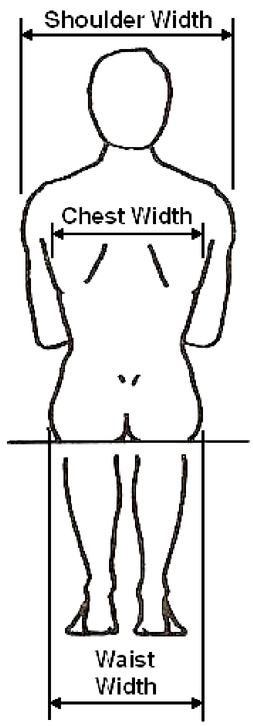

Figure 3.4 – Team member width measurements

As none of the team members had ever undergone a project of this nature the chassis designer, Chris Baker and myself, built a model (shown in figure 3.5) out of 19 x 19mm wood purchase from a hardware store, using dimensions from the initial solid model of the design.

Figure 3.5 – Full size model of initial chassis design

This model was very useful in identifying areas of concern with the initial design and as a result the design was changed, to give more room to accommodate for driver leg length and knee width around the expected placement for the steering wheel. With a concept of the true size of the cockpit; the analysis moved to virtual modelling using Pro Engineer Software. A solid model of the largest person, according to the maximum leg length, and shoulder, upper torso, and waist width data in conjunction with the measurements given in the rules for the 95th percentile man (rule 3.3.4.1 (A)) completed the basic sizing of the man model. Leg widths were estimated from measurements taken from my own body, which I thought would be acceptable, as I have the longest legs from the recorded team data. The generated 'solid model' of a man had the dimensions as shown in Figure 3.6.

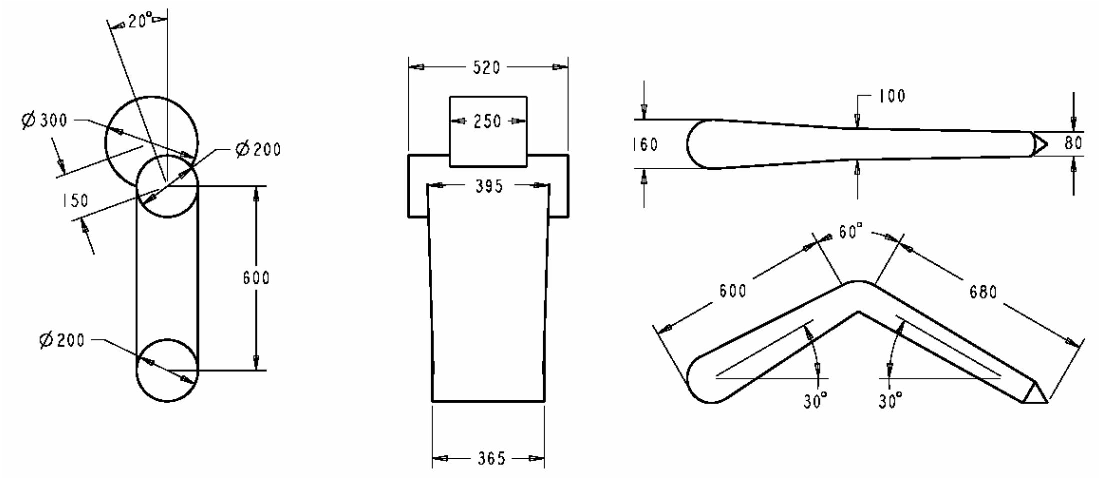

Figure 3.6 – Dimensions of maximum size man for use in solid models

The man was then fitted in a model assembly with the chassis; the chassis was modified in Pro-Engineer by placing a floor in the bottom of the cockpit, and a small straight extrusion was placed across the tangents of the front and main roll hoops so that a measurement could be taken from the this to the top of the head on the model (see Figure 3.7), to check the chassis compliance with rule 3.3.4.1 using the analysis-measurement function of Pro-Engineer.

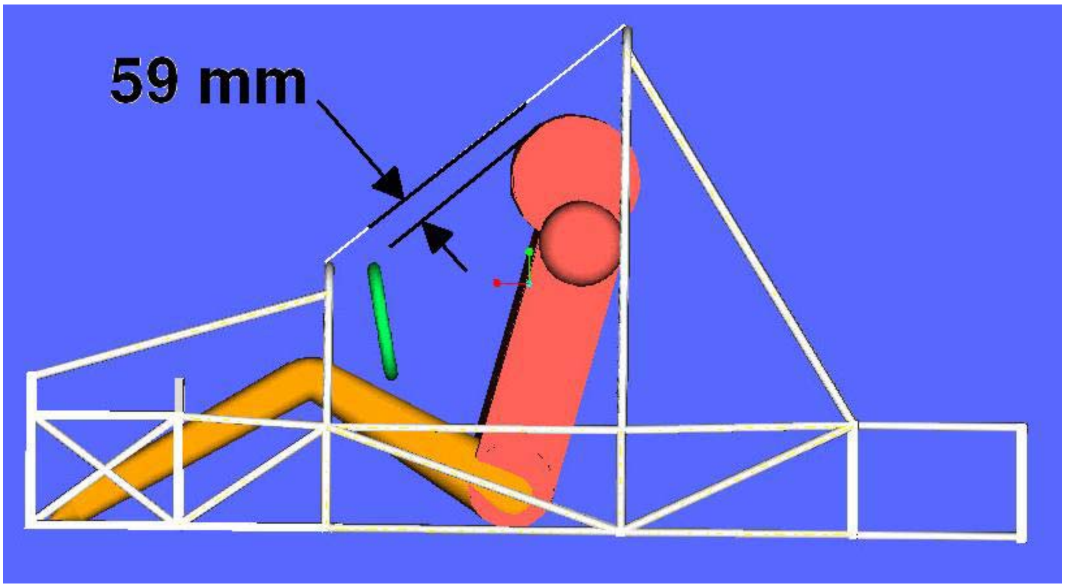

Figure 3.7 – Checking for compliance with rule 3.3.4.1 in Pro Engineer

The virtual model of chassis and driver also showed that the main roll hoop was too narrow as the driver's shoulders protruded outside the main roll hoop, as shown by the figure 3.8; which is unacceptable according to rule 3.4.12 of the competition.

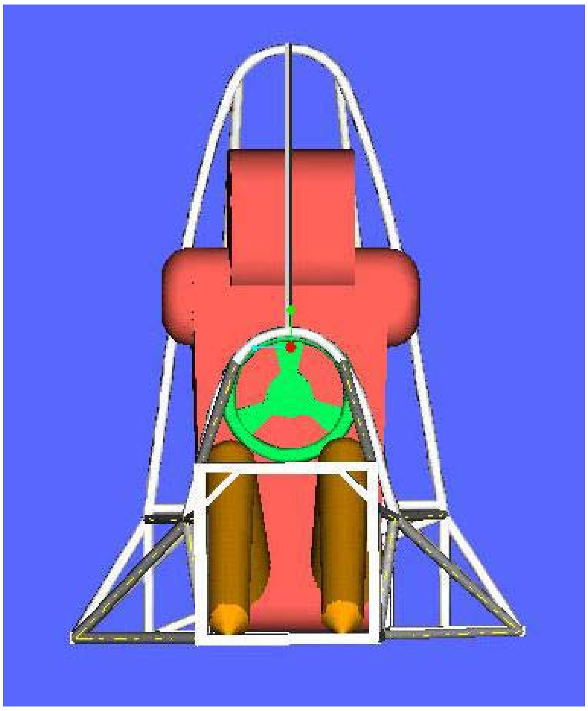

Figure 3.8 – Check for compliance with rule 3.4.12 in Pro Engineer

The size of the cockpit was also checked for length and it was decided it was still a little short, while the width around the knee area appeared to be sufficient. The knee space was further tested by the introduction of a mock steering wheel (figure 3.9), with an outside diameter of 280mm, as this was the size observed when looking at similar sized race vehicles. The size guide was considered to be suitable at this stage, as the torque required to turn the steering system has not been specified yet.

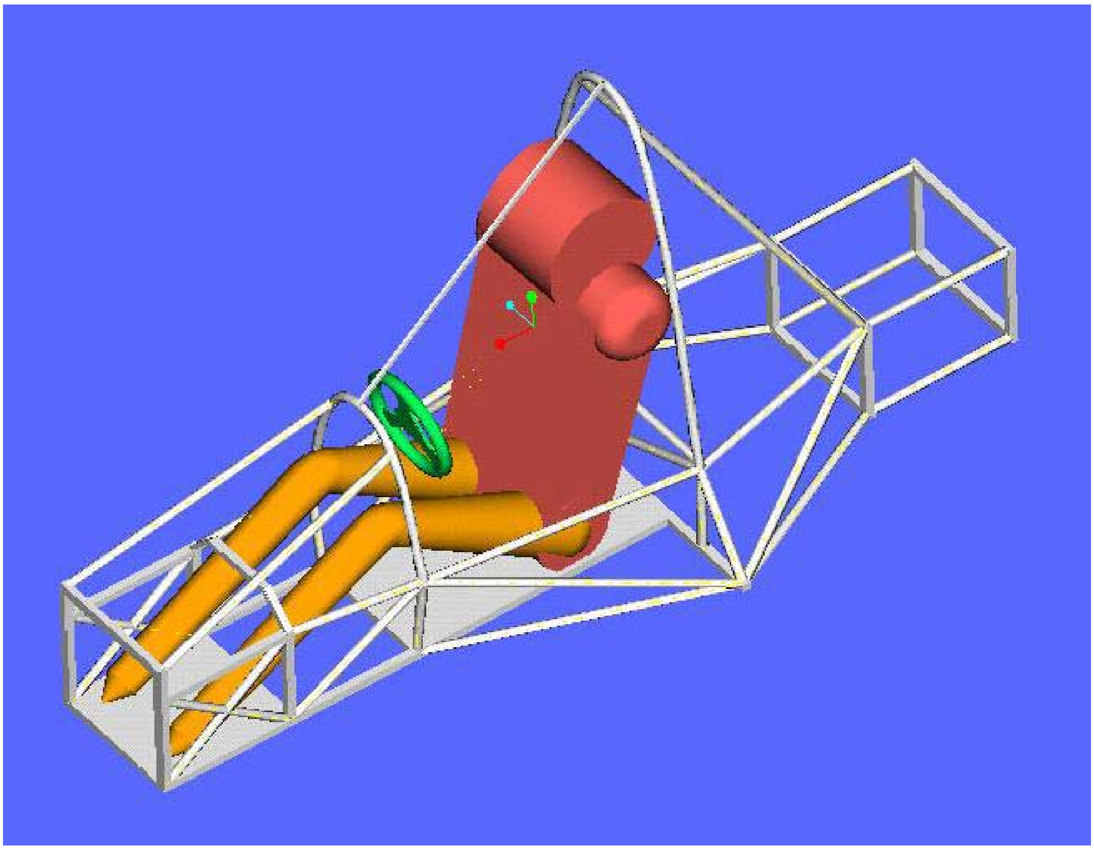

Figure 3.9 – Checking for leg length and room around steering wheel in Pro Engineer

The steering wheel was first placed in a position that appeared correct in relation to the model, then it was fine tuned using the analysis-measure function; measuring between the centre face of the steering wheel to the central axis of the cylinder representing the body's shoulders. This distance was found to be 580mm which was within the arm reach of the majority of the group; bearing in mind that, as the shoulder height is reduced this distance would be reduced. The resulting changes from the virtual analysis were that the chassis has been lengthened by 100mm and the main roll hoop has been changed to be wider at shoulder height as shown in figure 3.10. The new chassis design incorporating the above changes was checked using the above virtual modelling process for conformance with the required rules and confirming that the driver cockpit size was sufficient for the optimal and safe operation of the USQ formula SAE-A race car, the driver controls could then be allocated within the confines of the cockpit in accordance with rule 3.4.12.

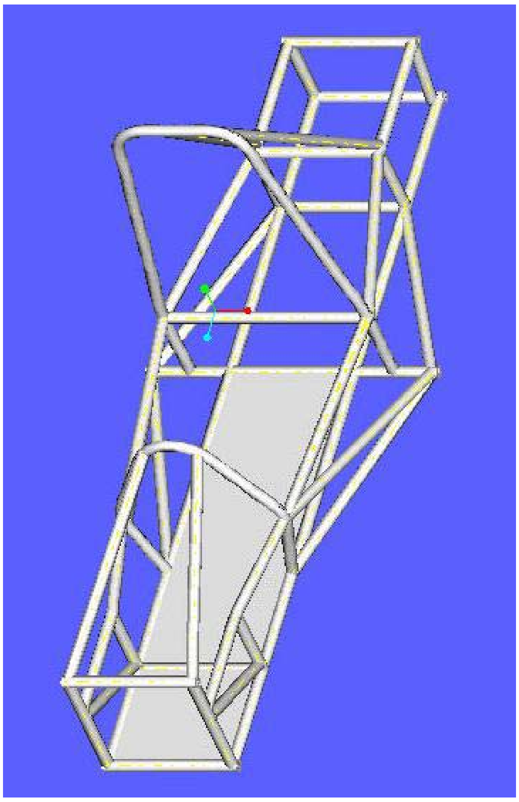

Figure 3.10 – Final chassis design with a driver cockpit floor added in Pro Engineer.

3.6 Conclusion

Within this chapter the general layout of the Formula SAE-A race car driver cockpit has been determined. This involved analysing the systems within the race car which required driver control, before determining the most appropriate method of control by the drive within this application, utilising knowledge gained from other forms of motor sport discussed in chapter 2. The chapter concluded by determining the size required within the chassis to fit a driver comfortably, using both full size and virtual models. The following chapter will build from this general layout by investigating the best method of seating the driver within the confines of the driver cockpit.

Chapter 4

4 Driver Seating

4.1 Introduction

A competitive entry into the Formula SAE-A competition requires drivers to feel comfortable within the confines of the driver cockpit, so that the race cars optimal performance is achieved. This section of the report will discuss issues directly affecting the seating of a driver within the USQ Formula SAE-A race car. Key requirements in the designation of a suitable seating solution will be highlighted, before seats of varying style and constructions are investigated. Possible solutions for the seating of a driver in the cockpit will then be discussed, before a solution is selected, positioned and mounted into the design of the USQ Formula SAE-A race car.

4.2 Key Requirements of Driver Seating

The key requirements of driver seating are all concerned with driver comfort. The design of a comfortable seat should include correct posture angle, lateral support and upper leg support and these areas will be discussed in the following sub section.

4.2.1 Posture Angle

The posture angle of a seat, affects both driver comfort and the centre of gravity of the complete race car. Increasing the posture angle by reclining the drivers seating position back, the centre of gravity will be reduced, however in performing this operation the required length for the driver cockpit, must be increased. For a comfortable seating position the driver's posture angle should be greater than 90° to a horizontal line running forward from the seats base to front of the car. This is because as the posture angle increases past 90°, pressure on the driver's spine and tail bone is reduced as the seats back support, supports a greater share of the upper body weight. Most seats that are commercially available have a posture angle of around 100° and this value only varies slightly throughout the range of different seat manufactures.

4.2.2 Upper leg Support

Upper leg support is another factor that affects driver comfort, and is related to posture angle. As posture angle increases the angle of the upper leg support is also affected, as racing seats often don't have a reclining adjustment, and are commonly manufactured as one piece. Upper leg support also removes pressure away from the tail bone of the driver, by spreading the weight of the driver's torso over a greater area. Also upper leg support that is too high will cause pain in the upper leg region, so a good balance is required for a comfortable driver fit.

4.2.3 Lateral Support

A seat must have good lateral support if the race vehicle is intended for cornering, which is the case for a Formula SAE-A race car. The level of lateral support required depends on the cornering g-forces created over the course of an event. To be allowed to compete in a Formula SAE-A competition, each race car must pass a tilt test equivalent to a 1.8 g-force of lateral loading. A force of this magnitude requires a seat with lateral support, so the driver feels comfortable when cornering, because if the driver feels uncomfortable when cornering the reduced concentration on the driving task, could result in a loss of driving performance. Lateral movement within the seat could also result in injury caused by the driver's body rubbing against the safety belts or side of a loose seat over an extended period, such as the endurance event.

4.3 Construction of a Seat

There are many types of seats that could be implemented into a Formula SAE-A car, however, all seats can be split into two specific commercially available or custom made. The reason for splitting these types of seats is that most commercially available seats are intended for use in saloon car racing, which often don't fit the requirements of a formula style car, for which seats are often custom made. However the construction methods used for seats that are commercially available, can be directly applied to custom designed seats, and an investigation into commercially available seats will be conducted throughout their entire price range, from $200 to greater than $2000, focusing on the type of construction and level of padding used.

The main body of commercially available seats are generally made from thermo-soft plastics or fibre-reinforced thermo-set plastics. Seats constructed from thermo-soft plastics are the cheapest available commercially, and are intended for recreational and low budget motor sport use. Due to the design intent for this type of seats they often have no padding to keep prices low, but usually have a good body fitting contour moulded into the body to provide a more comfortable fit, another negative aspect of this type of seat is the lack of strength, and they tend to break, often at the mounting points, where stress concentrations appear. Fibre-reinforced thermo-set plastic constructed seats are generally constructed using either a glass, carbon, or blended fibre-reinforcing, with glass fibre-reinforcing proving a cheaper alternative to more expensive carbon and blended fibre-reinforcing. Glass fibre seats can be purchased with no padding and a body contour included in the body for a low cost product; or is constructed with an internal foam padding covered with upholstery for a more comfortable and aesthetically pleasing product, at an inflated cost. The benefit of fibre-reinforced thermo-set plastic seats is the increased strength, which dramatically extends the products usable life. Carbon and blended fibre-reinforced seats are only available commercially with internal padding and upholstery covering as they are the top of the line models in all top level seat manufacture’s ranges, and they provide a light weight alternative to similar glass fibre-reinforce seats.

4.4 Possible Solutions

This section will asses possible solutions to the seating requirement previously discussed within this sector of the report. Solutions will be brought forward that broadly cover the previously discussed seating styles and construction.

4.4.1 Fibre-reinforced Seat with contoured body

The seat shown in figure 4.1 is a fibre-reinforced thermo-set plastic constructed seat. It is constructed using glass fibre and has a contoured body for a comfortable fit, it has a weight of around 6kg and has provisions for a 5 or 6-point harness to be fitted without modification.

Figure 4.1 - Glass fibre-reinforced seat with a contoured body from ‘The Edge Products’

This seat has a recommended retail price $270, which is within the viable price range for this application. However this seat lacks upper leg support as it is not designed to be mounted at the same height as the foot pedals, but it does provide good lateral support of the driver.

4.4.2 Fibre-reinforced Seat with internal padding and upholstery

This seat shown in figure 4.2, has a recommended retail price of around $530, and is Fibre-reinforced thermo-set plastic constructed seat.

Figure 4.2 – Glass fibre-reinforced seat with internal padding and upholstery from Sparco (UPRacing.com, 2004).

It is constructed using glass fibre and has internal padding and upholstery for a more aesthetically pleasing product, it also has provisions for a 5 or 6-point harness to be fitted without modification. This seat is upholstered using a distinct process that allows a micro-channelling effect of air between the seat and driver's body increasing comfort levels further (UPRacing, 2004). This seat has good upper leg and lateral support, and the only possible downside to its implementation into a Formula SAE-A race car would be, in the event of rain the upholstery would get wet which may cause rotting and the creation of unpleasant odours within the upholstery.

4.4.3 Formula Ford Seat

The custom made for a formula ford racing seat was donated to the USQ Formula SAE-A team, and is shown in figure 4.3, as a solid model.

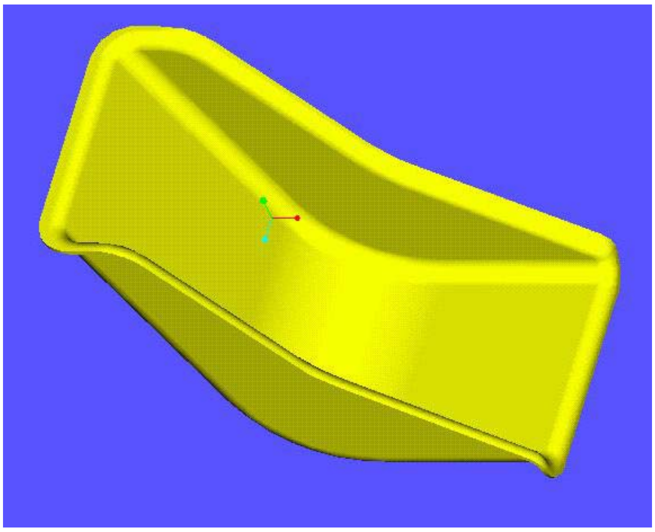

Figure 4.3 – Solid model of donated formula ford seat in Pro Engineer.

It is constructed from glass fibre-reinforced thermo-set plastic, featuring good lateral support and a degree of freedom with regard to posture angle, as the seat can be mounted within an approximate 20° range of angular positions. The weight of this seat is also of benefit as it only weighs approximately 2kg. Negative aspects of this seat are that the upper leg support is minimal and holes have to be cut to fit the 5 or 6-point harness. Also the seat is reasonably thin at the base of the seat and will break if a driver concentrates their body weight on an unsupported section, by stepping onto the seat.

4.5 Selection

For implementation into the 2004 USQ Formula SAE-A racing car, I selected the Formula Ford seat as it is light, inexpensive, and can be mounted in a variety of different positions. The mountings for this seat in the USQ Formula SAE-A race car will have to support the base of this seat, so that in the case of a driver placing their full weight on the base, the load is correctly distributed to the chassis. The issue of upper leg support will be rectified by the inclusion of foam padding mounted on the bottom of the seat and angled to fit the profile of the upper leg at this point. This will be looked at a date after the seat and foot pedals are positioned and the angle of the upper leg can be determined. Holes will be required in the seat to suit, a 5 or 6-point harness which will be looked at within the safety issues section of this report. With the seat selection completed the seat can now be positioned into the chassis.

4.6 Positioning

Correct positioning of the seat within the chassis is important as it will form the base point for all driver controls. A key requirement when positioning the seat within the cockpit is that it should allow for enough leg room to allow for foot pedals to be placed in front of the drivers feet, so to maximise the allowable space the seat will be placed as close to the rear of the cockpit as possible. Also the seat should be placed on the centre line of the vehicle, so that the percent weight distribution of each side of the car remains equal, however the effects of moving the driver with relation to the car and it’s effect on the weight distribution will not be looked at within the scope of this project, as this area is investigated by other Formula SAE-A team member’s research.

The initial step in the process of positioning the seat was to create a solid model, from measurements taken of the seat. In the solid model a datum axis was inserted approximately where the hip of a seated driver would lie (see figure 4.4), forming a hip datum axis allowing for future estimations of leg room, at different seating positions.

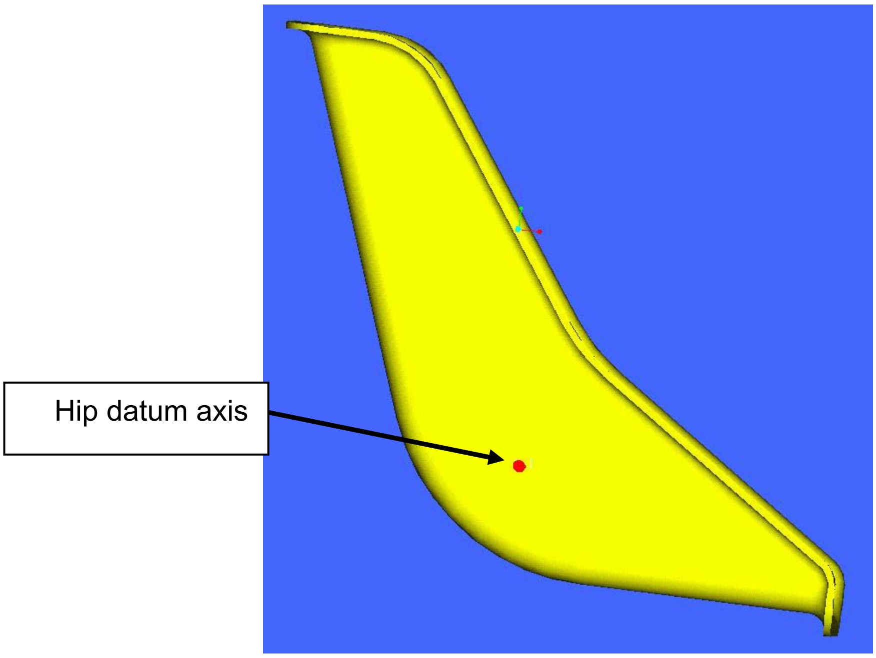

Figure 4.4 – Hip datum axis position in relation to selected seat.

The seat was moved through a variety of different posture angles while allowing for approximately 20 mm clearance between the back of the seat and a cross member of the chassis, in all instances within the solid model, see figure 4.5.

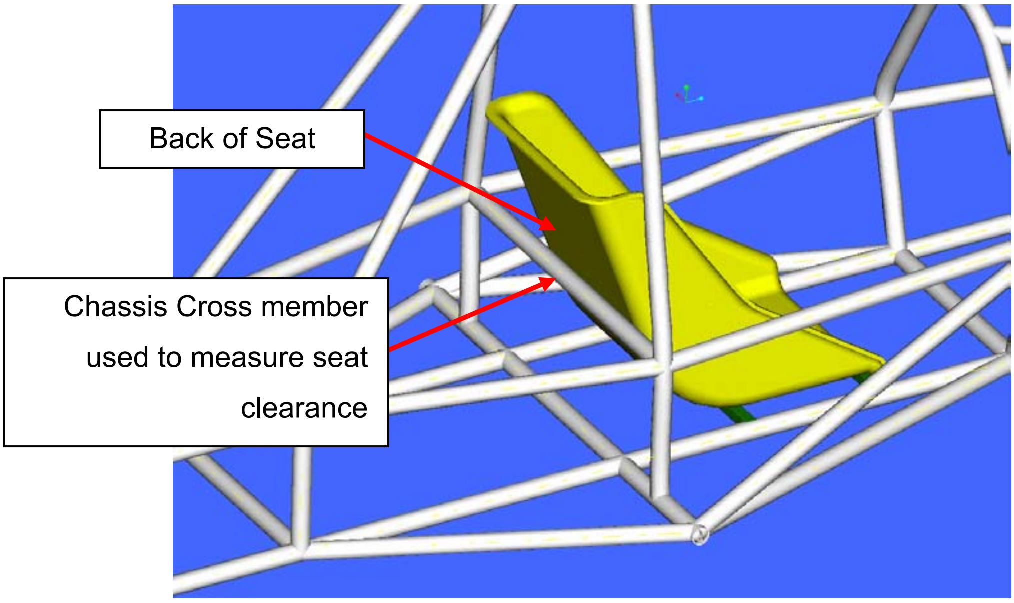

Figure 4.5 – Clearance between cross member and the back of the seat.

The length between the hip datum axis and the most extreme frontal surface of the chassis (as Formula SAE-A rules stipulate that no components can protrude past this point), was measured within the solid model using the Pro Engineer analysis feature, this allowed each situation to be assessed on the basis of whether leg room was sufficient, while allowing extra space for foot pedal assemblies. A seating position with a posture angle of 110° was selected, as shown in figure 4.6.

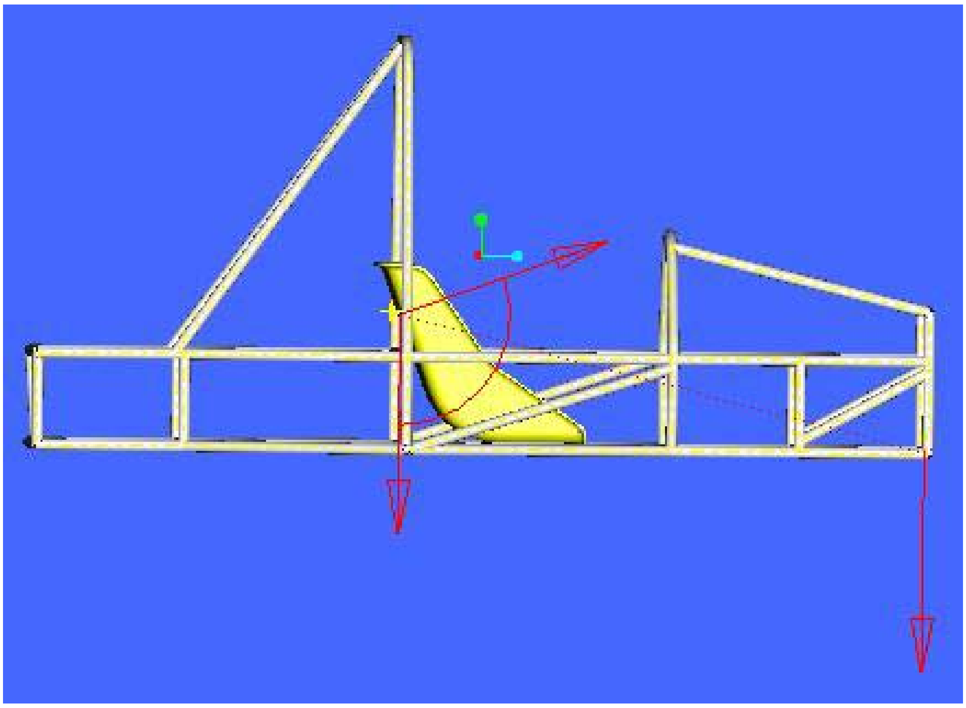

Figure 4.6 – Selected Seat position with a posture angle of 110°.

This solution maximised leg room, while conforming to the front to main roll hoop head clearance criteria set by rule 3.3.4.1of the Formula SAE-A competition and as the base of the seat is horizontal at this point, if the posture angle in decreased further allowing for greater leg room, the base of the seat will be angled so that the driver will naturally slip forward and out of the seat. With the position of the seat now determined, the seat mounting can now be investigated.

4.7 Mounting of the seat

Mounting of the selected seat is made easier by the base of the seat being horizontal and hence parallel with the floor of the car. Materials suitable for this application that are readily available within the USQ workshop are 25 x 25mm square tubing, 19mm diameter tube and 2mm aluminium sheet. For ease of construction, the seat mounting will utilise these materials.

The base of the seat is the key area of concern with regard to mounting support, because of the low strength in this section of the seat. For this reason there will be two mounting beams welded between bottom rails made from 25 x 25 mm square steel tubing and a 2mm aluminium sheet under the seat to provide sufficient support to the base of the seat as shown in Figure 4.7.

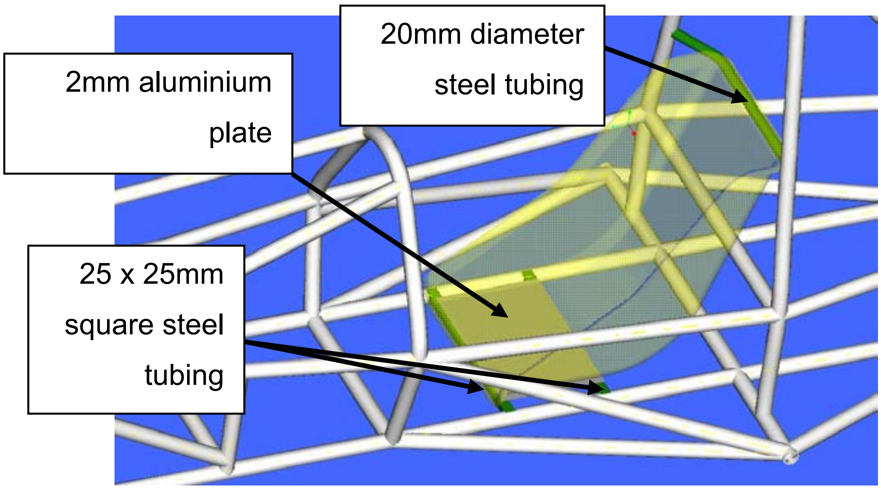

Figure 4.7 – Seat mountings for the USQ Formula SAE-A race car.

Support for the back of the seat will be provided by a 20mm diameter tube bent so that it passes around the back of the seat just under the upper lip mating with the main roll hoop on both sides and is welded into position. The seat will be fixed to provide a smooth finish on the critical inside surfaces of the seat, with the use of counter-sunk cap screws. These screws will be fitted with a counter-sunk washer and nylon lock nuts to prevent loosening, caused from vibration.

4.8 Conclusion

In conclusion, throughout this chapter the area affecting the seating position have been discussed and set. This will now form the basis of all designs throughout this report because as the seating position is now fixed, now also the shoulder and hip positions are fixed. With these positions of these body parts fix the position of the hand and foot controls can now be determined which will be discussed in the following chapters.

Chapter 5

5 Hand Controls

5.1 Introduction

This chapter is will discuss, design/or designate parts and implement their use in the USQ Formula SAE-A race car. As discussed in section 3.3 of this report the USQ Formula SAE-A race car will be fitted with three hand controls- steering wheel, clutch lever mounted on the steering shaft, and gear shift lever. Initially the steering wheel, will be selected and positioned, followed by the selection of an appropriate quick release as required by the Formula SAE-A rules. Design of the steering shaft will the follow, before the design of the clutch lever, and the mounting of the assembled steering shaft is completed. The design of the gear shift will conclude this chapter.

5.2 Steering Control

The steering control for the USQ Formula SAE-A race car will be via a steering wheel. Steering wheels are commonly used for steering control because they allow precise control and allow the provision of a steering system requiring greater than one turn, to move throughout the entire motion of the steering system, which is often referred to as lock to lock. The purpose of a steering wheel is to transmit a tangential force applied to the outer rim of the steering wheel to a torque applied down the steering shaft to the steering system. Within the following sections the ergonomics requirements of steering wheels will be discussed, this information will then be utilised in the selection of a steering wheel for implementation into the USQ Formula SAE-A race car. The selected steering wheel will then be placed within the cockpit in accordance with the ergonomic data discussed in following section.

5.2.1 Ergonomic requirements of the Steering wheel

The steering wheel has ergonomic issues which relate to its design and positioning; these issues will be highlighted within this section. The design of a steering wheel can be analysed using ergonomic principles in three areas, grip diameter, covering and padding, and diameter.

The grip diameter is important to the design of a steering wheel, so that a good grip can be achieved allowing for the force to be applied effectively without slip. The recommended design value for a hand wheel, an industrial term for a similar control to a steering wheel, is between 18mm and 53mm (Eastman Kodak, 1983). However on inspection of commercially available steering wheels, most are designed with a mean grip diameter of approximately 30mm, and are often slightly oval shaped to better suit the profile of a hand creating a more effective and comfortable grip.

The covering and padding of steering wheel is important to the comfort of the driver and a covering material must posses' good fictional properties with the driver's safety gloves. This results in the driver having to use less force to grip the steering wheel effectively, and will therefore reduce fatigue of the forearm muscles. A common steering wheel covering is suede leather, because it is durable, has good frictional properties when used in conjunction with common driver glove materials (often suede leather also). Steering wheel padding under the covering also assists in reducing fatigue, by creating more friction between the driver's gloves and the steering wheel. This is because to the driver's hands sink slightly into the padding of the steering wheel, increasing the contact area between glove and steering wheel, therefore increasing the frictional force to overcome before slip occurs. A steering wheel with excessive padding is also undesirable as loss of feeling through the control occurs, and driving performance may be impeded.

The diameter of a steering wheel determines the ease at which steering control is performed. The tangential force that can be applied to the outer rim of a steering wheel by a driver ranges from 20N to 220N for two handed operation (Eastman Kodak, 1983), which is greatly dependent on the wheels position in relation to the operator. As the driver applies a tangential force the outer rim of the steering wheel, knowledge of moments created about a point, torque applied at the centre of a steering wheel could be increased if the outer rim diameter is increased, while using input forces of the same magnitude. The downside to this is that a large steering wheel will cause problems associated with fitting with the confines of a small formula style car's driver cockpit. To assist the requirement of fitting a steering wheel into a confine space such as the USQ Formula SAE-A race car's drive cockpit, many steering wheel manufactures create different styles of steering wheel, that have a flat bottom, to increase the amount of leg room around the steering wheel. A steering wheel with this feature would be optimal for the USQ Formula SAE-A race car and the steering wheel selection will look exclusively at this type of steering wheel.

Ergonomic issues arise with the positioning of the steering wheel, with regard to the distance away from the driver's shoulders and the angle at which the driver's forearms meet the steering wheel, shown in figure 5.1. The height of the steering wheel must be lower than the height of the front roll hoop as set out by the rules. Within the USQ Formula SAE-A race car, it is desirable to mount the steering wheel height just below the height of the front roll hoop, so that leg room around the steering wheel is maximised.

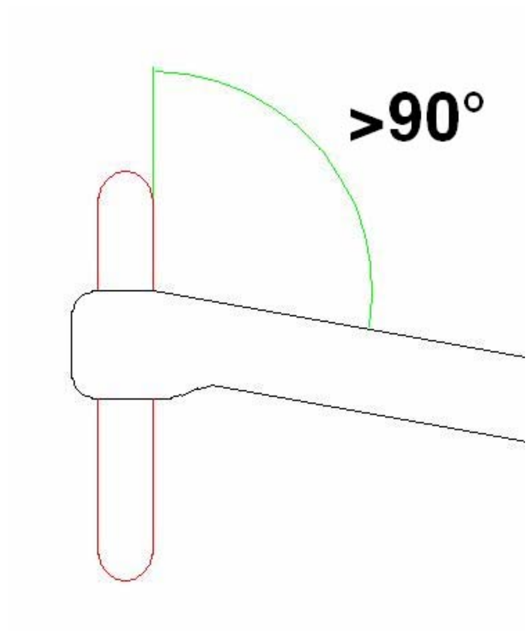

Figure 5.1 – A side view of steering wheel, showing the optimal angle created by the drivers forearm and the front plane of the steering wheel.

The distance from the driver's shoulders to the steering wheel should be sufficient that the driver doesn't feel cramped. The optimal distance from the driver's shoulders to the steering wheel, would allow for the driver's arms to be slightly bent when holding the steering wheel in the driving position. The optimal position of the driver's hands on the steering wheel is often taught in driving schools as positions 10 and 2, in relation to the numbers on an analogue clock.

Once the steering height and distance is set the steering wheel angle should be altered to so that the angle between the forearm and the steering wheel is slightly greater than 90°, as shown in Figure 5.1.

Now that all the ergonomic issues affecting the steering control has been identified the steering wheel can now be selected, and placed correctly.

5.2.2 Steering Wheel Selection

There are many different manufacturers of steering wheels for motor sport applications, so within the scope of this section only feasible solutions will be investigated and steering wheels of similar or same diameters will not be compared.

5.2.2.1 Possible Solution 1

The steering wheel shown in figure 5.2, is manufactured by MOMO, and is made from aluminum and the outer rim is covered in suede leather for good hand grip.

Figure 5.2 – MOMO, 270mm steering wheel with flat bottom (UPRacing, 2004).

A feature of this steering wheel is that the hand grips are larger than the mean diameter of the outer rim, and the center of the hand grip is also the maximum diameter found on the wheel. This feature creates a nice feel as the hand naturally fits this contour. The steering wheel diameter is 270mm and this product retails for about $250.

5.2.2.2 Possible Solution 2

The steering wheel shown in figure 5.3 is manufactured by OMP, it is made using aluminium and the outer rim is covered by suede leather. The outer rim is oval shaped to minimise the external diameter, and the hand grips are contoured to suit the profile of the driver’s hand. The diameter of this steering wheel 230mm and has a recommended retail price of around $230.

Figure 5.3 – OMP- Formula Quadro, 230mm steering wheel with flat bottom (ompracing.com, 2004).

5.2.2.3 Selected Steering Wheel

The steering wheel selected for use within the USQ Formula SAE-A race car is the OMP Formula Quadro. This steering wheel was selected because it maximised leg room, because it best fitted the profile of the front roll hoop of the chassis. The smaller diameter should also not cause the steering of the race car to be feel ‘heavy’ (hard to turn) to the driver, as the weight on the front wheels is considerably less than that of the front-engine car that the steering rack was originally designed.

5.2.3 Steering Wheel Positioning

To correctly position the steering wheel requires knowledge of the location of the driver's shoulders in the seated position, however at the time of this report the seat had not been mounted to the chassis. This means that the positioning of the driver's shoulder will have to be approximated and a virtual analysis technique will be used to determine the position of the steering wheel. For the purposes of positioning the steering wheel in a virtual model, a solid model of the selected steering wheel was created. The solid model of the steering wheel had datum points placed at the optimum driver hand positions, as described in section 5.1.1. The addition of a datum plane through these points at a 5° angle to the front plane of the steering wheel was to try to achieve an appropriate forearm to steering wheel angle, see figure 5.4.

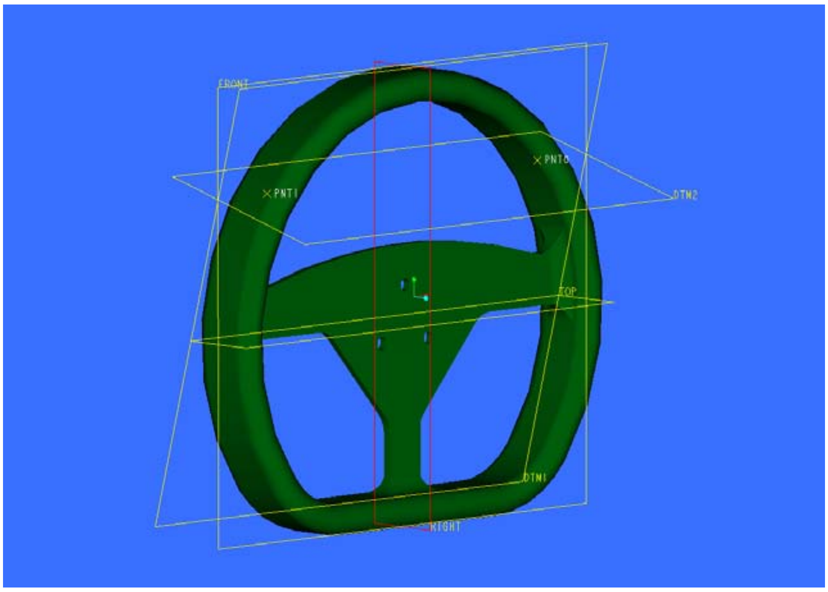

Figure 5.4 – Solid model of selected steering wheel with datum points and datum planes added.

Also the seat solid model was modified, by creating a datum plane through the hip datum axis, and parallel with the back support and another datum axis along this datum plane at the average shoulder height from the gathered group data. The steering wheel position was altered in Pro Engineer, until the desired results were achieved, the final result was a steering wheel placed 15mm lower than, and approximately 200mm behind the front roll hoop. A datum plane was created through the shoulder axis of the seat, and the steering wheel hand grip's datum point, which was then used to estimate the angle between the forearm and the front face of the steering wheel, see figure 5.5. This angle was measured at 92°, at a distance of 535 mm between the shoulder axis and the steering wheel hand grip points. These values are considered acceptable, and the steering wheel quick release mechanism will now be discussed.

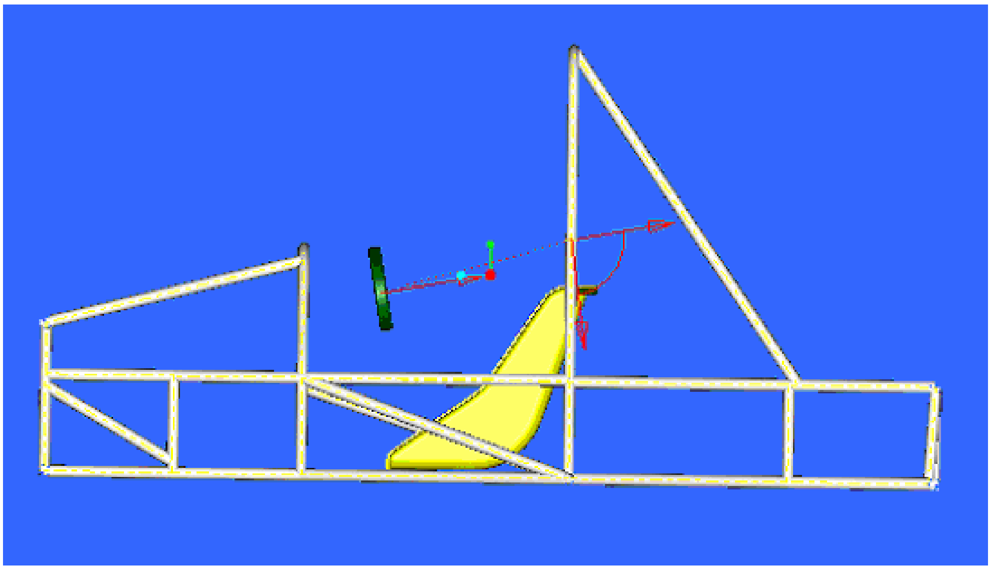

Figure 5.5 – Measuring the angle between a datum plane (created between steering wheel grip points, and shoulder datum axis) and the front surface of the steering wheel in Pro Engineer.

5.3 Steering Wheel Quick Release

The Formula SAE-A rules specify that a quick release mechanism must be fitted to the steering wheel. This section will discuss different types of steering quick-release mechanisms, and select an appropriate solution for the USQ Formula SAE-A race car. There are two main types of steering wheel quick release, and within this section they will be referred to by their torque drive style. The two types are called 'hex drive' and 'spline drive' quick release mechanisms.

5.3.1 Hex drive Quick Release

Hex drive quick release mechanisms, are called so because the steering wheel torque is transferred to the steering shaft, via a hex drive, as shown in figure 5.6. Generally the steering wheel is located on the steering shaft, using a groove in the hex drive, and is located by a spring loaded pin which locks into the groove. The steering wheel is released from the steering shaft by pushing the pin against the spring until a smaller diameter section of the pin, allows the steering wheel to be removed.

Figure 5.6 – Hex drive quick release steering wheel mount (wilwood.com, 2004).

The benefits of this type of steering quick release is the cost, at around $100 they are very affordable. However the design of the drive system means that when used over an extended period the drive sides begin to wear, because there is a minimal contact area transmitting torque.

5.3.2 Spline drive Quick Release

Spline drive Quick Release mechanisms are a more expensive alternative to the hex drive, however because the steering wheel torque is transmitted by an involuted spline there is greater load sharing among drive sides of the mechanism, the service life is increased. This type of quick release also uses a different method of location on the spline and steering wheel removal is performed by pulling the release ring towards the back of the steering wheel, as shown in figure 5.7.

Figure 5.7 - Splined steering quick release mechanism, by SPA Design (UPRacing, 2004).

The benefit of this type of quick release is the extended service life and also this type of quick release can be purchased with an electrical connection fitted inside the spline for a steering wheel with instrumentation included. The only negative relating to this type of quick release is the high price of around $300.

5.3.3 Selection

Ultimately the best type of quick release mechanism is a spline drive. However due to the relatively short life of the USQ Formula SAE-A race car, a hex drive quick release would be sufficient and is selected, because of it's low cost.

5.4 Steering shaft Design

The steering shaft for the USQ Formula SAE-A race car must be designed as no suitable systems could be implemented. The design of the steering shaft will first look at its specific requirements, before stress analysis is carried out, and the final design is developed.

5.4.1 Steering Shaft Requirements

The requirements of the steering shaft are to transmit the torque from the steering wheel to the steering rack. In the USQ Formula SAE-A race car the steering rack position has been approximately stated and the position of the steering wheel has been located, so all the requirements are fulfilled, to allow the steering shaft to be designed.

The ultimate way to design the steering shaft is with a universal joint linking the two shafts with a bend at this point, as shown in figure 5.8. This method will increase leg room and allow for a greater degree of freedom with regard to the location of the steering rack.

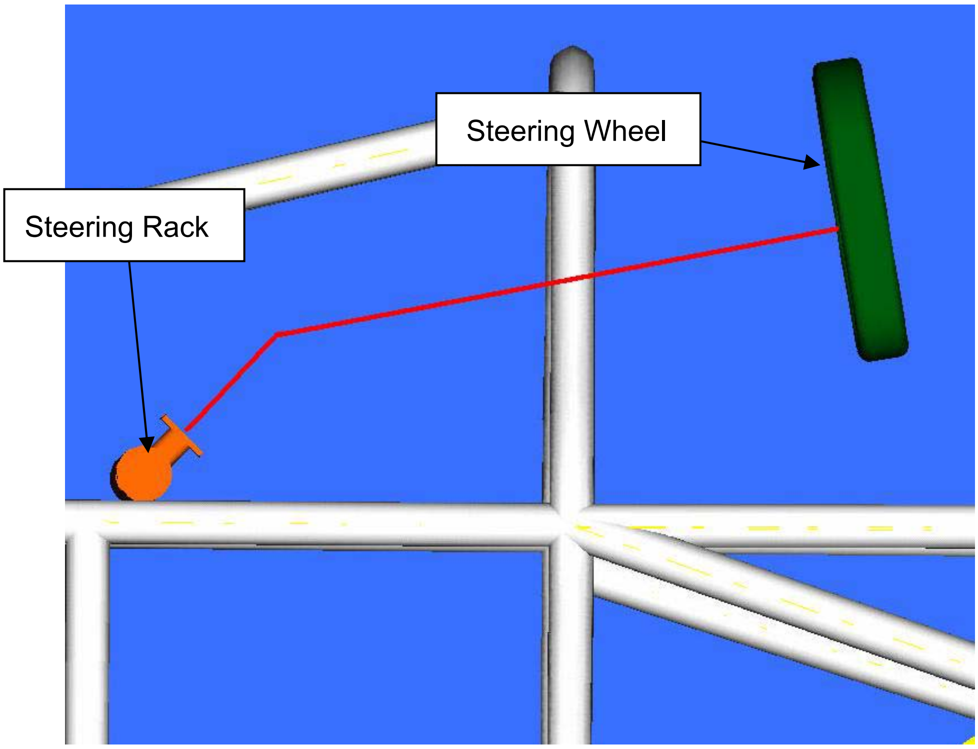

Figure 5.8 – Design layout for Steering Shaft

5.4.2 Stress Analysis

The steering shaft is an area that a possible fatigue failure could occur, which is a safety risk. The steering shaft will therefore be designed for infinite life and incorporate a factor of safety of 6. The standard factor of safety used throughout this project is increased (from 4 to 6) in this instance, because the stress analysis to be carried out will look at pure torsion loading of the steering shaft, however in service the steering shaft will undergo relatively small bending and shear forces also.

Due to material availability, I have preliminary selected a 19mm mild steel tube with a 2mm wall as it is readily available in the USQ Workshop. This section of the report will analyse this selection and find whether it fulfils the requirements of above. The mild steel is assumed to have similar properties grade 1015 steel which has the following properties defined in Table 5.1, and the fatigue strength for infinite life for the material is calculated in equation 5.1(Juvinall and Marshek, 2000).

Yield Stress (σ_{yield})	421 MPa
Young's Modulus (E)	207 GPa
Poisson's Ratio (v)	0.3

Table 5.1 – Properties 1015 grade Steel (Juvinall and Marshek, 2000).

$$S_n = S'_n C_L C_G C_S$$
$$S_n = 210.5 \text{ x } 1 \text{ x } 1 \text{ x} 0.8$$
$$= 168.4 \text{ MPa}$$

Equation 5.1 – Fatigue stress calculation for infinite steering shaft life.

Torsional stress is found using equation 5.2, for a maximum torsional stress in a hollow shaft. Where T is the torque applied to the shaft (steering wheel radius multiplied by the maximum possible tangential force), c is the outside radius of the steering shaft, and J is the polar moment of inertia for the shaft. Although the resulting steering shaft is going to be over engineered, by using the maximum possible tangential force, however with safety issues surrounding a possible steering shaft failure, this factor will give greater allowance for unknown shear and bending forces applied to the steering shaft.

$$\tau_{max} = \frac{T\,c}{J}$$
$$= \frac{25300 \text{ x } 9.5}{7824.14}$$
$$= 31 \text{ MPa}$$

Equation 5.2 – Torsion stress in steering shaft (Juvinall and Marshek, 2000).

This value is within the allowable stress value for infinite steering shaft life, therefore the steering shaft will be designed utilising this stock tube from the USQ workshop.

5.4.3 Universal Joint

Universal joints are commonly used throughout the automotive and motor sport industry for creating steering shafts, with an input shaft at a different angle to the output shaft. They are used to allow the steering wheel to be at the correct placement angle, with out jeopardising the positioning of the steering rack and associated componentry. The most commonly used type of universal joint for small angle bends is the pin and block type, which will be discussed within the following.

5.4.3.1 Pin and Block Universal Joint

Pin and block universal joints operate efficiently with bends up to 35º. The bend in the steering shaft of the USQ Formula SAE-A race car is approximately 25º; therefore this type of joint would satisfy the requirements. A typical pin and block universal joint is shown in figure 5.9.

Figure 5.9 – A typical steering shaft universal joint for motor sport applications (borgeson.com, 2004).

Most commercially available universal joints for motor sport application require a ¾ inch steering shaft with a flat drive machined to transmit torque though the joint. Due to the cost restraints within this project, a pin and block universal joint was utilised because it was donated by a local car wrecker (see advertisement appendix B). The donated universal joint required a ¼ circumferential spine to be cut on the end of each steering shaft section. To improve the production time of this prototype steering, shafts were also donated by the car wrecker to suit the spline required to fit the universal joint. These steering shafts were 19mm diameter solid steel, and would be utilised within the prototype, even though they were much stronger than required by calculations in chapter 5.3.2 of this report.

5.5 Clutch Control

Clutch control for the USQ Formula SAE-A race car is a left hand controlled lever mounted on the steering shaft as discussed in section 3.3, with the method of operating the clutch by a cable being retained. The design of the clutch lever begins with an initial investigation into ergonomics after which the design criteria will be outlined and the final design produced.

5.5.1 Ergonomics

The design of the clutch initially requires ergonomic data analysis on hand grasp circumferences, to determine the distance away from the steering wheel for the lever's static positioning. The clutch levers static position was found to be 58mm from the back surface of the steering wheel, which is modeled using a 2-d drawing. The path of motion for different length levers was also conceptualized; in this drawing, see appendix D. It was decided that the optimum lever length (distance between hand grip and lever pivot of the clutch lever) was between 100 and 200mm. As this would reduce the possibility of the driver's operation of the lever, being impaired by the mounting of the clutch cable, as the cable must travel away from the steering wheel, along the steering shaft so that the clutch operation doesn't require more force than otherwise necessary, by reducing the effects of friction within the cable by utilising where possible large radius bends. Therefore the clutch cable mount must be on the same side of the pivot as the hand grip.

5.5.2 Design Criteria

The design criteria for the clutch lever will include the 3 areas, of maintaining steering shaft balance, ease of clutch operation and a cable mounting. Each area will be brought forward and the solution discussed within this section.

Maintaining steering shaft balance is set as a design criteria, because the effects of an excessively out of balance steering shaft are undesirable. An out of balance steering shaft will naturally rotate until the heavier side is positioned at the bottom of rotation, this may become annoying to the driver, and should be avoided or minimized if possible. This issue could be reduced by placing the pivot point of the lever on the opposing side to the hand grip. The clutch lever mounting would be designed so that its centre of mass would counterbalance the centre of mass for the clutch lever, which would be by design, positioned further from the axis of rotation than that of the clutch lever mount. Therefore a steering shaft balance is achieved by utilizing a heavier material for the manufacture clutch lever mount, than that used for the clutch lever. Some possible combination could include aluminum for clutch lever mount and carbon fibre-reinforced plastic for clutch lever, or a steel clutch lever mount and an aluminum clutch lever. The optimal solution would be the first mentioned option, however due to the limited time frame and workability and availability of the later mentioned materials they will be utilised for this design.

Ease of clutch operation is also benefited by the fitting of the clutch lever pivot on the opposing side to the hand grip. This increases the scope of the design to increase the mechanical advantage of the system, while still generating enough linear displacement (as the motion of a cable will generally follow the shortest possible path) to effectively operate the clutch as it was originally designed.

A cable mounting system must be incorporated into the design of the clutch lever, and must transmit the rotation of the lever into near linear motion at the mounting point of the clutch cable. To satisfy this criterion, the most commonly used methods will be discussed within the following.

5.5.2.1 Looped Cable

This method of cable mounting is extremely simple and effective, it utilises a cable clamping device which clamps the cable to it self. The cable is passed though a small hole at the mounting point and then clamped to itself to create a fixed loop as shown in figure 5.10.

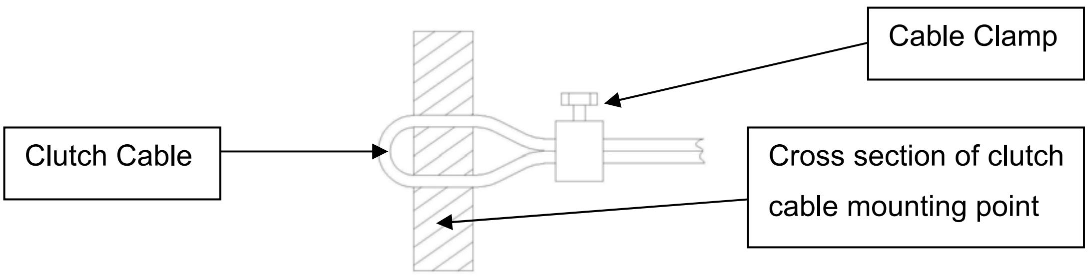

Figure 5.10 – Side view of looped cable method of cable fixing to clutch

Advantages

- Simple to manufacture
- Simple to adjust

Disadvantages

- Stress concentration, maybe caused by hole though component.
- Surfaces in contact with cable must be free of sharp edges and burs, so that cable life is not reduced.
- Sufficient distance between cable outer ending and mounting point must be provided.

5.5.2.2 Pinched Cable

This method is very similar to the above mentioned however in this case the cable is fixed at the mounting point, by a pinching action, usually in its most simple for by a bolt and washer, as shown in figure 5.11.

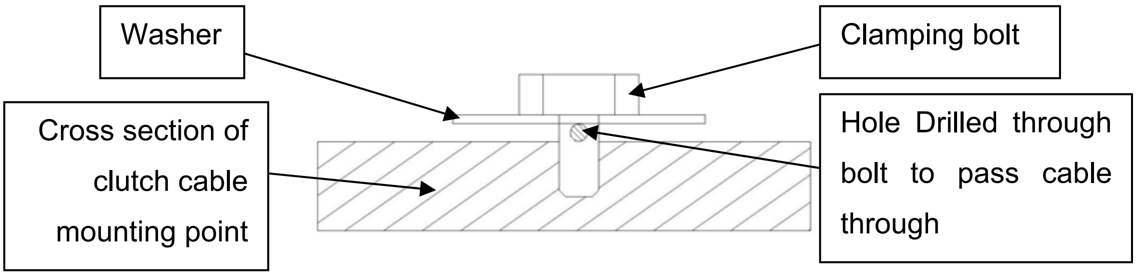

Figure 5.11 – Side view of pinched cable method of cable fixing to clutch.

Advantages

- Simple to manufacture
- Simple to adjust

Disadvantages

- High stress concentration at point near bolt pinch, on tension side.

- Cable damaged during pinching action, may cause failure if adjusted and damaged cable become part of the cable in tension.

5.5.2.3 Constrained ball

This method is more complicated than methods mentioned previously, however it is used more readily than other method in commercial application because of the below mentioned advantages. It utilises a soldered ball on the end of the cable, which is then constrained in the mounting, as shown in figure 5.12. The mounting in its most effective form will allow the ball to rotate naturally, which reduces stress concentrations in the area of cable near where the ball is fixed.

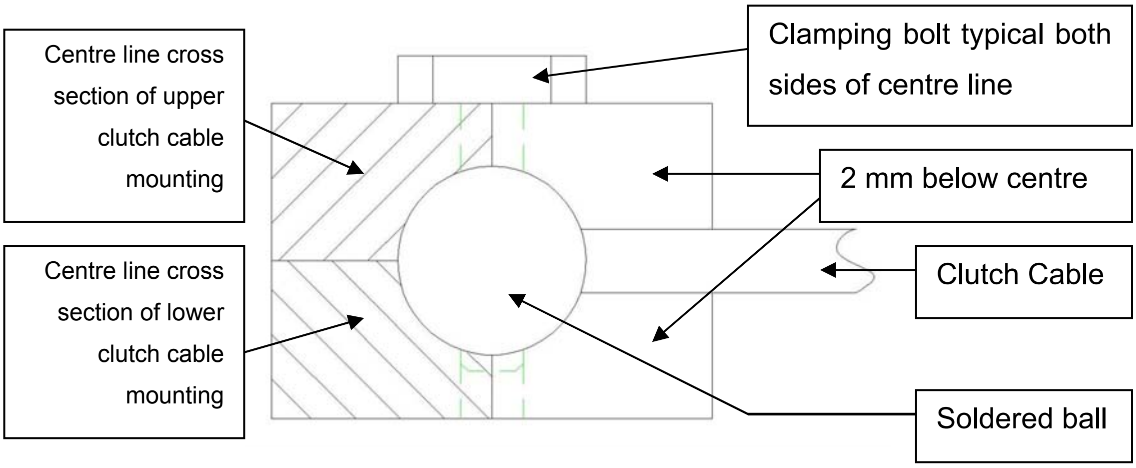

Figure 5.12 - Side view of constrained ball method of cable fixing to clutch

Advantages

- Low stress concentration at point of fixture
- Professional appearance

Disadvantages

- More complex design of cable mounting required
- Cable must have ball soldered on end
- Cable must be adjusted via movement of the cable outer.

5.5.2.4 Selected Clutch Cable Mounting

The clutch cable mounting selected for implementation with the USQ Formula SAE-A race car is the ‘Constrained method’. The disadvantages associated with the other method mentioned far outweigh the advantages, and I believe that the professional look of the constrained ball method will contribute to a professional looking cockpit.

5.5.3 Final Design

The final design of the clutch lever is an aluminum lever with 150mm from the pivot axis to the centre of the hand grip, and 58mm from the pivot axis to the clutch cable mounting point. This achieves a mechanical advantage of 2.6, which is approximately the same as what was previously used on the original bike clutch lever. The hand grip is curved and has a curved width of 140mm, which was gathered from the ergonomic data in appendix D. The clutch lever mount is made of steel and features a cable outer and a clutch lever static positioning adjuster. The completed components are shown 5.13.

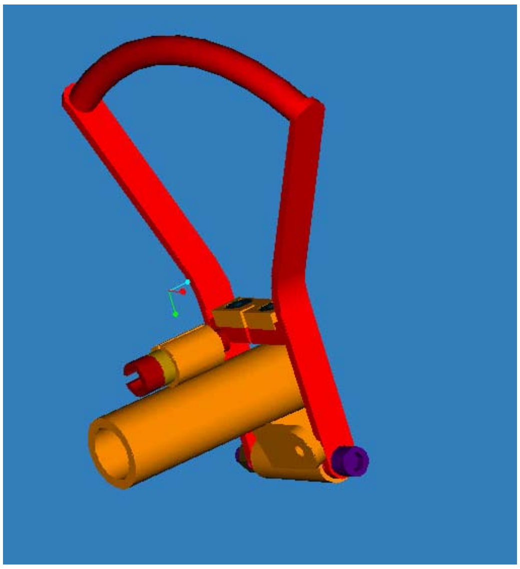

Figure 5.13 – Final design for clutch lever and lever mount modelled in Pro Engineer.

5.6 Steering shaft assembly mounting

The assembled steering shaft, with all attachments discussed previously within this chapter fitted, is shown in figure 5.14. With knowledge of the appearance assembled steering shaft and requirements to operate each mounted control, the steering shaft assembly can now be mounted. This chapter will discuss the requirements of the mounting solution, and design steering shaft mounts accordingly.

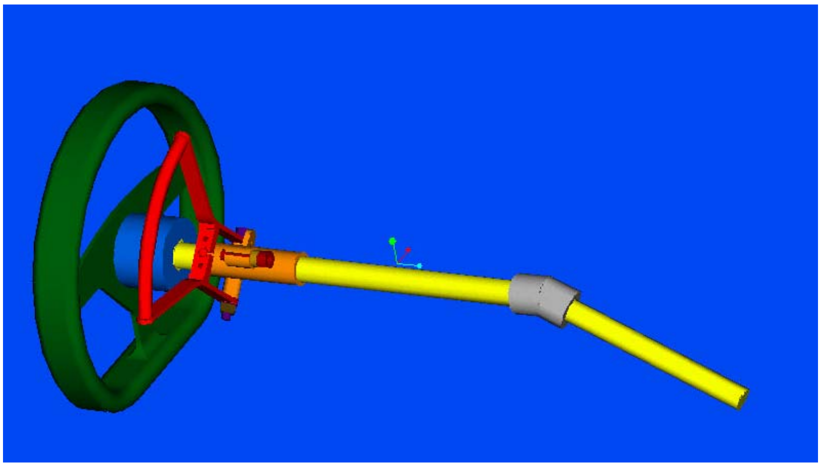

Figure 5.14 - The modelled steering shaft in Pro Engineer

5.6.1 Mounting Requirements

The steering shaft mounts must essentially allow for rotation of the steering shaft, while providing a solid fixture in both the lateral, linear and vertical planes. The steering shaft assembly’s rotation can be considered to be low velocity, as the steering wheel would rarely rotate more than a full revolution in less than one second. The steering shaft also incorporates a universal joint between two separate shafts, so the steering shaft assembly must be mounted at least 3 separate points to be effectively constrained.

5.6.2 Mounting Design

The steering shaft mounting design will focus on designing 3 separate mounting points. These points will each incorporate varying degrees of restraint in each of the 3 planes. As the steering shaft operates at a low angular velocity, the design will incorporate the use of bearing bushes, designed from a suitable nylon material. Other suitable materials such as brass and bronze where also considered, however the availability, ease of manufacture and cost, made these options unviable for this project.

The steering shaft mounts will be placed such that the critical input and output ends are constrained with a mount and the third mount will be placed near the universal joint the middle of the steering shaft. The output end of the steering shaft will be constrained by mounting to the steering rack and will not be designed within the scope of this project.

5.6.2.1 Input End Steering Shaft Mount

The input end steering shaft has its position set by the position and orientation of the steering wheel and quick release. The most obvious position for the mounting of this component is between the front roll hoop uprights. The mounting design must also allow the clutch cable to rotate within the mounting in conjunction with the steering shaft. This is due to an insufficient distance between the clutch lever and this mounting, to allow the cable to rotate separately to the steering shaft without the possibility of cable bind, caused by a tight radius cable bends.

The developed design for this mounting (shown in figure 5.15), featured an inner nylon bush fixed to the clutch mounting which rotated within two piece steel outer casing. The outer casing was then fixed to the chassis mounting which was a length of 25 x 25 square steel tube, running between the uprights of the front roll hoop. This design provided sufficient support for both linear and lateral loading while maintaining vertical stability of the steering shaft.

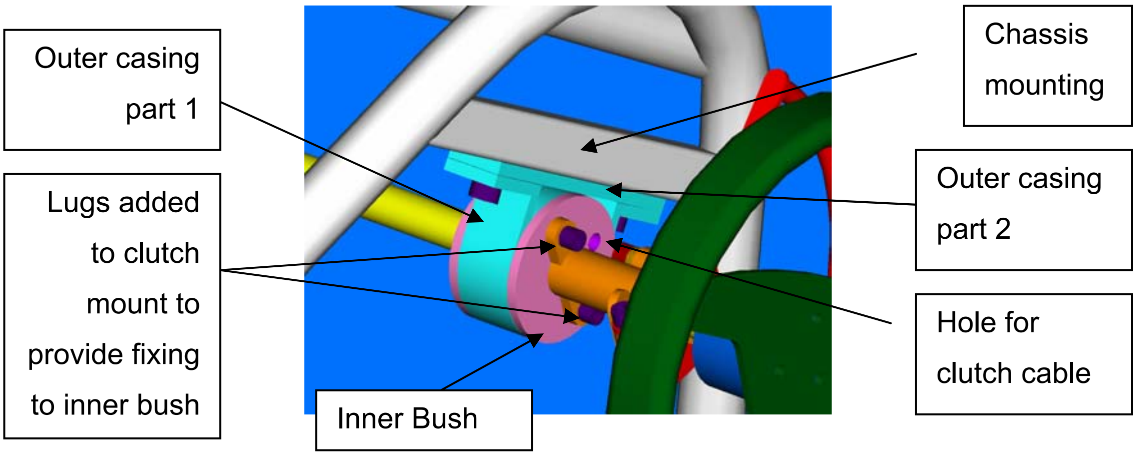

Figure 5.15- Input steering shaft mount modelled in Pro Engineer.

5.6.2.2 Third Steering Mount

The third mount is seen as a method of reducing torsional effects on the input shaft mount that is caused by lateral movement of the universal joint. This mount will be placed between steering rack and the universal joint so that it can also share linear loading with other mounts, while serving its main purpose of constraining the steering shaft laterally. It will utilise a nylon kart steering mount, which was chosen because they are readily available and can be purchased for around ten dollars. It was also designed to utilise readily available material from the USQ workshop. The mount to the chassis utilises 19mm tube bent to suit the profile of chassis tubes running forward from the front roll hoop, as shown in figure 5.16.

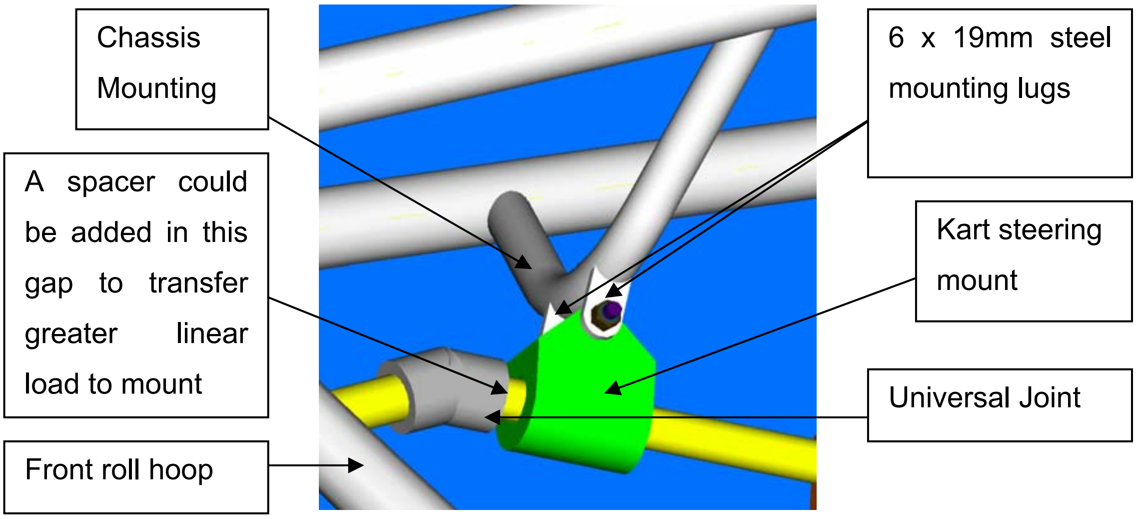

Figure 5.16 – Third Steering Mount modelled in Pro Engineer.

5.7 Gearbox Control

The final hand control required for the Formula SAE-A car is the gearbox control. The gearbox hand control must generate a turning effect on the gearbox selector, positioned on the left hand side of the motorcycle engine. This section of the report will investigate a design solution that allows the driver to change gears without impeding driving performance, including the position and method of gearbox control.

5.7.1 Gearbox Control Possible Solutions

The gearbox control must be positioned, such that the driver's concentration is not taken away from the driving task. This means that optimally it should be either mounted on or near the steering wheel; however each solution presents its own unique set of problems. Gearbox control can be feasible performed by three methods- push/pull cable, a series of linkages, or pneumatic system. Each method requires its own style of control mechanism, which will be discussed through out this section.

5.7.1.1 Mounting Gearbox Control on Steering Wheel

Mounting the gearbox control on the steering wheel creates a requirement that the system must be able to rotate with the steering wheel. This requirement means that a series of linkages would be to complex for this mounting position. A cable operated system would require an additional hole placed in the input steering shaft mount, which is already designed to allow cables to rotate in conjunction with the steering shaft to this point, reducing the radius of the bend required in associated cables. The cable would be connected to a paddle mounted behind the steering. Pulling the left hand paddle towards the steering wheel would change down gears and pulling the right hand paddle would change up as shown in figure 5.17. A pneumatic system would be the ultimate solution for this mounting position it could be operated by a pair of electric button type switches shown in figure 5.17 (left side for changing down gears and right side for up gears), operating solenoids to trigger movement of a two-way pneumatic ram. Air would be stored in a high pressure cylinder from a paint ball gun, running through a gas regulator to reduce it down to a usable system pressure. Using this method of gearbox control the position of the switch can be optimised with the driver's hands not leaving the steering wheel to change gears.

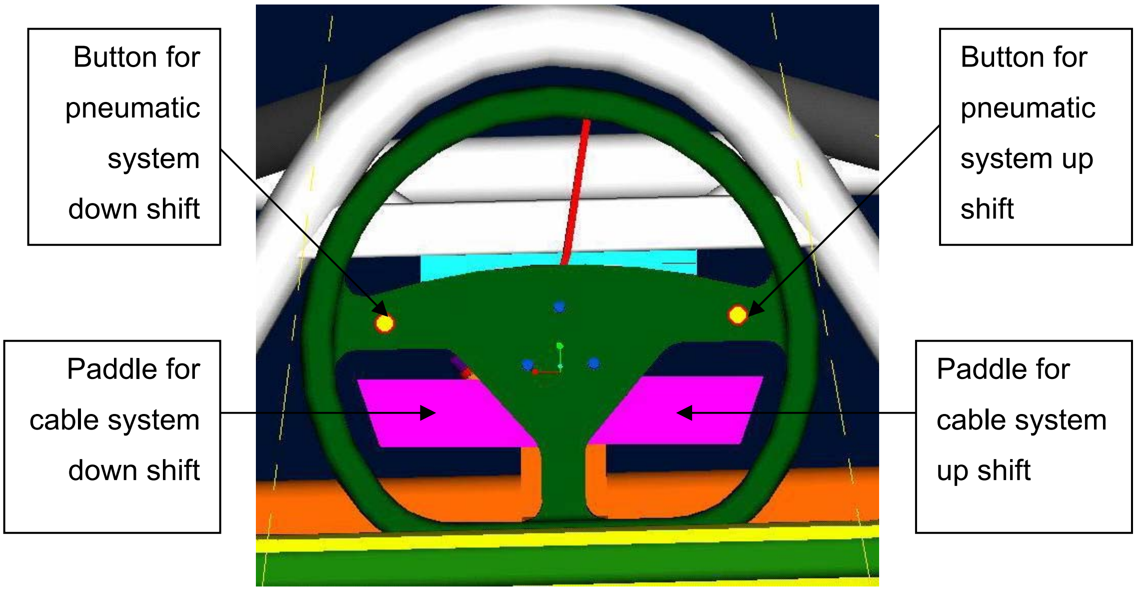

Figure 5.17 – Driver's view showing potential positions for both the cable and pneumatic gear control systems when mounted on steering wheel.

5.7.1.2 Mounting Gearbox Control near Steering Wheel

Mounting the gearbox control near the steering wheel, but not on the steering wheel is a more simple solution. It is easily performed by a chassis mounted lever bent to provide knee clearance when the driver is entering or exit the cockpit, shown in figure 5.18.

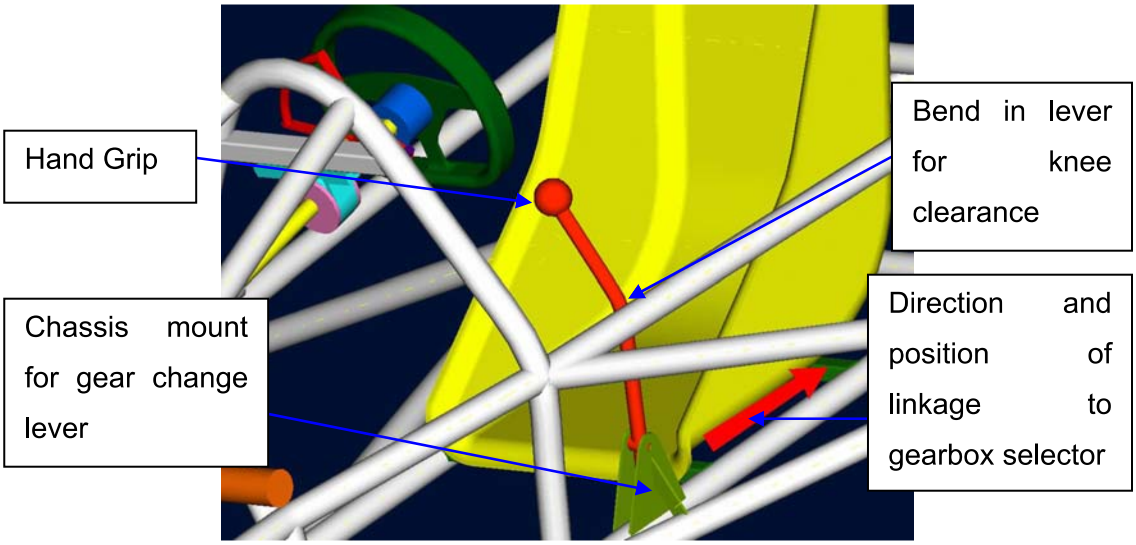

Figure 5.18 – Gearbox control lever mounted near steering wheel modelled in Pro Engineer.

The lever has to have some clearance between it and the steering wheel, so that the rotation of the steering wheel is not impeded. The gearbox control lever will be relatively long, when compared to the previously discussed paddle lever system; however a benefit of this will be the driver will have greater feel, of each gear change, with regards to gear meshing with the gearbox. This method of gearbox control will be most suited to a design incorporating a series of linkages because the bottom of the lever is close to the main chassis rails. This means that a linkage running backwards to the gearbox can run above the main chassis rails for easy mounting to a transfer linkage connected to the gearbox selector input.

5.7.2 Selection of Gearbox Control

The selected method of gearbox control for the USQ Formula SAE-A race car is a lever mounted near the steering wheel. This is because is represents the most cost effective solution, with a low possibility of system failure, and a reduction in manufacture and development time. If time permitted the optimal method of changing gear would be to develop a pneumatic system with electronic control, using gas solenoids, and a paint ball gun gas cylinder. This would allow for an optimal gearbox control position to be selected and may also decrease gear shift time, increasing the race cars performance capabilities.

5.8 Conclusion

Within this chapter of the report all hand controls for the USQ Formula SAE-A race car have been position and designed. All critical controls had an initial investigation into ergonomic issues surrounding the design, before the position and design was finalised. At this stage of the report, the seating position has been determined, which lead to the finalisation of hand controls for the formula SAE-A race car. The following chapter will investigate the design of foot controls for the race car, which will conclude the design element of this report.

Chapter 6

6 Foot Controls

Foot controls for the USQ Formula SAE-A race car were grouped within the cockpit layout section of this report (section 3.3). This chapter will investigate the design process followed for both the brake and accelerator foot pedals. Similar commercially available foot controls for motor sport use, retail for over $1000 which is outside the budget of this project. The design process for the foot controls will begin with an initial investigation into the ergonomics required for a foot pedal, followed by basic calculations to relate the transmission of force applied by the driver's legs to the brake master cylinders, followed by conceptualisation, before finalising the design analyses using both analytical and numerical techniques.

6.1 Positioning of Foot Controls

From basic trigonometry, the position of the foot pedals can be calculated by using the cosine function for triangles, shown in figure 6.1 and equation 6.1, while the angle between the lower leg and the floor of the race car can then be calculated by the sine rule, shown by Equation 6.2.

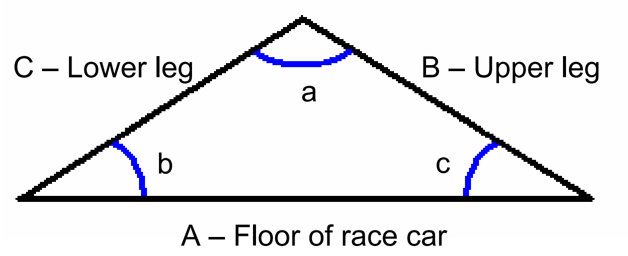

Figure 6.1 – Sketch of triangle used to find foot pedal placement

$$A^2 = B^2 + C^2 - 2 \times B \times C \cos(a)$$

Equation 6.1 - Cosine Rule

$$\frac{A}{\sin(a)} = \frac{B}{\sin(b)} = \frac{C}{\sin(c)}$$

Equation 6.2 - Sine Rule

Using the above equations it was found that the most ergonomic distance to mount the foot pedals was found to be 1060 mm from the seated driver's hip. At this distance, the angle of knee bend for team members ranged between 120° and 138°. This was considered acceptable as the maximum allowable knee bend for a race car driver, is 120° (gmecca.com, 2004). At this distance the angle between the lower leg of the driver and the floor of the car ranged from 21° to 31°, this value is important when designing the operation of foot pedals.

6.2 Foot Pedal Operation

The operation of a foot pedal is at the most ergonomically comfortable position when movement of the ankle is within 20° upwards and 30° downwards from neutral position of the ankle, which is when the base of the foot is perpendicular to the lower leg, as shown in figure 6.2.

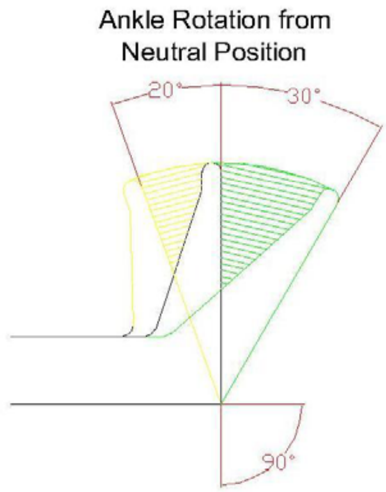

Figure 6.2 – Comfortable ankle motion from ankle neutral position.

However as all foot pedals found in the general automotive and motor sport industries, are operated by a pushing motion, generated by either ankle and/or leg motion, a pushing motion will be selected for this purpose to reduce driver confusion, by changing a process that is commonly used effectively, also using a pushing force will also slightly increase the force applied on brake pedal operation as the driver may will try to stop any force being applied on the torso by the seat harness under deceleration by applying a force on the foot pedals to push back into the seat. The design of the brake pedal will utilise the usable 30° of ankle motion downwards from the neutral position. To design a foot pedal that doesn't require adjustment to fit the different size drivers within the team, the 30° of angular ankle motion will be reduced to a maximum usable angular motion fitting all team members without adjustment. This is performed by subtracting the difference of the lower leg to floor angle of team members from 30°, resulting in a maximum angular motion fitting all team members of 20° downwards. The range of motion of 20° is considered sufficient to operate both foot pedals effectively.

The pedal contact surface area, to which the force is applied by the foot, is considered optimal for occasional use when it has a length and width of 80 x 90mm (Eastman Kodak, 1983), shown in Figure 6.3. Anthropometric data (Appendix C) states that a 95th percentile man's foot length is 285mm, which is set as the maximum height of the pedal pad; the data also gives the foot length of a 50 percentile man as 265mm. This data was used to correctly position the foot pedal contact surface height conforming to all team members. The required pedal contact surface conforming to the all driver's within this data range would result in the optimal pedal contact surface being extended to 100mm with the bottom edge of the foot pedal positioned at 185mm above heel resting position.

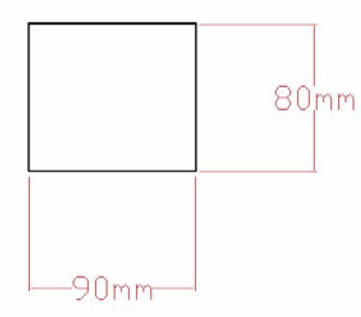

Figure 6.3 - Pedal Contact surface dimensions.

By designing a brake pedal incorporating the pedal range of motion and pedal contact surface area discussed with this section in conjunction with the positioning discussed in section 6.1, I believe all team members will be able to correctly operate foot pedals without prior adjustment.

6.3 Possible foot force applications for the Braking Pedal

The possible foot force applied to a foot pedal can be generated by using two different muscle functions, ankle generated force or a leg generated force. Ankle generated force gives the driver greater control over the applied force, and will be utilised for normal operation in the design of the brake pedal. The maximum force generated from ankle rotation is about 600N, however as the pedal angle will begin at about 65° and finish at 45°, the percentage of maximum force will vary over the pedal motion from 100% at beginning to 83% at after 20° of pedal motion (Kroemer, 1971). As this is a maximum value, the design of the brake pedal must take into account the muscle fatigue that would occur if this required for each brake pedal application. For this reason 100N will be used as the required foot force generated by ankle motion applied to the brake pedal for use in the Formula SAE-A race car. The design of the brake pedal must also take into account the possible affects of leg force being applied, under a driver panic situation. The maximum force possible when the entire leg is used is at least 2100N; however this requires the correct seating and pedal position. For the angle of knee bend and thigh angle that the driver will have when in the Formula SAE-A race car, the force from a brake application using the entire leg will approximately be 38% of the maximum possible (Kroemer, 1971). This results in the pedal being design to with stand infinite cyclic loading of 100N and whilst still being able to withstand a possible loading of 800N.

6.3.1 Brake Pedal Force Multiplication

Brake pedals are currently designed in many forms, but the one thing they all have in common, is a form of force multiplication to increase the relatively small force produced by the movement of the foot before the force is transferred to the brake master cylinder. Movement of the foot can be produced by contractions of lower leg muscle to create motion of the ankle or for greater forces from foot motion; upper and lower leg muscle contractions can be created. However for this requires the base of the ankle must be free to move with the lower leg. For only ankle motion the force can be considered as a moment created about the pivot between the ankle and lower leg, if upper leg and lower leg motion occurs the force will be considered as a force applied inline with motion of the foot at the padded section of the foot, just below where the toes join. For this to occur the heel must not be restricted, therefore no heel rests must be installed.

Methods of generating forces that are not feasibly possible by only foot force applied on a lever are called, ‘energy-assisted braking systems’. The most commonly used energy-assisted braking systems for applications in the automotive, are vacuum assisted braking systems. Vacuum assisted braking systems use a diaphragm between two air chambers. The foot pedal force acts on the diaphragm in an air chamber at atmospheric pressure. The other side of the diaphragm is connected to the master cylinder push rod. This side of the diaphragm has a vacuum acting within the air chamber which is generally produced by intake vacuum generated by the running internal combustion engine. However the force required to be transmitted has been approximated to 758N, which only requires a force multiplication between foot and master cylinder force of 1: 75.8. This can be achieved sufficiently by placing the master cylinder push rod close to the pivot of the pedal motion, and the foot pad at the end of the pedal lever.

6.4 Conceptualisation - Pedal type

There are two main types of pedals commonly used in motor sport applications and their names directly relate to their method of mounting.

Bottom mounted or floor hinged, pedals are the most common as they have all parts mounted low in the vehicle, which keeps the centre of gravity low. A negative aspect of a bottom mounted pedal is that heel movement is restricted in forward motion by the pedal base, resulting in mostly ankle rotation providing the force. One method to include some upper leg muscle force is to make the contact foot pad on the pedal more upright so the heel is further away from the pedal base at the beginning of a braking application.

Top mounted pedals are commonly used in some forms of motor sport, usually in sedan racing. The advantage of this mounting system is that the heel is not restricted in motion so that maximum pedal pressure is achieved when both upper and lower leg muscles are contracted. The major disadvantage of this system is that all the weight is mounted high in the cockpit which will raise the centre of gravity of the car. Also a top mounted pedal set mounted in a Formula SAE-A car may cause difficulties as the master cylinders would be mounted in the traditional area for a push rod suspension system, which has been specified for use in the completed race car.

6.5 Conceptualisation - Master Cylinder Placement and Braking Bias Adjustment

This section of the report will conceptualise the positioning of the master cylinders and method braking bias adjustment, as defined within the cockpit layout (section 3.2). Five possible solutions will be analysed showing both positive and negative aspects, before the optimal solution is selected

6.5.1 Possible Solution 1

Possible solution 1 (figure 6.4) shows a brake pedal that has the foot force transferred to a short rod, which is then connected to the bias bar, which transfers the force to both master cylinders. Braking force bias would be adjusted by sliding the master cylinders across to change the distance between the rod and each master cylinder.

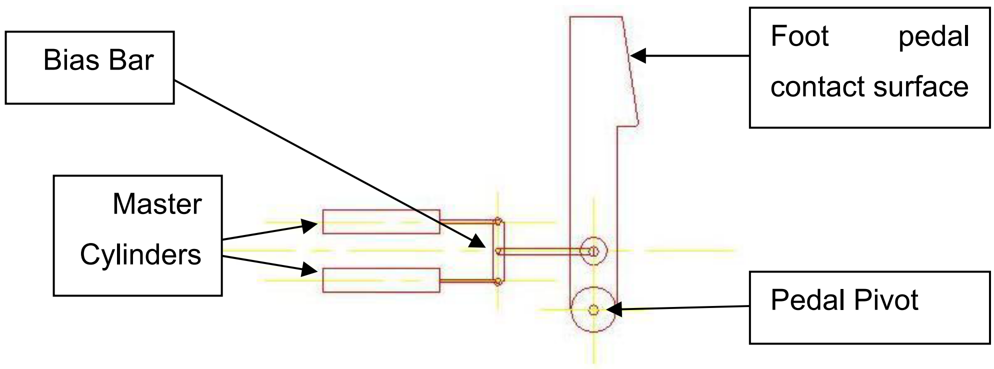

Figure 6.4 – Possible Solution 1 conceptualisation

6.5.1.1 Positives

- Good pedal feel for driver as deflection within system is low.

- Movement of the master cylinders to adjust braking bias means that no moment is created within the pedal, therefore only has to be designed for linear forces.

6.5.1.2 Negatives

- The length of device may cause the driver to become restricted in the cockpit.
- Movement of the master cylinders would also move the brake fluid lines which would cause fatigue of these lines, causing failure.
- The additional material required for a sliding attachment to mount the master cylinders would result in a much heavier pedal mounting system..
- Rod transferring force from pedal to bias bar must remain short as if it greatly affects the rod diameter which is required to prevent buckling under load.

6.5.2 Possible Solution 2

Possible solution 2 (figure 6.5) is similar to possible solution 1, however now the rod transferring force to the bias bar is in tension. Bias adjustment is performed by moving the position of the transfer rod along the bias bar by screwing it along a threaded section on the bias bar with pin joints included to allow for this movement.

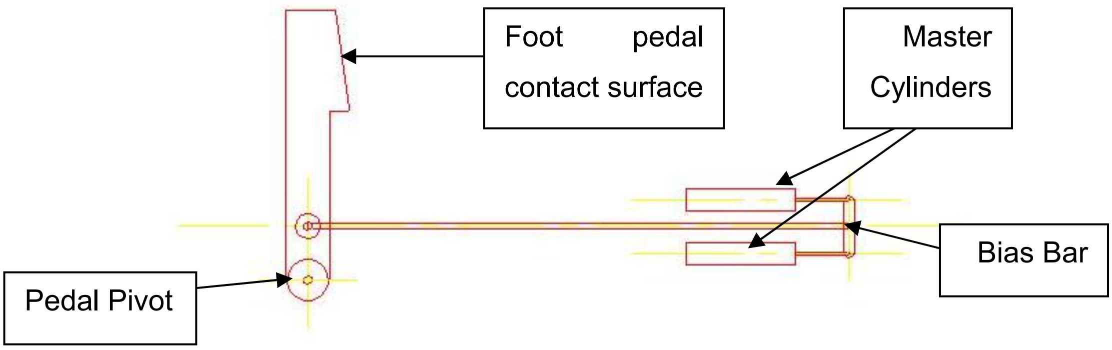

Figure 6.5 – Possible solution 2 conceptualisation

6.5.2.1 Advantages

- Same as possible solution 1.

- Master cylinders can be placed near driver entry point so that easy access to master cylinder reservoirs is achieved for maintenance.

- Transferring rod has less limitations on its length as in tension extra diameter to overcome buckling is not required.

6.5.2.2 Disadvantages

- Restrictions to heel placement as transferring rod passes through optimal heel position.

- Added weight of longer transferring rod.

6.5.3 Possible Solution 3

Possible solution 3 uses a cable to transfer the pedal force to the master cylinders. As a multi-strand cable can only transmit force in tension, the pedal pivot has been above the cable fixing point, as shown in figure 6.6.

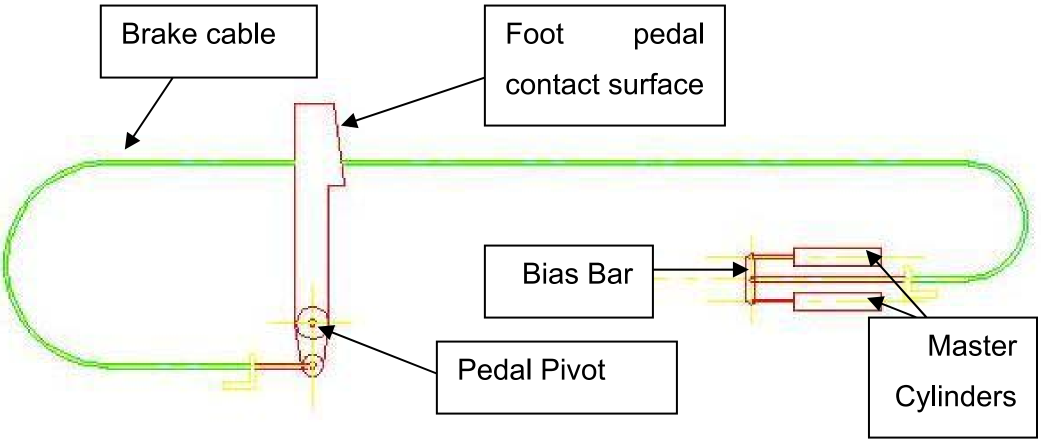

Figure 6.6 – Possible solution 3 conceptualisation

6.5.3.1 Advantages

- Master cylinders can be placed at almost any point within the cockpit for ease of maintenance.

6.5.3.2 Disadvantages

- Loss of pedal ‘feel’ as multi-strand cable requires pedal movement before cable takes up tension.

- Care must be taken that the minimum bend radius of the cable is adhered too, to prevent cable bind in outer casing, and increased cable fatigue.

- Reliability of multi-strand cable is less than that of a solid rod.

6.5.4 Possible Solution 4

Possible solution 4 (figure 6.7) has the bias bar running through the pedal between the two master cylinder push rods. Braking force bias is changed by moving the pedal along the bias bar. Pedal force is transferred to the bias bar via a spherical plain bearing, which is fixed inside the pedal.

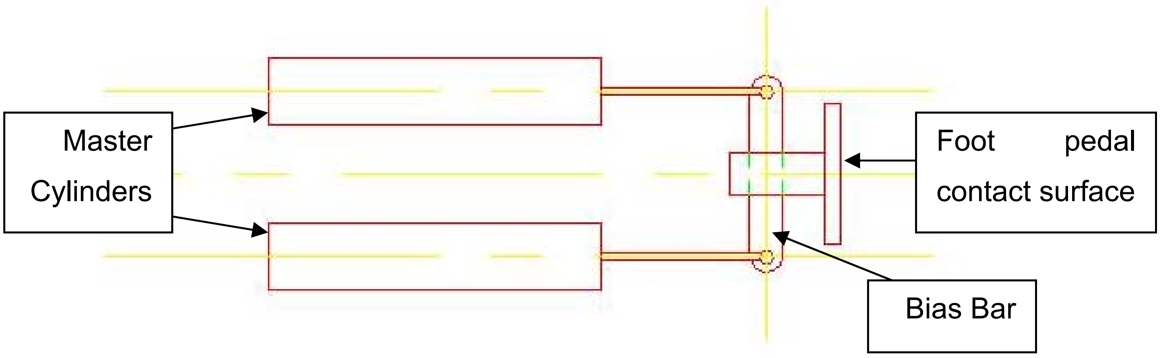

Figure 6.7 - Top view of possible solution 4

6.5.4.1 Advantages

- Good pedal feel as deflection is low.

- Shorter assembly length than possible solution 1.

6.5.4.2 Disadvantages

- The moving pedal may cause improper placement of foot resulting in ineffective braking application or driver hesitation.

6.5.5 Possible Solution 5

Possible solution 5 has the bias bar running through the pedal with two male right hand threaded ends, as shown in figure 6.8. The force is transferred from the pedal to the bias bar via a nylon bush and spherical plain bearing which is fixed to the bias bar, and slides within the pedal. The bias bar is connected to each master cylinder by a female right hand threaded attachment.

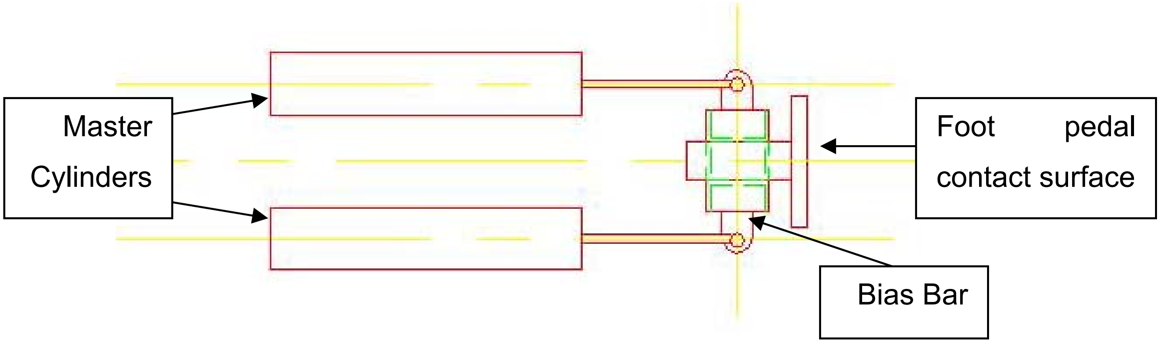

Figure 6.8 – Top view of possible solution 5

6.5.5.1 Advantages

- Good pedal feel as system deflection is low.
- Length of pedal assembly is shorter than possible solution 1.

6.5.5.2 Disadvantages

- Pedal must be designed to withstand a torsion created by non-centralised loading.

6.6 Solution

For the application of a Formula SAE racing car, the best solution is to have a bottom mounted pedal system, because the weight is distributed below the centre of gravity of the car. Also there is currently nothing occupying the space on the floor at the front of the cockpit. Braking force bias will be performed by the method described in possible solution 5. The only negative to this solution is that the pedal is subjected to torsional loading as well as bending. The torsional loading will be minimal however, when compared to the bending forces applied to the pedal.

6.7 Material Considerations

The two materials that the USQ workshop have access to are steel and aluminium. This is because these two materials are used extensively in general fabrication as they both have a reasonably low cost and good workability. Stress in a brake pedal is such that most of the material undergoes little or no stress. Excess material is brake pedal design is used to slow the pedal's modal frequencies to prevent resonance with vibrations caused by the running of the vehicle.

Steel would be a suitable material to manufacture a brake pedal, as it has good strength and good fatigue properties; however for application in the Formula SAE-A race car, weight considerations make is undesirable for use, as a lower strength light weight material would be sufficient.

Aluminium has a lower strength than steel; however it still has good properties for implementation in a brake pedal. The major benefit of aluminium over steel is the reduced weight as it is aluminium has a density of 2.8 Mg/m^3, compared to steel with a density of 7.7 Mg/m^3, making aluminium 64% lighter than steel (Askeland, 2001).

For the design of the brake pedal for use in the Formula SAE-A race car, I selected 6061-T6 aluminium, to create a low weight product and it has the following properties shown in table 6.1. The endurance limit will be used in the analysis of the aluminium brake pedal as a fatigue failure could possible occur in this part. The part will be design for infinite life, and the Fatigue strength for this situation was calculated using equation 6.3 (Juvinall & Marshek, 2000) to find a value of 88 MPa. Also included into the design of this part is a factor of safety of 4, which will be used for the design of key braking parts.

$$
\begin{aligned}
S_n &= S'_n C_L C_G C_S \\
&\quad \text{For Aluminium} \\
S_n &= 110 \text{ x } 1 \text{ x } 1 \text{ x } 0.8 \\
&= 88 \text{ MPa}
\end{aligned}
$$

Equation 6.3 - Fatigue Strength

The material selected for the bias bar is a high carbon steel 4340 (properties shown in table 6.1), as it is considered a high stress area and failure of this part would result in a total system failure.

Material	Aluminium - 6061 – T6	High Carbon Steel - 4340
Yield Stress (σ_{yield})	275 MPa	1020 MPa
Stress for Infinite Life (S'_n)	110 MPa	510 MPa
Young's Modulus (E)	27 GPa	207 GPa
Poisson's Ratio (v)	0.32	0.30
Density (ρ)	2.8 Mg/m^3	7.7
Fatigue Stress (S_n)	88 MPa	408MPa

Table 6.1– Material Properties for materials to be used in brake pedal design (Juvinall & Marshek, 2000).

6.8 Brake Pedal Design Calculations

To correctly design a brake pedal, the basic moment calculations are used to determine the increase in the force applied by driver's foot to a magnitude required for effective brake system efficiency. The specifications given by the brake system designer, approximated that a total force of 758 N would sufficiently operate the car's brake system. This force will be achieved through mechanical advantage, placing the point to which the total force is applied (point B) closer to the pedal pivot (A), than the mean distance of the foot pad (point C). It was established previously in section6.3 that the force applied to the brake pedal by motion of the ankle will be 100 N. To calculate the required distance from the pedal pivot to achieve the required total force, the moment is taken about point A see figure 6.9 and equation 6.4. The pedal pivot will be set as 15mm above the floor, to allow for mounting, so the mean distance of the foot pad will be 220mm above the pivot.

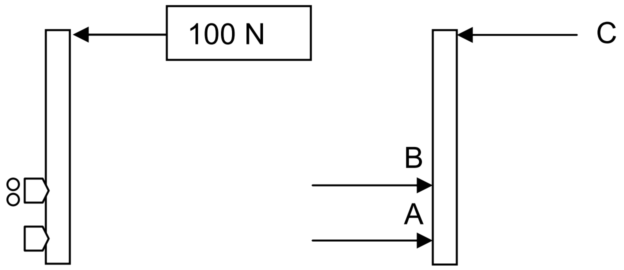

Figure 6.9 – Free body diagram of brake pedal forces.

Taking the Moment about A +ve

$$\sum M_A = 0 \quad \text{(In equilibrium)}$$
$$\sum M_A = R_B \text{ x } d_B - R_C \text{ x } d_C$$
$$0 = 758 \text{ x } d_B - 100 \text{ x } 220$$
$$d_B = \frac{100 \text{ x } 220}{758}$$
$$d_B = 28 \text{ mm}$$

Equation 6.4 – Moment calculation to find the required height of the pedal pivot.

The total force is to be distributed to each brake master cylinder to result in a braking force bias of 70% front and 30% rear. The braking force bias requires a greater percentage of the total force transmitted to the front, because a moment is created about centre of mass under deceleration resulting in a greater normal force being applied at the front wheels than the rear. This allows more braking force to be applied to the front wheels before slip between the road surface and the tyre occurs. The brake system implemented on the car is such that the total force cannot be simply split 70 % to the front and 30% to the rear, because of different disc braking methods used on the front and back wheels. The brake system designer calculated that the required split of the total force would be 471 N to the front master cylinder and 287 N to the rear. The master cylinders selected by the brake system designer require spacing between the centrelines of the master cylinder bore, which is the line of action that the force is applied to the master cylinder, this spacing allows the approximately 10 mm of free space between each of the master cylinders to ease future servicing of the part. So with a length and the two forces applied to each end the moment is taken about one end to find the positioning of the point to which the force is applied to the linkage, see figure 6.10 and equation 6.5.

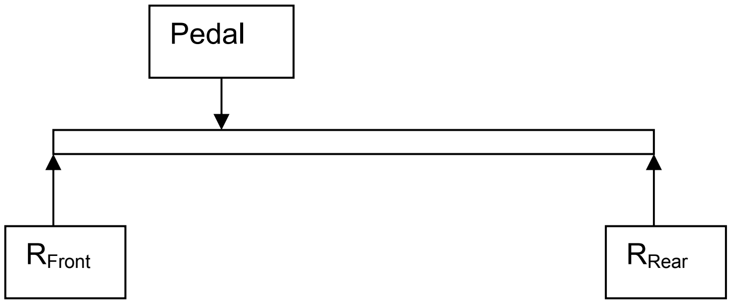

Figure 6.10 – Moment diagram for equation 6.5.

$$\sum M_{R_{Front}} = 0$$
$$\sum M_{R_{Front}} = F_{Pedal} \text{ x } d_{front\ to\ Pedal} - R_{Rear} \text{ x } d_{front\ to\ rear}$$
$$0 = 758 \text{ x } d_{front\ to\ pedal} - 287 \text{ x } 60$$
$$d_{front\ to\ pedal} = \frac{287 \text{ x } 60}{758}$$
$$d_{front\ to\ pedal} = 23mm$$

Equation 6.5 – Calculating the from front master cylinder push rod to pedal force application point.

It is also expected that is brake bias percentage may have to be changed during the testing stage so therefore adjustment will be made to the to the position of the pedal force point on this linkage to accommodate these possible changes. If possible a change of 10% in the braking force bias each way would be desirable. To achieve a brake force bias of 80% front and 20% rear, the distance from the front pivot to the pedal force point is approximately 15mm and to achieve a bias of 60% front and 40% rear this distance would be 29mm.

Also the change in height as the point transmitting the pedal force has to be calculated so that it is known whether it is acceptable of further linkages will have to be introduced to reduce the change in height entering the master cylinders. To minimise the change in height the usable range of 20° change in pedal angle is halved by the vertical plane going though the pedal pivot. The change in height is then calculated by equation 6.6, giving a value of 0.35mm which is considered allowable as the master cylinders have the push rod acting on a sightly dished surface on the piston.

$$\Delta h = d_{\text{pedal pivot to point}} - \cos(10) \times d_{\text{pedal pivot to point}}$$

Equation 6.6 – Finding the change in height over the range of motion for the bias bar location point.

To calculate the bias bar required diameter, the maximum stress was calculated by rearranging equation 6.7 (Juvinall & Marshek, 2000) to find d, using a maximum moment (M) created between the front master cylinder push rod to pedal pivot, and the stress max of 102 MPa (fatigue stress / factor of safety).

$$\sigma_{max} = 32M / \pi d^3$$

Equation 6.7 – Maximum stress in a cylindrical rod in bending.

The diameter required was found to be 10.08mm, but to allow for a greater factor of safety at the central high stress region this diameter will increased to 12mm. For ease a 12mm high tensile bolt will be used as the bias bar, with spacing either side to adjust brake force bias. This is not seen as the ultimate way to adjust braking bias as it can't be done whilst the car is in motion; however it will reduce manufacturing time considerably.

With the bias bar now confirmed, a spherical plain bearing can now be specified, and after a visiting a local bearing store suitable bearing was found. This bearing had an outside diameter of 22mm, which will have to be fitted into the pedal at the pedal pivot height.

With all the basic design calculations a simple pedal was modelled in Pro Engineer, and a finite element analysis could then be undertaken on the part.

6.9 Finite Element Analysis of Brake Pedal

An initial model of the braking pedal was created using Pro-Engineer software to create a piece of flat plate with corresponding holes and foot pad angles as previously determined. The model was considerably de-featured, with only critical elements of the component remaining.

The model was constrained in all degrees of freedom on the bottom mounting hole, and the pedal pivot hole was constrained in x-direction to simulate the reactive force applied at this point by brake master cylinders. Force was applied to the model by converting it to a pressure applied to the front face of the pedal where the pedal foot pad would usually be placed. The Pressure was determined by dividing the 100N application force by the area of the surface on which the pressure was placed, see figure 6.11.

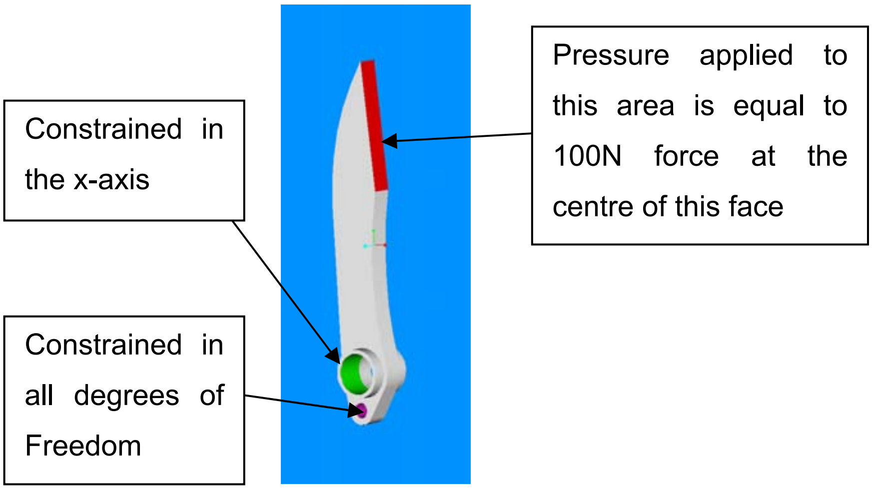

Figure 6.11 – Constraints applied to model in finite element software

This initial model found that most of the plate was under little or no stress, especially in the central region above the bias bar sleeve as shown in figure 6.12. This was expected as it complies with the stress distribution for beams in bending, which states that the outer most fibres from the neutral axis of a material will under goes the maximum stress when placed in bending.

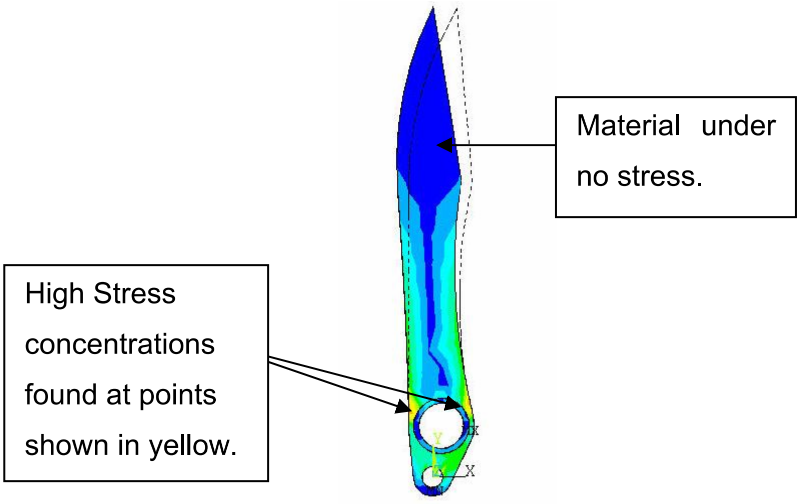

Figure 6.12 – Initial brake pedal design after finite element analysis (Full ANSYS printout found in appendix E).

The next model included a milled section from the plate in the central low stress area. The result was an I-beam cross section with only the outer 4mm of material on each side left at the original height, and the resulting thickness at the middle was 3mm (see figure 6.13). The milled section also stopped 10mm before the edge of the bias bar sleeve to prevent stress concentrations in this area. The benefit of this modification is the associated weight reduction with the removal of materials in areas of low stress.

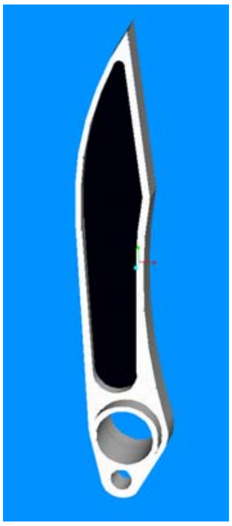

Figure 6.13 – Redesigned brake pedal upright, with black section indicating milled area, modelled in Pro Engineer.

The modified part was then constrained using the same method and analysed. The result was a considerably more even stress distribution, shown in figure 6.14.

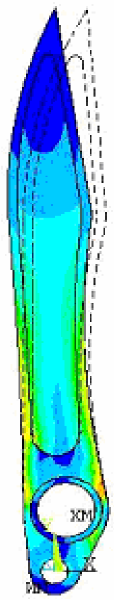

Figure 6.14 – Redesigned brake pedal after FEA, showing a more even stress distribution (full ANSYS printout found in Appendix F).

6.10 Accelerator Pedal Design

The accelerator pedal design is not as critical as the brake pedal, as it is not a safety concern. It will utilise the previously discussed ergonomic considerations relating to pedal angular displacement and foot contact height. The purpose of the accelerator pedal is to open the throttle of the engine's carburettor. This requires a minimal pedal force as the only resistance is supplied by the throttle return spring, which closes the throttle when no pedal force is supplied. The accelerator pedal must also have positive stops so that excessive pedal force doesn't cause the throttle valve to over rotate, which is when the throttle valve begins to close again. To effectively perform this operation these positive stops will be incorporated into the pedal mounting design, and is discussed in the following section.

Due to the time constraints of this project there will be no stress analysis performed on this component as it is not seen as necessary. The best way seen to design the accelerator pedal is to utilise a piece of 16mm steel tube, bent to form the accelerator pedal as shown in figure 6.15. The pedal pivot is a piece of 16mm steel bar with a 8mm hole drilled through, this is seen as sufficient as this joint will be rotating at a low velocity. The pedal has a slight bend in the upright section to stop the driver's foot siding off the pedal when cornering. Mounting of the throttle cable to the pedal will be by threading the cable, though a wire loop brazed onto the pedal upright. The throttle cable will be clamped together to create a loop fixing it to this point. This will allow for simple adjustment of this pedal.

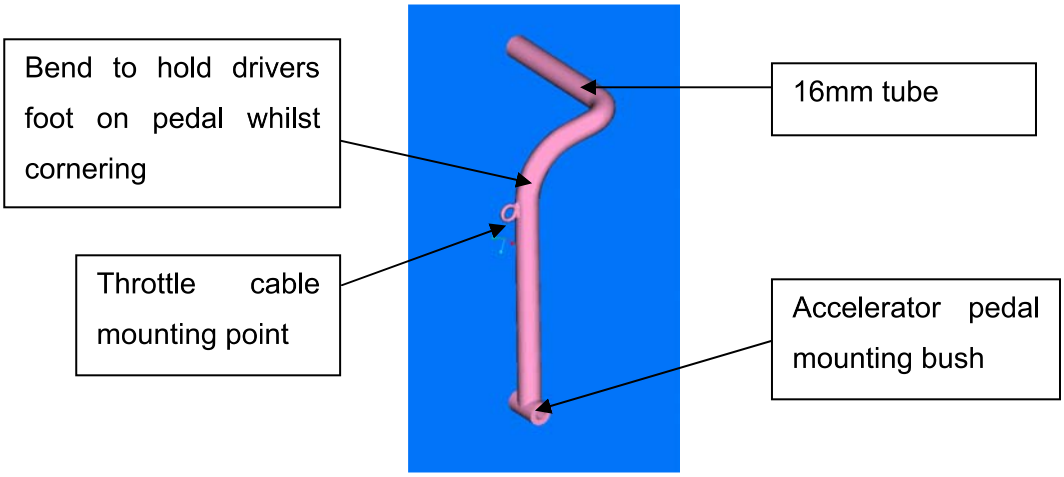

Figure 6.15 – Throttle pedal modelled in Pro Engineer.

6.11 Mounting

The pedal mounting will be designed as one unit, incorporating both the brake and accelerator pedal. This is a precautionary step that has been taken to reduce the effects of a situation where the pedals have to be moved to suit a certain driver. In this case both pedals would move by simply repositioning this single mounting. The pedal mounting must be able to with stand the large forces placed on the brake pedal while minimising weight, and also by not over engineering the accelerator pedal mounting to withstand the same large forces. It must incorporate positive stops for both off and full accelerator pedal positions, as previously discussed. With the criteria of the foot pedal mounting set the design of this component will now be discussed.

The mounting for the foot pedals will utilise common materials sourced from the USQ workshop, and will be manufactured primarily using 25 x 25 mm steel square tube. The points to which the mounting is fixed to the chassis will be placed on the left and centre of cockpit to produce an even sharing of high brake pedal forces. Areas of high stress around the brake pedal are appropriately braced to reduce loaded deflection, see figure 6.16. Positive stops on the accelerator pedal travel are created by 4mm steel plate bent and welded as shown below. Adjustment of the accelerator pedal is performed simply by two 6mm bolts fitted with locking nuts and threaded though the 4mm plate limiting the backwards and forwards travel of the pedal. This design also allows for scope to develop a quick adjustment system for both foot pedals, with the addition of sliding lock mechanisms between this mount and mounting to the chassis. Sliding lock mechanisms could be taken from the base of a seat frame from a standard passenger vehicle, as these would satisfy the above function.

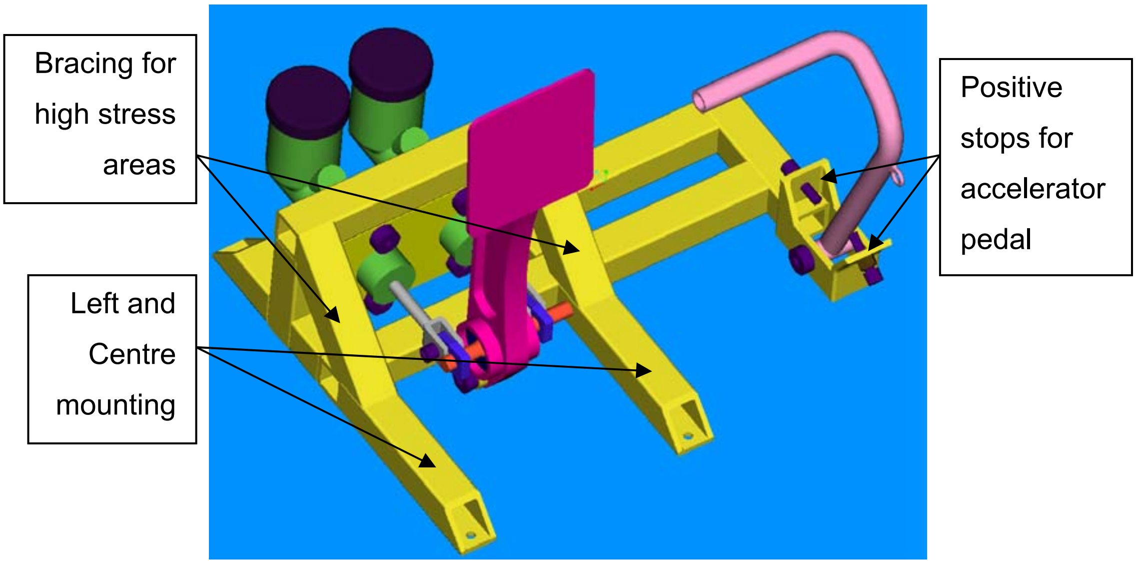

Figure 6.16 - Foot Pedal Mount modelled in Pro Engineer.

The foot pedal mounting would be fixed by four M8 bolts to the chassis. Two pieces of 30 x 30 mm angle steel, running parallel to the car's centerline at the front of the cockpit are to be welded at a spacing to suit the foot pedal mounting. A piece of 3mm aluminum plate would be added between the chassis and foot pedal mountings, to provide a safe platform for the drivers feet to rest on as shown in figure 6.17.

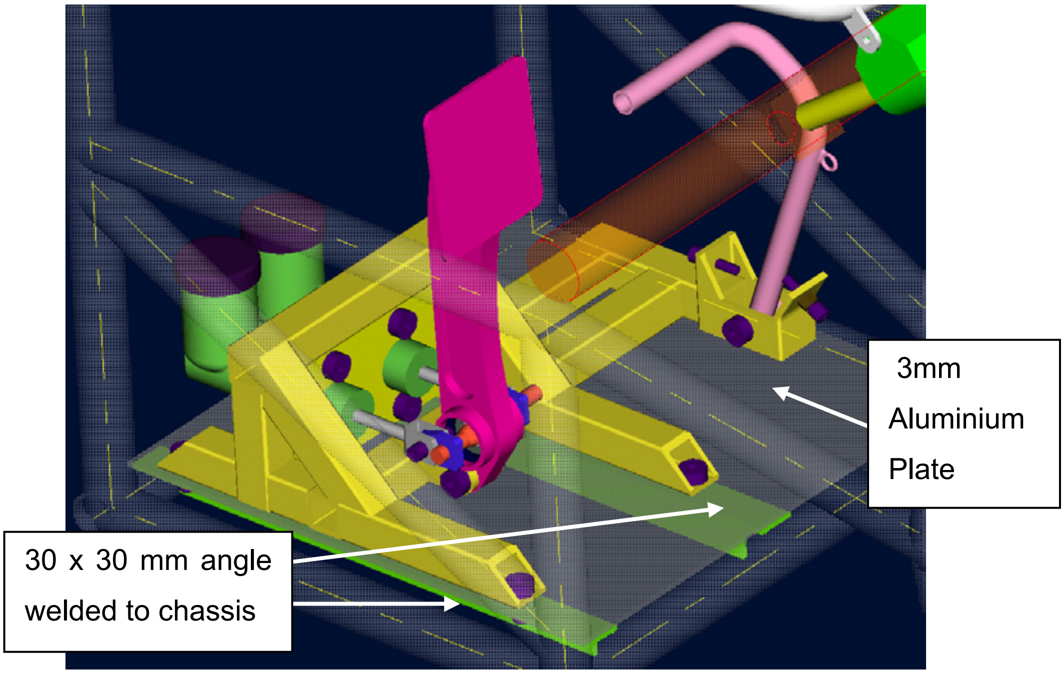

Figure 6.17 – Foot Pedal Mount, fitted Car modelled in Pro Engineer.

6.12 Conclusion

Within this section of the report the ergonomic consideration where first analysed, and foot pedal position determined. A detailed design investigation was conducted into the design of the brake pedal, as this is a major safety concern. The accelerator pedal was then designed followed by the foot pedal mounting method. This concludes the design element of this report, as all hand and foot driver controls are now complete. The following chapters will discuss the safety features of the formula SAE-A race car and driver safety equipment, before an investigation into instrumentation for possible implementation in the USQ Formula SAE-A race car.

Chapter 7

7 Safety Issues

There are many safety issues associated with motor sports and Formula SAE-A racing is no exception. Within this section of the report the safety issues relating to the design of the Formula SAE-A race car will be discussed. This section of the design is the most strictly governed by the rules, and most of the systems discussed will have to be designed once other team members design projects are finalised to ensure the completed Formula SAE-A car complies with the rules. Within this section safety issues will be broken into four separate parts which will cover driver restraint, driver safety equipment, fire protection and car safety systems.

7.1 Driver Restraint

The driver restraint is the one of the most important safety devices employed in the Formula SAE-A race car. It restrains the driver within the race car, so that the driver feels secure when the car is under normal operation, and in a crash or rollover situation the driver is restrained in such a way that no part of the driver's torso can come into contact with objects, that could cause driver injury. If the driver was not sufficiently restrained in a roll over situation the car could land on top of the driver which would result in serious injury if not a fatality. Driver restraint systems come in many different forms, with Formula SAE-A rules requiring a 5 or 6-point harness arrangement. Both these systems are considerably safer than the lap/sash arrangement commonly used in passenger vehicles. Harness adjustment is performed by steel buckles.

Driver restraint harnesses are designed to absorb energy to reduce the amount of energy absorbed by the driver's body. This means that harness belts must be high in strength while still allowing for some elongation. Simpson safety products in the USA state that their harness belt webbing is designed for a balance of high strength and an elongation of less than 9% with a non-abraded sample. This results in their harness belts elongating between 9 and 13% when loaded at 2,500lbs, which equates to approximately 11kN of loading. A higher the priced harness from Simpson has less elongation at this loading. Simpson are also in the selected category of safety harnesses that are approved by NASCAR, which because of the high speeds developed on oval racetracks has set a standard that the entire safety harness including both buckles and belt, must have a breaking load of greater than 15,000lbs (Simpsonraceproducts.com, 2004).

Formula SAE-A rules are less stringent than NASCAR, however the same principles still apply. A belt which complies with the Formula SAE-A rules must comply with SFI specification 16.1 or FIA specification 8853/98. Belts must also be less than 5 years old, with the rules recommending driver restraint systems be replaced every 3 years.

Belts complying with the above specification are to have an elongation of between 5 and 20% when loaded with a 2500 lbs load. They also must have a single point release for lap and shoulder harness, with a metal to metal type quick release system. Harness price determines whether it is made from either Nylon which is the cheaper option or Dacron polyester which at a higher cost offers greater strength when wet, and is acid and UV resistance (Simpsonraceproducts.com, 2004).

The following section will discuss the criteria set out by the Formula SAE-A rules including possible mounting positions of harness. Initially the shoulder belts, lap, and anti-submarine belts will be discussed, before the single point release concludes this section.

7.1.1 Shoulder Belts

The purpose of shoulder belts is to hold the driver into the back rest of the seat. Shoulder belts which comply with the Formula SAE-A rules must be 76mm wide. This distributes the loading of belts onto the torso more evenly to prevent bruising of the driver under high load situations. Shoulder straps must be firm and well fitted at all times so that the harness is slightly pretensioned before any additional loading occurs, which stops the driver's torso accelerating into the harness in a crash situation.

Shoulder harnesses are mounted behind the driver and pass over each of the driver's shoulders and down the front of the torso to just below the belly button. Formula SAE-A rules state that each shoulder straps mounting point must not be lower than a 40º line drawn from the drivers shoulders off the horizontal as shown in figure 7.1.

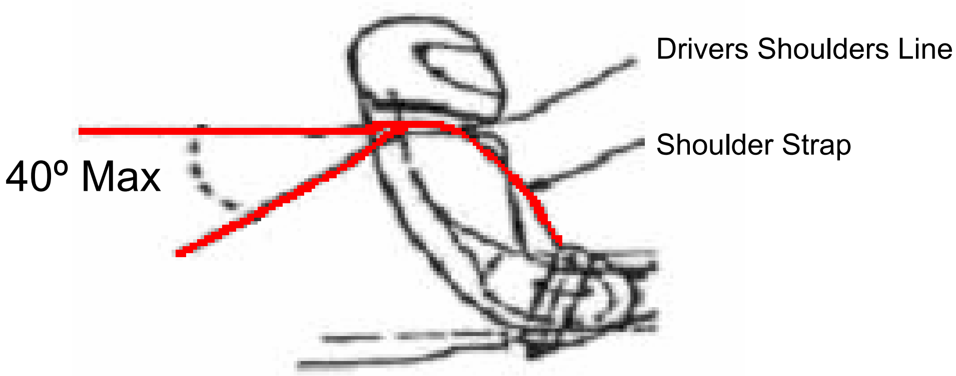

Figure 7.1 – Side View of shoulder harness mounting criteria (SAE, 2004).

The angle between the horizontal and the shoulder belt behind the driver is important, because if this angle is too great a large compression force can be placed on the spine under high decelerations. Both shoulder belts should be mounted with a spacing when view from the top, to adequately clear the sides of the driver's neck.

The shoulder belts for use in the Formula SAE-A car could be mounted with the addition of a 32mm tube between the main roll hoop and the main roll hoop rearward braces as shown in figure 7.2.

Due to time constraints on this project an optimal solution for this mounting could not be obtained, for application in the 2004 USQ Formula SAE-A race car, the mounting will be determined on a trial basis, once the chassis, engine and seating is built. After this time the shoulder harness mounting position will be more accurately determined.

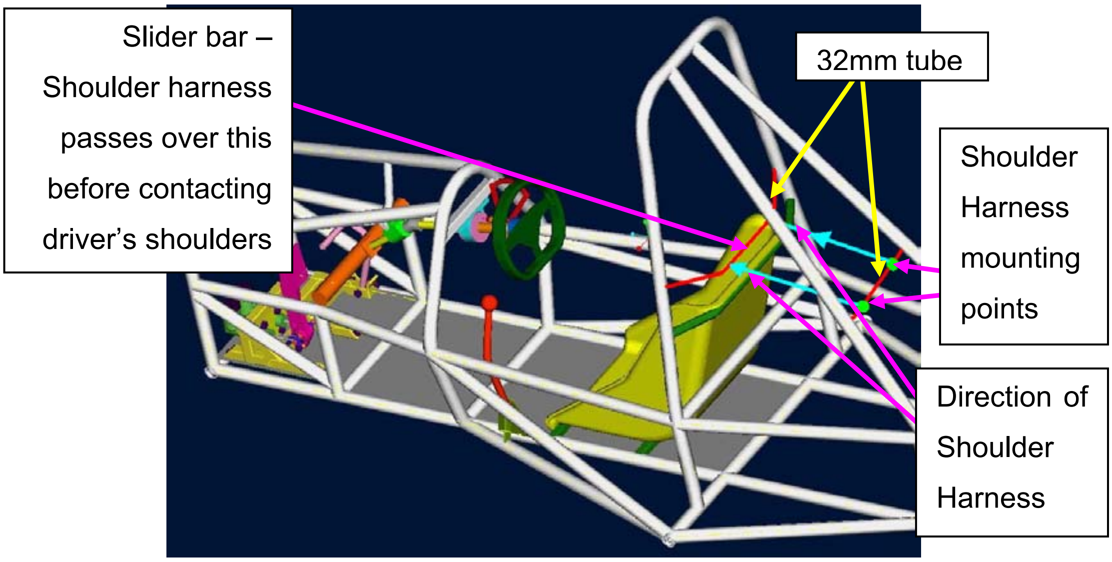

Figure 7.2 – Possible mounting technique for shoulder harness belts

7.1.2 Lap Belt

The lap belt of the harness is formed from two separate lengths, joined in the centre of the driver's body by the harness single point quick release. The lap belt must pass around the pelvic area below the hip bones, as the purpose of the lap belt is to hold the driver down into the seat. Under no condition is the lap belt allowed to pass over the abdomen or intestinal region of the driver. This criteria set by the rules because of the crucial bodily organs in this region, which is performed just below the hip bones. The belt should be mounted to the such that is 76mm forward from the seat back to bottom junction, so that also holds the driver into the back support of the seat. In order to fit these criteria a hole must be cut into the side of the driver's seat, to fit the lap belts comfortably through. The hole must also be fitted with a grommet so that the lap belt is not rubbing against the fibre-glass seat causing abrasion to the lap belt material.

The best way I can see to mount the lap belt is to utilise the seat mountings designed in chapter 4 of this report, with the addition of mounting lugs as shown in figure 7.3.

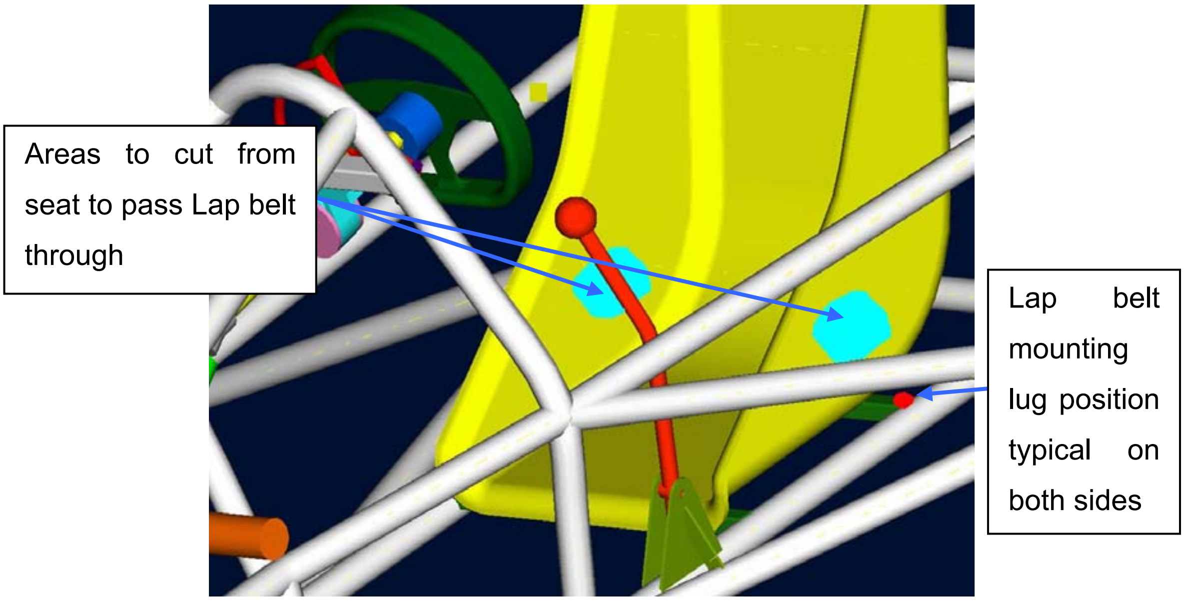

Figure 7.3 – Conceptualisation of lap belt mounting position and cut-outs in the seat.

7.1.3 Anti-submarine Belts

Anti-submarine belts restrain the driver's torso sliding forward underneath the lap belt. The method of anti-submarine belting is where the difference lies between a 5 and 6-point harness. A 5 point harness has one strap 51mm wide belt passing between the drivers legs and fixed between the harness quick release point and a mounting on the chassis, as shown in figure 7.4.

Figure 7.4 – Crow 5-point harness (UP Racing.com, 2004)

A 5-point harness is a cheaper alternative when compared to a 6-point harness; however the downside is that under rapid deceleration, all loading on the anti-submarine belt is transmitted to the groin of the driver, which is uncomfortable. For this reason racing cars fitted with a 5-point, are fitted with seats that have good anti-submarine qualities. The easiest method of performing this is by having adequate upper leg support which the USQ Formula SAE-A race car will have when the foam wedge is added to the front of the driver's seat as discussed in chapter 4.

A 6-point harness has two anti-submarine belts passing through the drivers legs, both 51mm wide as shown in figure 7.5.

Figure 7.5 – Sparco 6-point harness (UPRacing.com, 2004)

The most common mounting point for these belts is at the same point as the lap belt, which creates a loop around the leg, pulling the base of the torso into the bottom of the seat.

7.2 Driver Safety Equipment

With the driver securely restrained into the Formula SAE-A race car, the driver must be protected from impacts and fire. Driver safety equipment worn by the driver is designed for specific applications; exposed areas of the body such as the head must be protected from impacts, while other body parts must be protected from fire and abrasions. Within this section of the report the required driver safety equipment for the Formula SAE-A competition will be discussed which includes the safety helmet, driving suit, gloves, shoes, and arm restraints.

7.2.1 Safety Helmet

The Formula SAE-A rules state that helmets used must be closed faced and be approved with a Snell rating 95 or later. Snell memorial Foundation is a nonprofit organisation established in 1957, to promote research, education, testing and development of standard geared to improve the effectiveness of automotive racing helmets. Every five years it produces a new set of criteria five years for helmet designers to meet before receiving the Snell rating, their website 'www.smf.org' is a great source of information for details of the strict testing criteria set out for helmet designers to follow.

The purpose of a driver's safety helmet is to cushion the head against impact, thus reducing the chance of head injury. The head region is a fragile part of the human body; head impacts can cause brain damage, which is a major safety concern in the design of helmets. Brain damage occurs when; the brain accelerates at a different rate to the scull. This results in the brain making contact with the scull and bruising or in more serious cases damage to the brain occurs (Brain injury law office, 1997).

The safety helmet is designed to deform under impact, to reduce the kinetic energy of any impact. It is constructed with a hard outer shell with a soft inner foam lining. The outer shell is made from plastic, with cost determining the type of plastic used. Safety helmets priced up to $300 are often made from injection molded thermo-softening plastics. Helmets above this price are usually constructed from fibre-reinforced thermo-set plastics with price determining the type of fiber reinforcement used. The inner foam layer is constructed to deform around the drivers head at a rate of joules per millimeter of deformation, however this value is a closely guarded secret among helmet designers, and is greatly dependant on the thickness on the foam lining and other helmet design features. The foam lining must be well-fitted to the shape and contours of the driver's head, to prevent the drivers head from accelerating relative to the helmet before deformation of the helmet occurs.

7.2.2 Driving Suit

The driving suit is a safety device which mainly protects the driver from fire and abrasions. Driving suits approved for Formula SAE-A must, at a minimum meet SFI 3.2A/1 or 1986 FIA (Federation Internationale de L'Automobiles) standards. Driving suits satisfying these standards are often made from material such as-Nomex, Kynol, FPT, IWS(Wool), Fiberglass, Durette, PBI, Proban and Kevlar.

These standards relate to the time a person wearing a driving suit can be exposed to a 982ºC heat source before receiving 2nd degree burns to the skin. A suit which complies with SFI 3.2A/1, which typically has one layer of fire resistant material, give the driver three seconds of protection before 2nd degree burns occur. This compared to a top of the line 4-layer suit which complies with SFI 3.2A/20, with a 'safe' time of 40 seconds. The downside to these suits is their dramatically increased weight and price, along with their reduced ability to dissipate heat from the driver's body. This can be a serious concern in warm conditions and for extended periods of time. As a result the most common type of driving suit for circuit racing is a dual layer suit with a SFI rating of 3.2/5. (Simpsonraceproducts.com, 2004) For the Formula SAE-A completion I see it only necessary to use a driving suit complying to SFI 3.2A/1, because due to the driver egress rule in which a driver must be able to exit the race car in under 5 seconds; the probability of a driver being exposed to a heat source for longer than 3 seconds is very low.

7.2.3 Gloves

Driver's gloves are designed to resist fire and help the driver grip the steering wheel. They are often made from the same materials discussed above, with the addition of leather covering over the palm and griping surfaces of the fingers and thumb. This is because of the high coefficient of friction between two leather surfaces, which allows the driver to sufficiently grip the steering the wheel using less hand gripping force, resulting in less fatigue in hand muscles. Leather is also very durable in this application resulting in a longer glove life.

7.2.4 Shoes

Driver's shoes are designed to give the driver good feedback from foot pedal application. Driving shoe's often only have a very thin rubber sole to allow the driver to feel the foot pedal through the sole of the shoe, and provide a good grip on foot pedals. Driving shoe's come in two main types- high and low ankle designs. In previous years the shoe of choice for race drivers has been the high ankle design, as it provides greater ankle protection and support. With increased safety of modern day race car cockpits, race drivers are now opting for low ankle shoe designs which offer greater ankle mobility, allowing for more precise foot pedal applications.

7.2.5 Arm Restraints

Arm restraints restrict the drivers arm movement to within the confines of the cockpit. This is important in a roll-over situation where the driver's hand may become detached from the steering wheel; arm restraint will ensure that the arms cannot be caught between the rollover structure and the ground. Arm restraints can be adjusted to suit each driver, and are fixed to each of the driver's arms at the wrist with a padded Velcro wrist band. The arm restraints are then passed though the lap belt on the driver harness, which allows the driver to escape the cockpit without removing the arm restraints.

7.3 Fire Protection

Although Formula SAE-A rules state that the driver must wear fire resistant clothing, the car can also be designed to incorporate other fire safety features. The Formula SAE-A rules require there to be a fire wall between the driver and any potentially dangerous liquids. Another safety feature of the Formula SAE-A rules is a positive master switch, which kills all electrical circuits and the running engine, stopping any sources of ignition and reducing the risk of fire. The rules also encourage the use of onboard fire extinguisher systems.

7.3.1 Fire Wall

The fire wall is a device used in all automobiles, from passenger vehicles to racing cars. It can be constructed from any fire resistant material, such as fibre-reinforced thermo set plastic, aluminum or steel among others. For use in the USQ Formula SAE-

A car it would be most viable to utilise the supply of 3mm aluminum sheeting, as it has good workability in this application. Formula SAE-A rules state that the fire wall must extend upwards so that any part of the tallest driver which is below 100mm above the bottom of the driver's helmet; must not be in direct line of sight with any part of the fuel, cooling or engine oil systems. Due to this criterion, the firewall will be one of the last items to be designed in the USQ Formula SAE-A race car, as some of final design points relating the fuel and cooling system to be used on this year's car are yet to be completed.

7.3.2 Electrical Master Switches

Electrical master switches cut the power supply from the battery to all systems within the Formula SAE-A race car. This will stop all possible sources of fire, with the exception of the hot exhaust, in the event a fuel leak occurs. The Formula SAE-A rules state that each car must be fitted with two master switches, one located inside the driver's cockpit and the other at the driver's shoulder height mounted near the main roll hoop within easy reach from outside the car. The easiest and most reliable method of master switch inside the driver's cockpit would be to use an on/off toggle switch. The rules state that the switch mounted near the roll hoop must be a rotary type switch as shown in figure 7.6.

Figure 7.6 – A typical rotary master switch, with a removable key shown in red (UPRacing.com, 2004)

Both master switches are required by the rules to have a clearly marked 'OFF' position, and identified by placing an international electrical symbol (shown in figure 7.7) near both switches.

Figure 7.7 - International electrical symbol must be shown near both master switches.

7.3.3 Fire Extinguisher

The Formula SAE-A rules encourage the implementation of on-board fire extinguisher system. This section of the report will investigate the feasibility of such a system for a Formula SAE-A race car. An on-board fire extinguisher system utilises the same dry chemical as standard portable fire extinguishers. The difference lies in the fact that an on-board fire extinguisher is set up with a series of pipes and nozzles to distribute fire extinguishing dry chemical to the expected areas of fire. Also it can be remotely activated by an electrical trigger mounted inside the driver cockpit and/or outside the car. The feature of distributing dry chemical is a great benefit to teams using a expensive engine control unit and/or data logging equipment. The cost of a fire extinguisher cell is approximately $550, compared to around $3000 for an engine control unit. An on-board fire extinguisher system is well worth the investment. The entire investment into an on-board fire extinguisher system will cost approximately $1300, for a 3.375L fire extinguisher cell shown in figure 7.8, fitted with an electric trigger and four nozzles, which is recommended for single seater racing cars such as a Formula SAE-A car (UPRacing, 2004).

Figure 7.8 – 3.375L fire extinguisher cell, for an on-board fire extinguisher system (UPRacing, 2004).

7.4 Car Safety Systems

Although the driver is well protected from the previously discussed safety equipment, Formula SAE-A cars also have several key safety features incorporated into the design. They perform different functions: - from crash protection to general safety to danger avoidance. The bulkhead and incorporated crush zones and driver head protection features will be discussed in the next sections. The general safety protection of the floor closeout will follow before the increased safety associated with rearward visibility concludes this section.

7.4.1 Bulkhead

The bulk head is the most forward part of the chassis and Formula SAE-A rules state that all non-crushable objects, including the foot pedals, batteries, and brake master cylinders, must be located behind this point. In a situation where the Formula SAE-A car has a high impact frontal collision, the bulkhead by design, protects the driver’s feet from injury. In front of the bulk head is a crush zone which absorbs energy before any deformation of the bulkhead occurs. This is another safety feature incorporated into the design of the chassis, which reduces the amount of kinetic energy the driver feels in a frontal impact, by decelerating the car before the driver feels the impact. This crush zone is made from such material as foam and aluminum honeycomb material.

For implementation in the 2004 Formula SAE-A race car the chassis designer has chosen a thin aluminum casing with a foam inner filling as the crush zone material.

7.4.2 Head Protection

Head protection is also incorporated into the chassis design to work in conjunction with the previously discussed driver safety helmet. To prevent an impact with the ground in a roll over situation, the Formula SAE-A rules stipulate that cars must be fitted with a front and main roll over hoop and the driver's head must be greater than 50mm lower than the tangent line between these hoops, as discussed in section 3. In addition to this rule all areas that the driver's helmet may come in contact with must be covered with a nonresilient, energy absorbing material such as Ethafoam® or similar. A predicted area on this year's car that will require this covering is the main roll hoop at the driver's head height, and other places will be determined when the car is nearing completion. Another area that will have to be designed at a later date is the driver's head restraint, due to the large differences in driver size within our team. As this is USQ's first entry into this competition it has been decided to determine the head restraint position after there is a good idea of the most comfortable positioning of the head for all drivers. This will allow the head restraint to be positioned in the optimal position to satisfy the rules which state that the head restraint must not be more than 25m away from the driver's helmet at all times. The head restrain shall have a minimum area of 232 cm^2 and be of a minimum thickness of 38mm of a material fitting the same criteria set out above. The purpose of the head restraint is to limit the amount of rearward movement of the driver's head in a high acceleration or rear impact situation.

7.4.3 Floor Closeout

The floor closeout is designed to protect the driver's legs from the moving pavement under the car and debris. The floor closeout as set out by the Formula SAE-A rules can be made up of separate panels; however there must be a maximum gap of 3mm between panels. The floor close out must extend from the foot area back to the firewall, protecting both the legs and torso of the driver. For the 2004 USQ Formula SAE-A race car, the best solution is to utilise the aluminum plate from stock in the workshop. The floor close out would be constructed in 3 separate panels as shown in figure 7.9. Mounting lugs would be welded to the chassis rails below the aluminum panels to create a smoother finish.

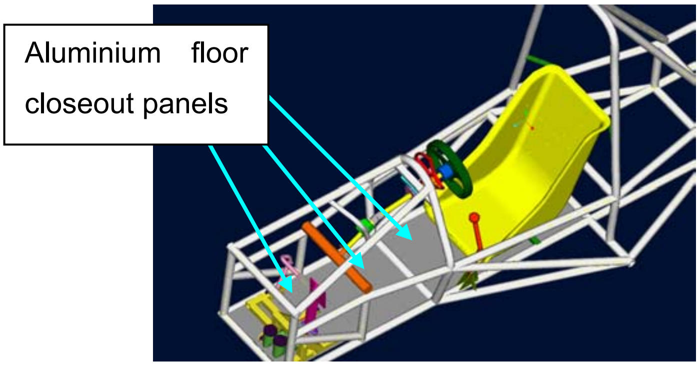

Figure 7.9 – Floor closeout panels for the 2004 USQ Formula SAE-A car.

7.4.4 Visibility

Driver rearward visibility is important when competing in the endurance event at the Formula SAE-A competition. It allows a slower driver to allow a faster driver though without the possible dangers associated with a fast car closely following behind a slower car. The driver visibility required by the rules of Formula SAE-A is 200º (100º either side). This rule means that mirrors must be fitted to the sides of the cockpit. To ensure maximum visibility is achieved mirrors will be placed on the sides at the front of the driver’s cockpit. Using a visual estimation while sitting in the unfinished chassis, I predict that if the mirrors are positioned approximately 100mm wider than the front section of the driver cockpit greater than 200º of vision can be achieve allowing for some margin of safety between the prediction and the finished car. Also using the lines to indicate the drivers line of sight in figure 7.10, it can be seen that a vision field greater than 200º in achievable.

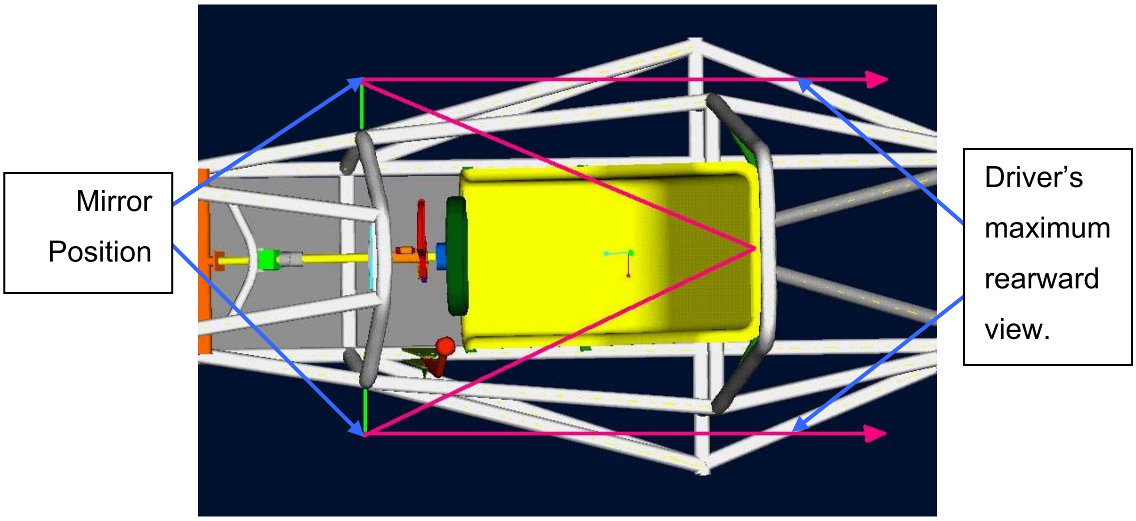

Figure 7.10 - Drivers vision rearward when mirrors are placed wide at the front of the cockpit.

7.5 Conclusion

Throughout this section of the report various safety issues have been highlighted and addressed. This section has detailed both driver and car safety requirements within the Formula SAE-A car and showed how these systems could be implemented into the USQ Formula SAE-A race car. Motor sport is dangerous; however by taking the appropriate safety precautions covered within this section of the report, the chances of driver injury is greatly reduced.

Chapter 8

8 Instrumentation

8.1 Introduction

The extent of instrumentation used for within racing cars is greatly dependant on the requirements of the competition. The Formula SAE-A competition is structured such that a broad range of commercially available instrumentation would satisfy the needs of a competing team. Effective use of instrumentation will result in more rapid design development and better results in the Formula SAE-A competition from year to year. This section of the report will investigate different instrumentation for possible implementation into the USQ Formula SAE-A race car. The investigation will initially look at the basic instrumentation requirements of a Formula SAE-A race car, and possible solutions to satisfy these requirements. This will be followed by a brief investigation into a feasible data logger and an engine management system, for future USQ Formula SAE-A race car.

8.2 Basic Instrumentation

Basic instrumentation is essential to the performance and reliability of any race car. Basic instrumentation displays to the driver general engine information, so that engine performance and life can be maximised by maintaining that the engine operates under conditions as it was originally designed. A good basis of what instrumentation is required to maintain these conditions are found on the original motorbike instrumentation panel. The original motorbike's instrumentation relating to the engine conditions consisted of an engine rpm dial, coolant temperature gauge and oil pressure warning light. The reasons associated with these instruments being essential to maintaining engine performance and life will now be discusses, including methods of displaying this information in a usable format to the driver.

8.2.1 Engine rpm

8.2.1.1 Effects of Engine rpm on Engine Life and Performance

Engines are designed to operate within a specific rpm range, where optimal performance and life are produced. Engine designers use the rpm range for the design calculations to determine internal component stress and hydro-dynamic bearing specifications. Therefore if the engine is operated outside the specified rpm range engine life is reduced. An engine's rpm range has both an upper and lower limit, which reduce engine life in the following different modes. If the engine upper rpm limit is exceeded, engine life is reduced because the forces generated on the internal componentry is greater than accounted for within the design, resulting in increased material fatigue and deformation, contributing to component failure. Conversely, if the engine lower limit is exceeded, engine life is reduced because the engine oil pressure is insufficient to properly lubricate the engine. Leading to increased wear in bearings, and cylinder bore among others; and as wear increases engine performance will be reduced.

8.2.1.2 Displaying Engine rpm

Engine rpm is a very dynamic measurement with the engine used in the USQ Formula SAE-A race car designed to accurate quickly from the lower to upper rpm limits. The rpm range for the engine used in this years USQ Formula SAE-A race car is from 3000 to 11000 rpm. The broad range covered by this measurement, in conjunction with the short amount of time that is taken to accelerate between lower to upper engine rpm limits, means that a high accuracy display is not required. The driver would probably only be able to take note of measurements to the nearest 1000 rpm, so a low accuracy display will be sufficient in this application. Common methods of displaying engine rpm are dial, digital number and progressive light displays.

Dial displays when used to display engine rpm are very effective. They are simple enough for non-professional drivers to use, while the pointer's angular speed can assist the driver to be prepared for a gear change at the upper rpm limit. This dial displays effectiveness at displaying engine rpm to a non-professional driver is shown by its common use within the automotive industry.

Digital number displays offer the ability to produce high accuracy readings. However as previously discussed this is not required for this application. Digital number displays also fail to easily indicate the direction and rat of change of the measurement through the rpm range, and a driver must take not of values at interval and calculate this whilst driving. For this reason digital number displays are not commonly used in geared race cars, and are effectively used in single speed cars as they allow drivers to accurately view maximum and minimum rpm values to effectively utilise the rpm range.

Progressive light displays are the most effective way to display engine rpm to the driver. As they utilise colours, to display different areas of the engine rpm range. Commonly colours are configured such that green indicates the optimal rpm range for engine performance, orange indicates that the rpm in nearing the upper or lower limit and red indicates that the upper limit has been reached. The driver is also shown that the lower limit has been exceeded as no lights will be illuminated. A common display configuration contains a number of LED's, in each colour with a possible configuration for the USQ Formula SAE-A race car shown below-

> The USQ Formula SAE-A car could use a 9 light display, with LED's programmed to come on as indicated below -
>
> 1. rpm > 3000 - Orange light
> 2. rpm > 4000 - Orange light
> 3. rpm > 5000 - Green light
> 4. rpm > 6000 - Green light
> 5. rpm > 7000 - Green light
> 6. rpm > 8000 - Green light
> 7. rpm > 9000 - Orange light

8. rpm > 10000 - Red light
9. rpm > 11000 - Red light

The main problem associated with this type of rpm display is that they are not readily available commercially. As a result most displays are constructed by teams to suit their individual engines rpm characteristics. From talking to people involved in racing teams, I found that it is relatively easy to produce one of these display's, and would be well within the design capabilities of a Formula SAE-A team, for future years.

8.2.2 Engine Oil Pressure

8.2.2.1 Effects of Engine Oil Pressure on Engine Life and Performance

Engine oil pressure is required by an engine to adequately lubricate moving internal components. In general operation oil pressure is a reasonably static measurement, however in cases such as oil pump failure oil pressure will change, and the driver should be aware, so that appropriate action can be taken. Insufficient oil pressure is caused by oil pump failure or oil loss, which results in increased wear lubricated componentry, leading to reduced engine life. Engine performance is also reduced by greater frictional forces acting against the direction of component motion, and over extended periods wear on internal component reduces the engine's efficiency. Conversely engine performance is reduced in cases of extreme oil pressure. In such cases oil pushes past oil seals and becomes in contact with the fuel burn, which causes reduced burn efficiency, resulting in lower engine power output. The possibilities of this occurrence are very low, because the engines oil pump's drive is fixed so cannot produce an excess pressure, also the pump is fitted with a high pressure relief valve which regulate oil pressure as engine rpm and oil pump rpm increases.

8.2.2.2 Displaying Engine Oil Pressure

Engine oil pressure is most damaging to engine life and performance, when it is insufficient, as highlighted above. For this reason oil pressure is most effectively displayed to the driver by the use of a low pressure alarm. The most effective method of performing displaying this alarm is to setup an electrical circuit containing a light mounted within the driver's line of sight and a pressure sensing switch, utilising power from the car's battery. The pressure sensing switch is positioned after the oil pump, on the engine so that the oil pressure acts on the pressure sensing surface of the switch. The switch is configured so that during normal running of the engine the oil pressure acts on the pressure sensing surface, pushing the switch to the off position. However when there is insufficient oil pressure to adequately lubricate the engine, the switch connects the circuit, illuminating the driver's warning light, so that the driver can stop the engine before serious engine damage occurs.

8.2.3 Coolant Temperature

8.2.3.1 Effects of Coolant temperature on Engine Performance and life

Coolant temperature is also critical to maintaining engine life and performance. The design of the engine has to account for the effects of heat on componentry, and most engines are designed to operate just below 100ºC, approximately 20ºC below the boiling point for the coolant fluid. If the engine is operated outside its designed coolant temperature range engine life is reduced and performance is comprised. Engine life is reduced when the engine is operated at full capacity, before the engine coolant has reached operating temperature. Engine life will be reduced in this case by head gasket failure, among other things. This is because as the engine is warmed to operating temperature, components expand in accordance with its materials thermal expansion properties. Engine designers account for each components growth in engine design and accordingly gasket tensioning specification is adjusted accordingly. This means that below normal operating temperatures, the pressure on gaskets within the engine is less than the desired, leading to failure. This is particularly the case for the head gasket, as this is area of the engine undergoes high pressures and thermal change. Head gaskets usually have thin sectors between the combustion chamber and coolant orifices surrounding the combustion area. This combination leads to a greater possibility of gasket 'blow out' on this section particularly when operating temperature is not reached. If the engine coolant exceeds the upper limit, the coolant begins to boil. This is commonly called over heating, and causes components such as the cylinder head, to warp or in worse cases crack, resulting in dramatically reduced engine life. Engine performance is compromised when operated outside the designed coolant temperature range, because fuel burn efficiency is reduced.

8.2.3.2 Displaying Coolant Temperature

Displaying coolant temperature is commonly performed using either analogue or digital methods. The purpose of the coolant temperature gauge is to allow the driver to see when the engine is sufficiently ‘warmed up’, ensure a suitable temperature is maintained during endurance events and to warn the driver when a maximum value is exceeded before the engine damage occurs. For the above reasons most racing driver’s and teams prefer a digital display of this measurement, as the changes in temperatures measured thought the course of an event should only change within approximately 5ºC or less, once the operating temperature is reached. An analogue display was used originally to monitor coolant temperature on the motorbike; however this is because the average person does not know what an engine’s operating temperature should be and the added accuracy of a digital display would be confusing.

8.3 Data loggers

8.3.1 Outline

Motor sport data loggers come in many different forms which are tailored to best suit the needs of each category. The main variable between different types of data loggers is the number of channels logged, which is cost dependent. High end data logging equipment can be priced in excess of $15000, for a professional use. This is well outside the cost restraints of the Formula SAE-A competition, also a non-professional competitor would not be able to utilise all the functions and data channels effectively, therefore this type of system is unfeasible for this application. However data loggers are available; well within the requirements and cost restraint of a Formula SAE-A team. These data loggers often have 12 data channels and are available as a stand alone unit or a unit which is integrated into the ECU (Engine Control Unit). Stand alone units are generally more expensive than integrated units, because integrated units share common sensors with the ECU. For a stand alone data logger suitable for a Formula SAE-A race car a team could expect to pay between $3000 and $4000, which would be a one off purchase as it could be shifted to each year’s new car. An integrated data logger and ECU can be purchased from between $4000 and $7000, which is optimal for a Formula SAE-A team with a fuel injected engine as the engine mapping is fully programmable to specific conditions, and desired performance characteristics. With a basic outline of data logging equipment covered, the following section will discuss the available features of data loggers of within this range and their benefits to a Formula SAE-A team's with regard to competition performance and quicker design optimisation.

8.3.2 Features

The key feature of motor sport data logging equipment is that is on-track data is recorded, to be analysed by team members either in between events for car performance tuning or after an event is complete for design alteration. A Formula SAE-A team can utilise recorded data from previous events in the design stage for each years new car, and also utilised new data recorded from the new car in pre-event testing to optimise design prior to the competition. Data is displayed on the data logger's, driver instrumentation, which shows the driver 'real time' information from a number of the data logger's channel sensors. The following section will discuss the driver instrumentation, typical sensors and data analysis available for data loggers.

8.3.2.1 Instrumentation displays

Data logger instrumentation displays are extremely versatile, because they are programmable by teams to produce an application specific display. Programmability of displays allow a team to display the information they wish the driver to monitor constantly while the car is in operation, such as engine rpm and coolant temperature, among others. It also allows teams the program alarms if upper and lower limits are exceeded. Data logger instrumentation displays consist of either a LCD screen or a combination of a LCD screen and LEDs.

Motec produce a typical LCD driver display, and because it is integrated with an ECU it has a number of added features, as shown in figure 8.1 (www.cityperformancecentre.com, 2004)

Figure 8.1 – LCD display for an integrated data logger and ECU unit by Motec

This is where the some additional benefits of an integrated system are found, because the driver can see such things as the current fuel map in addition to the traditional measurements shown. However a negative aspect of this display is that it mounts on a panel behind the steering wheel, which is not in the driver's direct line of sight. Also the display does not utilise the use of different coloured LEDs to show engine rpm, as discussed in section 8.2.1.2. Pi research produces a typical driver display utilising both a LCD screen and different coloured LEDs, as shown in figure 8.2 (www.pixpress.com, 2004).

Figure 8.2 – Pi Research driver display with both LCD screen and LEDs.

This type of display is very effective, however does have slightly less versatility than the previous, because of the display being divided into sector.

Because of the broad range available, an optimal driver display for a Formula SAE-A race car should be available. This would involve determining the specific requirements into the a driver display for the competition and investigating which company produces a optimal solution as producing a display such as the examples shown above would require resources out of reach for a typical Formula SAE-A team.

8.3.2.2 Typical Sensors

Sensors produce the basis for measurements taken by the data logger, for engine rpm, speed, linear and lateral acceleration, temperature, position, pressure, lap times, and air-fuel mixture. In order for the data logger to use a data channel, it must be fitted with a sensor. This section will give a brief description of how each sensor is fitted to the race car and how the data logger converts this into usable information.

Engine RPM is calculated by the data logger by counting the number of sparks on one high tension ignition lead over a set period of time. The sensor is usually a small insulated wire fixed to the outer silicon insulation of the high tension ignition lead and passing through an electrical filter back to the data. The current pulses passing through the high tension ignition lead produces a small electrical charge which is passed through the filter and to the data logger where the rpm is counted.

Speed is calculated by the data logger is a similar method. A magnet is mounted on a rotating component turning at the same rpm as the wheels. A sensor is positioned such that the magnet passes about 1 mm from the end of this sensor once every revolution of the wheel. The sensor then sends a pulse generated by 'hall effect' (www.pirresearch.com, 2004), to the data logger, from which speed is calculated by number of pulses over a set time period, multiplied by the wheel circumference (inputted into the data logger during calibration) and the number of set times periods per hour.

Linear and lateral acceleration is measured, using separate pre-calibrated accelerometers. Linear acceleration relates to the acceleration in the direction of the cars centreline, this is a useful measurement for the development of the Formula SAE-A engine and drivetrain package, as this can be used to calculate power at the rear wheels, which will include all loses, that often are not shown using engine and to a lesser extent chassis dynameters. Lateral acceleration relates to the acceleration normal to the car's centreline. This information is useful in suspension design optimisation; because the lateral force acting on the tires contact patch is know. Lateral acceleration when used in conjunction with a speed sensor, and lap timing equipment allows the data logger to produce a circuit map, which give the team a reference to utilise when looking a plotted data channels in the analysis mode, discussed the following section 8.3.2.3.

Temperature measurements are performed by K-type thermocouples. K-type thermo couples are chosen because they generate a linear output versus temperature, so temperature calculations are simpler. K-type thermocouple use two dissimilar metals-chromel and alumel joined together in an area where temperature measurement is required (Coggins, 2004). A voltage difference is created over the junction; the difference is read by the data logger and calculated into a temperature. Temperature measurements can be taken of coolant, oil, and exhaust gas temperatures, which is of benefit to engine design optimisation.

Position measurements can be taken for both linear and angular displacement, using potentiometers. Potentiometers produce different resistances throughout their range, and when they are used as a position sensor, the data logger uses the resistance to calculate the position from a zero point. The zero and maximum displacement positions are set during calibration of each sensor. These sensors can be used in any application a team wishes, to plot the position of during operation. A common use for these measurements is on foot pedals, to measure pedal displacement and therefore calculate pedal forces on brake applications, which can be used in foot pedal and braking system design optimisation. Also rotary potentiometers can be mounted on the steering shaft to measure steering input angle, which can reveal under-steer and over-steer handling characteristics in operation. This is useful information which can be used for steering, chassis and suspension systems optimisation.

Pressure sensors display a change in pressure to the data logger by a change is resistance. Pressure sensors used on data loggers usually have to be calibrated for each application before accurate data is obtained. Pressure sensors can be used in many different application through our the race car, however a commonly used to measure engine oil pressure, and in more advanced data logging systems tyre pressure can be logged.

Lap timing is a useful tool for teams wishing to accurately monitor on track development, over a set course. Lap timing on a circuit is performed by placing a sender on the edge of the course. This projects an inferred beam across the course at this point. The car is then fitted with a sensor which triggers the lap timing function within the data logger every time the beam is passed. Lap timing can also be performed on a course that doesn't form a complete loop by using two separate lap timing senders, one at the start of the course and one at the end.

Lambda sensor is a complex sensor which is used to calculate the air to fuel ratio of the engine. A basic description of how a Lambda sensor works is that is has ceramic body, with one part in the path of the exhaust gas and the other in the ambient air and at temperatures. The surface of the ceramic body is provided with electrode made of thin gas-permeable platinum layer. Above 300ºC the ceramic body begins to conduct oxygen ions and when there is a difference between the oxygen proportions surrounding each part of the body a voltage is generated (Bosch, 1986). The data logger can then calculate the air to fuel mixture entering the combustion process. This is of great benefit to engine development, so that both the engines fuel efficiency and performance can be optimised.

8.3.2.3 Data Analysis

Within this subsection a brief overview of the analysis software for motor sport data loggers will be presented. The section will focus on the Pi Research software called 'Club Expert Analysis', which has essentially the same features as other data logging software packages. All motor sport data logger fitted with a Lateral accelerometer, a speed sensor and lap timing equipment can produce a Track map (figure 8.3) when down loaded to a personal computer or laptop using the analysis software. The track map can be manipulated slightly within the software to produce a track, which appears the same as the actual track mapped.

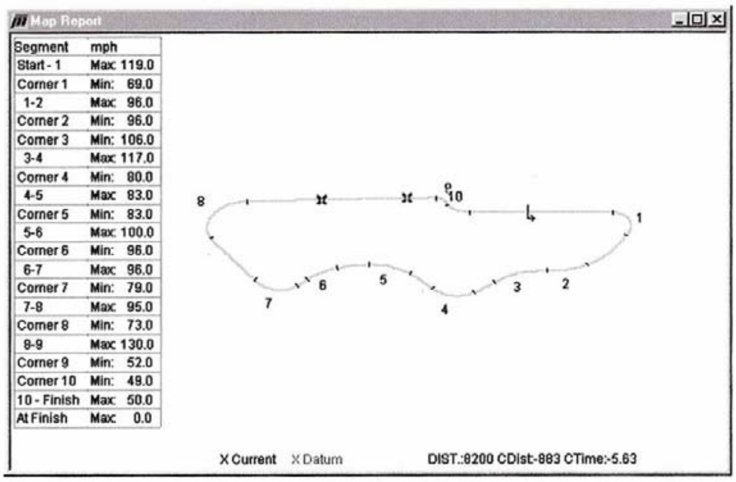

Figure 8.3 – A track map (greyscale) produced with Club Expert Analysis.

The analysis software numbers each corner, to provide easy referencing between track map and the available data plots. The straight section of the track are then numbered using the corner numbers that they join, for example a straight between corners No. 1 and 2, is called segment 1-2, as shown on the left side of figure 8.3. Data downloaded from the logger following a test, can be viewed in any number of configurations. For example in figure 8.4, the speed plotted over an analysis lap is plotted against speed of a datum lap, and also the time difference between the laps is also shown on the same graph.

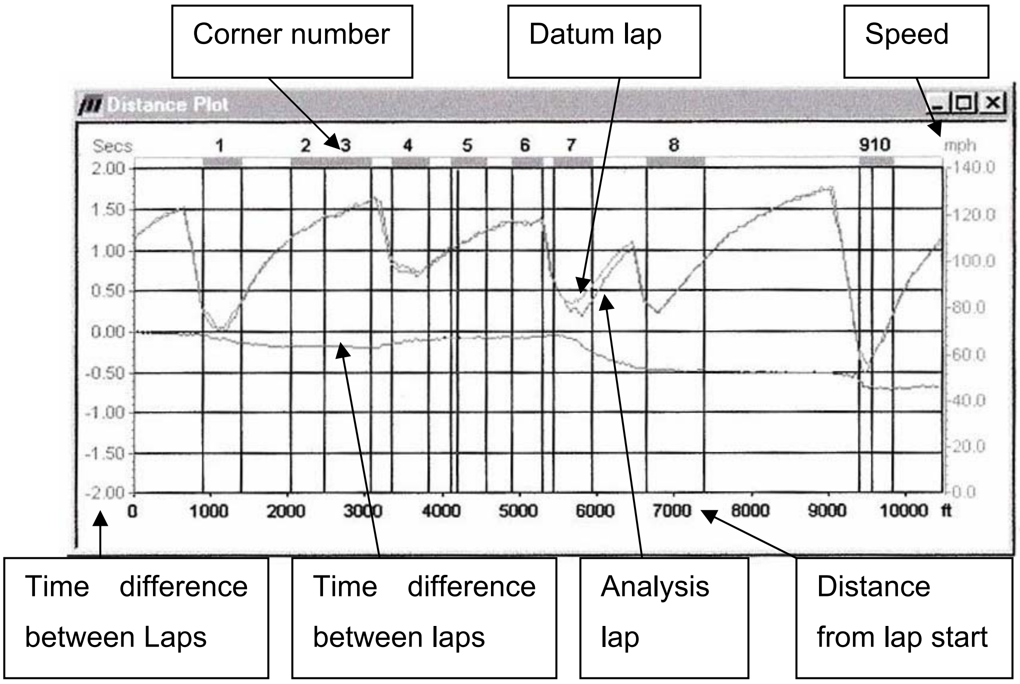

Figure 8.4 - A typical Speed, speed datum and circuit time graph (greyscale).

Graphs can be plotted of any number of data channels against time or distance from lap start, using data from the same or different laps. Other common analysis functions are histograms, and lap simulations. Histogram displays show data split into a number different ranges, which is then shows the data analyst the amount of time spent in each data range for the lap in question. Simulations within the analysis software simply represents where on the track map time one lap is faster or slower than a datum lap, it uses two different coloured dots moving around the track map to simulate the actual lap performed by the vehicle.

In conclusion, data analysis software that has been developed by data logger manufacturers is very effective. It shows data in a variety of different formats, and is extremely versatile, which would provide a solid basis of any development program. The USQ Formula SAE-A team would greatly benefit from the use of this analysis software and data logger system, as it would allow for faster development, and may allow USQ to reach the level of top teams in a reduced time.

8.4 Instrumentation Solution

The optimal Instrumentation solution would be to have a data logger with a driver display. The example shown in figure 8.2 manufactured by Pi Research, was the driver display that best suits the needs of a Formula SAE-A team, by using a combination of a LCD screen and LEDs, effectively display measurements the driver. Also a data logger for use on a Formula SAE-A race car would only require 12 data channels to effectively collect usable data, for car development. However due to cost restraints in this first USQ race car, the selected solution is to utilise the instrumentation from the motorbike, in a slightly modified form. The Speedometer is to be removed to allow the dash to fit into the space behind the steering wheel, and the oil pressure warning light to be moved in a position of where it can be easily seen by the seated driver.

8.5 Conclusion

Within this section of the report instrumentation solutions for the instrumentation with the driver cockpit for the USQ Formula SAE-A has been investigated. Initially basic instrumentation requirements and solutions where outlined with the optimal solutions found to be a progressive light display for engine rpm, a low oil pressure warning light, and a digital display for coolant temperature monitoring. This was followed by an investigation into the feasibility and features of data logging equipment including driver displays, typical sensors and analysis software. The chapter concluded that although the optimal solution was a data logging system, the USQ Formula SAE-A race car would utilise the motorbike dash in a modified form.

Chapter 9

9 Conclusion

9.1 Introduction

This research project on the control and instrumentation of the USQ Formula SAE-A race car has been completed and the design of a cockpit for the USQ Formula SAE-A has been achieved. Within the following section the project achievements will be summarised. This will be followed by a summary of chapter conclusions, and future work to be performed in this area.

9.2 Summary of Project Achievements

The objective of creating a driver cockpit with the USQ Formula SAE-A race car has been achieved. Throughout this report the following objectives set out within the Project Specification (appendix A) have been satisfied -

1. Research the background of the Formula SAE-A and what will be required to produce a competitive USQ entry.
2. Investigate why the control and instrumentation of cars is so important, and what control systems could be implemented for the safe operation of the car.
3. Evaluate these systems and select the appropriate systems according to the total budget of the project.
4. Design and analyse the appropriate systems for the USQ Formula SAE-A race car.
5. Implement these systems into the car and test there performance.

9.2.1 Research

Research was conducted into the background of the Formula SAE-A competition, and the associated rules. It was found that safety is a primary concern at the competition therefore most of the competitions rules relate directly to safety issues. The Formula SAE-A competition also requires a driver cockpit that is comfortable, and user friendly as non-professional drivers compete who are not accustomed to race car driving.

9.2.2 Why Control and Instrumentation is Important

Control and Instrumentation is important to the success of a Formula SAE-A team, because it allows the driver to maximise the car’s performance potential. A design that provides an excellent driver to car interface will require less of the driver’s thought to operate, which results in greater driver concentration on the driving task. As there was no previous data for a Formula SAE-A cockpit design, solutions were investigated throughout other forms of motor sport similar to Formula SAE-A. This resulted in developing the requirements for each system to be designed within this research project.

9.2.3 Evaluation and Allocation of Systems

Control and instrumentation required for the USQ Formula SAE-A race car, were evaluated. This evaluation often found an optimal solution, would be unobtainable for this year’s entry. Solutions for this year’s car were selected according to a limited cash budget, resulting in most of the systems selected thought this project being parts from the original motorcycle, that the team bought for the engine of the race car.

9.2.4 Design and Analysis of Systems

The design of systems within the driver cockpit began with an initial ergonomic study to determine what was required for each control to be driver friendly. This resulted in a set of ergonomic requirements, which were coupled with the mechanical requirements of each system, to produce the finished control. Controls were then analysed within solid modelling software. Components which were deemed as safety items where analysed using finite element analysis software, to ensure safety of the car was maintained.

9.2.5 Implementation and Testing

Implementation and testing of designed systems was limited to virtual modelling within solid modelling software. This was because the car was still being constructed in November when this research was finalised. However all componentry associated with this research has been fitted to the solid model of the chassis (see appendix H on the CD); to ensure they fit the requirements.

9.3 Summary of Chapter Conclusions

In chapter one the research project was outlined. The task of designing an optimal driver cockpit within the USQ Formula SAE-A race car was broken in seven different sections:

- Background
- Cockpit layout
- Driver seating
- Hand controls
- Foot controls
- Safety issues
- Instrumentation

These sections would then form the basis of chapters within this dissertation.

Chapter two researched the background and rules of the Formula SAE-A competition. This was followed by an investigation into cockpit designs in other forms of motor sport. The chapter concluded with a literature review, initially of previous research on similar topics, however as there was only limited resources available, the literature review covered ergonomic design principles and data.

Chapter three utilised the background knowledge found in chapter 2, to develop a general cockpit layout and sizing, which provided a good driver to car interface, while still within the capabilities of a Formula SAE-A team design. Systems that required driver control were highlighted and the chapter concluded that the optimal control layout as follows:

- Hand controls- Steering wheel, clutch control lever mounted on steering shaft for right hand, and gearbox control for left hand control

- Foot Controls- Accelerator pedal on right side and brake pedal on left side

Chapter 4 investigated the driver position and seating solution for the USQ Formula SAE-A race car. Ergonomic data was analysed prior to determining the driver position and seating solution. A solution was then chosen that optimised the allocated cockpit space to suit the team’s driver size range. A seating solution was selected that was comfortable for the driver, while fitting the USQ Formula SAE-A budget.

In chapter 5 hand control ergonomics was initially brought forward before each component was either designed or designated. Within this section it was found unfeasible to design all components within this section and components such as the steering wheel and quick release were purchased.

In chapter 6 foot controls where designed, as commercially available units where much more expensive than a self designed and built system. Foot pedal ergonomics was studied to determine foot pedal motion and foot forces available. A foot pedal design was achieved that fitted all team members with alteration, while still remaining functional.

Within chapter seven safety issues where highlighted, included both driver safety equipment and inbuilt car safety features, as determined by the Formula SAE-A rules. This also included some of the features within the safety equipment including fire resistant suits ‘safe time’ and safety harness webbing strength.

Chapter eight concluded the body of this report with an investigation into the available instrumentation for a Formula SAE-A race car. Basic Instrumentation requirements were highlighted and optimal solutions to basic instrumentation discussed. The chapter also included a study of feasible data logging equipment, which were found to decrease car development time, it implemented correctly,

9.4 Future Work

Further research and development is required in order to create the optimal environment for the driver within the USQ Formula SAE-A race car. It would involve an investigation into optimal mounting techniques for driver controls designed within this project. Also in order to manufacture each of these components detail construction drawings must be created, by utilising the solid models used for analysis throughout my research (see appendix H). Future research in this area would also have the benefit of hindsight as many of the unknowns associated with this project will be exposed after the 2004 USQ Formula SAE-A car is tested.

9.5 Conclusion

This research project has resulted in a designed driver cockpit for the USQ Formula SAE-A race car. This research should form a firm basis for future USQ Formula SAE-A cockpit designs, and allow for further design development throughout the following years.

In conclusion while the control and instrumentation is not directly related to a race cars performance. It is often the unrecognised element of race car design, with an effective design allowing the driver to optimise the cars performance, and achieve a more consistent on track results.

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Appendix A – Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/2 Research Project
PROJECT SPECIFICATION

FOR: **BRADLEY MOODY**

TOPIC: CONTROL AND INSTRUMENTATION FOR THE USQ FORMULA SAE-A RACE CAR.

SUPERVISOR: Selvan Pather

ENROLMENT: ENG 4111 – S1, D, 2004;
ENG 4112 – S1, D, 2004

PROJECT AIM: The project aims to investigate possible solutions for the control and instrumentation of the USQ Formula SAE-A race car, leading to the design and/or designation of these systems and their implementation within the car. This includes all control mechanism and instrumentation for the safe operation of the car.

SPONSERSHIP: USQ Faculty of Engineering and Surveying

PROGRAMME: **Issue A, 22nd March 2004**

1. Research the background of the Formula SAE-A and what will be required to produce a competitive USQ entry.
2. Investigate why the control and instrumentation of cars is so important, and what control systems could be implemented for the safe operation of the car.
3. Evaluate these systems and select the appropriate systems according to the total budget of the project.
4. Design and analyse the appropriate systems for the USQ Formula SAE-A race car.
5. Implement these systems into the car and test there performance.

As time permits:

6. Design improvements for the future success of the USQ Formula SAE-A race car

AGREED:

_____________ (Student) ____________, ____________ (Supervisors)
___/___/___ ___/___/___ ___/___/___

Appendix B – Team Size Data

	Brad	Bruce	Chris	Jeremy	Ken	Les	Rex	Average Team Member
Distances								
Ground to Knee Pivot	59.5	57	56	56	54.5	55	54	56.00
Knee Pivot to Back of Seat	60	55	53	53	54	50	55	54.29
Bottom of Seat to Shoulder Pivot	62	61	60	60	58	58	65	60.57
Bottom of Seat to Top of Head	97	92	80	80	88	87	89	87.57
Shoulder Joint to Elbow Joint	29	28	29	29	26	32	27	28.57
Elbow Joint to Mean Knuckle Line	37	38	33	33	31	37	33.5	34.64
Widths								
Shoulder	52	51	51	49.5	47.5	46.5	51.5	49.86
Chest	32	37	36.5	32.5	34	34.5	39.5	35.14
Waist	35	37.5	37.5	34.5	34	32	36	35.21

Appendix C – Ergonomic Data

Grandjean, E 1990, *Fitting the task to the Man,* 4th edn, Taylor Francis, London, pg 32, 33.

Table 3. Anthropometric data in mm of British adults aged 19−65 years.
The reference numbers of the dimensions are shown in Figures 23−28. According to Pheasant [209].

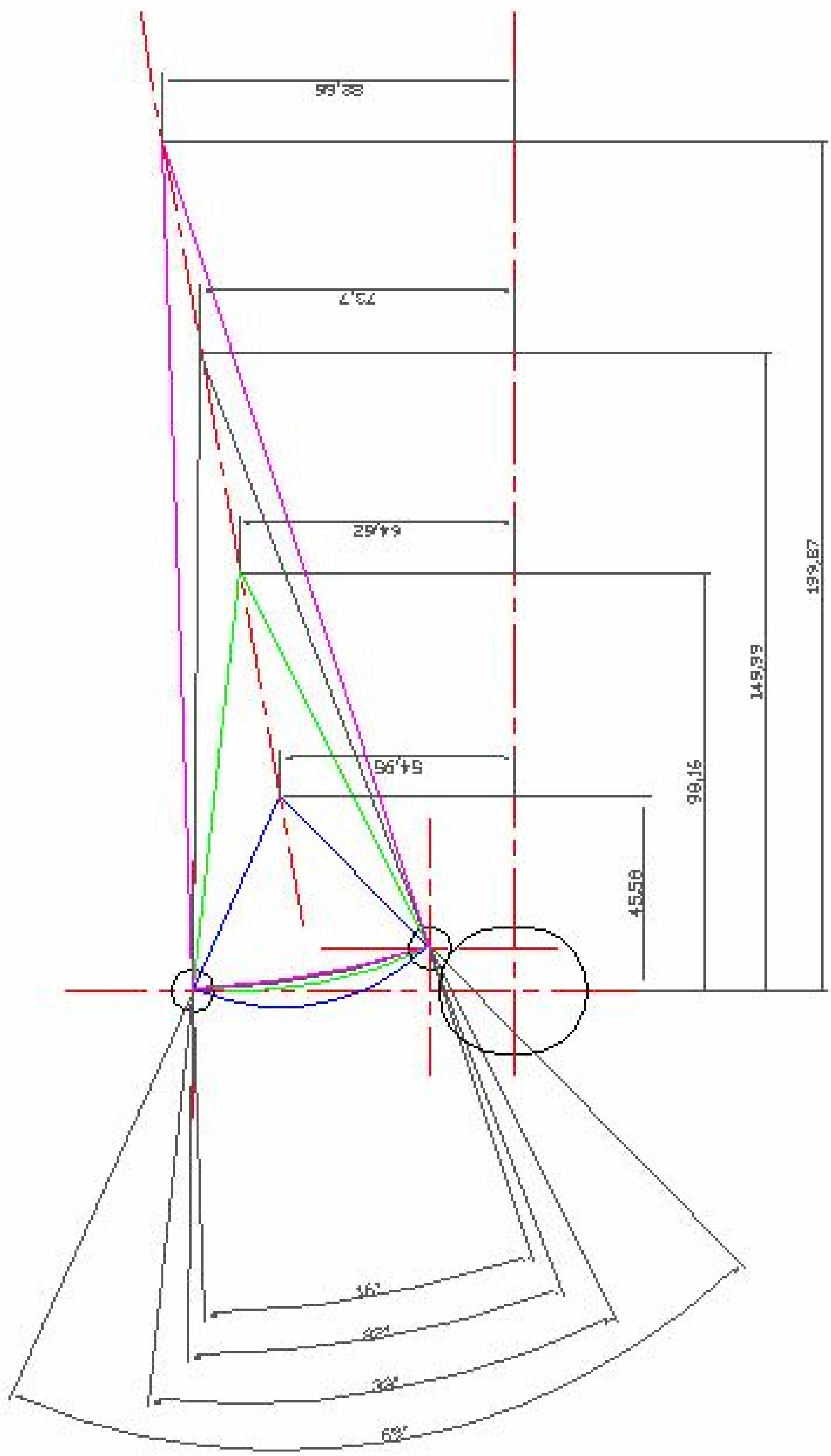
Dimension	Men 5th %ile	Men 50th %ile	Men 95th %ile	Men SD	Women 5th %ile	Women 50th %ile	Women 95th %ile	Women SD
1. Stature	1625	1740	1855	70	1505	1610	1710	62
2. Eye height	1515	1630	1745	69	1405	1505	1610	61
3. Shoulder height	1315	1425	1535	66	1215	1310	1405	58
4. Elbow height	1005	1090	1180	52	930	1005	1085	46
5. Hip height	840	920	1000	50	740	810	885	43
6. Knuckle height	690	755	825	41	660	720	780	36
7. Fingertip height	590	655	720	38	560	625	685	38
8. Sitting height	850	910	965	36	795	850	910	35
9. Sitting eye height	735	790	845	35	685	740	795	33
10. Sitting shoulder height	540	595	645	32	505	555	610	31
11. Sitting elbow height	195	245	295	31	185	235	280	29
12. Thigh thickness	135	160	185	15	125	155	180	17
13. Buttock-knee length	540	595	645	31	520	570	620	30
14. Buttock-popliteal length	440	495	550	32	435	480	530	30
15. Knee height	490	545	595	32	455	500	540	27
16. Popliteal height	395	440	490	29	355	400	445	27
17. Shoulder breadth (bideltoid)	420	465	510	28	355	395	435	24
18. Shoulder breadth (biacromial)	365	400	430	20	325	355	385	18
19. Hip breadth	310	360	405	29	310	370	435	38
20. Chest (bust) depth	215	250	285	22	210	250	295	27
21. Abdominal depth	220	270	325	32	205	255	305	30
22. Shoulder-elbow length	330	365	395	20	300	330	360	17
23. Elbow-fingertip length	440	475	510	21	400	430	460	19
24. Upper limb length	720	780	840	36	655	705	760	32
25. Shoulder-grip length	610	665	715	32	555	600	650	29
26. Head length	180	195	205	8	165	180	190	7
27. Head breadth	145	155	165	6	135	145	150	6
28. Hand length	175	190	205	10	160	175	190	9
29. Hand breadth	80	85	95	5	70	75	85	4
30. Foot length	240	265	285	14	215	235	255	12
31. Foot breadth	85	95	110	6	80	90	100	6
32. Span	1655	1790	1925	83	1490	1605	1725	71
33. Elbow span	865	945	1020	47	780	850	920	43
34. Vertical grip reach (standing)	1925	2060	2190	80	1790	1905	2020	71
35. Vertical grip reach (sitting)	1145	1245	1340	60	1060	1150	1235	53
36. Forward grip reach	720	780	835	34	650	705	755	31

Table 4. **Selected anthropometric data in mm of different nations.**
The references number of the dimensions are shown in Figures 23–28. According to Pheasant [209].

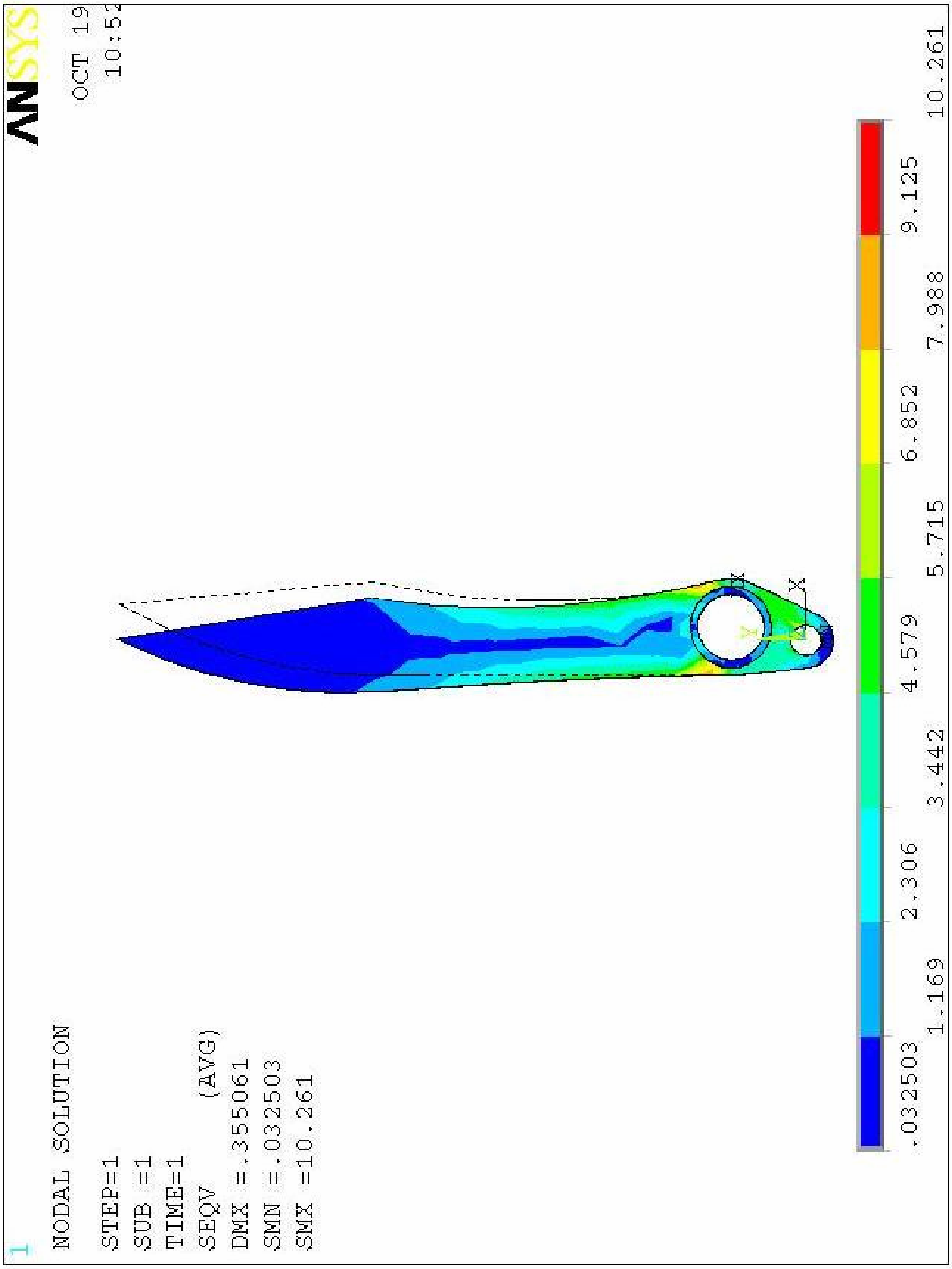
Dimension in mm	USA Men 5th %ile	USA Men 50th %ile	USA Men 95th %ile	USA Men SD	USA Women 5th %ile	USA Women 50th %ile	USA Women 95th %ile	USA Women SD	France Men 5th %ile	France Men 50th %ile	France Men 95th %ile	France Men SD	France Women 5th %ile	France Women 50th %ile	France Women 95th %ile	France Women SD
1. Stature	1640	1755	1870	(71)	1520	1625	1730	(64)	1600	1715	1830	(69)	1500	1600	1700	(61)
3. Shoulder height	1320	1440	1550	(67)	1225	1325	1425	(60)	1300	1405	1510	(65)	1210	1305	1400	(57)
4. Elbow height	1020	1105	1190	(53)	945	1020	1095	(47)	995	1080	1165	(51)	925	1000	1075	(45)
5. Hip height	835	915	995	(50)	760	835	910	(45)	815	895	975	(49)	750	820	890	(43)
8. Sitting height	855	915	975	(36)	800	860	920	(36)	850	910	970	(35)	810	860	910	(31)
9. Sitting eye height	740	800	860	(35)	690	750	810	(35)	735	795	855	(35)	700	750	800	(30)
11. Sitting elbow height	195	245	295	(31)	185	235	285	(29)	190	240	290	(30)	185	230	275	(28)
12. Thigh thickness	135	160	185	(16)	125	155	185	(17)	150	180	210	(17)	135	165	195	(17)
13. Buttock–knee length	550	600	650	(31)	525	575	625	(31)	550	595	640	(28)	520	565	610	(28)
15. Knee height	495	550	605	(32)	460	505	550	(28)	485	530	575	(26)	455	495	535	(24)
16. Popliteal height	395	445	495	(29)	360	405	450	(28)	385	425	465	(25)	350	390	430	(23)
17. Shoulder breadth	425	470	515	(28)	360	400	440	(25)	425	470	515	(26)	380	425	470	(27)
24. Upper limb length	730	790	850	(36)	655	715	775	(35)	710	770	830	(35)	650	705	760	(32)

Dimension in mm	F. R. Germany Men 5th %ile	F. R. Germany Men 50th %ile	F. R. Germany Men 95th %ile	F. R. Germany Men SD	F. R. Germany Women 5th %ile	F. R. Germany Women 50th %ile	F. R. Germany Women 95th %ile	F. R. Germany Women SD	Japan Men 5th %ile	Japan Men 50th %ile	Japan Men 95th %ile	Japan Men SD	Japan Women 5th %ile	Japan Women 50th %ile	Japan Women 95th %ile	Japan Women SD
1. Stature	1645	1745	1845	(62)	1520	1635	1750	(69)	1560	1655	1750	(58)	1450	1530	1610	(48)
3. Shoulder height	1370	1465	1560	(58)	1240	1320	1400	(50)	1250	1340	1430	(54)	1075	1145	1215	(44)
4. Elbow height	1020	1095	1170	(46)	925	1000	1075	(46)	965	1035	1105	(43)	895	955	1015	(36)
5. Hip height	840	910	980	(44)	760	840	920	(48)	765	830	895	(41)	700	755	810	(33)
8. Sitting height	865	920	975	(32)	800	865	930	(39)	850	900	950	(31)	800	845	890	(28)
9. Sitting eye height	750	800	850	(31)	680	740	800	(37)	735	785	835	(31)	690	735	780	(28)
11. Sitting elbow height	195	235	275	(25)	165	205	245	(23)	220	260	300	(23)	215	250	285	(20)
12. Thigh thickness	135	150	265	(70)	125	155	185	(19)	110	135	160	(14)	105	130	155	(14)
13. Buttock–knee length	560	600	640	(25)	525	580	635	(33)	500	550	600	(29)	485	530	575	(26)
15. Knee height	500	545	590	(28)	455	505	555	(30)	450	490	530	(23)	420	450	480	(18)
16. Popliteal height	415	455	495	(25)	355	395	435	(23)	360	400	440	(24)	325	360	395	(21)
17. Shoulder breadth	425	465	505	(23)	355	400	445	(27)	405	440	475	(22)	365	395	425	(18)
24. Upper limb length	735	785	835	(31)	660	720	780	(36)	665	715	765	(29)	605	645	685	(25)

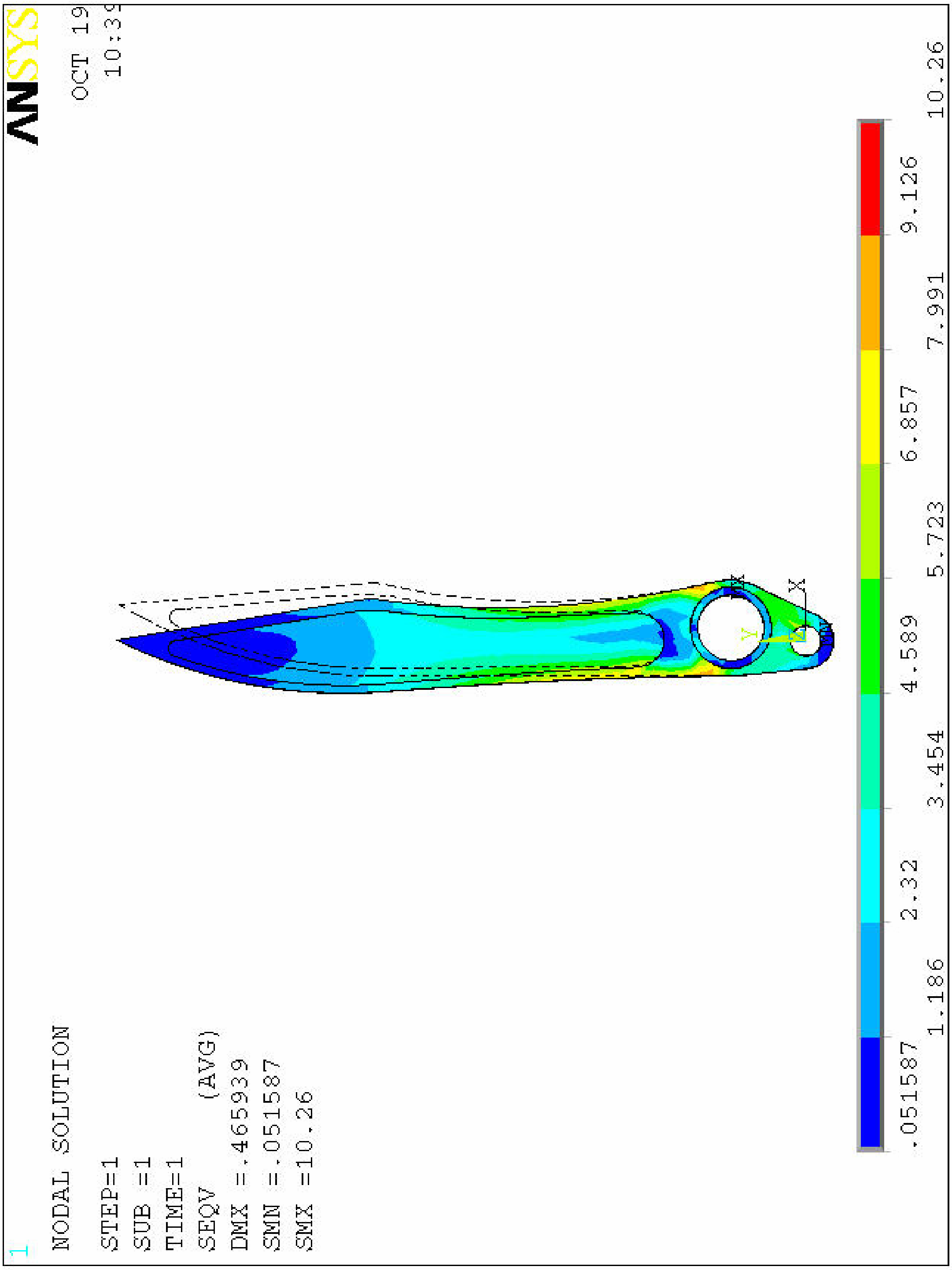
Appendix D – Clutch Lever Handle Path Drawing



Appendix E – ANSYS Printout of Initial Brake Pedal FEA


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.355061
SMN =.032503
SMX =10.261
ANSYS
OCT 19
10:52
.032503
1.169
2.306
3.442
4.579
5.715
6.852
7.988
9.125
10.261

Appendix F – ANSYS Printout of Redesigned Brake Pedal FEA


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.465939
SMN =.051587
SMX =10.26
ANSYS
OCT 19
.051587
1.186
2.32
3.454
4.589
5.723
6.857
7.991
9.126
10.26

Appendix G – Peugeot and Renault Parts and Service

PEUGEOT & RENAULT
PARTS & SERVICE

DRAYTON, TOOWOOMBA, QLD.

TELE 07- 46301699

FAX 07- 46301801

Appendix H – Component List for Pro Engineer Solid Models Used

COCKPIT.ASM is found on CD in Folder named 'APPENDIX H'. The following parts are found in this folder. The list below is the model tree of 'COCKPIT.ASM' -

Model Tree Level 1	Model Tree Level 2	Model Tree Level 3
CHASSISF.PRT		
SEAT_MOUNT1_.PRT		
SEAT_MOUNT1_.PRT		
SEATF.PRT		
BACK_SEATF.PRT		
BACK_SEATPLF.PRT		
BACK_SEATPRF.PRT		
STEERING_ASMF.ASM		
	STEERING_SHAFTF.PRT	
	STEERING_QRF.PRT	
	STEERING_WHEELF.PRT	
	CLUTCH_MOUNTF.ASM	
		CLUTCHMOUNTP1F.PRT
		CLUTCHMOUNTP2F.PRT
		CLUTCHMOUNTP3F.PRT
		CLUTCHMOUNTP6F.PRT
		CLUTCHMOUNTP4F.PRT
		CLUTCH_CABLEADJNUTF.PRT
		CLUTCH_CABLEADJF.PRT

CLUTCH_LEVERF.ASM

CLUTCHLEVERP1F.PRT

CLUTCHLEVERP2F.PRT

CLUTCHLEVERP2F.PRT

CLUTCH_P3F.PRT

CLUTCH_M6X08WASHERF.PRT

CLUTCH_M6X08WASHERF.PRT

CLUTCH_M6X60F.PRT

CLUTCH_M6X08WASHERF.PRT

CLUTCH_M6NUTF.PRT

STEERING_SHAFTBUSHF.PRT

STEERING_BUSHMOUNTF.PRT

STEERINGSHAFT_BUSHF.PRT

STEERINGRACKF.PRT

CHASSIS2STEERM1F.PRT

STEER2CHASSISM2F.PRT

STEER2CHASSISM2LUGF.PRT

STEER2CHASSISM2LUGF.PRT

GEARLEVERF.PRT

GEARLEVERL1F.PRT

GEARLEVERL1F.PRT

- GEARLEVERL2F.PRT
- CH_2_BRAKEF.PRT
- CH_2_BRAKEF.PRT
- FLOORF.PRT
- PEDALBOX_ASMF.ASM
  - ADJUSTER2_F.PRT
  - ADJUSTER2_F.PRT
  - CROSS_MEMBERS_F.PRT
  - UPRIGHT_F.PRT
  - UPRIGHT_F.PRT
  - CROSSMEMBERTOP_F.PRT
  - M_C_MOUNT_PLATE_F.PRT
  - PEDAL_ASM_F.ASM
    - PEDAL___222__F.PRT
    - NYLON_BUSH__F.PRT
    - SPHERICAL_BEARING__F.PRT
    - BIASBAR__F.PRT
    - BAIS_FEMALE__F.PRT
    - BAIS_FEMALE__F.PRT
    - MASTER_CYLINDER__F.PRT
    - MASTER_CYLINDER__F.PRT

PEDAL_LUG_F.PRT

PEDAL_LUG_F.PRT

LIN_MEM_P2_F.PRT

LIN_MEM_P2_F.PRT

LIN_MEM_P1_F.PRT

LIN_MEM_P1_F.PRT

LIN_MEM_P3_F.PRT

LIN_MEM_P3_F.PRT

BRACE_F.PRT

BRACE_F.PRT

CROSS_MEMBER2_F.PRT

LIN_MEM_P4_F.PRT

STOP_ACCEL_BACK_F.PRT

ACCELERATOR_PEDAL_F.ASM

- ACCEL_BUSH_F.PRT
- ACCEL_TUBE_F.PRT

M6_NUT_F.PRT

M6_NUT_F.PRT

PEDAL_M6X25_F.PRT

PEDAL_M6X25_F.PRT

PEDAL_M8X40_F.PRT

PEDAL_M10X40_F.PRT

PEDAL_M8X40_F.PRT

PEDAL_M8X40_F.PRT

PEDAL_M8X40_F.PRT

PEDAL_M8X40_F.PRT

FOOT_PADF.PRT

PEDAL_M6X25_F.PRT

PEDAL_M8X40_F.PRT

PEDAL_M8X40_F.PRT

PEDAL_M8X40_F.PRT

PEDAL_M8X40_F.PRT

FLOORF.PRT

FLOORF.PRT

FLOOR