Design and Analysis of a Pedal Box System for a small Race-car

by

Zarizambri Bin Ahmad

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
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Approved by,

(Ir. Masri Bin Baharom)
Ir. Dr. Masri B Baharom
Lecturer
Mechanical Engineering Department
Universiti Teknologi PETRONAS

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2008

CERTIFICATION OF ORIGINALITY

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

ZARIZAMBRI BIN AHMAD

ABSTRACT

The objective of this project is to study, analysis, enhanced and further optimize a pedal box system for a small race-car which is Formula SAE Third Race Car. For this new car, UTP FSAE team has decided to use CBR600 engine as it vital part. The proposed design will be based around a hybrid-composite space-frame chassis and the design will be optimized for the best ergonomics, performance and strength-mass ratio. Therefore a further study and analysis on the pedal box system needs to be done. The scope of study includes the usage of computer aided engineering software such as CATIA and ADAMs for modelling and analysis. First, the pedal box system design needs to be performed by using CATIA. Then, stress analysis for throttle, brake and clutch pedal being conducted by using the same software. In order to compare the new pedal box design with previous pedal box design (UTP FSAE Second Car), ADAMs software has been used to conduct dynamics and kinematics analysis. The results explained that the new pedal box design can minimize driver's foot load to depress the pedal for about half of previous pedal box design load. For stress analysis results, the brake pedal which is the crucial part in pedal box system can endure a 100kg of load. Therefore the results show that the new pedal design is safe to be proposed as a pedal box system for UTP FSAE Third Car.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATION

SAE	Society of Automotive Engineers
FSAE	Formula SAE
CV	Constant Velocity
CAD	Computer Aided Design
FEA	Finite Element Analysis
CATIA	Computer Aided Three Dimensional Interactive Application
ADAMs	Interactive Motion Simulation Software Modules
AutoCAD	CAD software application
EDM	Electrical Discharge Machine
TIG	Tungsten Inert Gas
CNC	Computer Numerical Control

CHAPTER 1

INTRODUCTION

1.1 Background of Study

It is crucial that the ergonomics input to a vehicle or a product takes place throughout the design process but nowhere it is important than at the concept and early development stages of design. Basic ergonomics criteria such as the implementation of healthy and efficient postures for the range of future users need to be satisfied at a very early stage as there is usually only limited possibility for modifications later in the process without incurring serious financial consequences.

However, automotive race car design has always been anxious with styling and tremendous engineering function. As a consequence, these aspects of the vehicle design typically take precedence over the ergonomics aspects of driver compartment and the interface.

1.2 Problem Statement

The quality of pedal box system provided by a vehicle is an extremely important issue, and this has been made the major focus of this project report. From the study of the previous Formula SAE car pedal box system, there were several disadvantages have been identified. The disadvantages such as the area of foot pressing for throttle and clutch pedals were smaller in size. Besides, the fabrication processes for pedal mounting could waste a lot of materials.

The previous pedal box system required larger driver's foot load to depress the pedals. This larger load condition will make driver lost their attention to the front of the car during racing. It is because they give more attention to their foot to depress the pedals. This is very dangerous to the car as well as the driver because it can cause an accident.

1.3 Objective

The objectives of this project are:

a) To perform design and analysis for the proposed pedal box systems
b) To improved the design for the best ergonomic, performance, strength-mass ratio and fabrication processes
c) To propose fabrication processes for limited production of the pedal box systems components

1.4 Scope of Study

The Formula SAE car will be designed in accordance with Formula SAE regulations. For the new Formula SAE car which is UTP FSAE third car, the proposed design will be based around a hybrid-composite space-frame chassis and the design will be optimized for the best ergonomics, performance and strength-mass ratio.

The project involves the ergonomic study, design, analysis and optimization of a driver interface systems for a small race-car for the third UTP Formula SAE race car, which is constrained by the regulations and design requirement. Therefore the analysis is based on the finalized design and the components that give the optimum result. This project will cover the simulation and analysis of the pedal box linkage system. For design, CATIA software has been used. ADAMs software has been used to simulate and analyze force distribution of the pedal box system. Calculation on theoretical also need to be done to make sure the reality is almost similar due to theory.

For the second semester, the project will cover on stress analysis, kinematic and dynamic analysis, fabrication process and design optimization within the time frame which is approximately 4 months.

CHAPTER 2

LITERATURE REVIEW

This chapter contains two main topics, which first about the Formula SAE Design Requirement and the last one is about driver interface fundamental. Below, literatures on driver interface fundamental concentrating on pedal box system has been described.

2.1 Formula SAE Target Specification

The strict rules pertaining to the driver interface system of the car are as follows:

a) Accessibility of controls [7]

All vehicle controls must be operated from inside the cockpit without any part of the driver, e.g. hands, arms or elbows, being outside the planes of the Side Impact Structure.

The driver must have adequate visibility to the front and sides of the car. With the driver seated in a normal driving position he/she must have a minimum field of vision of 200 degrees (a minimum 100 degrees to either side of the driver). The required visibility may be obtained by the driver turning his/her head and/or the use of mirrors.

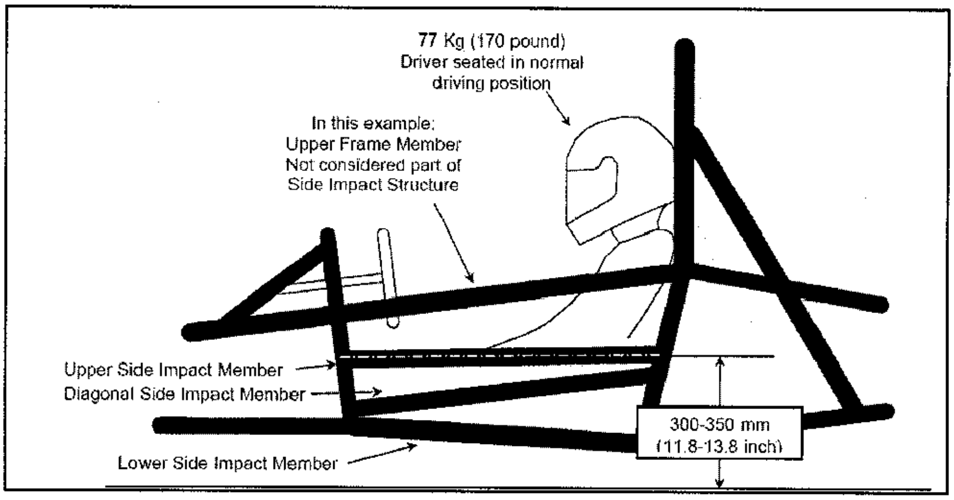


Figure 2.1: Side impact structure

b) Seat [5]

The seat is generally mounted to the chassis. Therefore the key of this structure is ergonomics to all sized drivers. Ergonomically, the important factors to be considered in constructing the seat are maximize the comfort, efficiency, and productivity for the human, while minimizing the risk of errors and injury and their related costs. Two most important components that need to be focus on are the posture of the driver and also the driver reach capability. The recommended calf portion of the leg when the pedal is released is not less than 120° angle in relation to the thigh. Thus it is important that the seat can be adjusted for ergonomics purpose. To achieve this purpose, the usage of adjustable seat, movable seating position or any combination can be applied.

c) Driver's leg protection [6]

To keep the driver's legs away from moving or sharp components, all moving suspension and steering components, and other sharp edges inside the cockpit between the front roll hoop and a vertical plane 100mm (4 inches) rearward of the pedals, must be shielded with a shield made of a solid material. Moving components include, but are not limited to springs, shock absorbers, rocker arms, anti-roll/sway bars, steering racks and steering column CV joints. Covers over suspension and steering components must be removable to allow inspection of the mounting points.

d) Pedal box system [7]

Under stress it is incredible how much pressure a frightened driver can apply to the brake pedal. The judges for Formula SAE race car will look for flexing in the pedal mountings. The brake pedal should not go 'over centre' when the brakes are applied. Ideally, at full application the pedal should be just before a perpendicular load is applied to the push rod.

2.2 Pedal Box System Fundamental

The pedal box mounts both the accelerator (throttle) and brake pedals which are the only point of contact with engine and brake respectively. Pedal box also can accommodate three pedals with additional of clutch pedals which are the only point of contact with engine clutch systems. Therefore, we should ensure that this pedal box system is reliable and comfortable for all drivers. The two main design philosophies are ergonomics and strength. If the car need to be used by many different drivers, different sizes, it is important that the pedal box can be adjusted so that long and short legs can be accommodated.

a) **Throttle pedal** [2]

Throttle is the mechanism by which the flow of a fluid is managed by constriction or obstruction. An engine's power can be increased or decreased by the restriction of inlet gases (*i.e.,* by the use of a throttle). The term throttle has come to refer, informally and incorrectly, to any mechanism by which the power or speed of an engine is regulated. In a petrol internal combustion engine, the throttle is a valve that directly regulates the amount of air entering the engine, indirectly controlling the fuel burned on each cycle due to the fuel-injector or carburettor maintaining a relatively constant fuel/air ratio. In a motor vehicle the control used by the driver to regulate power is sometimes called the throttle pedal or accelerator.

b) Brake Pedal [3]

The two most common arrangements of master cylinders are a pair of opposed pistons which are forced apart by the fluid pressure (drum brake), and a single piston which is forced out of its housing (disc brake). The master cylinder pistons then apply force to the brake linings (generally referred to as shoes for drum brakes and pads for disc brakes). The force applied to the lining cause them to be pushed against the drums and rotors. The friction between the linings and drum/rotor causes a braking torque to be generated, slowing the vehicle. For Formula SAE race car, disc brakes have been used.

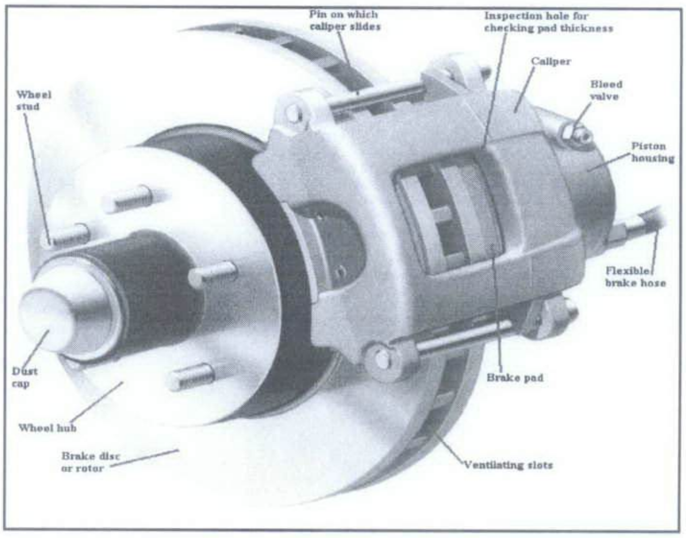


Figure 2.2: Typical disc brake

c) Clutch Pedal [8]

In a car the clutch is operated by the left-most pedal using hydraulics or a cable connection from the pedal to the clutch mechanism. Even though the clutch may physically be located very close to the pedal, such remote means of actuation are necessary to eliminate the effect of slight engine movement, engine mountings being flexible by design. No pressure on the pedal means that the clutch plates are engaged (driving), while depressing the pedal disengages the clutch plates, allowing the driver to shift gears or coast.

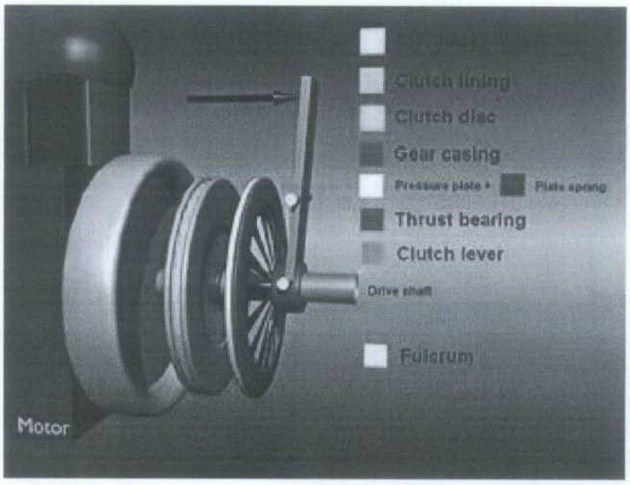


Figure 2.3: Clutch system

CHAPTER 3

METHODOLOGY AND PROJECT WORK[1]

3.1 Procedure Identification

Below are the processes that will be done due to come out with a great design of pedal box system:

a) Full understandings with the regulations and the requirement of Formula SAE race car specific on driver interface system mainly on pedal box system.
b) Study on theory understanding and parameters acquisitions of the component.
c) CAD designing by using CATIA
d) Study on kinematics and dynamics analysis of the system itself. The analysis consists of equations derivation and iterations and comparison between the analytical method and modeling simulation. For this purposes, ADAMs has been used.
e) After all the analysis meet specifications, FEA analysis will be done with focusing on material selection.
f) Next, is to go through critical design review where any comments or suggestions will be made in order to improve the design.

[1] Refer To **APPENDIX 1** and **APPENDIX 2** for Methodology and Gantt Chart respectively

3.2 Tools and Equipments Used

The tools and equipments used for this project are:

a) CATIA

To design and analysis the pedal box system design

b) MSC ADAMS

As kinematics & dynamic simulation tools

c) MICROSOFT EXCEL

To calculate the data on pedal box fundamental

3.3 Project Work

3.3.1 Pedals New Design[2]

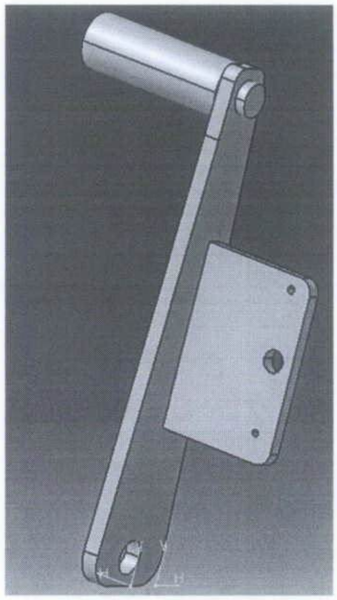
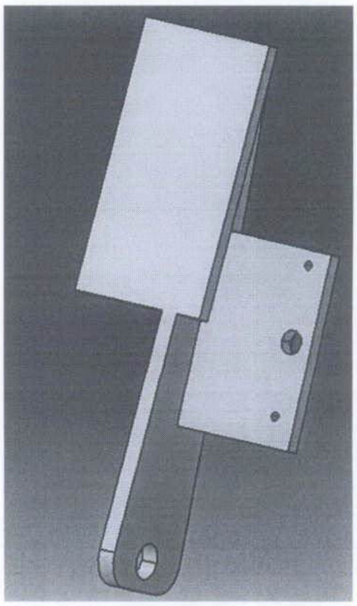
Throttle pedal is used to control the speed. It controls the throttle valve openings to determine the amount of air-fuel mixture reaching the cylinders. The control valve is controlled by the linkage connected to the throttle pedal. The throttle pedal was design so that it will attach to a mounting base so with respects to human ergonomics, the spring stiffness should allow the driver to put a minimum force to push the throttle pedal. Helical torsion spring is attached to the pedal as a counterbalance for the pedal. It is used to quicken the return motion of the throttle pedal upon release.

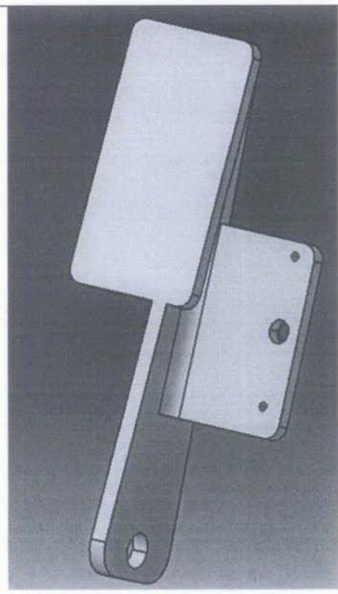
Designing process also take part in determining the ratio of the pedal. It is vital as it will determine the pedal output force and pedal displacement characteristic. For example if a driver input force is 50 pounds multiplied by 3:1 ratio, will resulting 150 pounds of output force. Raising the ratio would further enlarge driver input force, but the distance traveled by the pedal would be longer to achieve the same output. For this design analysis, it has been

[2] Refer To **APPENDIX 5, APPENDIX 6** and **APPENDIX 7** for pedals detail designs

assumed that the pedal force is 223N. **Table 3.1** below show the stages of design of the throttle pedal.

Table 3.1: The design stages of pedal

Previous design - Lower contact surface area for foot pressure distribution - Foot may slip upon pedal and shoes slippery* - Higher stress concentration on sharp edges - Assembly: bolts and nuts *refer sections 4.1 as prove	 *Figure 3.1: Previous throttle pedal design*
Initial design - Bulky design - Higher pedal contact surface area - Higher stress concentration on sharp edges and corners - Assembly: TIG Welding	 *Figure 3.2 : Initial throttle pedal design*

Second design - Improving the foot contact surface for force distribution on the pedal - Fillet sharp edges with 5 mm radius - Lower stress concentration on edges and corners - Flat pedals design - Assembly : TIG welding *refer sections 4.3.1 for stress analysis	 *Figure 3.3 : Second pedal design*
Finalized design - Improving force distribution on the pedal* - Fillet sharp edges with 5 mm radius - Lower stress concentration on edges and corners - Reduce foot movement angle - Curve pedals design - Material: Aluminium 7075-T6 Assembly : TIG welding *refer sections 4.3.2 for stress analysis	 *Figure 3.4: Finalized pedal design*

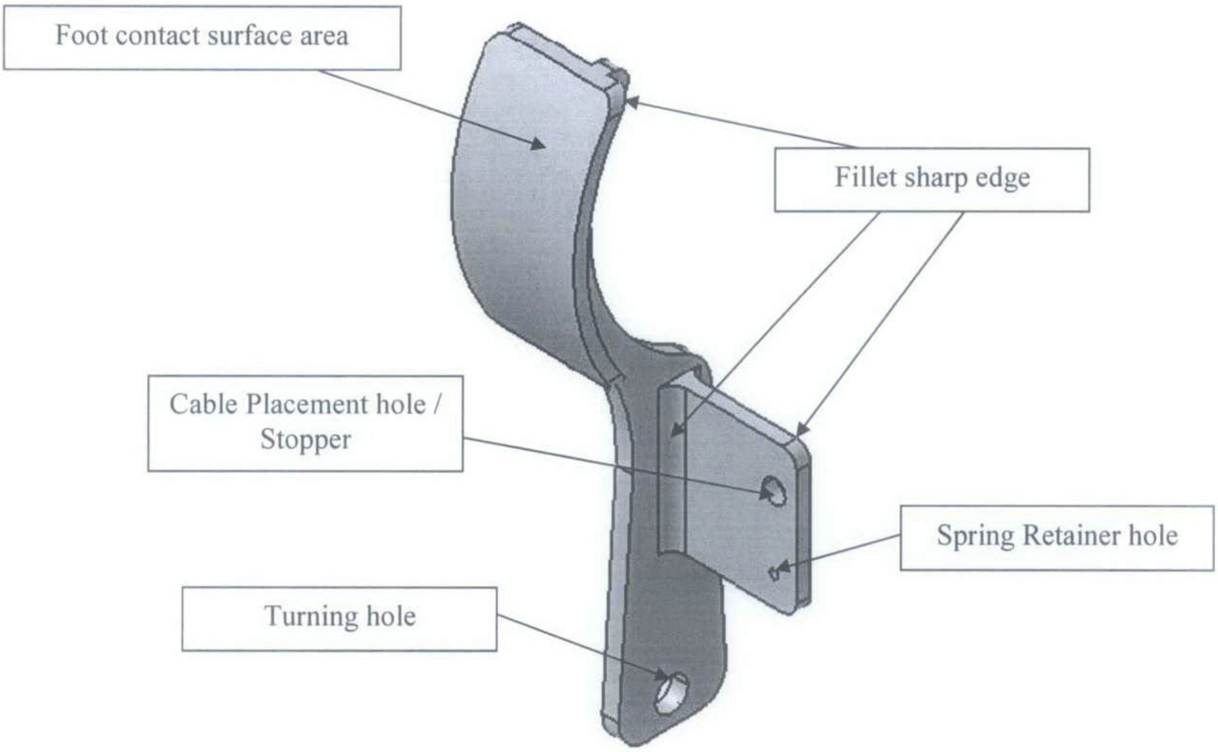


Figure 3.5: Finalized throttle pedal design

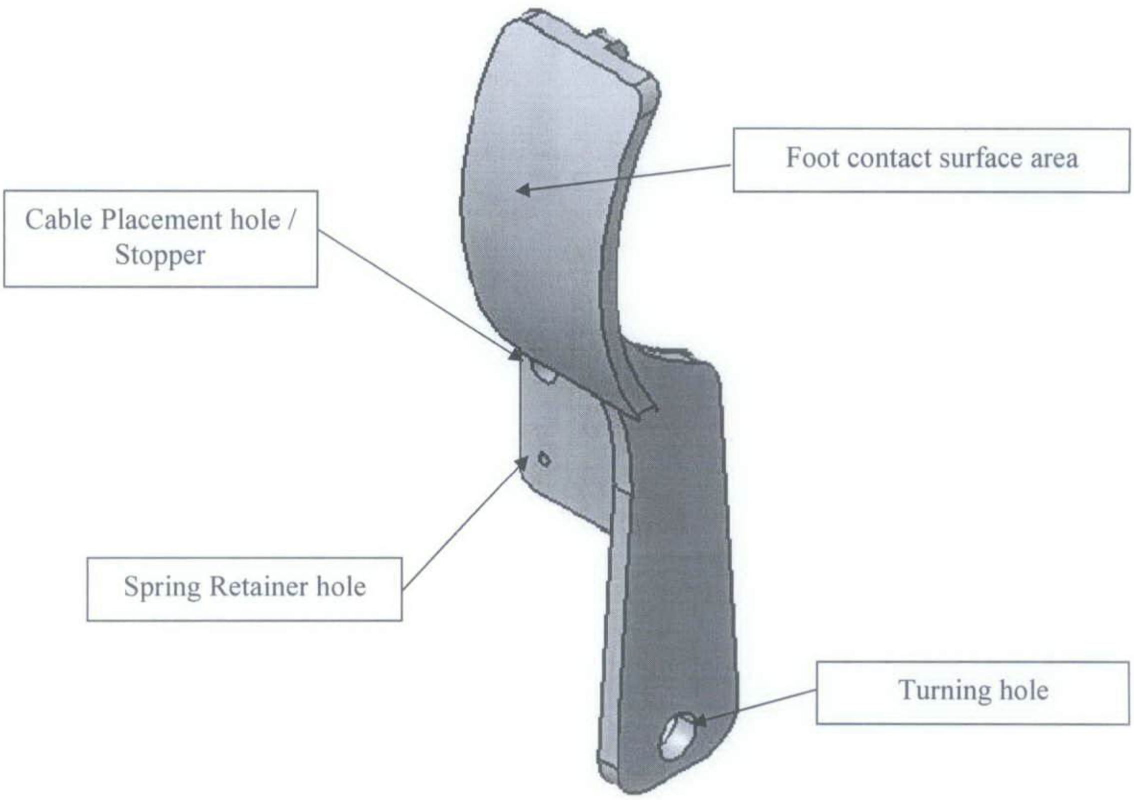


Figure 3.6: Finalized clutch pedal design

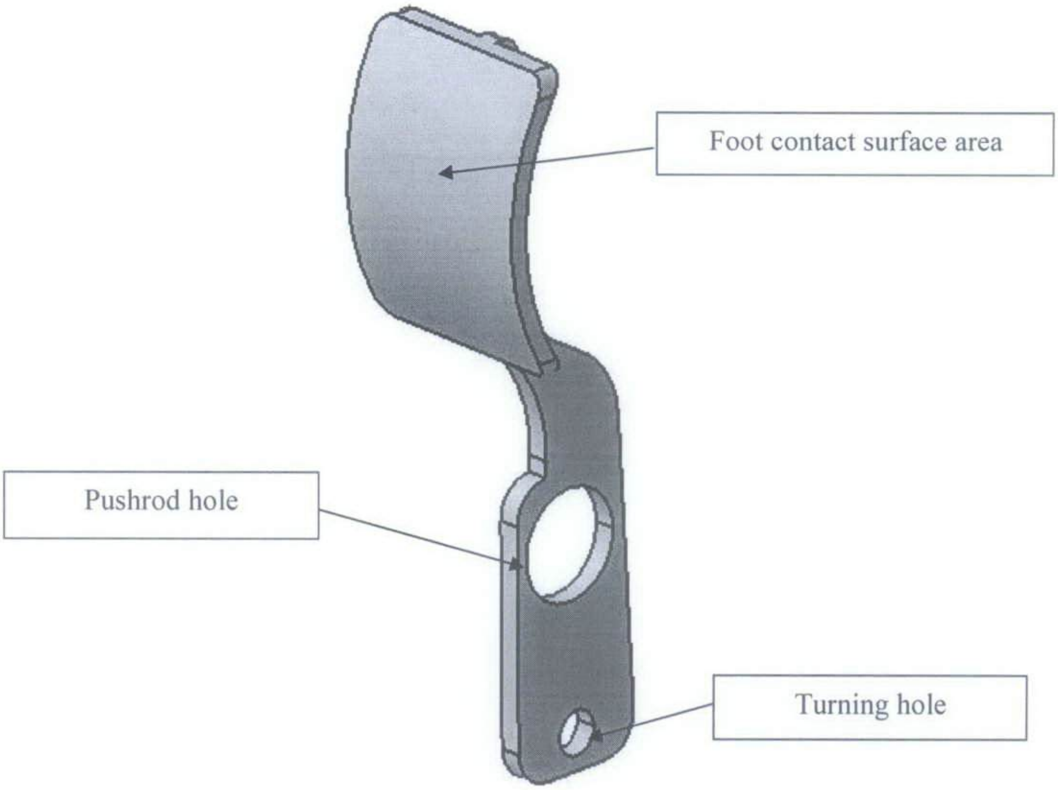


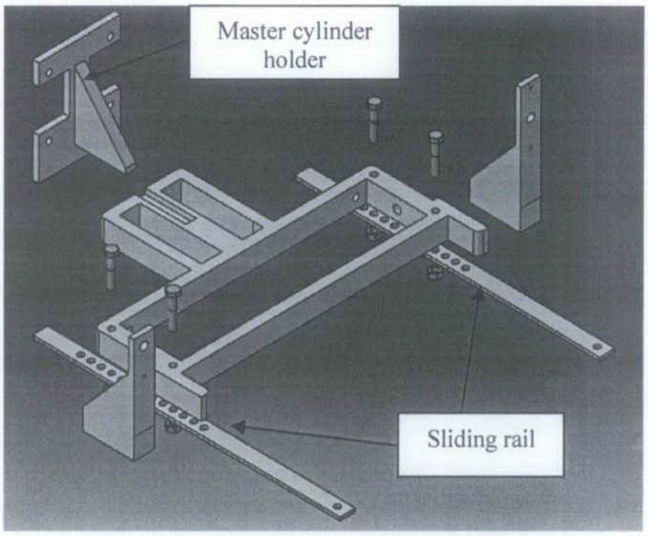
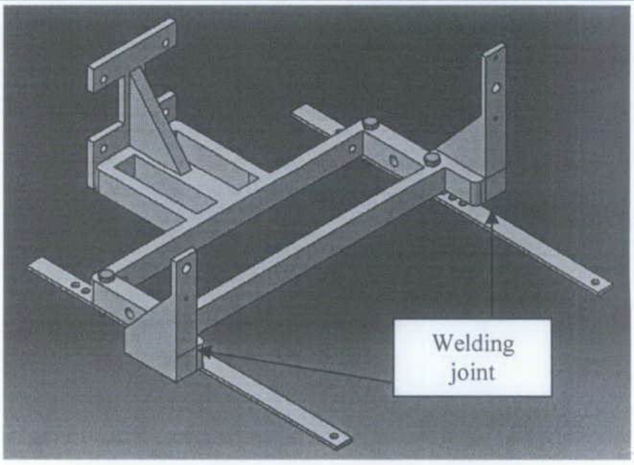
Figure 3.7: Finalized brake pedal design

All pedals have been continuously analysed in order to find the optimized design. After the pedals go through various analyses of stresses, kinematics and dynamics by using CATIA and ADAMs software throughout the project duration, the finalized pedals design have been proposed. For this case, it took two semesters to achieve the optimized design as illustrated in **Figure 3.5**, **Figure 3.6** and **Figure 3.7**. The finalized designs were from the optimized analysis result. The analyses of stresses, kinematics and dynamics of the pedals were described in detail in results and discussion section.

3.3.2 Pedal Box Mounting New Design[3]

For having a good pedal box system, the pedals itself need to be mount on a good pedal mounting. In pedal mounting; all pedals which are throttle pedal, brake pedal and clutch pedal; and other pedal box equipment for example brakes master cylinder, brakes balancer bar and part stopper need to be mount on the pedal mounting. A new pedal box mounting that can coop all pedal box system equipment has been proposed and the design itself is robust and easy to fabricate. Besides, the design might capable of eliminate excessive use of material in order to fabricate the pedal box mounting.

Table 3.2: The pedal box mounting design

Exploded view of pedal box mounting - Easy manufacturing process - Eliminate excessive material to manufacture - Higher stress concentration on sharp edges - Assembly: bolts, nuts and welding process	 *Figure 3.8: Pedal box mounting exploded view*
Complete assemble of pedal box mounting - Simple design - Can be adjusted in order to accommodate long and short leg of the drivers - Use sliding rail as sliding mechanism	 *Figure 3.9: Pedal box mounting assembly view*

[3] Refer To **APPENDIX 8, APPENDIX 9** and **APPENDIX 10** for pedal mounting detail designs.

3.3.3 Pedal Box Design[4]

Before come out with the new pedal box system design, a lot of ergonomic data of driver's posture, chassis and etc has been considered and taken. This is to ensure that the design can accommodate the different sized of drivers as well to maintain comfort ness and accessibility of the drivers. Before dynamics and kinematics analysis of pedal box being conduct, the initial design of the pedal box system was chosen as illustrated in **Figure 3.10**. The initial design was equipped with flat pedal design as illustrated in **Figure 3.3**. The flat pedals which require much foot movement angle to depress the pedal will make driver's foot become fatigue and thus reduce the ergonomic values of the pedal box design.

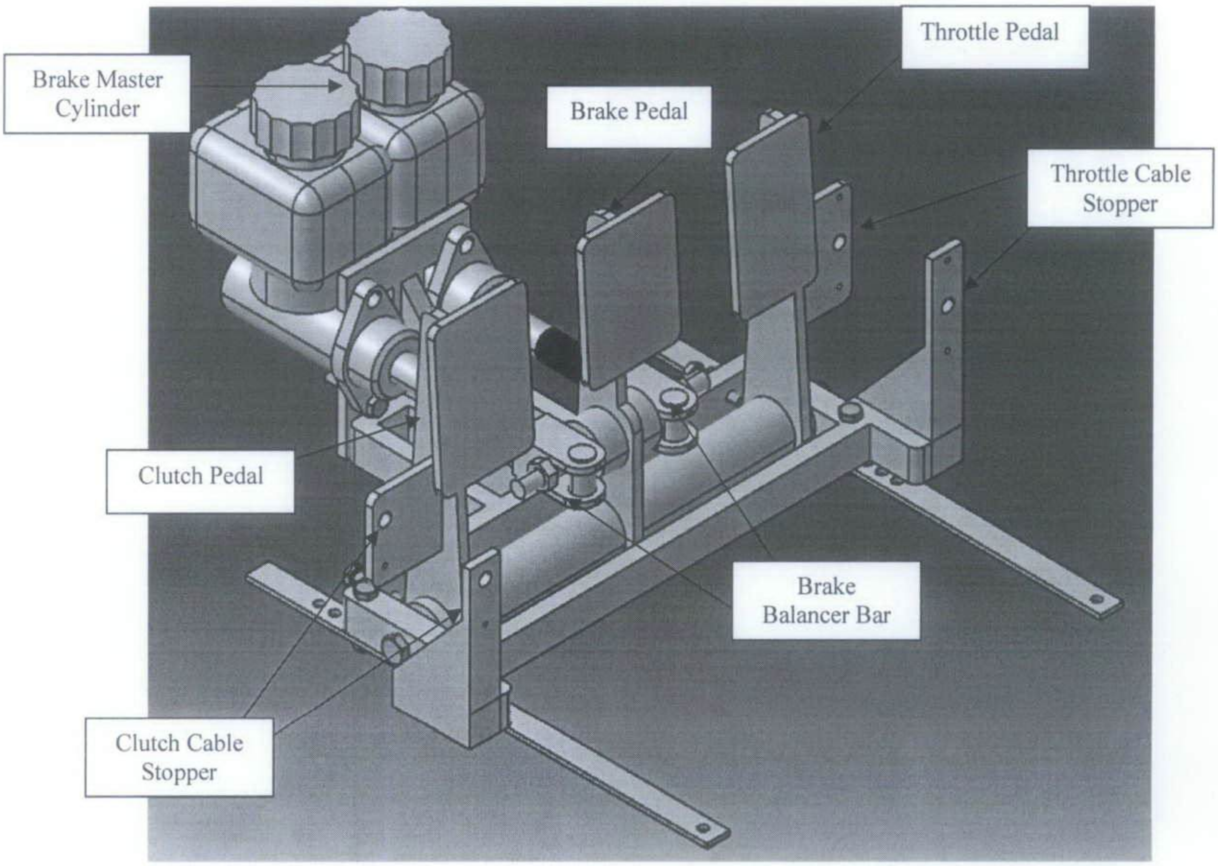


Figure 3.10: Pedal box initial design

[4] Refer To **APPENDIX 4** for new pedal box detail design

After finalized pedals have been proposed, the pedal box design has been modified to obtain the final or optimize pedal box design. Finalized pedal box design that will be equipping in small race car (UTP FSAE third race car) was illustrated in **Figure 3.11**. The design is made prior the study from previous UTP FSAE second race car design and optimized analysis result. The finalized design or new pedal box design was equipped with curve pedals as illustrated in **Figure 3.5**, **Figure 3.6** and **Figure 3.7**. So, the finalized pedals design can reduce foot movement angle than the previous pedal box system design (UTP FSAE second car). The finalized curve pedals design also can reduce load which required operating same amount of load of previous pedal box system design (UTP FSAE second car). This will ensure the ergonomic value of new pedal box design has been taking into consideration.

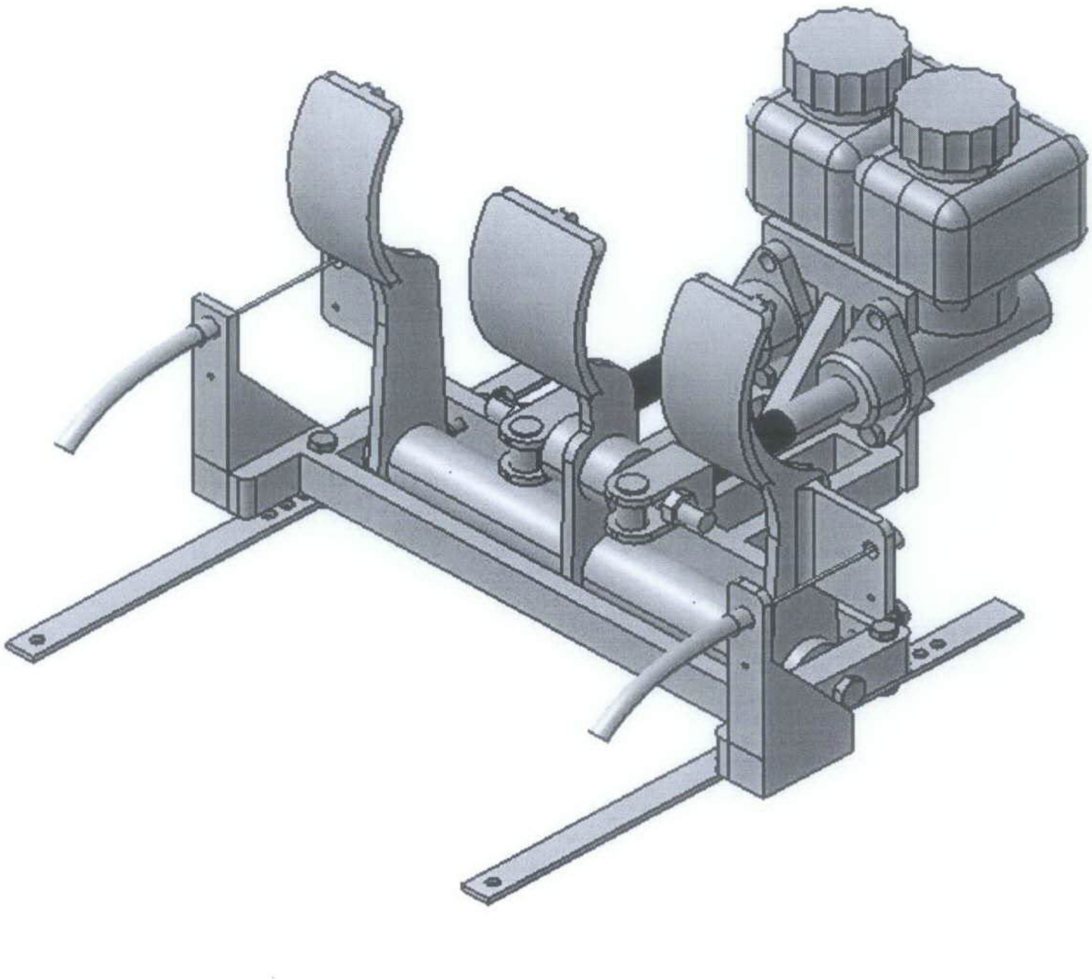


Figure 3.11: Finalized pedal box design

A lot of design improvements have been made to ease of fabrication process for Pedal Box Mounting. New pedal box design can give more comfort ness, safety features to the drivers as well driver's foot load reduction to depress the pedals.

3.3.4 Pedal Box Fabrication process

Height and angle are important when building for comfort and safety pedals. Things to consider are being able to lift driver foot from the throttle pedal to brake pad quickly and having the throttle pedal, brake pedal and if standard shift the clutch pedal spaced so there are no interference problems based on the driver foot size.

After the new pedal box system was proposed, it will come to fabrication stage. Where, it was the last stage in order to fabricate the pedal box become to reality as one of important part in FSAE car. After all detail designs of the pedal box system were illustrated, the fabrication process needs to be proposed.

For fabrication process of pedal box mounting, throttle pedal, clutch pedal and brake pedal, the most appropriate processes is Wire EDM Cutting and EDM Drilling Machine. Wire EDM (electrical discharge machining) uses an electrically energized thin brass wire to slice through metal - including difficult-to-machine metals. Wire EDM creates intricate profiles. The Wire EDM machine uses rapid, controlled, repetitive spark discharges. The work piece must be electrically conductive. The material for pedal box mounting and all pedals are Aluminium Alloy 7075-T651 plate, electrically conductive. That mean, Wire EDM can be use to fabricate pedal box system. For the pedal box mounting detail design, please refer to **Appendix 8, Appendix 9** and **Appendix 10**.

As for pedal box mounting base as illustrated in **Appendix 8**, the Wire EDM must be feet with 280mm x 200mm x 20mm Aluminium Alloy 7075-T651 plate. First, EDM Drilling must be use to drill the holes through the work piece and after that the plate will be cut using the Wire Cut EDM. Prior to machining, the pedal mounting should be design in computer aided design called AutoCAD. This software is chosen because the Wire EDM can only read the drawing from AutoCAD. The coordinate of the hole to be drill through the work piece should to be determined. After the work piece has been drilled, it should be transfer to Wire EDM. Then, Wire EDM will cut the work piece as per design. In order to join parts such as pedal box mounting base, cable stopper and master cylinder holder to become as one pedal box mounting as illustrated in **Figure 3.9**, TIG welding process is the most appropriate joining process.

The same fabrication method goes to throttle, clutch and brake pedals. Each part needs to be design using AutoCAD before it will be drill and cut by EDM Drilling and Wire EDM respectively. The appropriate dimensions of bar should be select as per design in order to minimize material waste. For throttle and clutch pedal, it is often possible to stack and cut work pieces simultaneously because of the similar dimension between those two pedals. The pedals' pads, which are the part that make contact between driver's foot and the pedal, can be also fabricating using Wire EDM. In order to join pedals pad and pedals itself, TIG welding process can be use.

The narrow kerfs and dimensional accuracy of Wire EDM make it possible to provide close-fitting parts. Work piece thickness ranges from only a few thousands of an inch to several inches. Wire EDM edges are smooth but matte. Typical surface finish is between 16 and 64 micro inches. The edges of the finished work piece will have virtually no burrs.

3.4 Material Selection

As for FSAE new race car, several designs of pedals are needed to be considered. In order to achieve the target or objective to develop the lightest pedal box system, the pedals will use Aluminium Alloy 7075-T6[5] as its materials can provide lightest weight compared to the other materials. For the pedal box mounting, Aluminium Alloy 7075-T651 plate will be use because it required thicker plate as per design.

The chosen of Aluminium Alloy 7075 series as the material type is based on the researches on this particular material. This material is widely used in aircraft and automotive industries because of its less weight and also known as very high strength material used for highly stressed structural parts [2].

As for pedal box spacer, Aluminium 6061-T6 has been chosen because the part itself not required much strength like the pedal. Besides, Aluminium 6061-T6 is cheaper than Aluminium Alloy7075-T6. In order to reduce the cost, Aluminium 6061-T6 is the most suitable material for pedal spacers.

3.5 Ergonomic Study on Driver Posture

Driver comfort; ease of entry and exit; driver relationship with the primary control of vehicle or race car – all these affect interior package dimension of race cars and passenger cars. While the moderate and expert builders invest heavily in studies to optimise ergonomics of particular designs, the specialist builder often needs to make recourse to more generalised published data to optimise driver spatial envelopes for a relatively low volume production race car.

Ergonomics is strictly the study of matching man to machine and is a surprisingly recent science [4]. The consequences from neglecting the ergonomics data can lead to several major problems to race car during racing. The ergonomics data have been collected by Driver Interface Department, Chassis Department and Suspension & Steering Department to identify the best posture of the driver and position of pedal box and steering; see **Figure 3.12** and **Table 3.3**. The drivers will varies in their sizes, so, several

[5] Refer To **APPENDIX 3** for aluminium 7075-T6 details

ergonomics data has been taken ranging from 165cm to 175cm of driver height.

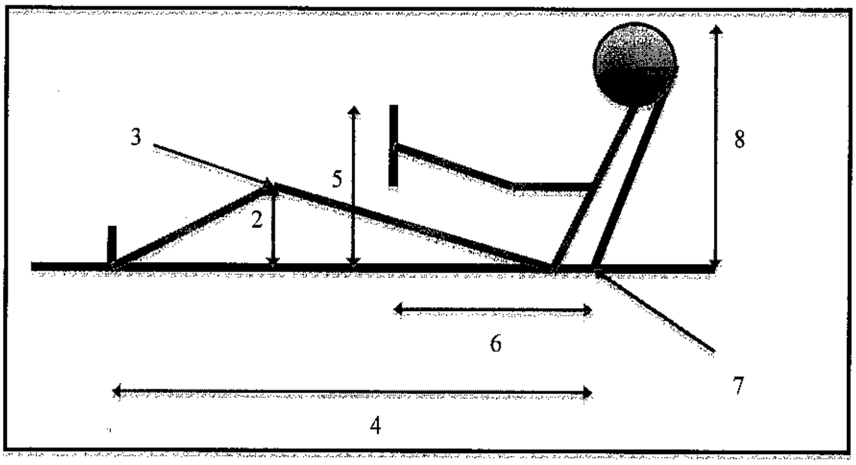


Figure 3.12: The schematic diagram of ergonomic data

Table 3.3: The ergonomic data

NO.	DATA DESCRIPTION	FIRST DRIVER	SECOND DRIVER
1	**Driver height (mm)**	1650	1750
2	**Leg height (mm)**	330	375
3	**Leg angle (°)**	125°	110°
4	**Length of leg (mm)**	945	1037
5	**Steering height (mm)**	570	610
6	**Length from steering to driver body (mm)**	530	535
7	**Driver seat angle (°)**	110°	107°
8	**Height from driver head to the wrist (mm)**	885	885

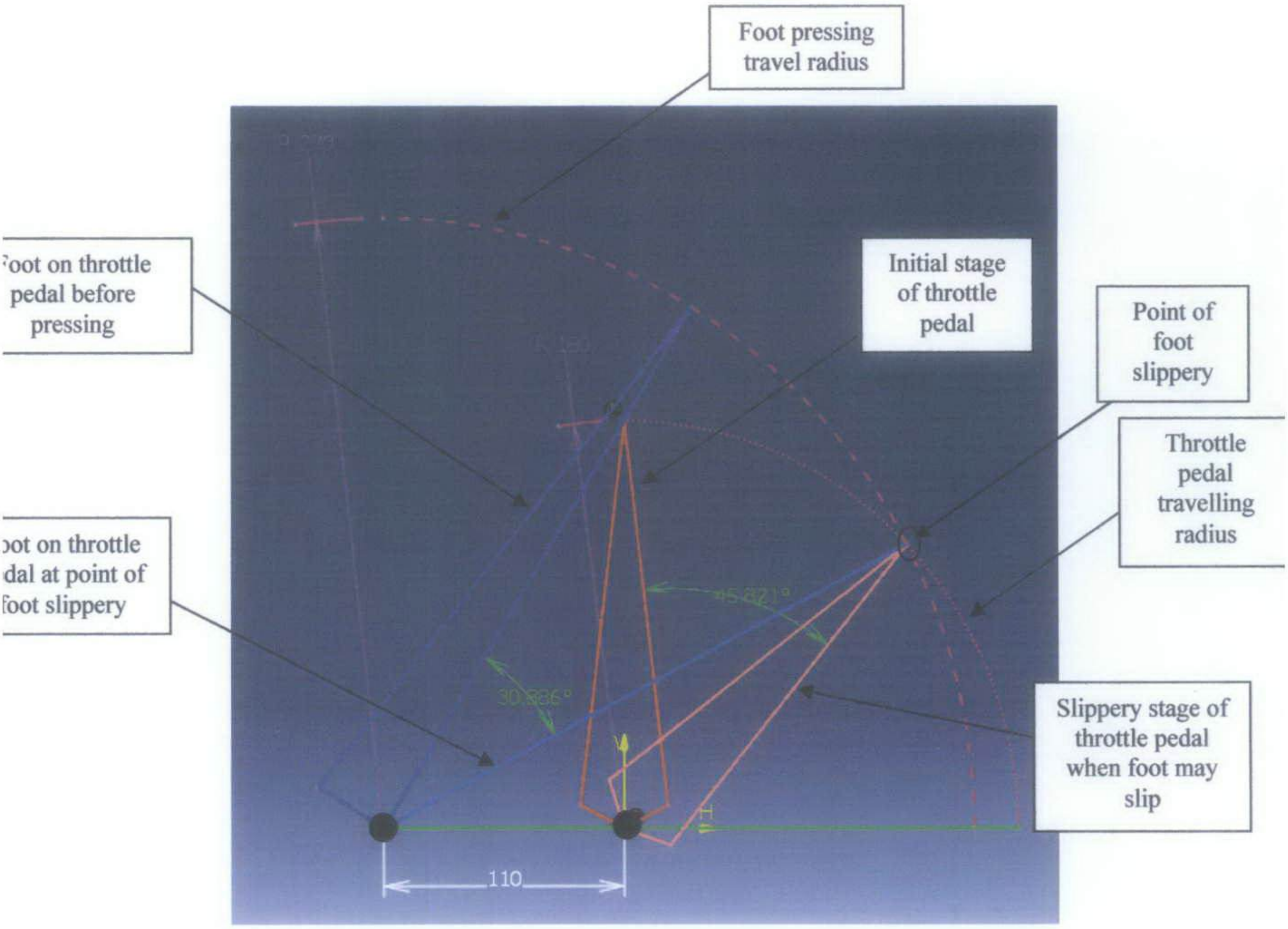


Figure 4.2: Diagram of foot depressing for previous pedal design

From the diagram analysis, new pedal was proposed in order to avoid slippery of foot. Foot slippage during racing is very dangerous for the driver and the car. It will increase the tendency of the driver's foot stuck behind the pedal. The consequences from foot stuck might obstruct the driver's foot to depress the brake in order to stop the car. This can lead the car into an event of accident. With the new design, foot slippery can be avoided, besides the higher contact surface of the pedal can distribute foot force evenly, give comfort ness to the driver and minimum force is required to depress the pedal.

4.2 Mechanical Advantage of The Pedal

In order to reduce the amount of foot force applied by the driver, the pedal should be design with appropriate mechanical advantage or ratio. This section was about to find the ratio of each pedals by calculation of all pedals moment.

4.2.1 Throttle And Clutch Pedal

First, the throttle and clutch pedal dimension need to be determine before moment can be calculated. The dimensions of both pedals are illustrated in **Figure 4.3**. Then, moment diagram has been draw as illustrate in **Figure 4.4** to ease of moment calculation.

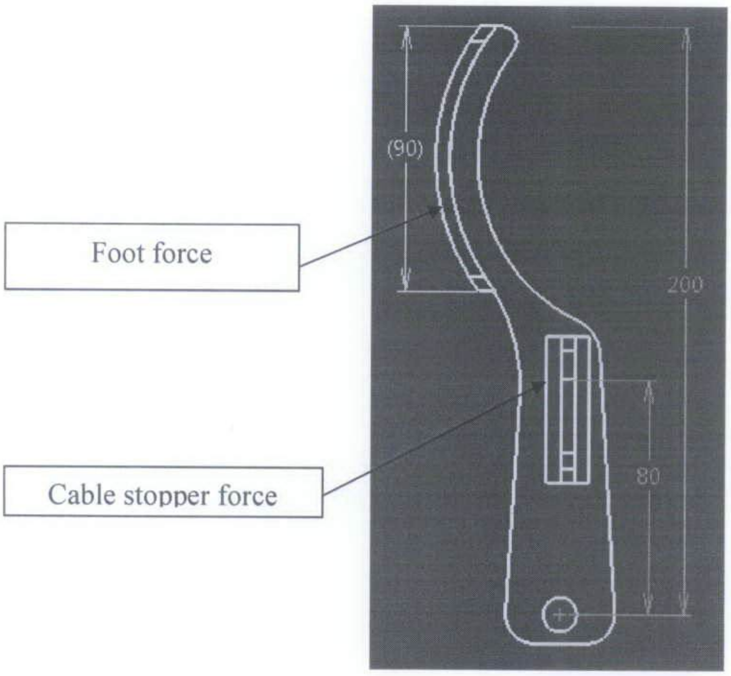


Figure 4.3: Throttle and clutch pedal dimension

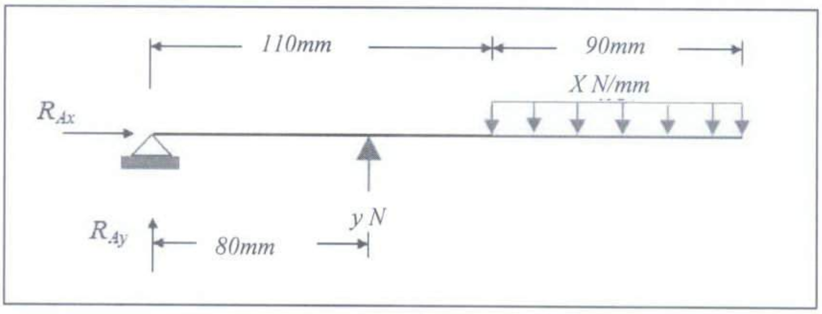


Figure 4.4: Throttle pedal moment diagram

Driver's foot force is assumed as XN/mm (x Newton per millimeter) and cable stopper force is assumed as y N. The distance between foot force and cable stopper force from point of pedal rotation, R_{Ax} and R_{Ay} are shown in the **Figure 4.4**. All pedals are assumed as a rigid body in this calculation.

$$\circlearrowleft^{+} \sum M_A = 0$$

$$= (90mm \times X\,N/mm)\left(110mm + {}^{90mm}/_{2}\right) -$$

$$(80mm \times y\,N) = 0$$

$$(80 \times y) = (90 \times X)\left(110 + {}^{90}/_{2}\right)$$

$$80y = 13950X$$

Foot force is 223N and throttle surface area being press by driver's foot is assumed along 90mm surface pedal.

$$X = {}^{223N}/_{90mm} = 2.478\,{}^{N}/_{mm}$$

$$80y = 13950 \times 2.478 = 34568.1$$

$$y = \frac{34568.1}{80} = 432.10125N$$

$${}^{y}/_{X} = {}^{432.10125N}/_{223N} = {}^{1.938}/_{1}$$

From the calculation, cable stopper force, Y which is the point that pulling throttle and clutch cable is equal to 1.938 times the amount of foot force, X. So, the mechanical advantage (ratio) between foot force, X and cable stopper force, y is **1.938:1**. This mechanical advantage value is same for the clutch pedal and throttle pedal because the dimensions of both pedals are the same.

4.2.2 Brake Pedal

Brake pedal is the most crucial part in pedal box system design because it is the only part that is used to decelerate and stop the car from moving. So, brake pedal should be design carefully with good strength and toughness. Mechanical advantage also one of the important criteria in order to reduce foot force to operate the braking system.

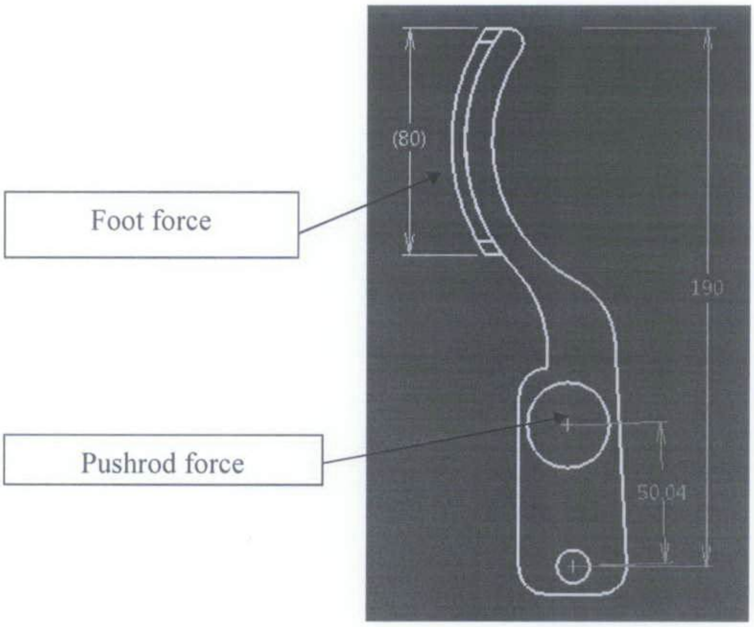


Figure 4.5: Brake pedal dimension

The dimension of the brake pedal is illustrated in **Figure 4.5**. Then, moment diagram has been draw as illustrate in **Figure 4.6** to ease of moment calculation.

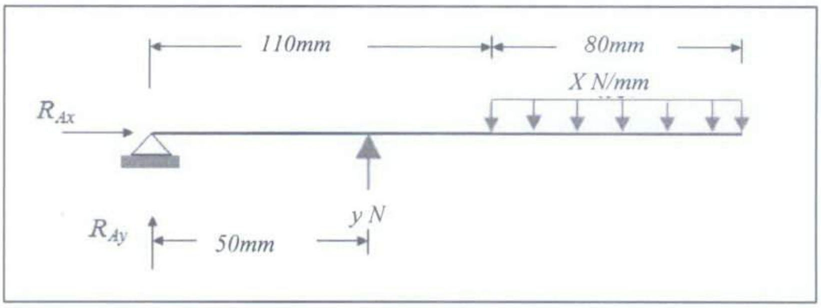


Figure 4.6: Brake pedal moment diagram

A foot force is assumed as X N/mm and pushrod force needed to push the master cylinder is assumed as y N. The distance between both forces from point of pedal rotation, R_{Ax} and R_{Ay} are shown in the **Figure 4.6**.

$$\circlearrowleft^{+} \sum M_A = 0$$

$$= (80mm \times X\,N/mm)\left(110mm + {}^{80mm}/_{2}\right) -$$

$$(50mm \times y\,N) = 0$$

$$(50 \times y) = (80 \times X)\left(110 + {}^{80}/_{2}\right)$$

$$50y \quad = 12000X$$

Foot force is 223N and throttle surface area being press by driver's foot is assumed along 90mm surface pedal.

$$X \quad = {}^{175.74N}/_{80mm} = 2.19675\,{}^{N}/_{mm}$$

$$50y \quad = 12000 \times 2.19675 = 26361$$

$$y \quad = \frac{26361}{50} = 527.22N$$

$${}^{y}/_{X} = {}^{527.22N}/_{175.74N} = {}^{3}/_{1}$$

From the calculation, push rod force, y which is the point that push the master cylinder is equals three times the amount of foot force, X. So, the mechanical advantage between foot force, X and cable stopper force, Y is **3 : 1**.

4.3 Pedals Stress Analysis

4.3.1 Analysis of Second Throttle Pedal Design

In order for the race car to move, throttle pedal need to be depress by foot. In worst condition, the load required to depress the throttle pedal is about 22.7kg. The assumption is made base on previous research by Formula SAE teams. The condition might be due to cable stuck, corrosion of the inner throttle cable or bearing failure.

Pedal surface force, $F_P = mg$

$$F_P = (22.7)(9.81 m/s^2)$$
$$= 222.687N \sim 223N$$

Spring force, F_S = 30N (each)

Total F_S = 30N x 2 (holes)

= 60N

Table 4.1: Loads for pedal analysis

Part	Load
Pedal surface area	223N
Cable stopper	60N
Spring retainer hole	30N (each)
Turning hole	Clamp

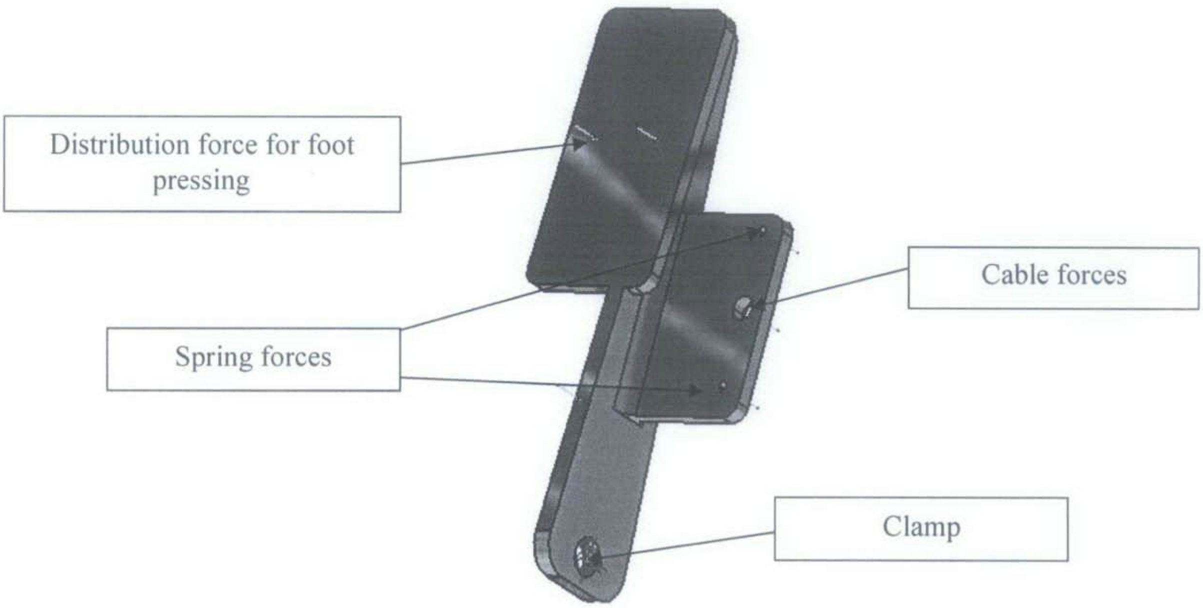


Figure 4.7: Applying loads and restraints

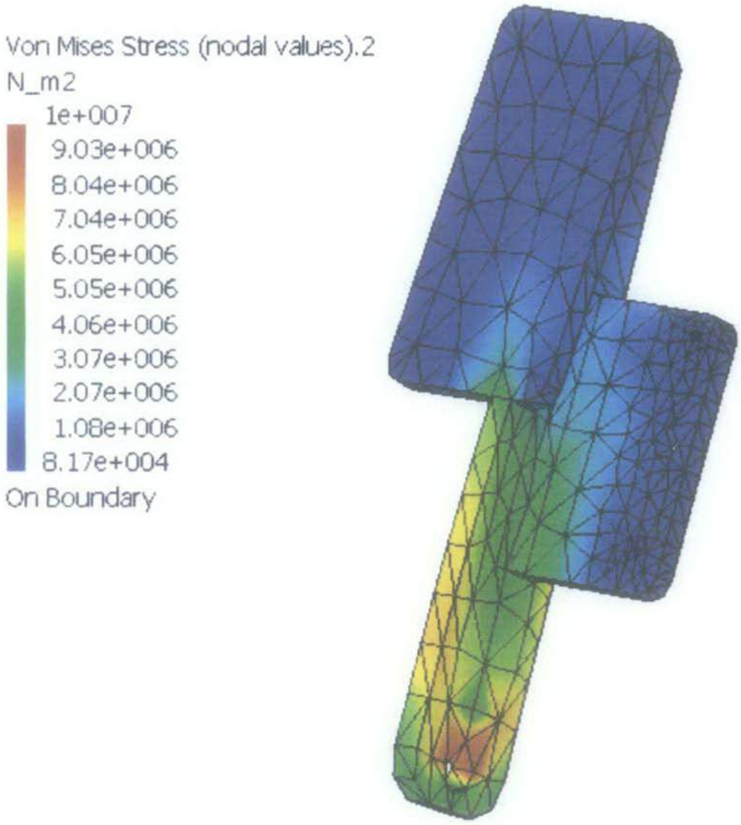


Figure 4.8: Analysis result of 223N load

From the result of analysis, it has been concluded that the pedal design is safe although a 223N of force has been applied. The highest Von Mises Stress values is 10MPa at the clamped turning hole as illustrated in **Figure 4.8**. Aluminium 7075-T6 has Tensile Yield Strength of 508MPa. The highest values of Von Mises Stress from the analysis in not exceed the Aluminium 7075-T6 Tensile Yield Strength. This proves that the design is safe and also Aluminium 7075-T6 is very high strength material used for highly stressed structural parts and suitable for the pedal design.

4.3.2 Analysis of Finalized Throttle Pedal Design

For stress analysis of finalized throttle pedal design, it has been assumed that worst condition load that driver might applied to the throttle pedal is about 75kg. This assumption is made to analyze the safety level of the throttle pedals although worst condition load being applied. More data on this analysis are illustrated in **Table 4.2**.

Table 4.2: Loads for finalized pedal analysis

Part	load
Pedal surface area	75kg x 9.81 = 735.75N
Cable stopper	735.75 x 2 = 1471.5N
Turning hole	Clamp

Cable stopper load is two times greater than pedal foot force because of pedal mechanical advantage (ratio) that has been calculated in **section 4.2.1.**

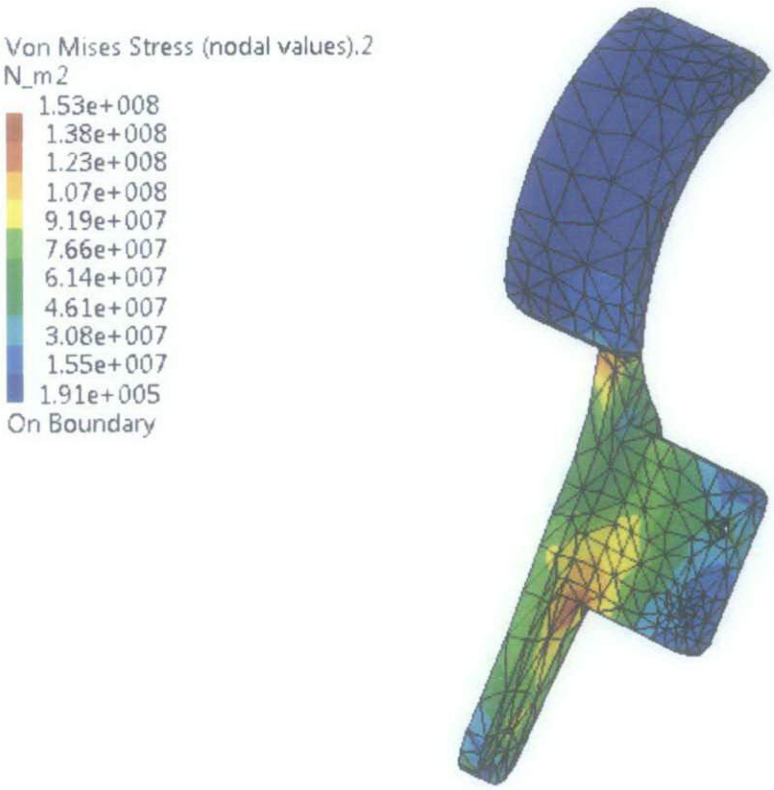


Figure 4.9: Analysis result of finalized throttle pedal design

From the result of analysis, the finalized throttle pedal is safe although a 75kg of load has been applied. The highest Von Mises Stress value is 153MPa at the red colour area as illustrated in **Figure 4.9**. Aluminium 7075-T6 has Tensile Yield Strength of 508MPa. The highest values of Von Mises Stress from the analysis in not exceed the Aluminium 7075-T6 Tensile Yield Strength. This proves that the design is safe although 75kg load is applied.

4.3.3 Analysis of Initial Brake Pedal Design

Before brake pedal is being analyzed, the data on braking system need to be gathered. First, the braking system's data are obtained from the person in charge for Formula SAE new brake design and analysis. The data on braking system has shown in **Table 4.3**.

Table 4.3: Data on braking system of 2008 FSAE (Third) Car

Section	Specification Parameters		Calculated Parameters	Front	Rear	Unit
Tires	Radius (m)	0.265	Weight Transfer	1103.63	1348.88	N
			Braking Force (BF)	1103.63	1348.88	N
			BF / Tire	551.81	674.44	N
			Torque / Tire	146.23	178.73	Nm
Rotor	Radius (m)	0.127	Heat Flux Applied / Rotor	15323.83	18729.20	J/s
			Heat Flux Applied/ Pad	7661.92	9364.60	J/s
			Heat Flux Density	945915.63	1156123.38	J/s.m2
			BF / Rotor	1151.42	1407.30	N
			BF / Pad	575.71	703.65	N
Caliper	Bore (m)	0.044	Normal Force/Caliper	2056.11	2513.03	N
	Area (m2)	0.002	Normal Force/Piston	1028.05	1256.51	N
Hydraulic Brake Line Press			Pressure	662494.46	809718.46	Pa
Master Cylinder	Bore (m)	0.018	Pushrod Load	164.4885	201.0423	N
	Area (m2)	0.0002				
Brake Pedal	Pedal Ratio	3.000	Pedal Force	68.5369	83.7676	N
	Pedal Efficiency	0.800				
Foot	Max Force (N)	445	Total Pedal Force	152.30		N
			Total Pedal force	15.53		kg
			% from Driver Capabiliy	34.23		%
Balance Bar			Balance Bar Setting	0.4500	0.5500	
			Brake Force Distribution	45.00	55.00	%

In order to decelerate the Formula SAE race car, brake pedal need to be depressed by foot. In worst condition, the drivers tend to hardly push the brake pedal if they encounter a panic state such as the car lost control and to avoid accident. The load need to operate the brake pedal is about 153N in normal condition. The assumption for the worst condition load is about two times the normal load which is 350N. The brake pedal ratio that has been calculated is 3:1. So, the load acting on the pushrod is about 459N and 1050N for normal and worst condition respectively. The brake pedal is assuming

100% efficiency in order to obtain maximum load for the pushrod to operate master cylinder. All loads are illustrated in **Table 4.4** and Figure **4.10.**

Table 4.4: Loads for brake pedal analysis

Part	Load
Total load (**normal condition**) of pedal on pedal surface	153N
Total load (**worst condition**) of pedal on pedal surface	350N
Pushrod load required to push master cylinder (**normal condition**)	459N
Pushrod load to push master cylinder (**worst condition**)	1050N
Turning hole	Clamp

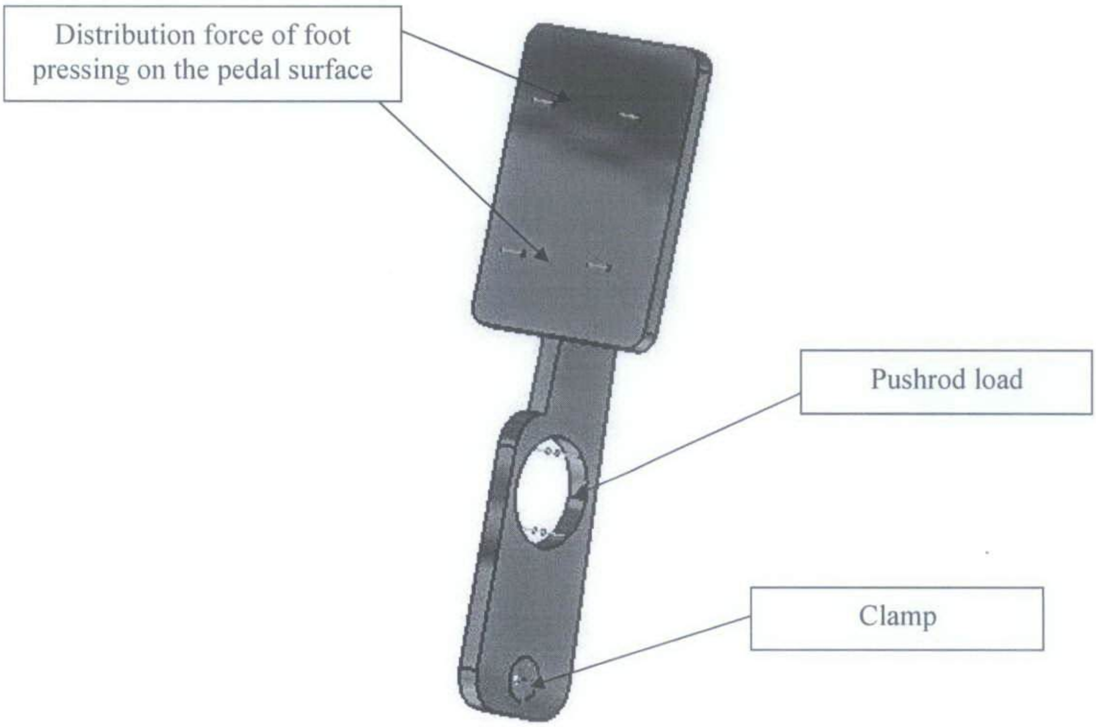


Figure 4.10: Applying loads and restraints

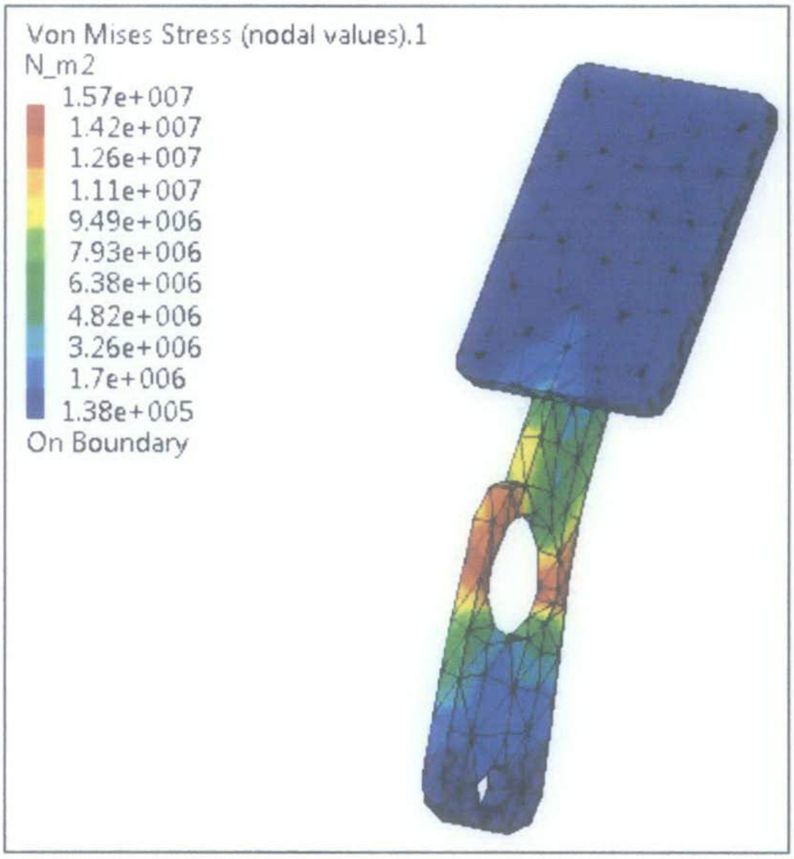


Figure 4.11: Resulting brake pedal analysis for normal load condition

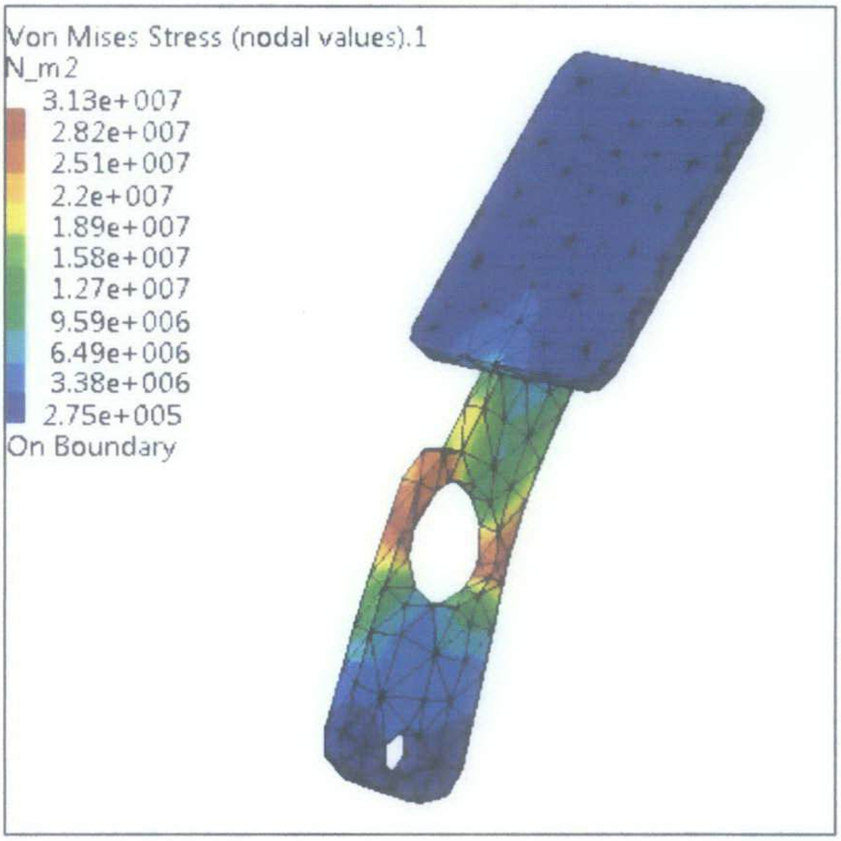


Figure 4.12: Resulting brake pedal analysis for worst load condition

From the analysis result, it was proven that the initial pedal design is safe although the worst condition load of 350N has been applied to the pedal. From **Figure 4.12**, the highest Von Mises Stress value is 31.3MPa at the pushrod hole. In the normal brake pedal operating condition, Von Mises Stress value is about 15.7MPa as shown in **Figure 4.11**. The highest value of Von Mises Stress from the analysis in not exceeds the Tensile Yield Strength value of Aluminium 7075-T6. For the analysis, it concluded that brake pedal design is safe although worst condition load is applied.

4.3.4 Analysis of Finalized Brake Pedal Design

The data on braking system is shown in **Table 4.3** and finalized brake pedal design is illustrated in **Figure 3.7**. For this analysis case for worst load condition, 100kg of load was assumed to be applied on brake pedal. The normal condition load for the brake pedal to operate is 153N. The brake pedal ratio that has been calculated is 3:1. The pushrod load required to operate the brake pedal is illustrated in **Table 4.5**.

Table 4.5: Loads required operating the brake pedal

Part	Load
Total load (**normal condition**) of pedal on pedal surface	153N
Total load (**worst condition**) of pedal on pedal surface	981N
Pushrod load required to push master cylinder (**normal condition**)	459N
Pushrod load to push master cylinder (**worst condition**)	2943N
Turning hole	Clamp

From the analysis result, it was proven that the finalized pedal design is safe although the worst condition load of 100kg has been applied to the pedal. From **Figure 4.14**, the highest Von Mises Stress value is 172MPa. In the normal brake pedal operating condition, Von Mises Stress value is about

30.8MPa as shown in **Figure 4.13**. The highest value of Von Mises Stress from the analysis in not exceeds the Tensile Yield Strength value of Aluminium 7075-T6. For the analysis, it concluded that brake pedal design is safe although 100kg of load is applied.

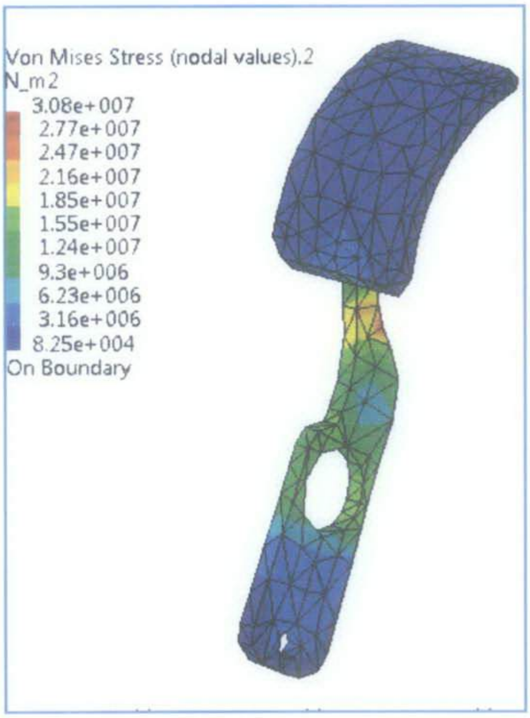


Figure 4.13: Resulting brake pedal analysis for normal load condition

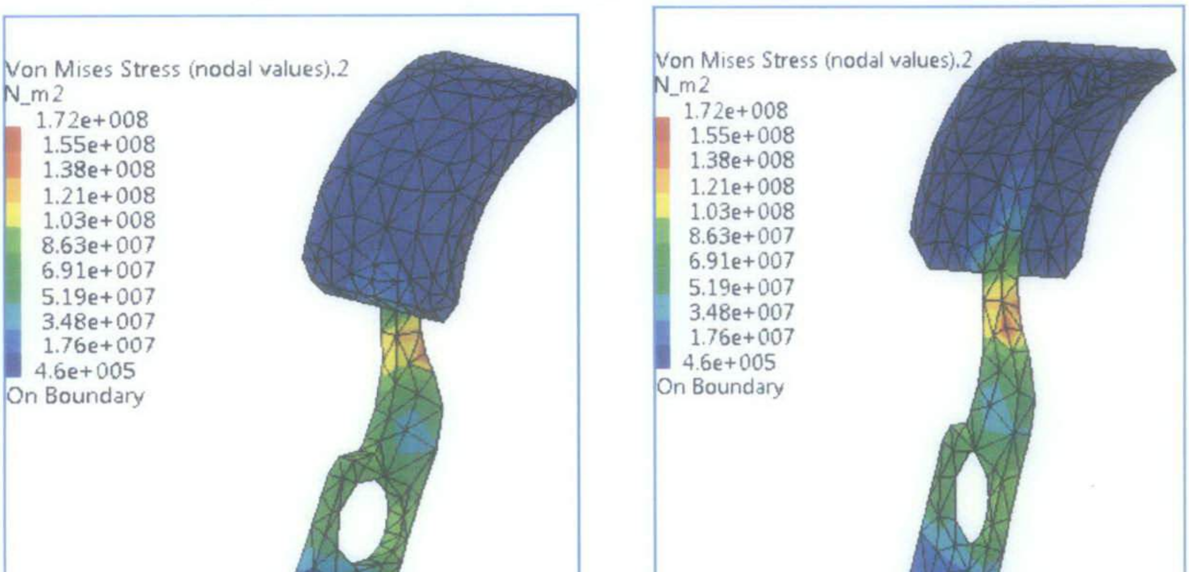


Figure 4.14: Resulting brake pedal analysis for worst load condition

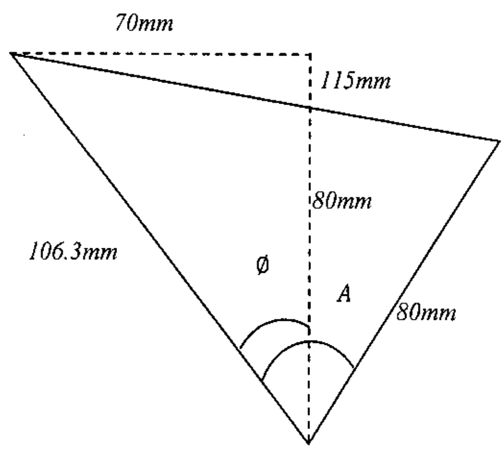


Figure 4.16: Throttle cable linkage diagram

The dotted line in **Figure 4.16** had shown the initial dimension between the fixed and moving stopper. The maximum pedal travel angle θ will pull the throttle pedal about 45mm.

$$hyp^2 = 70^2 + 80^2$$
$$hyp = 106.30mm$$

To find $\emptyset$ and A;

$$\cos\emptyset = \frac{80}{106.3} = 0.7526$$
$$\emptyset = \cos^{-1} 0.7526 = 41.18°$$

$$a^2 = b^2 + c^2 - 2bc\cos A$$
$$115^2 = 106.3^2 + 80^2 - 2(106.3)(80)\cos A$$
$$\cos A = \frac{4474.69}{17008} = 0.26309$$
$$A = \cos^{-1} 0.26309 = 74.746°$$

$$Throttle\ pedal\ travel\ angle, \theta = 74.75° - 41.18° = 33.57°$$

From the calculation, the throttle pedal needs to turn about 33.57° in order to fully open the throttle valve.

4.4.2 Clutch Pedal

No pressure on the clutch pedal means that the clutch plates are engaged (driving), while depressing the pedal disengages the clutch plates, allowing the driver to shift gears or coast. Clutch pedal controls the disengagement of clutch plates or clutch discs. This disengagement mechanism is controlled by the linkage connected to the clutch pedal. For the proposed pedal box design, the linkage that controls the clutch plate's disengagement is a clutch cable that attached to cable stopper. The clutch linkage system is similar with the illustrated **Figure 4.15**.

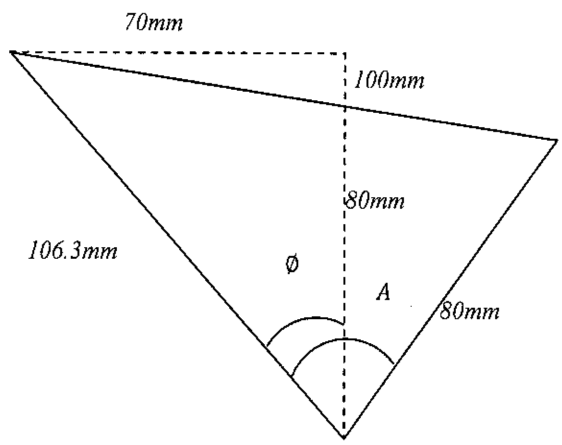


Figure 4.17: Clutch cable linkage diagram

In order to pull out the clutch cable, the clutch pedal needs to be depress to a certain angle. When the pedal moved, the cable stopper which is part of clutch pedal will pull out the clutch cable from the fixed cable stopper. From previous researches, the maximum distance of clutch cable that required disengaging the clutch plates is about 30mm. The initial distance of the cable stopper is70mm as illustrated in **Figure 4.17**. In order to fully disengage the clutch plate, the cable stopper needs to move apart from each other about 100mm.

To find $\emptyset$ and A;

$$\cos\emptyset = \frac{80}{106.3} = 0.7526$$

$$\emptyset \quad = \cos^{-1} 0.7526 = 41.18°$$

$$a^2 \quad = b^2 + c^2 - 2bc\cos A$$

$$100^2 = 106.3^2 + 80^2 - 2(106.3)(80)\cos A$$

$$\cos A = \frac{7699.69}{17008} = 0.4527$$

$$A \quad = \cos^{-1} 0.45271 = 63.08°$$

$$Clutch\ pedal\ travel\ angle, \theta = 63.08° - 41.18° = 21.90°$$

From the calculation, the clutch pedal needs to turn about 21.90° in order to disengage the clutch plates.

4.4.3 Pedals Simulation

After throttle and clutch pedals travel angle have been calculated, the pedal box system need to be simulate using CATIA software. This simulation was about to show the position of the throttle and clutch pedals when it fully depress to open the throttle valve and disengage the clutch plates respectively. The illustrated **Figure 4.18** shown the initial position of the pedals when there are no loads applied to the pedals. After the throttle and clutch pedals were fully depress, it will move in circular motion due to pivoted turning hole until its reach their appropriate angle, 33.57° movement for throttle pedal and 21.90° movement for clutch pedal. The final position of the pedals was illustrated in **Figure 4.19**.

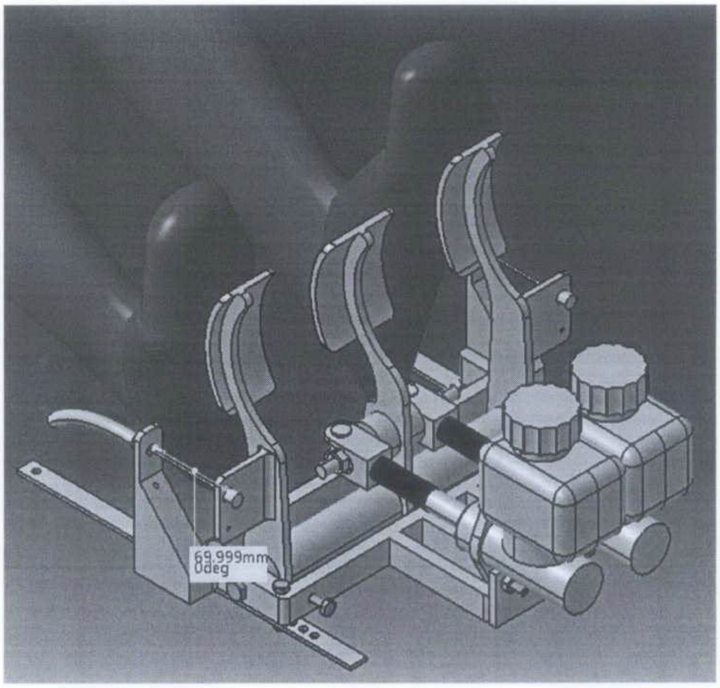


Figure 4.18: Pedal box in initial position

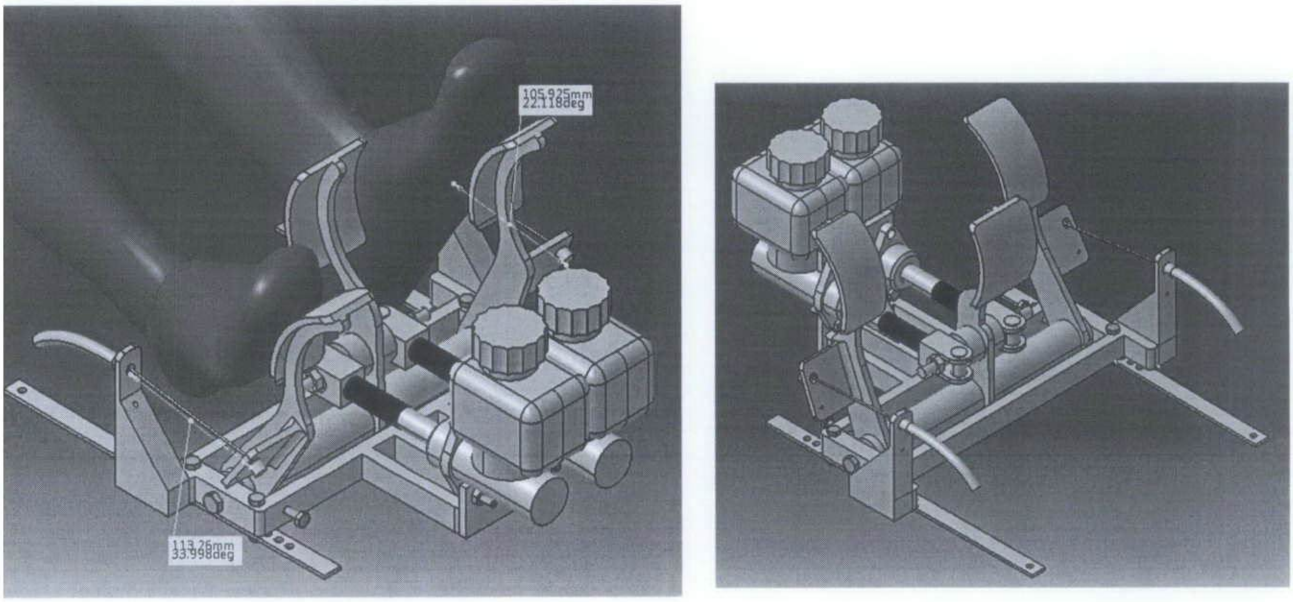


Figure 4.19: Pedal box in fully depress position

4.5 Kinematics Analysis of The Pedals

The main purpose of this section is to compare between new pedals design (UTP Formula SAE Third Car) and previous pedals design (UTP Formula SAE Second Car). From the comparison results, the optimized design between new pedals and previous pedals can be verify. For the dynamic and kinematic analysis, throttle pedal, brake pedal and clutch pedal are being compared with the previous pedals design. From this dynamic and kinematic analysis, force or load distribution of the pedals can be obtained by running the analysis in ADAMs View software.

First, each pedal need to be simulate in ADAMs. Each pedal simulation in ADAMs View must follow the exact dimensions of the designed pedals in order to obtain accurate result. After each pedal has been simulating, all joints, loads, contact surfaces and others need to be carefully verify.

4.5.1 Throttle Pedal

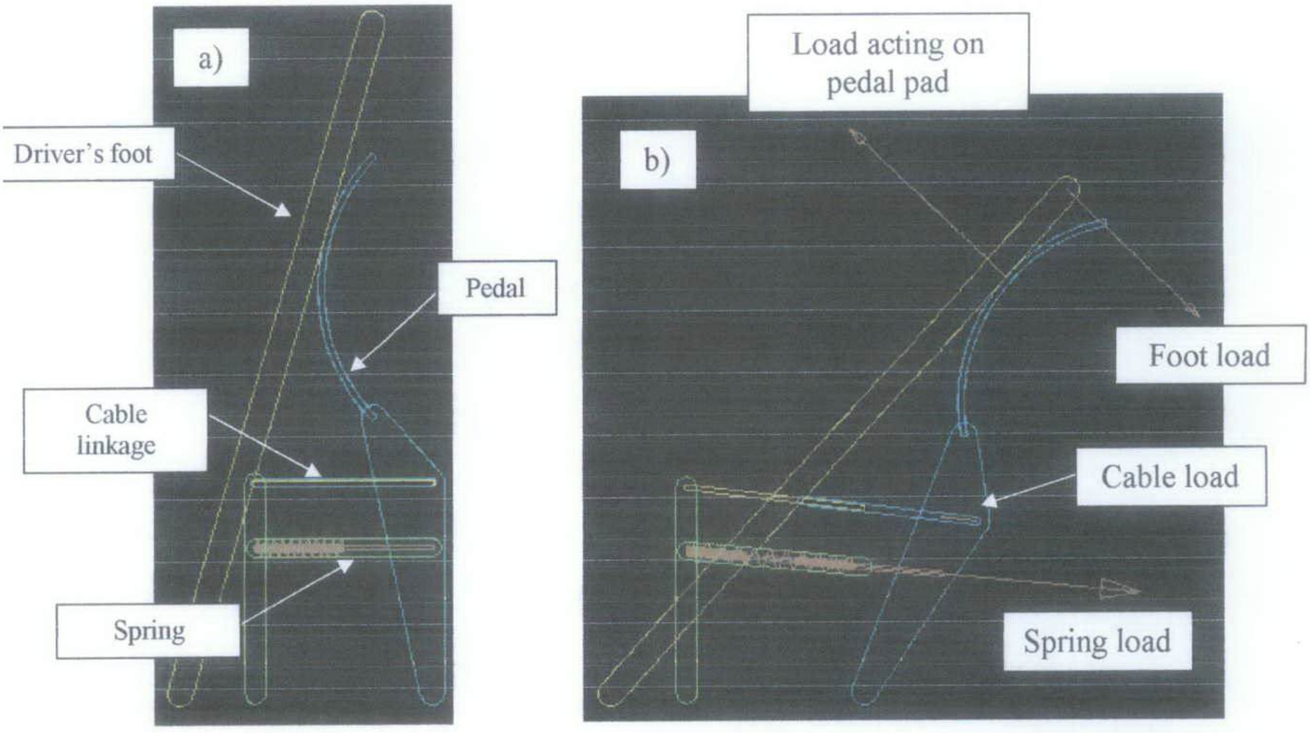


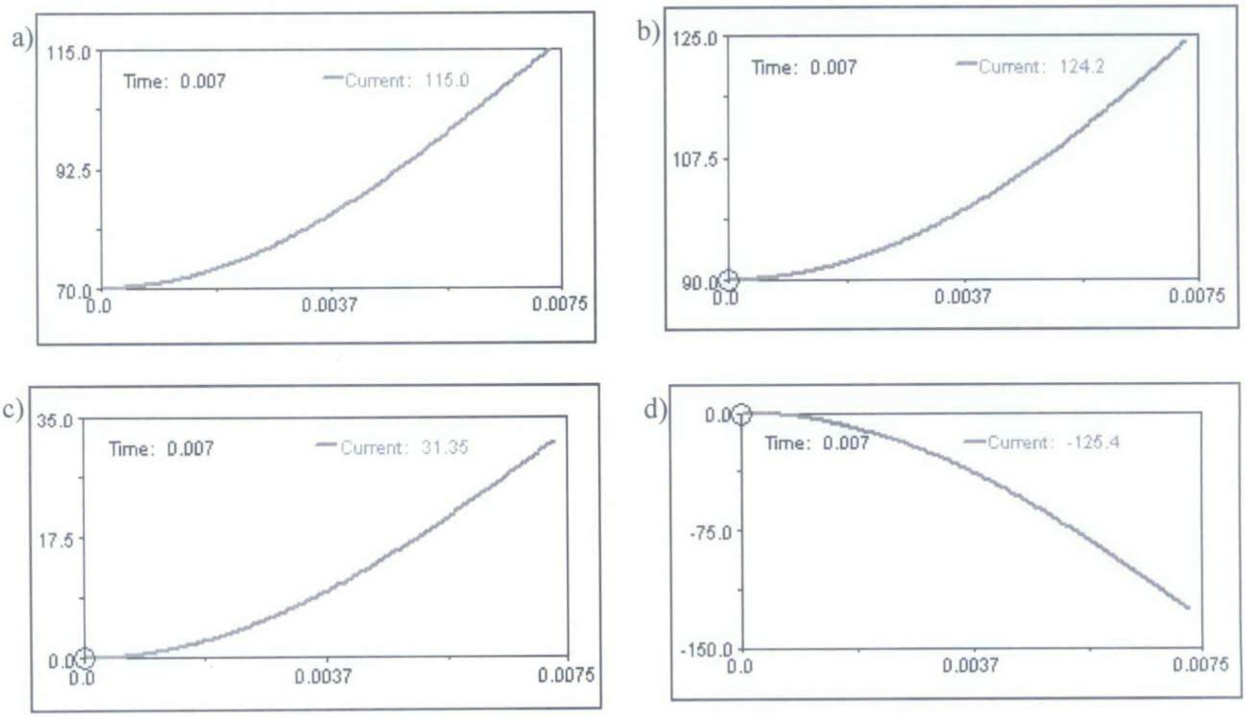
Figure 4.20: New throttle pedal simulation (UTP FSAE Third Car)
(a) Initial position (no load is applied)
(b) Final position (fully open the throttle valve)

Figure 4.20 shows throttle pedal that has been simulate in ADAMs View, initial position and final position. The red arrows in Figure **4.20 (b)** show the loads acting on the new throttle pedal linkage system.

Table 4.6: New throttle pedal loads (ADAMs)

Part	Load
Throttle foot load	50N
Throttle cable load	10N
Spring (stiffness coefficient)	4 N/mm

From various researches, throttle cable load that is needed to open and close the throttle valve is about 10N. Spring stiffness coefficient of 4 N/mm for throttle and clutch pedal has been chosen in order to retract the pedal back to initial position. **Table 4.6** shows the loads that have been applied to the new throttle pedal in order to identify pedal force distribution.



e)

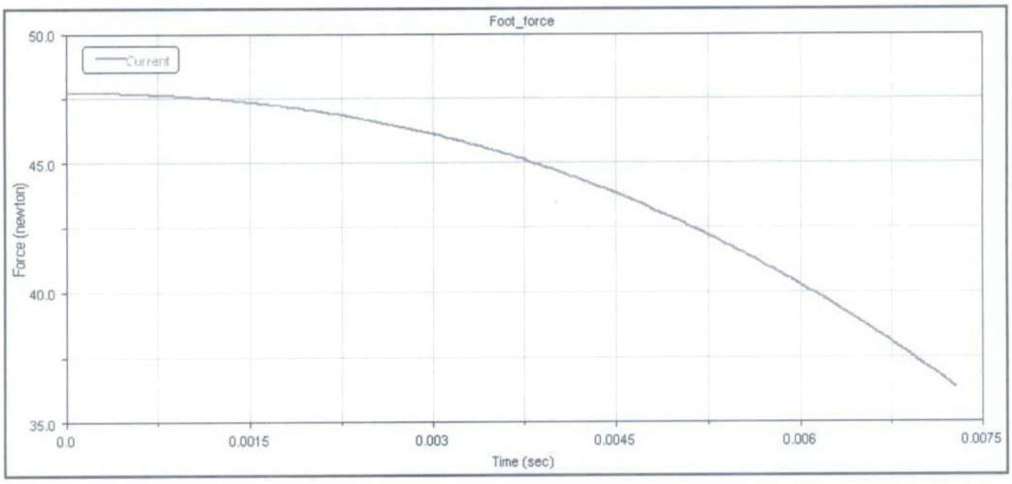


Figure 4.21: Analysis results on new throttle pedal (ADAMs View)
(a) Throttle cable travel distance (b) Throttle pedal travel angle
(c) Spring elongation (d) Spring pulling load (e) Pedal load (force) distribution

Figure 4.21 shows the results that have been obtained from ADAMs View dynamic and kinematic analysis. The analysis results in **Figure 4.21 (a)** and **Figure 4.21 (b)** are just similar with **section 4.4.1** calculation result. It justify that in order to pull the throttle cable about 45mm, the throttle pedal need to move about 34.2° in ADAMs View simulation analysis and 33.57° of pedal movement by calculation method. The spring elongation of 31.35mm and spring pulling load of 125.4N shown in **Figure 4.21 (c)** and **Figure 4.21 (d)**, justify that the chosen spring has enough load to retract the pedal back to initial position.

Figure 4.22 shows previous throttle pedal that has been simulate in ADAMs View, initial position and final position. The red arrows in Figure **4.22 (b)** show the loads acting on the previous throttle pedal linkage system. The throttle cable load and spring stiffness coefficient as shown in **Table 4.6** are applied to the previous throttle pedal. The throttle cable load and spring stiffness coefficient are similar with the new throttle pedal analysis because we want to compare the results. The comparison result of force distribution between these two pedals will verify which pedal is the best.

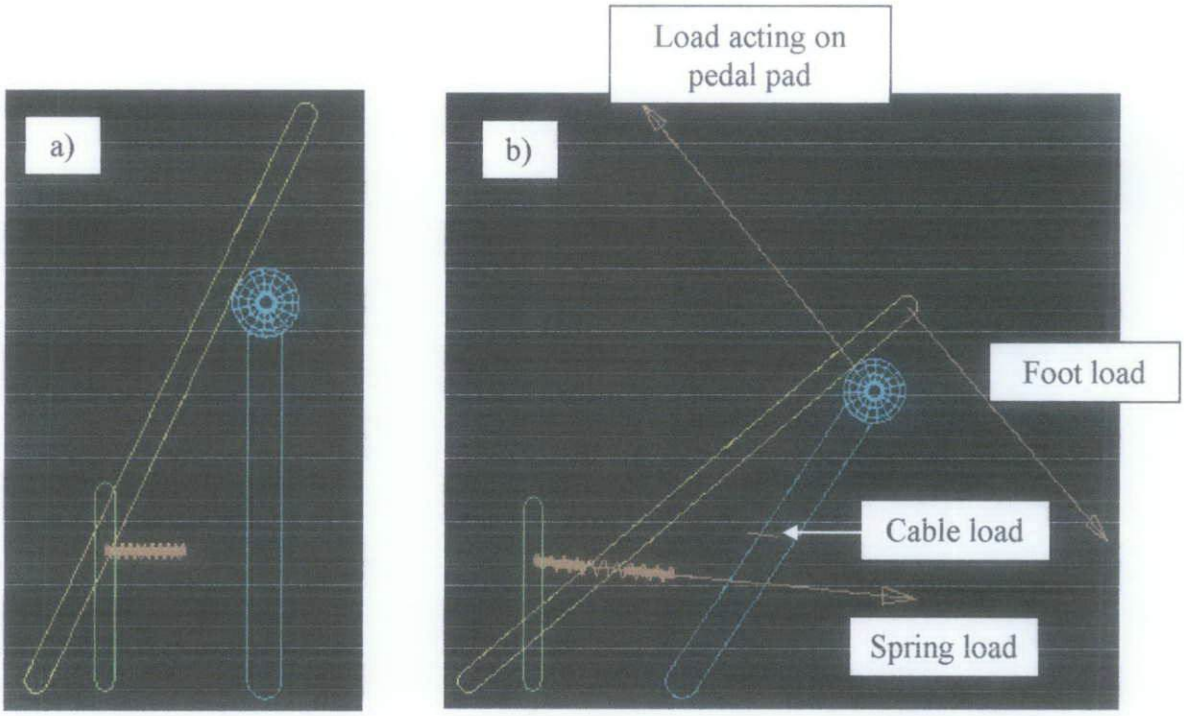


Figure 4.22: Previous throttle pedal simulation (UTP FSAE Second Car)
(a) Initial position (no load is applied)
(b) Final position (fully open the throttle valve)

In order to depress the previous throttle pedal for the same throttle cable load and spring stiffness coefficient, a 99N of foot load is required to depress the pedal. This foot load value is obtained from the analysis. The new throttle pedal linkage system just needs 50N of foot load to depress the pedal which mean the load different between the two pedals is 49N. The comparison of force distribution analysis results are shown in **Figure 4.21 (e)** and **Figure 4.23**. That conclude, the new throttle pedal design will reduce the load required to depress the pedal about 49N and thus the new design is the best to be proposed as the new UTP Formula SAE throttle pedal.

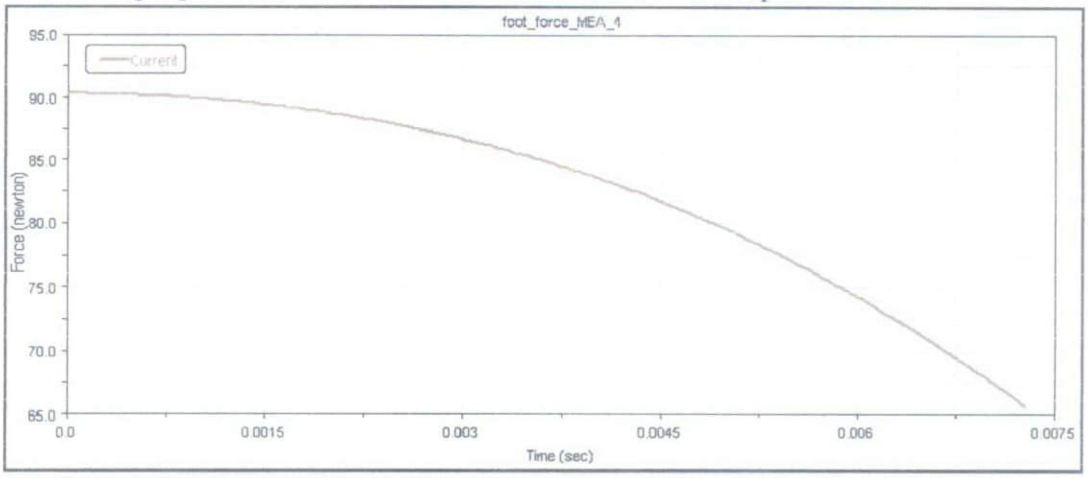


Figure 4.23: Previous throttle pedal load (force) distribution result

4.5.2 Clutch Pedal

For kinematic and dynamic analysis of the new and previous clutch pedals, the new and previous throttle pedals ADAMs' simulation as illustrated in **Figure 4.20** and **Figure 4.22** were used. The reason is the dimensions of both new and previous clutch and throttle pedals are just the same. For this analysis, only clutch cable load is modified to 35N. This is because, from various researches on CBR 600 engine, the load needed to disengage clutch plates is about 35N. The analysis data is shown in **Table 4.6**.

Table 4.7: New clutch pedal loads (ADAMs)

Part	Load
Clutch foot load	50N
Clutch cable load	35N
Spring (stiffness coefficient)	4 N/mm

Figure 4.24 shows the results that have been obtained from ADAMs View dynamic and kinematic analysis. The analysis results in **Figure 4.24 (a)** and **Figure 4.24 (b)** are just similar with **section 4.4.2**4.4.1 calculation result. It justify that in order to pull the clutch cable about 30mm, the throttle pedal need to move about 22° in ADAMs View simulation analysis and 21.90° of pedal movement by calculation method. The spring elongation of 20.73mm and spring pulling load of 82.95N shown in **Figure 4.24 (c)** and **Figure 4.24 (d)**, justify that the chosen spring has enough load to retract the pedal back to initial position.

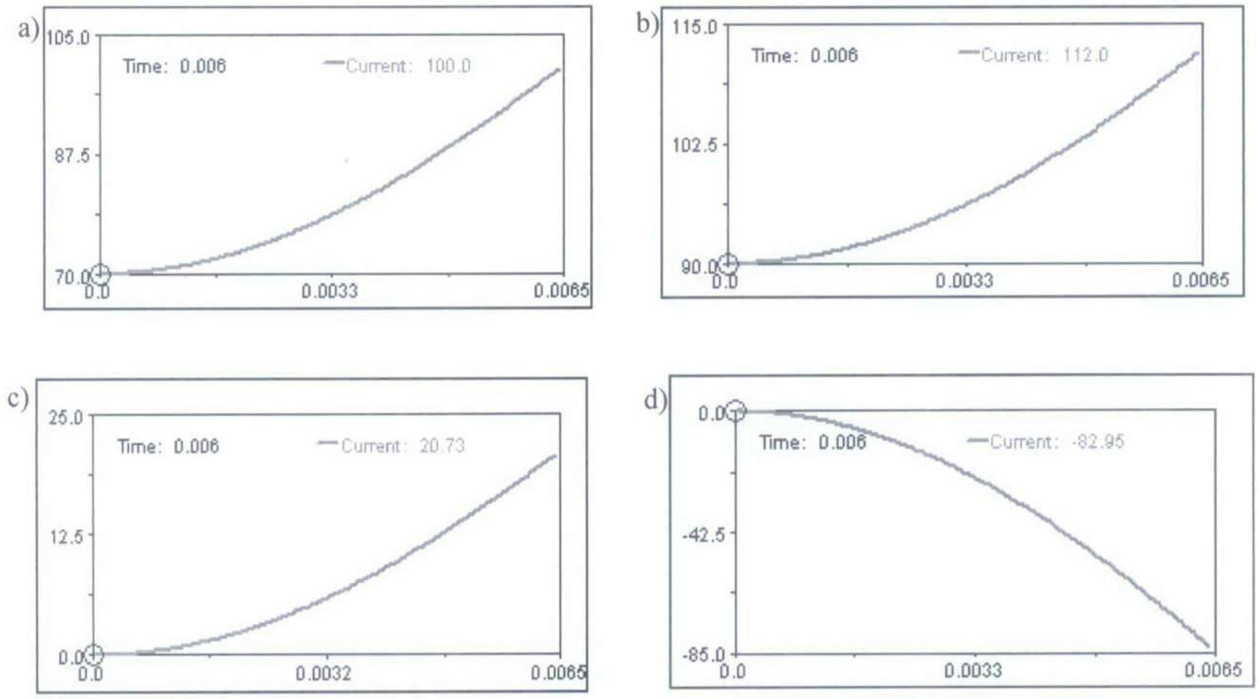
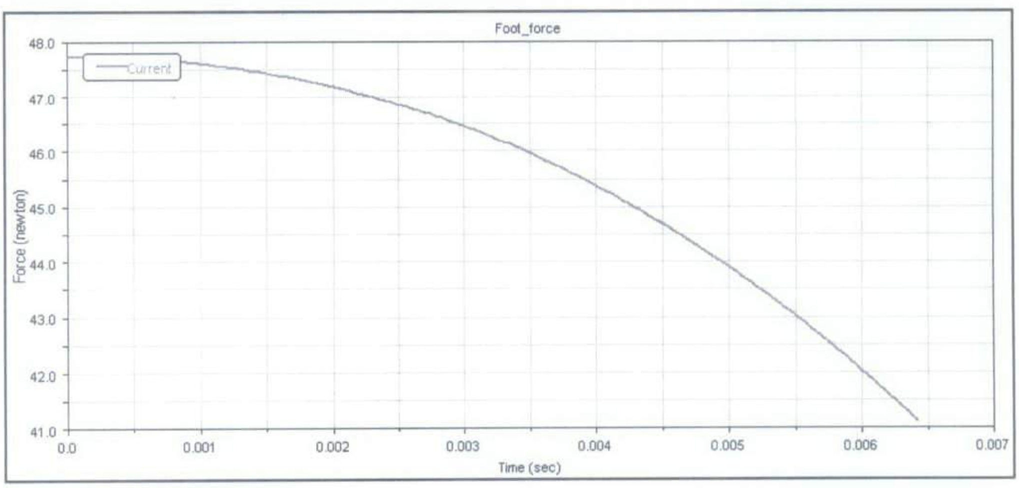


Figure 4.24: Analysis results on new clutch pedal (ADAMs View)
(a) Clutch cable travel distance (b) Clutch pedal travel angle
(c) Spring elongation (d) Spring pulling load

For previous clutch pedal analysis, clutch cable load and spring stiffness coefficient as shown in **Table 4.7** were used. This is because, by applying same parameters as new clutch pedal, we can find how much foot load required for previous clutch pedal. If the foot load required for the previous clutch pedal (UTP FSAE Second Car) is bigger than new clutch pedal (UTP FSAE Third Car), it shows that the new pedal design is the best because it just need smaller load to depress the pedal. Smaller load means that the driver just need to apply small load in order to depress the pedal. This can ease the driver to control the pedals.

a)



b)

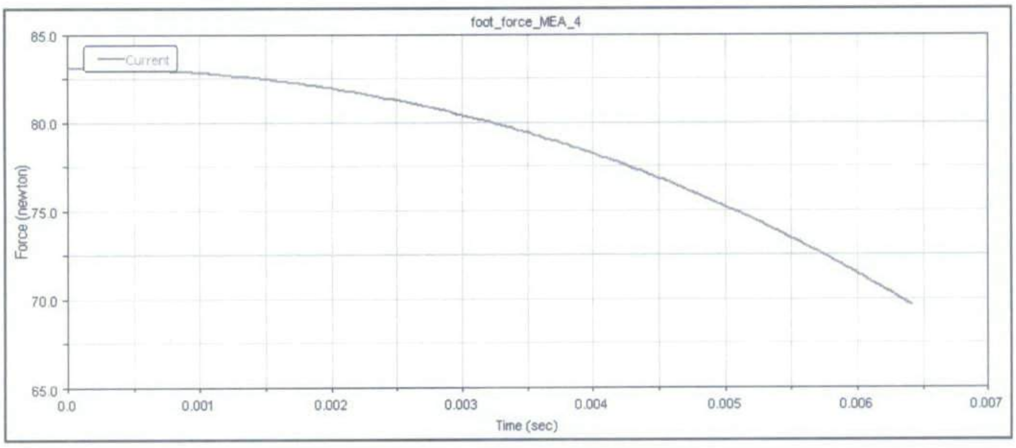


Figure 4.25: Clutch pedal load (force) distribution analysis result (a) New clutch pedal design (b) Previous clutch pedal design

In order to depress the previous clutch pedal for the same clutch cable load and spring stiffness coefficient, a 91.1N of foot load is required to depress the pedal. This foot load value is obtained from the analysis. The new clutch pedal linkage system just needs 50N of foot load to depress the pedal which mean the load different between the two pedals is 41.1N. The comparison of force distribution analysis results are shown in **Figure 4.25 (a)** and **Figure 4.25 (b)**. That conclude, the new pedal design will reduce the load required to depress the pedal and thus the new design is the best to be proposed as the new UTP Formula SAE clutch pedal.

4.5.3 Brake Pedal

For dynamic and kinematic analysis of new and previous brake pedal, the ADAMs design simulation is shown in **Figure 4.26**. Brake pedal uses balancer bar to push the pushrods. Then, the pushrods will push front and rear brake master cylinder. The front and rear brake master cylinder will activate the brake pad and clamp the brake disk. Thus, this action will decelerate and stop the car depends on how hard driver applied the force.

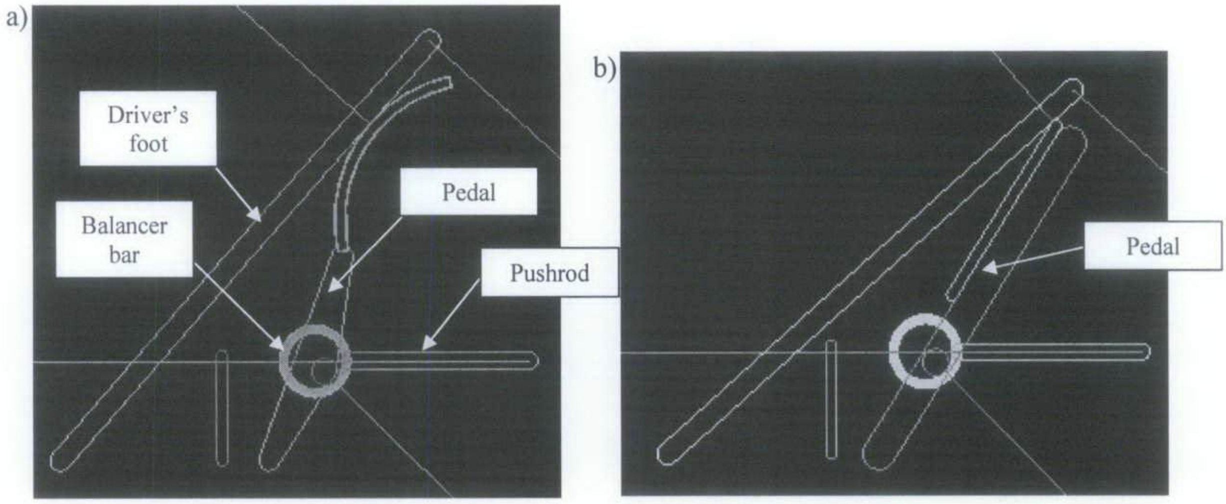


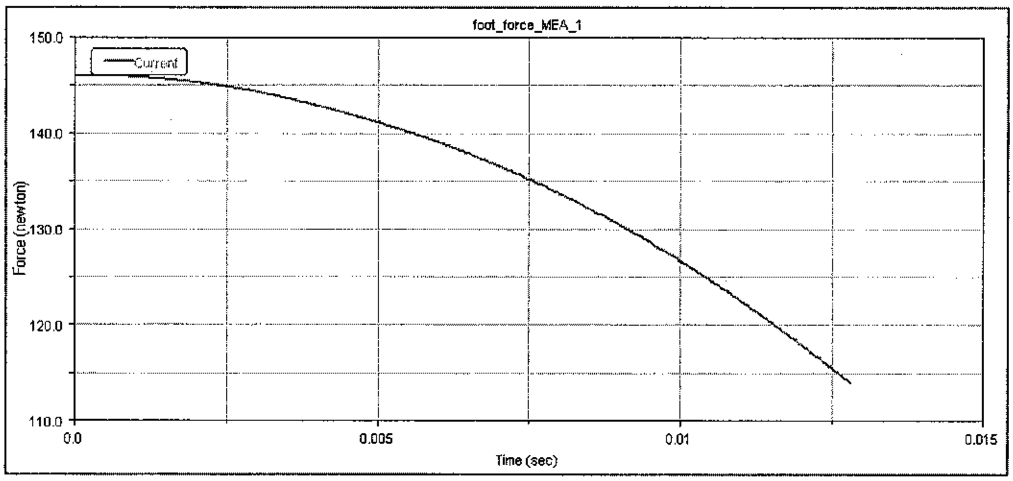
Figure 4.26: Brake pedal simulation and acting force (a) New brake pedal (b) Previous brake pedal

Table 4.8 shows the data on braking system that has been obtained from new UTP FSAE Brake Section. Brake master cylinder needs a 370N of load to activate the front and rear braking systems. In order to push the brake master cylinder, pushrod is connected between the pedal and master cylinder. By including the ratio of the brake pedal, a 153N of load is required to depress the brake pedal.

Table 4.8: New brake pedal loads

Part	Load
Brake foot load	153N
Pushrod load	370N

The results illustrated in **Figure 4.27 (a)** and Figure **4.27 (b)** show the force distribution between the new brake pedal and previous brake pedal. For the previous brake pedal, a 164.25N of foot load required to push a 370N of brake master cylinder load. This justify that the new pedal box design is the best because it just required 153N of load to push the master cylinder. The different between the loads is about 11.25N or about 1.15kg.

a)


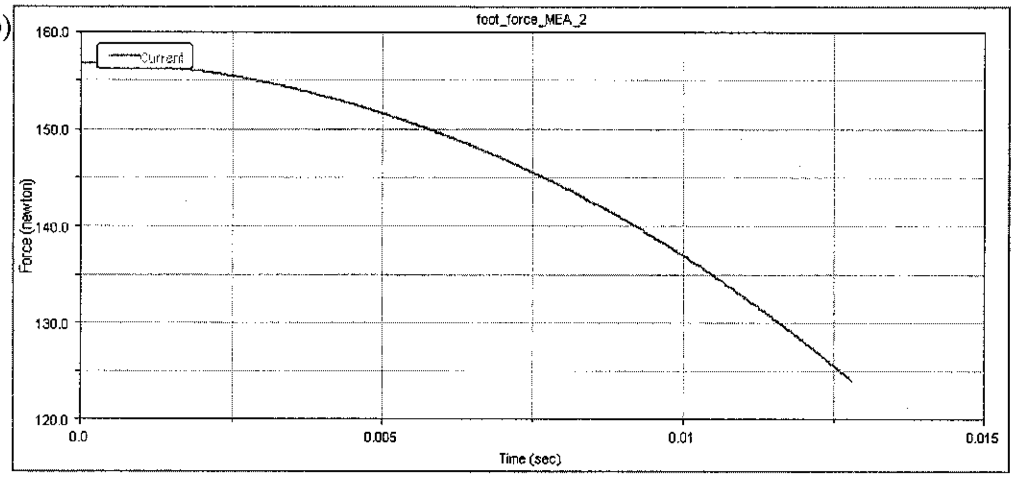
b)


Figure 4.27: Brake pedal load (force) distribution analysis result (a) New brake pedal design (b) Previous brake pedal design

From the analysis results, it is clear that the new brake pedal design is the best because it can minimize foot load for about 1.15kg. This ensures that the driver will not require much load to depress the brake pedal. The new pedal box system can ease driver's work to control the race car without loosen his/her focus to the race track.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Many factors were taken into concern when designing the pedal box system for the Formula SAE vehicle. Some of these parameters were common to all sections such as; safety, weight reduction, reliability, ease of manufacture, cost of components, complexity of design and previous design experience. The pedal box new design is believed can optimized driver's interface between the driver and the engine such as throttle and clutch, besides the design will enhance interface between driver and braking system.

The implementation of the new pedal box system design will improve performance of UTP FSAE race car by enhancing the pedal box system process to minimize the foot load required to depress the pedals. The new pedal box system design will also benefit the driver by providing a comfortable way to depress the pedal without compromising his/her safety.

5.2 Recommendation

For future development of UTP FSAE team, the documentation of research, designing and development process of all UTP Formula SAE peripherals should be properly recorded. In order to build a pin point accuracy race car, the fabrication process of FSAE car need to be fabricate using latest machining technology such as CNC machine, EDM and Profiling machine. This will ensure all tubing and bar cutting dimensions are accurate as per design.

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[8] http://www.howstuffworks.com (How Camp Cars Work)

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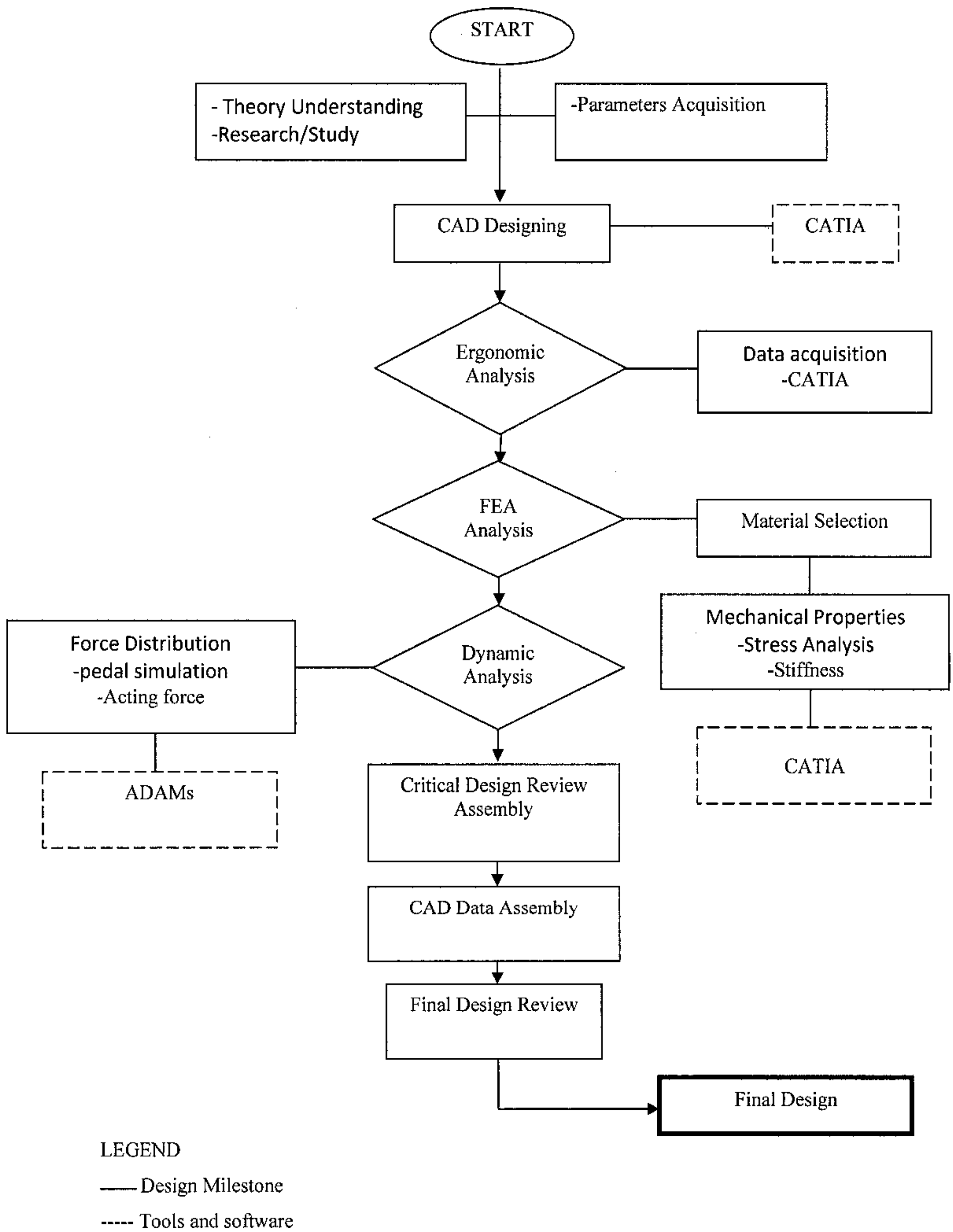
[10] Hibbeler R.C., Mechanics of Materials, Seventh Edition

APPENDICES

APPENDIX 1 - METHODOLOGY



APPENDIX 2 - GANTT CHART

First Semester

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■	■						Mid-semester break							
2	Preliminary Research Work		■	■	■											
3	Submission of Preliminary Report				●											
4	Project Work					■	■	■								
5	Submission of Progress Report									●						
6	Seminar (compulsory)									●						
7	Project work continues									■	■	■	■	■	■	■
8	Submission of Interim Report Final Draft														●	
9	Oral Presentation															●

● Suggested milestone

■ Process

Second Semester

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue	■	■	■					Mid-Semester Break							
2	Submission of Progress Report 1				●											
3	Project Work Continue				■	■	■	■								
4	Submission of Progress Report 2									●						
5	Seminar (compulsory)									●						
5	Project work continue									■	■	■	■			
6	Poster Exhibition											●				
7	Submission of Dissertation (soft bound)													●		
8	Oral Presentation														●	
9	Submission of Project Dissertation (Hard Bound)															●

● Suggested milestone

■ Process

APPENDIX 3 – ALUMINIUM ALLOY 7075-T SERIES

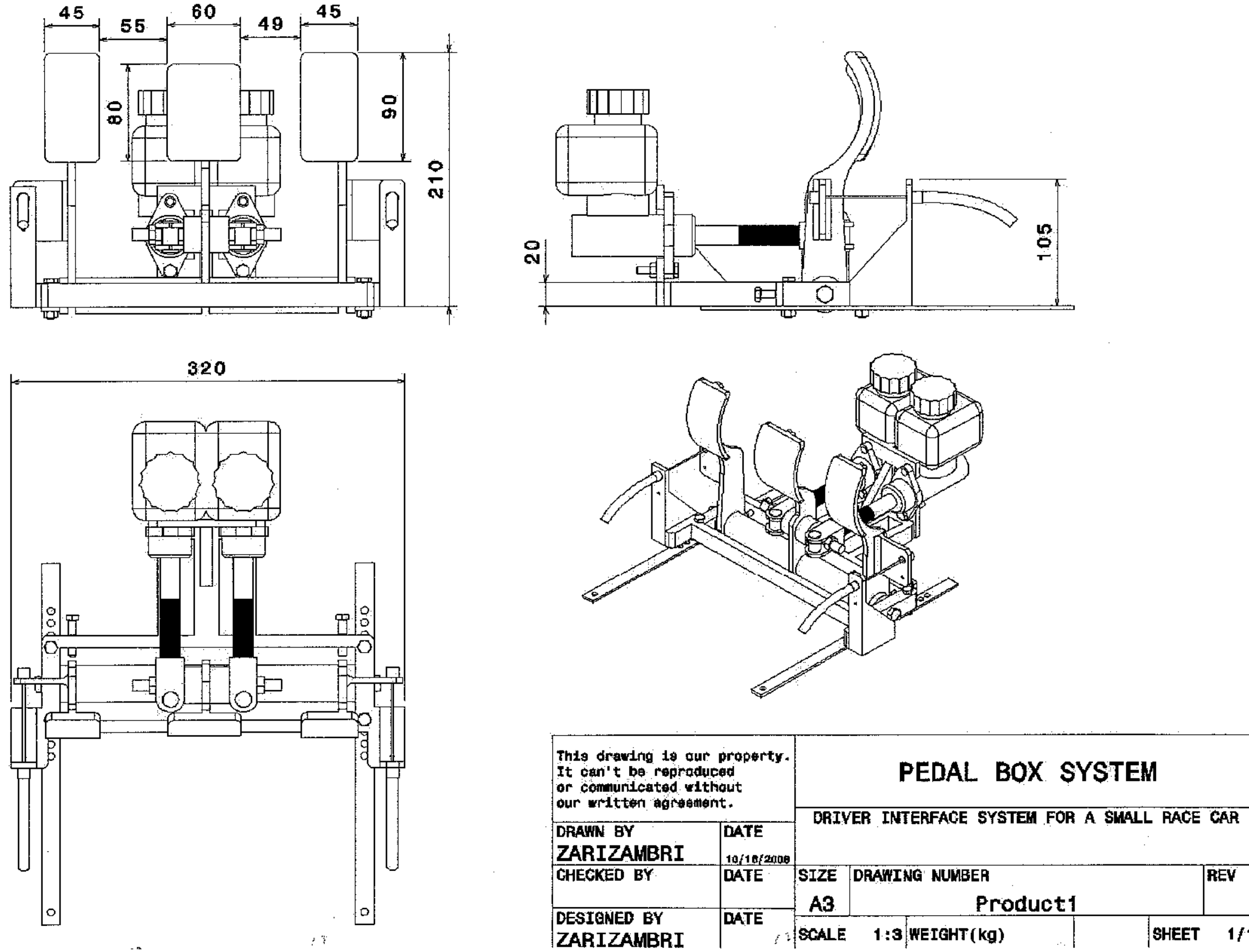
Aluminium Alloy 7075-T6 properties

Material	Aluminium
Young Modulus	7.17e+010N_m2
Poisson Ratio	0.33
Density	2810kg_m3
Thermal Expansion	2.36e-005_Kdeg
Yield Strength	5.08e+008N_m2

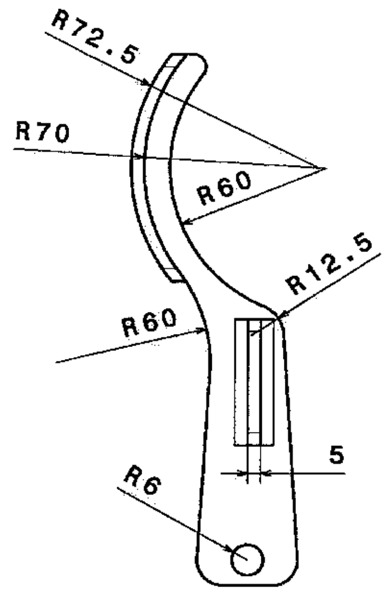
Aluminium Alloy 7075-T series properties

TEMPER	THICKNESS in. (mm)	TENSILE STRENGTH ksi (MPa)	YIELD STRENGTH ksi (MPa)	ELONGATION %
0 Sheet & plate	0.015-2.00 (0.38-50.80)	40 (max) (276)	21 (max) (145)	9-10
T6 Sheet	0.008-0.249 (0.203-6.32)	74-78 (510-538)	63-69 (434-476)	5-8
T651 Plate	0.250-4.000 (6.35-101.60)	78-67 (538-462)	67-54 (462-372)	9-3
T76 Sheet	0.125-0.249 (3.18-6.32)	73 (503)	62 (427)	8
T7651 Plate	0.250-1.000 (6.35-25.40)	72-71 (496-490)	61-60 (421-414)	8-6
T73 Sheet	0.040-0.249 (1.02-6.32)	67 (462)	56 (386)	8
T7351 Plate	0.250-4.000 (6.35-101.60)	69-61 (476-421)	57-48 (393-331)	7-6

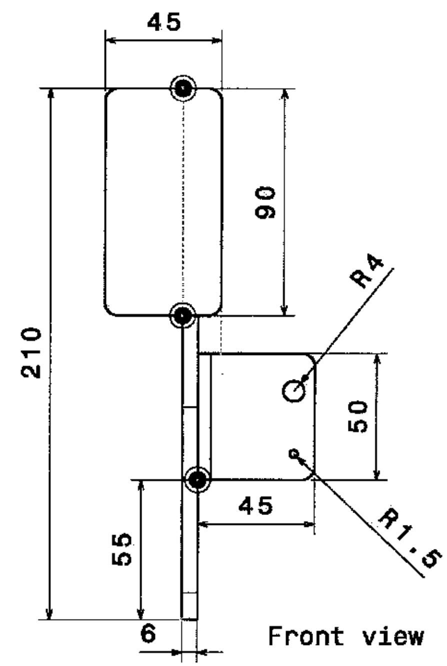
APPENDIX 4 – PEDAL BOX SYSTEM DESIGN AND DIMENSIONS



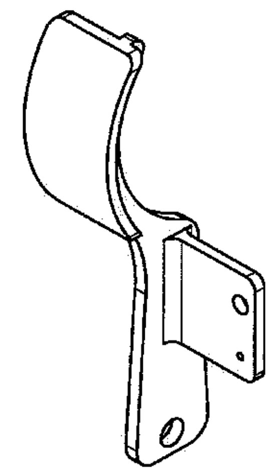
APPENDIX 5 – THROTTLE PEDAL DESIGN



Side view

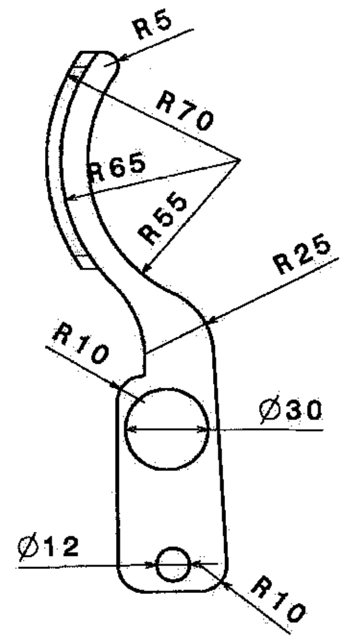


Front view

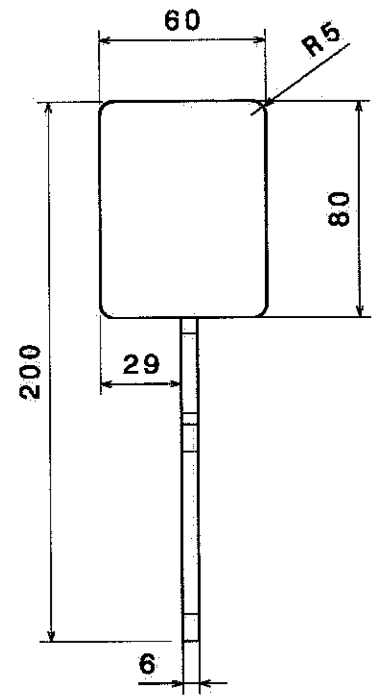


Isometric view

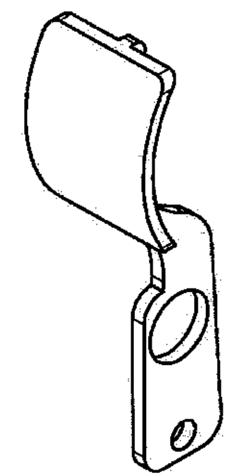
APPENDIX 6 – BRAKE PEDAL DESIGN



Side view

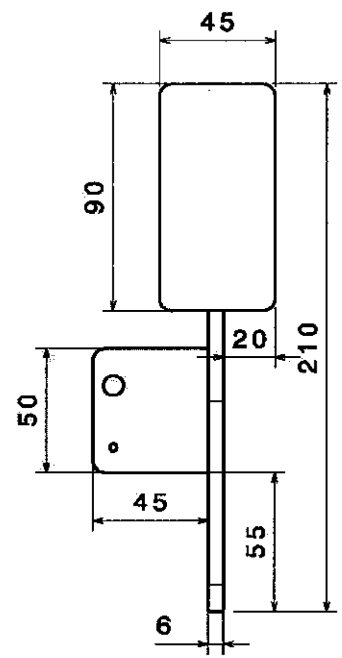


Front view

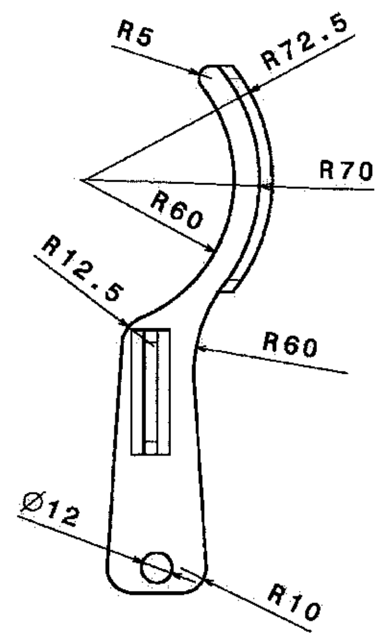


Isometric view
Scale: 1:2

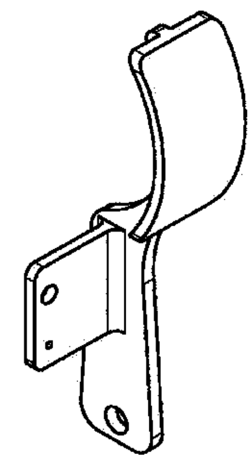
APPENDIX 7 – CLUTCH PEDAL DESIGN



Front view

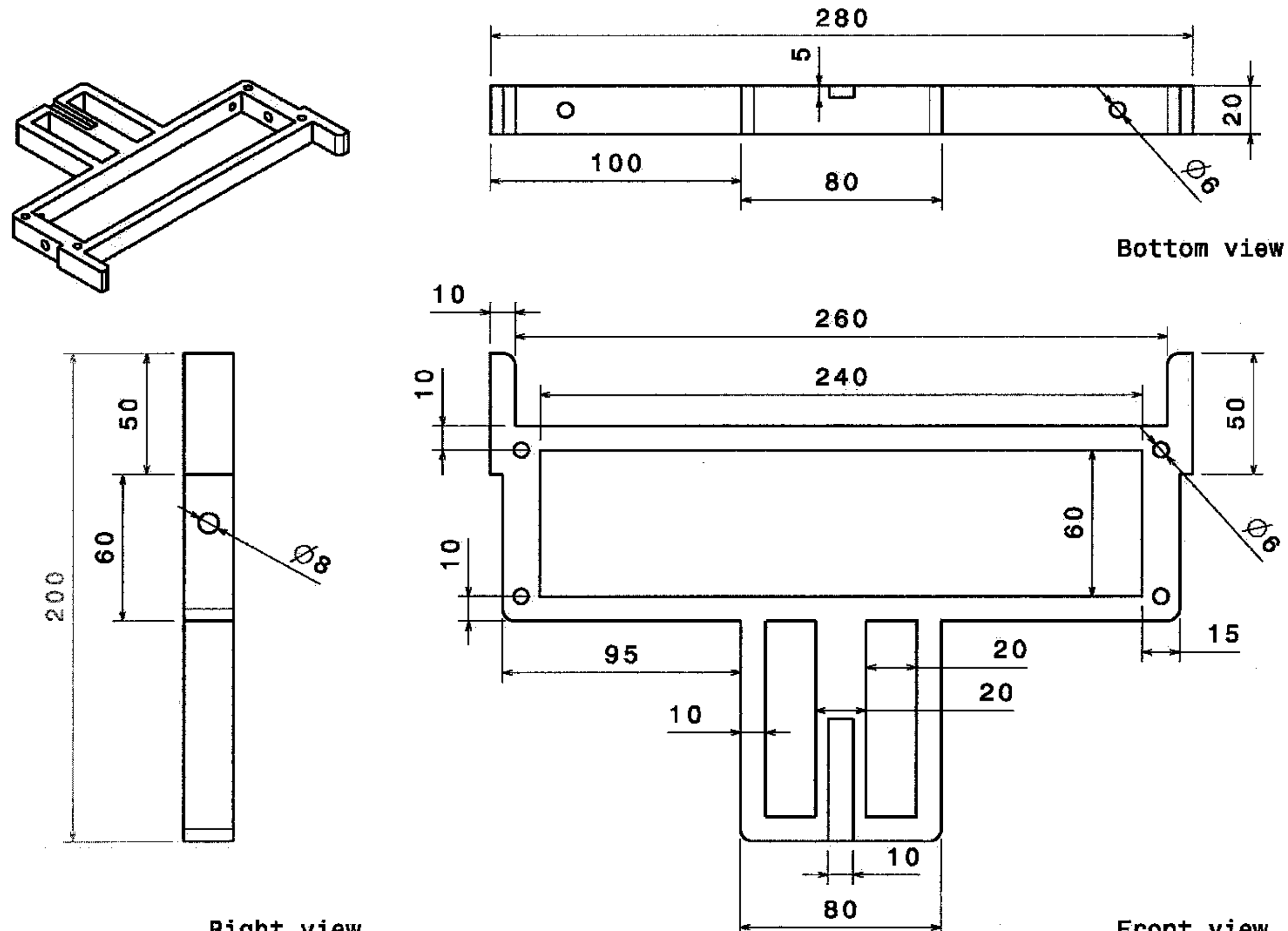


Side view

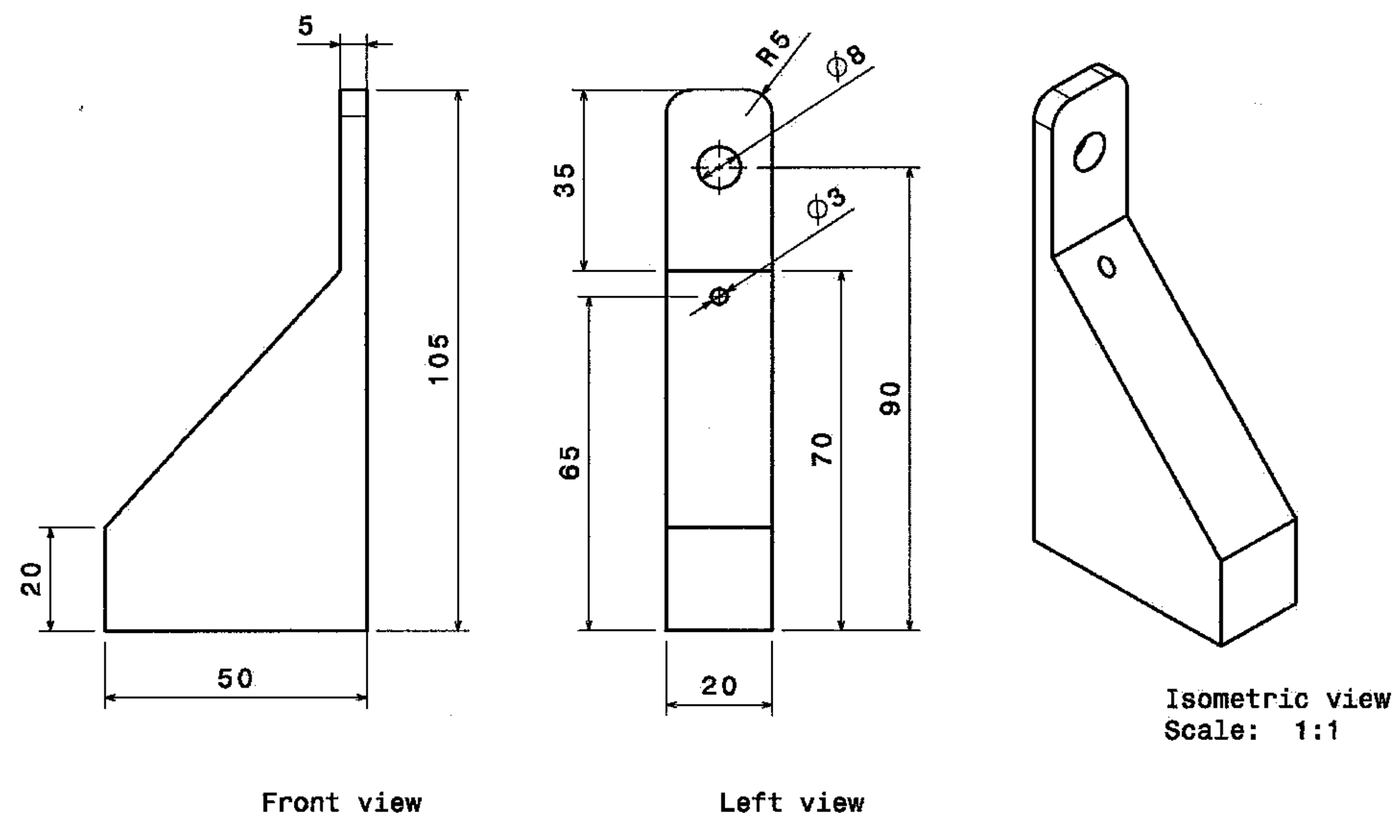


Isometric view
Scale: 1:2

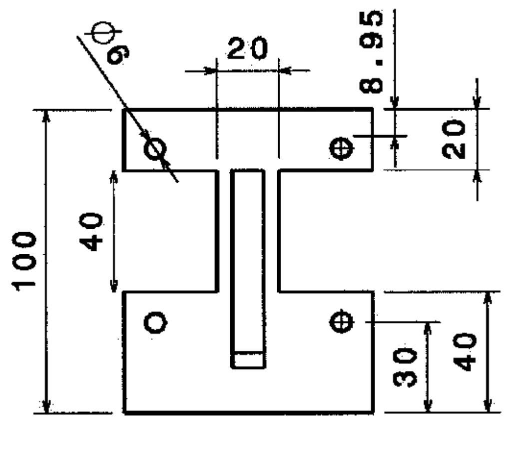
APPENDIX 8 – PEDAL MOUNTING BASE DESIGN



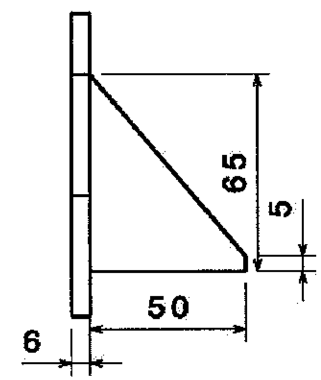
APPENDIX 9 – PEDAL MOUNTING STOPPER DESIGN



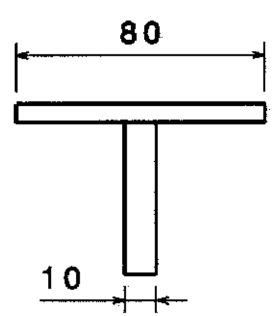
APPENDIX 10 – MASTER CYLINDER HOLDER DESIGN



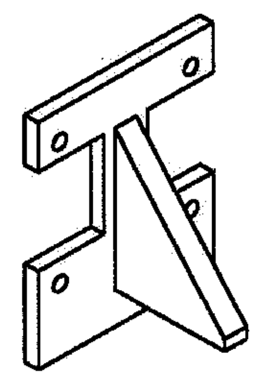
Front view



Left view



Top view



Isometric view
Scale: 1:2