DESIGN AND ANALYSIS OF FOLDABLE HUMAN POWERED VEHICLE

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive).

Signature :..............................
Name of supervisor :.............................
Date :..............................

DECLARATION

I declare that this project report entitled "Design and Analysis of Foldable Human Powered Vehicle" is the result of my own work except as cited in the references.

Signature :

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Date : 15/6/2017

DEDICATION

To my beloved family especially my mother, Fatimah Binti Muda and my father, Ahmad Bin Sulaiman

ACKNOWLEDGEMENT

In the name of Allah, the most Gracious and Most Merciful

All praise to God for His blessings and guidance. Thanks for giving me strength to complete this project report. I am really grateful as I have completed this Projek Sarjana Muda with the help and support, encouragement and inspirations by various parties. All the knowledge and information that they give are really helpful.

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Lastly, not forget to thanks to my beloved family, my entire classmate's and understanding. The sacrifice and commitment given towards me earning my bachelor's degree are indescribable and without them, this PSM thesis would have been impossible.

ABSTRACT

Human powered vehicle (HPV) is the eco-friendly vehicle that can help people achieve the green technology concept. Human powered vehicle was powered by muscular strength to move on road. In addition, HPV is more comfortable to use compared to bicycle due to stability and seating position. HPV is more safe to ride in term of stability because it uses three or four wheel. But, HPV is difficult to store or parking due to its size. HPV is bigger than bicycle. This study is to solve the size of HPV by reduce the size of HPV with design a foldable HPV. The frame of HPV will be design to be foldable to make the HPV is easier to store or parking. This invention will help people to save their space to parking after riding a HPV. Therefore, the foldable chassis of HPV will be analysed to find the size reduction and be tested with stress analysis to ensure the design is safe to use.

ABSTRAK

Kenderaan berkuasa manusia adalah kenderaan mesra alam yang boleh membantu orang ramai untuk mencapai konsep teknologi hijau. Kenderaan berkuasa manusia ini digerakkan oleh kekuatan otot manusia untuk bergerak di jalan raya. Di samping itu, HPV adalah lebih selesa untuk digunakan berbanding basikal kerana faktor kestabilan dan posisi kedudukan ketika menunggangnya. HPV lebih selamat digunakan atas faktor kestabilan kerana HPV menggunakan tiga atau empat roda. Tetapi HPV lebih sukar untuk meletakan kenderaan kerana saiz HPV adalah lebih besar daripada basikal. Oleh itu, kajian ini dijalankan untuk menyelesaikan masalah saiz HPV dengan mencipta reka bentuk HPV yang boleh dilipat. Kerangka HPV yang boleh di lipat boleh memudahkan HPV untuk di simpan atau diletakan di tempat meletak kenderaan. Ciptaan ini akan dapat membantu orang ramai untuk menjimatkan ruang untuk meletakan HPV selepas digunakan. Oleh itu, kerangka HPV yang boleh dilipat akan dianalisis untuk mencari pengurangan saiz dan diuji dengan analisis tekanan untuk memastikan reka bentuk lebih selamat untuk digunakan.

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LIST OF ABBREVATIONS

CAD	Computer Aided Design
FEA	Finite Element Analysis
HPV	Human Powered Vehicle
PDS	Product Design Specification
USS	Under Seat Steering

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Human powered vehicle is an environmentally friendly and affordable vehicle that can help people to achieve the green technology concept. Human powered vehicle is a one type of vehicle that powered only by muscular strength to move on the road. This HPV is a land vehicle with seat position that is inclined backwards and the bottom bracket and the pedals are attached front. The current HPV that has not foldable may be difficult to carry and stored for future use. This type of design is chosen for ergonomic factor cause this HPV also can be fordable and detachable. This HPV is designed in foldable and detachable by using fasteners at the joint. This type of design also to propose a compact foldable HPV this is reduce the size and overcome all the limitation in the current available HPV (Bohra et al. 2016).

Generally, the current HPV that shown in Figure 1.1 are not easy to carry to everywhere because due to the space that people can't store this HPV in the car. As we know, HPV may be bigger in size compare to the bicycle. This type of HPV design is to overcome this problem by reducing the insufficient space after this HPV is folded. With all the problem in current HPV, the next possible solution is the usage of foldable and detachable HPV since this HPV can be folded and carried around to the work place or everywhere it can be used.

Since this HPV is being folded and detachable, it may be use less space and can be easy to store because it doesn't require any special parking space (Bohra et al. 2016).

There is a part of this HPV is to be folding. The main body of this HPV can be folding and wheel and other component is to be fitted. This design of HPV also uses a compact joint which can provide on the main body so that the rear and front body can be overlap after this HPV is folded. Then, the seat of this HPV also can be folded and adjustable according to comfortable of user. The main reason to reduce the height and space of this HPV is folded the main chassis. This seat position is the most common design use today for a good reason which is for rider comfort and easy of riding.

Figure 1.1: Example of HPV (Source: Iniguez et al. 2012)

Besides, this type of HPV uses a three wheel which is two wheel in the front and one wheel at the rear. The transmission of this HPV which transfer the power from the pedal to the rear wheel. HPV use a roller chain that pass the power from the pedals to the drive-wheel and drive it. This HPV also have a suspension system that isolates users body from road vibration. Then, this mechanism will make this HPV increase the safety as control and road grip will be improved. Besides that, if the HPV has no any suspension system, it will change a certain amount of user's propulsion into movement of bike in a vertical direction. The HPV suspension system will show up only when riding heavily loaded or climbing steep hill (HP velotechnik, 2012).

The frame of HPV is the important part in the system. This is because the frame or body will support the load and also can be folded after using it. There are several options in term of frame geometry in the design space defined by the conventional, forward facing and recumbent rider position. The proper design and analysis is very crucial. Then, the material use in the frame for HPV also can affect the result and analysis in this report.

1.2 PROBLEM STATEMENT

Nowadays transportation has been important in society for many reasons. Transportation also has changed the life style and the way people travel. Transportation become important to people since everybody need a transport to travel or do some activity. Transportation also use a lot of resources like time, fuel, and material. But transportation also has a weakness in term of stability, safety, fatal accidents, and aerodynamic resistance while using a bicycle. Then, green house emission and cost actually the major weakness of transportation.

Human powered vehicle is the one of green technology vehicle that can keep our environment clean. As we know HPV is powered by human power to move it and not involves with any burning fossil fuels. HPV also not create a noise to the environment. But HPV also have some limitation which is the current available HPV is a bigger in size that can make it difficult to store and to carry anywhere. HPV is bigger than bicycle but these two vehicles has same problem which is both are difficult to bring anywhere and stored. It's mean that HPV require a more space to parking. This issue may give a minor impact in usage of HPV to the users. The unfordable HPV is difficult to take it with users when they go. HPV required a lot of space to place in car to bring it anywhere.

1.3 OBJECTIVES

The objectives of this project are as follows:

1. To design an eco-friendly vehicle that not harm the environment.
2. To design and analysis, the fordable human powered vehicle.
3. To design a compact human powered vehicle to reduce size and space.
4. To find the percentage of space reduction before and after foldable.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. Only result of design and analysis for foldable human powered vehicle are presented in this report.
2. The stress analysis is tested only at the frame of HPV.
3. The design and analysis is using a CAD drawing which is CATIA.

CHAPTER 2

LITERATURE REVIEW

2.1 Concept of Foldable Human Power Vehicle

Foldable Human Powered vehicle (HPV) are apply the concept of aerodynamic, which is the seating position of this foldable HPV are lower. The seating height can affect the drag force of HPV. The more increase the seating position from the ground, the highest value of drag force of HPV. The value of drag force will be increase directly proportional with the distance of the seat position from the ground. As we know, the principle of aerodynamic can be understood that wind flow must be smooth in order to reduce drag force. Therefore, with the low reclined position a smooth airflow can be produce a less drag force. The frontal area of this HPV also play the important role because it is the important part that can also affect the concept of aerodynamic (Alam et al. 2012).

This HPV was design to be foldable because it will reduce space and lighter. HPV are suitable to use for short distance but it also can be used for long routes. This concept of foldable HPV is same with bicycle, but it more easy to ride and more stable because the seat position of this foldable HPV is inclined backwards and the bottom bracket and the pedals are attached at the front. The foldable HPV are easy to bring anywhere because it uses less space. Other than that, the main chassis of this foldable HPV can be folded to reduce space when store it. The concept of foldable that was apply in this HPV are very easy to use and very friendly.

Type of material use for chassis also plays a major role in strength and safety of the foldable HPV. The design of foldable chassis for HPV more ergonomic by applying the best material on it. Analysis process can be done to find the best material that can be apply on the chassis of the HPV. The chassis of the foldable HPV was designed to improve the design of the existing HPV to be foldable with an igniting idea from the concept of existing foldable bicycle. Besides that, the foldable chassis of HPV is an aerodynamic natural structure that can make the HPV stable and strong (Raghuvanshi & Srivastav, 2015).

2.1.1 Design Consideration

The vehicle must free from the sharp edges that can harm the user in term of safety. The stability of vehicle due to the low center of gravity. Therefore, the material will be selected to applied on the foldable HPV. The total front and rear wheel of the HPV also be calculated. Then, this study will focus on the main point that can affect the comfortable of the rider which is elbow and knee of the rider. Hence, the basic need requirement for the ergonomic feature will be consider in this study. Lastly, this study focus on dimension of length for wheel base, height and track width.

2.2 Folding Chassis for Human Powered Vehicle

The ability of this HPV is it can be folded and easy to stored. Foldable HPV has three main part of the chassis that can make this HPV can be fold. The part of the chassis for HPV was joint by using a shaft, bolt and nut. The chassis may present separable assemblies which is a front part and rear part.

Therefore, the wheelbase can be folded to reduce space during parking or store it and can be extended when the user wants to ride it. The potential of foldable HPV is when the wheelbase can be shortening and lengthen with the design of chassis that can be folded. The foldable chassis play the important role cause the chassis must have the ability to hold the force by the rider and also can be folded. In the same way, the joint for the chassis is very important to link the main part of the chassis so that it can be folded (Lark, 2014).

The mechanism of joint for HPV can present the ability of chassis to keep maneuverability in the HPV's folded and unfolded state. However, the design of HPV still same with the existing HPV but transformable chassis. The improvement on the chassis of the HPV has many practical advantages such as the HPV can be folded to reduce it wheelbase. Then, the HPV can keep the maneuverability during unfolded without changing the chassis' geometry. In addition, the ability of the foldable chassis to perform as a rigid body in zero power failure situation is the objective in this project (Lark, 2014).

The foldable chassis of HPV also has a suitable center of gravity that can present the stability during ride on the road. As a result, the chassis also fulfil the basic need requirement for ergonomic needed in term of comfort. Besides, the position mechanical system of the HPV is maintaining after folded (Lark, 2014). For information, the transformable chassis can be lock after unfolded and also give a stability to the HPV. The foldable chassis are not affect the handling of this type of HPV due to the steering are place both side of driver. In addition, the foldable chassis was design based on the igniting idea of a Y shape (Raghuvanshi & Srivastav, 2015).

In addition, the front chassis includes a pair of wheel fork that can be folded to reduce the width of HPV while the rear chassis can be folded to reduce the length of wheelbase of the HPV. Besides, the wheel fork may be mounted at the front part of the chassis.

2.3 Drive Mechanism for Human Powered Vehicle

The drive and steering mechanism is the important parts to control the HPV during on the road. The HPV allow a rider to drive forward by moving the power from upper and lower body muscle group that present a motion similar to running or walking. Thus, the rider can transfer muscle-generated power by the movement of the both legs and arms to the drive mechanism (Yunaska, 2004).

This type of HPV is constructed of a foldable chassis, a drive means comprised of a leg powered. The crank set is placed at the front part of HPV that act as a drive sprocket and the middle and rear sprocket as a driven sprocket. Then, the crank set that is connected by a continuous chain to middle sprocket and continue to the rear sprocket communicating with rear wheel of the HPV. The crank set for this HPV apply the conventional bicycle crank set. In addition, the middle sprocket is link with rear sprocket that attached to the rear wheel of HPV by a continuous chain. Besides, the chain connected to the crank set to the rear sprocket through the middle sprocket. Furthermore, the steering mechanism are attached to the chassis at the middle part of the HPV. The steering mechanism control the steerable front wheel and the movement of the steering mechanism by the rider's arms produces an additional propelling force. In addition, the drive mechanism convert the steering motion into forward motion of HPV (Yunaska, 2004).

However, the performance of drive mechanism can be affected by the force required to apply on pedal and the number of rotation of the wheel. The best performance is by increasing the number of rotation of wheel and reduce the force required to use on the pedal to move the HPV. In addition, by increasing the diameter of drive sprocket it may result the higher drive mechanism efficiency. The value of velocity ratio also increases when increasing the diameter of drive sprocket (Urunkar & Deshpande, 2014).

Then, the value of efficiency for the drive sprocket transferring power to the rear sprocket can be state through the efficiency's test for the derailleur-type chain drive. But, there are some factors that can affecting the value of efficiency such as the sizes of the sprocket and the tension in the chain. Thus, the larger size of diameter sprocket present more efficient transfer of power while the small size of diameter sprocket may be less efficiency. Additionally, the higher chain tensions more efficiency than the lowest chain tension proved to be less efficiency. It was found that the normal chain drive use for HPV depends on the chain operation as it transferred from the drive sprocket on the high tension part of the drive sprocket. (Urunkar & Deshpande, 2014).

The drive mechanism element of HPV depends on it design and the way it being driven. In the same way, the configuration of the linkage joining the foot-powered section to the arm-powered section in this HPV almost same with the existing HPV. But, the difference is this type of HPV has a transformable chassis that can reduce the length of wheelbase. The position of drive mechanism can influence the comfort of the rider during on the road. In other hand, the steering mechanism also play the important role in term of comfort where the steering must give an equal angle or produce more angle than the steering to make the tire turn left or right with smoothly (Teja et al, 2016). The steering mechanism use for this type of HPV is suitable to use because it allows rider to control or steer the HPV easily while making a tight turning.

A steering mechanism for HPV is receiving the movement of the steering control from a rider commonly includes a handlebar that mounted to the middle of the chassis and connected to the foldable steering pivot. Besides that, the steering arm are mounted to each wheel fork and can be detach when the HPV is folded (Wilcox & Knapp, 2005). But, the handle bar is no need to disconnect from the main chassis in order to fold the HPV.

The foldable HPV also equipped with the disc brake and the absorber system to avoid the vehicle from safety failure. The absorber is placed under the seat area of the HPV to reduce the vibration and prevent the damage on the structure of the chassis. It also gives a comfortable and smoother ride to the rider during travelling on the road. Then, the disc brake is installed at the rear wheel while the brake lever is mounted at the handle bars to make the rider easy to apply the braking. In the other hand, the braking system was design to apply on the vehicle for the reason to have a better stability during braking (Gulati et al, 2012).

2.4 Ability of Recumbent Vehicle

Human powered vehicle than shown in Figure 2.1 is a vehicle that use four wheels and provides a low center of gravity. HPV can be categorised as a recumbent vehicle due to rider sit in a recumbent or semi recumbent position. Furthermore, the front part of the chassis is interconnected to rear part of chassis and can be folded. The chassis relatively close to ground and can maintaining the low center of gravity (Wilcox & Knapp, 2005). The recumbent vehicle also gives the more comfortable to the rider due to the basic need requirement for ergonomic.

Figure 2.1: Example of prototype for HPV (Source:Abdullah et al. 2016)

Due to this present invention, the foldable HPV can support the weight of the rider due sitting in recumbent position. The recumbent position sitting during riding also give comfortable when handling the steering. When the all chassis is assembled, the top front part of the chassis is substantially transverse to the main chassis. In other hand, this HPV use a simple design and easy maintenance. The most important thing that recumbent vehicle have is more safety than convectional bicycle due to stability. Besides, this HPV is more stable compare to convectional bicycle and this HPV will provide more safety to the user during travel on the road.

HPV is more efficiency, safety, and the most important thing it is the one of vehicles that can be proved as the suitable replacement for fuelled vehicle such as motorcycle due to the environment sustainability. The foldable HPV also cheaper to buy, comfort to ride on the road and the improvement of existing HPV. HPV also the technology that can give benefit to human being due to the 'Green Technology Vehicle' (Gulati et al. 2012).

The foldable HPV is invention that use a concept of recumbent position into the design which is more ergonomically designed and efficiency so that it can be used as daily transportation. The recumbent design for HPV allow the rider to feel a comfortable during riding on the road. The performance of HPV can give a major impact to the user while choosing a suitable vehicle for "Green Technology Vehicle'. The recumbent position for HPV is to prevent the rider from lose control and stability during travelling on the road. The recumbent position gives a positive impact to the design of HPV while the main reason is to enhance the overall safety of HPV in case of front impact and stability. The recumbent vehicle also prevents the rider from the any slip and side impact (Gulati et al., 2012).

The performance recumbent position can be influence by the changed value of distance from seat to the pedal. The minimum and maximum angle of hip and knee will change if the height of seat from the main chassis is changed even though the range of motion at the hip and knee will remain the same (Gerald, n.d.). By changing the height of seat, it may change the comfortable during riding except the crank set is in line with the seat position.

2.5 Mechanism and Properties for Human Powered Vehicle

The recumbent foldable HPV has an important part that play the major role in this vehicle. All part has followed the standard specification that use for existing HPV and convectional bicycle. All part also has their function to support this HPV to increase the performance and efficiency during travelling on the road without failure.

2.5.1 Transformable Chassis

The frame of this HPV has been design based on ergonomic and safety to keep the satisfaction of the users in term of comfortable. The chassis also mounted with the braking system, suspension system, drivetrain system and the steering mechanism. The chassis was separated with main part of chassis that can support a load for rider. Besides, the chassis was design for recumbent position and can be folded to reduce the wheel base and size of the HPV.

2.5.2 Wheel Base and Width of Foldable HPV

The length of wheel base is the important things that is to be consider before designing this foldable HPV. This is because the length of wheel base can affect the speed stability. The higher the length of wheel base, the higher speed stability. The reduction of length of wheel base after foldable also must be consider to achieve the main objective of this project. Moreover, the track width of HPV become safe when it more wider during cornering but if too wide, the vehicle become impracticable on most straight road (Gulati et al., 2012).

2.5.3 Weight

The weight at the front part may be higher than the rear part in term of weight distribution. The more weight at the front will give the better experience in cornering. However, over weight at the front part can give a negative result at the rear part because during hard cornering it cause the rear wheel become wear out.

2.5.4 Tyres and Rims

The tire was fits to the wheel of the HPV and make contact between the ground and vehicle. Tire also be important part in HPV because tire can be the source for suspension system in any vehicle. Tire also present the lateral forces and longitudinal force that necessary for balancing, turning, and braking. During HPV was travelling on the road, tire absorb the vibration between road and vehicle and transmitted to the suspension system to reduce the vibration. Therefore, tire must absorb the shock without affecting the performance and can avoid the vehicle from damage (Nayak et al., 2012).

2.5.5 Braking System

The foldable HPV apply the mechanical disc brakes on the rear wheel that can be lock simultaneously. The braking system was mounted to any vehicle to reduce the stopping distance of vehicle. Besides, the disc rotor was controlled by a double brake lever that mounted at the handlebars which can lock the brake simultaneously to avoid the HPV from skidding or slip. Furthermore, all vehicle required a braking system because it can avoid any vehicle from slipping and crash (Nayak et al., 2012). The braking system diagram is shown in the Figure 2.2.

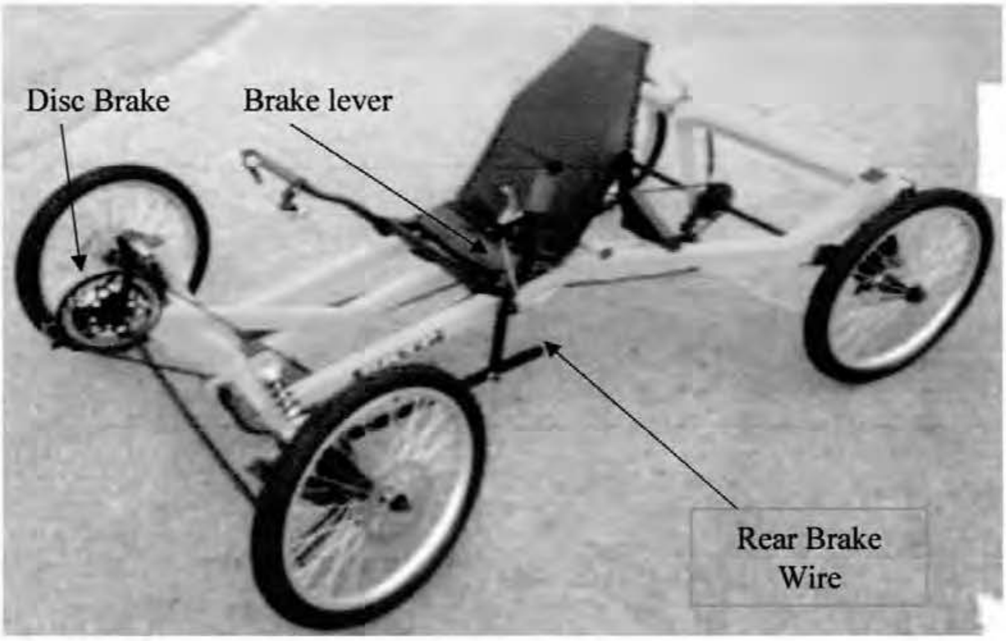

Figure 2.2: Example of braking system for HPV (Source: Abdullah et al., 2016)

2.5.6 Suspension System

An absorber is placed on the main chassis of foldable HPV that mounted under the seat in order to provides a comfort and smoother to the rider. The suspension system can give a better handling and braking for the HPV during on the road. This type of HPV only used one absorber at middle of the main chassis. The suspension system also has ability to support the weight and a road holding capacity (Gupta et al., 2015). The position of absorber at the main chassis is shown in Figure 2.3.

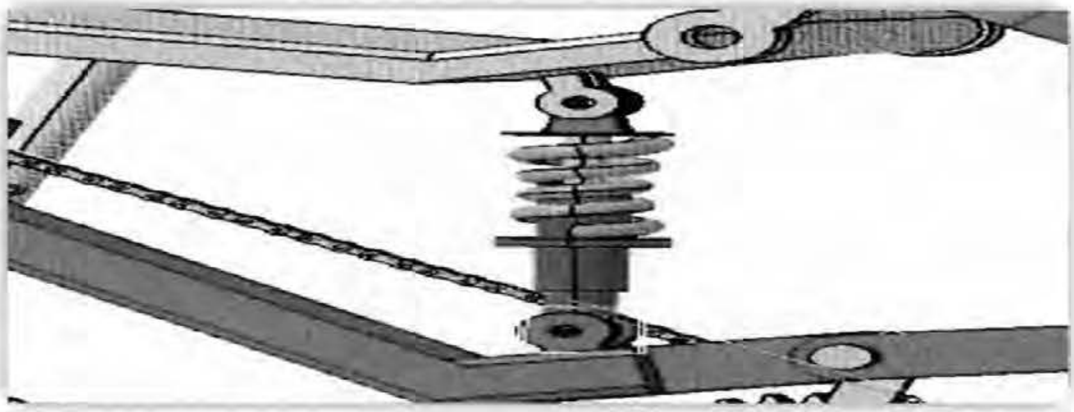

Figure 2.3: Absorber system

2.5.7 Seat for Recumbent Vehicle

The seating position for this foldable HPV is in recumbent position. The seating position and arrangement is necessary in any type of HPV due to comfortable, reducing the wheel base and also present stability to the HPV. The seat may use a fiber material and will be clamped by nut and bolts (Gupta et al., 2015). The seat also can be folded when the HPV is in foldable condition. Moreover, the seat was design based on the basic need requirement for ergonomic to provides a better safety to the user.

2.5.8 Transmission System

The foldable HPV is powered by the human power. The rider may transmit the power by using the two crank wheel at the front part of the chassis. In addition, the drive mechanism involves with drive and driven gear that can be the main component in the transmission system. The performance of the transmission system depends on some important parameter used which is the pedal crank length, chain drive efficiency and the diameter of drive gear (Urunkar & Deshpande, 2014).

2.5.9 Steering System

The HPV use an invention for steering that mounted at the middle chassis while the handlebars are position at the both side of the rider. The steering mechanism is the way how the HPV is steered and the steering linkage system complete the overall system by controls the wheel. The steering mechanism for this HPV can be categorise as Under Seat Steering (USS) that has a pros and cons. The type of steering provides a comfortable that support for arms and easier to control the handling. It also present support for the rider during high G turn and prevent from use of lateral seat support. But, this type of steering can increase the frontal area that can influence the aerodynamic of HPV (Horwitz, 2010).

2.6 Stress Analysis for Main Chassis

The chassis can be analysed by using the software CATIA to find the stress analysis on the chassis. The stress analysis must be done on the chassis in order to ensure that the design was safe to use. Besides that, the stress analysis can find the suitable material that can apply on the chassis (Gunjal et al., 2014). All part of the chassis is applying with the same load or force to find the deformation, von-misses stress, maximum and minimum stress, yield strength and factor of safety. The chassis was tested by using a different type of material such as iron, steel and aluminium. The sample for Von Misses stress analysis is shown in the Figure 2.4.

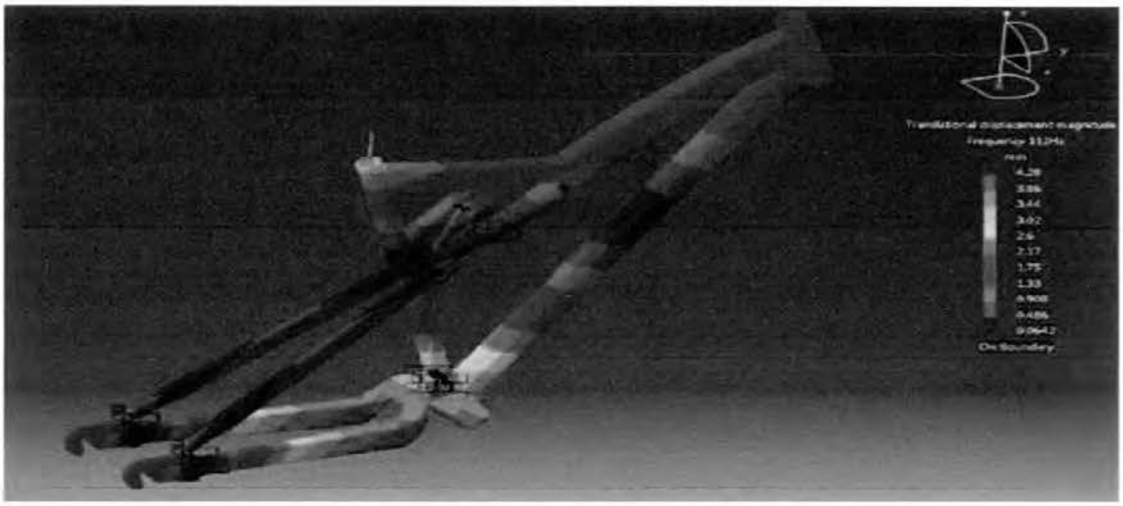

Figure 2.4: Von-misses stress analysis using CATIA

2.6.1 Factor of Safety

The factor of safety for stress analysis is the ratio of yield strength per von-misses stress. Factor of safety can influence the selecting material that was apply to the chassis. The formula for factor of safety can be refer below.

$$\text{Factor of Safety} = \frac{\text{Yield strength}}{\text{Von Misses strength}}$$

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to design the foldable Human Powered Vehicle. This project is starting by find some information that are important from do a research on journal and article that can be used in this project. The action that need to be carried out to achieve the objectives of the project are listed in this chapter. Then, the drawing for foldable HPV was design by using a computer drawing, CATIA. The design methodology for this foldable HPV is based on the ergonomic, highly engineered, easy to manufacture and fulfil the safety criteria for any vehicle.

3.2 Project Gant Chart

Table 3.1 shows the gant chart for PSM 1 that provide a schedule during conducting this final year project.

Table 3.1: Gant Chart for PSM 1

	Weeks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
NO	Items								M						
1	Introduction								I						
	1.1 History for HPV								D						
	1.2 Objective								S						
	1.3 Scope								E						
	1.4 Gant Chart								M						
2	Literature Review														
3	Research								B						
4	Conceptual Design								R						
5	Progress Report								E						
6	Drafting a Report								A						
7	Report Submission								K						

Table 3.2 shows the gant chart for PSM 2 that provide a schedule during conducting this final year project.

Table 3.2: Gant Chart for PSM 2

	Weeks	W1	W2	W3	W	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
NO	Items								M						
1	Do correction for PSM 1								I						
2	Size Reduction								D						
	a) Volume reduction								S						
	b) Area reduction								E						
3	Design selection								M						
4	Progress Report PSM 2														
5	Final design								B						
6	Design Analysis								R						
7	Material Selection								E						
8	Drafting Report								A						
9	Report check by								K						
10	Final Report														
11	Report Submission														

3.3 General Design Methodology

The methodology of this study is summarized in the flow chart as shown in Figure 3.2. Generally, three major cycle step are applying during design the HPV which is planning, implementing and design. The cycle was shown in Figure 3.1.

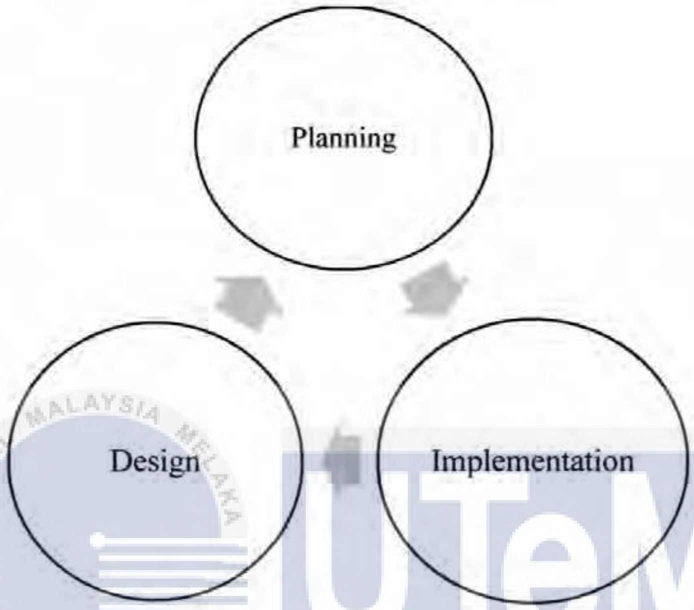

Figure 3.1: Designing process cycle

This project used three major steps to implement project design starting from planning, implementing and design. The flow chart of project will show in this section. All the methodology used for designing and analysing the foldable HPV are shown in Figure 3.2.

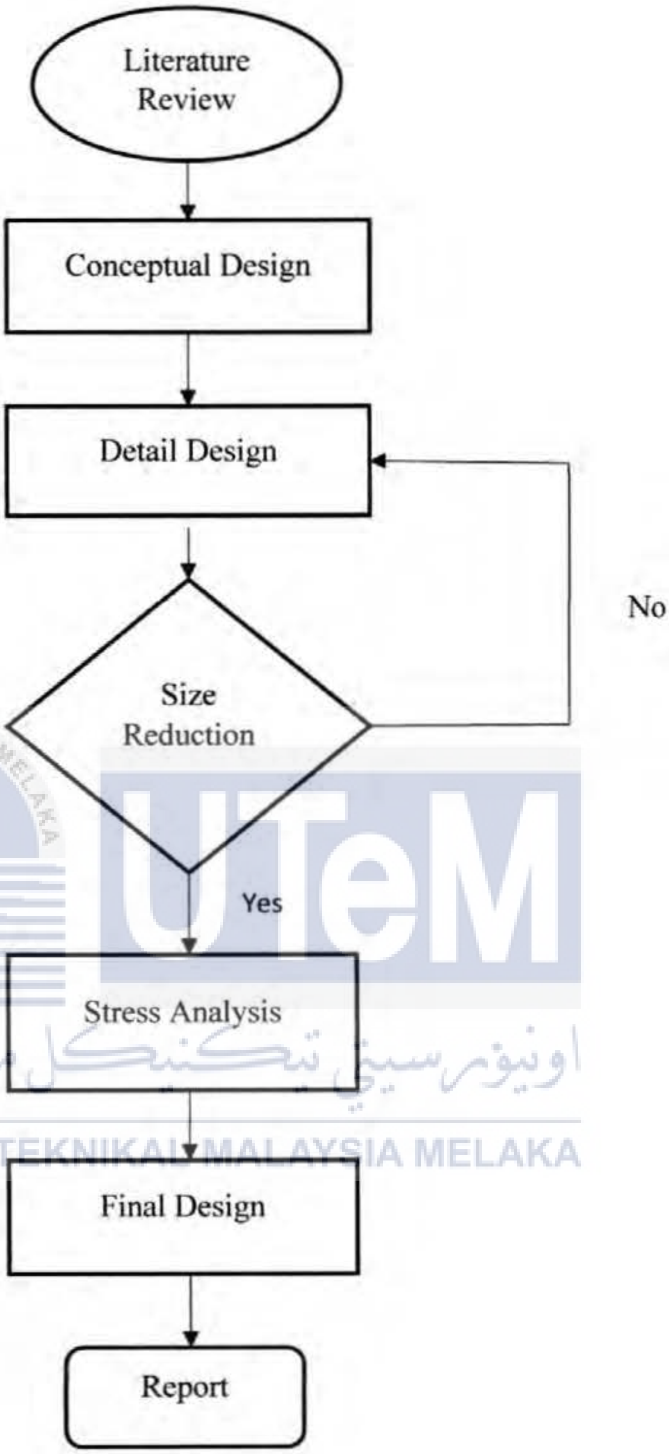

Figure 3.2: Project Flow Chart

3.3.1 Selecting Type of design HPV

There are two type of design for HPV which is use three wheel or four wheel. The design that was develop in this project must based on the foldable feature criteria in this study. Both design was evaluating and have been chosen based on some criteria which is ergonomic, highly engineered, easy to manufacture, fulfil the foldable feature and fulfil the safety criteria for any vehicle. The selecting type of design for foldable HPV was made by referring those criteria. These types of design were shown in Figure 3.3 and 3.4.

Figure 3.3: Four-wheel HPV (Source: Abdullah et al., 2016)

Figure 3.4: Three-wheel HPV (Source: Iniguez et al. 2012)

Based on Figure 3.3, four-wheel HPV is more stable to support the rider during riding on the road. But, the chassis for four-wheel design is more complicated to design into foldable chassis compared to three-wheel design on Figure 3.4. Therefore, the size for four-wheel HPV may be bigger than three-wheel HPV. Hence, the design for foldable HPV in this study may use a three-wheel HPV because of some factor which is the chassis for three-wheel HPV is easier to folded and manufacture.

3.3.2 Conceptual Design

The invention from this study will based on the design for the three-wheel HPV. All conceptual design in this study must be designed based on the criteria needed for foldable HPV feature. The design must be easy to folded. The most important factor for choosing the design is the size reduction of HPV after folded and easy to manufacture.

Product Design Specification

There is some process that should be done before choose the final design. The process are product design specification (PDS) that acting like mantle enveloping the whole core activity that used for analysis, design, manufacturing and construction of the structure or a component in order to achieve a specified degree of safety, efficiency, performance as a current existing HPV. In this section, there are have some PDS criteria which are performance, safety, installation, size, material and ergonomics were chosen for development a conceptual design.

These Table 3.3 shows the specification and criteria for PDS.

Table 3.3: PDS Criteria

No.	Criterion	Specification
1.	Performance	• A good rigid frame • The foldable chassis can support the load from rider.
2.	Safety	• The chassis should not break during riding.
3.	Installation	• Installation can be done by using simple tools (such as spanar, screwdriver or alen key) • HPV is easy to folded.
4.	Material	• Light • Strong • Anti-rust • Low cost • Hardness • Easy to assembly
5	Ergonomics	• No sharp edges • Design feature based on current existing HPV
6	Size	• Size must be suitable for the concept of HPV

3.3.3 Detail Design

The design for foldable HPV was design by using a CATIA that consist of part design, assembly design and drafting. The assembly design for foldable HPV will be shown in this section.

Design 1

Figure 3.5, 3.6 and 3.7 show the conceptual design for Design 1 before and after foldable. According to the characteristics of the conceptual design in PDS, Design 1 is in good rigid frame of performance. The seating position for rider is in recumbent position. The design ergonomics is based on the current existing HPV. This design only have two separate assemble chassis. Design 1 also can fold the rear chassis only.

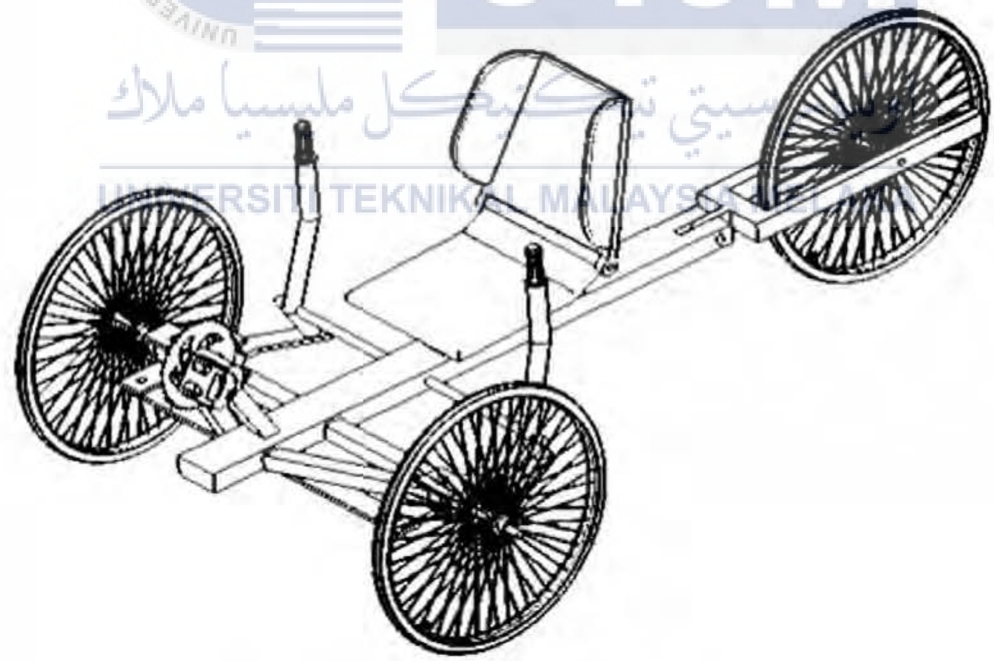

Figure 3.5: Isometric view for Design 1

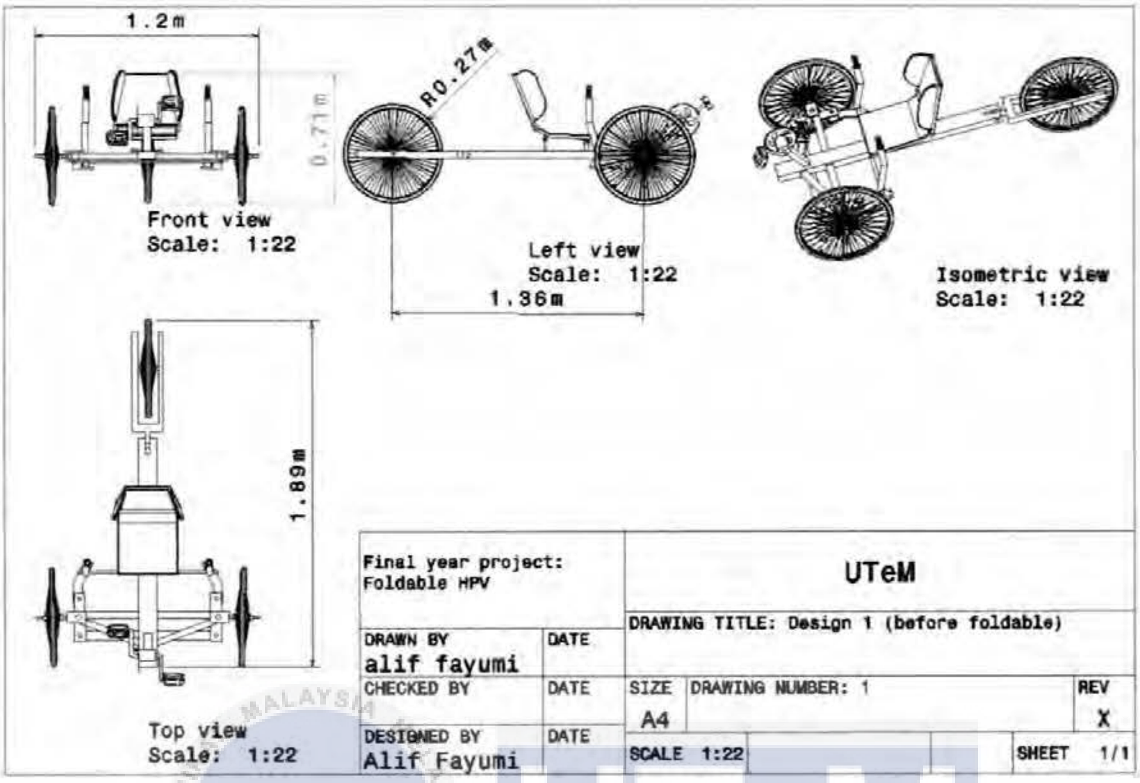

Figure 3.6: Projection view for Design 1 before foldable

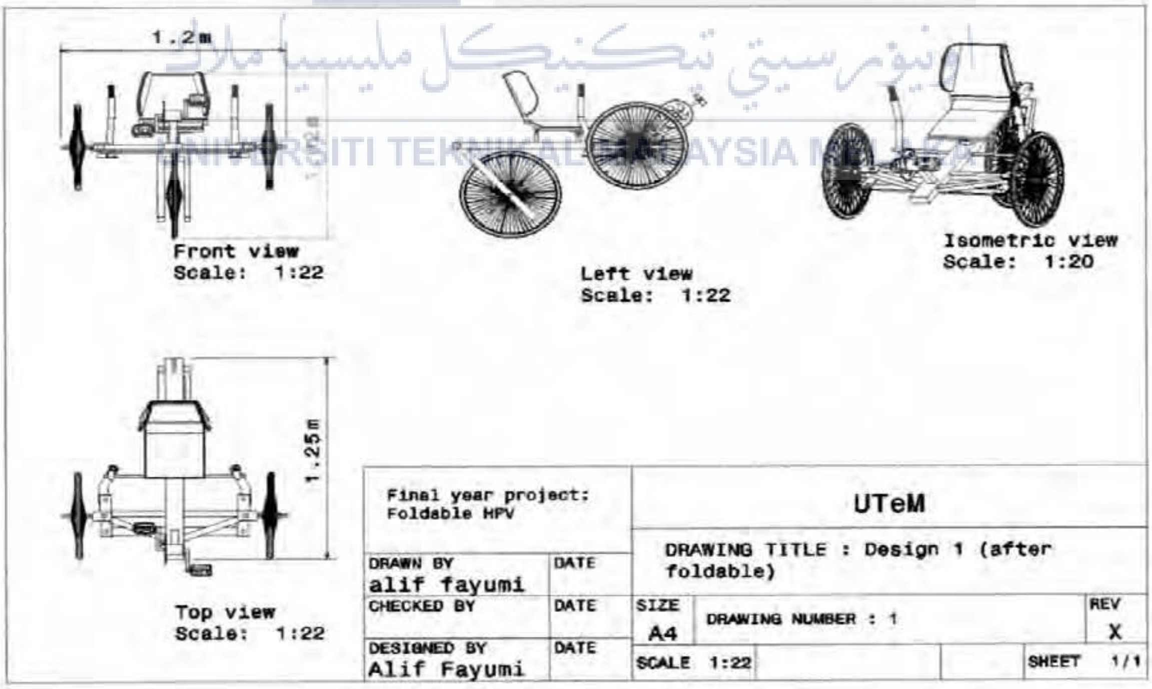

Figure 3.7: Projection view for Design 1after foldable

Design 2

Figure 3.8, 3.9 and 3.10 show the conceptual design for Design 2 before and after foldable. According to the characteristics of the conceptual design in PDS, Design 2 has the same characteristic with Design 1which is in good rigid frame of performance. The seating position for rider is in recumbent position. The design ergonomics for this HPV is based on the current existing HPV. Therefore, this design only have two separate assemble chassis. Design 2 also can fold the rear chassis only. Design 2 applied the concept of bicycle which is the main chassis is connected to the fork. Hence, the steering system for Design 2 is same with bicycle.

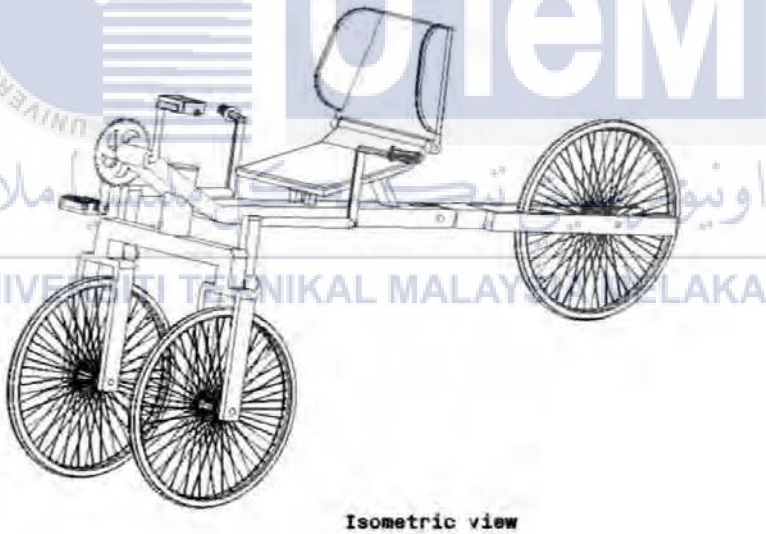

Figure 3.8: Isometric view for Design 2

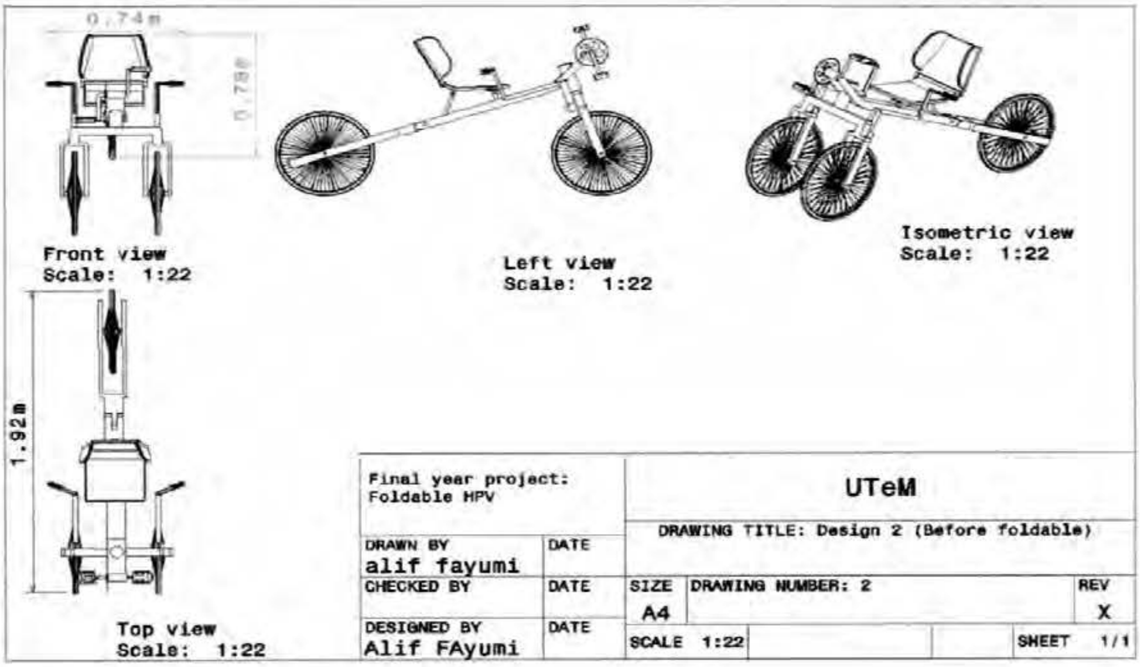

Figure 3.9: Projection view for Design 2 before foldable

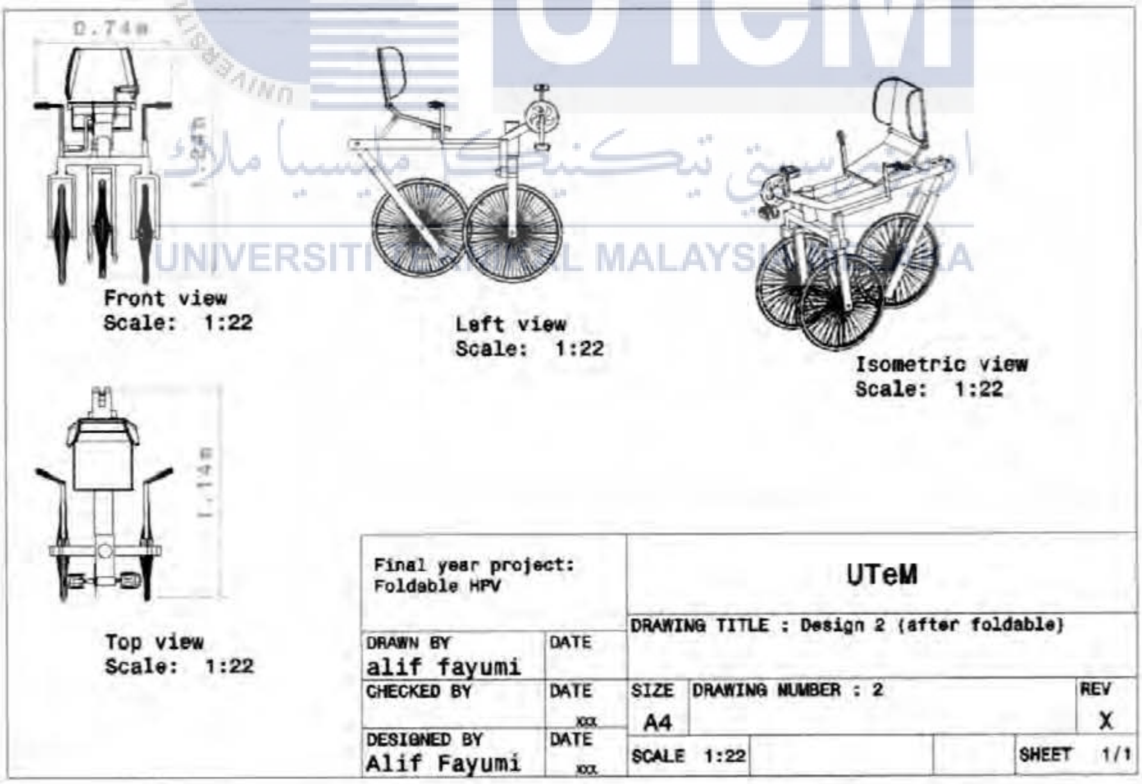

Figure 3.10: Projection view for Design 2 after foldable

Design 3

Figure 3.11, 3.12 and 3.13 shows the conceptual design for Design 3 before and after foldable. The design ergonomics for this HPV is based on the current existing HPV. The seating position for rider is in recumbent position. Therefore, this design fulfils the criteria needed for foldable chassis because it involves with many separate part for chassis. Hence, front and rear chassis for design 3 can be folded. The suspension system was installed on this HPV to reduce the vibration during riding.

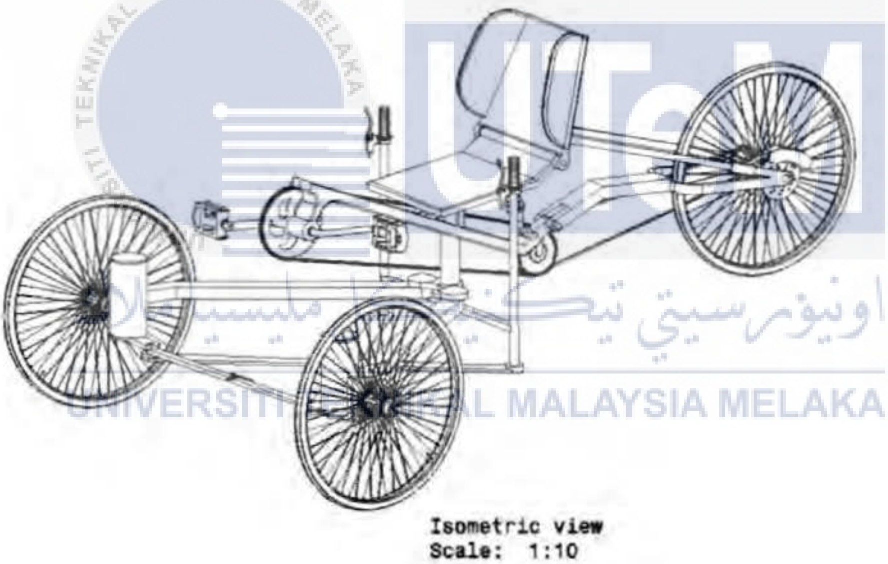

Figure 3.11: Isometric view for Design 3

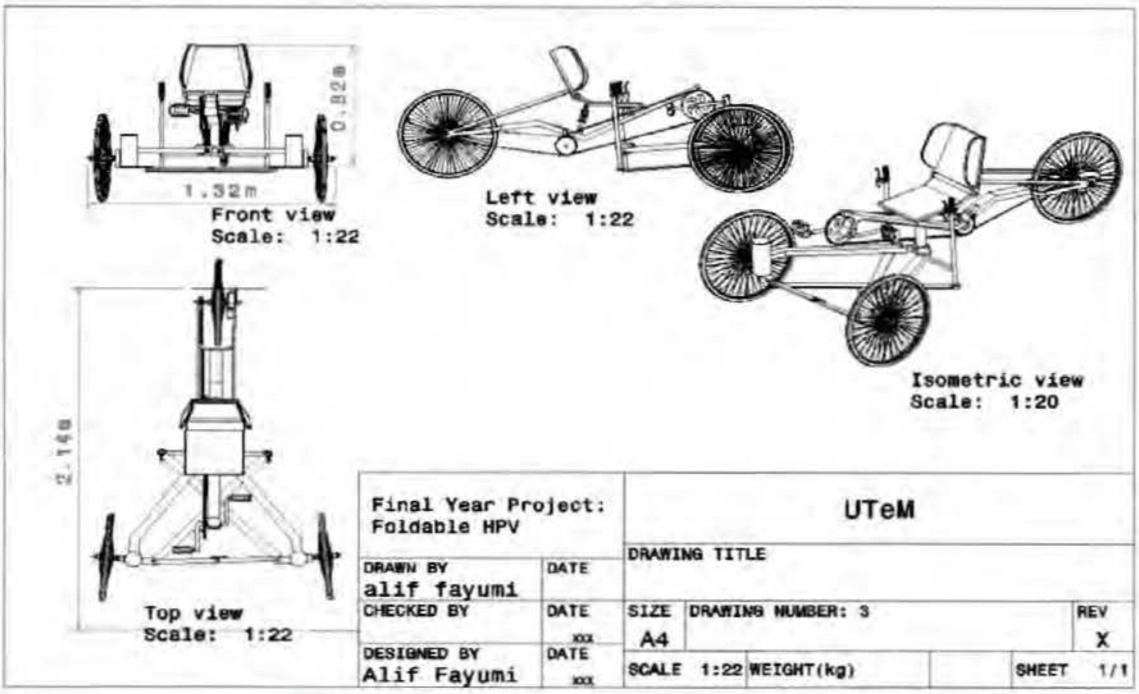

Figure 3.12: Projection view for Design 3 before foldable

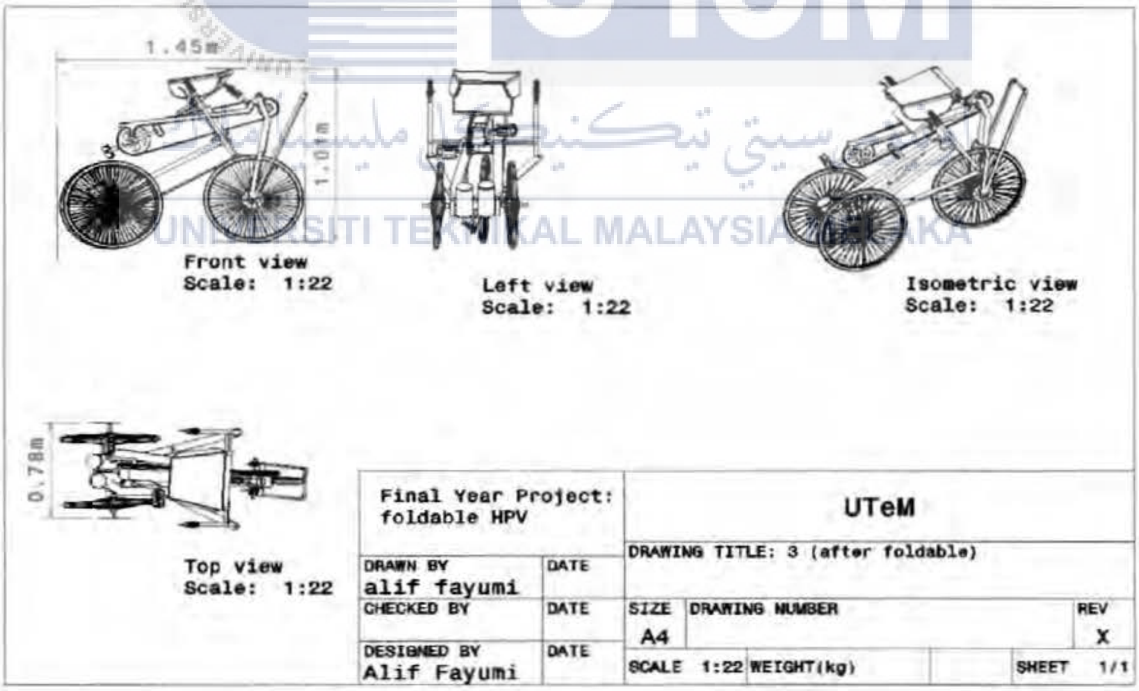

Figure 3.13: Projection view for Design 3 after foldable

3.3.4 Characteristic for conceptual design

Table 3.4 shows the characteristics for the three design for HVP based on the criteria in PDS.

Table 3.4: Characteristic for three conceptual design

Characteristic	Design 1	Design 2	Design 3
Performance	• Good rigid frame. • Consist of two separate chassis. • Easy to folded.	• Good rigid frame. • Consist of two separate chassis. • Easy to folded.	• Good rigid frame. • Consist of four separate chassis. • Easy to folded.
Safety	• The chassis can support the load from rider.	• The chassis can support the load from rider.	• The chassis can support the load from rider.
Installation	• Difficult to assemble. • Simple tools are used to fixed.	• Easy to assemble. • Simple tools are used to fixed.	• Difficult to assemble. • Simple tools are used to fixed.
Ergonomics	• Design based on the current HPV.	• Design based on the current HPV.	• Design based on the current HPV.

3.3.5 Percentage of Size Reduction

The main objective of this project is to reduce a space use for HPV. After the HPV was folded the percentage of space reduction will be calculated. The percentage reduction for HPV before and after foldable will be calculated after the all part design are completely folded.

Percentage of volume reduction

$$\text{percententage of volume reduction} = \frac{\text{volume before} - \text{volume after}}{\text{volume before}} \times 100$$

Percentage of area reduction

$$\text{percententage of area reduction} = \frac{\text{area before} - \text{area after}}{\text{area before}} \times 100$$

3.3.6 Design Analysis

The finite element analysis (FEA) is implemented to study the stress and safety of the HPV design. The stress analysis is performed by using the software CATIA. The stress analysis is done on the part of the chassis. The stress analysis will test on the part of the chassis by using a different type of material which is iron, aluminium and steel. After the finite element analysis is finish, the next process is to find the factor of safety. The result may be compare to find the suitable material use for the chassis. The FEA is to ensure safety against failure on the chassis and to ensure that the stresses in the part of the chassis in the system are not exceeding the allowable limit.

CHAPTER 4

RESULT AND ANALYSIS

4.1 INTRODUCTION

In this chapter will focus on the result obtained from the volume and area reduction and FEA process for the design of foldable HPV. The overall result and the complete design for foldable HPV from this project will be presented in this chapter. The drawing for foldable HPV is sketch using the CAD software which is CATIA. The percentage of volume and area reduction will be calculated to find the design that achieve the main objective for this project. The FEA analysis also using the same software to study the stress analysis for the main chassis of the selected design of HPV. Then, the safety factor also can be state after the result of FEA analysis is determined.

4.2 Volume and Area Reduction

This process is to find the percentage of volume and area reduction for the design of HPV before and after folded. The main objective of this project is to reduce the space and size for foldable HPV. Size reduction is the process to calculated the size of HPV before and after folded. This is the important process in this chapter because the best design for HPV will be selected based on the percentage of size reduction.

Percentage of size reduction for the designs of HPV will be evaluated based on the objective in this project. The higher the value of the percentage reduction, it will show that the design is achieve the project's objective. The percentage of size reduction is important in this project because it will influence the selecting design for foldable HPV.

Dimension such as length, width and height of HPV will be summarized on cubicle dimension that shows on Figure 4.1. The reading for all dimension will be taken before and after the HPV is folded. The main objective for applied the dimension of HPV into cubicle dimension is to figure out the space reduction of HPV after folded.

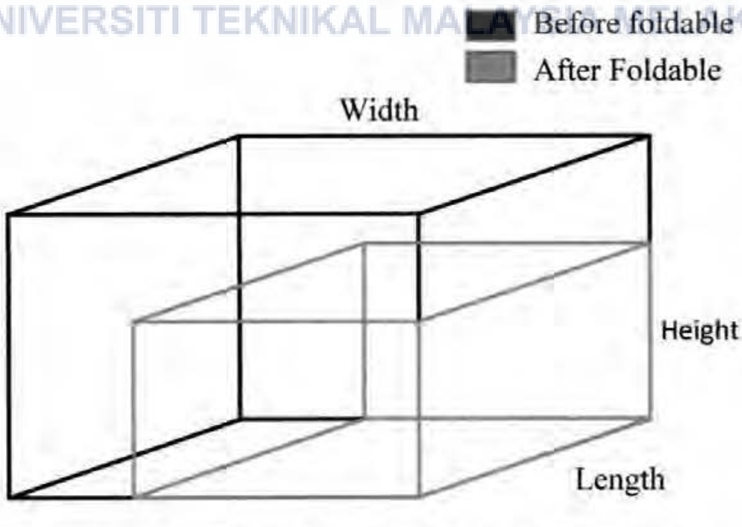

Figure 4.1: Size reduction in cubicle dimension

4.2.1 Volume and area reduction for Design 1

Figure 4.2 illustrates the design 1 before and after folded.

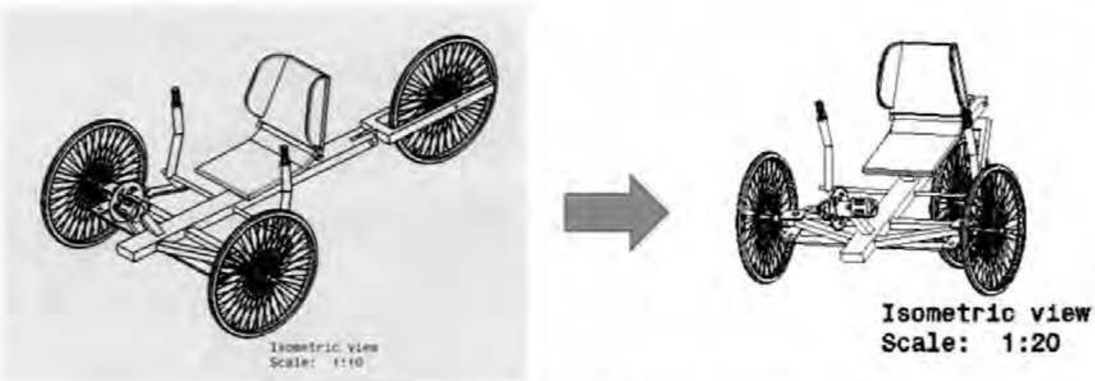

Figure 4.2: Design 1 before and after folded

Figure 4.3 shows the dimension of foldable HPV before and after folded in cubicle dimension. The dimension for length, height and width are summarize in the cubicle dimension.

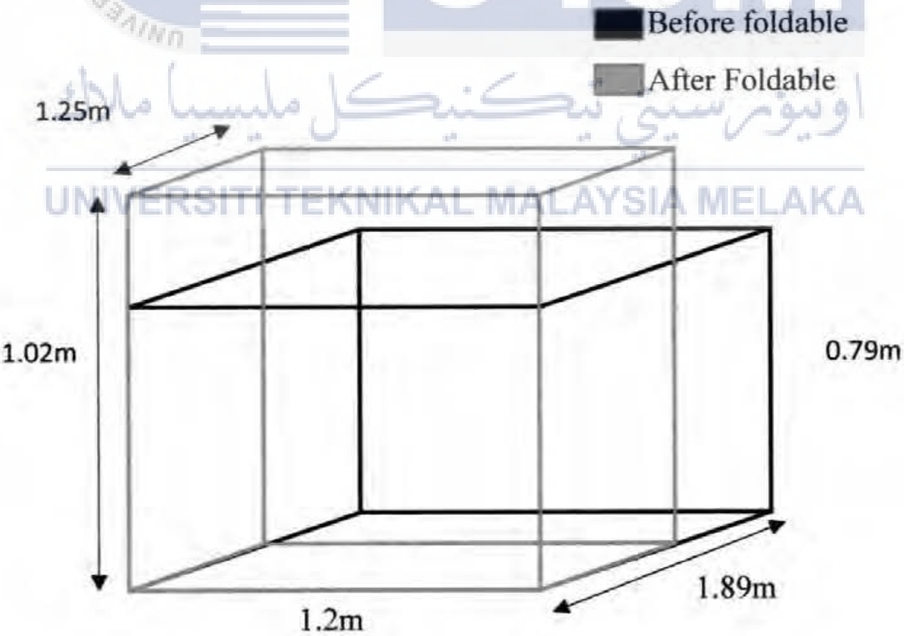

Figure 4.3: Size reduction for Design 1 in cubicle dimension

Percentage of Volume Reduction

$$\text{Percententage of volume reduction} = \frac{\text{volume before} - \text{volume after}}{\text{volume before}} \times 100$$

$$\text{Volume before}, v_b = 1.2 \times 1.89 \times 0.71 = 1.60\text{m}^3$$

$$\text{Volume after}, v_a = 1.2 \times 1.25 \times 1.02 = 1.53\text{m}^3$$

$$\textbf{Percententage of volume reduction} = \frac{1.60 - 1.53}{1.60} \times 100 = 4.375\%$$

Percentage of Area Reduction

$$\text{Percententage of area reduction} = \frac{\text{area before} - \text{area after}}{\text{area before}} \times 100$$

$$\text{Front area before}, A_{front} = 1.20 \times 0.71 = 0.85\text{m}^2$$

$$\text{Top area before}, A_{top} = 1.20 \times 1.89 = 2.27\text{m}^2$$

$$\text{Side area before}, A_{side} = 1.89 \times 0.71 = 1.34\text{m}^2$$

$$\text{Front area after}, A_{front} = 1.20 \times 1.02 = 1.22\text{m}^2$$

$$\text{Top area after}, A_{top} = 1.20 \times 1.25 = 1.50\text{m}^2$$

$$\text{Side area after}, A_{side} = 1.25 \times 1.02 = 1.28\text{m}^2$$

$$\text{Percentage of front area reduction} = \frac{0.85 - 1.22}{0.85} \times 100 = -43.5\%$$

$$\text{Percentage of top area reduction} = \frac{2.27 - 1.50}{2.27} \times 100 = 33.9\%$$

$$\text{Percentage of side area reduction} = \frac{1.34 - 1.28}{1.34} \times 100 = 4.47\%$$

4.2.2 Volume and Area Reduction for Design 2

Figure 4.4 illustrates the design 2 before and after folded.

Figure 4.4: Design 2 before and after folded

Figure 4.5 shows the dimension of foldable HPV before and after folded in cubicle dimension. The dimension for length, height and width are summarize in the cubicle dimension.

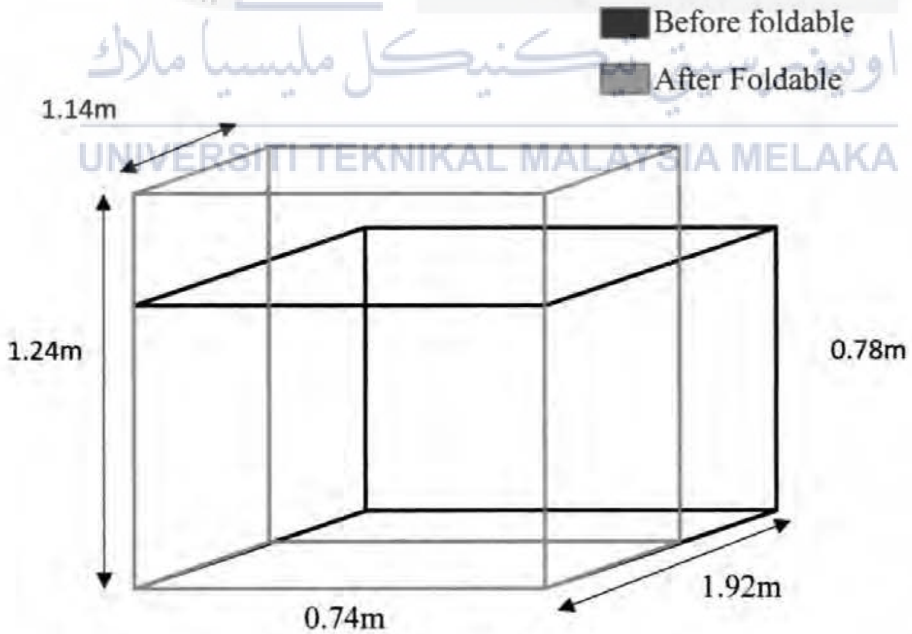

Figure 4.5: Size reduction for Design 2 in cubicle dimension

Percentage of Volume Reduction

$$\text{Percententage of volume reduction} = \frac{\text{volume before} - \text{volume after}}{\text{volume before}} \times 100$$

$$\text{Volume before}, v_b = 0.74 \times 1.92 \times 0.78 = 1.11 m^3$$

$$\text{Volume after}, v_a = 0.74 \times 1.14 \times 1.24 = 1.04 m^3$$

$$\textbf{Percententage of volume reduction} = \frac{1.11 - 1.04}{1.11} \times 100 = 6.3\%$$

Percentage of Area Reduction

$$\text{Percententage of area reduction} = \frac{\text{area before} - \text{area after}}{\text{area before}} \times 100$$

$$\text{Front area before}, A_{front} = 0.74 \times 0.78 = 0.58 m^2$$

$$\text{Top area before}, A_{top} = 1.74 \times 1.92 = 1.42 m^2$$

$$\text{Side area before}, A_{side} = 1.92 \times 0.78 = 1.50 m^2$$

$$\text{Front area after}, A_{front} = 0.74 \times 1.24 = 0.92 m^2$$

$$\text{Top area after}, A_{top} = 0.74 \times 1.14 = 0.84 m^2$$

$$\text{Side area after}, A_{side} = 1.14 \times 1.24 = 1.41 m^2$$

$$\text{Percentage of front area reduction} = \frac{0.58 - 0.92}{0.58} \times 100 = -58.6\%$$

$$\text{Percentage of top area reduction} = \frac{1.42 - 0.84}{1.42} \times 100 = 40.8\%$$

$$\text{Percentage of side area reduction} = \frac{1.50 - 1.41}{1.50} \times 100 = 6\%$$

4.2.3 Volume and Area Reduction for Design 3

Figure 4.6 illustrates the design 3 before and after folded.

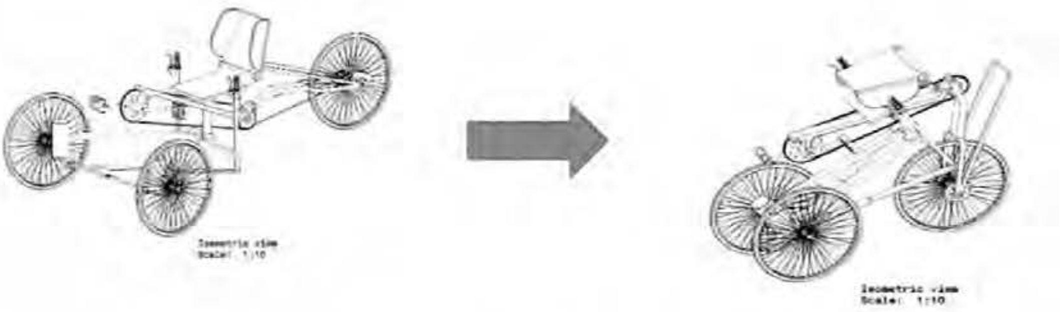

Figure 4.6: Design 3 before and after folded

Figure 4.7 shows the dimension of foldable HPV before and after folded in cubicle dimension. The dimension for length, height and width are summarize in the cubicle dimension.

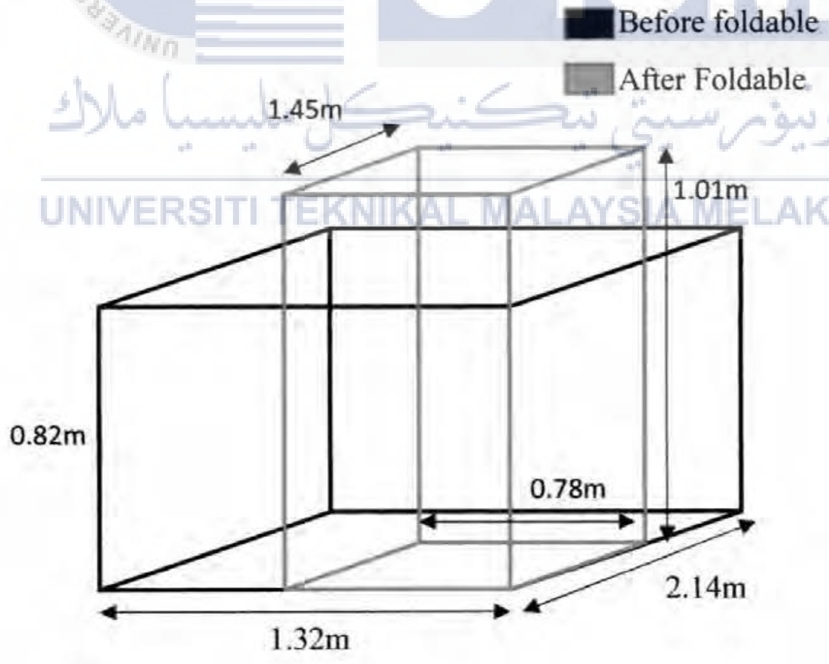

Figure 4.7: Size reduction for Design 3 in cubicle dimension

Percentage of Volume Reduction

$$\text{Percententage of volume reduction} = \frac{\text{volume before} - \text{volume after}}{\text{volume before}} \times 100$$

$$\text{Volume before}, v_b = 1.32 \times 2.15 \times 0.82 = 2.32\text{m}^3$$

$$\text{Volume after}, v_a = 0.78 \times 1.45 \times 1.01 = 1.15\text{m}^3$$

$$\textbf{Percententage of volume reduction} = \frac{2.32 - 1.15}{2.32} \times 100 = 50.6\%$$

Percentage of Area Reduction

$$\text{Percententage of area reduction} = \frac{\text{area before} - \text{area after}}{\text{area before}} \times 100$$

$$\text{Front area before}, A_{front} = 1.32034 \times 0.81905 = 1.08\text{m}^2$$

$$\text{Top area before}, A_{top} = 1.32034 \times 2.14735 = 2.84\text{m}^2$$

$$\text{Side area before}, A_{side} = 2.14735 \times 0.81905 = 1.79\text{m}^2$$

$$\text{Front area after}, A_{front} = 1.32034 \times 0.81905 = 1.08\text{m}^2$$

$$\text{Top area after}, A_{top} = 1.32034 \times 2.14735 = 2.84\text{m}^2$$

$$\text{Side area after}, A_{side} = 2.14735 \times 0.81905 = 1.79\text{m}^2$$

$$\text{Percentage of front area reduction} = \frac{1.08 - 0.79}{1.08} \times 100 = 26.85\%$$

$$\text{Percentage of top area reduction} = \frac{2.84 - 1.125}{2.84} \times 100 = 60.39\%$$

$$\text{Percentage of side area reduction} = \frac{1.79 - 1.48}{1.79} \times 100 = 17.32\%$$

4.2.4 Volume and Area Reduction Analysis

Table 4.1 shows the data needed for selecting the design of HPV. The table below consist the result calculation for determine the percentage of size reduction after the HPV is folded.

Table 4.1: Percentage of volume and area reduction

	Design 1	Design 2	Design 3
Percentage of Volume (%)	4.38	6.30	50.60
Percentage of Front Area (%)	-43.5	-58.6	26.85
Percentage of Top Area (%)	33.90	40.8	60.39
Percentage of Side Area (%)	4.47	6.00	17.32

The data from table prove that the design 3 has achieve the criteria needed in this project because design 3 can reduce 50.6 % of its volume in cubicle dimension. Design 3 has the higher value for percentage of volume among the other design while design 1 has the smaller value. Design 3 also has the higher percentage of reduction for front, top and side area compare to other design.

4.3 Weight Decision Matrix

Weight decision matrix is a helpful technique to use for making a decision on selecting design. A weight decision matrix also be a simple tool that can be useful in selecting design when there are many alternatives and many criteria of varying importance to be considered. It's also can be a best way to evaluate the all design for making a decision.

4.3.1 Selection by Design

There are three design of foldable HPV that need to be considered and the suitable design are chosen based on weight decision matrix. The design was selected by comparison of size reduction as shown in Table 4.1. The highest score is chosen based on the data analysis. For the process of Weight Decision Matrix, there are two equations of the score which are used to find the best score. Those equations are shown as below:

$$\text{Score} = [\ 1 - (\text{Data}/\ \text{Total Data})\ ] \tag{4.1}$$

$$\text{Score} = [\ (\text{Data}/\ \text{Total Data})\ ] \tag{4.2}$$

There are sample of calculation for first design from Table 4.2:

$$\text{Score} = [\ (\text{Data}/\ \text{Total Data})\ ]$$

$$= [(4.375/38.4)]$$

$$=0.11$$

Table 4.2 shows the decision matrix for size reduction of the foldable HPV.

Table 4.2: Decision matrix for size reduction of the foldable HPV

	Score		
	Design 1	Design 2	Design 3
Percentage of Volume (%)	0.11	-1.15	0.33
Percentage of Front Area (%)	-1.13	10.65	0.17
Percentage of Top Area (%)	0.88	-7.42	0.39
Percentage of Side Area (%)	0.12	-1.09	0.11
Total score	-0.02	0.99	1.00

Based on the data from Table 4.1 design 3 is more suitable to choose because design 3 has achieve the objective of this project to reduce the size of HPV after folded. Therefore, the reason for design 3 is more suitable to choose because the main part for chassis of design 3 such as rear and front part can be folded.

Therefore, based on Table 4.2 the highest score among those three design is the Design 3 of the foldable HPV according to the weight decision matrix analysis. Design 3 has the highest score between the size reduction which score 1.00. Thus, after the percentage of size reduction and weight decision matrix is determine, design 3 will be chosen to be the final design in this project.

4.4 Stress Analysis on Chassis

The stress analysis by using software CATIA is done on the part of the chassis. The chassis will be tested using a static analysis. The stress analysis will be test on the part of the chassis by using a three type of material which is iron, aluminium and steel. After the analysis was compute, the reading such as yield strength, maximum stress and minimum stress for Von Misses Stress can be determined. Then, the next process is to find the factor of safety. The factor of safety can be obtained by yield strength over maximum stress.

The result may be compare to find the suitable material use for the chassis. The stress analysis is to ensure safety against failure on the chassis and to ensure that the stresses in the part of the chassis are not exceeding the allowable limit. Before that, FEA analysis will show the part that has a maximum stress. Other than that, the deformation of chassis after the load was applied can be show after the analysis was compute.

FEA analysis was performed to find the weakness of the design structure. Therefore, FEA analysis is important process for making a design decision that ensure the structural stable and satisfy performance requirement. Before that, the stress analysis is done by applying the load 200KG on the chassis.

4.4.1 Stress Analysis on Front Chassis

Aluminium Material

Figure 4.8 shows the Von Mises stress for front chassis after the force was applied.

Figure 4.8: Stress analysis for front chassis (aluminium)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 9.5 \times 10^7 \text{Nm}^2$$

$$\text{Maximum stress} = 5.13 \times 10^7 \text{Nm}^2$$

$$\text{Factor of safety} = \frac{9.5 \times 10^7 \text{Nm}^2}{5.13 \times 10^7 \text{Nm}^2} = 1.85$$

Steel Material

Figure 4.9 shows the Von Mises stress for front chassis after the force was applied.

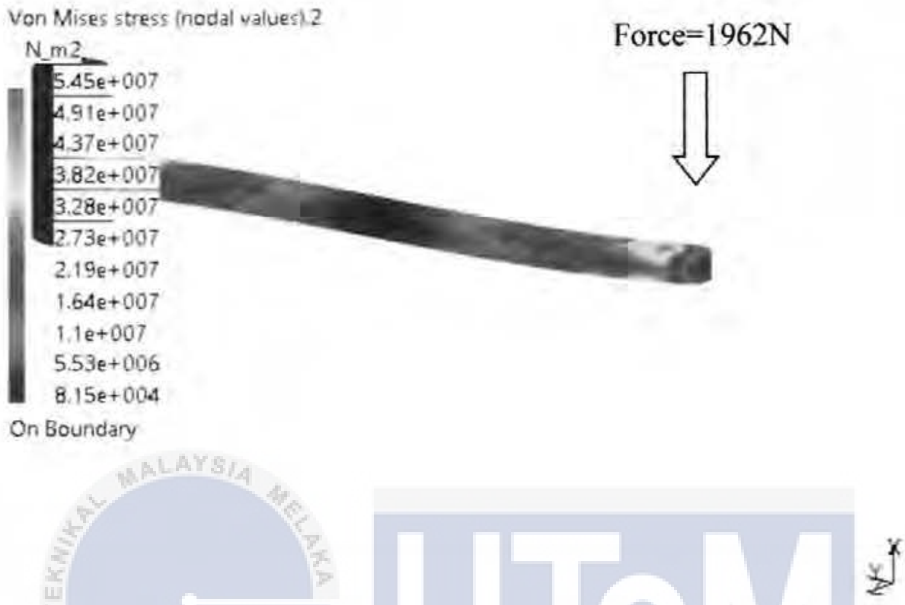

Figure 4.9: Stress analysis for front chassis (steel)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 2.5\times10^{8}\text{Nm}^{2}$$

$$\text{Maximum stress} = 5.45\times10^{7}\text{Nm}^{2}$$

$$\text{Factor of safety} = \frac{2.5\times10^{8}\text{Nm}^{2}}{5.45\times10^{7}\text{Nm}^{2}} = 4.59$$

Iron Material

Figure 4.10 shows the Von Mises stress for front chassis after the force was applied.

Figure 4.10: Stress analysis for front chassis (iron)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 3.1{\times}10^{8}\text{Nm}^2$$

$$\text{Maximum stress} = 5.35{\times}10^{7}\text{Nm}^2$$

$$\text{Factor of safety} = \frac{3.1{\times}10^{8}\text{Nm}^2}{5.35{\times}10^{7}\text{Nm}^2} = 5.81$$

4.4.2 Stress Analysis on Middle Shaft

Aluminium Material

Figure 4.11 shows the Von Mises stress for middle shaft after the force was applied.

Figure 4.11: Stress analysis for shaft (aluminium)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 9.5\times10^{7}\text{Nm}^{2}$$

$$\text{Maximum stress} = 1.37\times10^{8}\text{Nm}^{2}$$

$$\text{Factor of safety} = \frac{9.5\times10^{7}\text{Nm}^{2}}{1.37\times10^{8}\text{Nm}^{2}} = 0.69$$

Steel Material

Figure 4.12 shows the Von Mises stress for middle shaft after the force was applied.

Figure 4.12: Stress analysis for shaft (steel)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 2.5{\times}10^{8}\text{Nm}^{2}$$

$$\text{Maximum stress} = 1.46{\times}10^{8}\text{Nm}^{2}$$

$$\text{Factor of safety} = \frac{2.5{\times}10^{8}\text{Nm}^{2}}{1.46{\times}10^{8}\text{Nm}^{2}} = 1.71$$

Iron Material

Figure 4.13 shows the Von Mises stress for middle shaft after the force was applied.

Figure 4.13: Stress analysis for shaft (iron)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 3.1 \times 10^8 \text{Nm}^2$$

$$\text{Maximum stress} = 1.43 \times 10^8 \text{Nm}^2$$

$$\text{Factor of safety} = \frac{3.1 \times 10^8 \text{Nm}^2}{1.43 \times 10^8 \text{Nm}^2} = 2.17$$

4.4.3 Stress Analysis on Rear Chassis

Aluminium Material

Figure 4.14 shows the Von Mises stress for rear chassis after the force was applied.

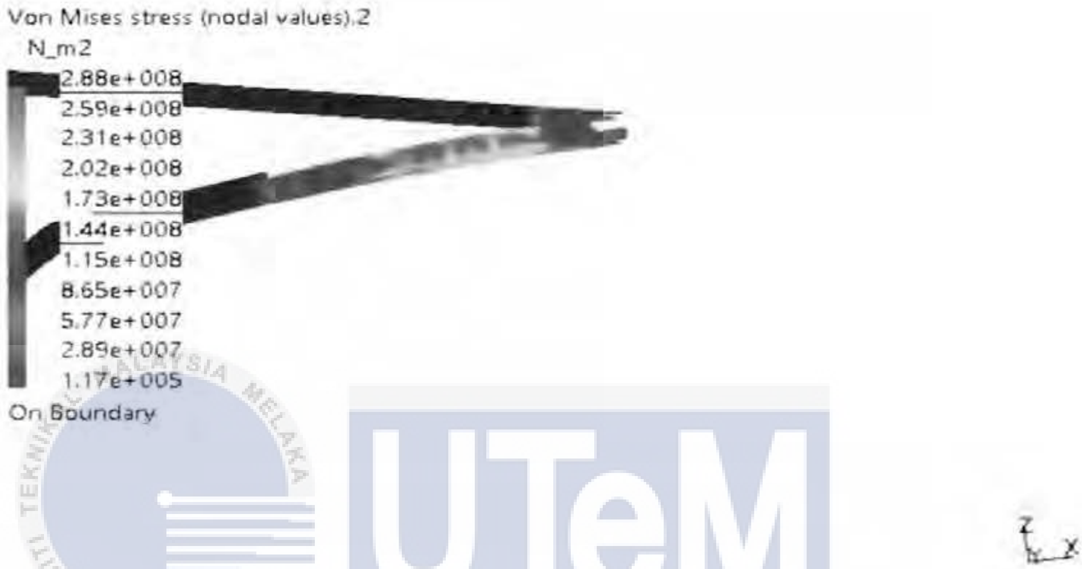

Figure 4.14: Stress analysis for rear chassis (aluminium)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 9.5\times10^{7}\text{Nm}^{2}$$

$$\text{Maximum stress} = 2.88\times10^{8}\text{Nm}^{2}$$

$$\text{Factor of safety} = \frac{9.5\times10^{7}\text{Nm}^{2}}{2.88\times10^{8}\text{Nm}^{2}} = 0.33$$

Steel Material

Figure 4.15 shows the Von Mises stress for rear chassis after the force was applied.

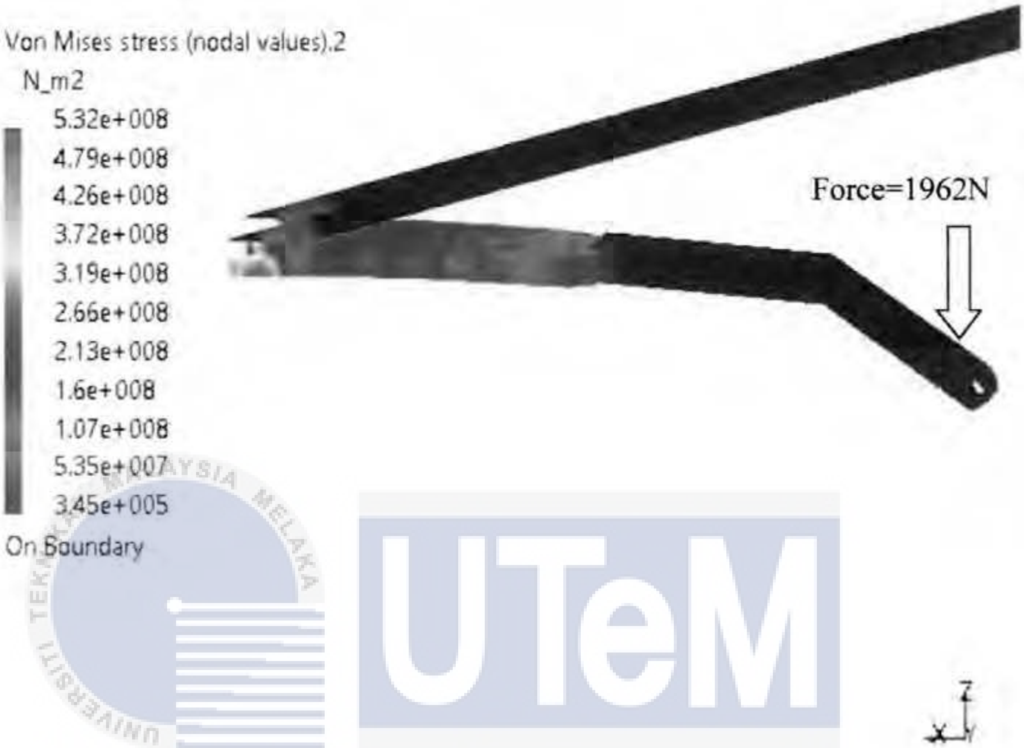

Figure 4.15: Stress analysis for rear chassis (steel)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 2.5\times10^{8}\text{Nm}^{2}$$

$$\text{Maximum stress} = 5.32\times10^{8}\text{Nm}^{2}$$

$$\text{Factor of safety} = \frac{2.5\times10^{8}\text{Nm}^{2}}{5.32\times10^{8}\text{Nm}^{2}} = 0.47$$

Iron Material

Figure 4.16 shows the Von Mises stress for rear chassis after the force was applied.

Figure 4.16: Stress analysis for rear chassis (iron)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 3.1\times10^{8}\text{Nm}^{2}$$

$$\text{Maximum stress} = 5.3\times10^{8}\text{Nm}^{2}$$

$$\text{Factor of safety} = \frac{3.1\times10^{8}\text{Nm}^{2}}{5.3\times10^{8}\text{Nm}^{2}} = 0.5$$

4.4.4 Stress Analysis on Middle Chassis

Aluminium material

Figure 4.17 shows the Von Mises stress for middle chassis after the force was applied.

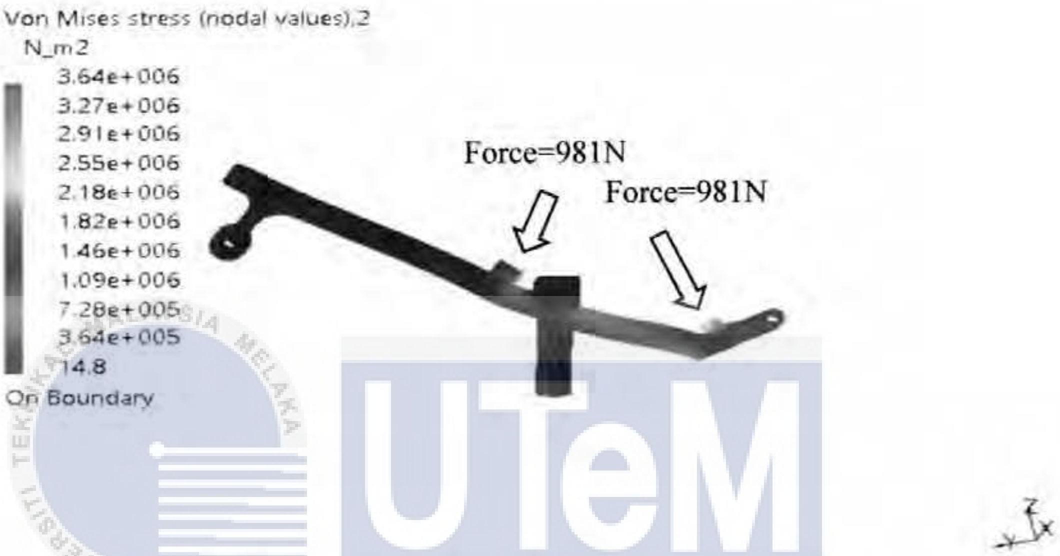

Figure 4.17: Stress analysis for middle chassis (aluminium)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 9.5{\times}10^7\text{Nm}^2$$

$$\text{Maximum stress} = 3.64{\times}10^6\text{Nm}^2$$

$$\text{Factor of safety} = \frac{9.5{\times}10^7\text{Nm}^2}{3.64{\times}10^6\text{Nm}^2} = 26.09$$

Steel Material

Figure 4.18 shows the Von Mises stress for middle chassis after the force was applied.

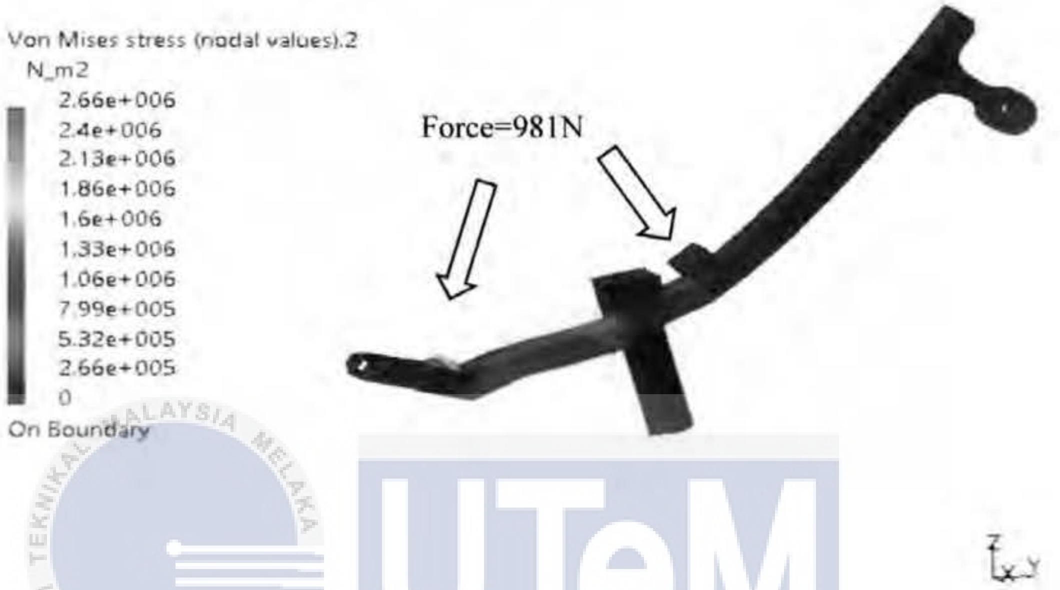

Figure 4.18: Stress analysis for middle chassis (steel)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 2.5{\times}10^{8}\text{Nm}^{2}$$

$$\text{Maximum stress} = 2.66{\times}10^{6}\text{Nm}^{2}$$

$$\text{Factor of safety} = \frac{2.5{\times}10^{8}\text{Nm}^{2}}{2.66{\times}10^{6}\text{Nm}^{2}} = 93.98$$

Iron Material

Figure 4.19 shows the Von Mises stress for middle chassis after the force was applied.

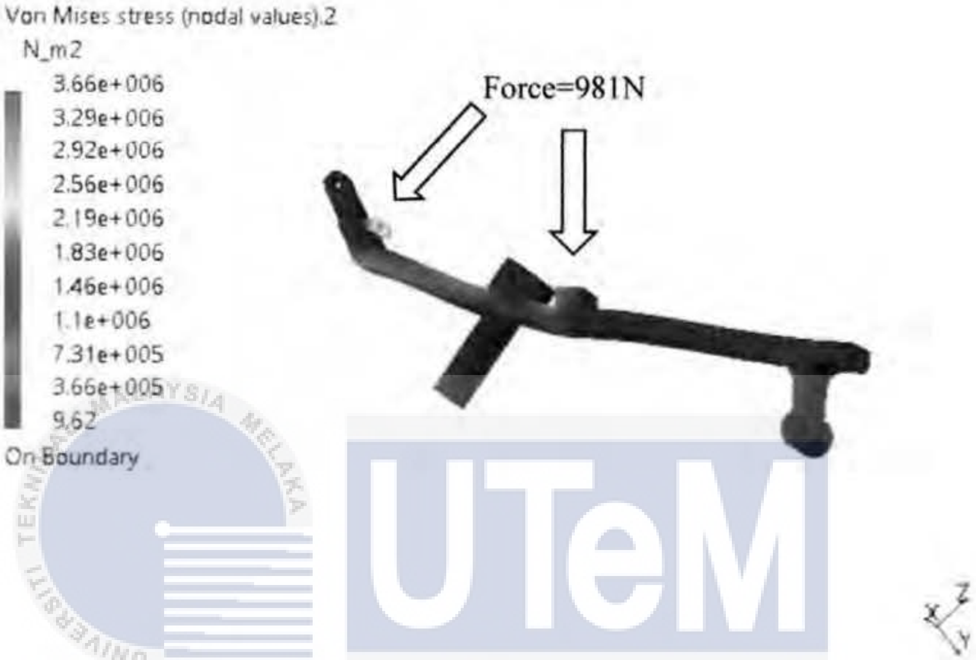

Figure 4.19: Stress analysis for middle chassis (iron)

$$\text{Factor of safety} = \frac{\text{yield strentgh}}{\text{maximum stress}}$$

$$\text{Yield Strength} = 3.1\times10^{8}\text{Nm}^{2}$$

$$\text{Maximum stress} = 3.66\times10^{6}\text{Nm}^{2}$$

$$\text{Factor of safety} = \frac{3.1\times10^{8}\text{Nm}^{2}}{3.66\times10^{6}\text{Nm}^{2}} = 84.7$$

4.4.5 Selection by Material

Selection by material are proceed after the process of selection design for foldable HPV. Since the design for HPV has been chosen, then the selection by material is done among the Design 3. This stage will determine the suitable material to apply for the chassis of foldable HPV. The overall safety factor and decision matrix analysis for the material selection is shown in Table 4.3 and Table 4.4.

There is sample calculation for safety factor for middle chassis with aluminium material from Table 4.4.

Score = [(Data / Total Data)]

= [(26.00 / 28.87)]

= 0.90

Table 4.3: Overall safety factor

No	Item	Material		
		Aluminium	Steel	Iron
1	Safety factor for middle chassis	26.00	93.98	84.70
2	Safety factor for rear chassis	0.33	0.47	0.58
3	Safety factor for front chassis	1.85	4.59	5.81
4	Safety Factor for middle shaft	0.69	1.71	2.17
Total Data		28.87	100.75	93.26

Table 4.4: Decision matrix for the material selection

No	Item	Score		
		Aluminium	Steel	Iron
1	Safety factor for middle chassis	0.90	0.93	0.91
2	Safety factor for rear chassis	0.01	0.04	0.01
3	Safety factor for front chassis	0.06	0.05	0.06
4	Safety Factor for middle shaft	0.02	0.02	0.02
	Total score	0.99	1.04	1.00

Based on Table 4.4, the highest total score between the material is steel which scores 1.04 while the second highest total score is iron with score 1.00. Therefore, the suitable material for the foldable chassis of HPV design is steel. The result for the selection materials is based on the weight decision matrix analysis. Hence, Design 3 with apply the steel as the material is the suitable design for this project theoretically.

4.5 Final Design for Foldable HPV

Figure 4.20 and 4.21 show the isometric view for the final design of this project. The final design of foldable HPV may consist of four separate part for chassis. The chassis for this type of HPV play the important part on this project due to it functional to be folded. Then, the HPV may be use a steel material after the result obtained from the selection material. Figure 4.20 show the condition of the chassis for this HPV before foldable.

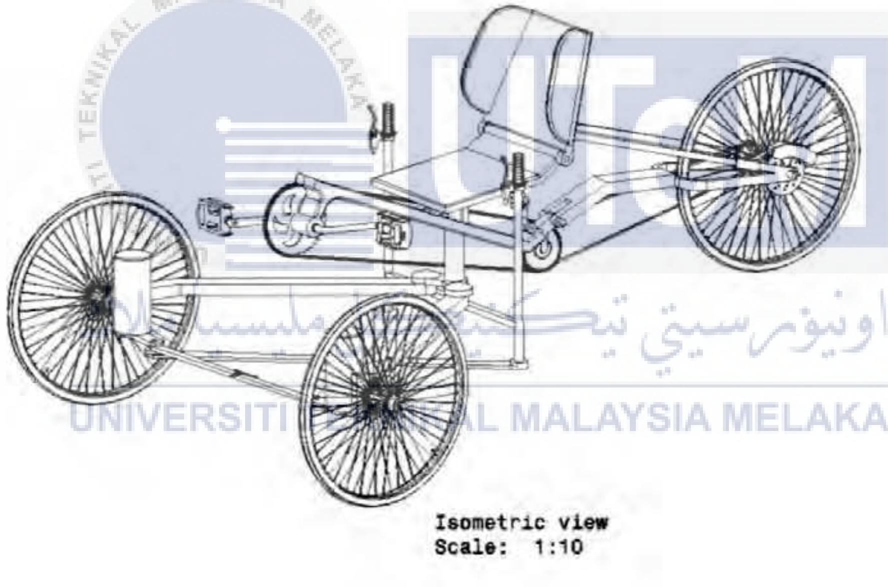

Figure 4.20: The foldable HPV

Figure 4.21 shows the condition after the HPV is folded and Figure 4.22 shows the chassis of HPV for final design. This type of HPV can reduce the size about 50.6 percent from the actual size.

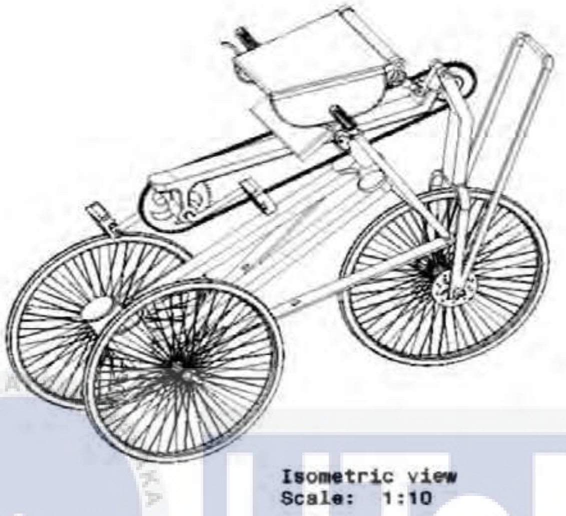

Figure 4.21: The design for HPV after foldable

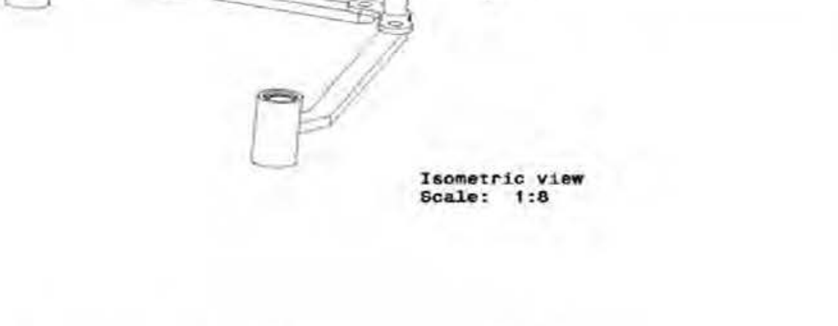

Figure 4.22: Foldable Chassis for final design.

CHAPTER 5

CONCLUSION

5.1 Introduction

Human powered vehicle was designed for green technology. HPV as a recumbent vehicle is giving more comfort during riding compared to bicycle. Every year, there are many innovations that give improvement for the design of HPV in term of comfort and ergonomic. The main reason to do some improvement for HPV is to overcome all the problem statement due to HPV size and the size of area used for HPV to parking.

5.2 Conclusion

In this study, the HPV was design based on the objective of this project which is to reduce the size of HPV is achieved. The HPV was design to be foldable to easier the user during parking or store it. Besides that, the foldable HPV was sketch by using CAD drawing which is CATIA. In this project, the final design for the foldable HPV was selected based on the result from the percentage of the size reduction. Hence, the final design for the foldable HPV can reduce 50.6 percent of volume after foldable.

In accordance to this present invention, the final design for the foldable HPV having two front wheels and a single rear wheel is provided. The chassis may provide four separable assemblies which is two front chassis, middle chassis and rear chassis. When the HPV is assembled, the chassis can be folded to reduce the size of HPV.

For the material selection, the result shows that the steel material is the best material among the other material such as iron and aluminium. From the result obtained, steel material is suitable to applied into this foldable HPV theoretically. Finally, Design 3 is the best design to choose as a final design because the design has achieved the main objective of this HPV to reduce the size and many assembled part can be folded.

5.3 Recommendation

Based on the conclusion above in this study, further research can be conducted by the following:

1. Design a foldable and detachable human powered vehicle that use four wheel.
2. Focus on the drive mechanism for foldable HPV.
3. Study about the weight of material that need to applied on the foldable HPV in term of lighter in weight. Therefore, high acceleration can be gained due its light weigh
4. Design the electric motor for the foldable HPV that can be use during riding. It also can be used for long journey travel and can be used for charging electrical appliances.
5. Design and analysis the movement of foldable HPV during cornering.

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APPENDICES

Appendix A: Final design (rendering)

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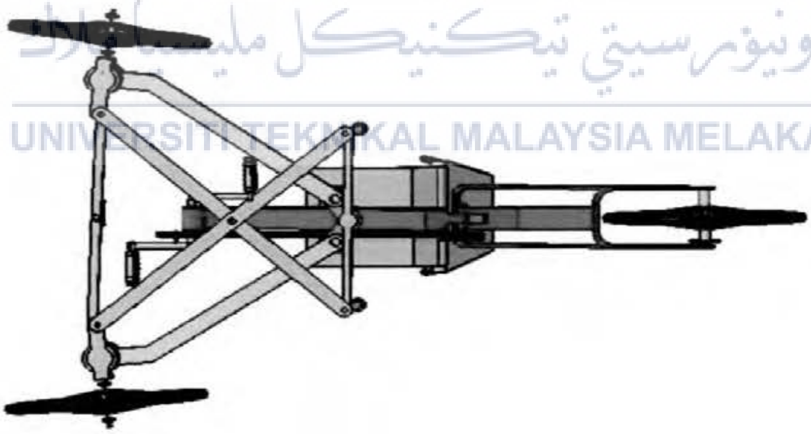
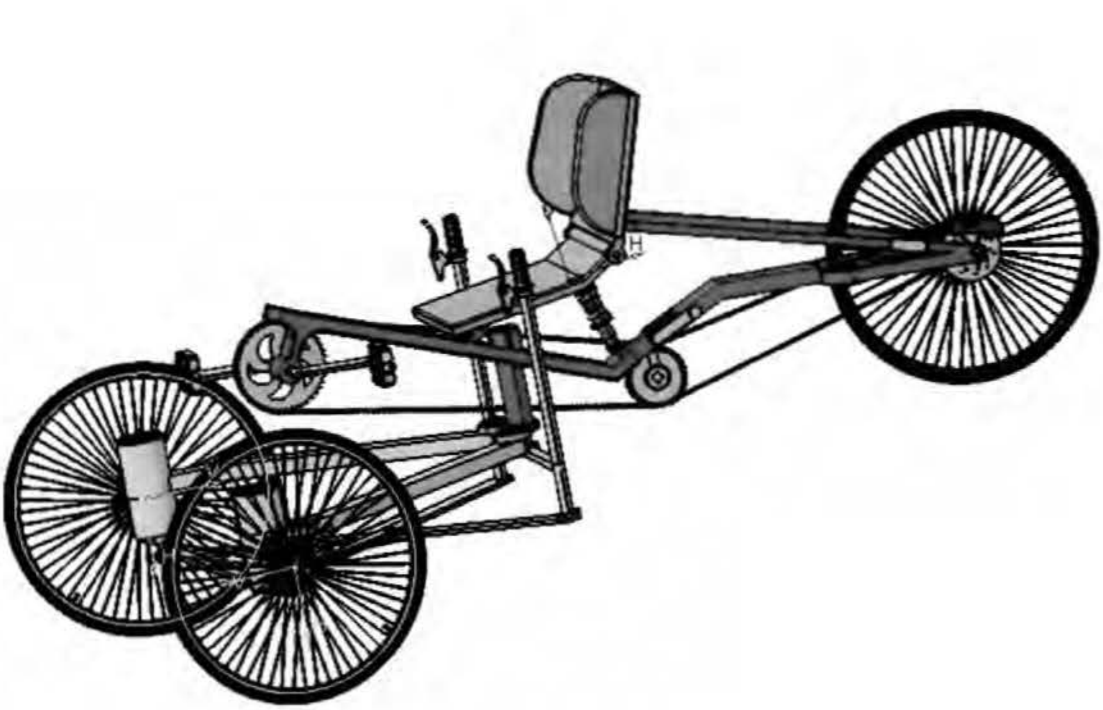
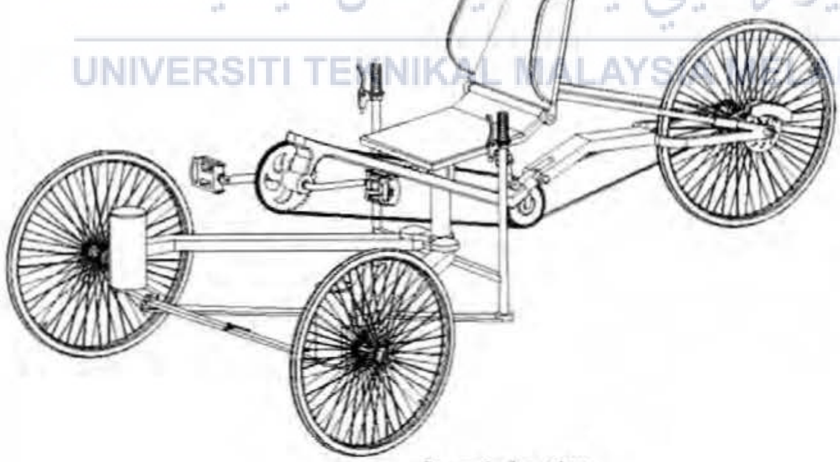


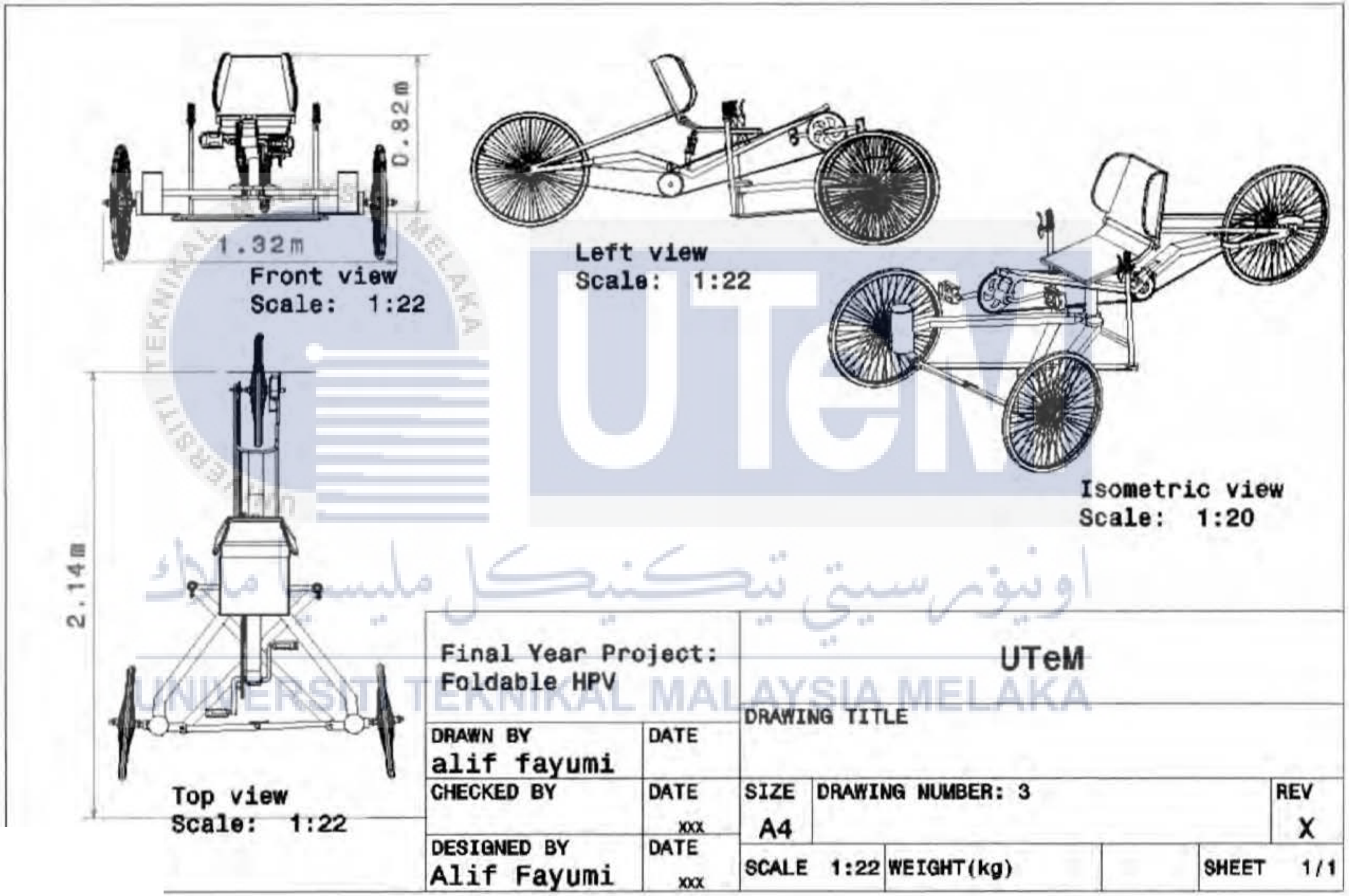
Appendix B: Steering system for final design



Appendix C: Isometric view for final design

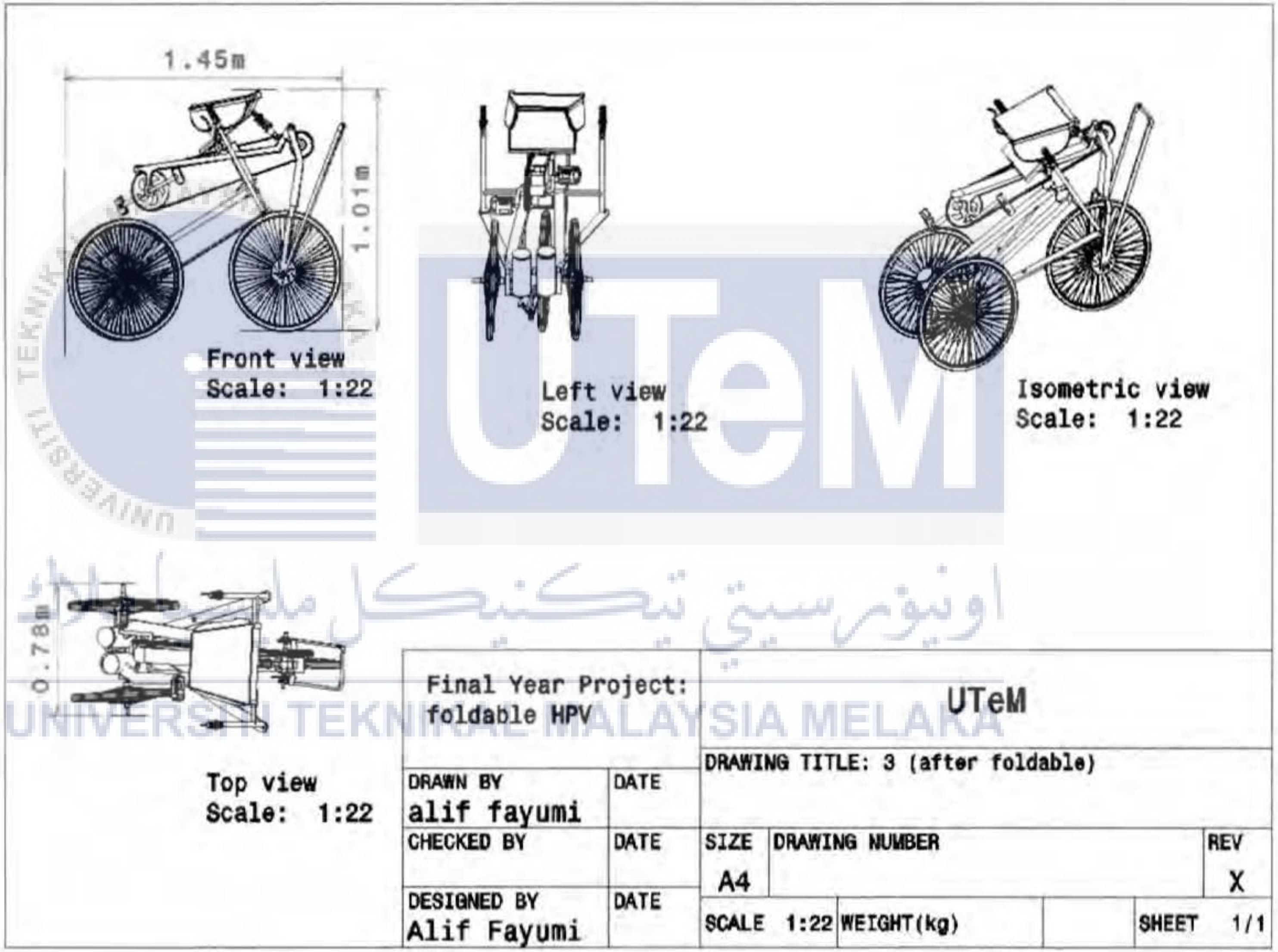


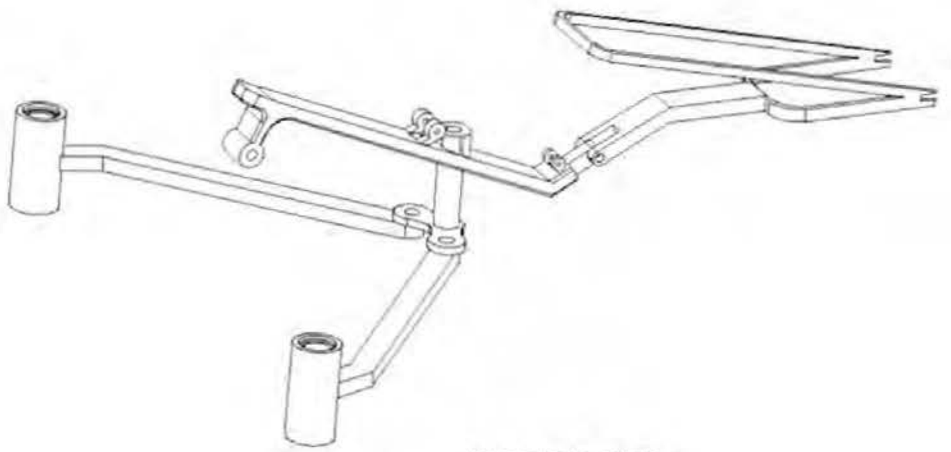
Appendix D: Isometric view for final design



Appendix E: Drafting for final design before foldable

Appendix F: Drafting for final design after foldable





Appendix G: Isometric view for chassis of final design

Appendix H: Exploded view of final design