DESIGN AND DEVELOPMENT OF A RUNNING CHASSIS FOR A SIMPLE VEHICLE
(BRAKE, SUSPENSION, STEERING SYSTEM)

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DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF
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CERTIFICATION OF APPROVAL

Design and Development of a Running Chassis for a Simple Vehicle (Brake, Suspension, Steering System)

by

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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 reference and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

YASSER PUTRA RIFEMI

ABSTRACT

As the name implies, a simple vehicle can be describe as vehicle which only has a few parts, doesn't have a complicated design, doesn't involve complex machinery, and easy to operate. Although simple, each and every component must be properly built to achieve certain purposes of the vehicle, including the running chassis. It comprises of braking system, suspension system, and steering system. A poorly designed running chassis would cause an uncomfortable ride of the vehicle, instability especially during corner, and eventually low fuel efficiency. The objective of this project was to produce braking system that can give adequate braking, rigid suspension system that can bear the whole weight of the vehicle and give stability to the vehicle and its cargo, and also a rigid and light steering system. They were achieved by conducting research and calculations, experimenting on different setups (trial and error) method and also research about local market availability of the required products. The vehicle's brake was tested both under static and dynamic brake test. Due to all calculations and modifications done to the vehicle, it could be stopped at a 30° inclined slope both using the front brakes and rear brakes individually. Under dynamic test, the vehicle can be stopped in less than 5m when the vehicle was driven at a speed of 25 km/h. The brake was also easier and less tiring to operate than the previous configuration thanks to foot operated brakes. Better parts tolerance was achieved due to better design and fabrication process. It reduced the clattering and eases the general operations, especially after proper usage of grease. A newly ergonomic and space efficient driving position was also achieved by simulating it digitally until a satisfying design was achieved. Lastly, the current vehicle can be controlled easily by having a steering ratio of 0.815:1, or also called fast ratio, which is desired for simple vehicle with limited cockpit space.

TABLE OF CONTENTS

LIST OF FIGURES, TABLES, AND EQUATIONS

LIST OF FIGURES:

LIST OF TABLES:

LIST OF EQUATIONS:

CHAPTER 1
INTRODUCTION

1.1 Background Study

Braking system is a very crucial part of a vehicle and is impossible for any means of vehicle not to have one. The history of automobile braking system dated back to 1902 when Ransom E. Olds founded drum brakes and also a patent by F. W. Lanchester for nonelectric spot disc braking system. In a simple vehicle, the braking requirement is different than ordinary vehicle due to speed of simple vehicles would not reach that of an ordinary vehicle. In a very slow application, bicycle brakes can even be used instead of automobile's braking system.

The function of suspension system is more than just making a comfortable and enjoyable ride; it also has to make sure that the tires are always in contact with the road. A vehicle that loses contact with the road will lose its ability to transmit power and the driver would lose control of the vehicle. A simple vehicle however, due to its functionality limit, might put this terms aside. For example, go kart does not have any springs and absorber due to its limited usage. A go kart would only be used in short distance and on almost flat surfaces, eliminating the need of suspension system.

The function of steering system is to ensure that the vehicle is going to the intended direction. Steering system exists in every form of transportation except trains, which follows the turns of the railroads. Nowadays, the simplest form of steering system can be found on motorcycles. The front tires assembly rotates about an axis which can be easily controlled by the handle bar. This simplest system however may not be applicable to simple vehicle as the driver most likely sits at the same level with the tires axle. The best option is therefore applying a simple linkage consisting steering shaft, pitman arms, and tie rods. The steering shaft is connected to the tie rods via pitman arms, which will convert the angular motion of the shaft into linear motion to steer the tires.

1.2 Problem Statement

The current project is a continuation of the first version of simple vehicle design. Making the first project as a benchmark, it revealed several problems for the second version to solve. Regarding the braking system, the rear brake could not stop the vehicle as it used conventional rubber pads instead of disc brake. There was also only one brake on the rear side of the vehicle, making it harder to stop as it has to hold most of vehicle's weight only on one brake. The front brakes however showed minimum failure and able to stop the vehicle, but problems occurred on the braking grips. It was said to be really hard and tiring to activate the brakes. Figure 1 demonstrates one of the possible reasons: the configuration of the braking wires that bended more than 90° (circled in red). Wiring which has sudden curve like so will cause friction with the wire tubing hence making it difficult to activate.

Figure 1: Previous braking lever installment

The steering system was reported to be well functional, but could not support the weight of the vehicle. Even during stationary condition, the steering column vibrated heavily when the body of the car was given light rocking. The cause might came from joints on the linkage that had too large of tolerance between the components, giving spaces for them to shatter. Figure 2 shows the previous installation of the steering system. The bar (showed in yellow box) interferes with the leg position and the red area was literally an excess space and can be cut out.

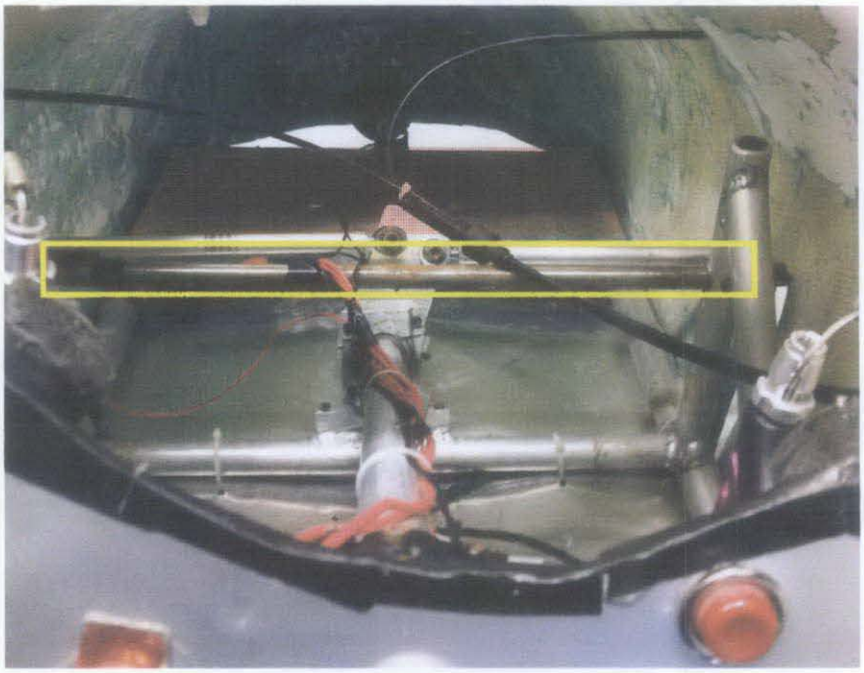


Figure 2: Previous steering linkage assembly

Apart from those, there were no other major problems reported regarding running chassis. Suspension system had no problems as the vehicle did not use any complex springs or dampers.

1.3 Objectives

The first objective of this project was to ascertain the problems encountered on the braking and steering system of the 1st version of the simple vehicle. This was done firstly by discussing with those involved with the previous vehicle about the ups and downs of it; the pros and cons, the strength and weaknesses from their point of view. Benchmarking was also done to find out which sectors that could be improved or even discarded if deemed unnecessary.

After necessary information was gathered, the next objective was to implement corrective measures in the design, fabrication and assembly of the braking and steering system. These were done by consulting with the pros, such as university's technician, as the fabrication process goes on. Inputs might come from anywhere, hence the importance of regular discussion with fellow colleagues and supervisors.

1.4 Scope of Study

The project was generally into 5 phases. The first phase was defining the parameters that would limit the working area of the team. There were certain guidelines that must be followed such as the maximum height of the chassis or even the maximum track width of the tires. The market availability of the components and materials also acted as a limitation for the project.

The next phase was to design the components using CATIA. The design started from scratch, starting from the ladder frame which was measured directly to the actual chassis to ensure proper dimensioning. All other components were then designed and positioned by making the frame as the reference point. The 3rd phase, which was analysis, took part almost immediately after the design was ready. The most important part of the analysis was the strength of the chassis itself; it must be strong enough to endure force from any directions.

The fourth phase was fabrication and procurement. Preferably, fabrication must be done within the university vicinity to ensure maximum fabrication process exposure for the student. Beside knowledge gain, the cost of production was on the house and fund can be allocated on more necessity parts. For the running chassis, investment was mainly to purchase new sets of braking systems.

After all parts had been fabricated and procured, the project entered the last phase: assembly and testing. All parts were assembled according to the blueprints of the vehicle. Only after this phase, unexpected glitches were detected and affect the overall performance of the vehicle. Adjustments were done wherever necessary to fix those problems.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Disc brake

Most of simple vehicles would not achieve the speed of an ordinary vehicle; hence complicated braking system is unnecessary. Bicycle braking system is still considered sufficient for low speed applications of simple vehicle. There are two types that are still widely used nowadays; the rim brakes and disc brakes. Rim brakes apply the brake directly to the rim by gripping it with friction pads on each side of the rim. The second type actually applies the same concept; two brake pads grip the rim but this time the rim is replaced with much smaller disc brakes that can be made of much stronger materials. The latter type is preferred because it's much more reliable.

The braking force of the vehicle is contributed by two forces; the friction force applied from the calipers to disc and the rolling friction force of the tire (Lie & Sung, 2009).

$$F_t = \frac{T_b}{R_0} + \mu_r \frac{W_0}{R_0} \rightarrow \frac{r}{R_0} F_d + \mu_r \frac{W_0}{R_0}$$

Equation 1: braking force equation

Where: F_t = total braking force (N)

T_b = braking torque (Nm)

μ_r = friction coefficient with respect to the ground

W_0 = load of tire axle (N)

F_d = friction force applied from caliper to disc (N)

r = radius of disc brake (m)

R_0 = radius of tire (m)

As with all other components, braking system might lose its quality overtime. There are three main contributors that should be avoided, if possible, regarding this (Breuer & Bill, 2008). The first one is known as fading, a drop of braking power and braking effect at high temperatures. The main cause of this phenomenon is the initial fading occurring to particularly new or hasn't yet been exposed to high temperatures. When the brake pads exceed a certain limit under high brake loads, in this case during the intensive testing period, the binding agents connecting the brake pad components may evaporate and disperse. Eventually this will create a cushion of gas between the pads surface and the disc brake, reducing the braking power dramatically despite the struggling effort from the driver.

The second phenomenon is formation of bubbles caused by evaporation. It's due to the brake fluid reaching boiling temperature especially at the area of contact between the disc and the pads. Once the fluid heat up, just like stated before, gas cushion is formed and the braking power will deteriorate. This effect is worsened when the vehicle stays stationary after intensive usage, as the disc will heat up the fluid even faster due to no cooling effect from the air rushing by. Can be seen on figure 3, the boiling point may be reached more quickly during this period (Breuer & Bill, 2008).

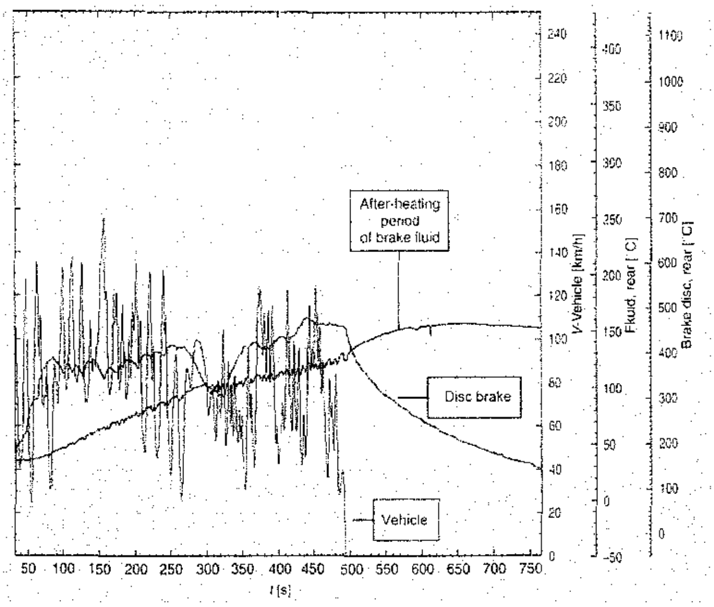


Figure 3: Vehicle, disc, and brake fluid temperature range

The last problem still involving thermal stability may come from brake disc deflection where it could make noticeable noises and give a significant amount of excessive heat as the disc brake aren't positioned exactly perpendicular about the wheel's axis.

Seen from above, the disc would create a wave-like movement when the tire's rotated. It would then scrape each side of the brake pads in turns even if the brakes weren't applied.Although the rear brakes were used less than the front brakes, it endured far more heat than the front brakes. Figure 4 gives a better illustration, where the piston must travel a certain distance to 'straighten the disc first' then only started braking (Breuer & Bill, 2008).

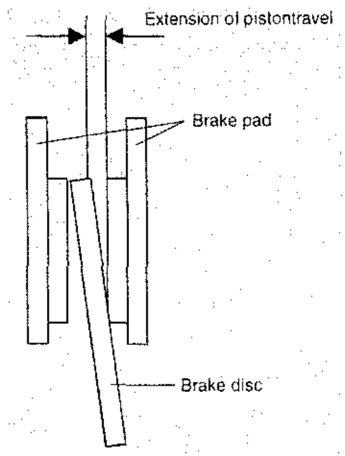


Figure 4: Brake disc deflection

2.2 Suspension

Suspension can be described as the system of springs, shock absorbers, and linkages connecting a vehicle to its tires. For simple vehicle however, as mentioned earlier, there might exist no necessity for such system to be installed on the vehicle. The ride height can also be said as one of the part of the suspension system. On simple vehicle however, it is considered a fix parameter as equipment to adjust the height cease to exist. It must be decided before the final fabrication process.

2.2.1 Camber angle

Camber is the inward or outward tilt of a wheel as viewed from the front of the vehicle (Kershaw, 2007). Specifically, it's the angle between the centerline of the wheel and tire and a true vertical line that is perpendicular to a level surface. Figure 5 give a better illustration. If the top of the tire is farther out than the bottom it is called positive camber, and vice versa. Negative camber improves grip when cornering because the weight shift during corner actually pushes the outer tire downwards, giving a better surface contact. On the other hand, for maximum straight-line acceleration, the greatest traction will be attained when the camber angle is zero and the tread is flat on the road, giving maximum surface contact at all times.

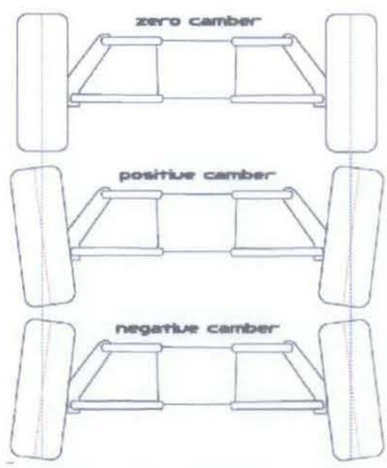


Figure 5: Camber angle comparison (retrieved from http://i215.photobucket.com/albums/cc25/celicamadnest/camber-1.gif)

2.2.2 Toe

Toe is defined as the measurement taken between the front edges of the tires on the same axle (Kershaw, 2007). Tires that are parallel to each other and to the car have a neutral toe angle. If the front of the tires point inward toward the car, the tires are in the toe-in position, and vice versa. Theoretically, the most efficient settings would be neutral toe for a straight line because there would be no tire slip that reduces fuel efficiency.

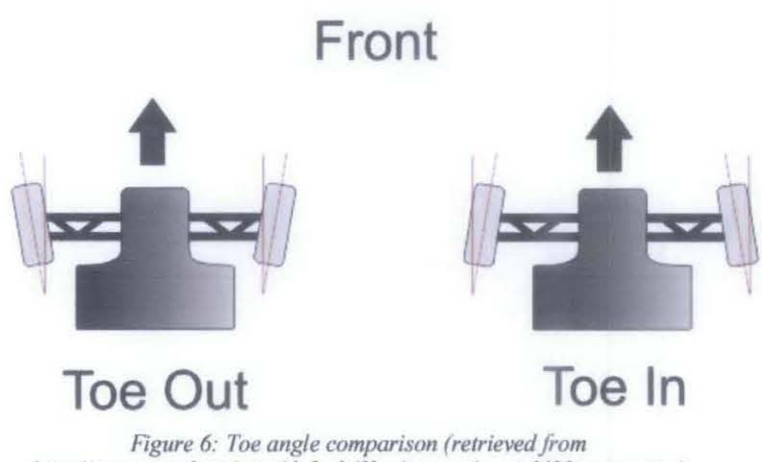


Figure 6: Toe angle comparison (retrieved from http://www.ustudy.in/sites/default/files/images/toe-in%20toe-out.jpg)

2.3 Steering systems

Compared to ordinary vehicles, the cockpit of simple vehicles is usually smaller and less convenience to the driver. The lack of space also makes it impossible to install pumps for assisted steering such as hydraulic power steering. The two widely used steering systems on commercial cars are the rack and pinion system and also the recirculating-ball steering (Kershaw, 2007). The first one is the most common type, having a pretty simple mechanism. The steering wheel is attached to the pinion gear which in turn turns the rack, which is connected to the tires through tie rods at each end of the rack. The latter one is more common to be found on trucks and SUV's. The system utilizes worm gears and ball bearings, providing a more precise and lighter handling. The steering for a simple vehicle however would resemble one of a go-kart. It's so simple one can find lots of DIY guides on how to make custom go-kart steering system. It only consisted of 2 independent push-rods that connect the steering rod to the steering arms.

The basic idea is developed from a centerpoint steering linkage which can be found on Volkswagen Type II van (Kershaw, 2007). Compared to figure 7, the steering that would be used in a simple vehicle would discard the pitman arm and drag link, using the steering shaft to directly rotate the intermediate steering arm.

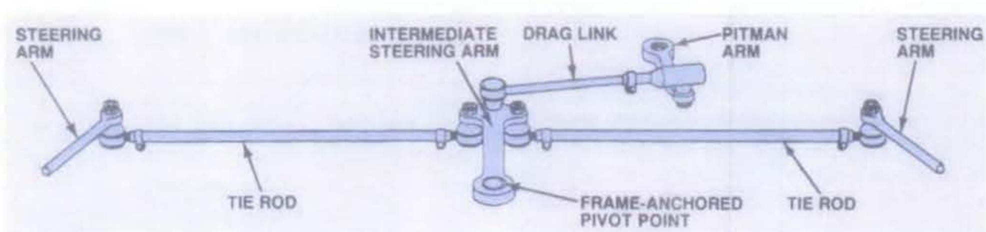


Figure 7: Centerpoint steering linkages

2.3.1 Ackermann steering geometry

Ackermann steering geometry governs the relationship between the front tires during cornering. The principal stated that the inside tire needs to turn tighter than the outer tire to avoid slip in either of the tires (Kershaw, 2007). Tire slip causes inefficiency and in greater scale could cause lose of vehicle control.

There are three types of Ackermann geometry, each of which can be differentiated by drawing lines from both kingpins through the steering arm mounting point and extending them until they intersect each other.

The first type of Ackermann geometry, True Ackermann geometry, occurs when both of the extended lines intersect exactly on the center line of the rear axle (refer to figure 8). When it intersects behind the rear axle, it is called Less Ackermann geometry. The last type, More Ackermann geometry, happens when the intersection is in front of the rear axle.

True Ackermann will give be the most efficient settings as no slip occurs on the front tires. Less Ackermann will give a quicker steering response while More Ackermann gives a smoother response. Figure 9 and 10 give better illustration regarding these settings.

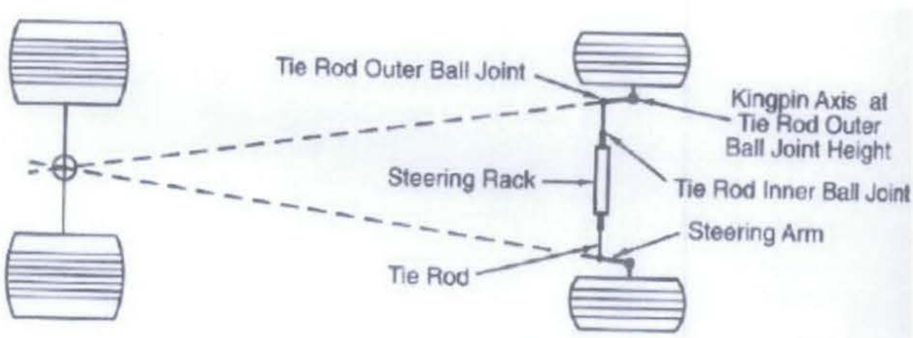


Figure 8: True Ackermann extension lines (retrieved from https://eee.uci.edu/wiki/images/0/07/Ackermann.JPG)

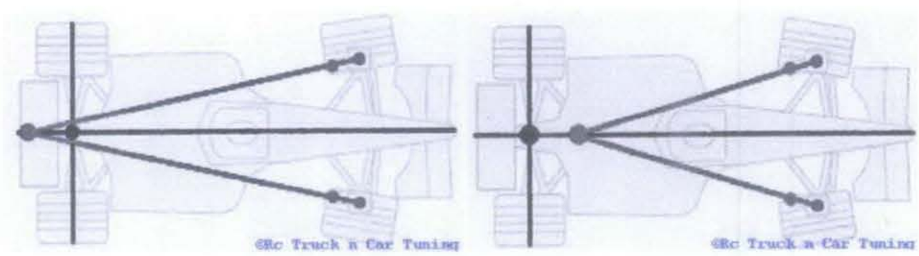


Figure 9: Less and More Ackermann extension lines (retrieved from http://www.rc-trucknear-tuning.com/ackerman.html)

The Ackermann Angle can be determined by using the following equations (Sasongko, Siswoyo, Sarjana, & Pratama, 2008):

$$\delta_0 = \tan^{-1}\frac{L}{R+\frac{t}{2}} \qquad \delta_i = \tan^{-1}\frac{L}{R-\frac{t}{2}}$$

Equation 2: Ackermann Angle

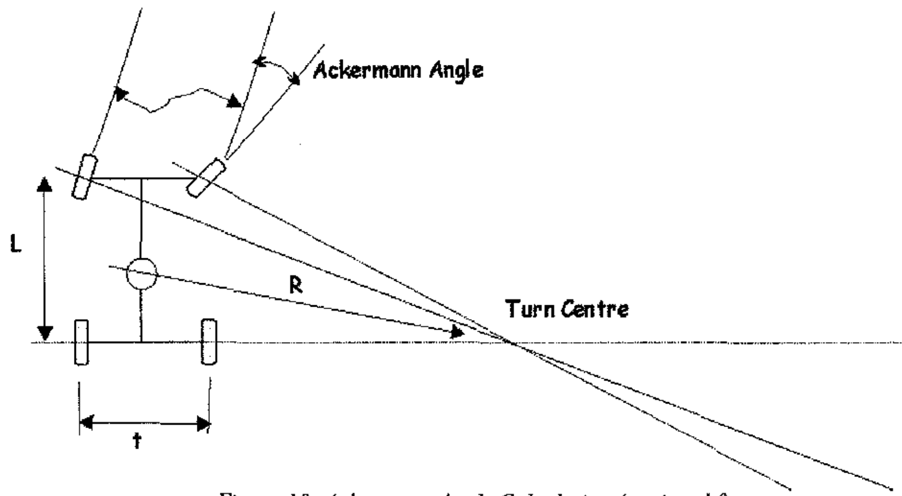


Figure 10: Ackermann Angle Calculation (retrieved from http://www.mech.uq.edu.au/courses/mech3100-old/steering/ackangle2.gif)

Where: δ_0 = outer tire turning radius (°)

δ_i = inner tire turning radius (°)

L = wheelbase length (m)

R = turning radius (m)

t = track width (m)

Another option which is much simpler would be to use the parallel arm steering system (refer to figure 11). Using this, any input from the steering would produce an equal amount of turning angle on both tires. The inner tire must turn at a greater angle to avoid scrubbing, and by using this last system, it can't be avoided. The inner tire would always undergo a certain amount of slide, producing unnecessary heat and wear to the tire. Under high speed and long period of usage, fuel consumption could be sacrificed substantially.

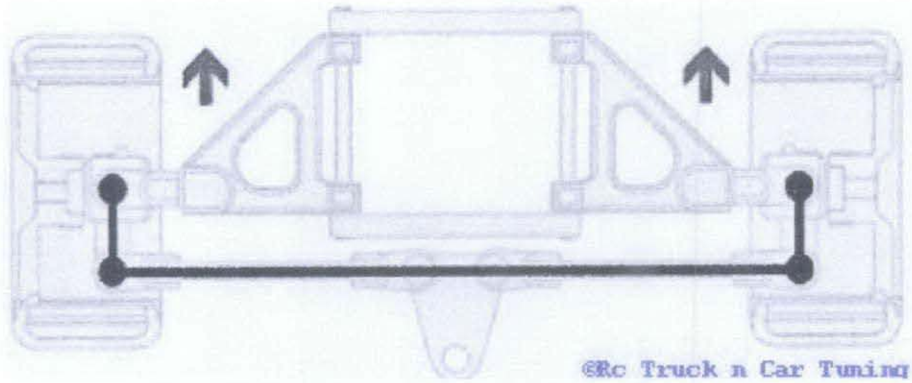


Figure 11: Parallel arm steering system (retrieved from http://www.rc-trucknear-tuning.com/ackerman.html)

2.3.2 Steering ratio

Steering ratio can be described as the "sensitivity" of the car. In high speed car applications, such as in racing industries, the desirable sensitivity of the car is very high, thus smaller ratio. In most passenger cars, the ratio is from 12:1 to 20:1. A 20:1 steering ratio means that for every 20° the steering wheel is turned, the tires will turn 1°. As mentioned above, the driver's space in a simple vehicle most likely would be cramped. A smaller ratio is therefore preferred due to this reason. On an unassisted steering system, a system that can reduce the amount of turns that drivers need to make is also preferred. Since the driving system uses linkage instead of direct system (like in bicycles), a proper calibration between the steering wheel and the tie rod angle is needed.

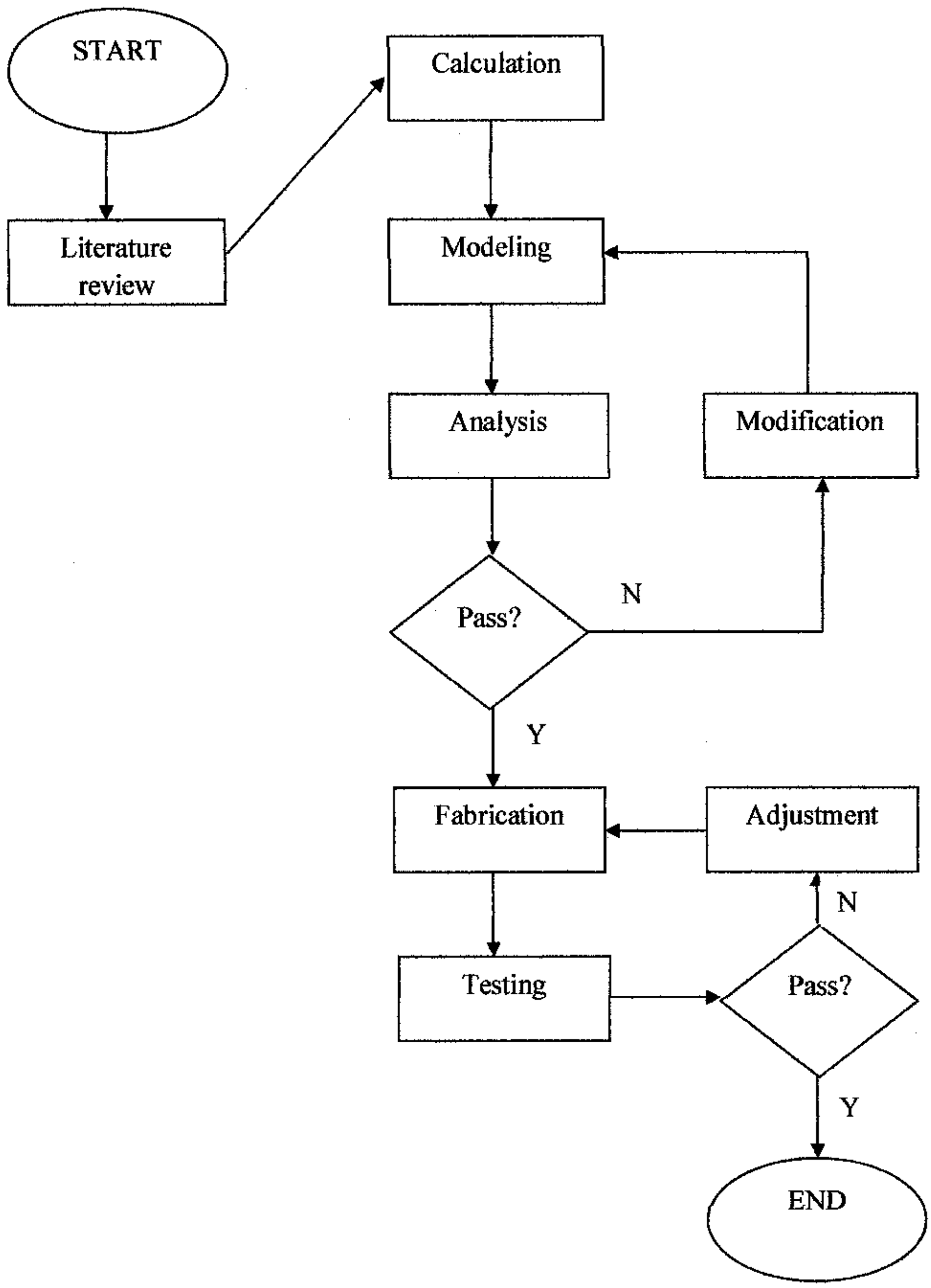
$$\text{Steering ratio} = \frac{\text{steering wheel motion angle}}{\text{mean turning angle of the tire}}$$

$$= \frac{\text{steering wheel motion angle}}{(\theta°_i + \theta°_o)/2}$$

Equation 3: Steering Ratio

CHAPTER 3
METHODOLOGY

3.1 Project Flow



3.2 Project Phases

The project commenced by reviewing various literatures gathered from the internet, books, and online journals. Report from the previous version was also taken as one of the most important inputs as the previous vehicle is the benchmark for this project. The information gathered acted as preventions to avoid doing the same mistakes. Calculations were also done based on gathered formulas and used as the pre-design phase considerations.

Modeling was done once all the needed parameters are calculated. Virtual modeling was preferred as the analysis phase was also done virtually. Analysis phase covered the material usage and its effect to stress residual forces. Fabrication starts after analysis gave acceptable results, otherwise redesign and reanalysis were done to the design.

Fabrication marks the beginning of FYP II, commenced after the designs are confirmed. Most of the fabrications were done in-house to cut cost and also acted as a mean to learn fabrication process. However, outsourcing was always an open option just in case the tools or skills required couldn't be obtained in-house. Once the vehicle was assembled as a whole, testing was done to make sure all components were working as expected. Testing itself was divided into two categories: endurance and intensive testing. The first one tested the braking and steering system at a minimum level, just to make sure that the vehicle was pleasant and safe to drive, and that it worked well with all other components assembled. The second testing tested the components to their limits by applying conditional testing such as hard braking and stopping from a high velocity as well as maneuvering through obstacles. Analysis was done afterward to know which sectors needed improvements and ways to mend it. Lastly, recommendation was listed down as means to avoid doing similar mistakes and produce a better running chassis in the future.

3.3 Tools and Software

CATIA was the main software in the design phase. Braking brackets, brake locations, disc brake size, and also tire size are part of braking system that were designed. Tie rod, kingpins, steering shaft, pitman arms, and steering wheel were also constructed using this software and adjusted them with the driver's position.

CATIA was also used to analyze the stress force exerted to the members of the frame. The stress came from the frame itself, the driver, the body cover, engine, tires, and other components that are attached directly or indirectly to the frame. The software determined whether the vehicle fail to bear the weight or not. Material alteration was also done easily using this software.

Fabrication began after all analysis results gave satisfactory results. The tools mainly used, in-house, were the power tools located at Block 21, which consisted of grinder, hand drill, stand drill, hack saw machine, manual lathe and milling machine, and the most important part to combine pieces of material, the GTAW machine. Because the main frame that we use was made out of aluminum, the work was done outside as our facilities couldn't weld aluminum.

For analysis purposes, the tools needed were digital micrometer, measurement tools, and a camera for documenting purposes.

3.4 Gantt Chart

Final Year Project 1 July 2010																
No.	Detail/ Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Journal Study & Literature Review															
2	Previous Team Data Gathering															
3	Submission of Preliminary Report															
4	Steering system calculation															
5	Steering system design															
6	Braking system calculation															
7	Submission of Progress Report															
8	Seminar 1															
9	Braking system design															
10	Team follow ups															
11	Submission of Interim Final Report Draft															

Final Year Project 2 July 2011															
No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Fabrication of steering system														
2	Fabrication of braking system														
3	Endurance testing														
4	Development and adjustments														
5	Intensive testing														
6	Post test analysis														
7	Post mortem meeting														
8	Submission of Progress Report														
9	Submission of Poster														
10	Final Report Draft														
11	Submission of Dissertation														
12	Oral presentation														

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 General Improvements

One of the problems complained regarding the previous project was the sturdiness of the front tire bracket. Presumably, the wobbliness came from too much tolerance provided by the bracket due to improper dimensioning. Figure 10 shows the differences presented in the current design. The bracket now has ball bearings (circled in red) in the middle of the rotating axis (one at the top and the other at the bottom), a shaft (circled in blue) that will penetrate the rims at just the proper tolerance, and also features a lower extension plate (circled in yellow) that will connect to the steering shaft at the correct height. The bracket for the caliper (circled in green) also underwent some adjustments where it ensures the caliper grips the disc at the maximum contact area achievable. The previous bracket didn't utilize the brakes properly as less than half of the brake pads came in contact with the disc.

Figure 12: 3 joints bracket comparison (old vs new)

The second improvement was replacing the mechanical brakes with hydraulic ones. TekTro Draco was used in both the front and rear brakes, costing a total of RM600. Similar to motorcycles, it utilizes open systems fluid reservoir to compensate the expansion of the fluid due to heating up during braking (Breuer & Bill, 2008). It also makes the pad adjust themselves easier. TekTro uses mineral oils instead of the well-known DOT brake fluids. These fluids are not hygroscopic and for this reason they do not need to be exchanged regularly. The pads are made of metal ceramic compound which need to resist very strong thermal strain caused by the disc brakes. This phenomenon, caused by the missing retarding effort of engine braking, might be the basis of brake fading.

The next problem was inadequate space for the driver's legs due to the push rod from the steering assembly interferes the legs. Improvements were made by constructing a new front end assembly, whereas the front end could be cut short and save space as well as weight reduction. The driver now has better flexibility as to adjusting legs as well as body position. A totally new tire holder was constructed as the previous one was discarded as means of safety factor. The new holder (refer to figure 13) was assembled from mild steels and bolted directly to the frame. Mild steel was chosen to aluminum as it was much easier to weld and could be done in-house, hence easier adjustments to the parts. The new holder also gave the vehicle a lower front end (25mm lower) to give better aerodynamics needed especially during gliding. The previous setup gave the vehicle tendencies to slide backwards even on flat surfaces.

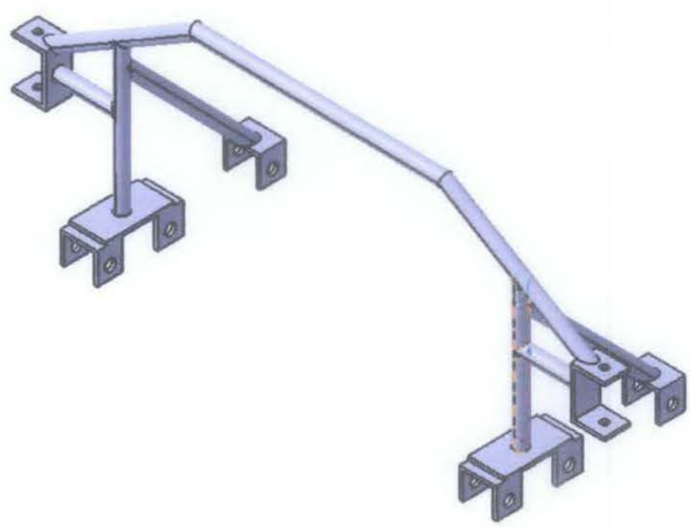


Figure 13: CATIA model of the front tire holder

Figure 14: Holder assembled to the vehicle

The fourth improvement was the location of the brake lever. The previous lever, which was located at the steering wheel, was complained to be too exhausting to the driver's fingers if operated intensively. Hence, foot operated lever was used as the new front brake lever (refer to figure 15). Both right and left lever are connected by a steel plate that would activate both brakes at approximately the same force. It would be best if all three levers, including the rear one, can be operated at the same time, but for safety reasons the operation of the front and rear brake must be independent of each other. Initially the rear lever would be located beside the front lever, on the right side of the legroom, but then throttle lever was prioritized to be put there as it was decided to be easier for the driver to control the throttle using foot instead of fingers. The lever for the rear brake is still operated by hand, but instead of the conventional location, it's located comfortably near the thigh of the driver (refer to figure 16). Research suggested that the use of the rear brake would be very minimal as compared to the extensive front end braking.

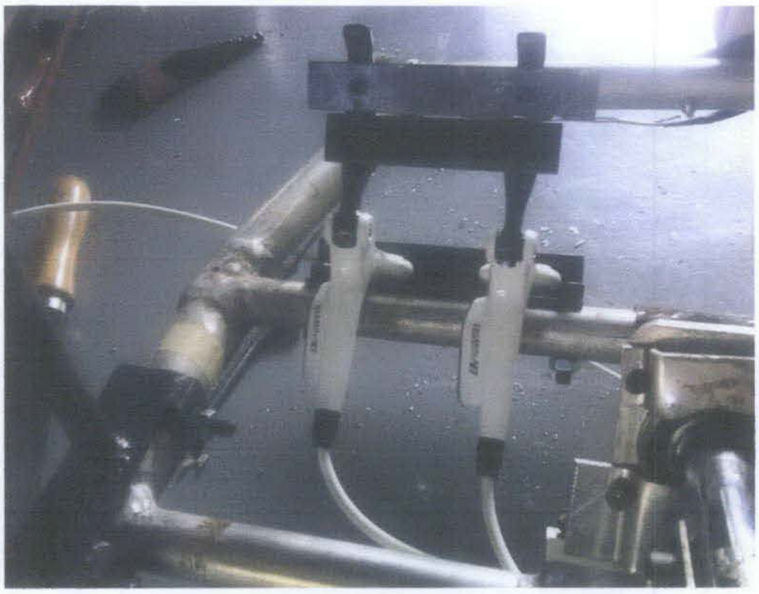


Figure 15: Front brake foot operated lever

Figure 16: Rear brake hand operated lever

The last improvement in the braking department was to install a ventilated disc and a hydraulic brake system at the rear tire. The conventional v-brake that uses rubber compounds and operated mechanically was deemed unsuitable for the vehicle's purpose. The braking system uses exactly the same system like the front brake. Problem arises when installing the disc as the rim didn't have holes for the disc brake to be bolted on to (unlike the built in holes on the front rims). On the other hand, the rim has threads on both sides of the hubs, making it possible for a small freewheel to be attached. The solution was then to enlarge the center hole of the disc brake so that the freewheel can be inserted, and then welded together (the connection is circled in red). The welded disc can now be easily attached to the rim as it has threads. Figure 17 shows an extra freewheel (circled in yellow) inserted to give adequate gap between the caliper and the rim. The bracket for the caliper itself was aligned merely by inserting and fastening it directly to the shaft.

Figure 17: Rear braking system

4.2 Braking system

The easiest way to find out the effectiveness of the pad was by measuring them using a digital micrometer, and then comparing the results with the initial pad thickness. The pad started off by having a thickness of 4 mm and had been used approximately 8 weeks including the intensive testing period. Table 1 shows the wear and the thickness of the brake pads.

	Pad 1	Pad 2	Δ1	Δ2	(Δ1+Δ2)/2	% wear
Front Left	3.974	3.868	0.026	0.132	0.079	1.975
Front Right	3.977	3.964	0.023	0.036	0.0295	0.7375
Rear 1	3.938	3.988	0.062	0.012	0.037	0.925
Rear 2	3.978	3.964	0.022	0.036	0.029	0.725

Table 1: Brake pads wear

Table 1 indicates that throughout 8 weeks of usage, out of which one week is extensively used, the brake pads seem to be in almost perfect conditions. The worst wear took only less than 2 percent of the brake pad. Judging from the pictures, it only made minor scratches to the pads. These conditions suggested that the brakes would still be in their prime conditions and would be able to deliver a great stopping ability.

The actual condition however, differed greatly. The performances of the brakes were, as if, deteriorating by time. Everything worked brilliantly even during the endurance testing, but as soon as intensive testing came to play, things started to behave quite differently.

First of all, the front brakes performed greatly at first. They could stop the vehicle with ease and still maintain a straight course after braking. During one of the test, the vehicle was driven up to 25 km/h and the brakes managed to stop the vehicle in less than 5 m. They could even hold the tire at a halt while a person forcefully tried to rotate the tire. However, during the intensive testing, the performance worsened.

The brakes seemed to have an unequally distributed force, having more force applied to the left tires. By mere inspection, after brakes were applied, the vehicle seemed to head left for a bit until the driver corrected the steering tire. Table 1 also showed that the left brake pads had more than twice wear than the right pads. The brakes also weren't able to hold the tire when a person tried to manually rotate it, let alone having the vehicle at top speed. Correction steps were taken such as adjusting the gaps between the pads to be slightly smaller to give a better stopping power. The

pads were also coarsened by making crisscross pattern on it. Despite the effort, the brakes still weren't showing their initial braking power.
Moving on, just like the front brakes, the rear brakes also performed well at first. Driver barely even uses them as most of the braking power were covered using only the front brakes. The rear brake managed to stop the rear tire (hanged in midair) in an instant when the engine was running at high speed. This was done many times and showed satisfying results every single time. It could also put a halt to the vehicle at a 20° slope with ease. However, just like the front brakes, the rear brake started to show poor quality during the intensive testing period.

It even reached a stage where a second caliper was needed just to be able to stop at a 30° inclined slope. That also didn't quite help as the lever had to be pushed really hard or else the vehicle would still move. Both disc brake and also the brake pads were roughened as well yet it didn't make much of a difference. Then another problem came regarding the installation of the disc itself. It was mentioned earlier that slight modification had to be done to the disc brake so that it can be attached to the rim by welding it to a threaded freewheel. After many hard braking done during the intensive testing, the thread connecting the rim and the freewheel seemed to wear out. Hence, the tire could still rotate even though the disc brake couldn't. This problem was dealt by welding the freewheel directly, full weld, to the rim making sure it would act as one whole piece altogether. For a brief moment, this solved the problem brilliantly, but then disaster happened when we hung the rear tire in midair, spun it at high speed and tried to stop the tire. The welding area broke apart, taking it back exactly like it wasn't welded at all.

The possible reason behind this deteriorating behavior is most of the problematic conditions discussed on the 2nd chapter occurred. The first condition was the pads underwent fading because they were exposed to sudden temperature change drastically that created a cushion of gas. The brake fluid might also boil up because the temperature still increases as the no cooling is provided when the vehicle is stopped. The last one might be caused by the rear disc deflection due to inappropriate disc fittings. This would cause unnecessary vibrations, noises, excessive heats, and also power losses as the pads must flatten up the disc first before actually have braking effects.

4.3 Steering system

As mentioned earlier, the two things that have to be considered are the Ackermann steering geometry theory and the steering ratio. Based on inputs and reports from the previous team, the steering wheel system had only minor problems, theoretically. The Ackermann steering geometry that was used wasn't exactly correct as the final design didn't manage to fall under the true Ackermann geometry and apply the less Ackermann angle instead. The outer tire turns at an angle of 30.0° while the inner tire at 24.7°. This caused the tires to always undergo slip during cornering, especially the outer tire as it had to cope with the weight shift to the outer side of the vehicle, and caused inefficiency and also a wider turning radius than supposed to. The inner tire was also experiencing slip as it tried to turn at a bigger circle than the outer tire. Despite the deficiencies, based on simulation the vehicle still managed to get a turning radius of 4 m which was acceptable.

A slight improvement was made to the steering rod. As the total length of the vehicle had been changed, the driving position was also affected, thus a new steering wheel position was required. The angle still stay the same, however the length of the steering rod changes to give an easier grip for the driver. The steering wheel could also be removed instantly by providing a custom quick release rod at the end of the steering wheel.

The current vehicle has a wheelbase of 1.93 m and a track width of 0.85 m. Hence, the most ideal setup to achieve a turning radius of 4 m, the calculations would be as follows:

$$\begin{aligned} \delta_0 &= \tan^{-1}\frac{L}{R+\frac{t}{2}} \\ &= \tan^{-1}\frac{1.93}{4+\frac{0.85}{2}} \\ &= \tan^{-1}0.4361 \\ &= 23.56° \end{aligned}$$

$$\begin{aligned} \delta_i &= \tan^{-1}\frac{L}{R-\frac{t}{2}} \\ &= \tan^{-1}\frac{1.93}{4-\frac{0.85}{2}} \\ &= \tan^{-1}0.5398 \\ &= 28.36° \end{aligned}$$

The results above would give almost no unnecessary forces to the tires. However, this would only be used as basic guidelines as the current steering setup doesn't actually imply the principle of Ackermann geometry; it uses the parallel arm steering system where both tires would turn at the same angle. The angle theoretically must fall among within those limiting angles; otherwise there must be something wrong with the setups. Figure 18-20 show the actual turning radius and at what angle the tire turns to achieve that radius.

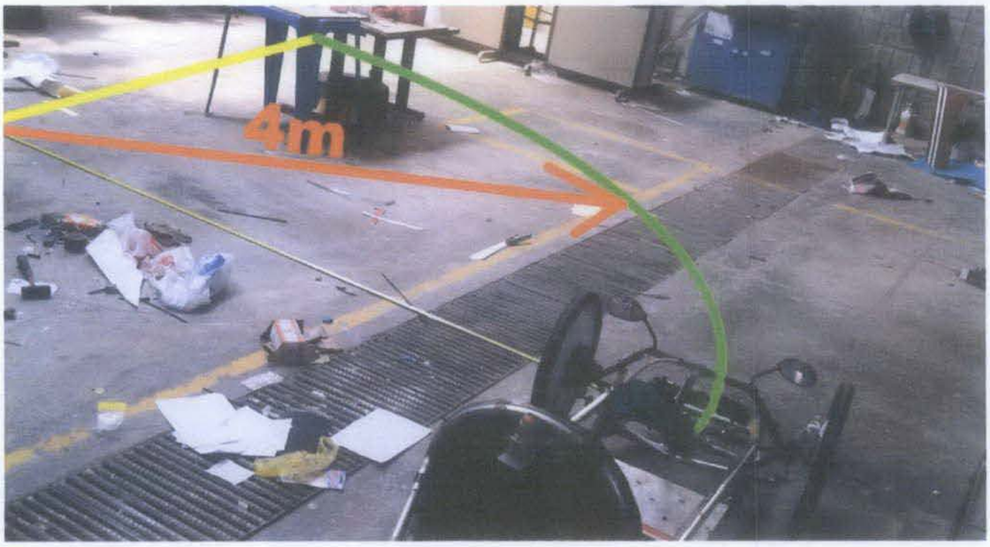


Figure 18: 4m turning radius

Figure 19: Outer vs. inner turning angle

The actual result showed that both tires turn at ±27°, as the implication of using the parallel arm steering system. The effect of this same angle, as mentioned, excessive wear would occur to the inner tire during cornering. On the other hand, calibration was achieved easiest using this configuration as no angles whatsoever is applied. If the steering ratio is 1:1, then the output would be exactly the same as whatever the input is.

A ratio of 1:1 has been the target as it gives a greater control of the vehicle even from a cramped up position. As mentioned earlier, the parallel arm steering system is the easiest one to setup among other steering system. To ensure a ratio of 1:1 was achieved, there were only two things that needed to be kept the same length. Those were the length of swing arm extension as well as the extension plate from the steering rod. Those two things were then connected by a push rod one on each side of the vehicle. Figure 20 shows the actual steering ratio achieved by the vehicle to the 4m turn.

Figure 20: Actual steering angle to achieve 4m turn radius

The previous team managed to get a steering ratio of 1.16:1, with a steering wheel angle of 31.8°. However, with the new target, the steering ratio can be recalculated as:

$$\text{Steering ratio} = \frac{22^\circ}{27^\circ} = 0.815:1$$

A steering ratio of 1:1, just like a motorcycle, would mean that the tire would turn exactly the same as the input from the driver. In our case however, the steering ratio was lower than 1:1, meaning the tire would turn even more than the driver's input. In a cramped cockpit, just like the current vehicle, a setup like this gave the driver benefits as he or she could control the vehicle without having to make too much movement. The driver however must maintain full concentration to the vehicle at all time because a slight movement, especially during high speed, would cause the vehicle to change direction abruptly.

Suspension wear also addressed another issue to the steering system. Overtime, components endured wear and fatigue, including the front tire holder assembly. It suffered excessive stress as 40% of the vehicle weight is concentrated on it. Rough surface worsen the stress. During the intensive testing period, the 0° camber setup on the front tire altered into a very noticeable negative camber. Once it went deformed, it would keep on changing as it meant it was on the yield strength region. Theoretically, this shouldn't have happened. Figure 21 shows the front view of the static analysis of the front tire holder.

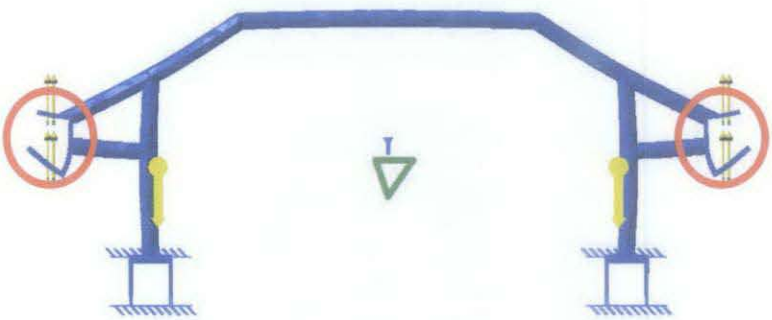


Figure 21: Static analysis result

The analysis was done, using CATIA, by clamping the parts on all 6 holes, representing the bolt connection on the actual part later on. Gravitational force was then applied to the whole product. As for the load, distributional load was applied upwards to the tire brackets on both sides. The value was set to 392.4 N, representing 40% of the total weight of the vehicle including the driver (assuming 40:60 weight distribution of a 100 kg mass). The result showed deformations at expected points. Figure 21 amplifies the deformation image for better viewing. The worst deformation under the stated condition was only 0.12 mm (noted by the red circles).

This analysis suggested that an error occurred as the theoretical front tire holder won't endure much deformation, let alone a noticeable one. A possible reason was that stress was concentrated mostly on the welding locations (analysis didn't specify welding points), fading the overall structure strength, hence the visible negative camber.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. The vehicle was able to be stopped at a 30° inclined slope.
2. From a speed of 25 km/h, the vehicle was stopped in less than 5m.
3. Components had less vibrations and frictions due to better parts tolerances (better design and fabrication process) and properly usage of grease.
4. A newly ergonomic and space efficient driving position.
5. Vehicle was able to be controlled easily by having a steering ratio of 0.815:1.

5.2 Recommendations

1. A brand new properly designed ladder frame to avoid uneven stress on the rear tire. Although aluminum frame give lots of trouble in adjusting afterwards should adjustment is needed, the weight saved is beneficial. With better design judgments and considerations, unexpected post-fabrication alteration can be avoided altogether. All other brackets must also be decided beforehand to avoid unnecessary hole being drilled on the frame, reducing its overall strength. To make things even simpler, avoid using smooth shape transitions such as bended pipe. Use pipes that are perpendicular to each other instead to ensure both sides are symmetrical.
2. Implement Ackermann steering geometry to the new steering system. Aim for true Ackermann to obtain the least wear to the tires. Ensure the dimension of the frame is fixed and agreed by all members so that additional changes can be avoided.
3. Change brake pads to high performance brake pads (e.g.: Kool Stop). Although they're also called metal ceramic compound, the composition itself might differ from the stock pads that come with the TekTro calipers. High performance pads won't change their property easily even under temperature or heavy usage, especially when it's not of daily basis usage. Such pads can be purchased locally for around RM60.

4. Increase the rear rotor disc brake size. With bigger diameter, the torque produced by the caliper would also increase (torque = force*distance) without changing it to a bigger caliper with more pods. If we assume that there is no slip (pure rolling) occurs between tire and the ground, the equation would be as follow.

$$F_t = \frac{r}{R_0}F_d + \cancel{\mu_r \frac{W_d}{R_0}}$$

$$F_t = \frac{r}{R_0}F_d$$

The typical bicycle disc brakes that are available in the market usually come in sizes of 160mm, 180mm, and 203mm. The previous vehicle used 160 mm. Assuming wheel radius and caliper force stays the same but the disc brake is increased to 203mm, the calculation would be:

$$r_2 = \frac{203}{160}r_1$$

$$F_{t1} = \frac{r_1}{R_0}F_d$$

$$F_{t2} = \frac{r_2}{R_0}F_d = \frac{203}{160}r_1 x \frac{F_d}{R_0}$$

The above calculation shows that the by changing the disc brake from 160mm to 203mm, a 26.875% gain in caliper torque increases without changing the caliper. One of the local bike shops offers a 203mm rotor in less than RM80 a piece.

5. Change to pulled activated rear brake lever instead of pushed activated. Purchase a longer fluid hose for the brake lever and extend it so that it could be placed on the steering wheel. Otherwise, to ease the driver place the rear brake lever on the foot and relocate the front brake levers to the steering wheel.
6. Always adjust the gap between the pads after every usage. This is to ensure that the gaps would be sufficient enough to allow the rotor to spin without having unnecessary friction with the pads. It would also allow them to always be calibrated to deliver equal forces, especially the front brakes to avoid sudden change of course when the brake is applied.

7. The simplest way, that proved to work, to achieve a promising stopping power for the rear tire is by simply using a motorcycle's rear tire assembly, dismantling and reassemble it to the vehicle's frame directly. This method was done by some universities including one from Pakistan, which is shown here on the side.

Figure 22: motorcycle rear brake system

8. Again based on benchmarking, a university from China came up with a radical rear tire steering concept, which worked brilliantly when designed properly. The advantage of using such configuration is the vast space saving in the frontal area. Can be seen below, the front tires now stay in place as they're not part of the steering anymore and can be placed inside the body without the need of huge bulge to compensate the tire turning area.

Figure 23: front vs. rear view of a rear tire steering vehicle

CHAPTER 6

REFERENCES

A., W., & B., B. 1987, *Examination of the Brake Behavior of Motorocycles with and without ABS.* Dusseldorf, VID-Verlag.

Breuer, B., & Bill, K. H. 2008, *Brake Technology Handbook.* Pennsylvania, SAE International.

Kershaw, J. F. 2007, *Automotive Steering, Suspension, and Wheel Alignment.* New Jersey, Pearson Prentice Hall.

Lie, D., & Sung, C.-K. 2009, "Synchronous brake analysis for a bicycle," *Mechanism and Machine Theory*: 543-554.

Nice, K. 22 August 2000 <http://www.howstuffworks.com/auto-parts/brakes/brake-types/power-brake.htm>.

Sasongko, A. W., Siswoyo, C. A., Sarjana, G. P., & Pratama, R. W. 2008, *Rancang Bangun Gokart Dengan Penggerak Motor Bakar Bensin 5.5 HP*, Politeknik Negeri Semarang, Indonesia.

Simionescu, P. A., & Beale, D. 2002, "Optimum synthesis of the four-bar function generator in its symmetric embodiment: the Ackermann steering linkage," *Mechanism and Machine Theory*: 1487-1504.

APPENDICES

APPENDIX A
Attempt to manufacture disc brakes

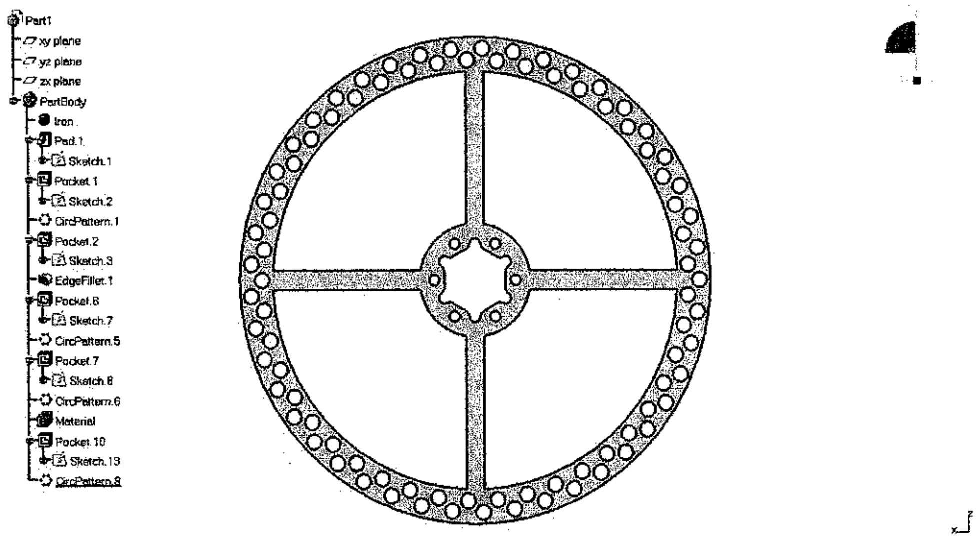


Figure 24: 1st 220mm disc design

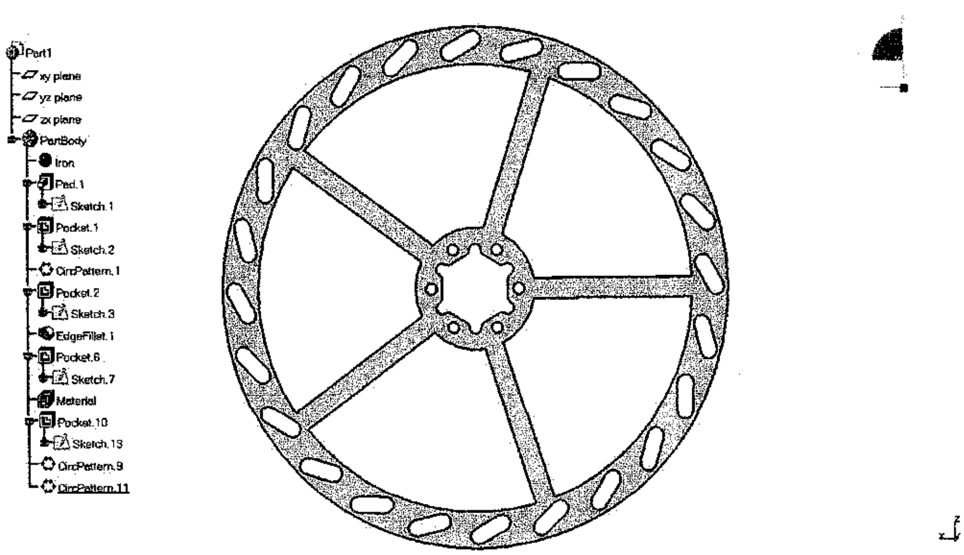


Figure 25: 2nd 220mm disc design

APPENDIX B
Driving position improvement

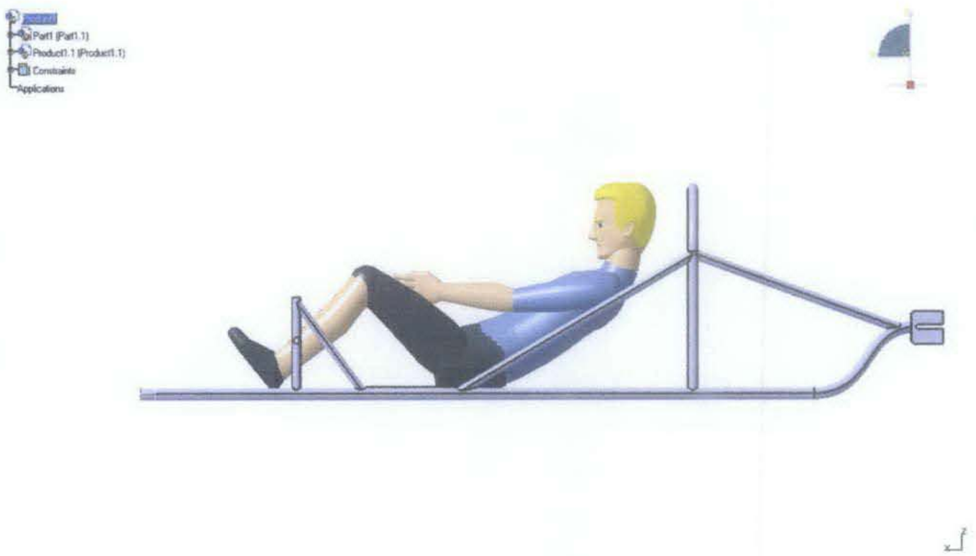


Figure 26: Previous driving position (leg interferes front tire axle)

Figure 27: New driving position (leg below front tire holder)

APPENDIX C
Final product prediction

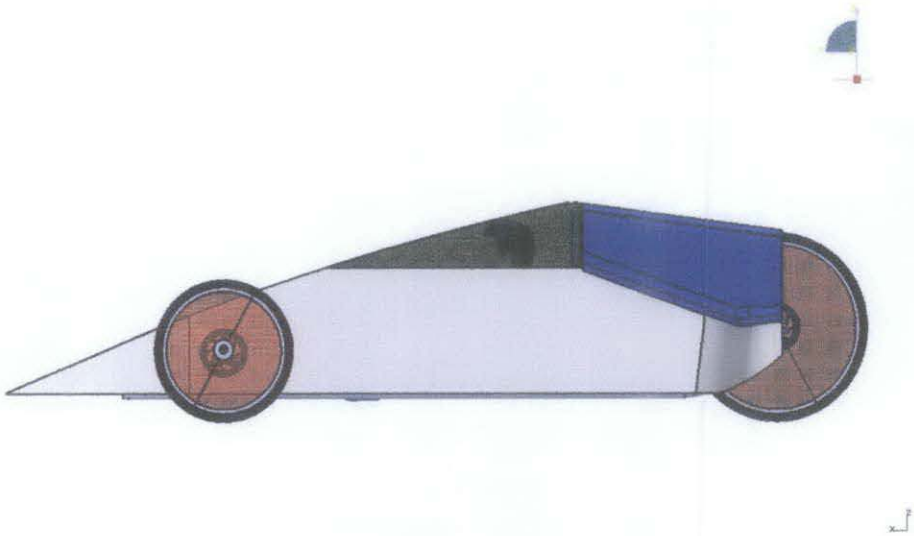


Figure 28: Side view final product prediction

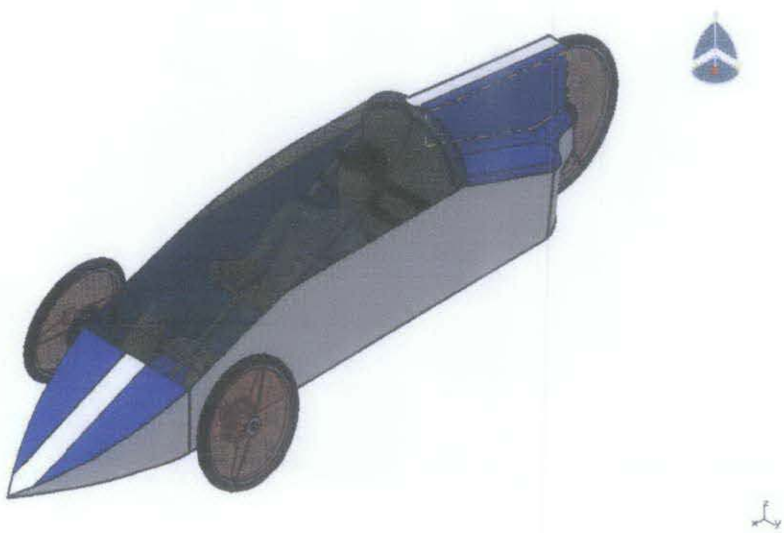


Figure 29: ISO view final product prediction

APPENDIX D
Documented fabrication processes

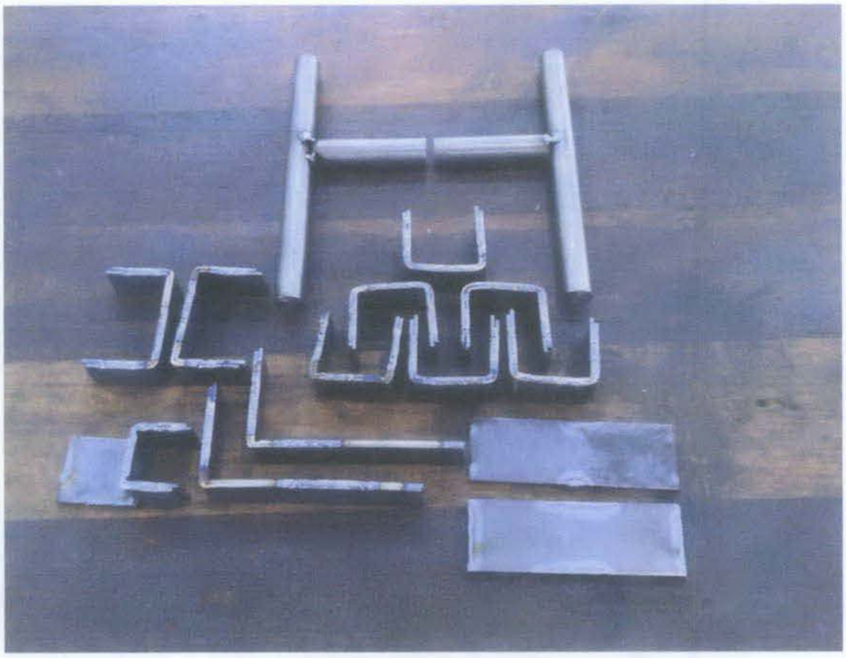


Figure 30: Front tire holder components

Figure 31: Frame alteration

Figure 32: Front tire bracket ball bearing

Figure 33: Steering linkage

APPENDIX E
Brake pads wear and thickness

Figure 34: Front left brake pads wear

Figure 35: Front left brake pads thickness

Figure 36: Front right brake pads wear

Figure 37: Front right brake pads thickness

Figure 38: 1st rear brake pads wear

Figure 39: 1st rear brake pads thickness

Figure 40: 2nd rear brake pads wear

Figure 41: 2nd rear brake pads thickness

APPENDIX F
Alternative vehicle design

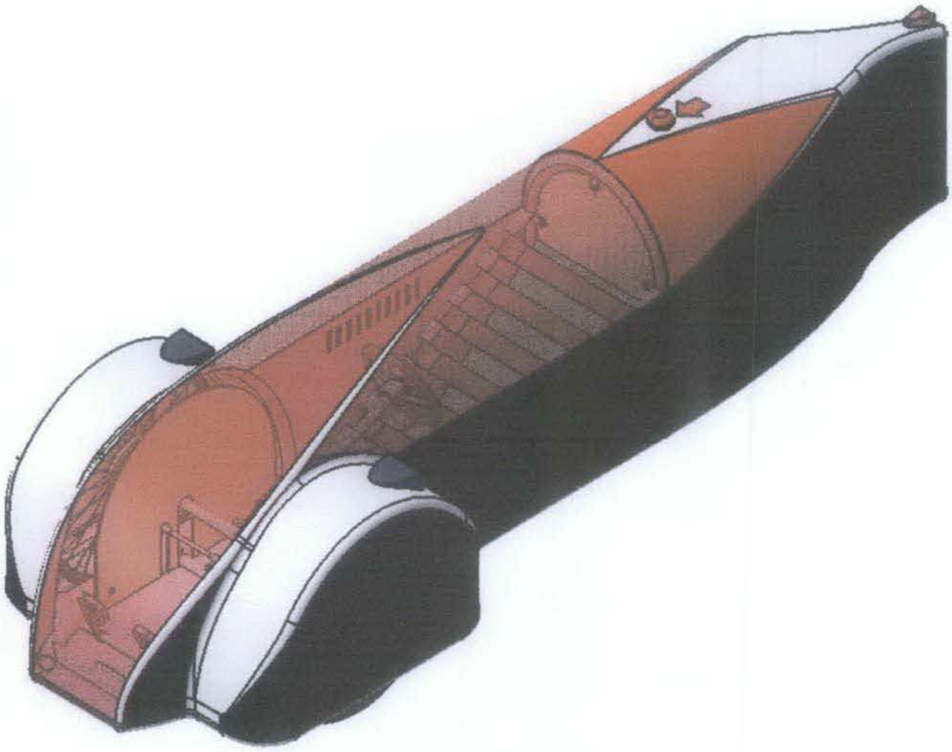


Figure 42: ISO view alternate vehicle

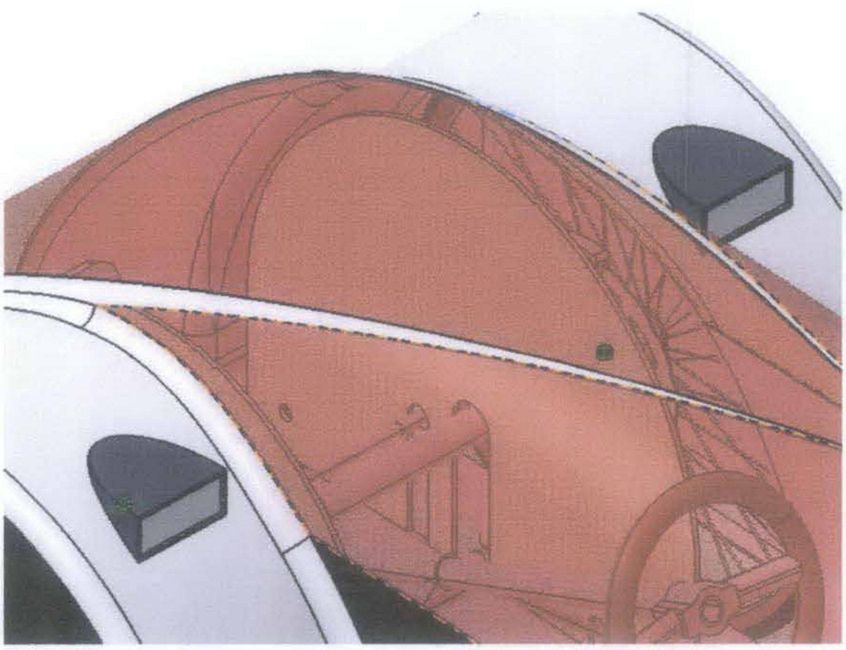


Figure 43: Frontal end alternate vehicle