University of Southern Queensland

Faculty of Engineering and Surveying

Steering and Suspension Design for a SAE-A Formula Race Car

A dissertation submitted by

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Abstract

1. INTRODUCTION

The design and development of the steering and suspension system for the USQ Motorsport team is presented. Formula SAE-A race car is presented.

2. BACKGROUND

Formula SAE-A is an annual competition for university students throughout Australia and around the world, it has been recognized by industry as providing some of the best graduating engineers because of the practical and teamwork experience obtained through participation. Each year SAE produces a list of rules for the design of the vehicles, the rules that directly affect this project are: 6.1 Suspension, 6.2 Ground Clearance, 6.3 Wheels, 6.4 Tyres, 6.5 Steering and 6.7 Rollover Stability. All vehicles are subject to a technical inspection to ensure the rules have been adhered to.

3. OBJECTIVES

The main objectives of this project were to identify and investigate possible changes to the existing design of the steering and suspension to improve the performance and reliability from a practical and safety aspect.

4. PROJECT DETAIL

The project is broken into two categories:

1- Steering and suspension performance and

2- Safety of the steering system.

The WIN Geo software package (Wm.C.Mitchell) was used to analyse and optimise the steering and suspension geometry for improved performance and reliability.

This design uses a rack and pinion steering with coil over shock absorbers and a double A-Arm suspension system.





The steering safety was analysed and investigations led to designing a steering transfer system that allows an improvement of the drivers' access and egress.

5. CONCLUSIONS

The results of this research will be given to the 2010 USQ Motorsport Team to determine the feasibility of their use in the 2010 car.

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Professor Frank Bullen Dean Faculty of Engineering and Surveying

Certification

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

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

Gary Coates

Student Number: 0050011431

Signature

Date

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<u> 1.0 Aim</u>

This project aims to investigate and further develop the steering and suspension design for the USQ SAE Formula Car and to provide a suitable design for the suspension geometry and adjustability, to result in improved handling, drivability and reliability of the vehicle.

2.0 Objectives

- 1. Research the background of steering and suspension design, and factors that may limit such design
- 2. Determine all relevant rules and regulations associated with SAE-A racer design.
- 3. Analyse previous designs and team data to identify the areas that require the greatest change.
- 4. Identify suitable materials for use as suspension components.
- 5. Produce a preliminary design for analysis and model testing.
- 6. Compile all relevant data, and produce the final design.

As time permits:

- 7. Offer the alternative design to the team, for investigation of the practicality of fabricating and installing into the vehicle.
- 8. Oversee the implementation of the components.



Photo of the crash of the 2008 Formula SAE Race car

3.0 Literature Review: Carroll Smith, Suspension Design and the Ackerman Principal

The following review contains both partial and full text from Smith, C. (1984) Engineer to Win, The essential guide to Racing Car materials Technology or how to build winners that don't break. (Pages 214-217)

3.1 Suspension Design

In the book Engineer to Win, Carroll Smith talks about a paper doll game he devised to determine best geometry for an independent suspension, he believes this to be a quick accurate way to get a feel for the various conditions of load that a suspension system will be put under and a way to evaluate how small changes can effect the suspensions performance. This may be a quick way but as you change the points on the cardboard it is easy to become lost with what works and what didn't. He then sets about talking about low cost ways of design, he mentions that computer programs are available for this function, some benefits for this would be you can keep a file of all the minor changes that are made and correlate the information as to determine a suitable accurate model of the suspension system. He says that a suitable program should be able to compute the lateral load transfer, integrate this with the roll centre movement, camber change and a host of other functions. The suggestion is then made that a law of diminishing then returns which means that you can calculate as much as you like on a computer but it cannot calculate for every conceivable condition so commonsense often takes over and manual adjustments and trial and error often prevail.

3.2 Ackerman Principal

In a previous book Tune to Win, also by Carroll Smith, he believed that the steering geometry mainly was associated with understeer, this was due to the load conditions of the car. The thought was that as you enter a corner the load transferred to the outer wheel and the inner tyre was "along for the ride" he states that these assumptions neglected certain external forces like down force, which is variable in the racing industry with the use of aerodynamic wings and splitters, as the SAE car does not have any of these I will not explain wings or splitters any further. Instead the analysis was to look at the balance of the vehicle and steering angles of the front tyres, the belief was that the angles will be small and the steering input would be smooth. The lateral load transfer would be gradual, but since the response time of a race car is quick then so would be the transfer rate. The outer tyre then is supplying most of the tractive effort for the steering process. This then indicates that the slip angles of the front tyres are required to be equal, this was the belief for several year and opposed the Ackerman principal and therefore became referred to as anti- Ackerman. Further testing found that by including a small amount of static toe out in the suspension setup was that as you enter a corner and the load transfer occurs, the entire toe out transfers to the inner tyre, the slip angle of the inner tyre increases and promotes Ackerman steering principal. The problem is that static toe out may make the car unstable under braking and that the rolling of the tyres may slow the car down in a straight line, so the plan was to tune the suspension to exhibit some bump steer to encourage toe out while cornering, this is done as the load transfers to the front of the vehicle during braking as the front dips the steering arm is positioned in a location so that it pushes the front tyres out with the downward force and then corrects itself as the vehicle returns to its normal height, thus giving the stability in a straight line and possessing the required toe out while braking and turning. A problem with this is that on a race track that produces load shift in the car in a straight line, like a dip or a crest, the bump steer may make the vehicle unstable. It is for these reasons that the suspension geometry is required to be easily adjusted, and that the cars are tuned to the race track often with a combination of bump steer toe out and also static toe out. So a return to the Ackerman steering principle was decided to be tested. The thought was that by increasing the Ackerman it may be possible to eliminate the dragging of the inner front tyre and an

effective increase in the slip angle of the inside front tyre. Through testing and adjustments it was found to be the case, the test vehicle exhibited reduced understeer and a greater Ackerman effect, this was noticed at both high and low speeds. It was also noticed that by bringing the Ackerman geometry too far forward that the car exhibited more understeer and the vehicle became darty over bumps and while braking.

There has been many advancements in the operating conditions of race cars since the initial anti Ackerman setup was being used. Some of the advancements include the tyres, they have become stickier, they have a lower profile and thus tend not to deflect as much while cornering, this has added to the increase in contact patch which was typically a long thin oval shape and is now a wide short oval which increases the traction level while cornering.

The general consciences it that it is difficult to determine the Ackerman and handling characteristics of a vehicle from a 2D model, this is because the caster angle and SAI makes steering geometry a 3D problem, however it is a good place to start.

3.3 Conclusion

From my research I have decided that the actual suspension type is not of a high relevance but may be restricted to a class or category. The main point to a good suspension design is to have predetermined plans and understanding of how adjustments can be made to improve the handling of the vehicle. For this reason I have decided to use suspension design software (WinGeo 3 Version 4), to develop a model, that will assist me in determining a suitable starting point for my design. From this I will be able to determine the effect of both minor and major adjustments on the suspension package, and then be able to determine the extent of adjustability that the suspension will require. This will give me a basic understanding of how the adjustments should affect the handling of the vehicle. Once this has been established it will then be possible to fabricate suitable components that allow for the limits of adjustability that I discover. My intention is to use Ackerman principal steering geometry with an initial setting of zero, but allow for this to be modified through adjustments that have been allowed for in my design.

4.0 Background on Steering and Suspension

4.1 Overview of steering and Suspension

A suspension system supports the vehicle, cushioning the ride while holding the tyre and wheel correctly positioned in relationship to the road. Suspension system parts include the springs, shock absorbers, control arms, ball joints, steering knuckles, and spindles or axles.

The steering system works with the suspension system. It allows the driver to steer the car while providing a comfortable amount of steering effort. Steering system components include the steering gear, the steering linkage, the steering wheel, and the steering column. There are two types of steering systems.

They are:

- 1) The parallelogram steering, this has a steering box (gear box) and a parallelogram linkage that is attached to a pair of tie rods.
- 2) The other is rack and pinion steering (figure 3.1 shows a typical rack and pinion steering) this is a simple long rack with straight tie rods extending from its ends.

Both of these steering systems are available in manually operated and power assisted (uses hydraulic fluid and a pump to assist in the turning of the component).



Figure 4.1 A typical Rack and Pinion.

4.2 Factors Effecting Handling and Drivability

There are many factors that affect the handling and drivability of a vehicle, some of these include the desired use of the vehicle, is it for road use or a high performance racing car. Some differences are in the basic design however most of the components that make up a suspension system are common to all types of vehicles.

The biggest differences in suspension design appear in the individual component design, a street car needs strong durable suspension that can handle a variety of road surfaces with a spring and shock absorber that is able to support the vehicle safely, and cushion the variety of conditions it will face. A race car has a more finely tuned often lighter suspension with a lot of one off fabricated components that assist in creating a package that has sufficient strength and durability for the desired application, often uses a firmer spring and shock absorber and does not need as much suspension travel as a street car.

This project will be using an unequal length double a-arm suspension with manually operated rack and pinion steering. The factors that led to this decision are:

- The 2008 car was damaged in an accident and the front suspension took the main impact of the incident, therefore the suspension requires repair or replacement.
- Intended use of the car
- Access for adjustability
- Availability of components
- The design of the vehicles chassis best suits the double wishbone style rather than an I-beam or Macpherson Strut type of suspension.
- Ease of manufacture and assembly.



Figure 4.2 :Left: Macpherson strut suspension, upper right I- Beam suspension, Middle right Sample of a lower A-arm Bottom Right: Sample Independent Front Suspension.

3.3 Chapter Summary

There are many factors that contribute to a good suspension setup, ranging from the type of tyres all the way to the initial suspension positions (where the suspension points are attached to the chassis). Any changes in the vehicle setup can have a vast effect on the handling characteristics of the vehicle.

5.0 Terminology and Definitions

5.1 Introduction:

Before we begin to develop a suspension system it is required that we know and can identify the phenomena that affect the handling and drivability of a vehicle. As this project is mainly concerned with the geometric association of the components that affect the performance not all types of suspension will be looked at, and for this reason the following list was developed to make the reader familiar with the required knowledge to undertake this project. Here are some definitions and terminology that my project will be using to determine a suitable suspension and steering design for the 2010 USQ SAE-A Racer.

5.2 Ackerman:

When the extended axis of the steering arms meet at the centre of the rear axle, and when the vehicle is following a curved path, the inside wheel will be steered to a greater degree than the outside wheel so that both wheels can follow their individual radii without skidding. The definition of Ackerman steering then follows as the difference in the angle of the front tyres when turned.



Figure 5.1: Identifying the difference in Radii.



Figure 5.2: The Ackerman Principal.

5.3 Camber:

The angle between the vertical axis of the wheel and the vertical axis of the vehicle when viewed from the front or rear of the vehicle. If the top of the wheel is further out than the bottom this is called positive camber, if the bottom is further out this is called negative camber. Negative camber is the better choice for the outside tyre when cornering. It allows for greater tyre and road surface contact and potentially improved grip this occurs because the tyre becomes closer to the optimal angle to the road and the forces are transferred through the vertical plane rather than the shear forces across it.



Figure 5.3: Identifying Camber. Left: Positive camber.

Right: Negative camber

5.4 Caster:

The angle to which the steering pivot axis is tilted forward or backwards from vertical as viewed from the side. If the top of the pivot positioned rearward of the lower pivot this is known as negative caster, negative caster makes it easier to steer but with less straight line stability. If the top pivot is forward of the lower pivot this is known as positive caster, positive caster can aide in straightening the wheels as the vehicle leaves a corner (while travelling forwards) and enhances straight line stability.





5.5 Toe:

Toe is a comparison of the distances between the fronts and rears of a pair of tyres. If the leading edges of the front tyres are slightly pointed out then the vehicle has toe out if the leading edges are pointed slightly in then the vehicle has toe in. Toe affects the straight line stability, tyre wear, and corner entry handling characteristics of the vehicle. A small amount of toe in will result in a more dynamically stable condition.



5.6 Steering Axis Inclination (SAI):

Also known as kingpin inclination angle, is the lateral inclination of the steering axis in the transverse vertical plane as measured from the ground.

Inclining the steering axis so that the intersection with the ground is as close to the tyre contact point on the ground will result in reduced torque about the steering axis during forward motion, this also helps to reduce the steering effort required to turn the wheels while the vehicle is stationary, but provides suitable resistance while the vehicle is at speed.

5.7 Scrub Radius:

Is a factor of the SAI. It is the pivot point for the front tyres footprint. The scrub radius is measured at the ground and is the distance between the centreline of the tyre and the intersection of the SAI. The greater the scrub radius the harder the vehicle will be to steer, positive camber may assist in correcting scrub radius but may result in decreased tyre life.



Figure 5.6: SAI and Scrub Radius

5.8 Instantaneous Centre:

The point in 2D space through which a body rotates at a given instant. In a suspension system this point is through which an individual wheel rotates.

5.9 Roll Centre:

Defined by SAEJ670e as : "The point in the transverse vertical plane through any pair of wheel centres at which lateral forces may be applied to the sprung masses without producing suspension roll", but this definition is only true for non independent suspensions as it assumes that the horizontal position of the roll centre is on the vehicles centre line

5.10 Jacking:

An upward reaction force generated by the tyres when a race car accelerates during cornering and the roll centre is above ground level. When the upwards force of the outer tyre is greater than the downwards force on the inner tyre, this results in an upwards reaction force that "jacks" the sprung mass when cornering. Jacking tends to cause the vehicle to become unstable due to changes in the camber angle, and for this reason should be avoided.

5.11Understeer:

Understeer is related to the front wheels. The condition exists when car refuses to turn into a corner but instead tends to continue in a forward direction instead of following the corner.



6.0 Rules and Regulations of SAE-A

6.1 Introduction:

As with any form of motor sport there are rules and design criteria that need to be met before any vehicle can take part in an event. These rules are clearly stated by the race organisers and are categorised for the different classes of vehicles, in general terms this means that there are different rules for a Formula 1 race car as to that of a World Rally Car. The rules for this competition are devised by the Society of Automotive Engineers International (SAE). Further information on SAE and a full list of rules for the 2009 competition is available from http://www.saea.com.au/wp-content/uploads/2009/02/2009-fsae-rules1.pdf.

6.2 Steering and Suspension Rules for 2009

The following rules are as stated by SAE International, and are the relevant rules that will govern the final design for this project.

6.3 Suspension:

- The car must be equipped with a fully operational suspension system with shock absorbers, front and rear, with usable wheel travel of at least 50.8 mm (2 inches), 25.4 mm (1 inch) jounce and 25.4 mm (1 inch) rebound, with driver seated. The judges reserve the right to disqualify cars which do not represent a serious attempt at an operational suspension system or which demonstrate handling inappropriate for an autocross circuit.
- All suspension mounting points must be visible at Technical Inspection, either by direct view or by removing any covers.

6.4 Ground Clearance:

• The ground clearance must be sufficient to prevent any portion of the car (other than tyres) from touching the ground during track events, and with the driver aboard there must be a minimum of 25.4 mm (1 inch) of static ground clearance under the complete car at all times.

6.5 Wheels:

- The wheels of the car must be 203.2 mm (8.0 inches) or more in diameter.
- Any wheel mounting system that uses a single retaining nut must incorporate a device to retain the nut and the wheel in the event that the nut loosens.

6.6 Tyres:

Vehicles may have two types of tyres as follows:

- Dry Tyres The tyres on the vehicle when it is presented for technical inspection are defined as its "Dry Tyres". The dry tyres may be any size or type. They may be slicks or treaded.
- Rain Tyres Rain tyres may be any size or type of treaded or grooved tire provided:
- The tread pattern or grooves were moulded in by the tire manufacturer, or were cut by the tyre manufacturer or his appointed agent. Any grooves that have been cut must have documentary proof that it was done in accordance with these rules.

• There is a minimum tread depth of 2.4 mms (3/32 inch).

Note: Hand cutting, grooving or modification of the tyres by the teams is specifically prohibited.

6.7 Steering:

- The steering system must affect at least two (2) wheels.
- The steering system must have positive steering stops that prevent the steering linkages from locking up (the inversion of a four-bar linkage at one of the pivots). The stops may be placed on the uprights or on the rack and must prevent the tires from contacting suspension, body, or frame members during the track events.
- Allowable steering system free play is limited to 7 degrees total measured at the steering wheel.
- Rear wheel steering is permitted only if mechanical stops limit the turn angle of the rear wheels to ± 3 degrees from the straight ahead position.
- The steering wheel must be mechanically connected to the front wheels, i.e. "steer-by-wire" of the front wheels is prohibited.
- The steering wheel must be attached to the column with a quick disconnect. The driver must be able to operate the quick disconnect while in the normal driving position with gloves on.
- The steering wheel must have a continuous perimeter that is near circular or near oval, i.e. the outer perimeter profile can have some straight sections, but no concave sections. "H", "Figure 8", or cut-out wheels are not allowed.

6.8 Rollover Stability:

- The track and centre of gravity of the car must combine to provide adequate rollover stability.
- Rollover stability will be evaluated on a tilt table using a pass/fail test. The vehicle must not roll when tilted at an angle of 60 degrees (60°) to the horizontal in either direction, corresponding to 1.7 G's. The tilt test will be conducted with the tallest driver in the normal driving position.

The above rules are from: http://www.saea.com.au/wp-content/uploads/2009/02/2009-fsae-rules1.pdf. p31-33

6.9 Conclusion:

By understanding the rules of the competition I am now able to start on a suitable design. With these rules and with the chassis blue prints I will be able to construct a model that will aide me in my final design.

7.0 Win Geo3, Steering and Suspension Design Program

7.1 Introduction

This chapter introduces Wm. C Mitchell's suspension geometry software, Racing by the Numbers Version 4.00 and demonstrates the power of the software for the calculation and display of steering and suspension geometry for the SAE-A race car. The information gathered can greatly improve the time taken to analyse steering and suspension set-up, thus giving us an indication of how the car will react under different conditions and will allow for concise adjustments during setup and testing.

7.2 WinGeo Program Background

Steering and suspension geometry is be modelled on Wm. C. Mitchell's, WinGeo software, this allows for quick adjustments, as opposed to manually measuring all the various important values repeatedly for the different settings you wish to try during testing. Doing this enables a comparison between the effects of small changes and how they will affect the design parameters of the 2010 SAE-A race car and an indication of how well the car will react while cornering. It will also allow a basic comparison of the initial 2008 car's design (as this vehicle is damaged no exact comparison will be available) and actual geometry after construction allowing for the optimum geometry to provide the best cornering and handling ability of the race car.

By measuring and entering the data into Wm. C. Mitchell's, Win Geo software, we can critically analyse the race car with regard to the handling and cornering characteristics. The software requires actual measurements taken from the car which will be done and recorded according to the geometry software requirements.

Once recording all the information that the software needs, we can analyse the way the steering and suspension reacts with the chassis. Moving up or down (ride) or rotating (roll) we are able to observe the change in camber, steering angles and caster at each of those changes. This is useful since during a corner, we may model the changes that the chassis will go and can see the result on the tyres (and contact patch) and get an indication of how well it will perform.

Wm. C. Mitchell's software can also be used to aid in the design of steering and suspension systems, through its design and build functions you may specify various values and the software will convert it into the required lengths of the arms and rods.

7.3 Measurements and Program Setup

The following information has been provided to give you enough information to be able to measure and analyse an SAE-A race car, using the WinGeo software, without needing to read the full software operations manual: Win Geo 3, Suspension Geometry Program, Version 4.00 for windows 95/98 and 2000, NT and XP.

It is strongly recommend that you allow at least half a day to measure up a car for the first time and to get someone to help. It will save a lot of time that would otherwise be lost dropping things, resetting the origins and other fiddly jobs that are not normally accounted for.

Once the program has installed, printing out some generic forms will make things much easier for entering information into the program once the measurements have been taken, as the forms are in a similar format to the program on screen.

Open the WinGeo program, select the help menu, then select quick start from the drop list. The help tree is on the left side of the page, from there open the Files menu and then Blank Forms, here is a list of all the blank forms that is needed. Click on Blank forms: Measuring cars for some general information and hints, for a double wishbone suspension with a push/pull damping system, click on the Blank forms: Double A-arm and Rocker Arm option and print this form. Also click on Blank forms: Pull-rod / Push-rod form and Blank forms: Auxiliary points and print these forms also. Be sure to print at least a second set of these forms, if a mistake is made use a new form as to minimise the using an incorrect value.

First you need to make sure that the car is set up already with the correct alignment and on a flat level surface as it would on the racetrack. For this project it is difficult as the vehicle has left hand front damage and is sitting on 3 tyres only. Remove any body panelling to ensure that access to the suspension points is possible and ensure that the suspension bolts are locked in place and that the vehicle cannot roll or move when you lean on the car. Once these checks and panels removed then determine a baseline or origin accurately and place strings on the surface plate or flat floor or tie to appropriate point, to represent the centrelines of the car (front to back, side to side). The X-Axis is the front to rear longitudinal dimension. The Y-Axis is the left and right sides of the car (driver's side - passenger side) and the Z-Axis is the vertical dimension from the ground up. Care must be taken when selecting an origin due to common suspension adjustments, such as changing caster, can move the tyre contact patch. Each such change requires a careful remeasurement (or re-calculation).

When the car is ready to be measured, follow these steps:

- Measure the track width of the front and rear tyres by taking the centre points of each tyre as low to the ground as reasonable, the WinGeo3 program measures track at ground level at the centre of the tyre contact patch. The easiest way is to measure to the middle of the tyre, but this can be misleading if the tyre has significant static camber, so as long as you are aware of the settings you should be fine.
- Measure the static toe for the front tyres while measuring the track at the front and do a quick calculation of the static angle pointing inwards or outwards that each tyre is at. This is done either by measuring the distance between the forward and rear of the pair of front tyres and taking the difference. Or by using a spirit level and a flat straight object (length of wood etc.) across the inside of the tyre (for cars with static toe-out, measure the outside for cars with toe-in) and measure the distance from the edge of the tyre to the flat object.
- Measure the pickup points of the suspension or the A-arm connectors (A and C) and the actual position of the ball joint (point B) as points in a co-ordinate system with respect to the central axis determined previously. The forms that were printed out previously depicts the points A, B and C for the lower A-arm and D, E and F for the upper.
- Repeat this for both upper and lower A-arms and left and right sides.
- Locate and measure the steering box/rack and the length of travel that the steering mechanism will go from lock to lock.
- Measure the points of the steering tie rods from the central axis.
- Finally locate the springs and shock absorber assembly and note these points with respect to the central axis also.

This will provide sufficient data to enter into the geometry program.

Create a new file corresponding to a push or pull rod that matches the suspension set up, and start entering all the information recorded in the appropriate spaces for the suspension, steering, auxiliary and pivot sections under the edit menu, check each value and hit compute and sketch to update the information on screen.

7.4 Entering Data into Win Geo3

Once all the data is entered into the program, it is ready to analyse the steering and suspension set up. On the main screen there is displayed information already about the setup, the camber, caster, and scrub for the left and right sides. Also other information that is useful but not needed at this stage. Right click anywhere on the screen and a window will open, click on the Values tab and make sure that the following are checked: Ride and Roll, Camber, Steer, Net steer, Scrub, Net Scrub, Instant Centre, Kinematic Roll Centre and Caster and Trail, uncheck the other options to keep the main screen less cluttered.

Now immediately you can see all of that data on the main screen, further analysis is done under the Analysis menu. Selecting Fundamental Analysis will show the instantaneous parameter based on the geometry and describes the movement of the tyre over small displacements. The important information from this section is the instantaneous ride and roll camber or camber gain during ride and roll. This is displayed in degrees/mm for ride and degrees/degree for roll. This is only for small displacements, to model the car traversing a corner we have to use a Path file, while entering force values for the weight of the car and the springs.

Right click on the main screen and go to the Forces tab and in the Z-Vertical box, enter the weight (or expected weight of the car not forgetting to include the drivers weight) of the car and make sure that both sides of the force side section is selected, and the Upright and the Truck arm boxes are checked and hit accept. Under the Edit menu, go to the Forces (springs and bars) option and enter in the left and right side spring rates that will be used, then click done.

Now that the spring rates and weight of the car has been entered, open up a path file under the Reports menu - Load path file and open path file, use the Demo1metric.pth file as a base that you edit to simulate a corner. Once opened the path file, again under the Reports menu, edit the path file to include steering angles. The values of roll and steer are in degrees, think about what the maximum angles that the wheels can turn and enter in appropriate steering angles.

What this path file will do is change the ride height, roll and steering angles of the car in the increments that have been defined. A corner can be simulated in five points, entering the corner under full braking, turning into the corner with half braking, full cornering (maximum steering angle), roll on power exiting the corner, and full power to complete the corner. The steering angle is half the maximum at half braking turn in and roll on power on exit respectively. Create two path files corresponding to a left hand and right hand turn using the default ride and roll values in the Demo1Metric.pth file as these figures are a good approximation to a maximum case scenario.

Loading the path files will turn on the Next button on the main screen, press the button and it will cycle through the settings defined in the path file and you can see the effect they have on the car.

7.5 Saving and Reporting the Data

Once you have the path files operating you may record data using the Table menu. Clicking on Show will bring up a spreadsheet on the bottom of the main screen, from the Table menu you may select any of the tables 1-10 for the corresponding data, the information we are looking for is under Table 9: Right and Left suspension, which tabulates the location of the Roll Centre, camber and caster for both sides and steering angles.

Run through the path file by clicking the Next button to jump to each setting. This fills the table with data and once a cycle is completed you may save the table content under the Table menu as a Comma separated ASCII file (CSV) which Microsoft Excel can read and tabulate, from there you may extrapolate graphs to show the change in camber, caster, steer and location of the roll centre, however the easiest and best way to monitor the roll centre is by checking the Mark RC button on the main window in WinGeo and cycle through the path, this highlights the path that the Roll Centre undertakes.

8.0 Analysis of the 2008 Car



Figure 8.1. Right hand front suspension of the 2008 car

8.1 Introduction

This chapter analyses the 2008 car by speaking with last year's team members, reviewing previous analysis on the suspension system being used and through analysis using the Win Geo software to find any flaws or areas of improvement that could be made for the 2009 vehicle. This chapter also attempts to determine why the vehicle crashed and destroyed the left hand front suspension assembly.

8.2 Problems with the 2008 Car

After talking with team members from the previous year it was found that the main areas of attention are:

- **Location Hazard** The steering shaft location within the vehicle is currently running between the driver's legs making it difficult for the driver's access and egress. The steering universal joint is quite large and adds to this problem. It is a requirement that all drivers be able to exit the car in an emergency situation within an allotted time period.
- **Steering Effort** Another problem was fatigue in steering the vehicle, the 2008 team changed the steering rack to a 1:1 ratio unit, this resulted in the vehicle being very quick to turn but also very heavy to steer the car thus causing fatigue. This is believed to be a contributing factor to the accident the vehicle was involved in.
- **Understeer** the 2008 car exhibited an undesirable amount of understeer although understeer can sometimes be used to benefit the driver this may also contribute to the steering effort required to steer the vehicle and possibly the accident.

8.3 Analysing the 2008 Race Car with Win Geo Software

By using the process outlined in the previous chapter and measurements taken from the 2008 car, the following information was found for the 2008 race car.

- Steering Axis Inclination / King pin axis- 5.509 degrees.
- Scrub radius- 43.921 mm this is more than excessive, the intended scrub radius was 20 mm.
- Castor- 4.097 degrees, this could have possibly been higher as the vehicle was propped at the front so all of the necessary measurements could be taken.
- Camber- 3.442 degrees, at first seems ok, but further analysis reveals it does not need to be this high more around 2 degrees is sufficient.
- Toe- The 2008 design had 3.327mm of toe in per wheel this is excessive and will contribute to the understeer and steering effort required to drive the vehicle.

The steering axis inclination and the scrub radius are directly related to the high steering effort experienced by the drivers of the 2008 car. The castor angle although not too high may also have contributed to the steering effort; this is due to the wheels constantly being forced into a straight line position. The above mentioned measurements individually may not be far from the desired settings however they are major contributors when used as a package.

8.4 Using the Win Geo Path Files

Using the path files (process outlined in the previous chapter) of the Win Geo software for the ride, roll and steer it is possible to view the instantaneous centres, roll centres and the ride and roll camber change of the 2008 car, see appendix A.1 for the path file output for the 2008 car. The locations of the instantaneous centres were 2556.9mm out and 357.7mm into the ground; this is not very desirable as it can contribute to a high rate of camber change during roll.

The roll centre is located 91.8mm underground. While a low roll centre is good in maintaining a low roll moment and therefore reducing the effect of jacking forces the position of the roll centre for the 2008 car is excessive. The ideal position for the roll centre is as close to the ground as possible, this positions the roll centre close to the centre of gravity and consequently reduces the roll moment and the roll resistance of the chassis.

The ride and roll data found that the maximum camber change occurred whilst under full cornering with a change of 0.987 degrees on the outer wheel and 0.935 degrees on the inner wheel. The roll change was then found to be 0.759 degrees / degree in roll and 0.021mm / mm in ride. This means that for every 25mm change in the chassis height the camber will change by 0.558 degrees this only appears to be small however could be improved. As for the roll a 1.5 degree change in the roll results in a 1.132 degree change in the camber, this also could be better.

From the analysis you can see that during cornering the outer wheel is definitely increasing the contact area with the road however there is still 2.455 degrees available before full contact is made, the other interesting point is that at the same time the inner tyre has increased to 4.377 degrees and thus significantly reducing the contact of this tyre on the road. These factors may make the car feel slippery in the front while cornering, and therefore make it undesirable to drive to its full potential.

8.5 Chapter Summary

There are a number of improvements that can be implemented from the analysis of the steering and suspension systems from the 2008 race car. Some of these include:

- Understeer
- Steering effort
- The location of the steering shaft
- And locating smaller universal joints are the main improvements.

How these improvements are implemented for the 2010 car will be discussed in further chapters. The other aspects of the steering and suspension performed reasonably well.

Improvements into the movement of the roll centre and camber change during cornering will further improve the suspension system and overall cornering and handling ability.

9.0Steering and Suspension for the 2010 Car

9.1 Chapter Overview

This chapter discusses the implementation of improvements from the analysis of the 2008 car and the individual steering and suspension designs.

9.2 Implementing Improvements

The improvements that can be made as result of analysis to 2008 car were understeer, Steering effort, the location and mounting of the steering shaft. To improve understeer a decrease in the Ackerman steering geometry and improved adjustments and geometry of the front a-arms will see better response from the race car.

Reducing the steering effort will include suspension geometry adjustments and upright setup that has less steering axis inclination and scrub radius, the Fundamental Analysis of the 2008 geometry with respect to these values are shown in Appendix A.1.

The location of the steering shaft will improved through the use of a steering transfer system and relocating the steering shafts to suit, this will remove the steering shaft from between the driver's legs and subsequently improve the access and egress of the driver.

All of the moving steering shafts will require 0.9mm aluminium fabricated mechanical protection to ensure the drivers clothing does not interfere with free operation of the components and for the drivers' personal safety.

Before any of these recommendations can be implemented they will need to be approved by the 2010 USQ Motorsport Team, and will be influenced by the following factors:

- Cost of components required to make the changes.
- Time availably to fabricate new components.
- Time to implement the changes.
- Available time to sufficiently test the changes.

9.3 Steering System

The steering system will be comprised of a rack and pinion that was purchased and fitted by the 2008 team. It is a 1:1 ratio rack and pinion, this means that for one full revolution of the steering wheel the car will turn from one maximum steering angle to the opposite steering angle. One problem with this rack is that it is promotes fast steering response and can be very difficult for the driver as the steering becomes "twitchy" and as driver fatigue sets in.

The steering system will incorporate an improved short ackerman principal. The positioning of the rack will be in front of the centreline of the front wheels, therefore a forward ackerman will exist. Positioning the steering rack and pinion forward of the front wheel centre axis also promotes a little more ackerman due to the slip angles generated in the tyres while cornering. If we move forward the intersection point of the extended steering axis to around 40%, it will provide a significant increase in steering response (Smith. C, 1978).



Figure 9.1 Short Ackerman Principal.

As we are not after greatly improved steering response, due to the 1:1 ratio steering rack, we will be aiming for between 5-20% of W.



Figure 9.2: Cornering develops slip angles which change the ackerman location.

9.4 Steering Safety

The steering transfer box will be located on the inside of the front of the chassis and forward of the control pedals. It will consist of a roller chain and sprocket arrangement with an aluminium casing, the shaft from the top universal joint to the transfer box will be of aluminium heat treated for optimum strength and torque requirements, all universal joints should also be replaced with light weight aluminium Borgenson universal joints, by replacing all of the shafts and universal joints with aluminium the total package weight will not be greatly increased. Appendix D.4 shows a solid model of the proposed transfer system and its associated components.

9.5 Suspension System

The suspension system is fully independent using unequal, non-parallel double wishbone links, very similar to the 2008 race car's setup. The front suspension will have a pull rod spring and shock absorber configuration, changing this system to a push rod was investigated but was quickly deemed to be of no great advantage, this was due to the fabrication required to move the shock absorber and spring from the floor of the vehicle to the upper chassis area, while the rear suspension will have a push rod setup. The difference between these systems is only the location of the spring/shock absorber and which wishbone (upper or lower) it is connected to. The performance for both push and pull rod systems are equal due to the motion ratio and wheel rates that are incorporated into the rocker or bell-crank design.

The 2008 race car suspension geometry proved reasonably successful and similar geometry will be employed but trying to incorporate some improvements to the design so that the vehicle has a better feel on the track. The wheelbase this year has been set at 1650mm and the track 1300mm at the front.

The front suspension wishbones consist of two members, with a boss that has a threaded hole to match the spherical rod ends welded at each end. The spherical rod ends have been previously purchased by past members of the USQ Motorsport Team. The design for the rear suspension will not be changed, it has been setup by past team members and has proved itself in performance and reliability. The rear suspension has been modified in the past few years to accommodate a toe control rod to prevent turning of the back wheels. This suspension arm is simply a single rod with two spherical rod ends fitted in a welded boss.

The mounting points of the suspension links to the chassis were redone in 2005, prior to that a flat plate was simply welded onto the chassis where it was needed. The improved method included carefully placed crush tubes that will allow shims or spacers between the chassis and suspension mounting points. The reasoning for this change was the new mounting points are lower in weight and they have greater adjustability, this style of adjustability will be continued in the 2010 car. The spring and shock absorbers are off the shelf items that have both rebound and bump adjustability, 450lbs/in springs and are all in good condition and will be reused.

9.6 Analysing the 2010 Geometry using WinGeo

By using WinGeo to analyse the suspension point it was possible to tune the suspension for the optimum performance and hopefully reliability. Refer to appendix B 2 for the Win Geo analysis. From this analysis the following information was obtained:

- Steering axis inclination / Kingpin angle is 3.859 degrees
- Scrub Radius reduced to 3.672
- Caster angle 2.339 degrees

Suspension Condition	2008 Design	2010 Design
SAI	5.509 degrees	3.859 degrees
Scrub Radius	43.91 mm	3.672 mm
Caster Angle	4.097 degrees	2.339 degrees
Instantaneous Centre Width	2556 mm	4597 mm
Instantaneous Centre Height	-357 mm	414 mm
Roll Centre	91 mm	59 mm
Camber Angle	4.097 degrees	2.339 degrees

The following table illustrates the differences between the 2008 and 2010 design figures.

Table 9.6.1 Differences between the 2008 and 2010 designs.

Using the Fundamental Analysis on the 2010 race car revealed the location of the Instantaneous centres, roll centres and the ride and roll camber change rates. The instantaneous centres are located 4597.404mm or 4.6m out and 414mm off the ground.

These are longer than the 2008 car, and will result in an improved cornering ability for the 2010 race car.

The caster angle has been reduced by about 2 degrees, this is to reduce the required steering effort without effecting the steering returning to centre after cornering.

The roll centre is located 59mm below the ground on the vehicle centreline, this is higher than the 2008 car, which was 91mm, but as the roll centre remains below ground level during the ride and roll testing the higher roll centre will assist in lightening the steering, without having a great impact on the vehicles stability. This also controls the Jacking forces but increases roll moment which affects the roll resistance of the chassis, this will reduce the amount the chassis rolls during cornering which is desirable, this is reflected in the reduction of roll camber change rate. Using fundamental analysis the roll and ride camber change rates are 0.880 degrees per degree in roll, and 0.011 degrees per mm, an increase in the roll camber change while reducing the ride camber. Overall this is very similar to the 2008 results but the instantaneous net scrub radius has reduced from 0.279mm to -0.158mm, this should result in improved tyre life.

9.7 Analysing the Path File

Analysing right hand cornering using the WinGeo path files, see appendix B.2 for the path file output for the analysis of the 2010 car and appendix C.3 for a comparison between the 2008 and 2010 designs, the movement of the roll centre indicates that the car will have reduced camber change during cornering. This will produce better results of camber change to the tyres, the 2008 car was -2.455 degrees while the 2010 is -0.116 degrees, this results in a greater tyre contact with the road and also a greater contact on the inner front tyre also, therefore allowing for greater cornering speeds. As the suspension travel is limited the likely hood of the tyre going into positive camber is reduced, if this does happen the resulting consequence will be will be reduce will be reduce will be reduced cornering and handling ability.

9.8 Chapter Summary

This year's design is intended to be better than the 2008 race car, with an improved ackerman steering geometry, and by adjusting the Steering axis inclination, scrub radius and castor angle we have improved the understeer and steering effort required to drive. This will increase the cornering ability, performance and reliability of the race car. The movement in the roll centre and reduced amount of camber change during cornering demonstrates the improved cornering and handling ability of the race car.

10.0Testing and Optimising the 2010 Car

9.1 Chapter Overview

This chapter discusses testing methods and optimising procedures to ensure that the 2010 race car has the best steering and suspension setup possible. The aim is to find a suitable venue or venues for various track testing, analysing the performance and changing settings in small increments and repeat to see their effect, with particular interest in toe, castor and camber settings.

10.2 Testing Methods

Previously track tests have been done at Greer Park, in Toowoomba with the team for both car testing and driver training. Greer Park is a bitumen track circuit which is ideal for general car running and tuning, and also to prepare for the autocross dynamic event. Another testing method is to set up a Skid pan area similar to the competition, the skid pan test measures the car's cornering ability on a flat surface while making a constant radius turn.

10.2.1 Skid Pan

First a large and flat area must be organised at a suitable venue for a day to allow for set up, testing and clean up. Supplies you will need to take are:

- Ideally you would need 32-38 witches' hats but 16 is the minimum to mark out the diameter of the circle.
- Measuring tape.
- String or another team member to hold measuring tape.
- Stopwatch.
- Car safety items, fire extinguisher, fuel etc.
- Driver safety equipment, helmet, fire retardant suit etc.
- Settings adjustment tools.
- Laptop with WinGeo software and data acquisition memory downloader.
- Any other associated items required for transporting the race car and using the venue.

The circular skid pan is 15.25 m in diameter, select the centre of the circle and have a team member hold one end of the measuring tape or anchor one end of the string to the centre. Measure out 7.625m and start lying witches hats every 3 steps until you have 16 around the circumference of the circle, adjust them so that they are evenly spaced. If you have enough witches hats, place another 16 on the outside that is 3m wide to create a road or path. Select a suitable start and finish point on the circle and move the witch's hats to create an entry/exit gate. This set up is exactly the same setup that will be used in Victoria at the national competition. This also gives the driver(s) the opportunity to familiarise themselves with this event.

When the car is up and running there are two ways to start, first is to enter the skid pan gate at a slow speed and gradually increase the speed around the skidpan, building up to a comfortable but fast pace. This is recommended to familiarise the driver and establish a benchmark for the speed at which it should be done. Second is to gain speed prior to entering the skid pan and enter the gates at that benchmark speed, the driver should complete 2 laps and then exit. This is the competition test method and should be done for consecutive tests.

10.2.2 Data Collection

A method for collecting data should also be considered, so that there is some hard data to show the performance of the race car. Data acquisition should be done using accelerometers placed

strategically on the race car to record the accelerations in the Lateral and longitudinal directions. These accelerometers need to be connected to an amplifier and signal conditioner, then to a portable data logger capable of a high sampling rate. The higher the sampling rates the more entries and faster memory is taken up, but accuracy is improved. Depending on the type of data logging equipment will determine the actual wiring and set up on the car.

Once setting up and checking the data acquisition works, complete a run using the method previously and collect the data. Using Matlab / Excel or some other suitable software, plot the lateral and longitudinal accelerations versus the time and/or speed of the car will give a rough indication of the cornering and handling ability of the race car. Repeating the process for the reverse direction should be done to ensure similar performance.

10.3 Optimising Procedures

Optimisation of the steering and suspension setup will involve adjusting the steering and suspension through the use of shims or spacers to place in between the mounting points of the suspension and the chassis, to adjust the geometry. Particularly the Toe and Camber settings, this will be quicker than undoing the points, screwing in the spherical rod ends the required amount, and then reassembling.

Using the WinGeo software is highly recommended, as you may want to try a few different setup's but only need or have time to actually test one because you have modelled it into the software and checked its validity.

Prior to running the car for the first time, measure the suspension points as detailed in chapter 6, and checking the steering and suspension setup. Construction usually deviates a little from the intended design parameters and may need adjustment.

Next step is to run the car on the test track/s and see how it performs, ask the driver how it performs from the driver's perspective while under acceleration and braking around corners. Any feedback here is important; particularly with the way it enters and exits the corners. If the driver believes the car is slow to exit a corner or exhibits understeering, go and check the camber and toe settings, SAI or kingpin angles and decide how much you would like to change things, if it is decided to change or adjust the setup start with small increments of about 0.5 - 1 degrees at a time and only make one adjustment per trial, this will assist in tuning the car to the track. Care must be taken with any adjustments as the rules and regulations to pass scrutineering at the competition may prevent certain conditions. For example, the competition requires that all Suspension and Steering bolts be Positive locked, this means that at least 2 turns of the thread must be visible through all Nyloc Nuts.

Take notice of the tyres and the wear patterns, if uneven wear is present, you need to check the settings again and adjust it so that the car is using the tyre tread evenly.

Once things seem to be running smoothly, only small adjustments should be made and repeating the process should find a good setup. Remember that each race track is different and that these adjustment procedures need to be followed when tuning the car for each different event or discipline.

10.4 Chapter Summary

Using these methods, it is possible to change an underperforming race car to a serious contender and possible race winner. The biggest difference between a top class race team and a weekend racer is the ability, experience and time to tune the car for each race.

By combining the sections of this chapter, testing using skidpan and the optimising procedures, will result a better performing and more reliably race car.

After testing on the skidpan for the first time and making adjustments to the settings to the steering or suspension, the race car should be taken back to the skidpan and tested in a similar manner to the first test, this will identify if the vehicle is performing better or worst than the previous test. Then the vehicle should be driven faster with each test to determine the ability of the vehicle.

<u>11.0 Conclusions and Further Work</u>

This project has been very enlightening, initially knowing only a little about steering and suspension systems for vehicles and have learnt a great deal. Working with the USQ Motorsport Team has invaluable, having the opportunity to work on a class specified vehicle is normally a task that a student would not have until after university, and then only if they were lucky enough to gain an apprenticeship or similar with a top class team, but being exposed to this working environment can be just as much a learning experience as finding the technical knowledge required for this project.

Some aspects of this project were assisted due to time constraints and design timelines where design work was not included, some of the components have made by the other team members from previous years, while some components will require modification by the 2010 USQ Motorsport team to meet the recommendations that I have suggested. Having understood what has been done in the past and how to improve the reliability and performance for the 2010 car has resulted in a suitable steering and suspension package for the 2010 competition. The most obvious conclusion will be when the car is repaired to my specifications, and is ready to run, only then will the opportunity to optimise the setup be fully understood.

The improvements to the problems from the 2008 car will greatly improve the safety, cornering and handling of the race car, through the introduction of the steering transfer system, the reduction of understeer and by providing an optimum steering and suspension package.

11.1 Further Work

As with past analysis of the steering and suspension design the benefits of anti roll bars in suspension design should be investigated with regard to the improvement of the cornering and handling ability of the race car. Another area to which I wanted to investigate (due to time constraints could not) was the possibility of using fibre composite materials for the suspension components and possibly the vehicles chassis this would require major design changes and could be very expensive but could result in a lighter, faster car.

12.0 References

Davidson, P. 2006 Management 3rd Australasian Edition, John Wiley & Sons, Australia.

Edmund F. Gaffney III and Anthony R. Salinas, 1996, Introduction to Formula SAE Suspension and Frame Design, University of Missouri – Rolla, paper number 971584. http://www.unr.nevada.edu/~mccart31/saepaper.pdf

Gilles, T. 2005, Automotive Chassis: Brakes, Suspension and Steering, Thompson Delmar Learning, USA.

Longhurst, C. 2009, The Suspension Bible. http://www.carbibles.com/suspension_bible.html

Mitchell, Wm .C. 1999, Racing By Numbers Suspension Geometry, Software Installation and Operation Manual, USA no publisher information available.

Nichols, W. G. 1998. Chilton's Easy Car Care. http://www.procarcare.com/icarumba/resourcecenter/encyclopedia/icar_resourcecenter_encyclopedi a_suspsteer1.asp

RC Tek 2009, "Ackerman Steering Principal' www.rctek.com/technical/handling/ackerman_steering_principal.html

Smith, C. 1978, Tune to Win, The art and science of race car development and tuning, Aero Publishers Inc.

Smith, C. 1984, Engineer to Win, The essential guide to Racing Car materials Technology or how to build winners that dont break, MBI Publishing Company

Smith, C. 2004, Racing Chassis and Suspension Design, Society of Automotive Engineers Inc, USA.

Smithees Race Car Technologies 2009, 'Pointed the Right Way, Camber, Caster and Toe what do they mean?'

www.ozebiz.com.au/racetech/theory/align.html

 $\underline{http://www.theory in practice engineering.com/resources/fsae/fsae\%20 suspension\%20 design\%20 brazil%20 style.pdf$

http://www.mech.uq.edu.au/courses/mech3100-old/lecturenotes/mech3100_suspension1.pdf

<u>13.0 Appendix</u>

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A.1 Analysis of the 2008 Car with Win Geo Software.



Figure A.1.1 2008 Zero Position.

Zero position for the 2008 car, this illustrates the dimensions of the 2008 car and gives a good picture of the overall suspension and steering setup that was used by the 2008 USQ Motorsport Team. Some of the problems that this also illustrates are the high scrub radius and the short instantaneous centres.



FigureA.1.2 2008 Full Braking.



Figure A.1.3 2008 Half Braking at Turn.



Figure A.1.4 2008 Full Cornering.



FigureA.1.5 2008 Roll on Power.



Figure A.1.6 2008 Full Power.



Figure A.1.7 2008 Ackerman Analysis.

This indicates that the 2008 car had a sightly long ackerman steering principal, this could have resulted in the understeer experienced by the driver.

B.2 Analysis of the 2010 Car with Win Geo Software.

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Files Rear Clipboard View Edit Design	Build Compute Table Reports	Analysis Utility Help Quit				
Left Bight BOTH SUSPENSION	Steering Auxiliary Swayba	r <u>3</u> rd <u>Pivot</u> <u>Halfshaft</u> <u>Clea</u>	arance Figture Sign	etch Drigin Notes		Keyboard
Both sides	X fore-aft Y width 2	vertical Check distance	Kingpin axis	3.859 degrees		Compute
Lower A-arm forward A	-110.000 + 192.500 +	100.000 A to B= 459.310	Scrub radius	4.009		Print
Lower ball joint B	0.444 + 637.861 +	120.525 C to B= 459.348	Caster	2.339 degrees		
Lower A-arm rearward C	110.000 - 192.500 -	95.000 A to C= 220.057	Caster trail	4.479		<u>D</u> raw
Upper A-arm forward D	-110.000 🛟 240.000 🛟	315.000 - D to E= 402.526	Upper A-arm	184.728		Sketch
Upper ball joint E	8.404 - 624.717 -	315.385 + F to E= 403.512	Lower A-arm	45.956		Help
Upper A-arm rearward F	130.000 240.000	310.000 + D to F= 240.052				
Wheelbase, track, tire diamete	z1650.000 ÷ 1300.000 ÷	520.000 - Rollout1633.628	Track at ground	1 1300.000		
Camber, Toesteer, Toe span	-2.000 .268 .	10.000 . HubTrak 640.926	Ifack at hub	1201.002		
Tire contact patch	0.000 - 650.000 -	0.000 B to E= 195.465				
Filename: C:\Program Files\Mit	chell\Geometry\2010car.GE	M Undo editing				
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Camber -2.000*			Roll 0.000			Camber -2.000*
Steer" 0.047+						Steer" 0.047+
NetStr" 0.094+ Spring -0.000++			T			Spring 0.000↔
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Figure B.2.1 2010 Zero Position.



Figure B.2.2 2010 Full Braking



Figure B.2.3 2010 Half braking at Turn



Figure B.2.4 2010 Full Cornering



Figure B.2.5 2010 Roll on Power



Figure B.2.6 2010 Full Power



Figure B.2.7 Ackerman Analysis 2010 Car

This illustrates the slightly short and forward ackerman that has been designed into the 2010 car.



C.3 Overlay of 2008 and 2010 Car Geometry

Figure C.3.1 2008 & 2010 Zero Position



Figure C.3.2 2008 & 2010 Full Braking



Figure C.3.3 2008 & 2010 Half Braking at Turn



Figure C.3.4 2008 & 2010 Full Cornering



Figure C.3.5 2008 & 2010 Roll on Power



Figure C.3.6 2008 & 2010 Full Power

D.1 Steering Transfer System

D.2.0 Components

D.2.1 Bearing

Type: R12-RS Quantity: 4 required. Cost: \$7.60 each from Consolidated Bearing Company.







D.2.2 Shaft

Type: Manufactured. Quantity: 2 required.

Cost: \$80 each.

SHAFT (Active) - Pro/ENGINEER Educational Edition (for educational use of the second secon



D.2.3 Circlip

Type: D1400-0190 19mm nominal diameter.

Quantity: 8 required.

Cost: \$0.31 each



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D.2.4 Key

Type: 8mm key steel.

Quantity: 1, 300mm length required.

Cost: \$7.75





Josco - Herboy - Key Steel

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	ATTAXOP	羽缘太竹修	ATKINGP	9/16 x 8/16	ATMOSTP	4×4
	ATK100P	3/32 × 3/32	ATK317P	9/16 x 5/8	ATK502P	5 x 5
	ATK300P	3/32 x 1/8	ATK319P	9/16 x 1.1/4	ATK626P	5 x 8
	ATK101P	1/8 x 1/8	ATK223P	11/16 x 11/16	ATK503P	6 x 6
	ATK301P	1/8 x 3/16	ATK315P	11/16 x 1/2	ATK627P	6 x 10
	ATK302P	1/6 x 1/4	ATK320P	11/16 x 5/8	ATK618P	6 x 12
	ATK219P	5/32 x 5/32	ATK322P	11/16 x 3/4	ATK628P	6 x 14
	AJK182P	3/16 x 3/16	ATENDE	教御王 5 66	ATHITRE	7.87
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	ATERNA	516 x 14	ATK368P	1 X ME	ATRADA	8×12
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	ATKSHP	编案键	ATRACEP	第4.1.1章	ATVERMP	8x 14
	ATK221P	9698 x 9553	ATERIA	13118 x 13110	ATHESSP	₩ × 22
	ATK1018	3.46 ± 5/18	ATHIT	T/8 1 7/8	ATKERP	18 x 10
	ATK225P	11/22 x 11/32	ATHERS	湖内省 2 15月6	ATISA177	10 x 12
	ATK213P	5/16 x 3/8	ATK318P	1 x 9/16	ATK605P	10 x 16
	ATK203P	7/16 x 5/16	ATK329P	7/8 x 1	ATK606P	11 x 18
	ATK204P	5/16 x 1/2	ATK330P	7/8 x 1.1/8	ATK607P	12 x 20

Josco | Misc Products Key Steel

eei					P	age 2 of 2
ATK308P	5/16 x 9/16	ATK209P	7/8 x 1.1/4	ATK621P	14 x 14	
ATK309P	5/16 x 5/8	ATK323P	7/8 x 11/16	ATK808P	14 x 22	
ATK105P	3/8 x 3/8	ATK324P	1 x 11/18	ATK609P	14 x 25	
ATK332P	3/8 x 7/16	ATK112P	1 x 1	ATK507P	16 x 16	
ATK310P	3/8 x 1/2	ATK331P	1 × 1.1/4	ATK610P	16 x 28	
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和控制部	治經2 %	ATKIT	1.90×1.514	APRIMUM	22 x 82	
ANCIN	建成 19 1945	ATEXAMP	1.394 2 1.200	ATAMATA	22 * 48	
ATK107P	1/2 x 1/2	ATK114P	1.1/2 x 1.1/2	ATK600P	25 x 22	
ATK216P	1/2 x 5/8	ATK115P	1.3/4 x 1.3/4	ATK509P	25 x 25	
ATK314P	1/2 x 9/16	ATK228P	1.7/8 x 1.7/8	ATK634P	25 x 28	
ATK206P	1/2 x 3/4	ATK117P	2 x 2	ATK614P	25 x 45	
ATK316P	1/2 x 7/8			ATK615P	28 x 50	

Josco Key Steel is also available in lengths up to 3.2m - Please contact your local Josco office for more details

Bright drawn carbon key stock suitable for the manufacture of keys to the following standards

- IMPERIAL BS 46 : PART 1 : 1958
- METRIC BS 4235 : PART 1 : 1972
- STRENGTH U.T.S. 35 to 45 TON/SQ.INCH (540 to 700MPa)
- ELONGATION 12% MIN
- MATERIAL EN6 (0.40 Max. Carbon 0.5 to 0.9 Manganese)
- LENGTHS AVAILABLE UP TO 3.2 metres (on request)

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http://www.josco.com.au/newsite/jia/products/miscellaneous/miscellaneous_ks.htm

6/09/2009

D.2.5 Sprocket

Type: Browning H4012X3/4

Quantity: 2 required.

Cost:





Emerson Power Transmission Corporation

Page 1 of 1

Braning

EPT E CATALOG - PART DETAIL

	Recompleg H4013X246	
	Producel Doce Rober C 40, 107 Pilote Abler Ce	kado Agenadast, Marol, timologiad Throll, 1927 Rosh, † Bibrosk, Laren Ho. Alt
	Singled that of Singleton:	
2	Weingen:	
	Packaged Length:	2.56
	Packaged Width:	2.56
	Packaged Height:	1.38
	No. Links/Ft.:	0
	Product Type:	Finished Bore Roller Chain Sprocket
	Alerie Lénnis Pholi Chromion	MA 40, 122 IA PERIONAL CROSS 1,982
	tikali Bine Munistri Bingda:	
		12 Read Martines Tanta
	Feature 1:	Furnished with Standard Keyway on Centerline of Tooth and Hollow Head Setscrew over Keyway.
	Feature 2:	Additional Setscrew at 90 Degrees to Keyway.
	Warranty:	1 Year
	Std Package Quantity:	1
	Std My Dolbrory:	Normasiy Stocked
	Typical Applications;	
	an a	
121	CHARLES CONTRACTOR	

http://www.emerson-ept.com/EmersonPT/Site/Catalog/MoreInfo.asp?PartId=1128016&Brand=BROW&... 6/09/2009

D.2.6 Chain

Type: RS40SN

Quantity: 1 required.

Cost:


TSUBAKI DRIVE CHAINS

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Nete: When one-pitch offset links (OL) are used, the Max. Allowable Load becomes 65% of the values shown above.

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RS408N kW Ratings Table (Single strand Chain Drive kW)

D.2.7 Chain Adjuster

Type: Manufactured.

Quantity: 1 required.

Cost: \$120.00



D.2.8 Housing

Type: Manufactured, CNC machined from aluminium.

Quantity: 2 required.

Cost: \$95.00 ea



D.2.9 Roll Pin

Type: SPM020030ASF

Quantity: 2 required

Cost: \$0.55 each.



METRIC SIZE SPRING PINS (DIN 1481)



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17 to 50 +1 0mm	6.0	6.4	6.7	1,2	6.0	6.12	7055	1.2	1.4
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D.2.10 Chain Adjuster Bolt

Type: M10 X 50 grade 8.8 all thread.

Quantity: 1

Cost: \$ 2.25



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Assembled Steering Transfer Unit



Cut away showing the internal components of the steering transfer unit.



Alternative view of the steering transfer unit.



Alternative view of the steering transfer unit.



Alternative cut away view of the steering transfer unit.



Alternative cut away view of the steering transfer unit.



Chain adjuster assembly with shaft, sprocket, bearings and circlips installed.