University of Southern Queensland
Faculty of Engineering & Surveying

Steering System and Suspension Design for a Formula SAE-A Racer

A dissertation submitted by

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Abstract

This dissertation documents the steering and suspension design of the 2006 Formula SAE-A racer made at the University of Southern Queensland.

The dissertation includes information on various steering and suspension systems and the various geometry set ups that define handling and performance of the Formula SAE-A racer. It also introduces Wm. C. Mitchell's suspension geometry software and how it can be used to analyse and optimise steering and suspension setups.

An analysis of the 2005 Formula SAE-A racer to determine improvements that can be implemented into the 2006 design has been included followed by the design intentions of the 2006 Formula SAE-A racer.

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ENG4111/2 *Research Project*

Limitations of Use

Certification of Dissertation

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.

B. Freeman

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Signature

Date

Acknowledgments

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Chapter 1

Introduction

The aim of this project is to work with a project team to design, build and optimize the running of a Formula SAE-A racecar, with particular interest in the Steering and Suspension systems. The Formula SAE-A project team aims to produce a competitive racecar that will compete in the Formula SAE-A competition in December.

To achieve this I was required to, research the important aspects of steering and suspension systems used frequently in a nonprofessional racecar and select a suitable steering and suspension system that is within the motorsport teams limits. This project includes suggestions for the design and construction of these systems, the installing and optimising (or tuning) the steering and suspension systems and future recommendations to provide the most cornering and handling ability.

Identifying the critical areas that are important for competitive steering and suspension systems, I can improve the effective handling and cornering capability of the racecar. Improving the handling and cornering power of the racecar will allow faster speeds into and exits out of corners, which will result in quicker lap times, better performance and higher overall standing in the 2006 FSAE-A competition.

Adhering to the rules and regulations for the 2006 FSAE-A competition I aim to select suitable systems that are within the project teams limits by considering the financial cost versus benefit or performance to the car, complexity and time to design and manufacture of each system.

Critically analysing the 2005 teams racecar enables me to evaluate the cars steering and suspension setup performance and find any flaws or ways to improve them. This will give me a better understanding of the steering and suspension systems and how to find the optimum settings to perform with the 2006 car at the FSAE-A competition. Using a suspension geometry computer program developed by Wm. C. Mitchell software, I can model the 2005 teams racecar to compare the accuracy of the program, and then apply the program to optimise the 2006 racecar.

The ideal outcome of this project will see that this years FSAE-A racecar have a working and well-tuned or optimised steering and suspension system that has high cornering ability and handling. Most of this projects work will become evident once we have manufactured our design and are able to test the car by running it on a test-track. If all things go to plan, I should be able to make small adjustments to improve and finally optimize the handling and cornering ability of the car which will be paramount to the performance at the FSAE-A competition.

1.1 Cornering Ability and Handling

The cornering ability and handling of the racecar is very important to the overall performance of the racecar. Having excellent acceleration and braking power is good but without sufficient cornering ability and handling, the racecar will not be able to use the full potential and is more likely to run off the racetrack than take a podium position. Cornering ability and handling will be discussed in detail and how the steering and suspension systems affect it.

1.2 Explanation and definition of terminology

Here is a number of terms and names that will be used in this dissertation to avoid confusion with other names and meanings.

Ackerman - Is both a principle and definition, where the principle is that the extended axis of the steering arms projected rearward meet at the centre of the rear axle (shown in figure 1.1). This allows the tyres to traverse an arc without skidding, which would otherwise oppose the steering forces making it harder to steer. The definition is described as the difference in the angle of the front tyres when turned. This dissertation will only refer to Ackerman as the principle from herein.

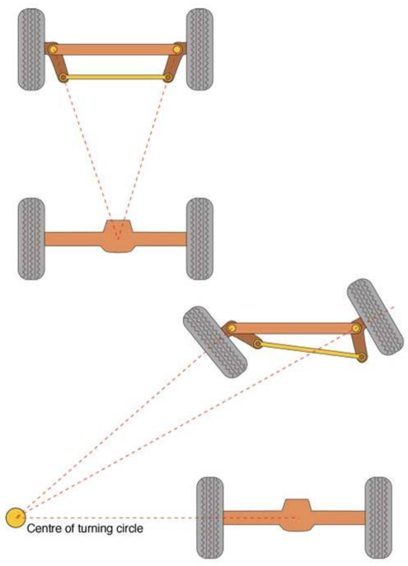

Figure 1.1: The Ackerman principle

Camber - Is the angle between the vertical plane and the centre angle of the tyres (shown in fig 1.2), which can be positive or negative. This changes the size and shape of the tyres contact patch during a corner which in turn affects the amount of lateral acceleration or force it can produce (cornering and handling ability). A small amount of negative camber is ideal (around 1.5 degrees) to induce camber thrust and ensure a good contact patch during cornering (smith. C. 2004).

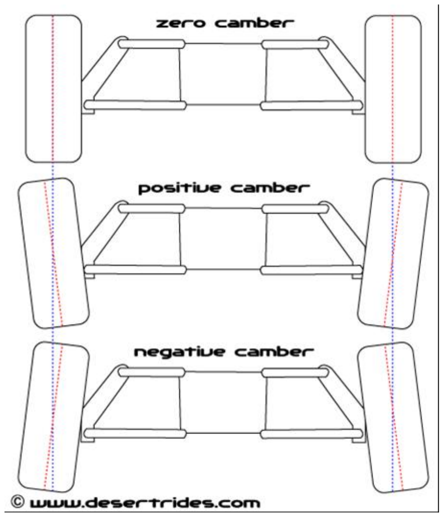

Figure 1.2: Camber

Camber Gain - Or the rate of camber change in roll (or as the chassis rotates laterally).

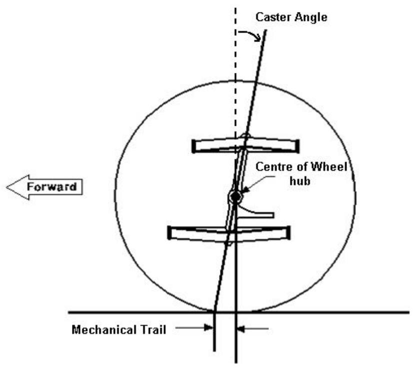

Figure 1.3: Caster angle

Caster - Is the angle between the steering axis and the vertical from the side plane (see fig 1.3). Positive caster improves straight line stability but makes it slightly more difficult to steer, while negative makes it easier to steer with less stability.

Jacking - Is an upwards reaction force generated by the tyres when the racecar is accelerated during cornering and has its roll centre above ground level. Where the upwards force on the outside tyre is greater than the inner tyre having a net resultant force that lifts or *Jacks* the sprung mass. This is unwanted and unsettling to the driver and should be avoided.

The roll centre - Indicates the point at which the chassis rotates (at the front and rear respectfully) during lateral acceleration. The two moment arms between the roll centre, the CG and the ground plane determine the racecar's sensitivity to lateral acceleration by the production of rollover movements and jacking (Smith. C, 2000).

The roll axis - Is the straight line joining the roll centre's of the front and rear tyres

The roll moment - Is the distance between the roll centre and the mass concentration at the front or rear of the car. The mass concentration is the equivalent mass or point of the CG if it were split into 2 points, one front and rear.

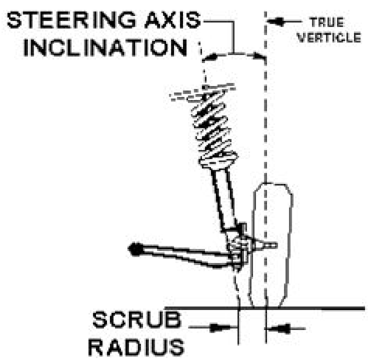

Figure 1.4: Steering Axis Inclination and Scrub Radius

Steering Axis Inclination - or Kingpin Axis, is the angle between the vertical and the steering axis (figure 1.4). This helps the car to exit a corner by naturally trying to align the wheels back to centre. The SAI works with caster to allow more directional stability but less effort on steering (more sai and less caster).

Scrub Radius - Is the pivot point for the tyres footprint or the distance between the centre of the contact patch, to the extended SAI to the ground (figure 1.4). This allows more feel in the steering, a little is good, too much can be detrimental due to the increased steering effort for the driver.

Slip angles - Are the angles between the direction that the tyres are facing, and the direction that the tyres want to go. Deformation is due to the elastic nature of rubber when a vertical load is applied. This will be explained in detail in Chapter 2 and its effect on cornering and handling.

1.3 Overview of the Dissertation

This dissertation is organized as follows:

Chapter 2 Discusses cornering and handling of a FSAE-A racecar and describes various steering and suspension systems.

Chapter 3 Explains the rules and regulations of the FSAE-A competition and how it affects the steering and suspension systems.

Chapter 4 Introduces Wm. C. Mitchell's suspension geometry software, describes its uses and strengths for this project and how it will be used to improve the steering and suspension systems.

Chapter 5 Describes the analysis of the 2005 FSAE-A racecar and documenting areas that can be improved and implemented into the 2006 car.

Chapter 6 Describes the analysis of the 2006 racecar and recommendations for improving the cornering and handling ability.

Chapter 7 Discusses testing methods and ways to document and record actual performance of the racecar, followed by processes for optimisation of the steering and suspension systems for the best cornering ability and handling.

Chapter 8 Outlines the project's achievements, findings and future recommendations.

Chapter 2

Steering and Suspension Systems for a FSAE-A Racecar

2.1 Chapter Overview

This chapter discusses the steering and suspension systems that are commonly used in cars on the road and in professional racing, their benefits and limitations, the ease of manufacture and complexity of design. This chapter also discusses cornering and handling in detail and how the steering and suspension can improve it's cornering and handling ability.

2.2 Cornering and Handling

Handling defines the racecars ability to maneuver around a corner at maximum speed without losing traction. C. Smith (1978) remarks that being able to travel around a corner faster reduces the overall lap time on a circuit for 2 reasons. First is simply that the car traverses the distance in less time, secondly, if the car exits the corner at a faster speed, there will be no time lost from having to accelerate from a slower speed.

Smith (1978) also says that the factors that determine the cornering power of a racecar include the cornering capacity of the tires, which is influenced by:

Vehicle gross weight

Vehicle downforce

Height of the vehicle's centre of gravity

Vehicle load transfer characteristics

Suspension Geometry

Size and characteristics of the tyres

So you can understand, the tyres are arguably one of the most important parts of the racecar because all the moments and forces that the car undergoes is transmitted through the tyres. The acceleration and direction of the car is passed through the small footprints or contact patches of each tyre. Understanding what happens here will help to get the most out of both the tyres and racecar's handling ability (Smith, C. 1978).

2.2.1 Tyres and slip angles

The tyres ability to grip the road is a combination of vertical load applied to the tyre, the coefficient of friction between the tyre and the road, adhesion between the road surface and tyre, and slip angles developed between the tyre and direction of travel. The vertical load that is imposed on each tyre is changing continuously on a racecar maneuvering around a racetrack due to the load transfer from acceleration, deceleration and cornering. As the racecar travels around a corner, the tyres are subject to forces which result in deformation in the compound that the tyre is made of, this elastic deformation results in the contact patch pointing in a different direction to the angle of the tyre (Smith, C. 1978).

Figure 2.1 shows the deformation of the tyre compound in the contact patch and the slip angle developed. The path of the rolling tyre defines the actual direction of the tyre as it continues around the corner.There is a relationship between the slip angles and the potential grip that the tyre has to the road. Some tyre data has shown that

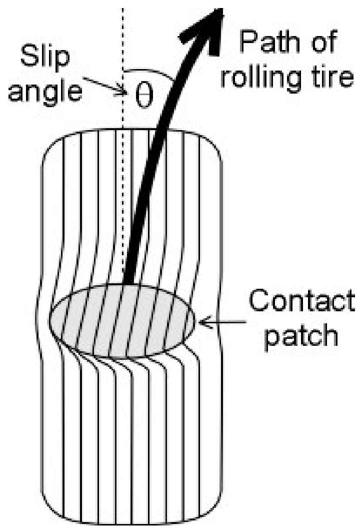

Figure 2.1: shows the generated slip angles in the tyre contact patch

as slip angles increase, the lateral or cornering force increases up to a maximum which then either begins to drop or plateaus then drops, usually sliding occurs soon after the drop in force. The flat portion of the curve at or near the maximum is the optimum range of tyre grip that experienced drivers remain in to maximize the cars cornering potential. Figure 2.2 shows the relationship between tyre grip and the developed slip angles.

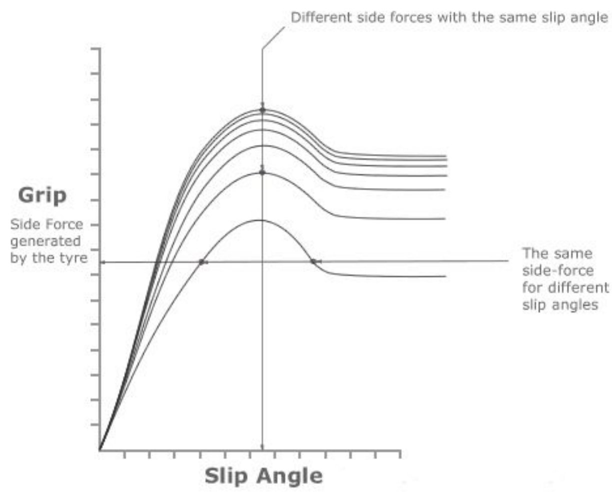

Figure 2.2: shows the relationship between tyre grip and developed slip angles, picture from `http://www.donpalmer.co.uk/cchandbook/modelgrip.htm`

2.2.2 Factors influencing tyre cornering capacity

The other factors as mentioned before, vehicle gross weight, downforce, height of the CG, tyre size and characteristics, suspension geometry and load transfer characteristics, all can be factored into the design or used to improve cornering and handling. The cornering force is proportional to the increase of the vehicle gross weight and generated downforce from wings or aerofoils. The increased pressure on the contact patch generates a higher lateral force component (Smith, C. 1978). The height of the vehicle's centre of gravity from the ground affects the moment between the vertical force on the tyre and the CG, this will affect the lateral load transfer during a corner.

The lateral load transfer changes the vertical loads from one wheel to another due to the CG tendency to move sideways during a corner, which will decrease the total amount of cornering force generated from the tyres. For example, a 400kg car with a 50-50 weight distribution front to rear will have 100kg vertical weights at the two front tyres. Assuming the CG height is 250mm above the ground, the track width is 1300mm and during a corner the car is subject to a cornering acceleration of 1.4g's we can determine the load transfer.

$$LoadTransfer = \frac{1.4 \times 200kg \times 0.25}{1.3} = 53.85kg$$

So this gives us 46.15kg on one side and 153.85kg on the other and is a 53.85% load transfer to the outer wheel. Obtaining tyre data in the form of Tyre cornering force versus Vertical load will allow us to determine the total cornering force with this load transfer, however getting the tyre data is difficult. Generally the tyre data is curved with less tyre cornering force as vertical load increases, so measuring the data of each vertical load and summing together will be less than the equal load distribution. Reducing the load transfer is done by lowering the height of the CG and widening the track width which will improve cornering ability.

The suspension geometry determines the location of the instantaneous centres and roll centres of the racecar, these control how much the chassis rolls or pitches during cornering and accelleration, which moves the CG and hence affects the lateral load transfer.

During roll, the suspension geometry also controls the amount of camber gain in the wheels during a corner, the change in camber affects the contact patch (increase or decrease in proportion) which changes the cornering capacity of the tyres. Ensuring that an optimum contact patch is maintained through the control of camber gain and good roll centre location is key to good handling and cornering.

2.3 Steering Systems

Common types of steering systems are:

Rack and Pinion - basic steering system

Recirculating Ball Bearing - more complex system

Power Steering - fluid assisted steering

2.3.1 Rack and Pinion

The rack and pinion steering system is a simple, cheap and relatively easy system to implement. It comprises of a rack, or toothed bar/rod which slides left and right due to the rotation of a pinion gear that sits on the teeth (Fig 2.3). The steering wheel turns the steering shaft which rotates the pinion gear, resulting in the rack pushing/pulling the steering rods. The rods are attached to the wheel hubs which turn the wheels to the desired angle (Gilles, T. 2005).

The most difficult parts to design or manufacture are the pinion and the rack, the pinion defines the turning rate of the steering wheel which affects the responsiveness of the steering. The rack need to have hardened teeth which could be difficult to manufacture to some groups or would involve a significant cost to have it done. Besides these two parts the rest of the system is relatively simple, as a whole the rack and pinion setup is a cheap and common system that is reliable and resiliant.

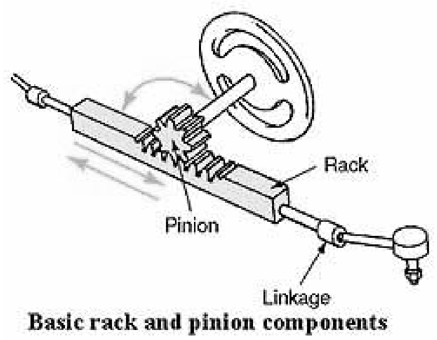

Figure 2.3: Rack and Pinion steering, picture from www.imperialclub.com/Repair/Steering/terms.htm

2.3.2 Recirculating Ball Bearing

A typical Recirculating ball-bearing steering system uses a worm gear to shift ball bearings that are located within a channel such that when moved, pushes or pulls the housing in which they sit. The housing has teeth located on the outside which are in line with a sector gear that rotates a pitman arm (Fig 2.4). The pitman arm is attached with the track and tie rods, which aligns the wheels. This system can also be described as a parallelogram steering linkage system in which the linkages trace a parallelogram (Gilles, T. 2005).

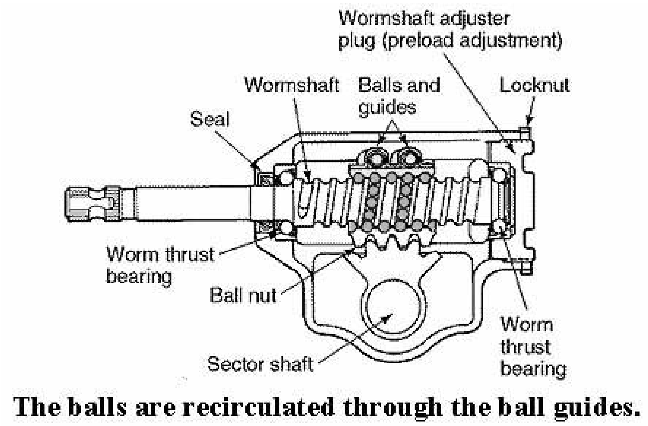

Figure 2.4: Recirculating ball bearing steering, picture from www.imperialclub.com/Repair/Steering/terms.htm

A Recirculating Ball Bearing can also be used in a similar setup to aRrack and Pinion gear system, where the recirculating ball bearing housing replaces the pinion gear with a sector gear that pushes/pulls the rack to align the wheels. The recirculating ball bearing system is significantly heavier than the rack and pinion system, due to the extra linkages, housing and gears. Friction needs to be managed in the design stage, i.e. including grease input points, dust covers etc. However the Recirculating ball bearing steering provides more sensitivity to the steering and minimum slack or 'loose feel' in the steering wheel. Costing is also increased due to the extra material and the complexity of design makes the recirculating ball bearing system less attractive.

2.3.3 Power Steering

Power steering systems are the same systems as rack and pinion and recirculating ball-bearing but with a significant modification. In a rack and pinion power steering system, the rack contains a cylinder with a piston inside it, driven by fluid supplied by a pump (see Figure 2.5). The fluid lines run to a rotary valve controlled by the steering shaft which determines the sides of the piston that the high pressure fluid acts on. This pressure assists the steering action which requires less force to rotate the steering wheel. Similar to the rack and pinion power steering, the recirculating ball housing is assisted by the pressure respectively in the ball-bearing steering (Gilles, T. 2005).

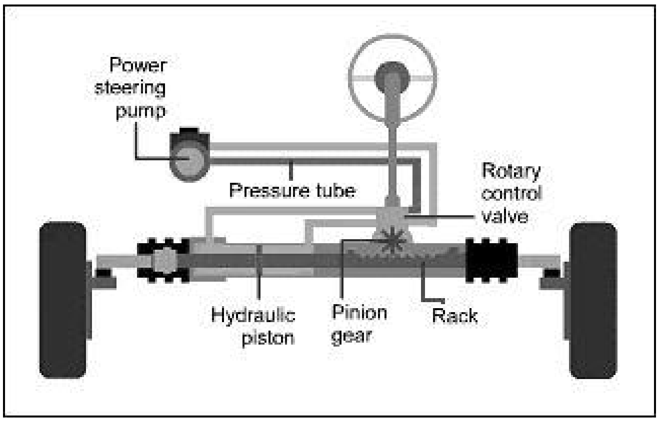

Figure 2.5: Rack and Pinion power steering, picture adapded from `www.cars.com/carsapp/boston/?srv=parser&act=display&tf=/advice/caradviser/steering_fluid.tmpl`

2.4 Suspension Systems

There are two common types of suspension systems used frequently today, dependant and independant systems. The various types of both are similar but have their differences and functions. Some of these sytems are described below.

2.4.1 Dependant Suspension Systems

Solid or Beam Axle

Panhard Rod

Watts Linkage

Dependant suspension systems are variations of a simple beam axle that holds the wheels parallel with each other. So when the vertical angle of one wheel (camber) changes, the opposite wheel also changes (Gilles, T. 2005). Examples of the Panhard Rod and the Watts Linkage are shown in Figures 2.6 and 2.7, these types of suspension are generally different ways of attatching the solid axle to the chassis.

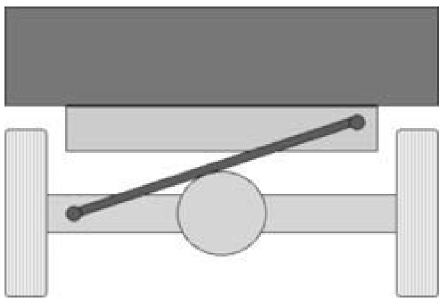

Figure 2.6: Panhard Rod suspension.

2.4.2 Independant Suspension Systems

Double Wishbone, A-Arm or Four-Bar link

MacPherson Strut

Multi-link

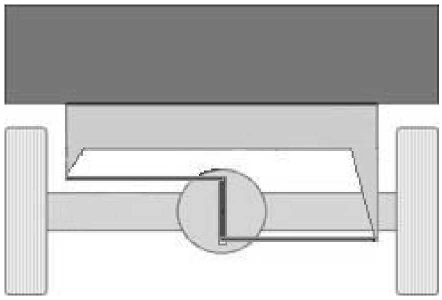

Figure 2.7: Watts linkage suspension.

Independent suspension systems allow the wheels to move independently of each other, e.g. if one wheel were to move up or down, the other would not be affected directly. It is common for racecars to have all four wheels with independent suspension as this usually provides the most customizable setup options to maximize the handling potential of the racecar.

Double wishbone suspension systems are also known as double A-Arm or Four-Bar link systems. They all comprise of equal or unequal parallel links from the chassis to the wheel hub, with the shock absorbers configured in a Push or Pull rod setup, as Figure 2.8 illustrates.

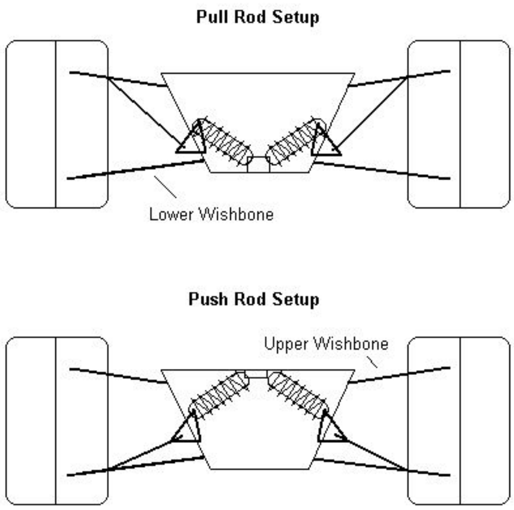

Figure 2.8: Unparallel and Unequal double wishbone suspension with Push or Pull rod shock absorber setup.

The MacPherson strut suspension system (Figure 2.9) is very popular with passenger cars and some sports models since it is a relatively cheap system to produce that provides reasonable camber control (Smith. C, 1978). The MacPherson strut suspension is good for everyday commuting but does not provide sufficient stiffness to avoid movement within the components (compliance or slack) and would not fit comfortably with wide tyres (Smith. C, 1978). Multi link suspension systems are simply Four-Bar link systems with one or more extra links to attain extra control.

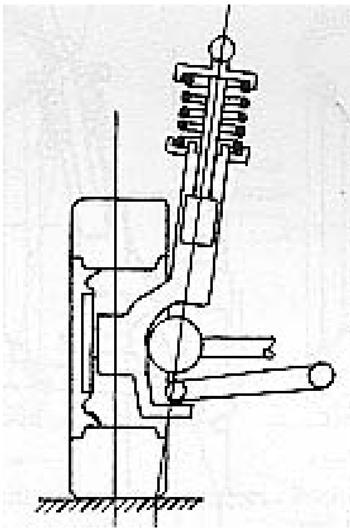

Figure 2.9: MacPherson strut suspension, from `www.autozine.org/technical_school/suspension/tech_suspension2.htm`

The objective of the independent suspension is to provide enough vertical wheel movement to absorb surface bumps and compensate for the accelerations of the sprung mass, prevent changes in the distance between tyres (static toe) as they are moving, control the change of wheel camber angle and change of track distance with the wheel and/or sprung mass movement, and to ultimately allow the most grip or traction available out of the tyres while minimising weight and maximising stiffness in the links (Smith, C. 1978).

2.5 Chapter Summary

Having discussed the cornering and handling ability in a Formula SAE-A racecar and what factors can influence the performance, helps to have an understanding of what is happening when a racecar traverses around a corner. With this in mind we can apply this knowledge into the design to maximise the cornering and handling ability of the racecar. Also selecting an appropriate steering and suspension system that will provide the best cornering and handling but also takes into account the motorsport teams' resources (time, materials and complexity of design).

Chapter 3

Rules and Regulations of the FSAE-A Competition

3.1 Chapter Overview

This chapter covers the rules and regulations that will affect the steering and suspension sytems. Starting with the more specific rules that affect the steering and suspension systems, then moving into the general rules and regulations like material strength. These rules and regulations have been put into the competition to give the entry teams maximum design flexibility and the freedom to express creativity, but also to ensure that a safe and working car that minimises chances of damage and injury.

3.2 Steering Requirements

The specific steering system rules and requirements are as follows:

The steering must affect at least two wheels

The steering system must have positive steering stops that prevent the steering linkages from locking up.

Free play is limited to 7 degrees measured at the steering wheel.

Steering must be mechanically connected to the wheels i.e. steer by wire prohibited

These requirements do not severely limit the steering system design at all as for most of the previously mentioned systems, none of which include steer by wire and all affect at least 2 wheels. The rules that need to be kept and monitored is the free play in the steering wheel and steering stops, otherwise the design is virtually open.

3.3 Suspension Requirements

The rules state that the car must have a fully operational suspension system with springs and shock absorbers, front and rear, with a minimum useable wheel travel of 50.8mm (2 inches), 25.4mm (1 inch) in jounce and rebound with the driver seated. So the rules again do not restrict the specific suspension system but merely sets a benchmark that it must perform to.

3.4 Other Requirements

Other requirements set out in the rules define that the wheelbase must be of at least 1525mm (60inches) and that the smaller track must be no less than 75% of the larger track. The minimum material must be; either round mild or alloy, steel tubing (min 0.1% carbon) with minimum dimensions as outlined in table 3.3.3.1 in the FSAE rules handbook; or an approved alternatice material that is tested and proved to meet the alternative material guidelines in section 3.3.3.2 of the FSAE rules handbook.

The wheelbase requirement affects the suspension geometry design, setting a minimum length for the suspension linkages.

3.5 Chapter Summary

Knowing and understanding the requirements and rules set out by the Formula SAE competition provides a starting point for our design, also talking with the previous team and the performance will help to identify areas needing improvement and investigaiton. Once finding sufficent information a start can be made to get the ball rolling on design and construction of the steering and suspension systems.

Chapter 4

WinGeo3 Suspension Geometry Program

4.1 Chapter Overview

This chapter introduces Wm. C Mitchell's suspension geometry software, *Racing by the Numbers* and shows its most useful power of calculation and display of steering and suspension geometry of any four wheel vehicle. The information it can tell us will greatly improve the time taken to analyse steering and suspension set-up and will allow fast optimisation when the time comes to testing.

4.2 WinGeo3 Geometry Program

The steering and suspension geometry can be modeled on Wm. C. Mitchells software which is quicker than manually measuring all the various important values repeatedly for the various settings you wish to try during testing. This enables a comparison with the originally intended design parameters of the 2005 racecar and an indication of how well the car will react while cornering. It also allows a comparison of the initial 2006 car's design and actual geometry after construction and allows us to optimise the geometry to provide the best cornering and handling ability of the racecar. By measuring the data and entering into Wm. C. Mitchell's software, we can critically analyse the racecar 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.

4.3 Set-up and initial measurements

I strongly recommend allowing at least half a day to measure up a car for the first time and someone to help. It will save alot of time that would otherwise be lost dropping things, re-setting the origins and other fiddly jobs that are not normally accounted for. Once installing the program, printing out some forms will make things much easier for entering information into the program once the measurements have been taken, as the forms sets out the required information neatly and in similar format to the program screen.

Open the geometry program and from the help menu open quick start. The help tree is on the left side column, from there open the Files menu and then Blank Forms, here is 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. Also click on Blank forms: Pull-rod / Push-rod form, Blank forms: Auxiliary points, and Blank forms: Swaybar form and print them all out. These all will be sufficient for the front suspension and rear (remember to print a second batch of forms for the rear) unless you have a control arm / panhard rod rearaxle suspension setup, for which there is a seperate form.

First you need to make sure that the car is set up already with the correct alignment and on a flat surface as it would on the racetrack. Ensure that access to the suspension points is possible and that they are locked in place so they do not move if you lean on the car (within reason). 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 centerlines of the car (front to back, side to side).

Once an Origin for each Axis has been made, where the X-Axis is the fore-aft longitudinal dimension (front to rear of the car). The Y-Axis is the lateral dimension, or left and right sides of the car (drivers 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 tire 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 center of the tire contact patch. The easiest way is to measure to the middle of the tire,but this can be misleading if the tire 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 (lenth 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.

Repeat the above process for the rear suspension.

This should provide sufficient data to enter into the geometry program. At this stage recording the required information of the anti-roll bar is useful, but is not essential for an initial entry into the program.

4.4 Entering information into the 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 (see Fig 4.1).

4.5 Analysing the Data

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

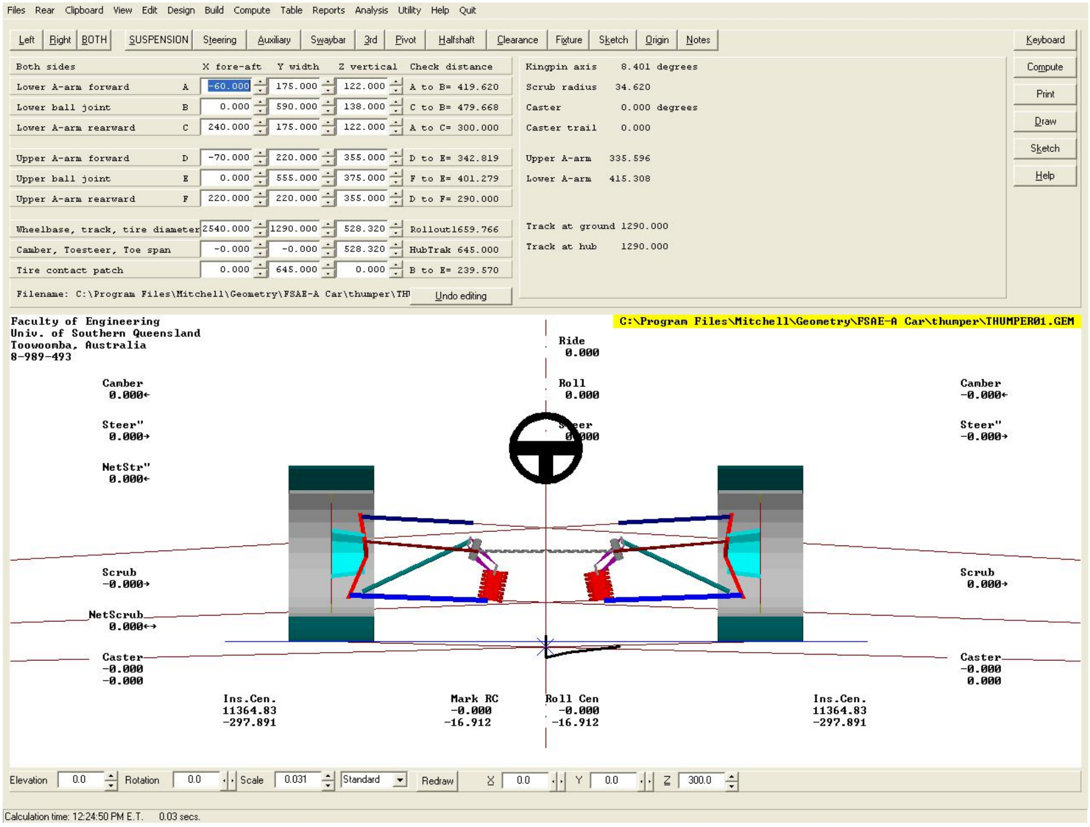

Figure 4.1: Entering the Geometry

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 parameters based on the geometry and describes the movement of the tire 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. As mentioned before, 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.

4.6 Forces and Loading the Path File

Right click on the main screen and go to the *Forces* tab and in the Z-Vertical box, enter the weight (or anticipated weight) of the car and make sure that both sides of the force side section is selected, and the Upright and the Truckarm 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 (see Fig 4.2).

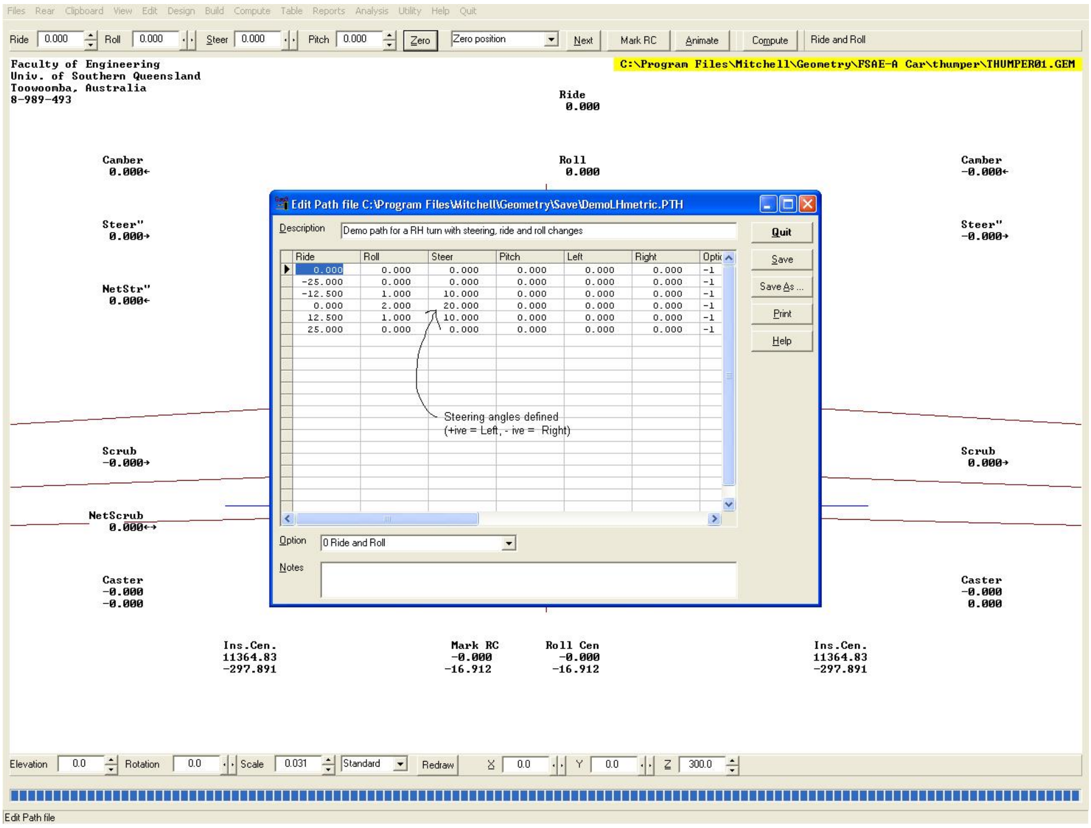

Figure 4.2: Editing the Path File

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 *Animate* 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.

4.7 Saving and Reporting the data

Once you have the path files operating satisfactory 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 (see Fig 4.3).

Run through the path file either by clicking on Animate and waiting for the cycle to complete, or by hitting 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 (CSA) 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 udertakes.

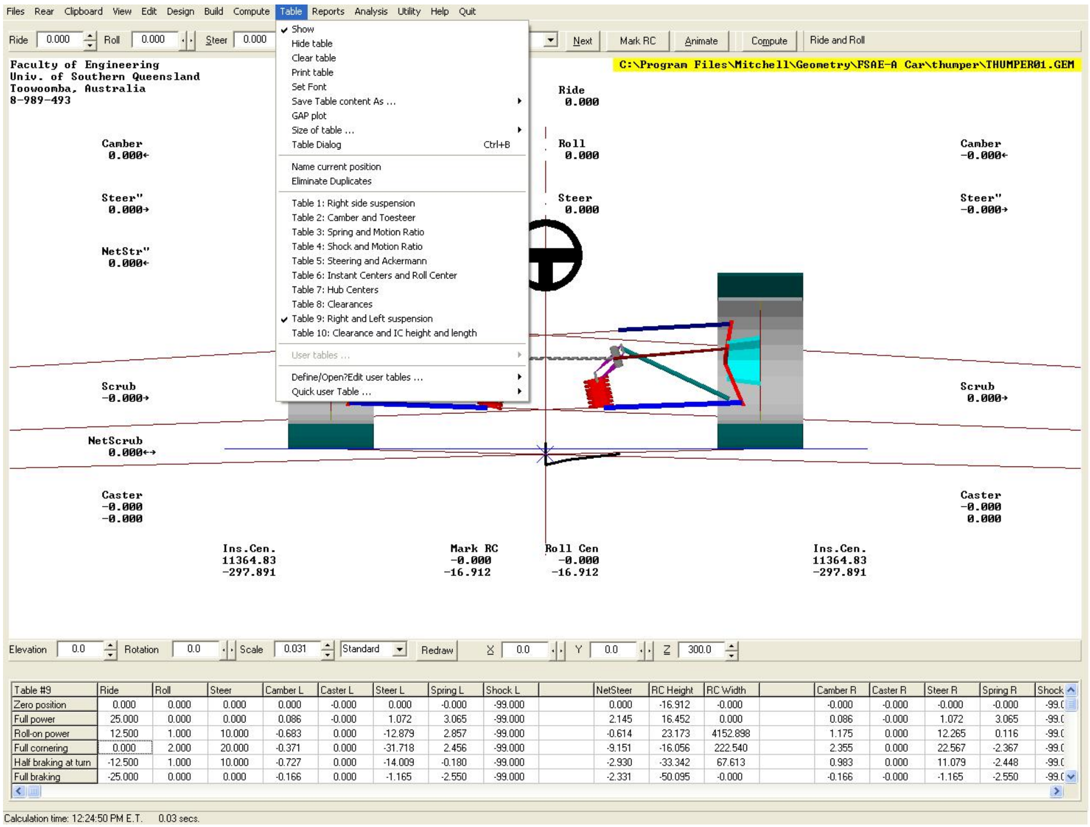

Figure 4.3: The Table Menu

4.8 Chapter Summary

The WinGeo3 suspension geometry program is able to compute and show much information based on measurements taken from the racecar. Information like, roll centres, instantaneous centres, ride and roll rates, scrub, roll centre location and numerous other figures are all computed in a very short time. This allows for quicker adjustments and comparisons during design and can be used to simulate a different setup that you may wish to try. Simulating the effect of a corner on the chassis and monitoring the effect it has on the steering and suspension is key to assessing the cornering and handling characteristics of the racecar.

Another powerful feature that the WinGeo suspension geometry program has that will be briefly mentioned, is its design and build funcitons of the suspension and steering points. The process outlined in the beginning of this chapter locates the steering and suspension points and calculates the Kingpin Inclination, Caster, etc. But if designing a new suspension system, you are able to start with a basic push/pull rod system and using the *Design* and *Build* menus, you may specify the Kingpin Inclination, Caster, Scrub radius, Instantaneous Centre locations etc, and the program will alter those points to suit. This will save much time and effort in design and can be quickly used to produce drawings into CAD software ready to put drawings into the workshop to be built.

Chapter 5

Analysis of the 2005 racecar

5.1 Chapter Overview

This chapter analyses the 2005 racecar both logically, speaking with last years team members for their opinions, and through the use of the WinGeo suspension geometry software to find any flaws and areas of improvement to implement into the 2006 racecar.

5.2 Problems with the 2005 Racecar

Speaking with the team members, problems with the 2005 racecar included:

Understeer - The 2005 racecar exhibited a large amount of understeer, while not undrivable, was still far from ideal steering performance.

Steering effort - The steering effort was immense, steering forces to drive the car was high where doing a number of laps would result in a huge effort and quickly produced driver fatigue.

Chassis Twist - When the steering wheel is turned, the reaction forces from the ground resistance twists the chassis at the steering mounts. This chassis twist adds to the chassis roll during cornering which would probably not been accounted for and resulted in extra camber gain.

Location hazard - The location of the steering box was up off the base of the chassis, forward of the knees at normal driver seatimg position. During a frontal collision there could be a possibility of the steering box would collide with the upper shin's and/or knees of the driver.

5.3 Analysing 2005 car using WinGeo

Using the process outlined in chapter 4, some interesting values were found that were consistent with the performance of the car. Upon initially entering the measurements the following values were found (see appendix b):

Steering Axis Inclination / Kingpin angle - Was found to be 8.4 degrees, which is a lot in general and probably was not intended with the design.

Scrub Radius - The static scrub radius is 34.62mm which is much higher than the anticipated 20mm in the design.

Caster - Zero caster recorded/calculated.

The high Steering Axis inclination is the cause of the higher than anticipated scrub radius which is consistent with the high steering effort. Having a zero caster value does not indicate bad performance but shows that there was no consideration of the effects of caster or that perhaps during the construction, some 'workshop engineering' was required to make things fit, resulting in zero caster.

Using the Fundamental Analysis on the 2005 racecar revealed the location of the Instantaneous centres, roll centres and the ride and roll camber change rates.

The location of the instantaneous centres were 10715.927mm or 10.7m out and 300mm off the ground, to the opposide side of each wheel (i.e. right wheel IC is (10.7,+0.3)m on the left side of car). Wide instantaneous centres are good as it keeps the rate of camber change low during roll.

The roll centre is located 16.9mm below the ground in the vehicle centreline, this eliminates Jacking forces while having a low roll moment which affects the roll resistance of the chassis. The closer to the ground level means the closer the roll centre is to the CG, this reduces the roll moment and reduces the roll resistancce of the chassis.

The roll and ride camber change rates were 0.943 degrees per degree in roll, and 0.005 degrees per mm. To put into perspective, for a 1 inch increase in ride height changes the camber of the wheels by 0.127 degrees, this is desirable as the change in camber is very small. For a 1.5 degree change in roll however, the camber of the wheels will increase by 1.41 degrees, this could be improved.

5.3.1 Cornering using the Path Files

Using the process outlined in chapter 4, the changes in camber and location of the roll centre is very clear and shows how instability could arise. In Appendix B.1.2 you can see the way that the roll centre moves a lot and in one particular position (Roll on power) is not seen on the screen. It is located approximately 4m from the centreline of the car, this is excessive unless it is an error in the program but continuous running of the path and checking the geometry, this "random point" does not change.

The movement of the roll centre indicates a susceptability to roll during cornering, which means that the tyres are more likely to go into positive camber. Depending on the amount of positive camber, the tyres are more likely to break traction the further into positive camber due to a smaller contact patch being maintained on the ground. Analysis into how much camber change during the right hand cornering path is shown in Appendix B.1.3.

From the results you can see during maximum cornering the right hand (outside loaded) tyre is at just over +3 degrees caster. Which is a significant amount and if the racecar is travelling at a reasonably high speed, the tyre would most likely break traction, causing the car to lose control at the apex of a corner. However the analysis did not include static camber that would have been set up during the competition and would reduce the amount of positive camber at this point, thus reducing the risk of losing control.

5.4 Chapter Summary

There are a number of improvements that can be implemented or learnt from the 2005 racecar with respect to the steering and suspention system. Understeer, Steering effort and the location and mounting of the steering box are the main improvements. How these improvements are implemented into the 2006 car will be discussed in chapter 6. The other aspects of the steering an suspension performed well and was a good improvement from the 2004 car. Improvement into the movement of the roll centre and camber change during cornering will further improve the suspension system and overall cornering and handling ability.

Chapter 6

Steering and Suspension for the 2006 Car

6.1 Chapter Overview

This chapter discusses the implementation of improvements from the analysis of the 2005 car and the individual steering and suspension designs.

6.2 Implementing improvements

The improvements that can be made as result of analysis to 2005 car were understeer, Steering effort, the location and mounting of the steering box, and reducing the roll centre movement. To improve understeer an increase in the ackerman steering geometry and a faster steering box will see better response from the racecar.

Reducing the steering effort will include a suspension and upright setup that has less steering axis inclination and scrub radius, the Fundamental Analysis of the 2006 geometry with respect to these values are shown in Appendix B.2.

The location of the steering box will be on the base of the chassis or floor of the racecar, this will remove the hazard to the drivers legs and remove the need for rocker arms that create extra weight. The steering box will also be located forward of the front wheel centreline axis which is incorporated into increasing the ackerman steering geometry.

6.3 Steering system

The steering system will be a basic rack and pinion setup, power steering was briefly investigated and found that even though it would be more comfortable to the driver in the endurance dynamic test. The design team decided that it would not outweigh the increased weight and power reduction from the motor. The steering system will incorporate increased ackerman steering geometry and is based on the floor of the car. Positioning the steering box forward of the front wheel centre axis also induces 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).

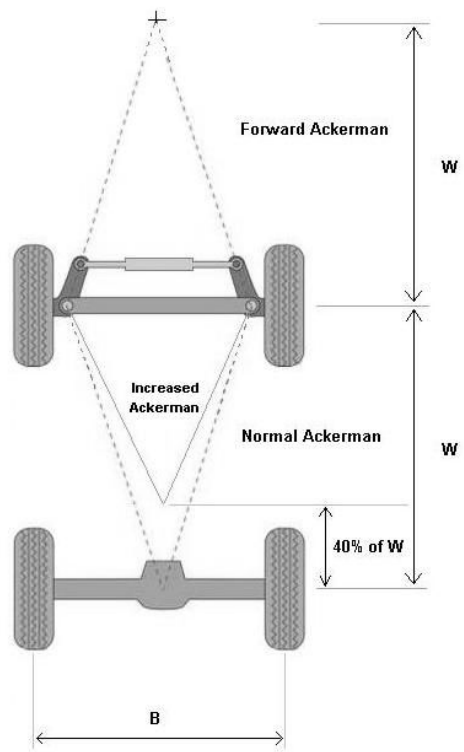

Figure 6.1: Increased Ackerman

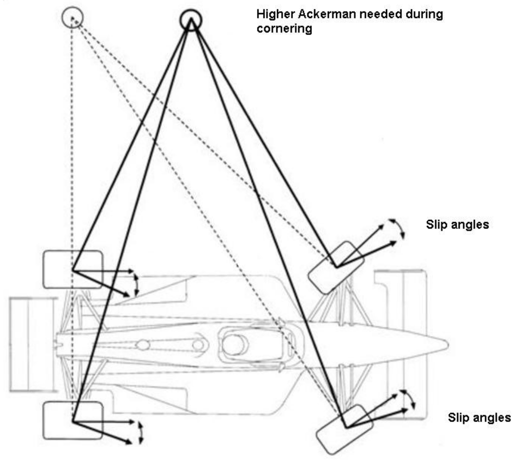

Figure 6.2: Cornering develops slip angles which change the ackerman location

Parts for the steering box have already been sourced by Bruce Llwewllyn, the steering rack and a pinion gear that meshes with it. The pinion gear has a movement ratio of 52mm of travel per turn and is much greater than the 43mm per turn of the 2005 steering rack. Due to time constraints, the team leader Bart Smith has already undertaken the design and construction of the steering box and is completed ready to be mounted onto the chassis.

6.4 Suspension system

The suspension system is fully independant using unequal, non-parallel double wishbone links, very similar to the 2005 racecar's setup. The front suspension will have a pull rod spring and shock absorber configuration, 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 the motion ratio and wheel rates that are incorporated into the rocker or bell-crank design. The Suspension components are displayed in Appendix C.

The 2005 racecar suspension geometry proved very sucessful and similar geometry will be employed but taking into consideration the changed wheelbase and track width dimensions. The wheelbase this year has been set at 1650mm and the track 1200mm at the front. Jared Armstead has undertaken the chassis design this year and incorporated last year's mounting points into the chassis while Scott Coombes has constructed the wheel uprights and the wishbones and suspension arms.

The front suspension wishbones consists of two members, with a boss that has a threaded hole to match the sperical rod ends welded at each end. The sperical rod ends have been supplied by Linear Bearings Pty Ltd. The upper wishbones needed an extra join to be welded to the upright end to connect the pull rod to the spring/shock absorber assembly. The same design for the rear suspension except the rear has 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 linnks to the chassis has also been redone, previously on the 2005 car, flat plate was simply welded onto the chassis where it was needed. The new method included carefully placed crush tubes that will allow shims or spacers between the chassis and suspension mounting points. These mounting points are lower in weight and they have greater adjustability.

The spring and shock absorbers are shop-bought that have both rebound and bump adjustability, 450lbs/in springs and are all brand new.

6.5 Analysing 2006 Geometry using WinGeo

Analysis by WinGeo onto the suspension points found in the ProEngineer design folders, came up with the following (see Appendix B.2):

- Steering axis inclination / Kingpin angle is 2 degrees
- Scrub Radius reduced to -4.7mm
- Caster angle +2.98 degrees

Using the Fundamental Analysis on the 2006 racecar revealed the location of the Instantaneous centres, roll centres and the ride and roll camber change rates etc. The instantaneous centres are located 3245.409mm or 3.2m out and 471mm off the ground. These are shorter than the 2005 car, but are still wide enough to limit the roll camber change.

The caster angle will need to be adjusted to a negative value between 1-2 degrees, hopefully without affecting much other geometry. This is to assist the steering returning to centre during cornering to keep consistent with the improved steering effort.

The roll centre is located 106mm below the ground in the vehicle centreline, which is alot further than the 2005 car. This also eliminates 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 (reflected in the reduction of roll camber change rate).

The roll and ride camber change rates are 0.777 degrees per degree in roll, and 0.021 degrees per mm, a reduction in the roll camber change while increasing the ride camber change by a small amount. Overall this is an improvement since the amount of roll camber change is greater or more significant than the ride camber change rate.

6.5.1 Cornering using the Path Files

Analysing left and right cornering using WinGeo's path files shown in Appendix B.2.2, the small 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 and will be less likely to go into positive camber, reducing the cornering and handling ability. Further analysis into the actual camber changes during a right hand corner (Appendix B.2.3) shows that the maximum camber is just under +2 degrees, which is an improvement to the 2005 car.

6.6 Chapter Summary

This year's design is intended to be better than the 2005 racecar, with the increased ackerman steering geometry, faster steering rack, adjusted Steering axis inclination and scrub radius we have eliminated or improved the understeer and steering effort required to drive. This will increase the cornering and handling ability and overall performance of the racecar. The reduced movement in the roll centre and reduced amount of camber change during cornering also shows the improved cornering and handling ability.

Chapter 7

Testing and Optimising the 2006 Car

7.1 Chapter Overview

This chapter discusses testing methods and optimising procedures to ensure that the 2006 racecar 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 and camber settings.

7.2 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 bituman 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 costant radius turn.

7.2.1 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.
- Settings adjustment tools.
- Laptop with WinGeo software and data acquisition memory downloader.
- Any other associated items required for transporting the racecar and using the venue.

The circular skid pan is 15.25 m in diameter, so 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 (or as best you can) and start laying witches hats every 3 paces 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 witches hats to create an entry/exit gate. This set up is exactly the same setup that will be at the competition, this will also give the driver(s) an opportunity to familiarise with the 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 benchmark 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 benchmarked speed, the driver should complete 2 laps and then exit. This is the competition test method and should be done for consecutive tests.

7.2.2 Data Collection

A method for collecting data should also be considered, so that there is some hard data to show the performance of the racecar. Data acquisition should be done using accelerometers placed strategically on the racecar 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 rate 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 or other suitable sofware, plotting the lateral and logitudinal accelerations versus the time and/or speed of the car will give a rough indication of the cornering and handling ability of the racecar. Repeating the process for the reverse direction should be done to ensure similar performance.

7.3 Optimising procedures

Optimisation of the steering and suspension setup will involve having 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, then reassembling. Using the WinGeo software here is highly recommended, as you may want to try a few different setup's but only need 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, measuring up all the points as per chapter four 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 whichever test track and see how it performs, ask the driver how it felt under acceleration and braking around corners. Any feedback here is important, particularly with the way it enters and exits the corners. If they mention it seems slow to exit or is understeering, go and check the camber and toe settings, SAI or kingpin angles and decide how much you would like to change things (0.5 - 1 degree steps are a reasonable start). However care must be taken to remember that the rules and regulations to pass scruitineering at the competition may prevent certain settings. For example, the competitiion requires that all Suspension and Steering bolts be Positive locked, this requires at least 2 turns of the thread visible on bolts with Nyloc Nuts.

Take notice of the tyres and the wear pattern, 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.

7.4 Chapter Summary

Using these methods, it is possible to change an average handling racecar to a competition winning machine. The difference between formula one and the weekend racers, is the tuning teams.

By combining the sections of this chapter, testing using skidpan and the optimising procedures, should allow a faster cornering and handling capacity than when first began. After testing on the skidpan for the first time and adjusting the settings to your specifications, the racecar should be taken back to the skidpan and driven faster than previously. This should continue until no further adjustments can be made and/or the car is unable to handle the faster speed.

Chapter 8

Conclusions and Further Work

This project has been both challenging and rewarding, initially knowing little about steering and suspension systems of vehicles and have learnt so much. Working within a design team is almost invaluable, normally a student would not have this experience until after university, but being exposed to this working environment can be just as much a learning experience than 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, the components were made by the other team members. Having understood what has been done and the main objective now is to ensure a great steering and suspension setup for the competition. The most obvious conclusion will be when the car is completed construction and is ready to run and have the opportunity to optimise the setup.

The improvements to the problems from last year's car will greatly improve the cornering and handling of the racecar, mainly through the reduction of understeer, reduction of weight in the steering components and provide the opportunity to optimise the steering and suspention setup.

8.1 Further Work

The benefits of an anti roll bars in suspension design should be invesigated with regard to the improvement of the cornering and handling ability of the racecar. Including the possibility of an adjustable anti roll bar for the driver to obtain better handling and cornering around different sized corners.

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Appendix A

Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG4111/2 Research Project
Project Specification

FOR: **Barry Richard Freeman**

TOPIC: Steering System and Suspension Design for a Formula SAE-A Racer

SUPERVISOR: Mr. Chris Snook

ENROLMENT: ENG4111 – S1, X, 2006;
ENG4112 – S2, X, 2006

PROJECT AIM: To work with a project team to design, build and optimize the running of a Formula SAE-A racecar, with particular interest in the Steering and Suspension systems.

SPONSORED BY: The Faculty of Engineering and Surveying, USQ

PROGRAMME: **Issue A, 27th March, 2006**

1. Research information on various steering and suspension systems and identify critical or important areas relevant to an FSAE-A racecar.

2. Critically analyze the steering and suspension geometry and setup with respect to handling and performance of the USQ 2005 FSAE-A racecar.

3. Select suitable systems to integrate with the project team for use in the 2006 car.

4. Design appropriate steering and suspension systems for the 2006 FSAE-A racecar.

5. Liaise with Faculty technical staff and other team members in the construction of the 2006 FSAE-A racecar and integration of the steering and suspension systems;

If time and resources permit:

6. Analyse and optimize the setup of the steering and suspension systems for 2006 racecar during testing.

7. Critically examine steering and suspension systems of the 2006 car with respect to performance.

AGREED: __________________ (student) __________________ (supervisor)

DATE: ___ / ___ / ______

Appendix B

WinGeo Software Results

B.1 2005 WinGeo Analysis

Here is information outputted from WinGeo suspension geometry program, it shows the values of Steering Axis Inclination or Kingpin angle, Scrub radius and Caster as indicated.

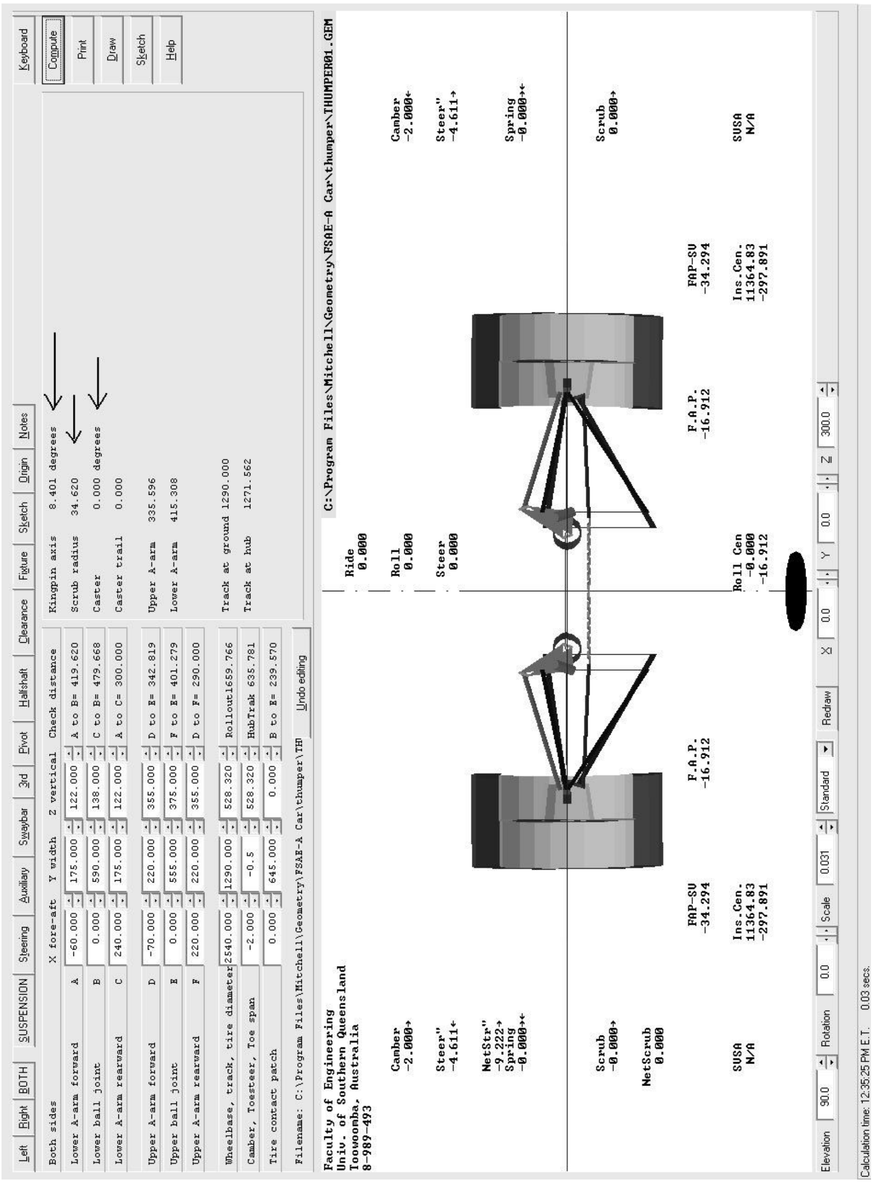

Figure B.1: Result of Analysis of the 2005 racecar

B.1.1 2005 Car Fundamental Analysis

Fundamental Analysis:

This analysis of instantaneous parameters is based on the instant center. This describes the movement of the tire over small displacements.

Right side: The Instant Center is at -10715.927 horizontal and -297.891 vertical. The distance from the IC to the contact point is 11364.832

The instantaneous Ride camber is 0.005 Roll camber is 0.943 Ride scrub is 0.026 Calculated derivative Ride Camber 0.005 vs. 0.005 length of IC arm is 11491.218 vs. 11364.832 Calculated derivative Ride Scrub 0.026 vs. 0.026 height of Ins.Cen is -304.505 vs. -297.891 Instant Center is at -10842.183 and -304.505

Left side: The Instant Center is at 10715.927 horizontal and -297.891 vertical. The distance from the IC to the contact point is 11364.832

The instantaneous Ride camber is 0.005 Roll camber is 0.943 Ride scrub is 0.026 Calculated derivative Ride Camber 0.005 vs. 0.005 length of IC arm is 11491.218 vs. 11364.832 Calculated derivative Ride Scrub 0.026 vs. 0.026 height of Tns.Cen is -304.505 vs. -297.891 Instant Center is at 10842.182 and -304.505

The instantaneous Net scrub is 0.052

Calculated Roll Center is at 0.000 and -17.098

B.1.2 Analysing Left and right Cornering using the Path File

The following show the 5 points during a Left hand Corner and highlited location of the Roll Centre:

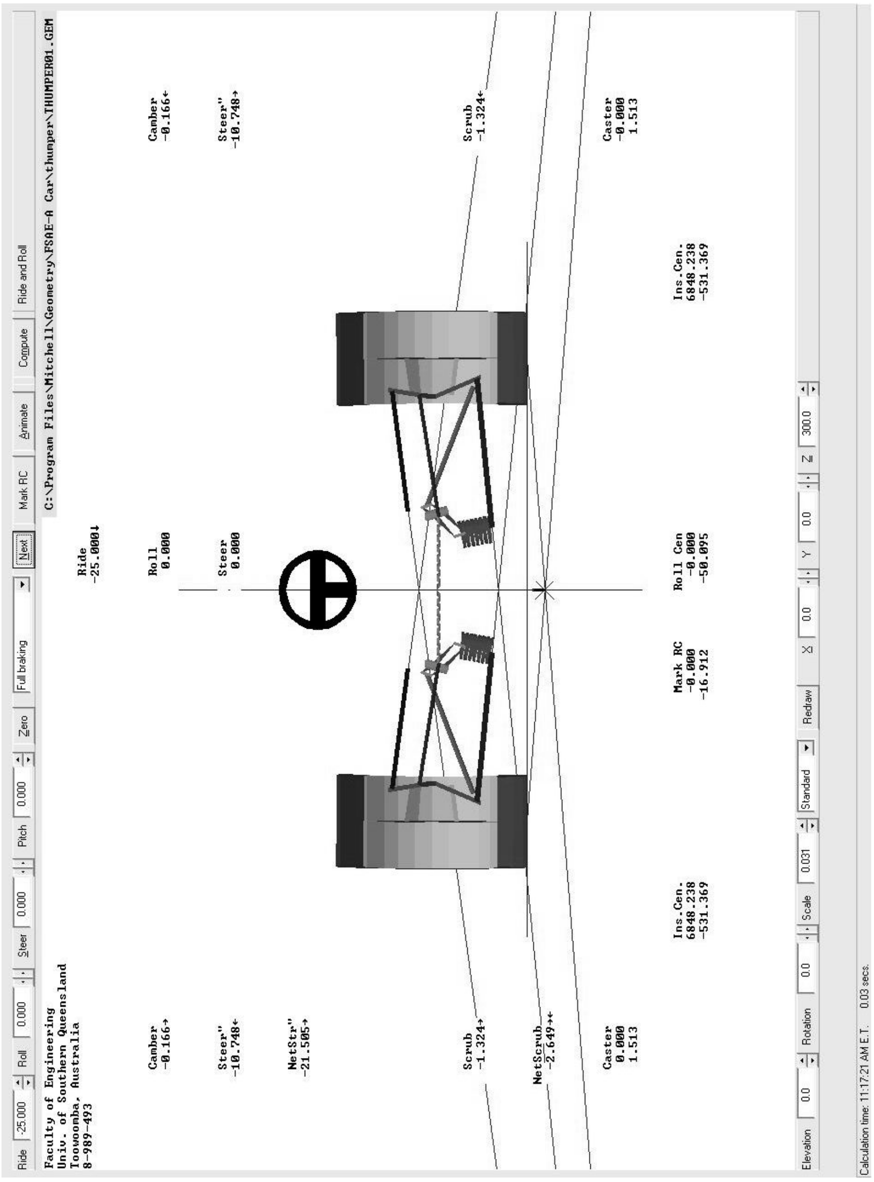

Figure B.2: Entering LH turn - Full Braking

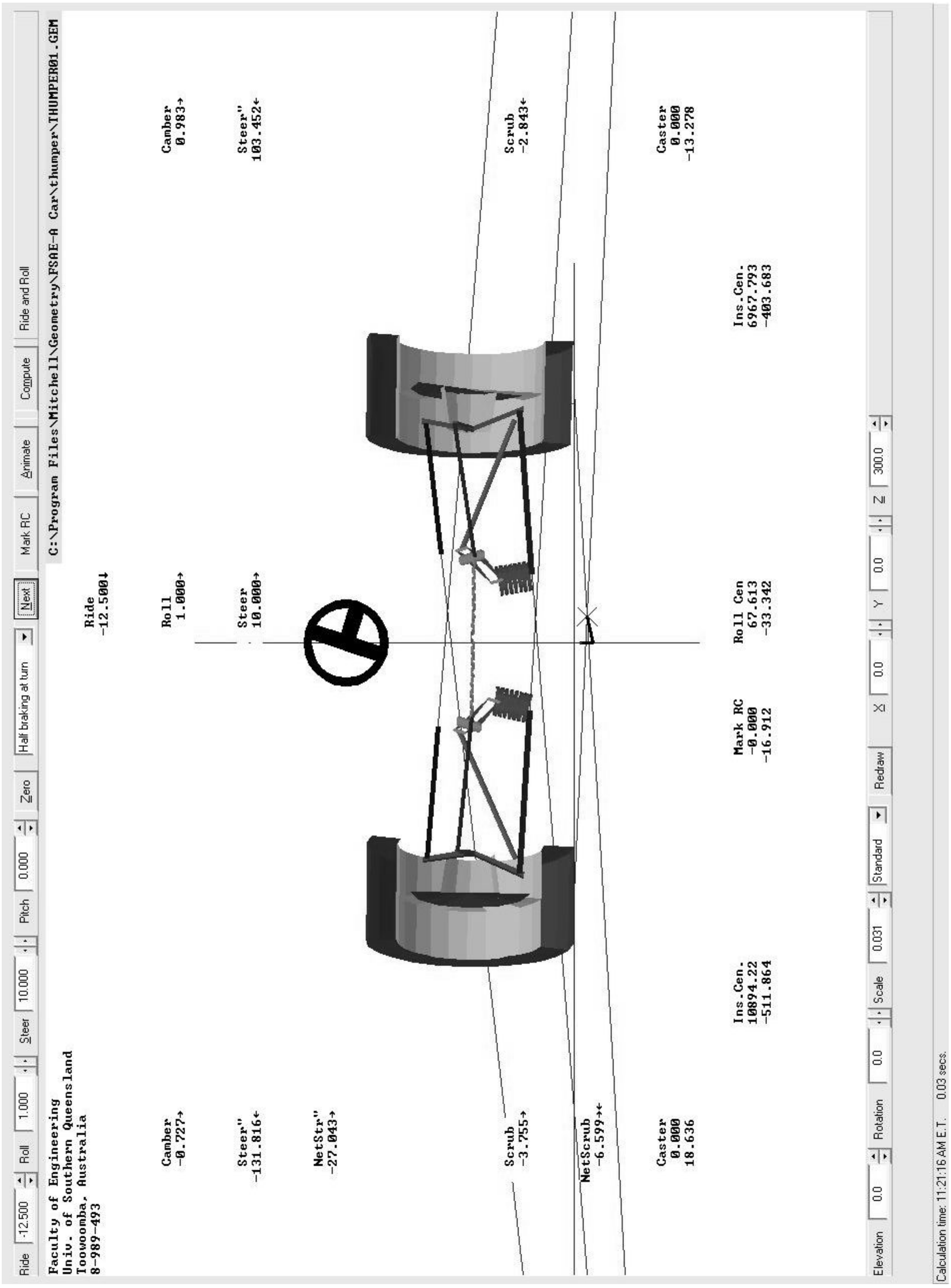

Figure B.3: LH turn - Half Braking

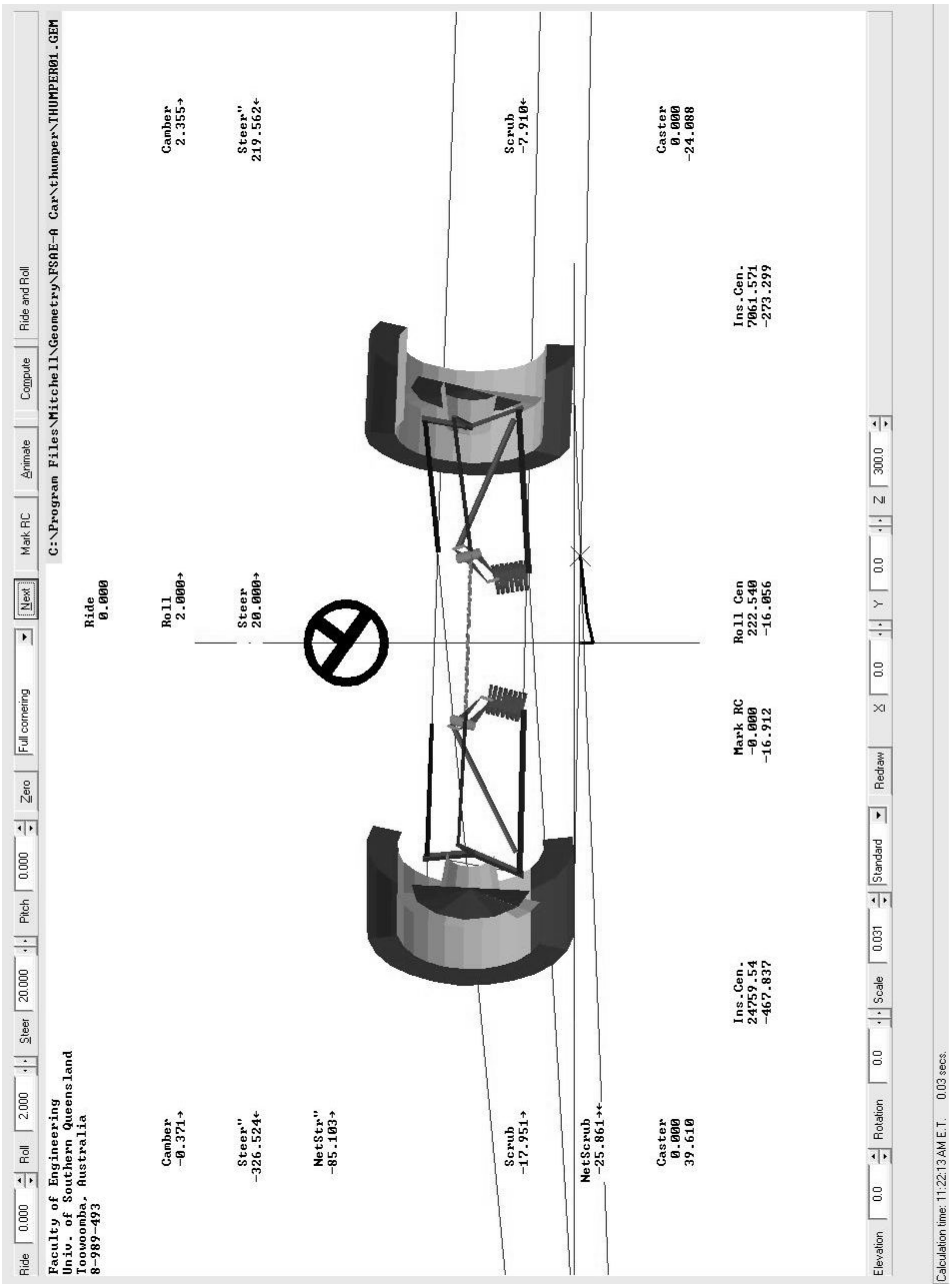

Figure B.4: LH turn - Full Cornering

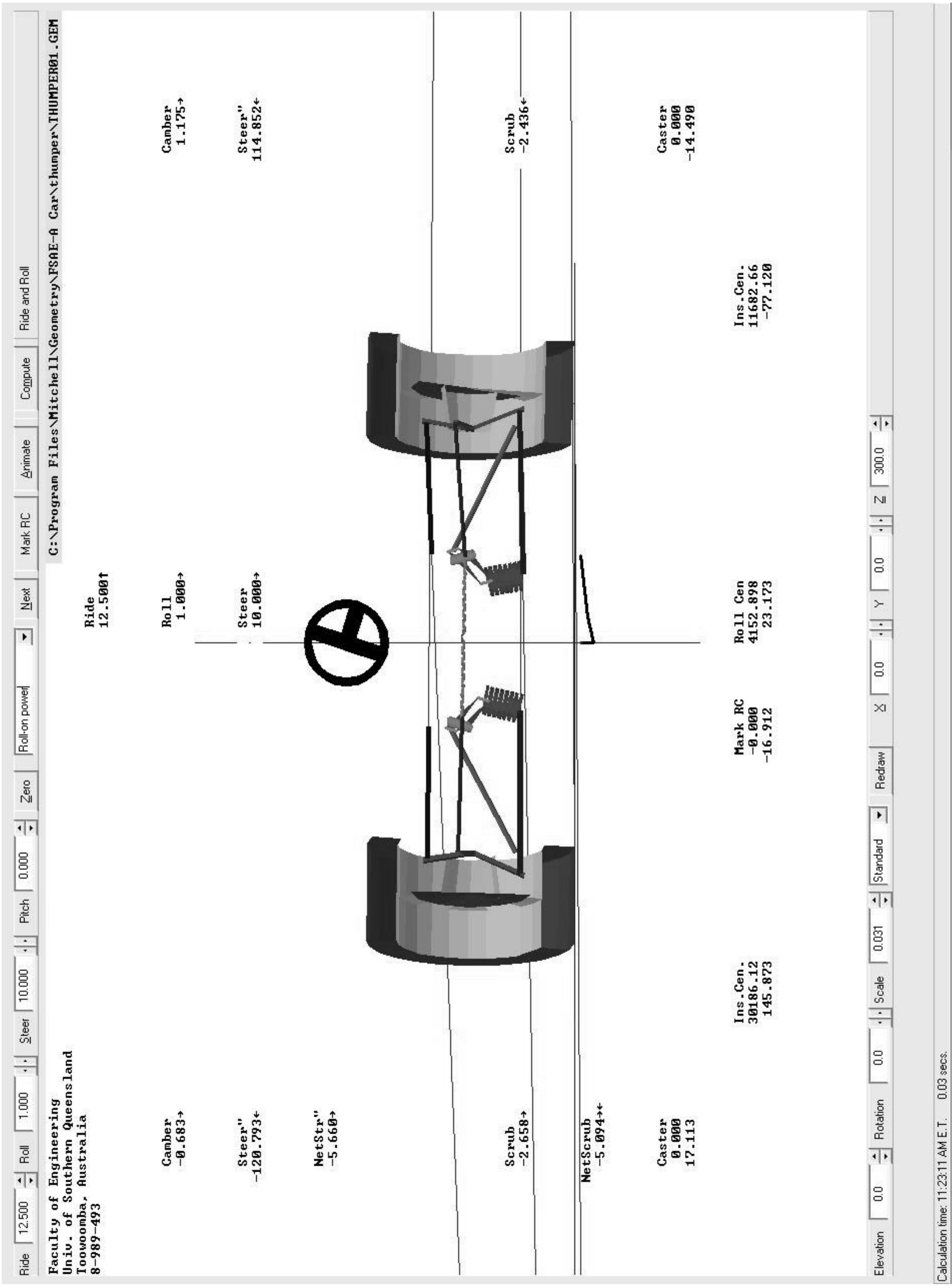

Figure B.5: Exiting LH turn - Roll on Power

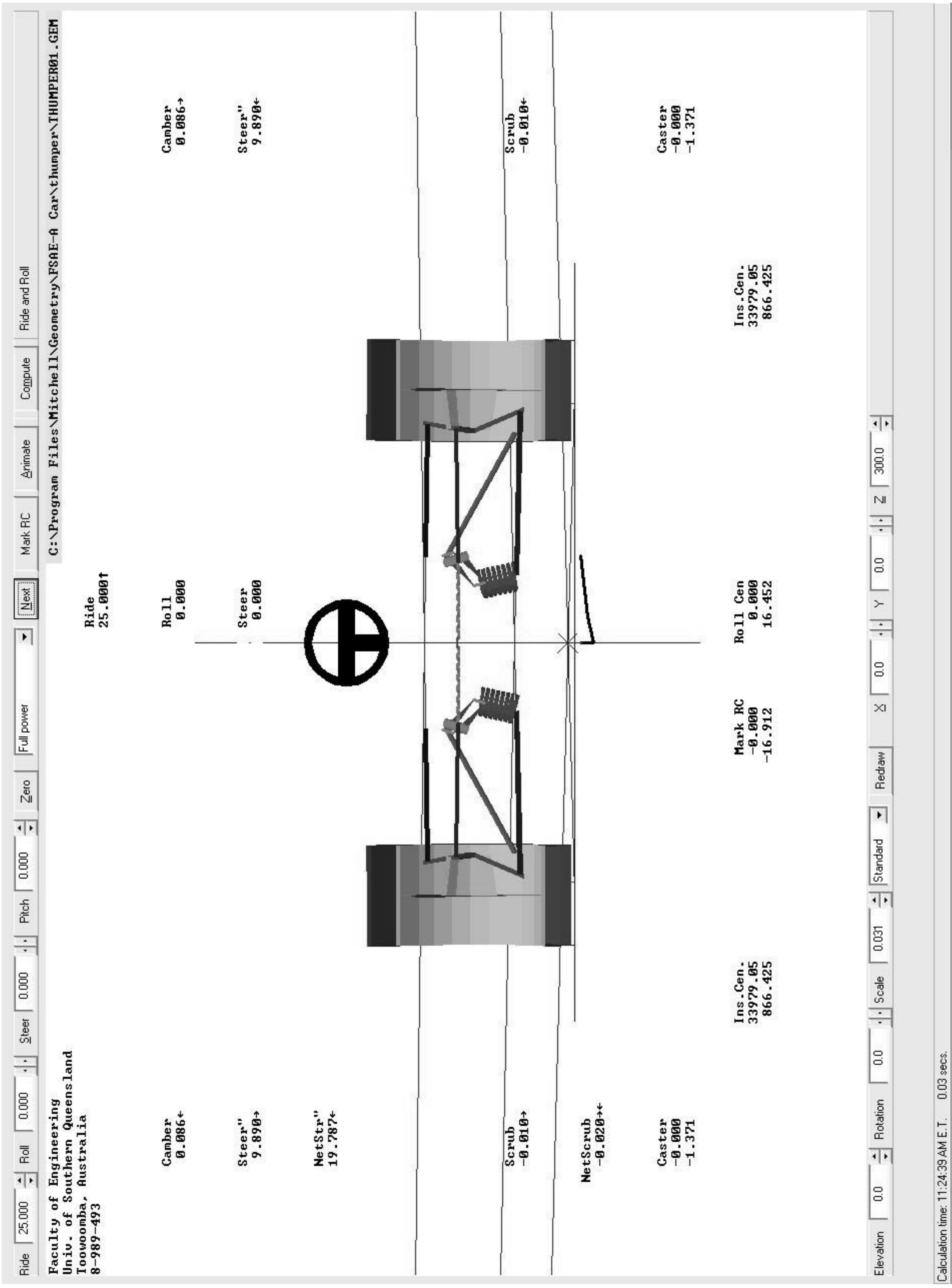

Figure B.6: Exiting LH turn - Full Power

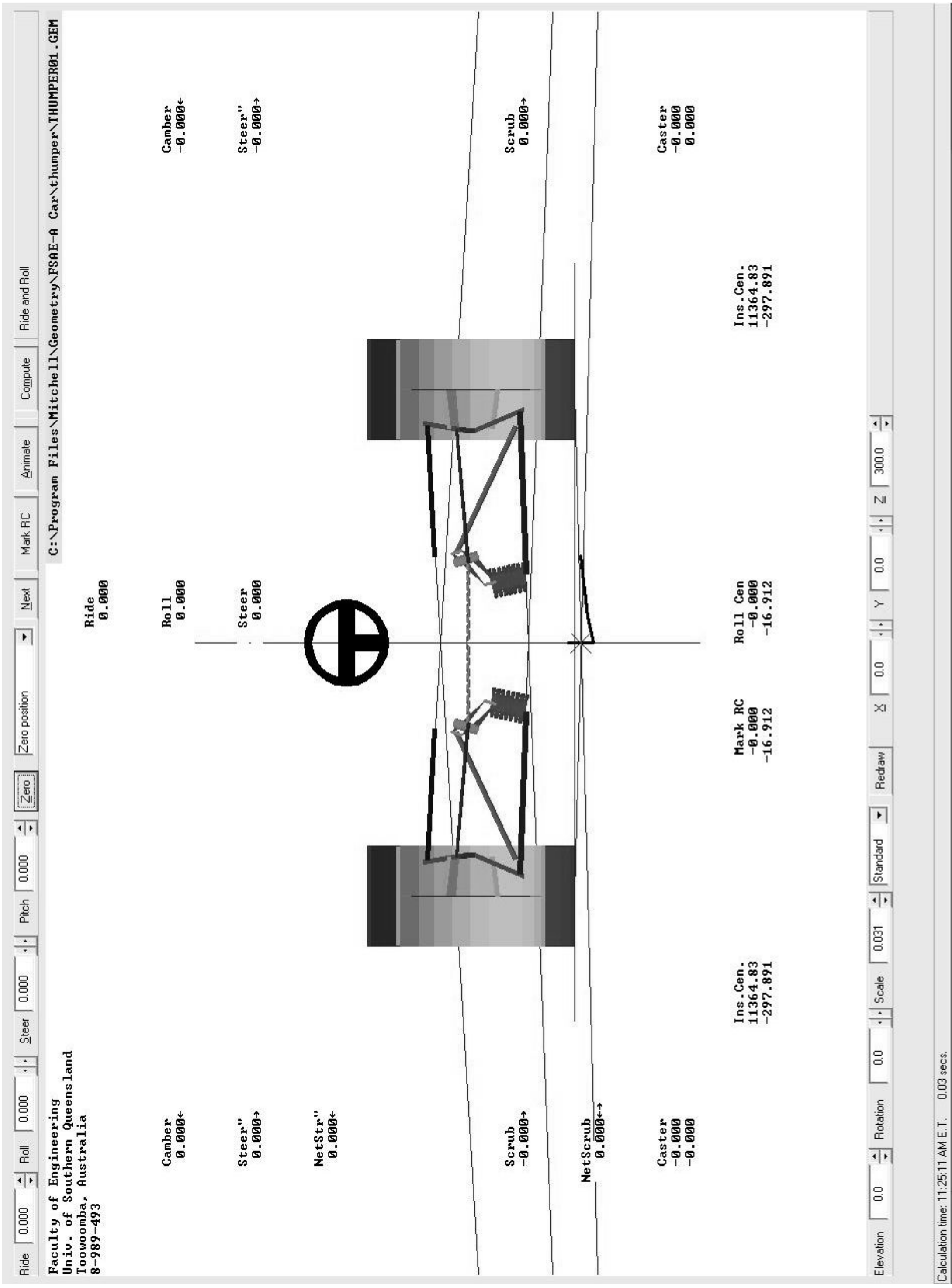

Figure B.7: Zero Position

The following show the 5 points during a Right hand corner and highlighted location of the Roll Centre:

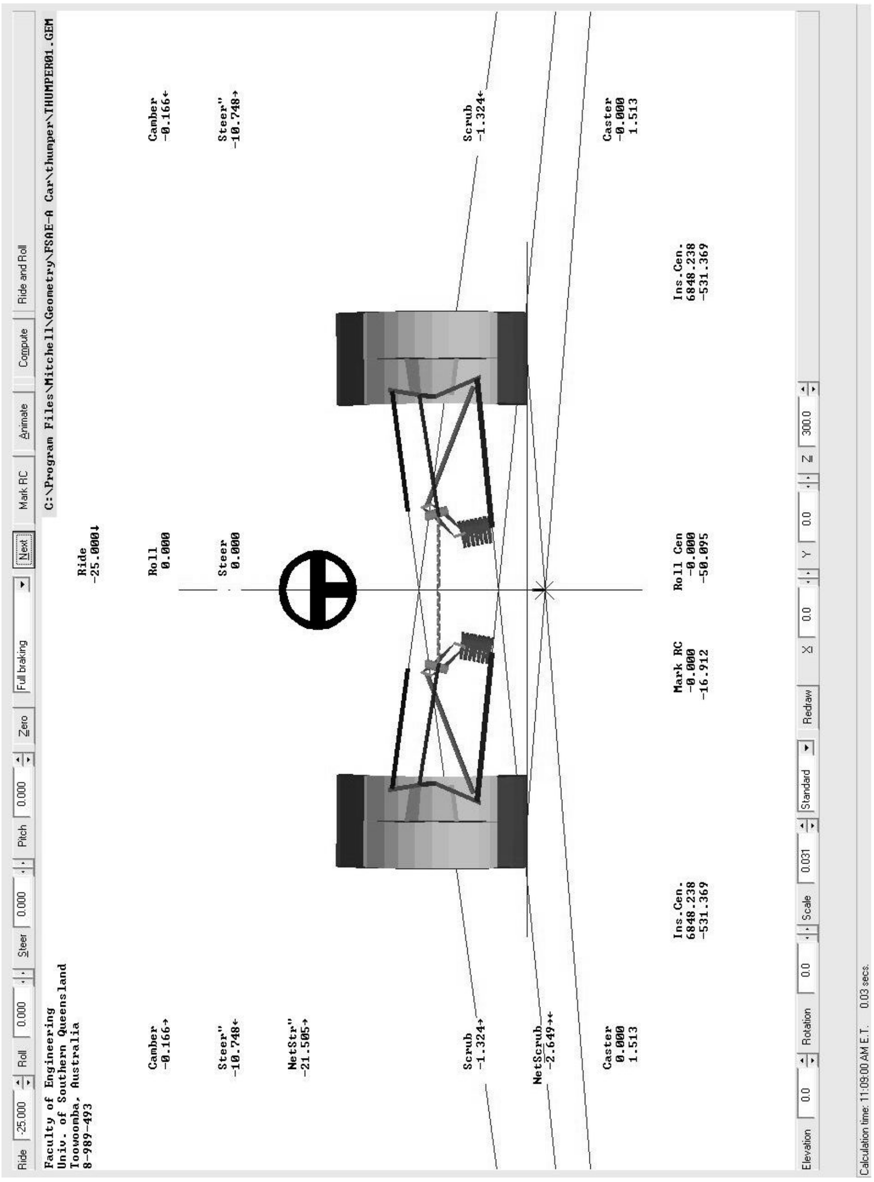

Figure B.8: Entering RH turn - Full Braking

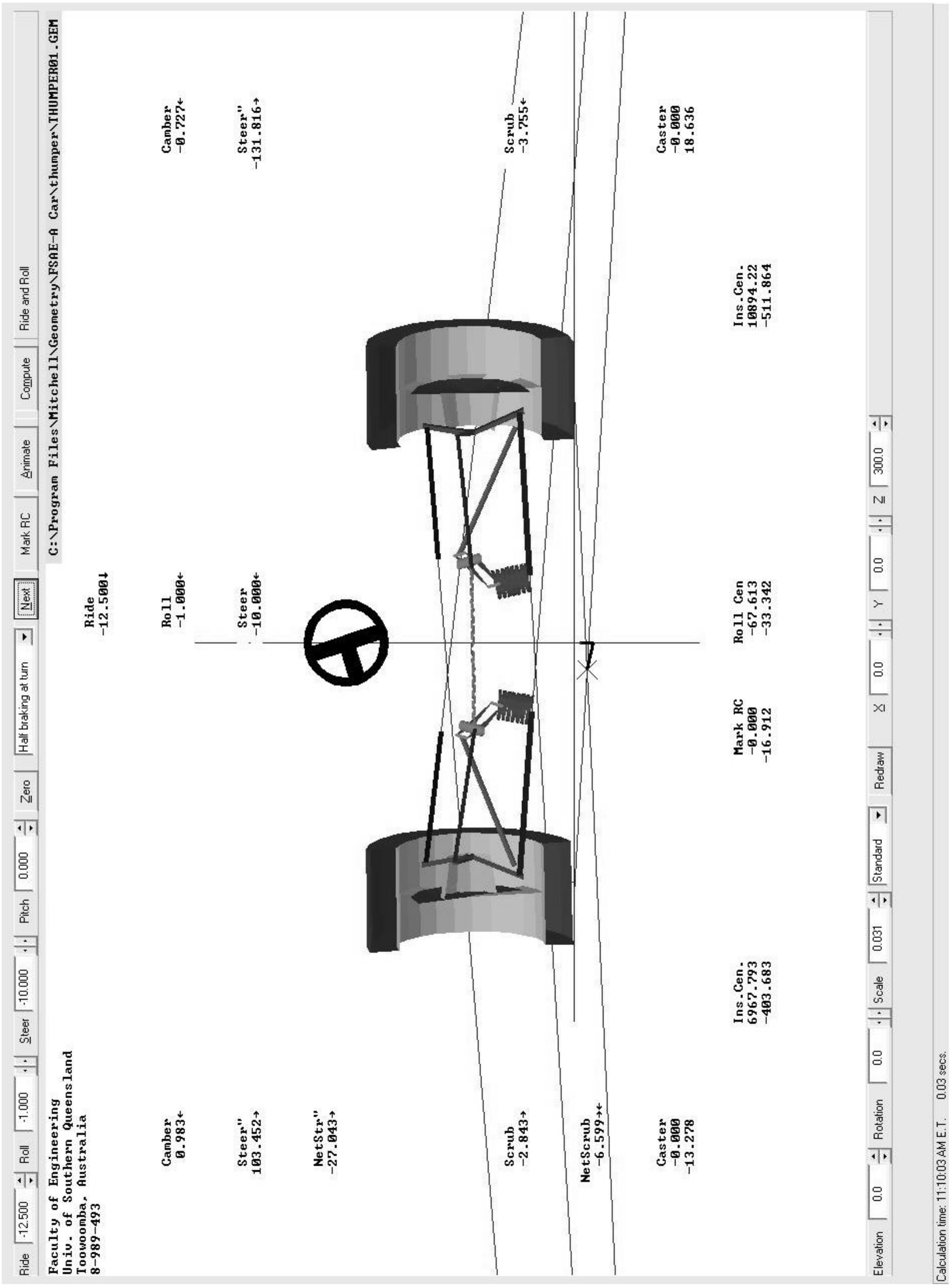

Figure B.9: RH turn - Half Braking

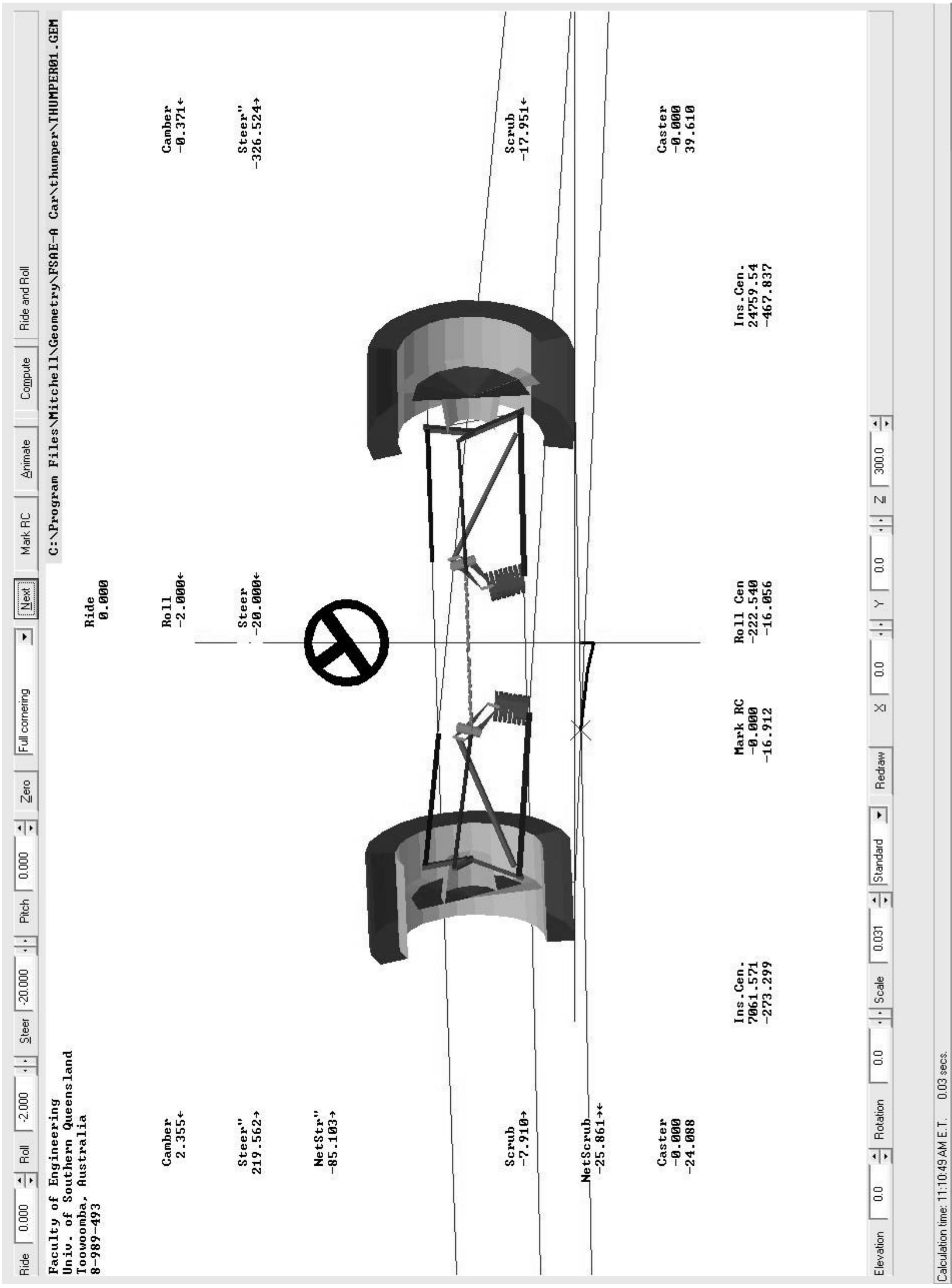

Figure B.10: RH turn - Full Cornering

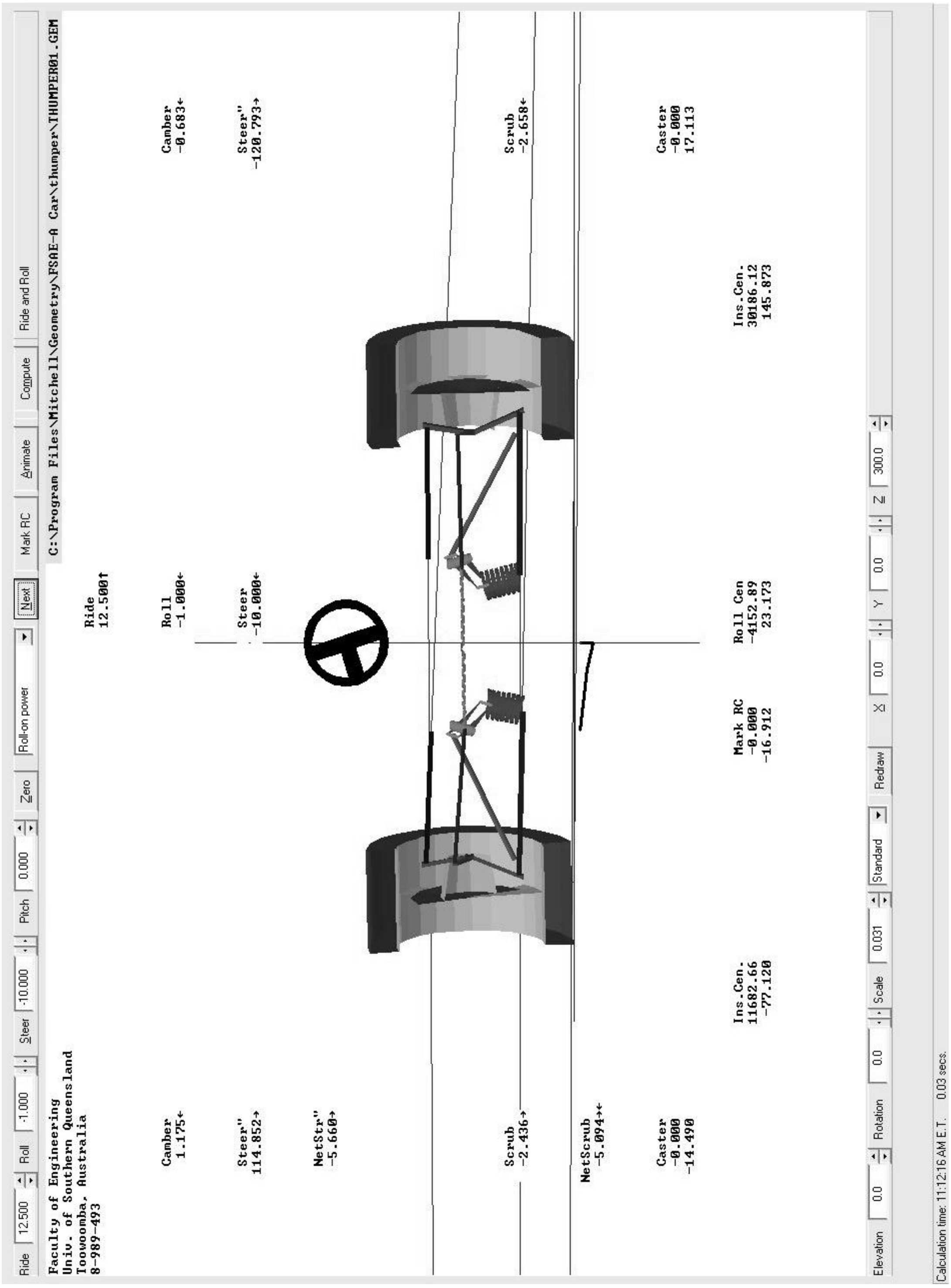

Figure B.11: Exiting RH turn - Roll on Power

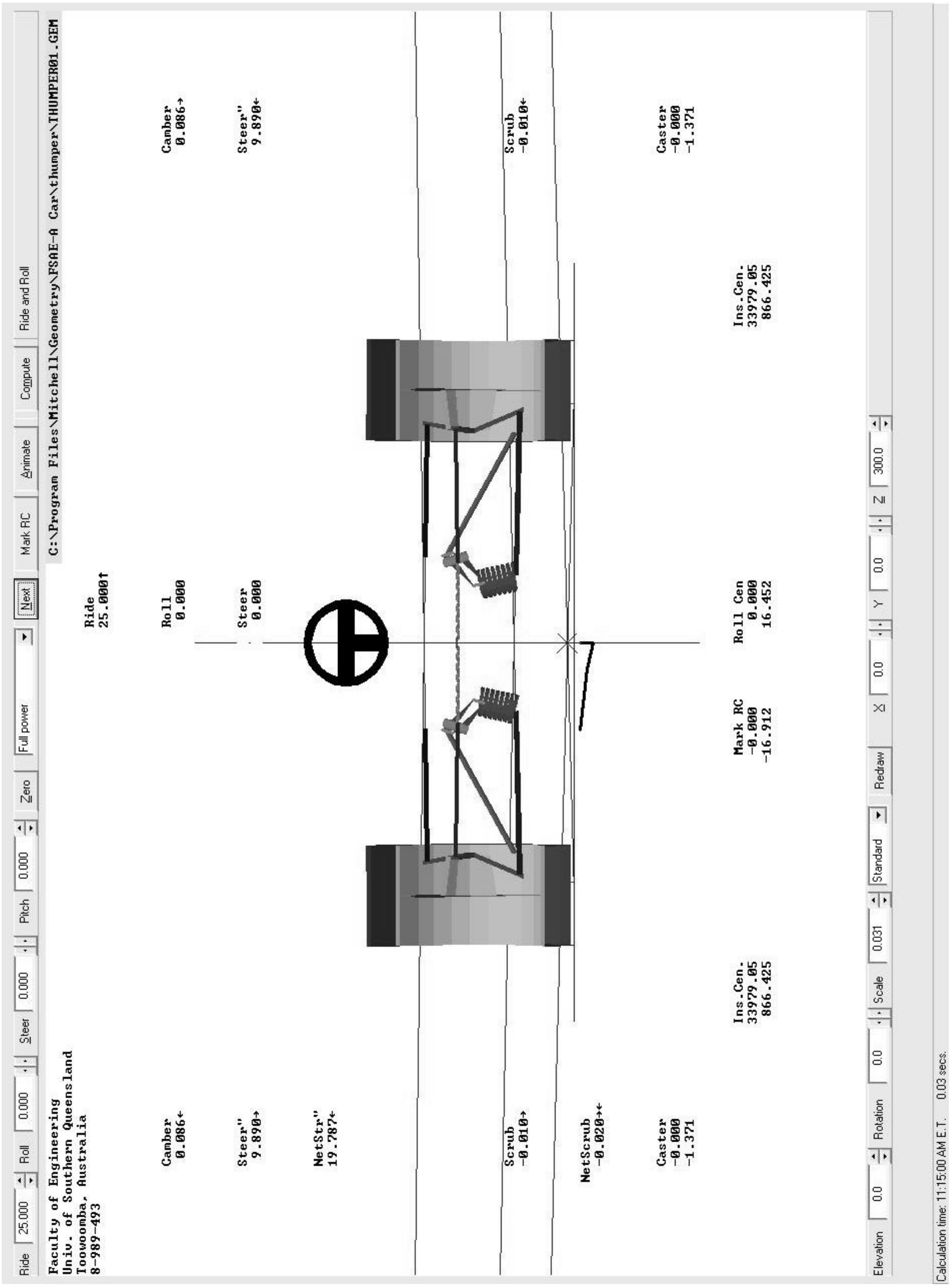

Figure B.12: Exiting RH turn - Full Power

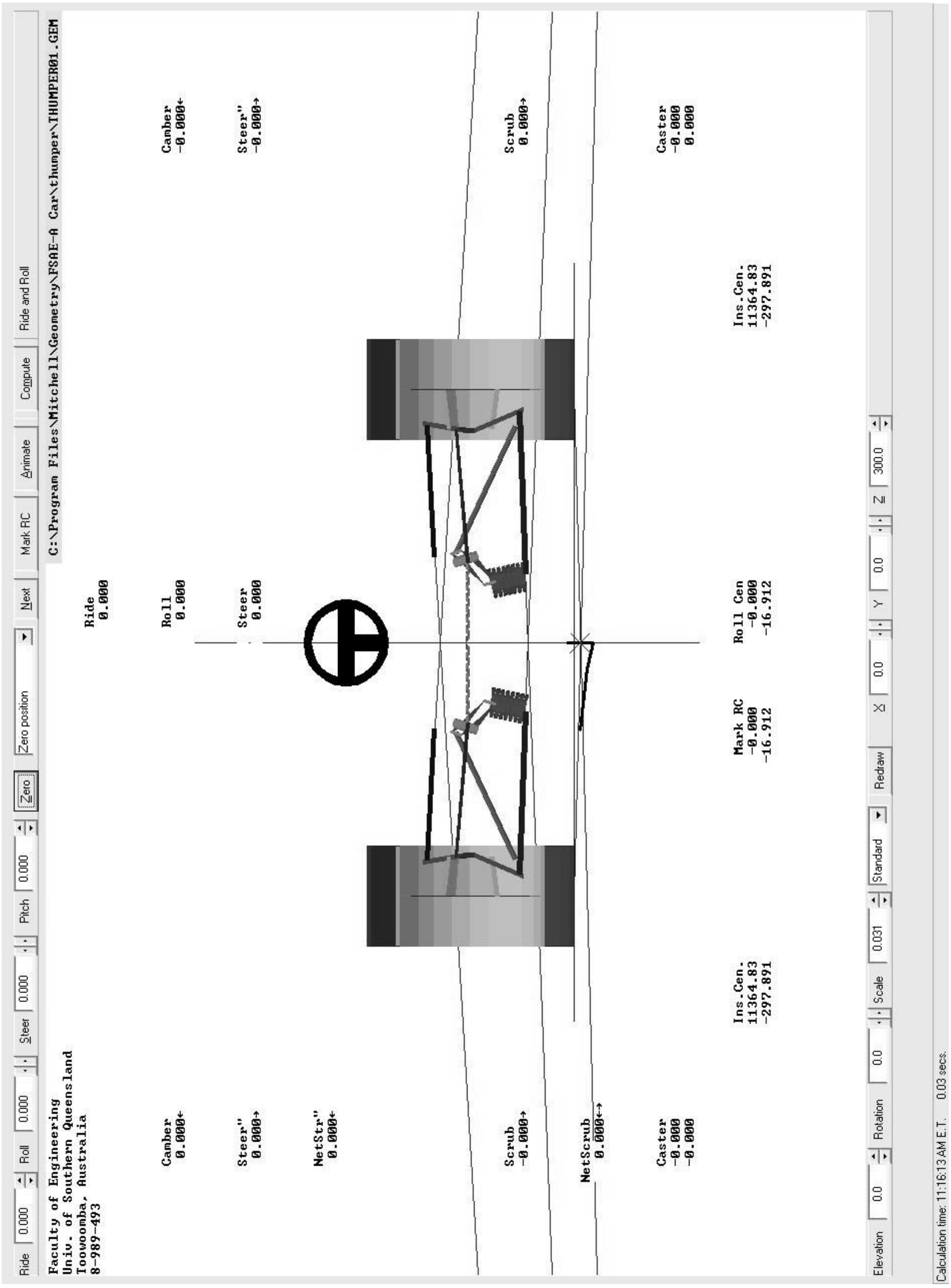

Figure B.13: Zero Position

B.1.3 Analysis of Camber Change during a Right Hand Corner

Data collected during the path file in the WinGeo suspension geometry program was tabulated and converted to Excel to produce this graph that shows the Camber change during a right hand corner.

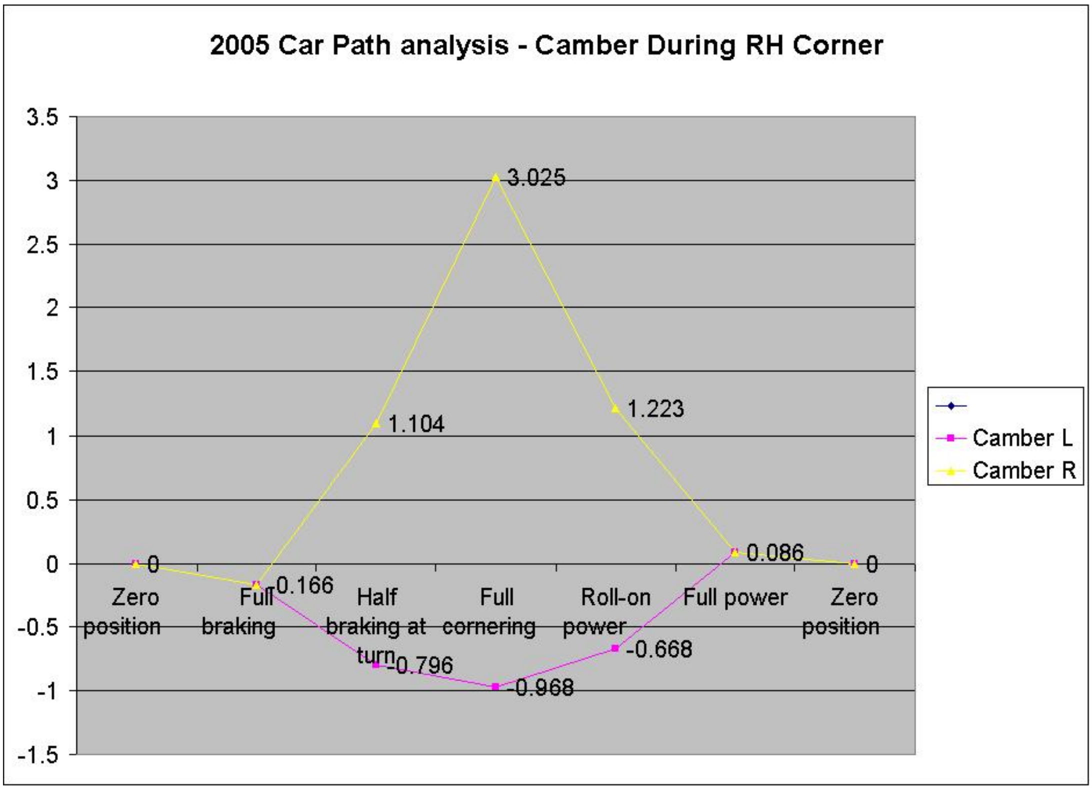

Figure B.14: Camber Change during Right hand corner

B.2 2006 WinGeo Analysis

Here is information outputted from WinGeo suspension geometry program, it shows the values of Steering Axis Inclination or Kingpin angle, Scrub radius and Caster as indicated.

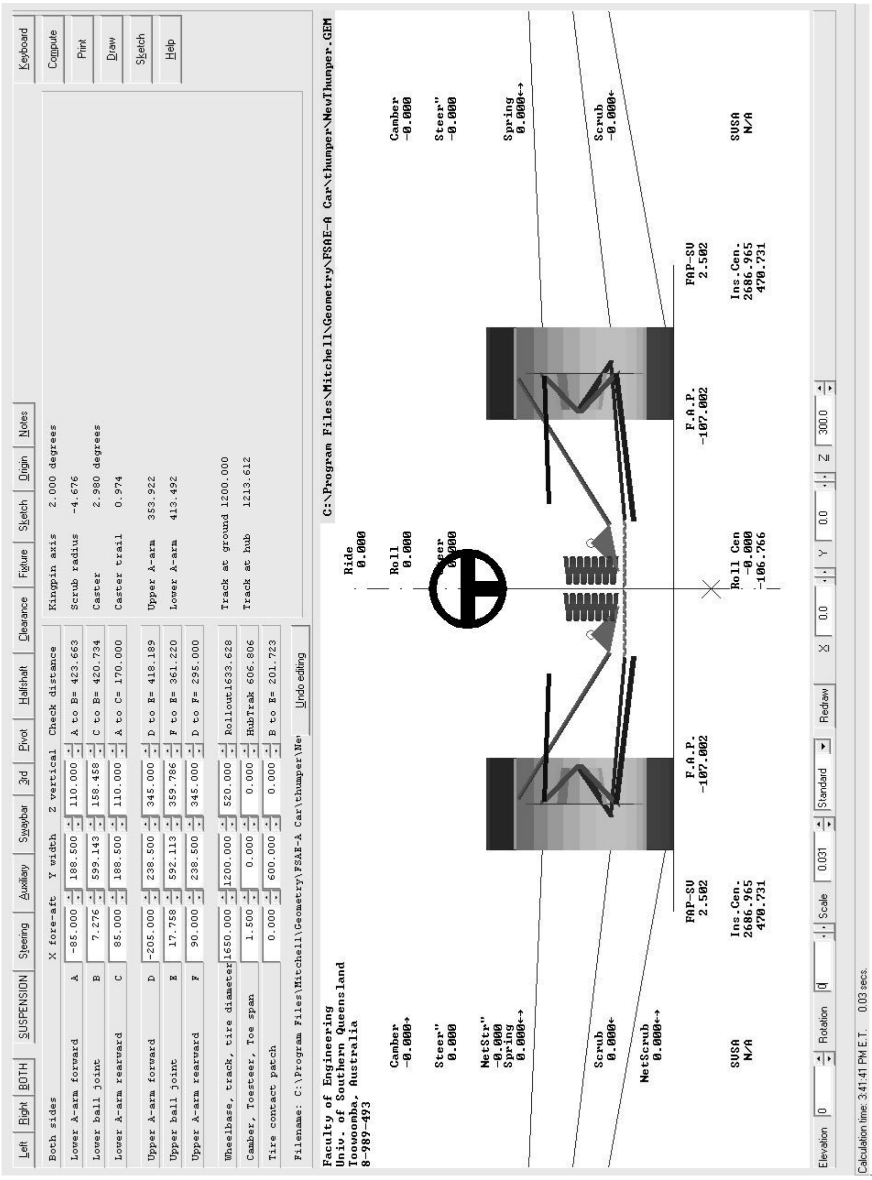

Figure B.15: Analysis of the 2006 car from ProEngineer figures

B.2.1 2006 Car Fundamental Analysis

Fundamental Analysis:

This analysis of instantaneous parameters is based on the instant center. This describes the movement of the tire over small displacements.

Right side: The Instant Center is at 3245.409 horizontal and 470.731 vertical. The distance from the IC to the contact point is 2686.965

The instantaneous Ride camber is 0.021 Roll camber is 0.777 Ride scrub is -0.175 Calculated derivative Ride Camber -0.023 vs. 0.021 length of IC arm is -2500.579 vs. 2686.965 Calculated derivative Ride Scrub 0.178 vs. -0.175 height of Ins.Cen is 445.974 vs. 470.731 Instant Center is at -1860.488 and 445.974

Left side: The Instant Center is at -3245.409 horizontal and 470.731 vertical. The distance from the IC to the contact point is 2686.965

The instantaneous Ride camber is 0.021 Roll camber is 0.777 Ride scrub is -0.175 Calculated derivative Ride Camber -0.023 vs. 0.021 length of IC arm is -2500.579 vs. 2686.965 Calculated derivative Ride Scrub 0.178 vs. -0.175 height of Tns.Cen is 445.974 vs. 470.731 Instant Center is at 1860.488 and 445.974

The instantaneous Net scrub is -0.350

Calculated Roll Center is at -0.000 and 108.752

B.2.2 Analysing Left and right Cornering using the Path File

The following show the 5 points during a Left hand Corner and highlited location of the Roll Centre:

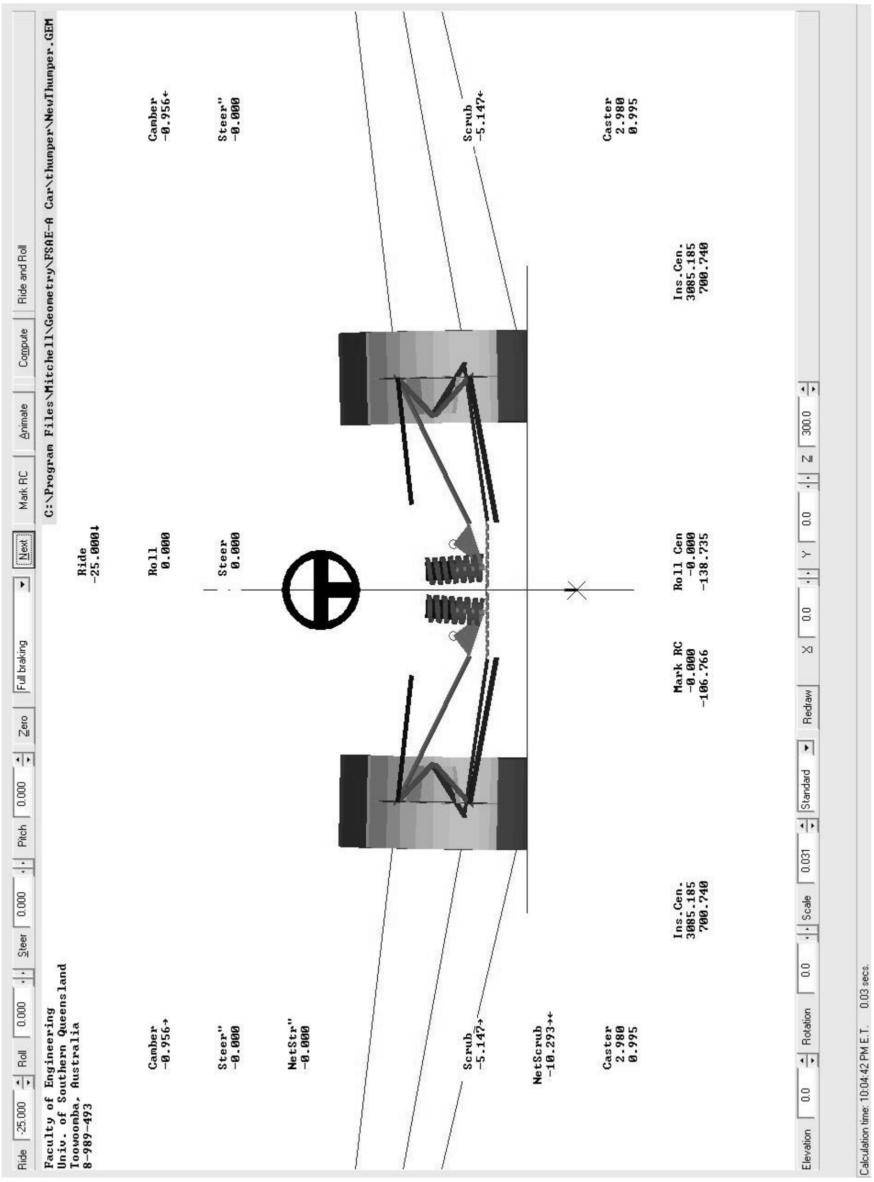

Figure B.16: Entering LH turn - Full Braking

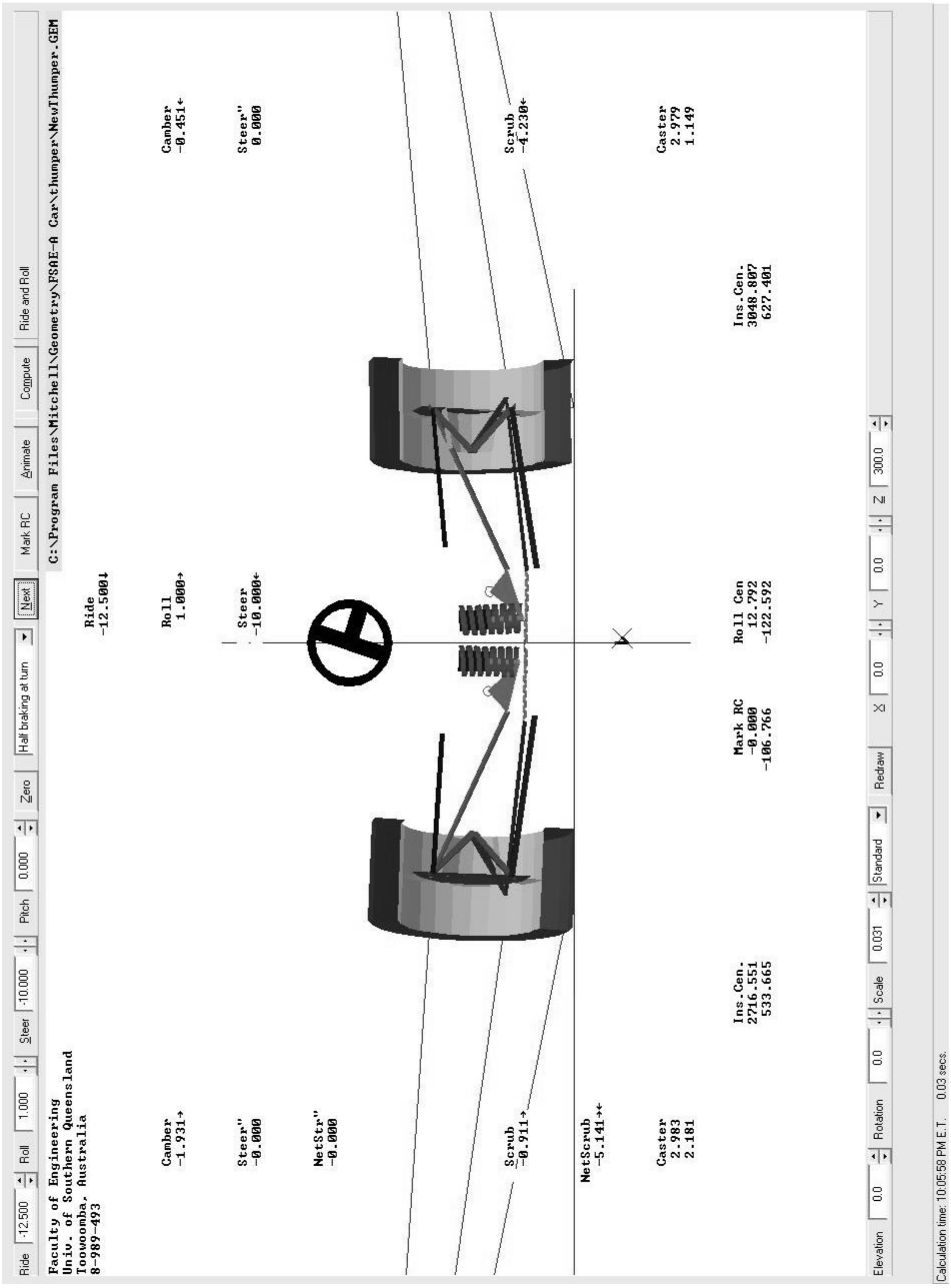

Figure B.17: LH turn - Half Braking

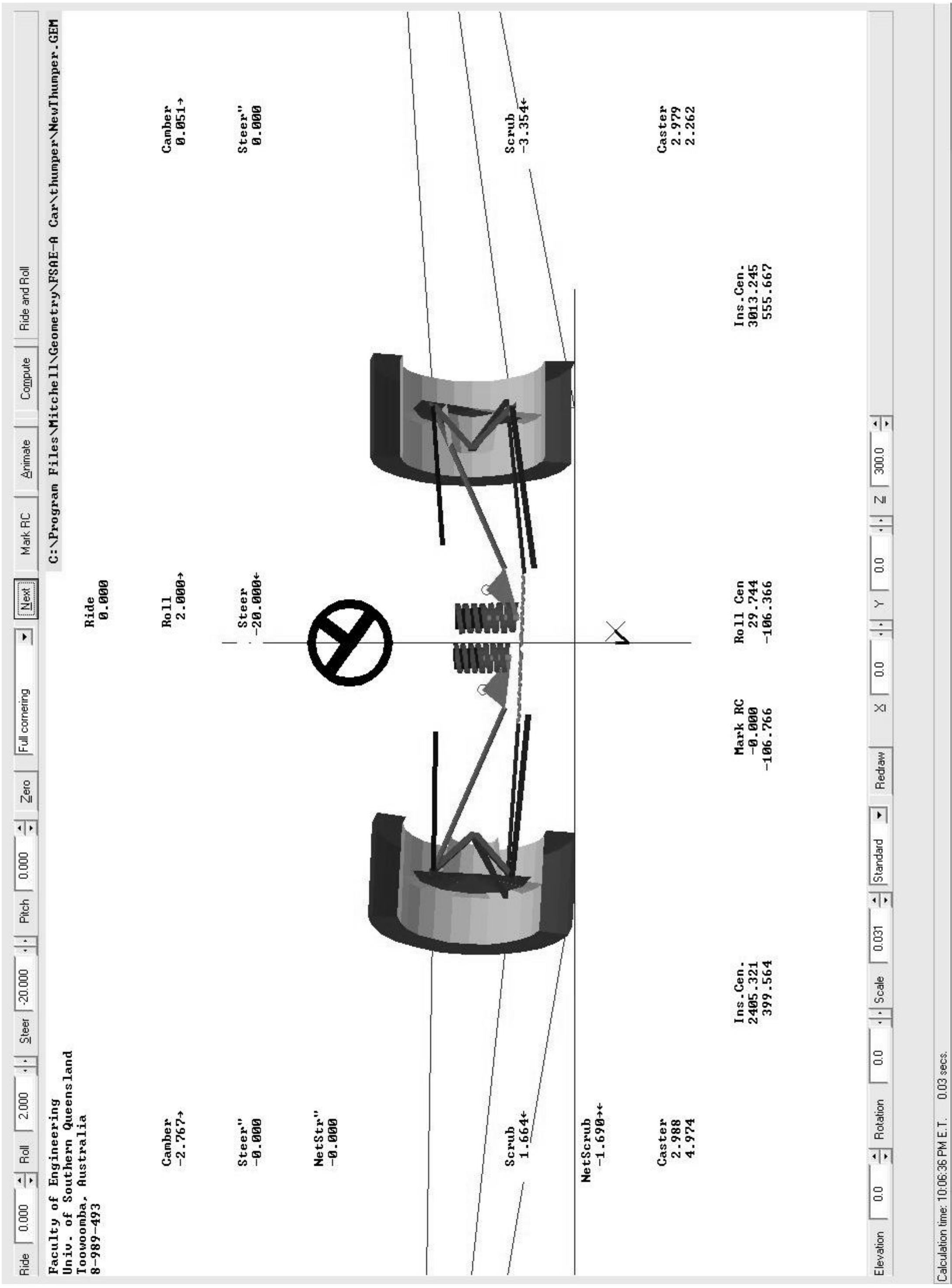

Figure B.18: LH turn - Full Cornering

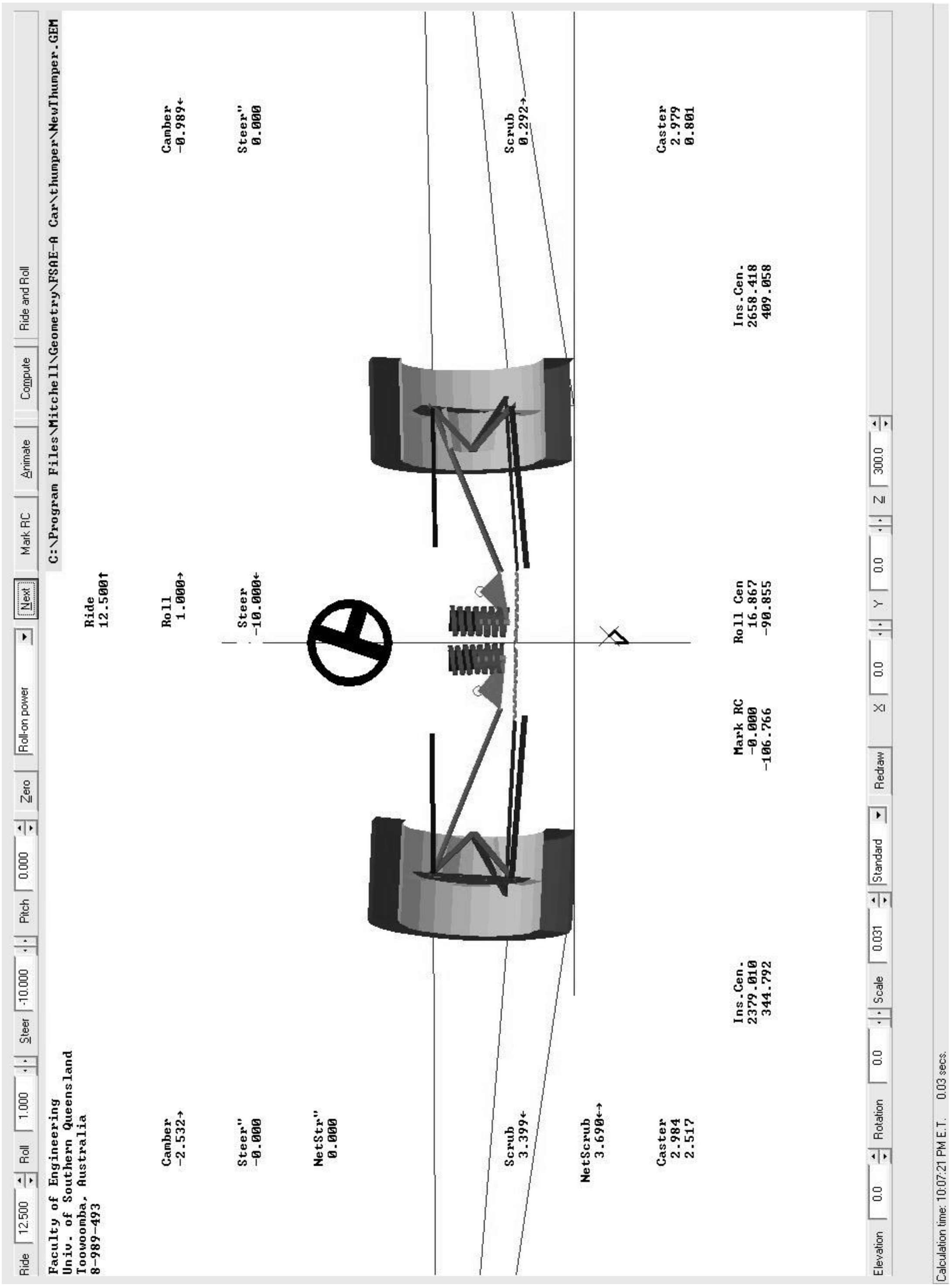

Figure B.19: Exiting LH turn - Roll on Power

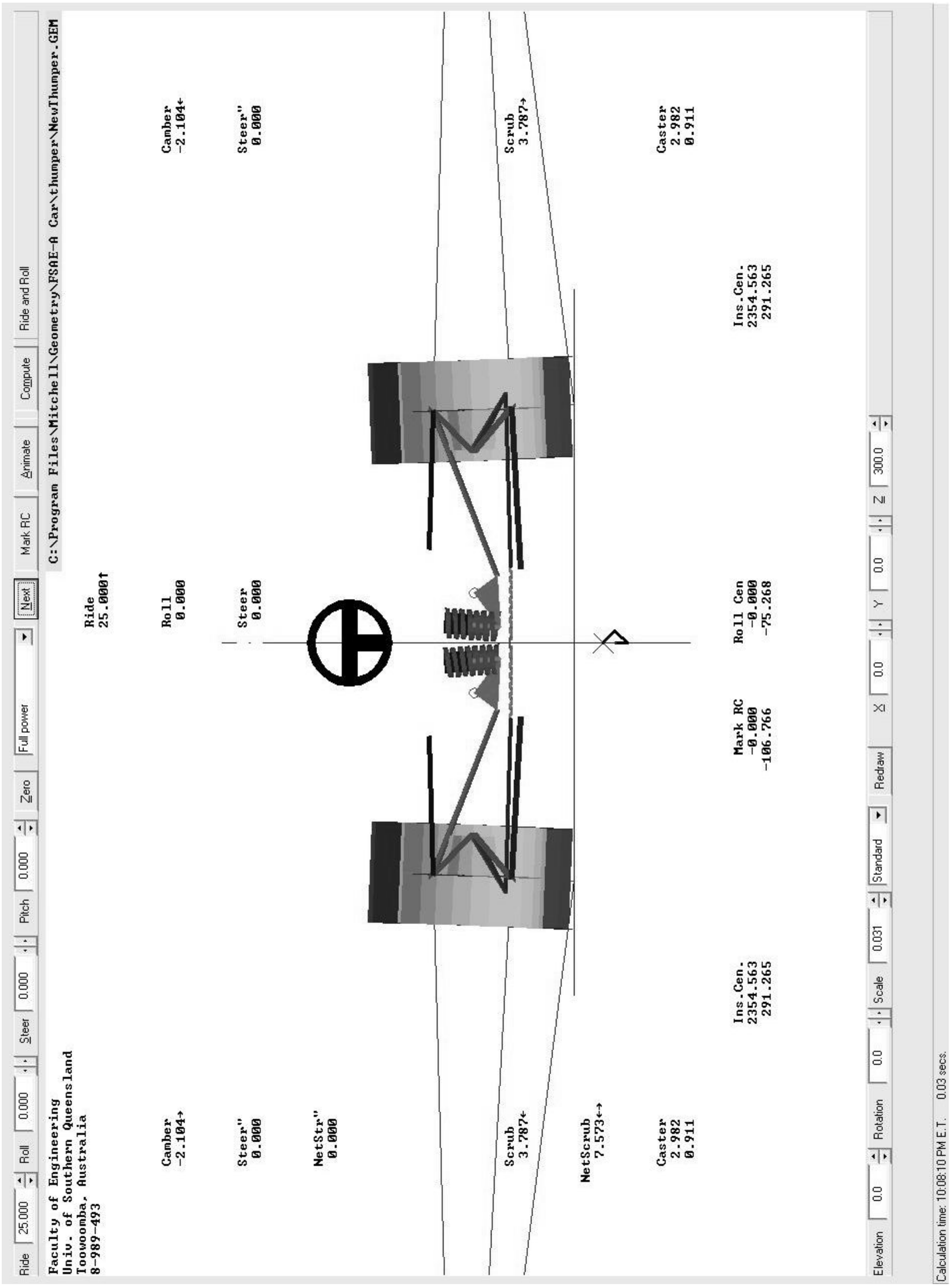

Figure B.20: Exiting LH turn - Full Power

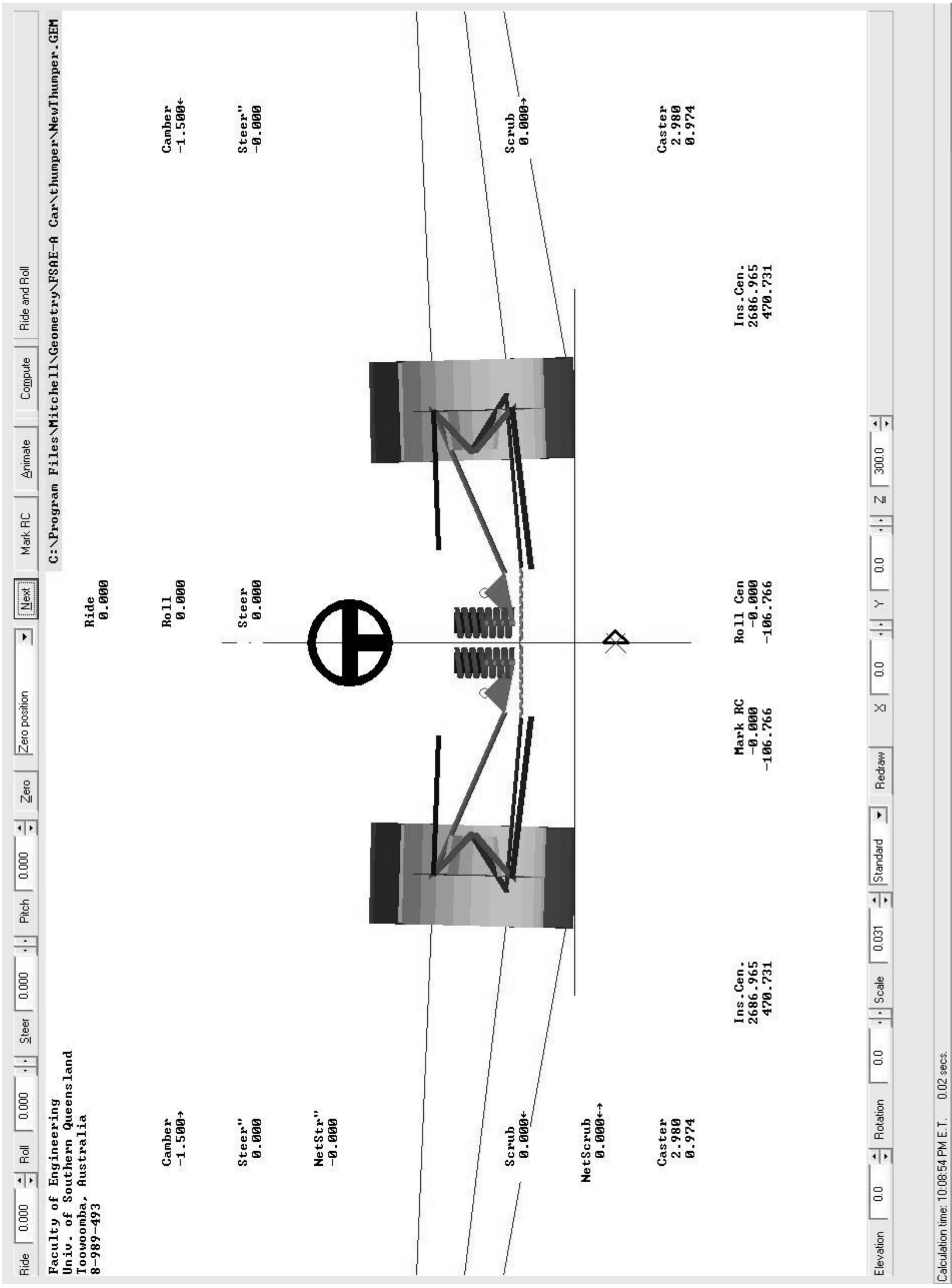

Figure B.21: Zero Position

The following show the 5 points during a Right hand corner and highlighted location of the Roll Centre:

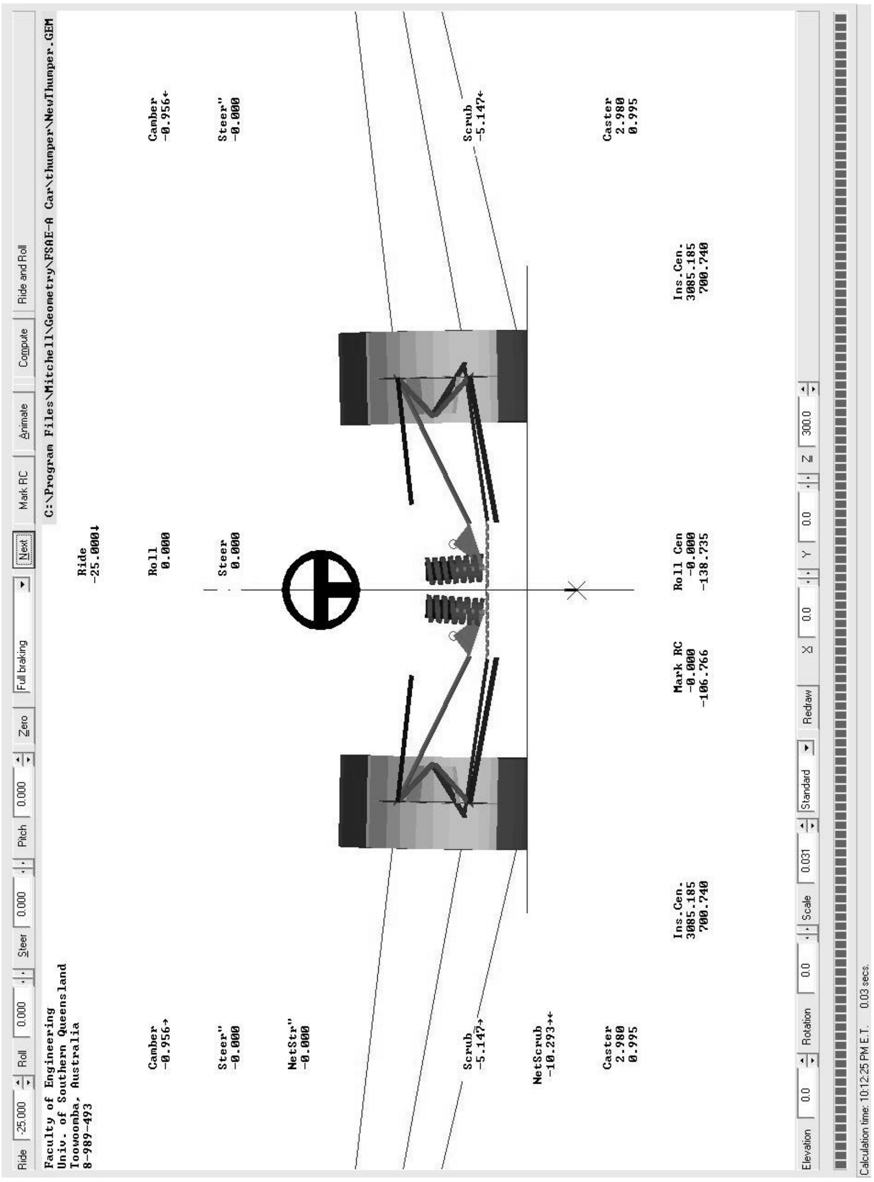

Figure B.22: Entering RH turn - Full Braking

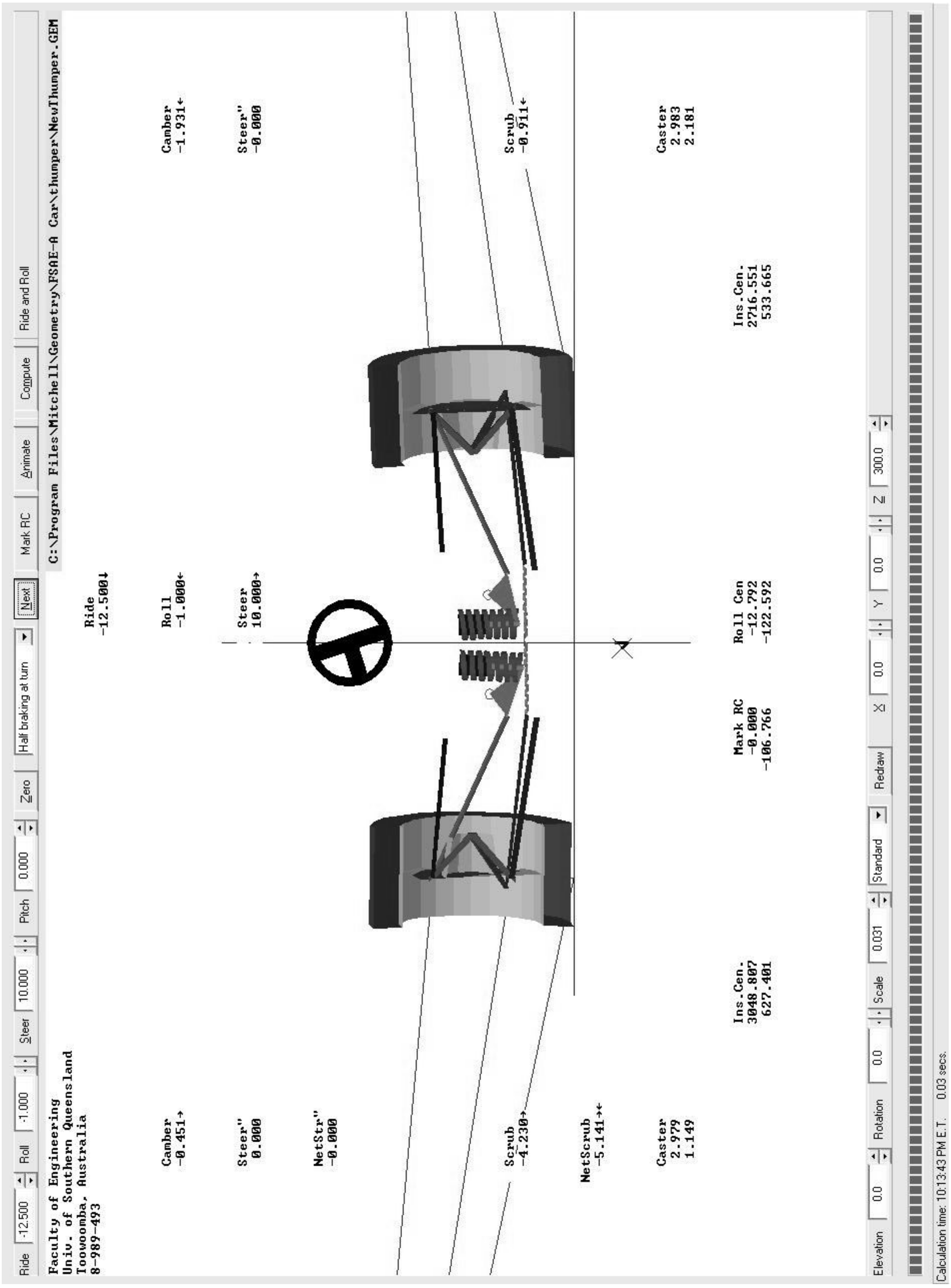

Figure B.23: RH turn - Half Braking

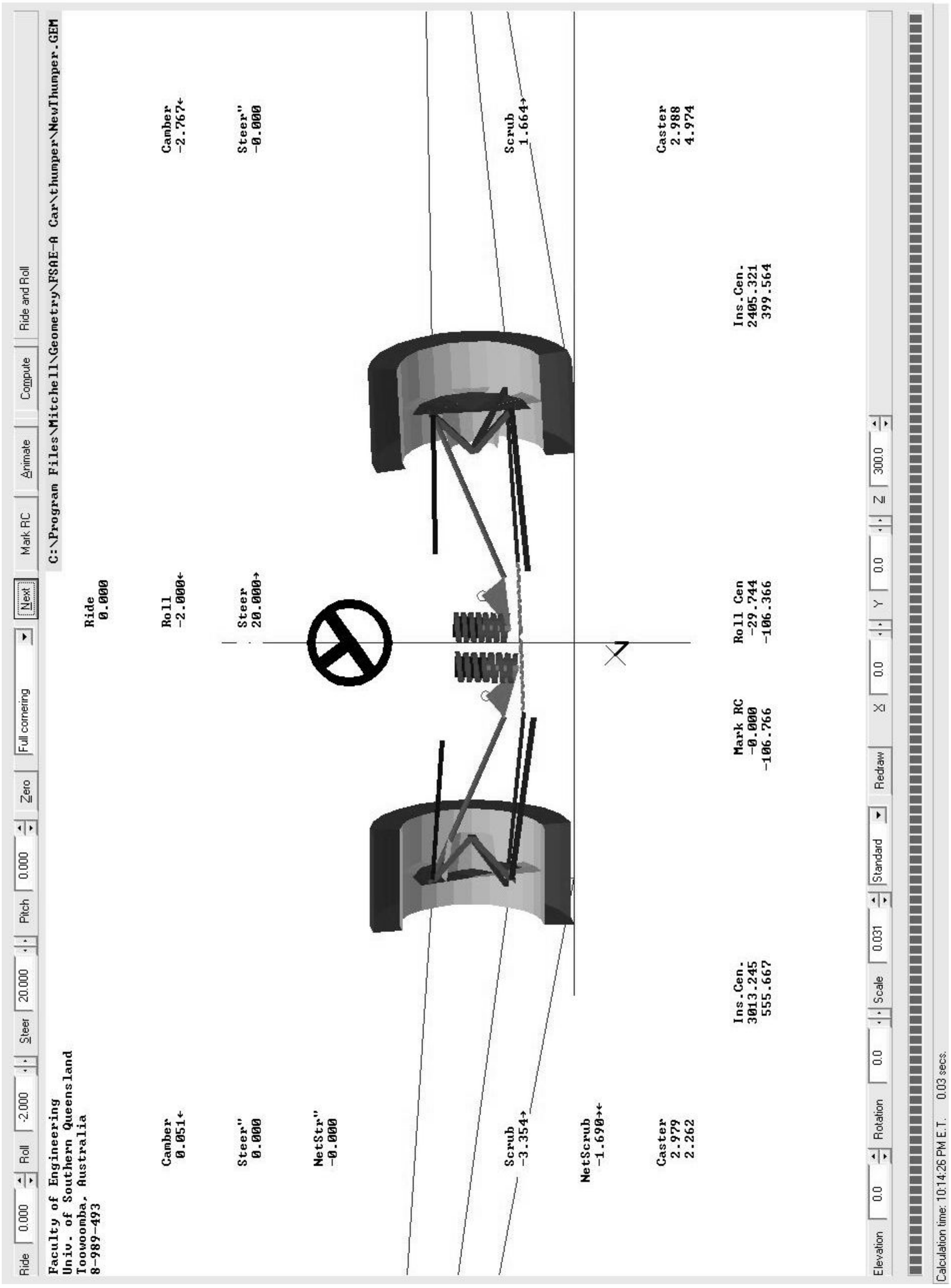

Figure B.24: RH turn - Full Cornering

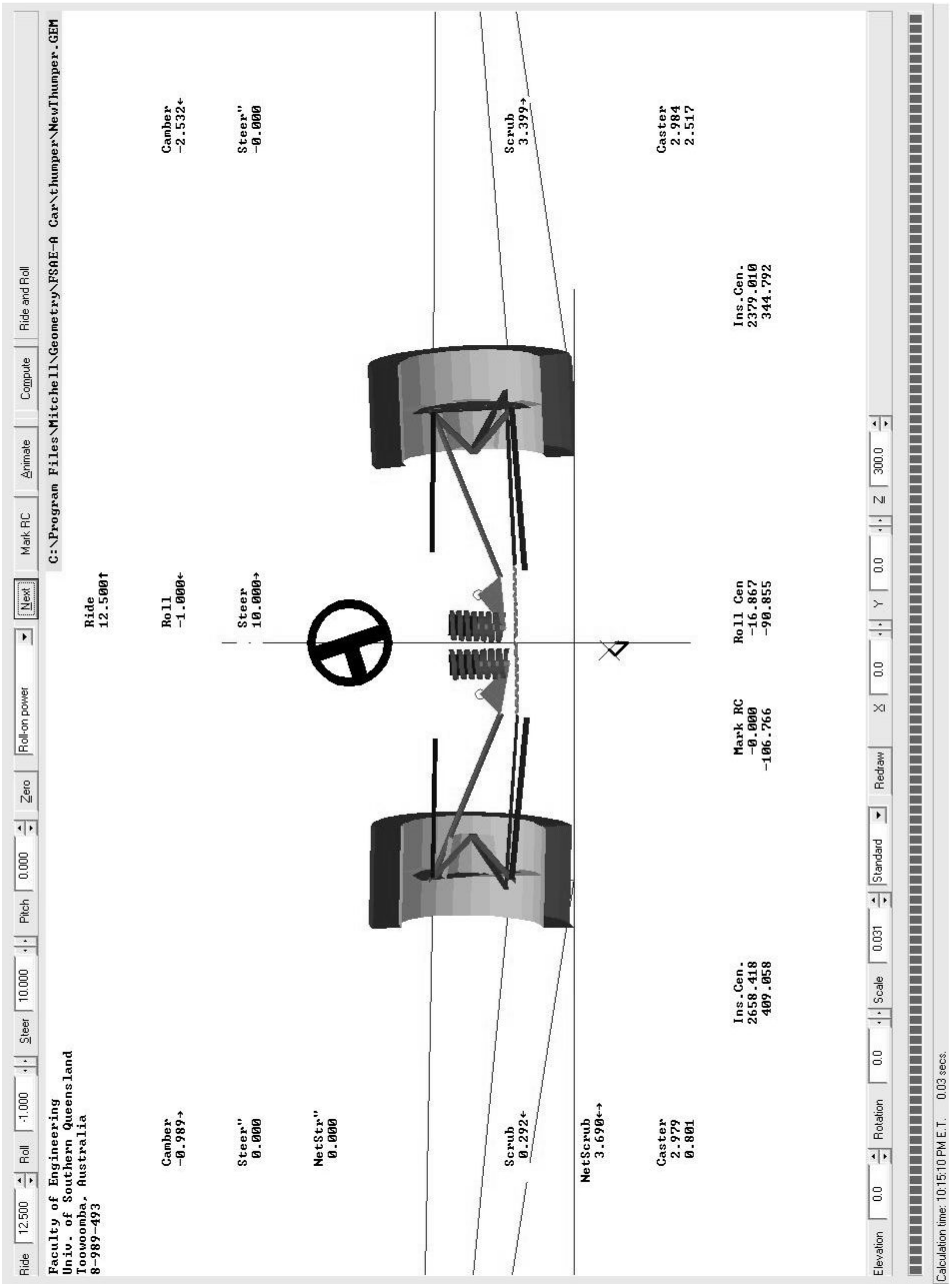

Figure B.25: Exiting RH turn - Roll on Power

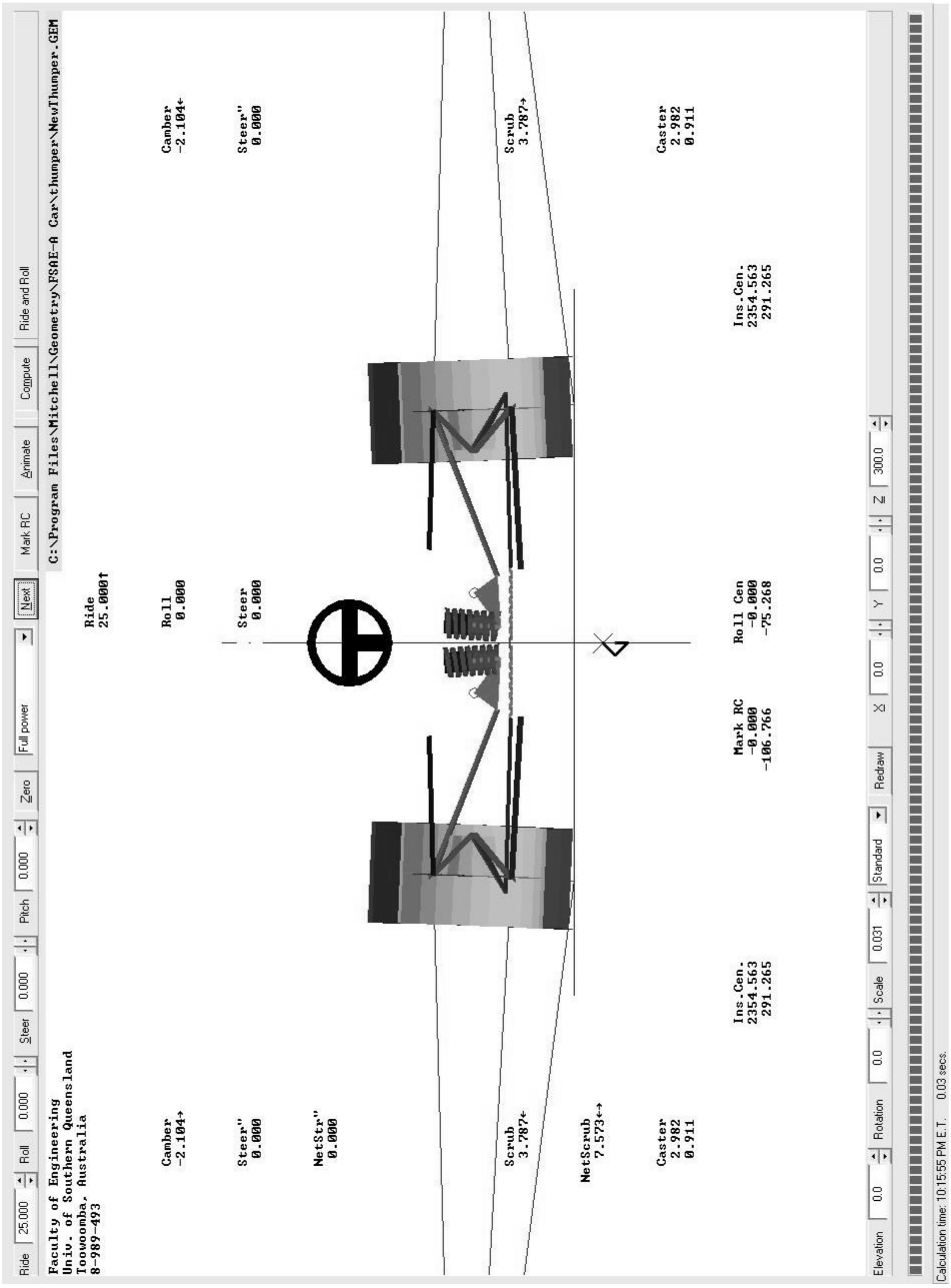

Figure B.26: Exiting RH turn - Full Power

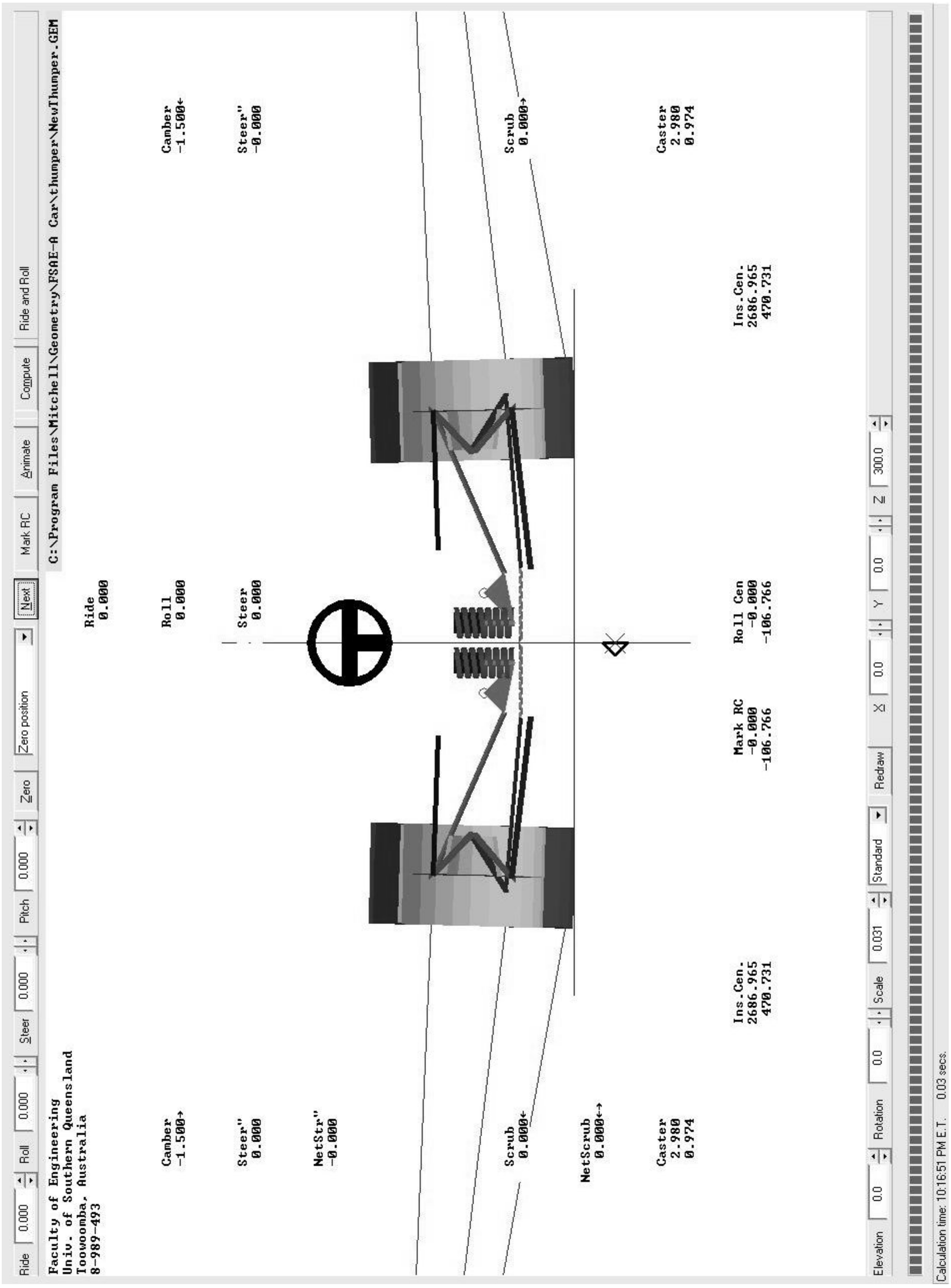

Figure B.27: Zero Position

B.2.3 Analysis of Camber Change during a Right Hand Corner

Data collected during the path file in the WinGeo suspension geometry program was tabulated and converted to Excel to produce this graph that shows the Camber change during a right hand corner.

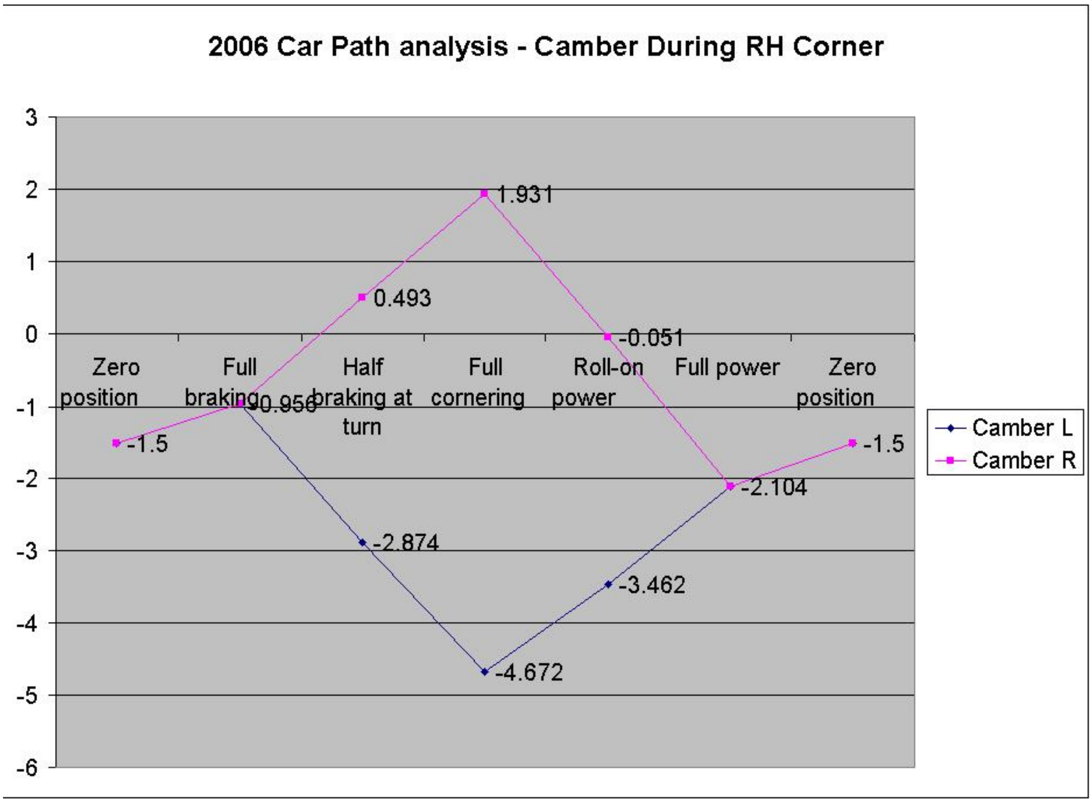

Figure B.28: Camber Change during Right hand corner

Appendix C

Pictures of Steering and Suspension Components

The following pages contain photographs of the Front and Rear, Upper and Lower Wishbone suspension connected to the chassis and the wheel uprights.

Figure C.1: Front Left Suspension Wishbones

Figure C.2: Front Right Suspension Wishbones

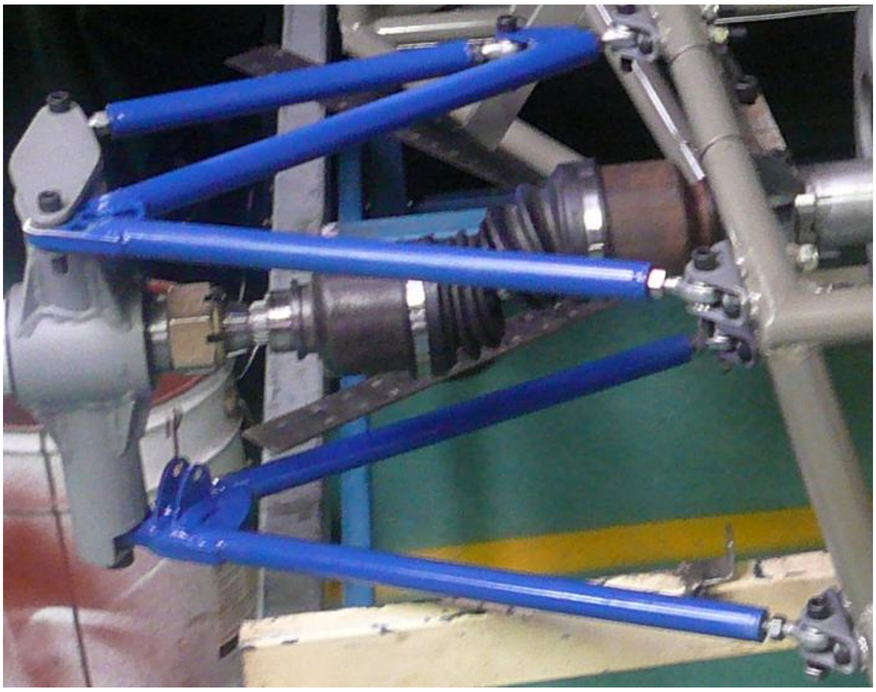

Figure C.3: Rear Left Suspension Wishbones

Figure C.4: Rear Right Suspension Wishbones