Traction Control and Torque Vectoring with Wheel Hub Motors

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Abstract

Internal Combustion Engines have dominated the transport and motor-vehicle industry for the majority of the last century. However, powering vehicles with renewable energy sources provides ecological, economical and sustainable benefits. In particular, Electric Vehicles have proven to be far more cost effective per kilometre driven than their petrol powered counterparts.

There are also other benefits to using electric motors such as significantly improved torque response from the motors, more accurate control over motor output and greater flexibility in motor design.

This project aims to combine all of the benefits of electric motors to produce an electronic stability system that improves both the stability and performance of a vehicle. This will be achieved through the design and construction of an open-wheel racer specifically tailored to incorporate individual motors in all four wheels.

The system will incorporate driver input and vehicle feedback to individually control the motors in an all-wheel-drive setup. This allows us to predict torque requirements and limitations in real-time. This, in turn, can enable maximum performance during safe operation.

Acknowledgements

First thanks must go to Professer Thomas Bräunl and his work for The REV Project. It has been his efforts over the last few years that has built the project to where it is today. Without him this project, and the UWA FSAE Electric car, would simply not be possible.

Thanks must also go to the rest of the REV team. All of you have been extremely helpful this year. And to Ian Hooper in particular, whose unrivalled technical knowledge and general good sense has seen the vehicle progress far beyond what it otherwise would have. Thanks also to Val, our favourite German exchange student, who brought German engineering efficiency and an exceptional sense of humour to the team.

To all of my friends, fellow sporting members and workmates who have provided a more than enjoyable retreat from the endless days of study. Although I can't name all of you individually, please know that I am grateful for my relationship with each and every one of you.

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Mum, Dad, Luke, Sam, Bec and Lawrence: My family. Whether it was a roof to live under, someone to talk to, someone to play XBOX with or a trip to Norway in January to look forward to, what you have so generously provided me this year I hope I can someday repay. Without any of you I would not be the person I am.

And most importantly, to Cait. You are the best thing to ever happen to me and I will love you always. Thanks for putting up with me, for laughing with me, for dancing with me (for continutally making me go dancing), for enduring my early starts at work and most of all for loving me in return.

This paper is dedicated to all of you.

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Chapter 1

Introduction

1.1 Renewable Energy

Awareness of the effects that pollution can have on our environment has propelled the industry of power generation into the future. Sources of energy such as solar, wind and hydro have become much more prominent in the public domain. This has been accelerated by events such as the *Kyoto Protocol* [1] and more recently in Australia the Government's *Clean Energy Future* [2] legislation.

Figure 1.1: Solar Farm [3]

Many power providers now offer the option of purchasing "Green Energy" at a

Figure 1.2: Power Transmission

premium and the prevalence of solar panels on suburban houses is rapidly increasing. This has also led consumers to reconsider their carbon footprint in other areas of their lives such as organic foods, environmental home design and personal transportation.

1.2 Electric Vehicles

Electric Vehicles (EV) are an alternate mode of transport to Internal Combustion Engine (ICE) vehicles. They are usually more efficient in their use of power. On the whole, considering the power consumed when charging the batteries of an EV, EV's produce fewer emissions and use less energy than there ICE counterparts [4].

The 20th century was mostly dominated by ICE's due to the invention of the electric starter in the early 1900's. They provided a convenient, speedy mode of travel and developments in ride comfort quickly overcame the negatives of noise and vibration in the vehicles. As such, most of the research and development into modes of transport over the last 100 years has been conducted in the area of ICE's.

As the EV once again becomes popular thanks to improvements in battery, motor and computer technology it's infiltration into the production car market will be accompanied by the appropriate research and development [5].

Figure 1.3: Electric Vehicle from the 1900's

1.3 Renewable Energy Vehicle Project

The Renewable Energy Vehicle(REV) Project at The University of Western Australia (UWA) has been conducting research into the technologies used in Electric Vehicles (EV) since 2008 through the conversion of a 2007 Hyundai Getz and a 2002 Lotus Elise. Figures 1.4 and 1.5 show these vehicles, courtesy of [6].

In 2011 the REV project has been developing a purpose-built electric vehicle for the Formula SAE-A(FSAE-A) competition run by the Society of Automotive Engineers-Australasia (SAE-A) to be held in Melbourne in December. The competition is designed to provide university students with an opportunity to learn in a simulated work-place environment that incorporates real-world deadlines, restrictions and situations. This has also provided the REV project with the opportunity to develop and test some existing EV technologies in a performance environment and measure these technologies against comparable ICE vehicles.

The production of this car has involved many students, the majority of whom are also completing their final year project paper on different aspects of the vehicle.

Figure 1.4: The REV Project Lotus Elise

Figure 1.5: The REV Project Hyundai Getz

1.4 Aim

The project aims are outlined as follows:

1. To develop a model for torque vectoring which improves efficiency and performance in an All Wheel Drive Electric Vehicle.
2. To develop a Traction Control system which enhances the enhances the safety, stability and performance of an Electric Vehicle utilising wheel-hub-motors.
3. To manage the design and construction of a purpose-built vehicle that will provide a test-bed for Electric Vehicle research, and compete in the 2011 FSAE-A competition.
4. To design and test an algorithm which incorporates both the torque vectoring and traction control models developed.

Figure 1.6: Formula SAE-Australasia

As will become evident throughout the paper, the magnitude of the third aim was underestimated at the beginning of the year. Managing the design and construction of the vehicle became extremely important early on, and as a result the importance of the other aims of this project diminished. The final aim of designing and testing an algorithm is now completely unachievable as the vehicle will not be completed in time.

Chapter 2

Literature Review

2.1 Electric Motors

Electric motors are most commonly used in industry. Some examples include use for the propulsion of conveyor belts, elevators and mixers. They are also used in various forms of transportation around the world. Electric trains are common in many major cities, including Perth, and light rail trams can be found in cities such as Melbourne.

Electric motors were used as a common method of propulsion for motor vehicles as early as the 1890's, after charge accumulation difficulties were slowly overcome [7]. As mentioned in section 1.2, the invention of the starter motor provided a catalyst for the development of ICE's thanks to their convenience and reliability. However, the electric motor offers several performance benefits over ICE's that can now be exploited due largely to significant advancements in technology [5, 8–13] including

1. Faster Torque Response,
2. Bi-Directional Torque Output,
3. Precise Torque measurements and
4. Smaller motor size.

These properties open possibilities for electric motors to be used in high precision control environments where safety is paramount. Two examples where these properties can be properly explored and subsequent systems developed are Torque Vectoring and Traction Control.

2.2 Torque Vectoring

Torque Vectoring is defined as

> "Creating a difference in the braking or driving forces at each wheel to generate a yaw moment (torque)" [14]

Research into torque vectoring is quite extensive. It has been utilised in industry for quite some time and can provide benefits such as improved precision and energy efficiency [10, 15].

Torque vectoring in motor vehicles has traditionally been achieved through mechanisms such as a Limited Slip Differential(LSD)[15, 16]. In vehicles with traditional electric motors this is still easily implemented as the electric motor simply replaces the ICE within the system. However, with wheel-hub-motors this style of vectoring can no longer be mechanically achieved as the individual wheels drives are not mechanically linked.

Several proposed models can be found in current literature. [17] has incorporated four separate wheel drives and shows how using torque vectoring might achieve superior results to a control system that does not. The simluation results predicted an improved performance for the theoretical vehicle.

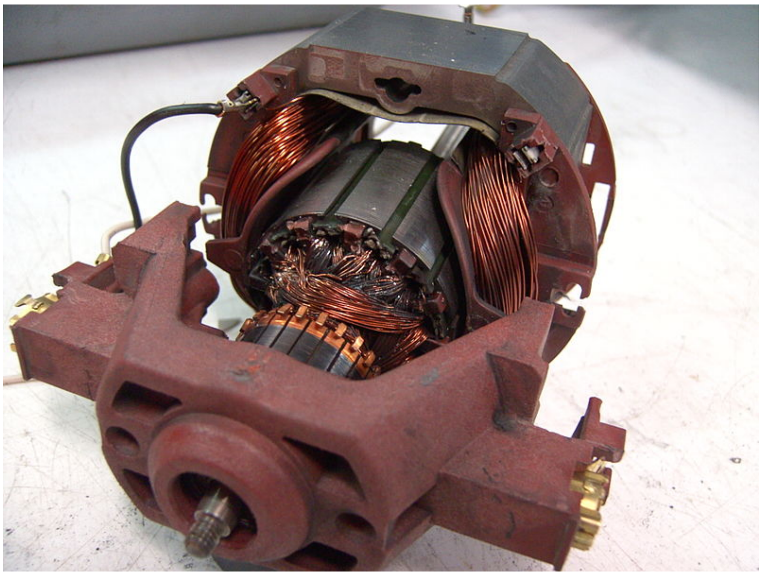

Figure 2.1: Electric Motor

[18] develops Direct Yaw Control (DYC) using two in wheel motors. The simulation results showed that yaw control can be achieved directly through motor torque differential. That is, no steering input is used, the power to each motor is controlled to produce the turning force.

A similar system is presented in [19] utilising feedforward and feedback loops in the control sequence. Side slip is dramatically decreased in simulations and yaw control using the drive motors is successful.

[20] explored workload equalisation between the driven wheels to improve yaw-rate control for an electric vehicle. The experimental results show that an improved response time, and improved yaw rate are both achieved through the application of DYC to the driven wheels.

2.3 Traction Control

Traction Control is defined as

> "a method of preventing wheels from spinning when traction is applied by limiting the amount of power supplied to the wheel" [21]

[22] states that the earliest forms of traction control developed as Anti-Lock Braking Systems (ABS) to reduce braking distances on aircraft needing to land on short runways. The main purpose of ABS is to prevent the *locking* of wheels under extreme braking conditions [22–24]. ABSs generally aim at maintaining an average slip ratio, λ, during braking or cornering. [24] postulates that angular velocity of the tyres also has an impact on λ, not just road surface conditions.

[25] explains that producing a mathematical model to accurately predict traction control performance under highyl varying conditions is extremely difficult. As a result there has been development in several directions. Fuzzy Logic, Sliding Mode, Neural Networks and Hybrid Control theories have all been developed, modelled and simulated for most circumstances [5, 11, 22, 25, 26]

2.3.1 Maximum Transmittable Torque Estimation

[27] experimented with traction controlled torque vectoring in a two wheel drive vehicle in response to a changing road surface. The approach in [27] is titled the Maximum Transmittable Torque Estimation (MTTE) approach. This approach incorporates a variable road surface condition as it uses the ratio of measured wheel velocity to measured vehicle velocity in its control algorithm.

A traction control algorithm based on road condition estimations is also developed in [9]. This estimation is calculated using the trailing wheels in a two wheel drive vehicle. This allows the control system to calculate the slip ratio, and subsequently the maximum usable friction force between the road and the tyres. The experiments conducted in [9] showed that this type of traction control can effectively limit the slip ratio of the vehicle.

2.3.2 Fuzzy Logic

Many modern traction control systems incorporate *Fuzzy Logic*. The state of the vehicle is most often the quantity being estimated by the fuzzy controller. Computing the exact state of the vehicle, given the numerous unknowns when driving on the road, is an expensive process. Using Fuzzy controllers to approximate vehicle state significantly reduces computational costs.

[22–24] discuss potential implementations of Fuzzy controllers for ABS. [22] uses vehicle speed and acceleration as inputs to the controller.

[11] also proposes a model that incorporates both traction control and Active Yaw Moment Control (AYC) through the use of torque vectoring. The results of the simulations for this study indicated that using four individual wheel drives to control the torque output at each wheel can greatly improve both the handling and stability performance of the vehicle.

[13] presents a more complicated Neuro-Fuzzy controller to achieve yaw control through torque vectoring. The simulations of the model reveal that this system is robust to modelling errors even though only one gyroscopic sensor is used in the main feedback loop. A similar system is developed in [28] and simulations of this system also display robustness towards modelling errors and rapidly changing environments.

A fuzzy proportional-integral-derivative (PID) controller is utilised in [29] to control torque output by the electric motors and prevent wheel spin. Experimental data proved the system to be effective and provided adequate traction control for the driven wheels. The road surface condition was estimated using a slip ratio between the driven and non driven wheels.

[30] uses a fuzzy controller that incorporates ABS and engine torque control. The vehicle stability is improved and yaw rate response decreases in the control system simulation results. Similar results are obtained in [31], which implements fuzzy control of the braking torque output of electric motors on a hybrid vehicle.

2.4 Outstanding Issues

The current available literature provides many possible solutions to torque vectoring and traction control. However, these options are limited when considering the restrictions that our project must face.

While there has been significant testing in the areas of torque vectoring, there is comparatively far less information available for all wheel drive systems than two wheel drive systems. Many simulations have been conducted but not many projects have been able to produce empirical data. This project, through funding discussed in 6.3.4.2, will be able to gather this data to aid in the progress research into EV's.

Similarly, traction control for electric vehicles is a relatively new concept. As such there are not many projects able to provide statistical evidence to support the theories and simulations currently being circulated. In collaboration with numerous other students involved with the REV project, the purpose of this project is to provide that evidence.

Chapter 3

Systems

The FSAE vehicle is comprised of numerous systems. These system are paramount to the correct functioning of the vehicle and have been designed to work together. This chapter outlines the systems in the vehicle that have control over its operation.

3.1 Driver Control

The first system that must be considered is that where the driver has direct input. The vehicle is ultimately designed to be used by the driver and must therefore have the capability of measuring the driver's desired response.

This is achieved through the use of the following

- Steering Wheel - The steering wheel is mechanically linked to the front wheels and controls the steering angle of the car. It is a standard hydraulic system which utilises approximately perfect Ackerman steering through push/pull rods.
- Acceleration Pedal - The accelerator pedal is electronically measured using redundant hall sensors that track position. This pedal has no mechanical linkage to any components of the vehicle.
- Brake Pedal - The brake pedal has two components. It is mechanically linked to the brake callipers on all four wheels through a master hydraulic cylinder located in front of the pedal box. Secondly, it is also measured by redundant hall sensors as the acceleration pedal.
- Start/Stop Button - The start stop button/switch will be used by the driver to start and stop all systems under normal operation. It will be located on the dashboard and be electronically linked to all other car systems to indicate a start/stop signal.

- Emergency Stop Button - The driver will also have access to one emergency stop button. This will be a simple push/pull and lock button that will need to be set to safe for the car to operate. In the event of being pressed it will force an immediate shutdown of all systems on the vehicle.

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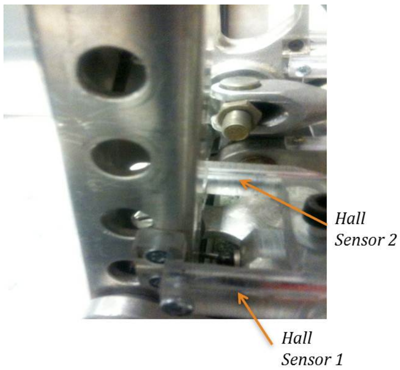
2 

Figure 3.1:
1. Steering Wheel
2. Accelerator Pedal with Hall Sensors

3.2 Instrumentation

The Instrumentation system will provide all diagnostic data for the FSAE vehicle, as well as collate the majority of required operational data. The instrumentation takes readings and measurements from various sensors around the car and then completes two tasks;

1. Forward required operation information to the tractive system, this includes
   - Steering Wheel position
   - Accelerator Pedal position
   - Brake Pedal Position
   - Lateral and Longitudinal Acceleration
2. The instrumentation system also sends diagnostic data to both an on-board storage device such as an SD card, and via wireless transmission to a remote receiver which can display the data in real-time. This diagnostic data includes all of the above mentioned information and also includes
   - Wheel Speed (x4)
   - Yaw Rate

- Battery charge/current

Figure 3.2: Instrumentation Control Box

The Instrumentation system will be run by an ATmega16A microcontroller and has been designed by Alexandros Andronis, a final year student with the REV project.

3.3 Motors

The motors provide the tractive force the vehicle requires to move. The FSAE vehicle possesses four Turnigy CA120-70 motors, figure 3.3, one located in each wheel (wheel-hub-motors). These motors were originally designed for use in ultra-light aircraft and have been modified with hall sensors to make them suitable for use in a motor-vehicle. Each motor is controlled using a motor controller. Currently we are using Kelly KBL72301 motor controllers as shown in figure 3.4, however we are also researching the Sevcon Gen4 450A as a possible substitute.

The motors are connected to each wheel through a pinion and spur reduction gearbox with a ratio of 12:80 ($\approx 1 : 6.6$). The motor and gearbox set-up proved a significant challenge to designing the suspension for the vehicle, both for the unsprung mass and the required dimensions 3.5. The gearbox and motor protude from the inside edge of the tyre and force the placing of the suspension mounts, figure 3.6 The tyres are Hoosier racing tyres with a 520mm diameter.

3.4 Tractive System

The tractive system is the central control centre for the motors and motor controllers. This system will accept inputs from the instrumentation, battery management system and emergency shut-off systems. Chapters 4 and 5 cover the tractive system in more depth as it is one of the focuses of this project.

Figure 3.3: Turnigy CA120-70

Figure 3.4: Kelly KBL72301 Motor Controller

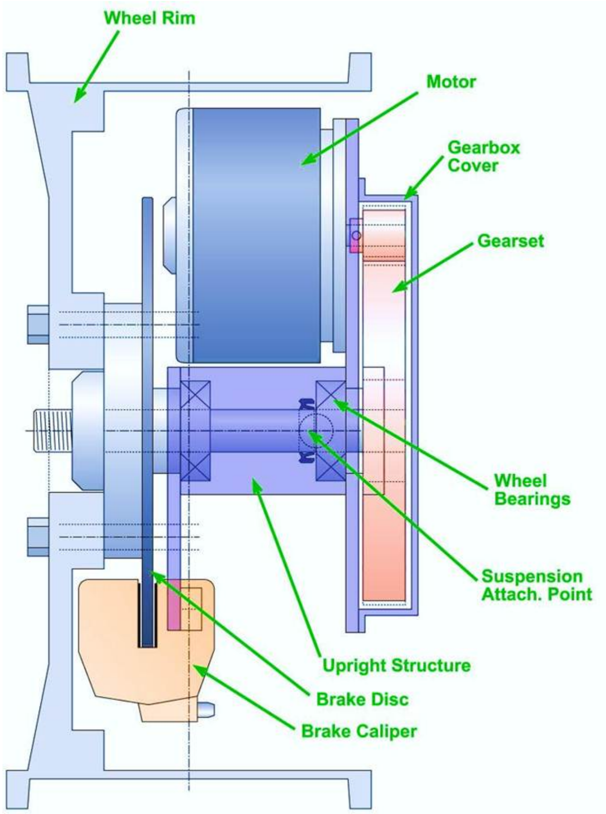


Figure 3.5: Unsprung Mass

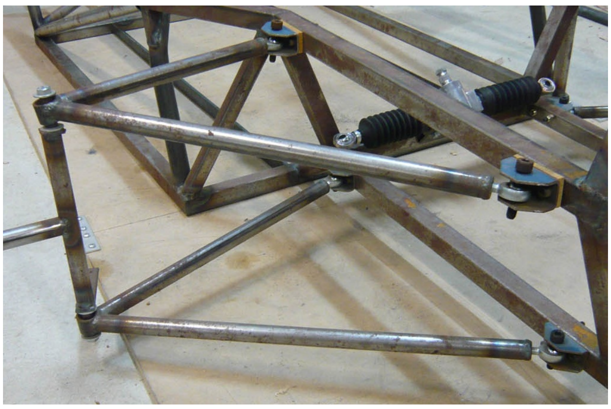


Figure 3.6: Suspension Mounts

Figure 3.7: K2 26650EV

3.5 Batteries & Battery Management System

The FSAE vehicle will be using and array of K2 26650EV batteries, figure 3.7, as the sole accumulator for electric charge. This array will be managed by a custom designed Battery Management System which will monitor both individual cell and pack status, and administrate the recharging process. The BMS will provide the driver with a basic set of indicators to relay health status of the battery pack and will also have direct connections to the tractive and instrumentation systems.

Chapter 4

Torque Vectoring

4.1 Introduction

This chapter will discuss the torque vectoring model that will be utilised by the REV SAE vehicle. It will also discuss what the model aims to achieve and how results will be measured.

4.2 The Torque Vectoring Model

Before the model is derived, we must first develop a concept of what this model is aiming to achieve. The vehicle discussed in section 3 is the vehicle this model will be applied to. Of particular relevance is that it is powered by four individual motors driving each of the four wheels.

By controlling these motors independently we have direct control over the torque that can be applied at each wheel. By utilising the theory of Ackerman Steering we can calculate the distance travelled by each wheel for any turning circle of radius r.

We will then use a state-based system to approximate theses calculations in order to reduce computation time for the on-board processor. This state-based system will scale the output torque to each wheel depending on desired driver response.

4.3 Calculating Torque Distribution

4.3.1 Calculations

Figure 4.1 shows the how the model will operate. For this project the torque vectoring model will not incorporate any feedback except that experienced by the driver. Feed-

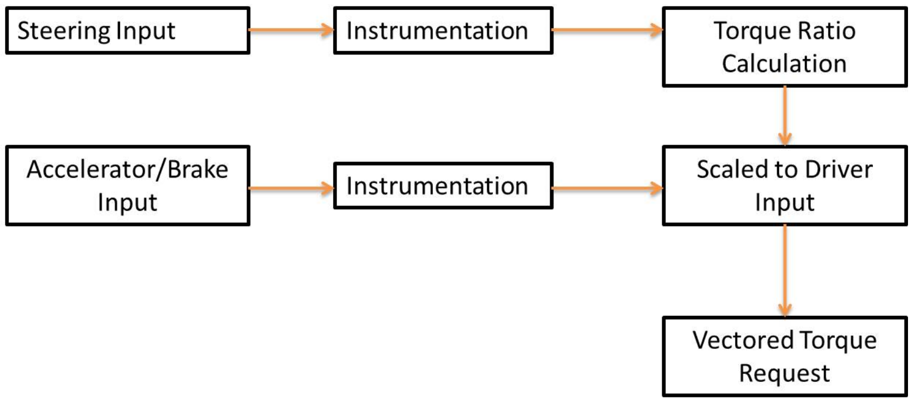


Figure 4.1: Torque Vectoring Flow Diagram

back will be obtained and provided during the traction control process as discussed in 5.

This model will apply torque based on wheel track length. Figure 4.2 shows the general layout of a vehicle during cornering.

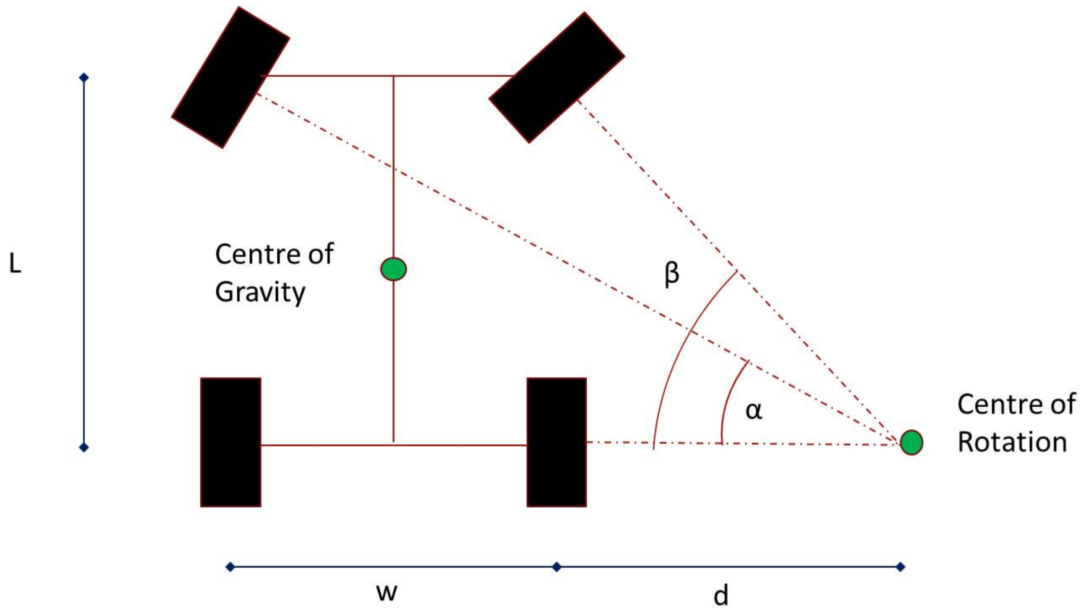


Figure 4.2: Vehicle Block Diagram

Calculating the radius of the turning circle is a simple process applied to each wheel.

FR	-	Front Right Tyre
FL	-	Front Left Tyre
RR	-	Rear Right Tyre
RL	-	Rear Left Tyre
CoG	-	Centre of Gravity
CoM	-	Centre of Mass
r	-	Radius of turning circle
l	-	Length of the vehicle
w	-	Wheel track (rear wheels)
d	-	Distance to centre of turning circle from RRT
α	-	Angle of FLT to centre of turning circle
β	-	Angle of FRT to centre of turning circle
μ	-	Friction Coefficient
g	-	Gravity
g_{ratio}	-	Gear Ratio
τ	-	Torque
a	-	Acceleration
F	-	Force

Table 4.1: Parameter List

$$r_{FR}=\frac{l}{cos(\beta)} \tag{4.1}$$

$$r_{FL}=\frac{l}{cos(\alpha)} \tag{4.2}$$

$$d=\frac{l}{tan\beta)} \tag{4.3}$$

$$r_{RR}=d \tag{4.4}$$

$$r_{RL}=d+w \tag{4.5}$$

The torque applied to the outermost wheel will be equal to the maximum torque required by the driver ($\tau_{required}$). To achieve this we use r_{ref}, set to the radius of turning circle of the outermost wheel. This will be either r_{FR} or r_{FL} when the vehicle is turning left or right respectively. The torque distribution will then be scaled based on the ratio of the radii of the respective turning circles to produce a Vectored Torque Request (VTR) [τ_{FR}, τ_{FL}, τ_{RR}, τ_{RL}].

$$\tau_{FR}=\tau_{required}\frac{r_{FR}}{r_{ref}} \tag{4.6}$$

$$\tau_{FL} = \tau_{required} \frac{r_{FL}}{r_{ref}} \tag{4.7}$$

$$\tau_{RR} = \tau_{required} \frac{r_{RR}}{r_{ref}} \tag{4.8}$$

$$\tau_{RL} = \tau_{required} \frac{r_{RL}}{r_{ref}} \tag{4.9}$$

The VTR is then used by the traction control system to send torque requests to each motor individually. This will produce a longitudinal force at each tyre shown in figure 4.3.

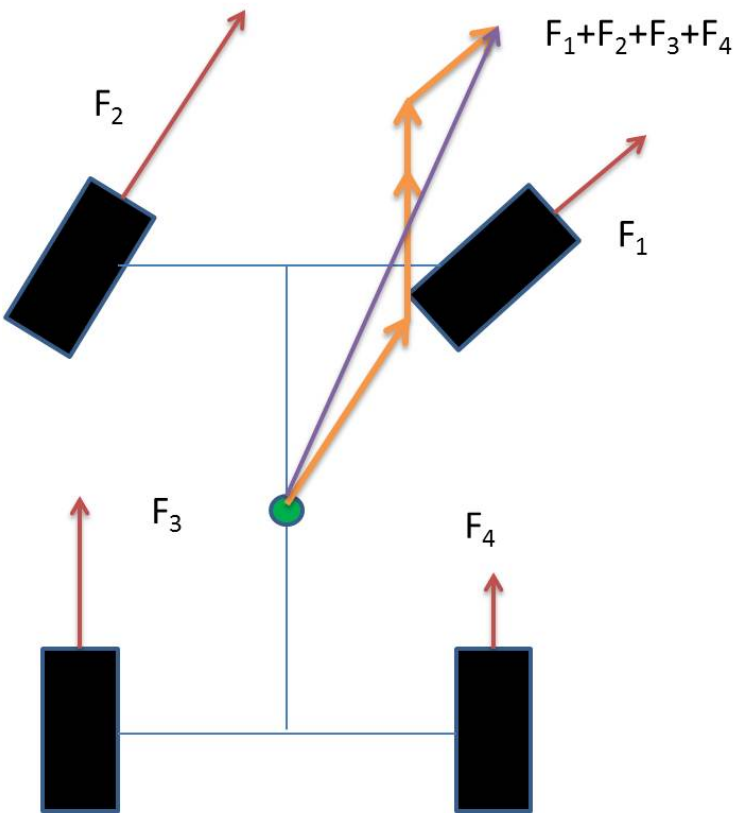


Figure 4.3: Torque Vectoring

Torque output is proportional to current. The outermost wheel was selected as the reference to avoid drawing excess current. As all of our motors are of equal performance this method ensures that the maximum power required at any individual wheel will not exceed the maximum performance capabilities of the motor. An alternate method for calculating the torque to be distributed is to use the CoG as the reference and apply the ratios from there. This will result in higher torques, and higher currents, for the outer wheels.

When the car is travelling in a straight line $\alpha \approx \beta \to 0$ and $r \to \infty$ for all tyres. Therefore $\frac{r}{r_{ref}} \to 1$ and $\tau = \tau_{required}$ for all wheels. This provides equal torque and will maintain a straight line travelling forwards (or backwards in reverse) for the vehicle.

4.4 Fuzzy Controller

The proposed system presents major difficulties in calculations as vehicle steering response is highly non-linear. As such, the model should be approximated through fuzzy logic to accommodate irregularities.

The controller will operate on two dimensions. The first will describe the desired longitudinal motion of the vehicle. The possible states will be accelerating, neutral, braking and stopped. The second dimension will describe the required lateral yaw of the vehicle ranging from hard left and incrementing to hard right. Table 4.2 shows the resultant state table of the torque vectoring controller.

Table 4.2: Torque Vectoring State Table

Condition	Value	Accelerating	01	Neutral	11	Braking	10	Stopped	00
Straight	000	000	01	000	11	000	10	000	00
Slight Right	001	001	01	001	11	001	10	001	00
Mid Right	010	010	01	010	11	010	10	010	00
Hard Right	011	011	01	011	11	011	10	010	00
Slight Left	101	101	01	011	11	101	10	101	00
Mid Left	110	110	01	110	11	110	10	110	00
Hard Left	111	111	01	111	11	111	10	111	00

The lateral condition specifiers will dictate the torque ratios calculated in section 4.3.1. For the longitudinal specifiers ‘Accelerating’ and ‘Braking’ denote a change in direction of desired torque. This will be achieved through acknowledgement of the use of either the accelerator or brake pedal by the driver.

The ‘Neutral’ and ‘Stopped’ states are independent states of the vehicle. In neutral no torque is applied as neither the brake nor the accelerator pedal will be operated. Under the stopped condition, the driver will have their foot on the brake pedal. If the vehicle is in motion this will apply a negative torque value to the tyres, however we do not want torque to be applied if the vehicle is already stationary.

If the vehicle is stationary and no pedal is pressed then it will the car will be in the

'Neutral' state. This facilitates manual movement (pushing) of the vehicle if required.

4.5 Model Discussion

This particular model has been chosen for a number of reasons.

Firstly, by scaling the amount of torque at each wheel to the radius of its turning circle (and therefore to the length of the turning circle), each tyre will experience less drag and slip during cornering. Although this will still occur, minimising it using torque vectoring will prolong the life of the tyres.

Figure 4.3 shows the resultant forces when applying separate torques to each wheel individually. These forces do not account for the lateral friction force that acts across the direction of rotation for each tyre.

As a difference in force is supplied to each side of the wheel during a turn an extra turning moment is created by the motors as shown in figure 4.4. The moments in figure 4.4 are the resulting moments from the forces on each tyre shown in figure 4.3.

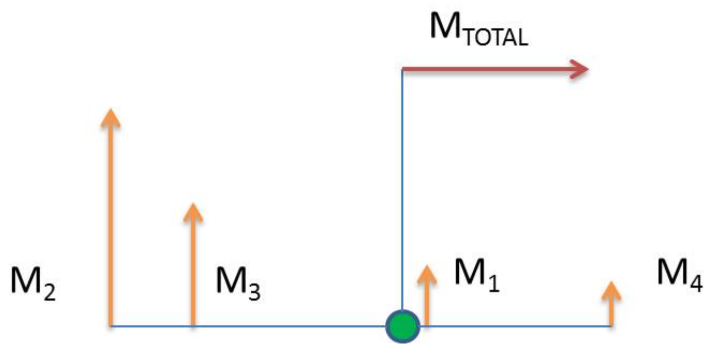


Figure 4.4: Torque Vectoring Moment

This will produce two effects

1. The driver will be able to achieve the same vehicle yaw rate with less steering input when compared to a drive system without torque vectoring [18] and
2. The vehicle will achieve the desired yaw rate in a shorter period [17]

These effects lend themselves well to racing environments where vehicle handling is important. For the FSAE-A competition handling is considered to be the most important performance factor in a vehicle as the track being used rarely lets vehicles reach tops speed.

Chapter 5

Traction Control

5.1 Introduction

As discussed in chapter 2.3, traction control can be applied through various methods in modern motor vehicles. Most commonly it is applied under reactive circumstances in the form of ABS. However, due to the restrictions of the FSAE competition we will not be exploring this as a traction control method. We will be continuing the developments of [9] and [27] with the Maximum Transmissible Torque Estimation technique. The advantages and disadvantages of using this method over other traction control methods is discussed in section 5.3.

Where [9] and [27] have both developed their system using two wheel drive vehicles, we will be developing a similar system for a four wheel drive vehicle. This will provide the opportunity for a more comprehensive traction control system at the cost of easily measuring road surface condition. As this project is aiming to provide results on the traction control methodology we will be assuming a constant road surface condition. Developing a system to accurately measure road surface condition for a four wheel drive vehicle falls outside the scope of this project.

5.2 Traction Control Process

The MTTE technique utilises knowledge about the road surface condition to predict the coefficient of friction between the tyres and the road surface, μ_{road}. This prediction is then used to calculate the maximum force that can be applied through the wheels in a given situation.

As the FSAE vehicle is utilising four individually controlled motors, one for each wheel, we will be applying the MTTE technique to each tyre individually. The aim of employing this technique in this manner is to achieve maximum vehicle performance without losing control of the vehicle.

Figure 5.1 shows the traction control process.

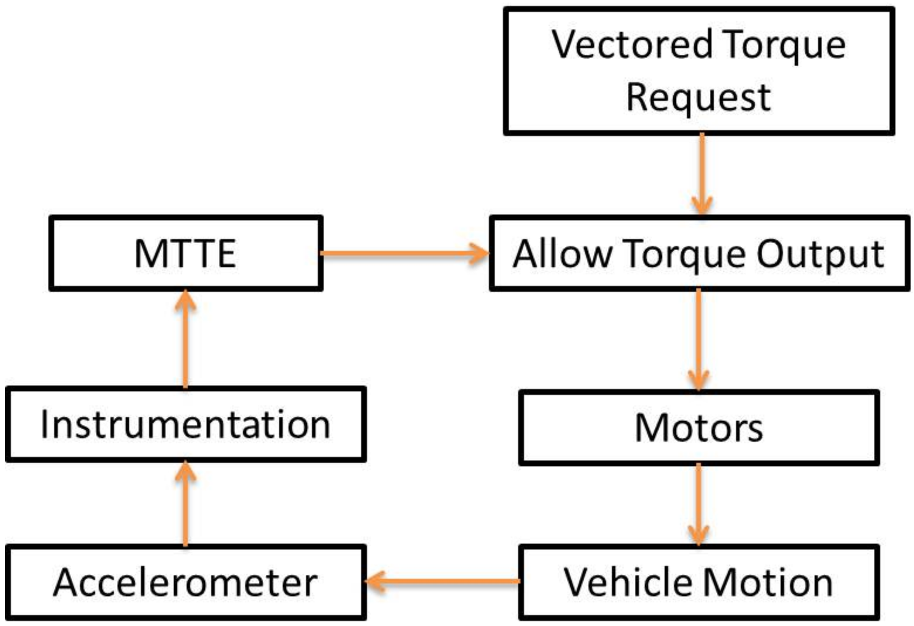


Figure 5.1: Traction Control Process

5.2.1 Maximum Transmissible Torque Estimation

To calculate the MTTE we will be receiving information from an on-board accelerometer via the instrumentation system. The accelerometer will provide information on both lateral acceleration (a_{lat}) and longitudinal acceleration (a_{long}). This information will then be cross referenced with known vehicle parameters such as weight, weight distribution and size to calculate the vertical force being applied at each wheel. An MTTE for each tyre, $[\tau_{FRmax}, \tau_{FLmax}, \tau_{RRmax}, \tau_{RLmax}]$, can then easily be calculated using the known variable μ_{road}.

Lateral acceleration, as that produced during cornering, will produce a load transfer from left to right, or from right to left, for the vehicle. An example is shown in figure 5.4.

The lateral load transfer is calculated as follows;

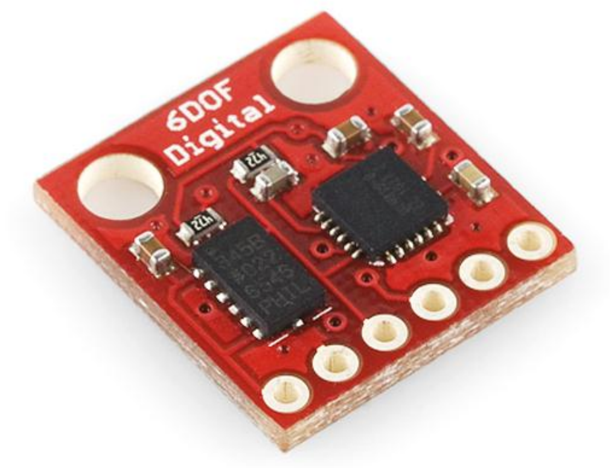


Figure 5.2: Accelerometer

$$transfer_{lat} = \frac{a_{lat}mh}{w} \tag{5.1}$$

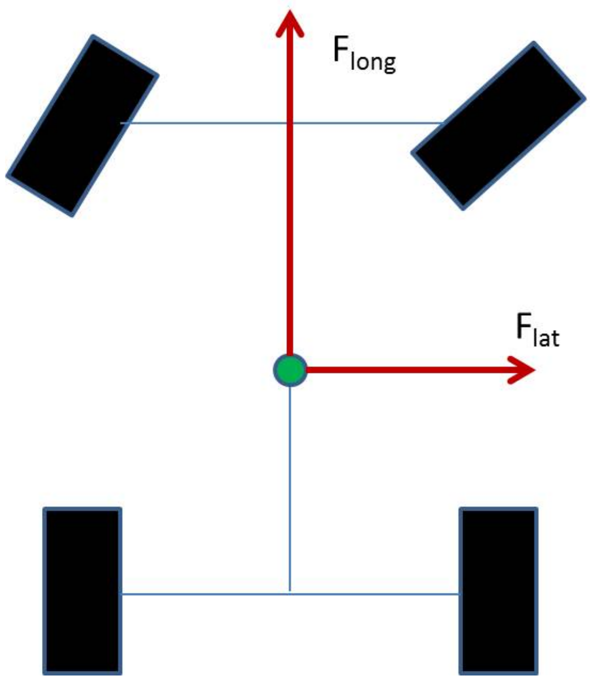


Figure 5.3: Lateral & Longitudinal Forces

m is the mass of the vehicle (in kg), h is the height of the Centre of Mass (CoM) and w is the vehicle width. For convention, we will assume a_{lat} to be positive when turning right and negative when turning left.

Longitudinal acceleration, as experienced when accelerating or braking in a straight line, will produce a load transfer between the front and rear tyres. Similarly to the lateral acceleration, it is calculated as follows;

$$transfer_{long} = \frac{a_{long} m h}{l} \tag{5.2}$$

Intuitively, we will assign a_{long} to be positive when accelerating and negative when braking. l is the length of the wheel base.

To calculate the total force acting vertically on each wheel we must also know the original load on that wheel. This is calculated using the standing weight distribution for

Figure 5.4: Lateral Load Transfer [32]

the vehicle. For the FSAE car the distribution is 45:55-Front:Rear and 50:50-Left:Right.

Due to design symmetry, each tyre will be subject to one half of the load transfer in both the lateral and longitudinal directions. The total downward force on each tyre is as follows;

$$F_{FR}{=}(0.45)(0.5)mg - \frac{a_{lat}mh}{2w} - \frac{a_{long}mh}{2l} \tag{5.3}$$

$$F_{FL}{=}(0.45)(0.5)mg + \frac{a_{lat}mh}{2w} - \frac{a_{long}mh}{2l} \tag{5.4}$$

$$F_{RR}{=}(0.45)(0.5)mg - \frac{a_{lat}mh}{2w} + \frac{a_{long}mh}{2l} \tag{5.5}$$

$$F_{RL}{=}(0.45)(0.5)mg + \frac{a_{lat}mh}{2w} + \frac{a_{long}mh}{2l} \tag{5.6}$$

To convert this total vertical force on each tyre into a maximum torque for each motor we need to incorporate μ_{road}, translate that maximum allowed horizontal force into a torque for the tyre using r_{tyre}, and then adjust for the reduction gearbox using g_{ratio}. Thus

$$\tau_{FRmax}{=}\frac{\mu_{road}F_{FR}r_{tyre}}{g_{ratio}} \tag{5.7}$$

$$\tau_{FLmax}{=}\frac{\mu_{road}F_{FL}r_{tyre}}{g_{ratio}} \tag{5.8}$$

$$\tau_{RRmax}{=}\frac{\mu_{road}F_{RR}r_{tyre}}{g_{ratio}} \tag{5.9}$$

$$\tau_{RLmax}{=}\frac{\mu_{road}F_{RL}r_{tyre}}{g_{ratio}} \tag{5.10}$$

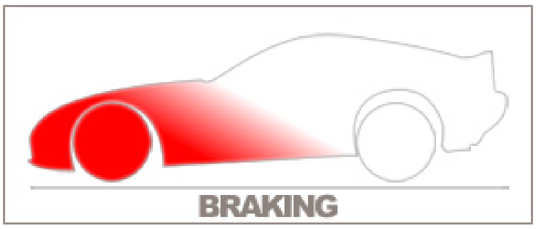


Figure 5.5: Longitudinal Load Transfer under extreme braking

5.2.2 Torque Request

In the next step, the traction control method will compare the values from the MTTE with the values of the Vectored Torque Request (VTR - section 4.3). Provided the absolute value VTR does not exceed the MTTE for each tyre individually it will forward the torque request to the motor controllers.

5.3 Advantages & Disadvantages

This traction control method has a major drawback of needing a new system to measure road surface condition. As stated in [16] and [25], this is not very easy to achieve in a four wheel drive vehicle.

Currently, as stated earlier we are assuming a constant road surface condition in order to test the viability of the traction control system. This can, and should, easily be tested on different road surfaces to compare the performance of the system under different (but constant) conditions.

One option to overcome this issue is to use a flywheel, or trailing wheel. Using such a wheel which is in constant connection to the ground but not capable of producing a driving force will be able to provide the information needed for this system to be applicable in varying surface conditions.

However, applying a fly-wheel to the vehicle is not practical for use on the road. It will produce an unnecessary drag force and, if situated outside the main silhouette of the vehicle, could cause hassles with parking and road safety.

Another, more advanced option that might be considered is laser technology. Similar to that used in computer mice, laser technology may be able to provide information on actual vehicle speed to compare with measured wheel speed.

On the positive, the systems biggest advantage is its flexibility. By providing an MTTE for each individual wheel the system is permitting the car to perform even if one tyre must be restricted due to limited availability of traction.

For example, during take-off the REV SAE car will experience rapid acceleration. Design estimates suggest that 0-100km/h will be acheivable in approximately four seconds. This rapid acceleration will apply a large load transfer to the rear wheels and potentially will cause the front wheels to reach their MTTE, even at low speeds. However, the rear wheels will be permitted to continue drawing larger currents until their MTTE's are reached separately. This is shown in figure 5.6.

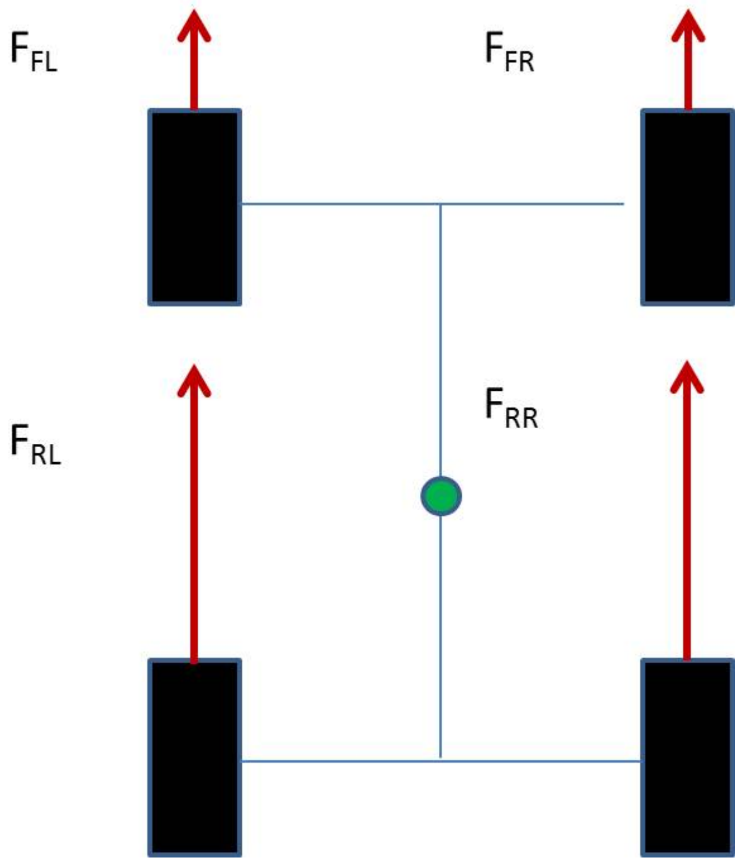


Figure 5.6: Resulting Forces using MTTE - Straight Line

This will prevent wheel slip and therefore slow the tyre degredation process. It will also reduce energy wastage as current drawn is directly proportional to torque output.

As the system is preventative, and not brake-based reactive (ABS), the torque output and performance of the motors is not being mechanically limited. This will also save energy.

Another major advantage of using this system is that the vehicle will remain stable during more extreme driving conditions such as racing. The preventative traction control system will provide the driver with enhanced vehicle stability. While it will not be completely "fool-proof", it will ensure a safer driving situation, especially for inexperienced drivers.

Unfortunately, the drawback of using this system is that it is only an estimation. In order to ensure the traction control works as desired a safety factor will need to be applied to the final product. This will reduce the final capabilities of the system and may limit the maximum performance of the vehicle. However, this should not affect the REV SAE car as we will be applying the system during testing and for a race event. The safety factor in these cases is likely to be very small in order to extract maximum performance from the vehicle.

Chapter 6

Project Management

6.1 Introduction

This chapter will outline and discuss the management of the REV-SAE project. It includes components of the executive management and design decisions regarding the vehicle. The discussions will consist of the processes involved, obstacles encountered and solutions to those obstacles. Finally, there will be an outline of the work still to be completed and recommendations for future REV-SAE teams.

6.2 Vehicle Concept

The REV-SAE vehicle is to be a purpose built vehicle that will facilitate research into electric vehicles for the REV project. By designing the vehicle from scratch, REV will be able to incorporate designs and components that are suitable for the areas of research we wish to explore. This provides many opportunities for undergraduate, and post-graduate, students to apply theory learnt in university in a practical manner that far exceeds the experiences obtained from laboratories and tutorials.

In previous projects, such as the REV Commuter and the REV Racer, commercially available vehicles were obtained and then converted to an electrical propulsion system. This method was employed mainly due to cost restrictions and the infancy of the REV project itself. It imposed many design limitations on the vehicles as already existing components had to be accounted for and system design was required to fit into a pre-determined space. This vehicle would allow students to design the vehicle as necessary before construction began, making the implementation of electrical power a much easier process.

In addition to being a research vehicle, the REV-SAE car is to compete in the FSAE-A competition to be held in Melbourne, in December of this year. This is an even greater opportunity for students to apply their knowledge and experience project execution in a real-world environment. It is to compete in the Electric Category at the competition.

6.2.1 Project Initialisation

Professor Thomas Bräunl was the instigator of the project. As the conversion of the Lotus Elise (REV Racer) was coming to completion in mid-2010, a new project needed to be implemented to ensure the continuation of the REV research group. The FSAE-A competition provided an excellent setting, providing a main goal to be achieved and facilitating continued active research into electric vehicles.

6.3 Resources

6.3.1 Students

The REV group is comprised of mostly undergraduate students completing their Final Year Projects (FYP). Few remain involved after completion of their project to pass on knowledge and provide assistance if necessary. At the beginning of the year we had very limited human resources to work with.

The REV project is comprised mainly of Electrical & Electronic Engineering and Computer Science students. As this vehicle was to be designed from the very beginning, we also needed to employ mechanical knowledge to achieve our goals. Three mechanical engineering students were sourced for the team: Brendan Waterman and Jacob Salter designed and built the chassis as their FYP's and Marcin Kiszko completed the designs for the suspension as his FYP.

As the vehicle will be designed and run on electronics, computer science students were also involved. Frank Yi Tan developed performance testing software and Alexandros Andronis designed the Instrumentation system.

Midway through the year we were joined by several international students who would be studying at UWA for the second semester. Valentin Falkenhahn from Universität Stuttgart, Adam Wojcik, Michael Mellitt, Eric Huston and Megan from Notre Dame in the United States of America. Their areas of expertise allowed them take up some of the minor mechanical and mechatronic components of the car that would need to be completed.

Ian Hooper, a masters student at UWA, was already involved with REV through the Western Australia Electric Vehicle Trial. His research into WHM's provided an avenue for the development of the propulsion system of the car. Professor Bräunl had instigated the new project with the view of researching WHM's. Ian also has extensive experience working with Electric Vehicles and this experience has been utilised extensively throughout the vehicle.

Throughout the year several students have been involved briefly who could not commit to the team on a regular basis. All of the students who are involved will be receiving academic recognition. This has proved the main motivation behind attracting team members.

6.3.2 Prototype

In 2010, the REV Project acquired the UWA Motorsport chassis from 2001 to do a prototype conversion. This prototype was modified slightly to fit the electrical components required. It consists of two

Figure 6.1: Prototype REV SAE Car

6.3.3 Workshop and REV Lab

The REV project currently works out of the G.50 automotive lab in the Electrical Engineering building at UWA. This laboratory is subject so university and faculty safety guidelines [33] and all students must complete a Safety Induction [34] before being allowed access to the lab.

No dangerous work may be conducted in the lab, which includes various mechanical processes such as welding, cutting or drilling and electrical work classified as High Voltage (HV) or Low Voltage (LV). Only Ultra-Low Voltage (ULV) work was permitted.

Figure 6.2: The REV Project Lab

This limited the amount of work that could be performed in the lab outside of design and fitting.

Additionally, due to an accident involving the REV Racer and the REV Commuter during semester 2 of this year, extra safety restrictions were imposed by the faculty. Initially this composed of a complete access ban to the lab except under special circumstances. This lasted for 3 weeks. Subsequently, the following were implemented;

- A ban on *all* work, dangerous or not, conducted on *any* vehicle within the lab unless an academic or technical supervisor was immediately at hand;
- Limiting lab access times from 24/7 access to between the hours of 8am and 6pm on weekdays and
- Students were required to sit a further safety induction outlining the changes and emphasising the repercussions of breaching any safety rules.

The REV project also works closely with the Electrical Engineering Workshop. The workshop has performed much of the mechanical and mechatronic work on previous vehicles in order to meet Western Australia Road Laws.

6.3.4 Funding, Sponsorship & Public Relations

6.3.4.1 University Funds

The main limiting factor for the development of the REV-SAE vehicle was access to funds. The University already supports the UWA Motorsport Team and was reluctant to dedicate further funding to support a second team at the same event. This limited REV to what allocated funding it already received from the University and to funding from sponsorship.

6.3.4.2 Sponsorship

The REV Project had received major funding from industry for previous projects. These funds had extended to cover those projects but little remained to support the construction of a new vehicle. In order to proceed, the REV-SAE team needed to find additional sponsorship from elsewhere.

In-line with previous projects completed by the REV team the initial approach was to ask suppliers for sponsorship in the form of goods in return for advertising with the group, mostly as sticker space on the car. However, the REV-SAE car was to be significantly smaller in size to the other REV vehicles and thus space on the bodywork would be limited. The decision was made to seek out one major cash sponsor and then use those funds to cover the costs of entering the competition and building the vehicle.

The REV-SAE team canvassed widely in the industries of engineering, energy, motor vehicles and electronics. An example of the letter sent to business is included as appendix A. Contact was mostly through email or phone call. Understandably, the response rate was quite low. Very few companies responded to the requests and even fewer accepted an invitation to visit the REV lab.

Swan Energy, involved in the Renewable Energy industry, agreed to sponsor the car in return for sole ownership of sticker space over the vehicle. FSAE-A competition requirements state that the nose must be be kept clear for the competition sponsors, but the rest of the vehicle is at the discretion of the team within certain guidelines. The sponsorship was worth $25,000 AUD and would cover the majority of costs associated with building the car and entering the FSAE-A competition.

Figure 6.3: Swan Energy Logo

This partnership has proved useful to Swan Energy, as will be discussed in section 6.3.4.3, but could potentially lead to much greater benefits for the REV Project. The parent company of Swan Energy, Korean conglomerate LG [**?**], has shown great interest in the REV Project. This has resulted in visits from LG executives form Korea and has the potential to lead to further sponsorship deals for REV in the future.

Figure 6.4: LG Logo

6.3.4.3 Public Relations

As our Principal Sponsor, Swan Energy are entitled to certain benefits from the REV-SAE car and the REV Project. This includes acknowledgement in all press releases and access to the sponsored car for marketing purposes. A copy of the REV Sponsorship brochure is attached as appendix B.

This has included newspaper articles, photography and university based events such as open days. Swan Energy had only one major marketing request of the REV-SAE vehicle, and that was to have the car available for display at the Perth Royal Show, October 1-8. This ensured that the car was in a transportable state by the beginning of the show. However, it was also a week during which we would have no access for the continued production of the car.

Our next major event will likely be the official vehicle launch as a thank you and formal recognition to both the university and Swan Energy for enabling the REV-SAE project to be undertaken. This will be a press-release event with invites to industry and media to be sent out to ensure maximum value to Swan Energy for their sponsorship.

6.4 Team Structure & Communication

The REV-SAE team, as outlined in section 6.3.1, is mostly comprised of undergraduate students completing their FYP's across several different schools within the Faculty of Engineering, Computing and Mathematics. Therefore, a strong structure and extensive coordination would be required to complete a working vehicle.

6.4.1 Team Structure

The team structure developed itself in an ad-hoc process. As the students who were involved have been sought out to complete specific components it is quite clear how the team fits together.

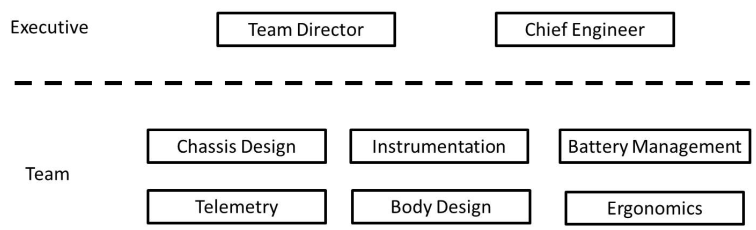


Figure 6.5: REV-SAE Team Structure

Figure 6.5 shows a flat structure with only two layers of hierarchy. The Team Director and Chief Engineer both have executive authority in the team, while all other team members have discretion over their vehicle components.

The Team Director (TD) and Chief Engineer (CE) positions were necessary for reasons of design cost and integrity.

All team members would consult the CE for advice, information or inspection of their designs. The CE ensured that all components would work well together and informed team members of necessary adjustments where required. The CE also oversaw the majority of construction methods required, material selection, component selection and vehicle safety.

The TD also provided a point of contact for advice, but was mostly concerned with cost and timeline management issues. If components would be too expensive, take too long to make or needed to be sourced from overseas then the TD would offer alternative solutions or suggest that further work needed to be done to improve the design. Additionally the TD coordinated all team meetings, organised sponsor or university related events, was the point of contact with FSAE-A officials and was responsible for ensuring that the required documents be submitted on-time for competition entry as discussed in section 6.5.

6.4.1.1 Communication

There were two prominent methods of communication between team members.

The main method of communication, and by far the most effective, was face-to-face. Section 6.3.3 outlines how the team was given access to the REV Lab in the Electrical Engineering (EE) building. This allowed very easy communication as members would often be completing work in the same workspace. It also allowed for easy clarification, understanding and development of ideas that needed to be discussed. Consequently, the REV team now know each other very well and will no doubt enjoy the lack of each others company on completion of the project!

Secondly, where face-to-face communication was not possible, email was used between members. This was often the case from the TD as team notices needed to be issued, meetings organised and information passed on. All team members had easy access to email, so there was no concern over not receiving them. However, team members would often not respond to emails from the TD due to the high volume of emails sent each week. This sometimes caused issues when extremely important information was accidentally missed by team members.

The team also employed the use of the *subversion* server that the REV access utilised on campus [35]. This was used for the storage of up-to date design documents and access to information regarding other sections of the vehicle. This served as an extremely useful tool during the design and manufacture stages, and has significant potential if it can be improved.

Having a centralised information centre provides significant advantages over physical filing systems and having to source information from other team members. If this centre can be improved to also include discussion pages, notices and upcoming deadlines then it

Figure 6.6: Team Discussion

would provide benefits to deadline adherence, communication and overall team progress. In concert with this would be the ease of dissemination of information and the ability to recall earlier discussions that had taken place, all of which would have a positive impact on team management.

6.5 FSAE-A Requirements

6.5.1 FSAE-A Rules

As the REV-SAE vehicle is being entered into the FSAE-A competition, as mentioned in section 6.2, we must also conform to the rules and guidelines set by the competition organisers.

FSAE set the main competition rules each year and the local competition organisers issue addendum as required by law or preference in their particular country.

The Electric category of the competition is a recent addition (2010 was the first year it was held in the Australasian competition, and only two cars competed!) with little development in comparison to the ICE categories. FSAE-A requires that cars entering the in the Electric category in 2011 conform to three sets of rules.

1. The FSAE 2011 rulebook;
2. The Formula Student Electric (FSE) 2011 rulebook. Where there is conflict

Figure 6.7: RMIT 2010 Electric Vehicle, courtesy RMIT

between the FSE and FSAE rulebooks, the FSE will overrule the FSAE; and

3. The FSAE-A Addendum. Where there is conflict between the FSAE-A Addendum and either of the other two rulebooks, the FSAE-A addendum is to be adhered to.

This caused many problems when conforming to the necessary safety requirements for the competition as it took considerable time to ensure that the correct guidelines were being followed. The REV-SAE team will be submitting a report to the FSAE-A competition to outline our issues with such a procedure as the efforts involved are onerous and are often repeated due to confusion.

6.5.2 FSAE-A Competition

The FSEA competition is an Engineering Design Competition. It is aimed at providing university students with real-world experience and learning that is seldom achievable within university courses. FSAE competitions are held throughout the year in multiple locations around the world [36].

The structure of the competition requires competing teams to design, build and eventually race open-wheel formula race cars in a supervised environment. The vehicles are completely designed and assembled by students and in many cases the components are manufactured by them as well.

Figure 6.8: UWA Motorsport ICE Vehicle [37]

In order to promote well designed cars in an equal playing field the competition is scored on a points-based system that incorporates both static and dynamic events. The maximum score available is 1000 points, however it is extremely unlikely that any team would achieve this. The static events total 350 points, but they do not require the vehicle to be completed. Teams that struggle to finish building their car due to a lack of manpower or funding can still score points for their engineering design. They are

- Cost Event - 100 points
  The cost event measures how much the vehicle would cost based on a theoretical cost table (reference cost table and EV cost table here) provided by the competition organisers. Scores are spread evenly from 50 - 0 with the car that is theoretically cheapest to build scoring maximum points, and the most expensive scoring 0.
- Engineering Design - 200 points
  This is a judged event completed in stages. Cars that impress the judges with innovation, implementation or *"cool engineering"* and are scored according to certain criteria. The top cars are then put through to the Design Final for the top teams to be ranked. The best ranked team is awarded points determined by the judges, to a maximum of 200, with subsequent teams awarded points based on there ratio to the score of the winning team.
- Presentation - 50 points
  The presentation event is also a judged event. This is an opportunity for teams to *"Sell"* their car to a hypothetical business.

The Dynamic events total 650 points for the competition and are the physical test of what the teams set out to achieve. In each event, maximum points are awarded to the team with the best score for that event. Subsequent teams earn points based on their relative score to the winning team for each event.

- Accerleration - 50 Points
  This event is a straight line event. It measures the time it takes for a car to travel 100m from a standing start.
- Skid Pad - 75 Points
  The Skid Pad is designed to test the maximum handling capabilities of the car. Drivers complete a figure of eight track in the quickest time possible.
- Autocross - 100 Points
  The Autocross is a single lap sprint of a pre-determined course. Teams complete the track in the quickest possible time. This also determines the starting order for the Endurance event.
- Endurance - 350 Points
  The Endurance event is carried out on the same course as the Autocross, however it is multiple laps and also requires a driver change. In total it is a 22km time trial. Teams aim to achieve the quickest time.

- Fuel Economy - 125 Points
  For the Electrical teams, this is a measure of how much charge is used during the endurance event. The team with the lowest energy usage is awarded maximum points.

6.5.3 FSAE-A Action Deadlines

In addition to conforming to the rules a significant amount of documentation is required by FSAE-A to prove compliance. These were to ensure the vehicles entered into the competition are safe to drive and that no teams have an unfair advantage due to available funding or other resources.

Appendix C shows the action deadlines for the FSAE-A 2011 competition. In hindsight, it would have been much easier to dedicate a single student to completing the forms as required as many of them took quite some time. The Design Report and Electrical Safety Form were particularly time intensive. Our inexperience as an FSAE team proved to be the biggest obstacle to overcome in completing these forms ahead of time.

6.6 Design & Planning

The design of the REV-SAE vehicle was a recursive process which involved heavy communication between various team members.

6.6.1 Budget

After acquiring the additional sponsorship required (section 6.3.4.2) the team needed to be aware of what funds were available for the car. The initial draft budget produced is attached as appendix D. This budget required all team members to provide researched cost estimates for their components. Once these estimates had been put in team members would be advised of necessary changes in order to stay within our monetary restrictions. Additionally, the FSAE-A Competition requires a Cost Report to be submitted prior to the competition.

This Cost Report normalises the cost of all systems used by a vehicle that is entering the competition. Values are partly based on an average of actual component costs found in industry. They are determined by FSAE-A and a cost look-up table is provided for teams to reference during reporting. This report is extremely time consuming.

6.6.2 Electrical Design

The main focus of the Electrical Design of the vehicle was the implementation of Wheel Hub Motors. While the REV-SAE team did not design the motors, the incorporation of these motors into the vehicle design was student driven. Cost was the main factor in motor selection.

The team purchased four Turnigy CA12070's. They are 15kW, PMSM motors designed for light aircraft use. They have been fitted with hall sensors to make them suitable to use in the tractive system of a motor vehicle. They are to be installed in each of the wheels on the REV-SAE car.

The electronic systems on the car were designed to utilise four wheel hub motors. Consideration for traction control, driver control, vehicle stability, vehicle feedback and vehicle safety needed to be considered. The traction control system forms a component of this project and is developed in Chapters 4 and 5.

6.6.3 Mechanical Design

The mechanical design of the REV-SAE vehicle was performed mostly in the *SolidWorks* programming environment. The mechanical team members of REV-SAE had to keep the rules of the FSAE competition in mind (section 6.5) and the budget available to the group (section 6.6.1).

The mechnical components of the vehicle were broken down to Chassis, Unsprung, Suspension and Bodywork. The Battery Management System(BMS) also formed part of the mechanical design as there are strict rules regarding the energy storage devices for electric vehicles and how they must be protected.

All of these components are interdependent and, importantly, they must also incorporate all of the Electrical Designs of the vehicle. In particular, the suspension must allow for the wheel hub motors. This presented many difficulties in design and in production. The chassis must allow for the batteries, but it does not have to allow for engine space. This provided the mechanical designs a lot of freedom and also considerably reduced the length of the car.

6.7 Manufacture & Construction

Due to the restrictions outline in section 6.3.3 the majority of the manufacture of the REV-SAE vehicle was completed off-site. The schedule for construction and testing attached as appendix E.

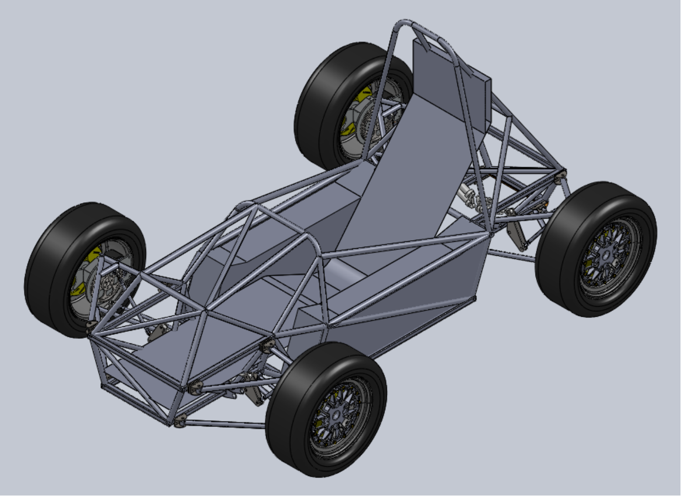


Figure 6.9: Isometric View of Chassis Design

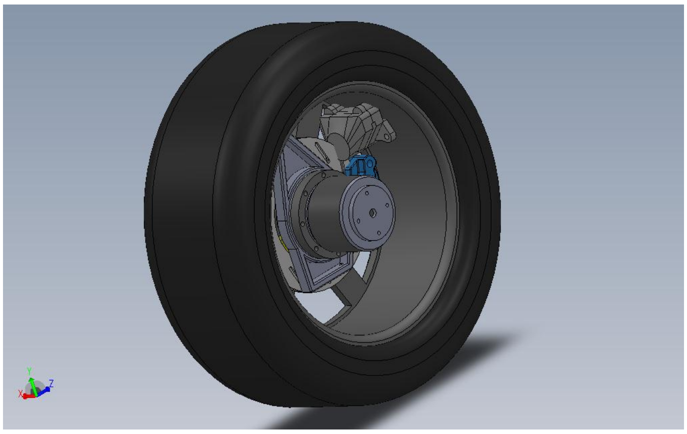


Figure 6.10: Draft Unsprung Setup

6.7.1 Chassis & Main Components

6.7.2 Subsystem Design & Installation

Many systems on the REV-SAE vehicle, once designed, were able to be built prior to the main chassis being completed. However, this wasn't realised until late September and the construction was already behind schedule. It was also made difficult due to the limited number of team members able to contribute to the construction phase of the car.

The benefits of having the subsystem and components built early are immense.

Instead of the vehicle being built and then waiting for each component to also be completed, the finished components can simply be installed once the car is ready to receive them.

6.8 Future Recommendations

The REV SAE team of 2012 can make countless improvements on how the 2011 team was run and organised. In order to work towards optimising team management the team should consider the following recommendations.

6.8.1 Team Director

The Team Director should be someone who is not also completing a technical component of the vehicle. The time requirements of running and organising the team are substantial and any future team director will need exceptional time management skills to perform well. In particular there are many tasks that need to be required which fall outside of required university commitments and assessment. These include public relations, sponsor relations, communication with competition organisers and discussions with other FSAE-A teams.

6.8.2 Planning

The planning this year was inexperience and subsequently unrealistic. The general 'rule of thumb' among formula SAE teams is the rule of π. That is, make your realistic estimation of how long it will take to complete a project/component and multiply that estimation by π. This will give you a very good approximation of how long that project or component will actually take.

All team members need to be actively involved in planning. Those who are completing segments of the car are often in the best position to provide information on their progress status. Also, if the team members are involved in setting their own deadlines they are more likely to meet them. Externally imposed deadlines are generally met with resistance or scepticism and should only be applied when necessary ie. when the rules require it.

As an extension, the team plan should be created and published at the beginning of the year. A program such as Microsoft Project can be used to show the Gantt chart and project progress at any given time. Team members should have access to the team plan at all times. This team plan should include, but not be limited to, items such as

- Gantt Chart
- Project Progress
- Project Deadlines
- Component Progress
- Tasks to be completed and personnel requirements
- Tasks currently being completed
- Upcoming events and
- Additional Personnel Requests

6.8.3 Communication

As discussed in section 6.4.1.1 there is room for improvement in the communication between team members.

An active discussion board for the team would provide an effective method of discussing and distributing up-to-date information between members. In conjunction with a published and updated team plan team members will now have access to all items that have been formalised (drafts, deadlines, tasks etc) as well as ideas and thoughts suggested by other team members. It would also provide an excellent tool for the team director and chief engineer to disseminate important information as they receive it such as competition updates or new upcoming events for the team.

Additionally, team members should be required to attend a minimum number of team meetings. This could be enforced through rewards (extra driving time, meal vouchers) for attending the required number *or* penalties (academic penalties, cleaning tasks) for not attending at least the required number of meetings. These meetings are an important process and provide an excellent opportunity for in depth discussion of ideas and issues. If team members miss them then the whole team loses productivity as that persons knowledge is no longer able to contribute to the team's progress.

6.8.4 Team Size

Team Size was the biggest hurdle encountered by the 2011 team. Ultimately, the team did not have the manpower to accomplish the tasks required in order to meet the competition deadlines. Other university studies were often postponed or given a lower priority in order to complete items such as the design and cost reports, Structural Equivalency form and Failure Modes and Analysis form.

Where possible, vehicle components should be broken down to their smallest tasks and then those tasks assigned on an individual basis. This will enable more accurate tracking of project progress and also make the tasks to be completed less daunting for students who may want to be involved.

6.8.5 Collaboration

The 2011 team did not enjoy a healthy relationship with any other FSAE-A teams. Unfortunately, UWA Motorsport considered the REV SAE as a 'threat' to their possible future funding. Several approaches were made by the team director, chief engineer and academic supervisor but the Motorsport team were generally unwilling to provide any assistance or advice until very late in the year.

The Royal Melbourne Institute of Technology has offered to be of assistance in the coming years. They have extended an invitation for some of the UWA REV team members to visit and help out with their efforts at the 2011 FSAE-A competition in order to gain some first hadn experience about what is necessary in preparation. They have also expressed interest in sharing knowledge and methodology with UWA to help both teams progress further in their designs for the coming years.

6.8.6 Continuation

The 2011 team has built a chassis for the FSAE-A competition that has not been used. This gives the 2012 an almost 12 month head start if they continue to use the current chassis and build on the design. It conforms to all of the FSAE-A rules but still needs a fair amount of work to be completed. Continuing with the current project, instead of beginning a new one, would provide enormous time savings to the 2012 team. This will assist in ensuring that a car is produced in time to compete in the 2012 FSAE-A competition.

Chapter 7

Conclusions

This project turned out to be quite ambitious in nature.

A Torque Vectoring model for the REV SAE vehicle has been designed and suggested, as has a Traction Control System. These have both been designed with the view of competing in the FSAE-A competition later this year.

The management of the REV SAE vehicle itself constituted more than one full unit load throughout the year with regards to time.

Overall, the design and construction of the mechanical components of the REV SAE car dictated the development speed of the electronic components. In particular, the construction and testing of the tractive control system has been delayed until beyond the end date for this project.

While the car was ultimately not completed during the lifetime of this project, the management of the car to this point has still proved invaluable. The REV group is in a good position to continue development and begin real-world testing with the REV SAE vehicle. It is also in a very strong position to use the vehicle in the 2012 FSAE-A competition as the majority of the mechanical work has now been completed.

The REV group has earned valuable experience during the construction of the REV SAE vehicle. The students involved have been exposed to many aspects of large engineering projects that are rarely experience by university students.

The final aim for this project was to design and test an algorithm that incorporated both the Torque Vectoring Model and the Traction Control Systems that were developed. This aim proved too ambitious as the afore mentioned aim of managing vehicle design and construction proved to be far more time consuming than expected.

7.1 Future Work

This project laid the foundations for a number of projects to be completed in the future. In order to compete in the 2012 FSAE-A competition an enormous amount of work still needs to be undertaken over the next 12 months.

7.1.1 Electronics

The Battery Management System has been designed but still needs to be constructed. This will adequately prove to be a 3rd year project. This will need to be in concert with the construction of the accumulator housing on the vehicle.

The instrumentation system is ready to be constructed and installed. Alexandros Andronis has designed the system and produced a program to run the instrumentation, physical construction and implementation is the next step.

The design and programming of the tractive circuit still needs to be completed as this project did not achieve this aim. This can be performed and annexed with all performance testing on the vehicle to assess the effectiveness and efficiency of the torque vectoring model and traction control system.

This can also be supplemented with developing a system to accurately estimate the road surface condition for the vehicle to further enhance the capabilities of the traction control system.

7.1.2 Coordination

All of these projects will needed to be managed and coordinated. The REV SAE vehicle should aim to be completed mid-2012 in order to be completely ready for the 2012 FSAE-A competition.

All of the required documentation will need to be completed for the competition. This process in itself is best assigned to a single person as an individual project. Documentation preparation and submission can be time consuming and poorly completed if not handled correctly.

Most importantly, all of these tasks must conform to the FSAE-A rules. Ensuring and achieving this has proved to be an onerous task. Project coordination and management should also be a stand alone role assigned to someone not completing a technical aspect of the REV SAE vehicle.

The final aim for the current REV SAE car should be to compete in the FSAE-A competition at the end of 2012. The future work suggested in this project should be undertaken with that goal in mind.

The Electric Vehicle research that The REV Project pursues will be produced as a direct bi-product of achieving this end.

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THE UNIVERSITY OF WESTERN AUSTRALIA

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01 April 2011

Dear REV Follower

You may already have heard about the Renewable Energy Vehicle Project (REV) at UWA. We are pioneering the development of electric vehicles and are the only Australian university that has built road-licensed electric cars. In 2008, we converted a Hyundai Getz to electric drive to show the feasibility of an everyday electric commuter vehicle. We have also recently completed an electric Lotus Elise, demonstrating that electric cars do not have to be slow, but can be powerful sports cars as well.

Our next project is involves developing an open-wheel formula electric race car. Our aim is to compete in the Formula Student Electric competition (http://www.saea.com.au/formula-sae-a) to be held in Melbourne in December of 2011. The competition provides a platform for university students from around the world to participate in cutting edge research projects and apply them in a real world situation. We currently have a very dedicated team of staff and students working on the project, designing the vehicle to meet competition requirements.

The project does require funding and we would like to invite your company to financially sponsor Formula REV. Any sponsorship you may be able to provide would be much appreciated and will be mutually beneficial to both the REV team and to you. Your sponsorship funding will enable us to develop cutting edge renewable energy technologies that are both applicable to Formula REV as well as the other vehicles involved in The REV Project. It will also allow students involved in the project to showcase their ingenuity and help keep UWA ahead of the innovation curve.

Our sponsorship levels for the Formula REV car are as follows

- Principal Sponsor - $20,000
- Silver Sponsor - $5,000
- Bronze Sponsor - $2,500

As a Team Sponsor you will have your company logo displayed appropriately on the Formula REV car. You will also be acknowledged in all written press releases associated with Formula REV, have first-hand access to the work we do, be invited to all REV events and meet our team of final year and postgraduate students. We will even organise a track day for you and your staff to test drive the Formula REV car and other REV vehicles.

If you decide to become our Principal Sponsor you will also have naming rights for the racing team and exclusive access to the Formula REV car for your evaluation or marketing purposes.

If you are interested in being a sponsor but none of the above categories suit you, then please contact us to discuss further options. We are always grateful for any support that can be provided and would love to organise a solution that works well for everybody involved.

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01 April 2011

This is a fantastic opportunity for your business to help in the development of Renewable Energy Vehicle technologies.

For further details please contact me on 08 6488 1763 or visit our website at http://theREVproject.com

Regards

Thomas Braunl

The University of Western Australia
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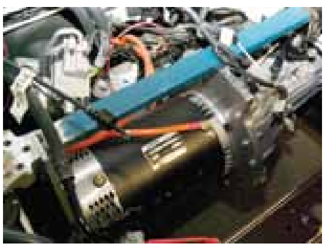
Renewable Energy Vehicle Project (REV)

2011 Project Information



The Renewable Energy Vehicle project (REV) is an initiative formed by The University of Western Australia to design and develop environmentally sustainable technologies for future transportation. In times of rising fuel prices, growing air pollution and global warming, finding ways for sustainable, environmentally friendly transportation is a fundamental goal.

REV re-started in 2008 under new leadership and has set the goal to demonstrate the viability of renewable energy sources for transport in a pollution-free environment. After evaluating hydrogen techniques in previous years, REV decided to go electric and has developed a plug-in electric commuter car in 2008 and an electric sports car in 2009/2010. Although electric cars are not a new invention as they have been around for over a century, recent advances in motor, battery and controller technology make electric cars a viable alternative to petrol cars today. REV students and staff at UWA are developing electric zero-emission vehicle technology using the latest research and technology.

Emission-free power generation for charging the vehicle is an important part of the REV strategy, as power generated by burning fossil fuels would only shift the pollution problem elsewhere. This is why REV generates its own clean power using grid-connected solar panels on the building's roof (much more efficient than on a car's roof) and draws power from the grid for charging.

In 2008, REV established itself by building a commercially viable, cheap and efficient electric single charge. The vehicle can achieve speeds of up to 125km/h and costs as little as $1.40/100km to operate (the petrol version of this car costs over $10.00/100km to run). The car incorporates cutting edge technology developed within UWA, including outside volunteer developers.

This document describes the many aspects of the REV project and welcomes interested parties to join us in this fantastic endeavour either through volunteering, sponsorship, donations/subsidies or just by coming down for a visit.

For further information please visit our website:
www.theREVproject.com

The Team

The project is the co-operative effort of a team consisting of:

- Over 45 students from graduate, penultimate and final years from varying disciplines of Engineering including Mechanical, Mechatronics, Electrical, Computer and Software.
- Industry-leading academic staff with industry experience supervise, moderate and assess student reports and work, of which form a component of student marks.
- UWA technical support staff who support students in project development and installations, offer assistance, resources and advice on practical components of the project.
- Volunteer support staff who are members of local organisations and business groups (such as WAEVA) that volunteer their time and advice with project direction and often lend a hand in the project.

Funding

The project is funded primarily by The University of Western Australia and The WA Department for Planning and Infrastructure. In addition, it is supported by donations from industry and government organisations in the form of cash or in-kind sponsorship. In-kind sponsorship is a non-cash based contribution of goods or services. REV values all levels of sponsorship and recognises these efforts through returned support, exclusive event invitations, vehicle advertising and media exposure.

Media

A key component of the project is raising public awareness of the need for sustainable transportation, therefore the project aims to gain significant media exposure over the coming years. This will not be difficult to achieve – the technology is as interesting and exciting as it is a vital goal for a sustainable future. REV participates in and is expected to attend the following events in upcoming years: Perth Motor Show, ResourCity, Greenhouse, Sustainable Living Expo, Perth Sun Fair, and UWA Expo, as well as a number of various related motoring and sustainability related events. The vehicles will also be displayed around Perth schools and developed into an awareness program to educate primary and secondary school students about sustainability.

Internet

The project has a website which lists more information about the project, including specifications, achievements and upcoming events, as well as photos and videos of our vehicles at various events.

Partnership

Industry partnerships can be established between the UWA REV Project and an organisation that wishes to have research and development conducted in an area of interest to both parties. For example, if a company has a proposed design of an electric motor, an agreement can be established whereby UWA REV team members perform the required R&D.

Levels of Sponsorship

All sponsors will:

- Have access to research and testing results within their area and receive a certificate with recognition of their support, according to sponsorship level;
- Have the opportunity to join the UWA REV Project Sponsor's Database, enabling sponsors to share contacts, information and resources with each other;
- Receive invitations to REV events and regular project progress reports;
- Be featured on the REV website.

PLATINUM (AUD $50'000+)

- Large logo on the REV car, posters, newsletters, pamphlets, websites
- Support acknowledged in media (radio, television, print, presentations)
- Detailed description of company/services on certain promotional material
- Presentation and display of REV car and team at company events
- Exclusive 30 day REV car access for company events, evaluation or promotion

GOLD (AUD $25'000+)

- Medium logo on the REV car, posters, newsletters, pamphlets, websites
- Presentation and display of REV car and team at company events
- Exclusive 7 day REV car access for company events, evaluation or promotion

REV Specifications

REV Spec Sheet	REV Eco (2008)	REV Racer (2009/2010)
Base car	2008 Hyundai Getz	2002 Lotus Elise S2
Seats/doors	5 seats / 5 doors	2 seats / 2 doors
Original engine	1.4l, 4 cylinders, 70kW	1.8l, 4 cylinders, 116kW
Electric motor	Advanced DC FB-4001, DC	UQM Powerphase75, AC
Controller	Curtis 1231C, 500A	UQM DD45-400L, 400A
Power, Torque	28kW, 136Nm	75kW, 240Nm
Regenerative braking	No	Yes
Instrumentation	EyeBot M6	Automotive PC
Batteries	Lithium-Ion-Phosphate, 45 x 90Ah	Lithium-Ion-Phos.,83 x 60Ah
Battery weight	135kg	191kg
Voltage	144V	266V
Total capacity	13kWh	16kWh
Total weight (petrol, electric)	1160kg, 1160kg	780kg, 936kg
Top speed	125km/h	200km/h (estimate)
Range	80km road-tested	100km road-tested
Charging Time	6h (full charge)	6h (full charge)

SILVER (AUD $10'000+)

- Small logo on the REV car, posters, newsletters, pamphlets, website
- Guided tour and presentation by the REV team at UWA

BRONZE (AUD $5'000+)

- Small logo on posters, newsletters, pamphlets, websites
- Guided tour and presentation by the REV team at UWA

Contact

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Phone: +61 8 6488 3897
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Website: www.theREVproject.com

APPENDIX PDA - 1

Action Deadlines for 2011 Formula SAE Australasia

See www.sae-a.com.au/fsae/index.htm for rules specific to FSAE-A

All submissions must be received at the SAE-A Office by 5:00 PM on the defined date.
Note that due to time zone differences, teams may need to submit ahead of this time.
Early submission of all items is highly recommended.
Email confirmation of receipt will be given for all submissions within two business days of receipt.
Note that the US Rules for late receipt apply except where otherwise noted earlier in this Addendum.

1. Registration - Opens June 27, 2011. Closes July 29, 2011
Registration forms may be obtained by:
Email from the SAE-A Office: formulasae@sae-a.com.au
On-line from SAE-A: www.sae-a.com.au/fsae/index.htm

2. Safety Structure Equivalency Form - September 9, 2011
See Appendix B-1 of US Rules
Submit on line in Adobe Acrobat.
Formula SAE-A Technical Committee
formulasae@sae-a.com.au

3. Impact Attenuator Data Requirements – September 30, 2011
Submit on line in Adobe Acrobat.
Formula SAE-A Technical Committee
formulasae@sae-a.com.au

4. Design Report, Design Spec Sheet
& Student Activity Disclosure Form – September 30, 2011
Submit as Adobe Acrobat format
E-mail: formulasae@sae-a.com.au

5. Cost Report must be received by - Electronic Version October 14, 2011
- Hard Copy Version October 21, 2011
Post: Formula SAE-A Technical Committee
SAE-Australasia
Level 2, Suite B – 70 Dorcas Street
Southbank 3006
Australia
E-mail: formulasae@sae-a.com.au

6. ESF & FMEA – (Electric Vehicles Only)

Formats will be made available on the SAE-A website as well as via Formula Student.
Submit ESF as both Adobe Acrobat format as well as hard copy.
Submit FMEA in hard copy. **- Electronic Version September 30, 2011**
- Hard Copy Version October 7, 2011

Rules Enquiries concerning **Formula SAE Australasia only** Send via email to:
SAE-A Rules Committee. Email: formulasae@sae-a.com.au

Chassis		Electronics		Cabin Design		Wheels		Misc	
Component	Cost	Component	Cost	Component	Cost	Component	Cost	Component	Cost
Chassis	$ 1,000.00	Contactor	$ 300.00	Seat	$ 300.00	Brakes	$ 1,460.00	Transport	$ 2,000.00
Suspension - Wish Bones	$ 800.00	Emergency Stop	$ 300.00	Dashboard	$ 250.00	Tyres	$ 2,000.00	Driver Training	TBA
Suspension - Shocks	$ 1,600.00	Fuse	$ 300.00	Harness	$ 300.00	Wheel Rims	$ 1,200.00	Spare parts?	TBA
Rolling Shell	TBA	Batteries	$ 4,000.00	Pedal Box	$ 400.00	Gear Boxes	$ 900.00	Nuts & Bolts	$ 250.00
Bodywork	$ 1,000.00	Battery Caging	$ 800.00	Brake Cylinder	$ 500.00	Hub Components	$ 1,000.00	Materials	$ 500.00
Steering	$ 200.00	Charger	$ 1,000.00	Brake Lines	$ 100.00			Fire Extinguishers	$150
		Motors (for 4)	$ 1,500.00	Brake Lights	$ 20.00			Race Suits	$500
		Motor Controllors	$ 2,000.00						
TOTAL	**$ 4,600.00**		**$ 10,200.00**		**$ 1,870.00**		**$ 6,560.00**		**$ 3,400.00**

$ 26,630.00

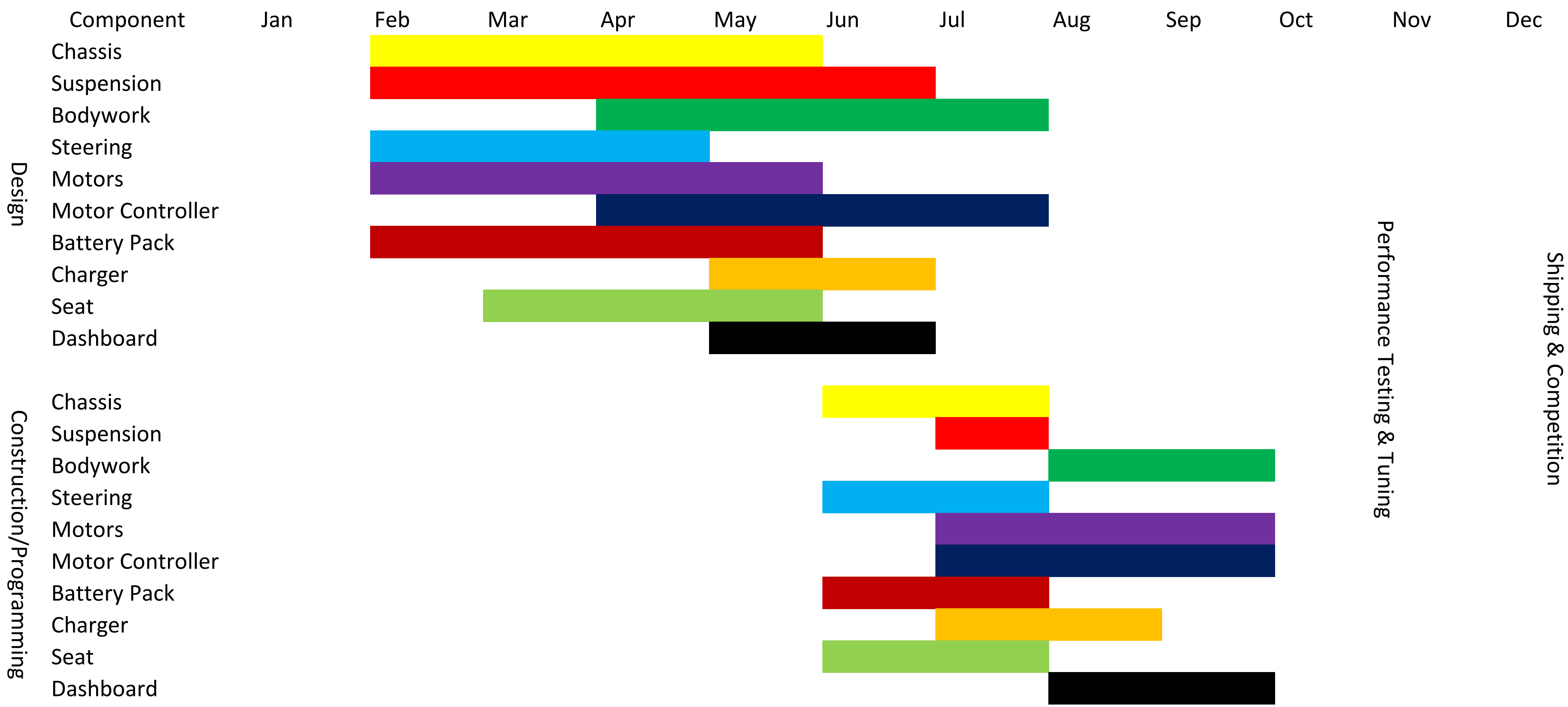
NOTES

Ian may be able to source the batteries from EV Works. We will have to look into the benefits of getting them from EV works for cheap versus the cost of buying some extremely high performance ones.

The Cost of the motors is assuming the Turnigy motors are purchased. Once Ian has done some further testing with the two test motors in the lab we will be able to decide whether to purchase the German motor or the Chinese Motor for the other 3 we require.

I have not included any travel allowances for the team as of yet. This is something I think we should seriously consider closer to the competition date.

This is only a draft budget at this point in time based on estimates made by Ian and myself at the beginning of the year. We will review it this week to see if it needs updating.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Bodywork
Steering
Motors
Motor Controller
Battery Pack
Charger
Seat
Dashboard
Performance Testing & Tuning
Shipping & Competition