Towards All-Electric FSAE Race Cars

S. Watkins, G. Pearson and M. King

Abstract—Formula SAE is described, which is the largest student-based competition in the world, with over 200 university teams involved. An overview of the RMIT team from Australia is provided, which has won competitions in USA, UK and Australia, including concurrently setting lap records and using the least amount of fuel. The first all-electric FSAE car is described, utilising electricity generated entirely sustainably. We also detail a second generation car which builds on the lessons learnt from the first and features regenerative braking.

***Index Terms*—FSAE, Electric, Sustainable, Race, Car**

I. Introduction: What is FSAE?

The Society of Automotive Engineer International (SAE-Int) defines FSAE as follows;

"The Formula SAE® competition is for SAE student members to conceive, design, fabricate, and compete with small formula-style racing cars. The restrictions on the car frame and engine are limited so that the knowledge, creativity, and imagination of the students are challenged. The cars are built with a team effort over a period of about one year and are taken to the annual competition for judging and comparison with approximately 120 other vehicles from colleges and universities throughout the world. The end result is a great experience for young engineers in a meaningful engineering project as well as the opportunity of working in a dedicated team effort" The above statement reflects the rules and numbers of teams for the major event in the USA circa 2009. However, a similar competition has been run in the USA for over three decades. Environmental concerns have led to the adoption of a hybrid competition (run in parallel with the standard IC event), the allowance of ethanol fuel (with minor revisions to the rules, including reducing restrictor size) and a new event for all electric cars, which will be held in Germany in August 2010.

The history of the competition can be traced to 1976 when SAE-International started to run student Mini Baja competitions; off road races named from the Baja 1000 race in Mexico. The push for a road race equivalent of this – Mini Indy - came from the company Briggs and Stratton, who in 1979 supplied 5 hp engines and thirteen teams competed. The first FSAE competition, held in 1981, permitted any four stroke engine and limited the power via an intake restrictor – a regulation that remains to the present day. Events are now running around the world including in the UK, Brazil, Italy, Germany, Australia and Japan, with more events planned.

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Simon Watkins is a Professor, Geoff Pearson is a lecturer and Matthew King is an honours student in the School of Aerospace, Mechanical and Manufacturing Engineering at RMIT University, Melbourne, Australia. Contact for Simon Watkins: phone +61399256084, fax +61399256108, email simon@rmit.edu.au

Figure 1 RMIT 2007 IC-Powered Car

Figure 2 RMIT 2008 First Electric FSAE Car

Whilst there are slight variations between countries, the rules are based on the USA competition outlined below:

The competition is made up of eight separately evaluated events – three of which are static (i.e. static studies on each car and sometime a presentation to an industry panel) and five dynamic (i.e. evaluation based on measured car performance parameters). A complete version of the rules covering the events, regulations pertaining to the cars etc. can easily be found on the web [1]. A brief description of each event, including the points allocated, is given below.

Presentation 75 points: Here one or two students from each team must present their business case to a panel for the limited volume production of their vehicle. Many aspects of

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the car, (e.g. design for mass manufacture) are usually presented and other aspects often include potential plant layout and return on investment. We have found it useful to consider this as presenting to venture capitalist to give confidence in achieving a good return on investment.

Design 150 points: "The car that illustrates the best use of engineering to meet the design goals and the best understanding of the design by the team members will win the design event". A relatively short document is produced by each team, backed up with design information via stand alone posters (often for each car subsystem) and/or laptop-based visuals. In some countries there is a design final after the dynamic events, where five teams selected via the initial judging are questioned in considerable detail. Judges include well-known race car designers.

Cost Analysis 100 points: Each component on the car is costed (including machining, fabrication etc.) and compiled into a relatively large report. Individual team members are questioned at the event for their understanding on how some purchased components are manufactured. Such items could be ignition coils, rose joints, suspension springs. Teams have prior knowledge of which components will be selected.

Acceleration 75 points: Cars are timed over 75 metres from a standing start. Some of the faster cars can achieve times of 0 to 100 km/h in under four seconds.

Skid Pan 50 points: Here cars are assessed on cornering ability, with time being measured around a simple figure-of-eight track, with minimisation of time being the objective.

Autocross 150 points: The cars are driven separately around one lap of a tight twisty track, with the objective again being to minimise lap time. Since there are no long straights, designs that exhibit good handling with the ability to turn quickly do well. Top speeds are kept low (average speeds of about 50Km/h), aerodynamic devices that are used on other types of race cars (e.g. F1 and Indy) have questionable merit. This is an area of on-going debate for some teams, with some cars opting for lightweight simple designs and no aerodynamics downforce aids, (e.g. Figure 1) and others having multi-element wings.

Endurance 300 points: A staggered start event where cars are driven for multiple laps around a tight twisty track, with the objective again being to minimise lap time.

Fuel Economy 100 points: Here the fuel used during the Endurance Event is measured, with the objective of minimising fuel used. Note that the event was 50 points until 2009 (and the Endurance event was 350).

II. General Lesson Learnt from Competing in the Fossil-Fuelled FSAE Event

A. The Non-Reversible Nature of Time

RMIT University has competed in Formula SAE every year since the competition was first introduced to Australia in year 2000. After four years of learning the competition and establishing internal management processes and support structures, the team began travelling to international competitions in year 2004. Since that time the team has been highly successful in Formula SAE competition, having won four events outright and finishing outright second on two other occasions. Our lessons learnt are presented below and whilst the intent of this paper is not to provide a detailed technical description of our cars, details are available on our website [2].

A student design team has to consider many different and often competing factors to achieve success. Aside from the various vehicle performance compromises that need to be considered (e.g. engine power versus fuel economy, chassis weight versus stiffness, suspension geometry for cornering versus straight-line acceleration, etc.), the students also need to approach practical project issues such as how their design decisions affect cost, manufacturability and marketability. It is worth noting that the first three events listed above, totalling 325 of the 1000 points are based on reports and student knowledge, and a further 100 points are allocated to fuel economy, none of which are traditional criteria for success of a racing car. A holistic, systems approach is necessary to achieve success across the range of events.

Whilst the primary intent of the competition is to expose engineering students to a complete product development cycle (design, build, test), result indicate that this is not being successfully implemented in many cases. Competition results indicate a large proportion of teams fail to complete all the events, and in some cases fail to get a completed car to the competition at all. For example at the 2006 FSAE Detroit competition, only 41 of 121 attending teams completed all events (a completion rate of 33.9%), and a further 19 teams registered for the event failed to attend [3]. Analysis of further recent competition results indicates that this is typical. Students' prior exposure to motorsport (either directly or through the media) often leads to the impression that success is directly related to such factors as large budgets, cutting edge technology and complicated gimmickry. This philosophy is therefore transferred to the team's FSAE project, leading to overly complex design programs and stretched time and monetary resources. This also leads to the non-performance related aspects (i.e. static events) of the competition being overlooked as the team focuses primarily on getting more speed from the car. your manuscript electronically for review.

III. Towards Sustainable Racing: The Challenges and Lessons Learnt in Electric Racing

Several lessons were learnt in this process of designing, building and testing the all-electric cars, and whilst much of the standard IC racing car experience could be utilized the following technical areas provided new challenges:

1) Detailed knowledge of energy and power flows are far more important than in IC racing, since sizing of batteries (and, if utilised, supercapacitors) is crucial to provide a well-balanced vehicle design. The philosophy was to initially size batteries to ensure that there would be sufficient energy and voltage at the end of the longest race (the Endurance Event) to still ensure fast lap times. Further refinement and optimisation could take place using banks of supercapacitors where the electrical energy produced from the motors could be stored temporarily before being fed back

to the batteries or diverted to assist acceleration. Rather than all the energy being turned into heat (as in traditional disk brakes) the short-term stored energy could then be used in subsequent acceleration and thus reduce the required battery capacity. (NB this is similar to the Kinetic Energy Recovery Systems – KERS - used by some Formula One teams in the 2009 season.) To this end an energy simulator was most useful. Inputs included the typical vehicle mass, motor and battery characteristics, estimated velocity/time profiles for typical tracks and tyre grip coefficients. However the practical realisation of the designs and the control strategies was very challenging.

2) Regenerative braking poses other challenges; particularly reliable failsafe mode(s) to ensure driver authority vs computer control authority. Whilst optimum energy regeneration may be dictated by the logic of the electrical control system (changes in battery/supercapacitor energy levels monitored and controlled by on-board computer) this can be in conflict with fast track times. For a rear wheel drive race car, the fact that relatively little braking takes place on the rear (driven) wheels under high deceleration also makes the use of regeneration (and the associated system complication) questionable. NB a graphical illustration of the latter is the ability of motorcycles to perform "stoppies" where the rear wheel is raised off the ground due to weight transfer.

3) A good general design philosophy for a race car is for the unsprung mass (i.e. anything that is between the tyre contact path and the suspension) to be minimised. In an electric car it is desirable from a packaging and design viewpoint, for a hub-mounted motor/generator to be utilised. This conflicts with the requirement for minimising unsprung mass – thus we have mounted the twin motors of our regeneratively-braked car in-board, as can be seen in Figure 4.

4) To permit the relative motion during cornering a rear differential is usually required. In IC racing vehicles (with a single drive from the IC engine) a variety of differentials are employed, including limited slip, or torque-sensing. With twin rear wheel- drive (or all wheel drive) in electric vehicles there is the possibility of varying the velocity and torque to each wheel. Whilst this provides considerable flexibility it provides new challenges in control systems. A simplified control system overview is shown in Figure 5. The sensory inputs to achieve differentiation can include steering wheel angle, or feedback from the motors and encoders to give limited slip or forms of torque splitting.

5) Safety in electrical cars (where volts and amps are present in their hundreds) is critical; this was a learning exercise for both the team and the race scrutineers. In terms of driver safety, a steel space frame chassis is considered less risk that a CF monocoque chassis.

A starting point for sizing motors, batteries and supercapacitors was the lap simulator that was designed to help understand the sensitivities in car design parameters and energy and power tradeoffs. Note that a traditional (IC racing) lap simulator focuses on the simulation of vehicle parameters for minimum lap times – this is usually achieved by maximizing the longitudinal and lateral accelerations and decelerations around a circuit, utilizing concepts such as G-G diagrams, where the lateral and longitudinal accelerations are plotted as the vehicle travels around race circuits. However in an all-electric vehicle there is a much greater sensitivity of vehicle mass to energy carrying capacity (i.e. the energy density of batteries are orders of magnitude less than fossil fuels). Four of the main outputs of the simulator are illustrated in Figures 3 and 4.

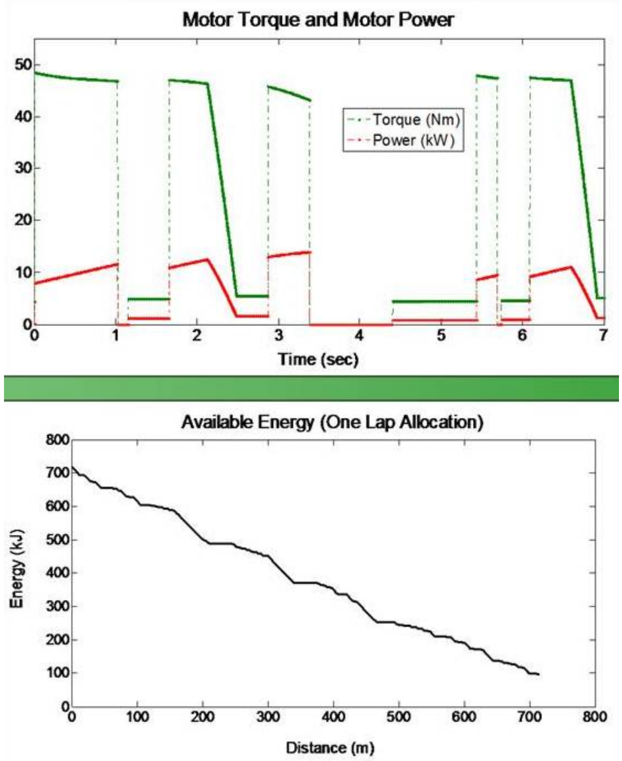

Figure 3 Torque and Energy Performance Simulation

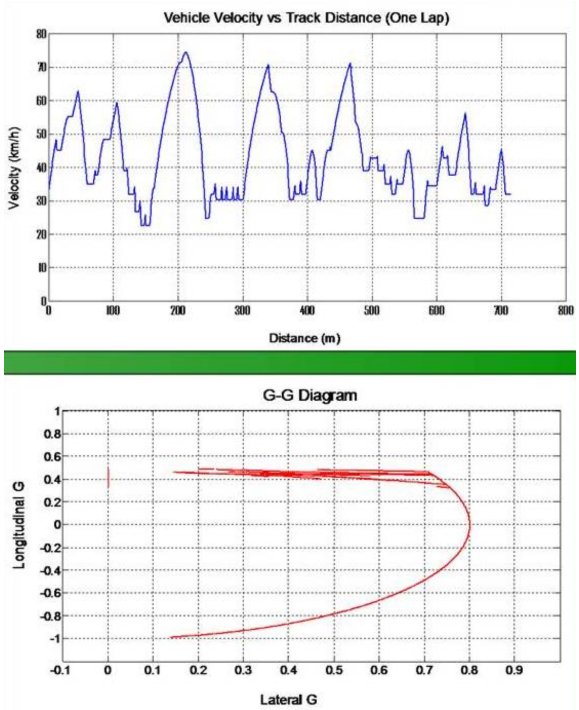

Figure 4 Velocity and Acceleration Simulation

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The graph of available energy is the most important for the team because it is approximating how many batteries should be used to have enough energy to complete the 22km Endurance Event. More simulation work on energy consumption is still to be completed by the team, because as the electrical system is developed further, more information on the performance of motor regeneration and its interaction with the hydraulic brake system and the driver can be input into the analysis to create a more realistic and therefore accurate energy simulation. However, to confirm the simulation results, some physical testing must be done to simulate the driving conditions at the competition and therefore confirm that the vehicle is capable of lasting the Endurance Event.

IV. Concluding Remarks

The changing face of the automotive industry, as it moves away from traditional fossil fuels, is providing both barriers and opportunities for FSAE. Sponsorship for the "traditional" IC cars is increasingly difficult to obtain, yet for bio-fuelled, all-electric and hybrid cars there are new sponsorship opportunities. Technical challenges are many; particularly balancing the requirements for minimum lap times with good endurance in a safe manner. The technology associated with electric cars is in a state of flux; in particular battery technology is advancing rapidly and selection of the "best" batteries and supercapacitors can be likened to hitting a moving target!

Universities must be flexible enough to accommodate increasing interdisciplinary efforts in order to train the engineers needed to ensure a sustainable world – part of which will be sustainable racing. In our experience FSAE has provided a motivating experience like no other, and has resulted in graduates having very strong skills in a wide range of areas, that are directly transferable to their future work opportunities. This is clearly recognised and rewarded by the automotive industries, but not always by academia. FSAE results in enhanced skills that include self and team management skills that are reinforced in a manner that does not usually occur in traditional subjects. Here a challenge to the universities is to provide adequate subject credits for the enhanced learning that occurs. In particular the nature of electric car racing is highly interdisciplinary and crosses the boundaries between the disciplines of automotive and mechanical engineering and electrical and software systems. Whilst the adoption of FSAE in a traditional university environment can prove problematic and at times very challenging, the outcomes are well worth it and include being the most motivating thing that one is likely to encounter in the university environment.

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References

[1] Website giving an overview of the competition and details of the rules and regulations; http://students.sae.org/competitions/formulaseries/
[2] FSAE Results of all teams and events for the 2006 competition; http://www.sae.org/students/fsae2006results.xls
[3] RMIT FSAE website (2009) describing the team, cars and recent history; http://www.fsae.rmit.edu.au/