Chipping Sodbury's Rotary Racer 9

Design and Development - 2011/2012

Introduction

The design for Rotary Racer 9, the 9th car that the team has produced, started after the 2011 Greenpower national final. Rotary Racer 8 had been an exceptional car. During the years of its steady development, the team had managed to win 3 out of the 4 national finals it had entered and it had won a podium position at all of its F24 races (bar one at Merryfield where it was running with a broken motor that had a loose magnet; even so it still remarkably managed 4th in that race). In 2010 the car took a bit of a tumble at Castle Combe, rolling at 29mph round a corner. This provided a good test of its structure, and especially roll bar, it passed this with honours. The car was then modified with a higher roll angle for the subsequent years, just in case. It was a highly reliable car, the only major fault was a failed throttle potentiometer at the 2010 final and even that did not require a trip on Greenpower's trailer. RR8 had many many modifications during its competing years. It was probably modified for almost every race including large modifications, such as moving from the older large car batteries to the smaller AGM batteries and increasing the length with a new tail. As well as the races, it had been shown at many other events including alongside Bloodhound SSC mock ups.

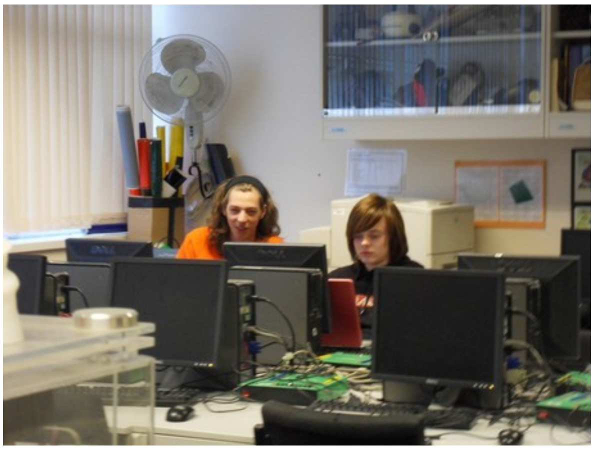
So we started the 2011/2012 season with a quandary. RR8 would no longer match the rules coming in in 2012/2013 so we would have to modify it or build a new car. RR8 was designed for the large car type batteries and the shorter car length rules and was now quite heavy with all of the mods and changes done to the car. We also now had quite a few new members in the team who hadn't gone through the research/design/build of a car. As this is an engineering challenge there was only one solution, a new car. I did suggest we could produce more of a concept car rather than a competitive car, but the youngsters were having none of that; they are competitive :)

A lot of ideas were bounced around the team members both young and old. Finally they coalesced into the following main points:

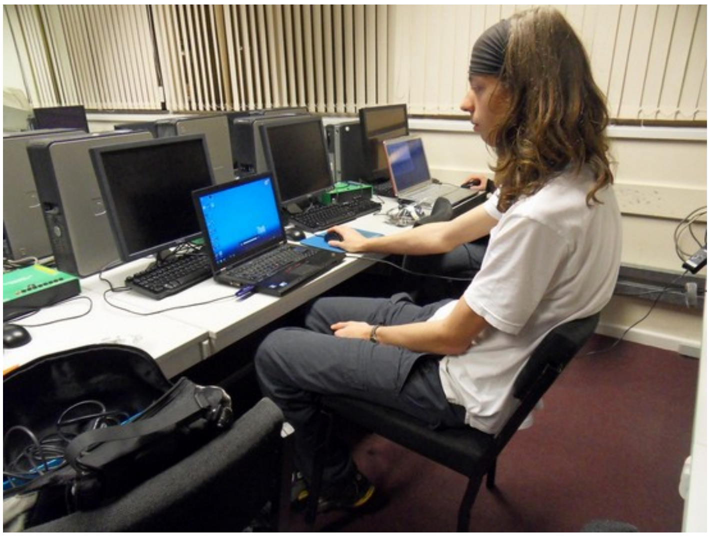
- Need to match 2013 rules. Mainly drivers and batteries bottom less than 100mm from road.
- RR8 was excellent, so base the design on that car but improve bits.
- Improve aerodynamics by reducing cars frontal area and improve the shape.
- Reduce rolling resistance by reducing the weight. Target weight 50Kg (compared to the 75kg of RR8).
- Make driver opening bigger for pit stops to speed this up.
- Improved electronic power control system. Work on new speed controller.
- The car needed to be able to accommodate year 7's through to year 13's. So at least a 6ft driver (ended up allowing a 6' 4” driver).
- Use enclosed rear wheels to improve aerodynamics at the rear end.
- All of the work should be handled by the pupils as much as possible, even more than RR8. We wanted to make sure that the pupils had a large involvement at all stages of the cars development.
- Use even less gaffer tape that RR8!

The Research and Design

Three of the older lads: Gareth, Dan and Ben had turned 16 and thus couldn't compete in the F24 challenge, so they had turned their sights on F24+. They needed a car and with the design and build of RR8 immanent and funds tight we couldn't build one just for F24+. So a deal was made between them and the younger F24 team members. The older lads would design and help with the build of RR9 as long as the F24 members did the work to get RR8 working for the F24+ series in 2011/2012. We hoped to get the build of RR9 well under way before the 2011/2012 season was completed. Gareth, Dan and Ben had been with the team since 2006 and had experience of 3 different cars and building both RR7 and RR8. In particular the new tail added to RR8 during the 2010/2011 season (when car lengths were increased) was designed by Gareth using 3D CAD and the teams VWT. This led to the dominance of RR8 during this season.

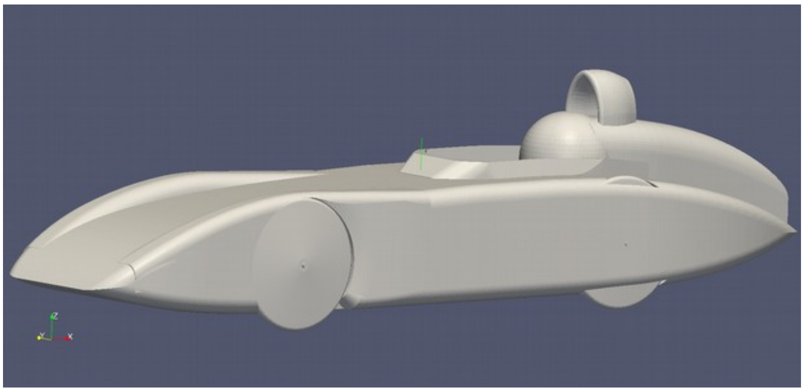


Designing something new is an iterative process and not linear. Initially you approach the design from all angles before a core design idea emerges. We did have RR8 and all of our team's previous experience of building 8 cars and Chipping Sodbury School's other teams' experiences as a basis. We did investigate using composite monocoque construction using carbon fibre and/or GRP. However the costs of doing this were outside of our budget and we didn't have any experience of using this technique. So we planned on using our normal method of 25.4mm aluminium tube and bungs to build a chassis cage, with plywood top and bottom as well as RR8's famous foam sides. We knew we could get maximum pupil involvement in the actual build using this technique and it also would not take too long. However, we still planned on using some carbon fibre composite for some parts to experiment with this technique.

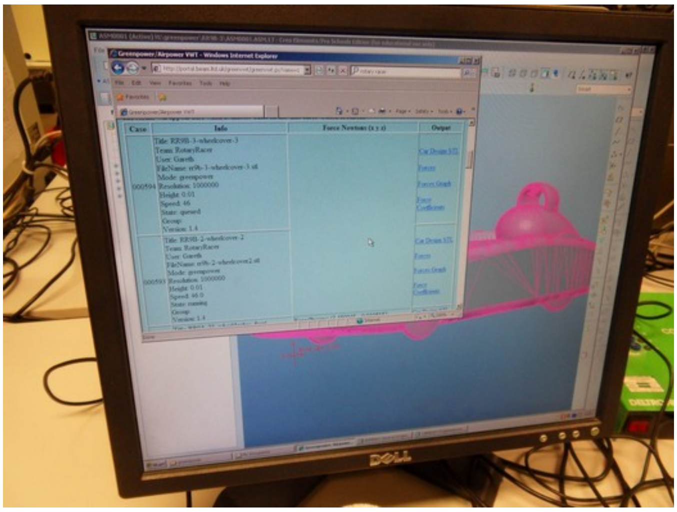


We have found, over the years, that to get the youngsters fully engaged in the build of a car, the oldie helpers need to well understand how to do the work. This allows us to help plan a GP session, have all of the bits available and be able to show the pupils, where needed, how to do things. If the helpers haven't done it before, they end up doing the work, rather than the pupils, as it is difficult to tell/show someone how to do something when you haven't a clue yourself.

As stated, most of the research and design work for RR9 was carried out by the older lads. Looking at the VWT logs, Gareth created at least 124 x 3D CAD design variations that were tried out in the VWT. This was about 2000 hours of individual CPU processing time and I don't know how many hours using the 3D CAD tools. This resulted in a design that had a significantly lower aerodynamic drag than RR8, or at least the VWT said so.



The main changes from RR8 was the reducing the height of the body to reduce frontal area, reducing the width behind the head of the roll-bar and improvements making a better tail shape. But there were many other smaller details. At various stages the design was shown to the team. Us oldies did think the thickness was too small, but the lads and ladesses showed that they could get in and out using a mock-up in RR8. We did veto going down to a 500mm wheel track on safety grounds.



We have developed a Greenpower race simulator (greensim) which is available on the web for all Greenpower teams to use should they ever wish. This allows the performance of the car's design to be simulated on a virtual race track. It uses science and mathematics to model the car, track and basic conditions. It is useful for investigating the main areas to look at in a car's design and to gauge the gearing needed for a race.

The 3D CAD was used for the overall body shape and basic placement of things (driver, wheels, roll-bar etc). For the more detailed internal design and tube design, simple 2D CAD was used. The lads used this to generate the side and top views, and to create the aluminium tube layout. The seat, motor and battery placement was also done at this stage. This did lead to a few 3D CAD changes. 3D and 2D CAD was also used to design the steering and subframe components.

Detailed design bits

The way we have designed the car is to do an overall design with shape and basic placement of parts and then, while the chassis build is under way, do the more detailed design of components such as steering, subframes, motor mounts etc. In engineering terms it would be better to do more of the design upfront, but with the time available and nature of a GP project this allows the actual building work to go on while detailed design work is carried out. Pupils can get actively involved in the building work earlier. Some pupils prefer the building activity and some the design activity. In the past the detailed design work of steering components, brake fittings and sub-frames was done more by the helpers. For RR9 it was much more in the students ball park, probably a mix of about 70/30 between the students and helpers.

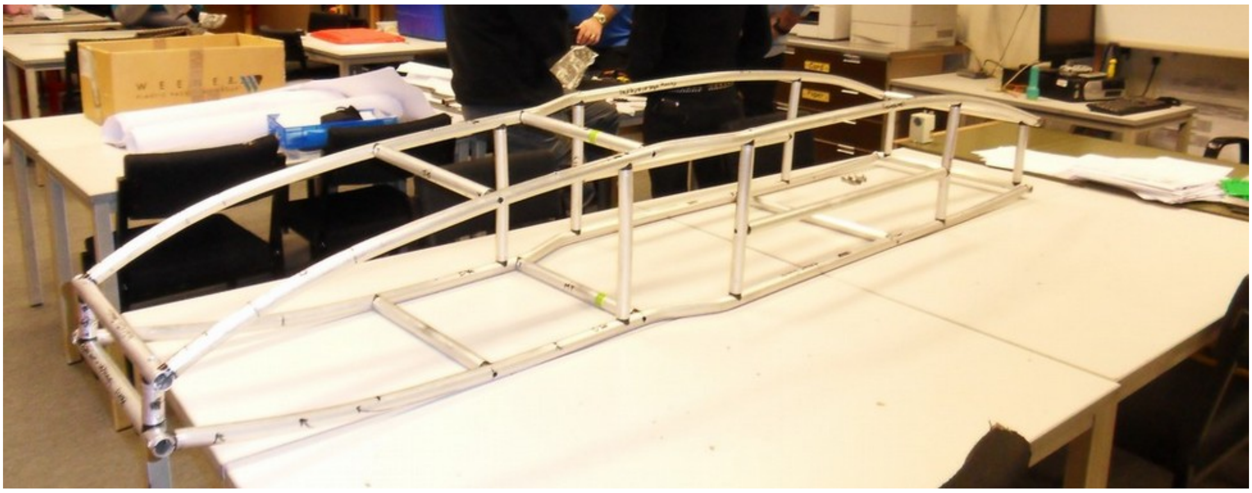
Chassis

We decided to use our age old aluminium tube and plastic bung chassis building technique as we have done on all Rotary Racer cars to date. We did look at using Carbon Fibre/GRP but none of the schools teams had any real experience of doing this and we felt that pupil involvement would thus suffer. The aluminium tube and bung technique is also very adaptable. We can change the car during its development phase relatively easily, providing more engineering work after the initial cars build.

The Greenpower Goblin cars and new kit cars use this technique. The only tools needed are a tube cutter and/or hacksaw and some allen keys and/or allen screwdrivers. All pupils, including year 7's, can handle this work. This generally resulted in having teams of both younger and older students working together, with an adult on hand to provide support and help when needed. Having a full sized 2D plan helps as they can then measure and cut as needed. We also used a parent's tube bender to allow us to get a more complex curved chassis, again the pupils can use this aluminium being a reasonably soft material.

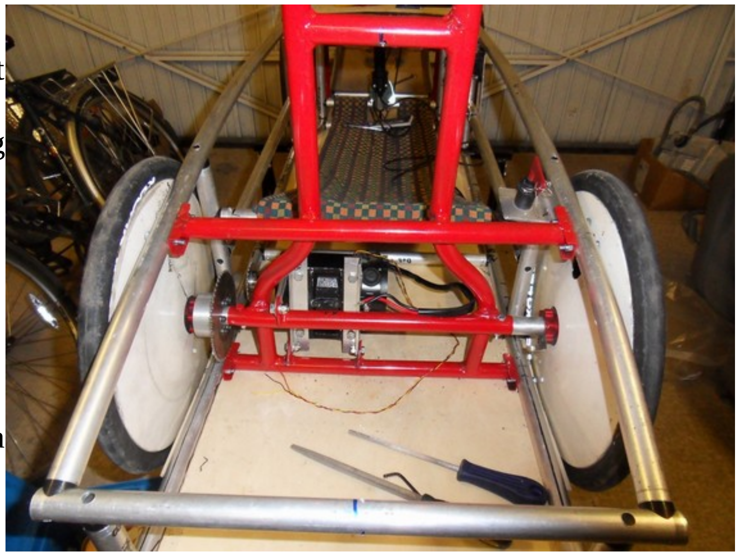
The pupils decided to name rather than number all of the plans tubes, So we have Boris alongside NooNoo and Papa Smurf etc :) Something that the adult engineers found pretty confusing :) The chassis build took about 4 Monday evenings ,lasting 2 hours each, to build.

The chassis design includes many safety related aspects including: cage around the driver, side impact bars, sheet aluminium sides next to the driver, front crumple zone etc.



Rear subframe and Rollbar

The rollbar is an essential safety component in the car and needs to be securely mounted to the chassis. Although aluminium can be used, we have always favoured using steel tubing for this. We can work and weld steel reliably in the workshop and have had lots of experience doing this in the past. As part of our weight saving approach though, we minimised the amount of steel work in RR9 by combining the roll-bar with rear axle and chassis mountings. This probably reduced the about of steelwork by half compared with RR8 and made it stronger in the process. The steel tubing was cut by the pupils using hacksaws, and steel brackets were also made up, again with hacksaws, drills and files. The main tubes were bent using a parent's tube bender and were welded at the school. A parent, who can weld well, did the main welding but nearly all the pupils had a go at doing some welding on the brackets and also test welds on scraps of steel.



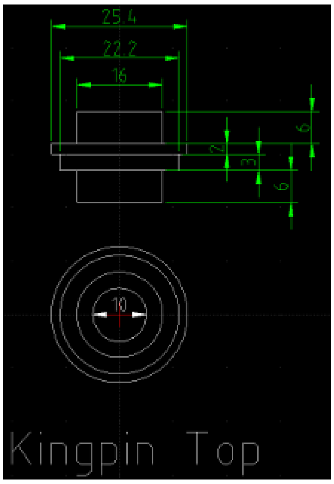
The wheels are mounted to the steel axle with 13mm high tensile bolts into aluminium stub axles. The aluminium stub axles were made by the pupils from bar stock using the school's lathes. The subframe was spray painted and bolted to the aluminium chassis using 8 x 6mm steel bolts.

Also a part of this system is the motor mount. This was designed using 3D CAD. It is mounted using an alternator style system employing some aluminium angle strip. Previous cars used steel angle strips, a small example of weight saving in RR9.

Steering and brakes

There was a lot of discussion on the steering and braking system, mainly in an effort to reduce weight. In the end we decided to use a similar arrangement to RR8 but with simplified and reduced steel content. The design uses 25.4mm steel tubing and lathed and milled 25.4mm steel bar to create the parts. The 3D and 2D CAD designs were done by the older

lads and the parts made predominantly by the pupils. Some 8mm rose ball joints were used for the steering axis pivots and smaller 6mm joints for the steering tie rods.



From CSS's experience the steering geometry is quite critical to a car's stability. The initial idea by new teams is to use a simple go-kart style with no caster, camber or Ackerman angles. This is unsafe on a car that is capable of 40 MPH or more. On RR9 we have a caster angle of 4 degrees, a camber angle of 18 degrees and a calculated Akerman angle based on all aspects of the steering geometry. Why do we need these ?

- **Caster angle:** This is the side on angle of the steering axis (king pin front/back angle) such that the pivot point at the track level is ahead of where the tyre meets the track. It is CRITICAL to have a reasonable degree of caster angle. This provides the negative feedback, self centring nature of steering. If the angle was reversed, the cars steering would simply snatch solidly to the left or right and going straight ahead would be very difficult indeed. Having a 0 degree caster angle (vertical king pins) would mean the car can go into an uncontrollable side to side drive possibly leading to a following roll. This would probably occur at some inopportune moment such as when a side wind hits or at a bump on a corner. Higher levels of caster angle make the car less twitchy and smooth at the expense of quick agile steering. It is better to err on the side of smooth steering for new young drivers, but having too much might make the steering to heavy in young hands.

- **Camber Angle:** This is the front on angle of the steering axis (king pin sideways angle) such that the pivot point at the track level is close to where the tyre meets the track. This is less critical than the camber angle but still important. Ideally the pivot point should be close to where the tyre hits the track. When this is so (called centre point steering) then if you hit a bump or object with one wheel the steering will not suddenly pull to one side. Also when applying the brakes, if one wheel loses traction there is not a yank on the steering. However, the driver can lose some "road feel", so a cm or so inside the tyre is often chosen as we have on RR9.
- **Ackerman angle:** This is important for efficiency and thus for doing well in the GP challenge. When cornering, the inter wheel follows a tighter curve than the outer one. Its turn steering angle should thus be greater than the outer wheels. If not, the tyres will scrub losing precious energy as friction. A rough angle is to point the steering arms from the kingpin to the centre of the rear axle. This however is often quite inaccurate, especially if simple tie rods to a joystick arm are used. There are on-line

spreadsheet based calculators that can be used for a more accurate (and thus more efficient) angle to be calculated.

The steering design required some lathe and milling work as well as some mig and gas welding. The brakes use cycle disk brake mechanisms that use a mechanical cable linkage for operation. The AVID BB5 units were used as they were relatively low cost but of a good quality. The students also had bikes using these which helped witch checking out the design.

Seat and Joystick

The seat uses a similar arrangement to RR8. This is a hammock style seat made from woven cloth and woven webbing strip. The pupils have always favoured this from a comfort view as well as allowing a large range of driver sizes to be accommodated and being relatively easy to make.

The seat was designed by some of the younger pupils and then made by them using sewing machines. It was difficult to find a sewing machine which was strong enough to handle the thickness of cloth, especially where the webbing was, but they managed to achieve it. The seat is tensioned by wrapping it around a tube that can be rolled to increase tension. This had to be done a few times as the cloth stretched during initial use.

A Greenpower car has a major challenge over a road car. The size of drivers it has to accommodate is huge. We wanted to accommodate small year 7's up to huge 6' 4” year 12's. That is a tall order :) The hammock style seat helps with this as does our adjustable Joystick. We had planned on designing and making a new Joystick assembly for RR9, but time got the better of us and so we took the one we made for RR8. This has an aluminium bar with a key-way to allow around a 50mm adjustment in position.

The Body

In order to produce an efficient car, aerodynamics is a key factor. In fact, it is the major factor. Most of the design work focused on this. In order to achieve it we had to have a good shaped body to fit the design. One method would be to use composite techniques. We didn't really have the experience or time for this and so we used the technique we had used on RR8. This uses 50mm Styrofoam sheets glued together with thin epoxy glue and shaped using simple tools.

Due to the main chassis shape, most of the top and the bottom of the car can be flat across the car's width and hence we used 4mm plywood for this. Shaping of the foam was done with a mixture of: jigsaw, power plane, sureform, rasp files and course sandpaper.

One good thing about using foam is that the car's shape can be easily developed during the following years. Bits can be cut, glued and shaped as needed.

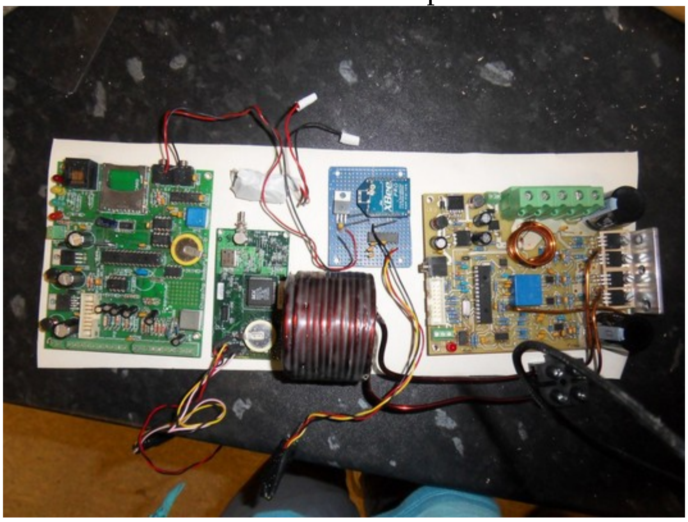
We did use a bit of carbon/kevlar composite material in its construction. The battery platform consists of the 4mm bottom plywood, with a two layer carbon/kevlar composite with 4mm foam internals on top. Below the driver we also used a layer of carbon/kevlar composite to strength this area where the driver steps in and help protect the drivers back. The rear wheel covers also had carbon/kevlar treatment to strengthen the thin 1mm plywood used.

One innovative idea was the opening bonnet. This was one of the main ideas fed back by the pupils from the pit stop aspects of the race. They were finding it difficult to adjust the seatbelts properly, adjust the steering position and show the marshals that all was done up correctly. The solution they came up with was a hinged bonnet. With the bonnet closed the opening was still large enough for the largest students to exist in a timely manner, but with the bonnet open everything was easily accessible and it was easier for the drivers to get in and out. This improved pit stop safety and the speed of pit stops.

Once shaped the whole car was given a coat of kitchen emulsion paint. This is by no means ideal but it was quick, cheap and easy for the pupils to do. We hope to better finish our cars in the future ...

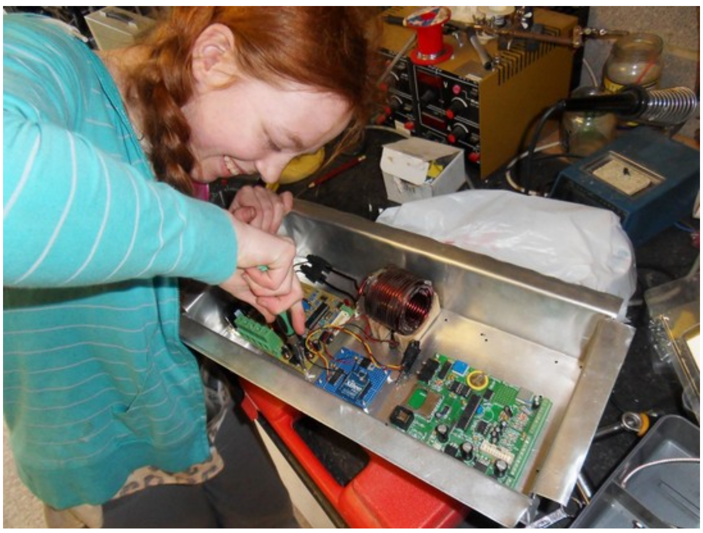
Electronics

Due to the new build we decided to use most of the electronics from RR8. During the 2011/2012 season the RR8 car was going to be used for both F24 and F24+. This caused a problem in that to maximise performance in these two race formats, we would need to change the gearing in the 30mins between races. In actual fact the time available is more like 15mins, so it was quite tight and the F24 crew would not get their car anywhere near the front of the grid. As we were not building a car this year we decided to have a go at building an electronic solution, a buck/boost speed controller. This is a simple addition to a conventional buck speed controller that we, and a lot of other GP teams, have used. The controller can operate in buck mode, where it will produce a voltage less than or equal to the input voltage based on the PWM duty cycle, or it can operate in boost mode where it will produce a voltage equal to or greater than the input voltage.



The idea was to use the controller in buck mode in F24 as normal, but to boost the voltage in F24+ mode. An electric motor's RPM is proportional to the voltage on its terminals. So with a higher voltage the motor would turn at the RPM necessary for F24+ without changing the gearing. Theoretically the motor should be more efficient as its power loss is I^2 x R (current squared multiplied by armature wire resistance). We would be using the same power so at the higher voltage the current would be less. However at the higher RPM the mechanical efficiency of the motor is less and the extra electronics has a lower efficiency. So all in all we thought the overall performance would be about the same (a bit less in F24 but maybe a touch more in F24+) but the switch from F24 to F24+ would be much easier.

The electronics is only slightly more complicated in having two additional MOSFET's and a big inductor (coil of wire). The PCB design was tracked by all the pupils in shifts (about an hour each) and sent away to get made (2 layer PCB about £35). Then the pupils soldered all of the components onto the PCB, again in shifts to make sure everyone had a go. The first run saw a MOSFET blow up, but the fault was rectified and the unit worked quite well from then on. Unfortunately the efficiency in F24 was quite low, so for the final in 2012 we ditched it and used gear changes. However, later in 2013 we found a problem



with it during one of the races and tracked it down to a dodgy solder joint (who did that one? :)). It worked well in RR9 and was used in the 2013 final although the older buck controller would have still been more efficient in F24.

Otherwise there was no change to the electronics in RR9, most of the work was focused on the car design/build. We hope to change and improve much of the cars electronics over the next year or 2 involving more pupils in the electronics side again.

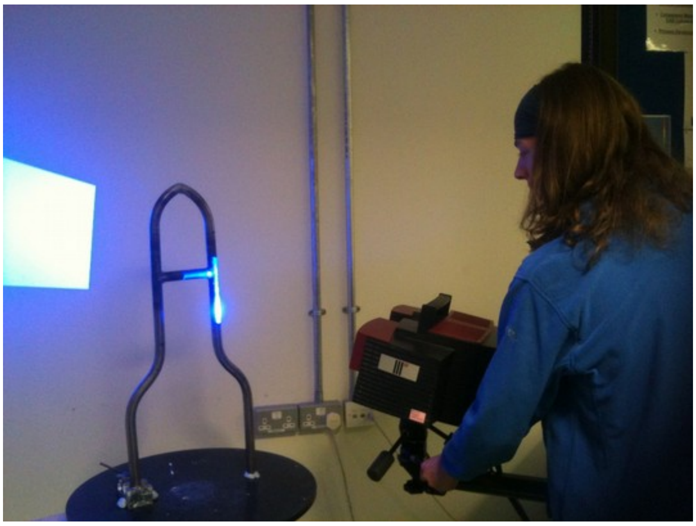
Weight reduction

One of the primary focuses of RR9's design, after aerodynamic improvements, was to reduce weight. RR8 was up to about 75kg plus batteries and driver. Rolling resistance is proportional to weight so a weight reduction is useful. Also it was getting bad on the various backs to pick up and really only the adults could do this safely.

We did this by attention to detail. Each aspect of the cars design was looked at and changed to shave a bit of weight off. A few less tubes in the chassis, simpler roll-bar/back axle, reduced steel in steering, use of carbon fibre to strengthen plywood base under driver and batteries rather than thick plywood and a change to lighter 8mm chain drive rather than 3/8 inch. These were the main aspects but there were many little changes from RR8's design.

Roll-bar fairing

We were very fortunate to have a parent helper from Rolls Royce Bristol. His input to the team, especially in working with the pupils on lathes and other items was exceptionally useful. As one of the many inputs he managed to arrange a work placement for one of the pupils to design and build a 3D printed aerodynamic roll-bar fairing. Some info from Rolls Royce on this:



During a work placement at Rolls-Royce Plc in Filton, Bristol Gareth was able to reverse engineer the car’s roll bar which is an important safety feature on the car that is designed to protect the driver’s head in the event of the vehicle rolling over.

Gareth’s roll bar design had been hand made by the team. It’s size and shape can cause drag and slow the car down losing much needed performance that can be the difference between winning and losing a race.

Using blue light scanning techniques, he produced an accurate, full 3D model of the part.

The resulting 3D model of the roll bar then allowed him to design a fairing to fit around the component and ensure a precise and accurate fit for optimum performance.

The fairing was then built using Rolls-Royce Plc’s Rapid Prototyping equipment using an additive manufacturing process called Stereo Lithography.

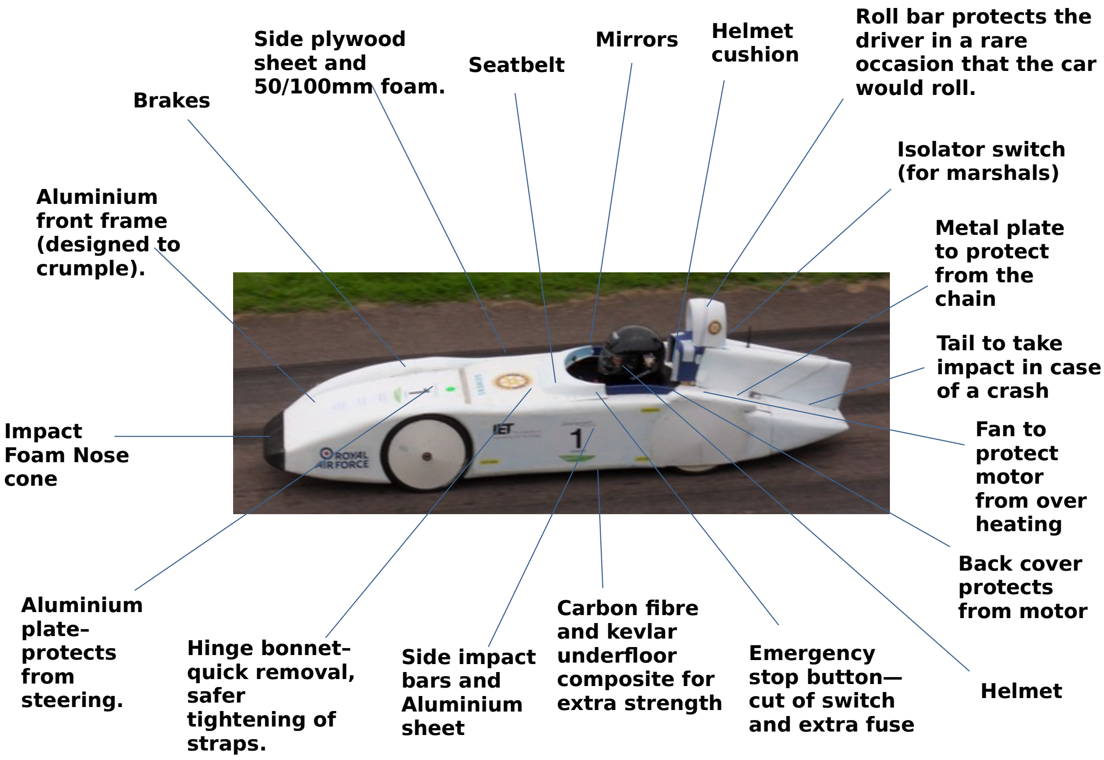
The process took the model of the fairing and sliced it into very thin layers. The part was then built layer by layer in a liquid vat of resin. Each layer is curing when a laser passes over the liquid which turns it into a solid. A new layer is then built on top of the previous layer and the process continues layer by layer until the part is built.

The custom made finished part was then fitted to the roll bar and mounted on the car.

These small but very important details are what it takes to design and build a race winning car.

Safety

Safety of the challenge is always utmost in our minds, perhaps especially as it is our offspring who drive the car. Any safety concern is always acted upon, especially as our car is one of the faster cars in the event. We have often been ahead of the rules, with front end foam, driver cage, 6 point harness, side impact bars etc. The picture below done by the pupils shows some of the safety features built in to the car.



Most of these are normal safety features, but some are unusual.

- About 500mm of the front aluminium tubed chassis has no vertical bracing members. It is designed to crumple in a large impact.
- Side impact bars and aluminium sheet with 25mm of faorm inside.

- Below the drivers back, in addition to the chassis, is a 4mm plywood base with a carbon fibre/kevlar layer and a 10mm thick foam area.
- The sides are 50mm and 100mm styrofoam. This can absorb blunt impacts and also take the speed of the car off quickly in roll or wall contact situations.

Project Management

We always try and show engineering ways of doing things. So we had team meetings about every month or so. These short (not according to the pupils but it was often them who caused the extensions in time :)) meetings allowed everyone to see where the project was going, guide it and keep it on track. Both helpers and pupils contribute and team consensus guides the project. We did use a GANT chart to show the basic plan at the start, but our main tool was our todo list. In this list we have the main overall work to be done and the list of names (initials) of who will do it. Then on a week by week basis we create a list of the jobs to do for the next week. We rarely complete all of the jobs so those get rolled on to the next week and so forth. The todo list helps us plan resources, keep the project on track and help with pupil involvement. See the documents listed at the bottom for more info.

Resources

Chipping Sodbury School has excellent DT facilities. There are quite a few machines and tools available. They are a bit old and worn but at least that shows they have been extensively used :)

The school has 4 lathes, 2 milling machines, about 5 drill presses, a sheet metal cutter, a sheet metal bender, two powered metal saws, a band saw, a forge with oxyacetylene and MIG welder, a vacuum forming unit, two very small CNC mills and one larger one, a laser cutter and a small 3D printer as well as numerous benches with metal vises. There is also a woodwork room with saw bench, drill presses etc. The DT teachers, including Mr McMorrow, ensure that the pupils get to use all of these and in Greenpower sessions all of Chipping Sodbury's four Greepower teams use them extensively.

The availability of these has steered our cars design to a fair degree allowing relatively easy working of metal and wood materials.

Chipping Sodbury's Greenpower Teams

From what I understand Chipping Sodbuiry's approach to Greenpower differs from most schools. The school is a typical state school with very little funds. The school provides the DT rooms and facilities and Mr McMorrow's time but no funding. All funding is obtained from sponsors and we are very lucky with support from the local Rotary Club and a local charity - the Townsland Trust - as well as a number of other sponsors whom the students have found.

Mr McMorrow is the king pin of the activities. He organises the sessions and places pupils/parents into the teams and steps in with design help or internal team issues as needed. But overall the teams are run in the main by the pupils and parents. The deal is every pupil needs to have a helper attend with them. This provides a great deal of helping resource with a wealth of varying experience. There are quite a lot of engineering orientated companies in the Bristol area, so there are quite a few engineer helpers but experience from many other areas of work is present and extremely helpful as is the contacts these have. This can be harsh for pupils who cannot get a helper, but the teams will take them if there is sufficient help in the team already. This method has led to Chipping Sodbury generally having 4 separate Greenpower teams, involving about about 38 pupils and probably just under 30 adult helpers. The teams cooperate to a reasonable degree, but are also competitive against each other and follow their own ideas, have their own funding sources and internal experience. Having such a large number of people involved has kept the project running well over the years. Both pupils and parents come and go and so the challenge does not become stagnant. Experience is shared across the teams and not in only one or two people.

This method seems to work very well, increasing pupil/parent/school interaction and the volunteer nature of the method makes it quite easy for the school, providing no cost but still keeping interest high.

Pupil Involvement

Pupil involvement is very high on our priorities, especially in the engineering side of things. This is what the Greenpower challenge is about. Although our team has been competitive and won a lot of events, this has not been achieved by adults doing all of the work. Actually I find it difficult how to name the pupils. Are they pupils, students, young adults ? They come in very much children, but when they leave they are very much adults with their own strong views and high abilities.

Over the years we and the other CCS teams have done our best to get pupils involved to the max. We have found it difficult and failed sometimes but generally, I believe, have done a good job. It is difficult for us parents who have no teaching experience to achieve this. Some of the core points that I think help are these:

- Involve the pupils in the design/planning of the project as much as possible. You need to make sure all of the team knows what is going on and has input into the decisions made.
- When designing/building a car make sure you use the materials, techniques and equipment that the helpers and/or pupils are familiar with. It is very difficult to get the pupils involved and show them what to do if the helpers have no experience themselves. What tends to happen is you start showing them but get carried away trying to do the work while the pupils sit around bored and starts face-booking on their phone.
- If parents are involved, get the parents to work with small groups of pupils who are not their own children. Pupils rarely listen well to their own parents and rebel to a degree. Mind you, later on in the challenge their mutual respect grows and parent/child interactions become excellent and equal.
- Planning is essential. I think any teacher would tell you that. The vast majority of the work I, as a parent, do for GP is trying to plan the sessions and make sure the resources are available. Cost management is also essential, work to the budgets you can afford.
- Although some money is essential, it is not a critical factor in the challenge. Much engineering experience can be gained by making do with what can be

found for free.

- Make sure you KISS (Keep it simple s...), organise your team and don't try to do too much. It takes significant time and knowledge to design,build and race a Greenpower car. If you try and do too much you will end up by having the adult helpers do most of the work in the last two weeks before a race.
- Generally we take our own set of tools to be used. You do get losses and a lot of wear and tear, but you have to let the pupils play, experiment and be completely free to use them without feeling restricted.
- If you are an engineer keep at least one hand behind your back. It is extremely hard for an engineer to keep out of doing this fun work! You have to look on at this as giving the youngsters an incite into the subject area you find so interesting and fun. You need to plan and show but try not to DO. Watching them progress, talk to others about their Greenpower experience with passion and ask the interesting and informed questions is an excellent experience and reward.
- Try and get an experienced engineer on the team, but make sure they understand and work as above. These can impart what it is like to be an engineer to the pupils as well as help create a good, manageable car design. Links to local engineering companies is also excellent, but make sure they understand that pupil involvement is the name of the game.

- Research Science and Maths. You need to get them involved in and understand the basics of the science and maths that underpins engineering. Engineering is not primarily about nuts and bolts, it is about using science/maths and other structured/logical disciplines to understand then create new or better items/systems/machines. Engineering is a mix of academic and practical skills. Unfortunately, the education system tries to push pupils in one of these directions only.
- Although the races are fun, really try and make sure the focus is on engaging the pupils in engineering aspects rather than winning the races. The doing well and winning is likely to come from this approach anyway.
- Make sure team work and responsibility is encouraged. Although overall management of a cars design/build is probably under adult control in F24 (sometimes an exceptional student can do this) make sure the pupils have total responsibility for other items. For example in our team the students alone decide amongst themselves the drivers for a race, the driver order or pit order, the people who will carry out pit stops, make sure everyone is in place to do this, pit-stop practice etc etc. Also try and give small teams of pupils sole responsibility for sub projects such as battery trolleys, pit-boards, website information, car horns you name it.
- Get the pupils to create display books, boards and websites about what they do. This helps their understanding and helps get them involved. It is especially useful for the more media interested students. It also forms a tool for them to talk about what they do with knowledge and confidence.
- Remember most of the engineering aspect of GP is in the car design/build phase. Don't keep

a car for too long. I would say a maximum of 3-4 years is best then scrap it. Using some of its parts for the new car reduces costs and speeds up the design/build phase. With a 3 year life span pupils coming through will probably get the chance to build two cars. One just learning about things and the second being very active.

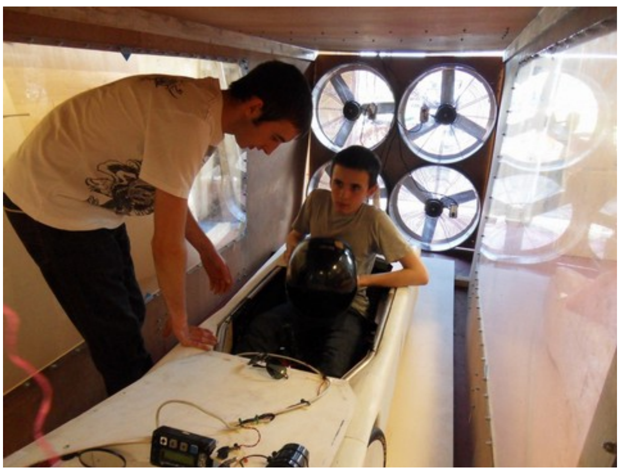
First Race

The car was completed just in time for the Goodwood Southern County's race on the 9th June 2013. As ever it did take some extra work in the last couple of weeks to complete it with the pupils and helpers doing work in various garages as well as at school. It arrived at Goodwood untested, apart from a push 100 metres up and down a track, and with no logos or stickers as the paint had yet to dry as usual (oops). There was no behind head fairing or wheel covers and the tail was a rough job added by the pupils as they wanted to try and beat the team from the USA :) We had intended this race as a testing day, however the F24+ guys were having none of that. After a very successful testing/practice session, they went out with new batteries, hell for leather and achieved a great 3^{rd} place result in the first race. In the F24 race we took it more cautious as there were newer drivers. The team used older batteries, 7 drivers and had slow and messy pit-stops due to no pit-stop practice. However, the car still went very well, with no real car issues (although a cell collapsed in one of the old battery sets) and still managed a respectable 9^{th}.

Development

As normal it was all a bit of a rush to get the basic car finished for the first race. After that the development work started. During the year we did the following:

1. Adjusting and tuning. The brakes were rubbing and the tracking not quite right.
2. The behind the head fairing was added and rear wheel covers.
3. The car was put into the schools wind tunnel and tests carried out leading to a list of



improvements that could be done. The schools wind tunnel was designed and built by the older pupils during the 2011 season.

4. The speed controller was getting hot and cutting out sometimes, so some investigative work was carried out and the problems fixed.
5. The battery leads were replaced with thinner shorter wire to make installing the batteries easier.
6. The tail and behind the head area was improved following the wind tunnel testing.
7. Vacuum formed rear wheel tops were made and added.
8. A new wind shield and driver side foam was added.

Some Facts

Speeds

- F24: Peak speed about 69 Km/Hour (43 Miles per Hour)
- F24: Average speed about 52Km/Hour (33 Miles per Hour)
- F24: Average speed (including pit stops) 48 Km/Hour(30 Miles per Hour)

Equivalent Petrol consumption:

- Castle Combe (18.5 Amps 118 Miles): 3122 MPG

Costs

- Build Costs in 2011/2012 season (Used parts from previous car): £740
- From Previous Car: Wheels, Motor, Chain, Electronics: £600 approx
- Competing Costs: GP race entrance fees, Tyres, Battery Pack (one per year): £380

Time for building

- Time to design: November 2011 to November 2012 in bits
- Time to build: October 22nd 2012 to 8th June 2013
- 22 * 2 Hours Monday/Tuesday DT nights
- 6 * 4 Hours Peoples houses (approx)
- Developed after basic build

Electronics

- Computer board designed, built and programmed by team.
- Computer calculates and sets power level 10 times per second.
- Motor speed controller designed and built by team.
- Motor switched on/off 40,000 times per second
- Current limit at 60 Amps
- Zigbee Telemetry

Virtual Wind Tunnel

- Uses web based interface with OpenFOAM CFD software

- Design divided into 1,000,000 cells
- Simulation runs on 12 processor parallel computer system
- Simulations take about 45 minutes to run

Sponsors

The car's design and development was solely funded by our sponsors either financially or by giving us materials to use. The cost of building and racing this car was about £1222.00 using the drive batteries, motor, electronics, and wheels from our old car. Development costs were extra. Our main sponsors are:

- Rotary Club Chipping Sodbury (funds)
- Towns Land Charity (funds)
- RAF
- Saint Gobain performance plastics
- FairDiesel
- Schwalbe (tyres)
- Beam Electronics

A massive thank you to all of these people who allow our team to have the enjoyment that comes with this project.

Management and Web Info

- Todo.html
- Budget
- PartsRequired.html
- Notes.html
- Design files
- Website
- Pictures
- Build Diary

Why does it go so fast ?

Just the same as the other fast cars in GP, there is no magic, no cheating. Just knowledge, sound basic engineering and hard work. The core factors are:

- An excellent well informed team that works well together and has years of experience.
- Research and knowledge of the science/mathematics behind the cars and good engineering practices.
- Solid hard work by all of the team members.
- Low frontal area and very good aerodynamic shape. This is a key factor.
- Relatively low weight and high pressure tyres. Weight is important but no where as important as aerodynamics.
- A great deal of attention to tracking, chain tension, bearings etc.
- Low friction forces.
- Strong attention to driving, pit-stops etc.
- Good degree of control over the cars power levels and feedback on what it is doing.

It also has to obviously be safe. It is the small percent here, another percent there. They all add up.

Conclusions

This document just describes how we have designed/built and raced our car. I hope it is interesting and informative. It is just one way of doing this challenge. There are many other methods and techniques that are equally as valid and/or better.

Chipping Sodbury School has been in this challenge for quite a few years now (Rotary Racer was founded in 2005) and so we have been able to extend the depth of work that pupils can get involved in. However one thing nice about the Greenpower Challenge is that you don't need to do all of this to do well in the races. A very simple car with basic work can compete in the races to do well.

This is just how we do it. Just get out there and do it your way.

Some more pictures