Model Solar Racing Car Design for Dummies.

2010 upgrade.

or

(Definitely) Building to Win, Without the Cow Manure.

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History. Where I'm coming from.

As a competitor. The early years.

I was first introduced to model solar car racing back in 1994, when Mr. John Sheppard was teaching at The Hutchins School in Hobart. His students had just won the Tasmanian event and were trying to raise funds to go to the Nationals. As I have my own electronics business, I was targeted by the students for a donation. The accompanying letter explained a little about the event. Sufficient enough to whet our appetite so with eldest son Sturt at Clarence High the next year the die was well and truly cast.

We had very little idea of what we were doing, probably a lot like most teams when they start, but a few phone calls later we had the basic concept. So, a car was built to the fairly basic rules of the day, using a few sticks of balsa from an old kite, bits and pieces of old slot cars and wheels from a science lab block and tackle. The solar panel was hired from CSIROSEC in those days and an old hobby motor and gears were used. The car had a pair of close in front wheels steered by a pair of small ball races on a forward facing outrigger, and a triangular chassis that pivoted from that arrangement. There were two rear wheels on a rigid live axle running in miniature ball races but only one wheel was driven. There was no body. We had still never seen a model solar car but just used what we thought were reasonably sound engineering principles. The car went, but too slowly. John Sheppard volunteered the information about where to obtain precision motors and gears. The result was that the car swept all before it and won the 1995 Tasmanian event. The trip to Canberra for the Nationals was a real eye opener. To see what was happening in other states was invaluable. To this day I still believe that you can learn more at one National event than from 5 years in state events. Sturt's car made it to the quarter finals and missed out on 4th place by less than a metre.

Sturt competed again in '96, coming 3rd behind 2 Sheffield High teams, and went to Adelaide for the Nationals. He kept the same basic triangular chassis concept but experimented with 2 motors and using different sized wheels to alter the gearing. He competed again in '97, coming 2nd behind a Rosny College car and got to go to the Nationals in Surfer's Paradise. His chassis was now just the minimum required to mount the wheels as the panel supplied all the strength. He went back to one motor and experimented with relays to change the panel voltage. Again he was the only Tasmanian car to make the finals, which he did in all three years. However, the rental panels were far from ideal and caused no end of intermittent problems, probably because everyone used them as stressed chassis members!

1998 saw Sturt retire from competition. Kent started at Clarence High and took up solar car racing. Because the old APSYS panels were beginning to die we purchased a Solarex MSX10. This panel weighed almost 1.4kg and was one heck of a penalty to carry around. We also started to play with electronics and despite the huge weight penalty the car made 3rd place in Tasmania behind 2 Woodbridge cars and then made the finals in Melbourne in the rain. Craig Lowndes did the presentations that year and eggs for drivers were introduced. The car was still a further version of the triangular layout.

For '99 Kent stripped down the panel so it 'only' weighed 1kg. The new rules required the cars to have proper bodies rather than just a stick chassis and we redesigned the electronics to basically the circuit we use now. It had a pair of wide set casters at the front and two wide set rear wheels with one driven. The front guides were close in and the rears were set out at a distance chosen on track. (see later) The car was just beaten into 2nd by Queechy High and went to the

Adelaide Nationals. Kent experimented with a quick-change gearbox and we were lucky enough to be able to spend quite a bit of time in Adelaide doing track testing. He made the finals again, even though the car kept lifting its drive wheel off the track at high speed and the front casters got the death wobbles. We learnt from this and never suffered from either of these conditions again.

2000 saw Ewen start at Clarence and also take up racing. Kent went for a radical looking streamlined car using 14 Dick Smith panels. A change in the rules had opened up a loophole that many teams exploited. Ewen opted for a more conventional car using the Solarex panel and some of Sturt's old running gear. Both cars used electronics. Kent experimented with fixed front wheels and tried tyred and non-tyred drive wheels. Kent easily came 1st, Queechy came 2nd and Ewen took 3rd so it was off to the Nationals in Sydney. Ewen changed to a 14 DSE panel and the question of steering and tyres was resolved once and for all. Kent again made the finals but Ewen's car fell foul of the atrocious National track and was eliminated before the finals. However, some quick modifications to the guide system saw the car win all its repechage heats and take out the 2nd fastest lap of the day.

Further rule changes in 2001 saw both boys go for fairly basic but streamlined box shaped cars, again with 14 DSE panels and electronics. This time Ewen took 1st, Queechy 2nd and Kent 3rd. At the Nationals in Adelaide both Kent and Ewen made the finals, and Ewen shocked the organisers by taking out 4th place overall.

Yet another rule change for 2002 but the boys were able to come up with totally radical, and still often controversial, designs using two castering front wheels, a single castering rear drive wheel and offset guides. Both cars were ultra streamlined with Kent (now at Rosny College) going for a teardrop shape and Ewen a flying wedge. A bit of lateral thinking (and electronics) meant that both cars used only 10 DSE panels but totally demoralised the much higher powered opposition. Ewen narrowly defeated Kent and both cars went to Sydney. They both experimented with spring suspension to overcome the rough National track, but Kent had a suspension failure which saw his car T-boned when leading a race and it never ran quite as well afterwards. It still made the finals, took out 2nd fasted lap time and won the Best Engineered Car award. Ewen won 32 races in a row and was undefeated until the best of 5 grand final where he won the first 2 races before the other car suddenly received an amazing and mysterious performance boost and narrowly won the next 3. So Ewen had to settle for 2nd place overall. He had already recorded the fastest lap of the day, both of our cars taking over ½ second of the old lap record.

In 2003 the boys tried to refine their cars again, Ewen sticking with the wedge and Kent going for a weird stealth shape. They reduced yet again to 9 cut down DSE panels. Through the use of electronics, they were the only 2 cars to be able to reliably complete laps of the track in overcast and often rainy conditions, yet still be faster than all other cars in sunshine. This time Kent narrowly beat Ewen into 2nd so both went off to Adelaide. They both tried to further reduce the weight of their cars by using separate bare solar cells fixed to polystyrene panels but fell foul of the dubious power measuring system being used at the Nationals. Reducing the size of the panels was not an easy option so they both were required to carry an extra 400gms of ballast. Two weeks before the Nationals in Adelaide I ended up in hospital having a stent put in my heart and Ewen decided at the very last minute to make a new car from foam. It had never actually turned a wheel until it went on the Adelaide track. There were quite a few teething problems that were not all able to be eliminated, especially since it rained for most of Saturday. Still, despite that and the weight penalty, both cars made the finals and Ewen once again took out 4th place overall. Both cars were eliminated by the same extremely dubious NSW car which officially ran only 4 watts. Yeah, right.

Next year Kent finished school and went off initially to do engineering at Uni but now is in the RAAF and repairs FA18 Hornets for a living, while Ewen, who could have competed for another 2 years, was totally cheesed off and retired, saying simply "they'll never let us win anyhow", a reference to the rather liberal interpretation of the rules by some of the more fancied teams. He now takes his frustrations out teaching heavy metal drumming. He still really has a soft spot for solar cars and did return to help out at the 2008 Nationals in Hobart.

To sum up:- In 9 years of competing in the Tasmanian Model Solar Car Challenge, we entered a total of 12 different cars, took 3rd place 4 times, 2nd place 4 times and 1st place 5 times. We represented Tasmania at the Australian International Model Solar Car Challenge in every one of those years with 12 (not always the same) cars and made the finals 11 times. For 7 of those years we were the only Tasmanian cars to make the finals. We made the quarter finals 11 times, took 4th place overall twice and 2nd place overall once. We had the fastest lap of the day twice and the second fastest lap four times. We held the lap record for 4 years. If only we had come from a 'better' school in a more favoured state….

As an administrator. The later years.

In 2004 I went to Perth to represent the Tasmanian co-ordinator who was unable to go and ended up assisting with the scrutineering. I was involved in calculating the ballast weight for each car and I was responsible for checking the weight of every car before it raced. Hence I got to see all the cars up close and personal. In general the standard of cars was quite low, compared to previous years. The track condition was ordinary to say the least, with the result that the best cars did not necessarily do well. Despite the brilliant sunshine the winning times were quite slow, and the 'successful' cars were basic to say the least. I also saw first hand some of the things that we had suspected had been going on for years regarding dodgy solar panels and 'performance enhancing' practices. A couple of teams were not allowed to race, but some teams seemed to get away with just about anything because "so and so teacher is a good guy and everyone knows that he wouldn't cheat!!!!" Who did they ask? The Tooth Fairy or Santa Claus?

For 2005 I was invited onto the National committee so I got involved with rewriting the rules to remove a lot of ambiguities and to try (not always successfully) to remove avenues for 'creative interpretation'. At the Nationals in Melbourne I was again involved in scrutineering and was responsible for checking the car and panel wiring and testing the panel power output, so I got to examine all the cars internals as well. In general the standard was much better than the previous year, although a few teams did try a couple of the old tricks, with less success. . The most obvious thing was a complete change at the top. There were still a few very ordinary cars, a lot of reasonable cars and a handful of very good cars. The top three cars all fitted into the latter category, I am pleased to say. The most exciting thing, from my point of view, was the fact that the top three cars were all built in the same basic configuration as our 2002 cars.

Sydney 2006 was interesting for a number of reasons. Stan Woithe had to depart early to attend his son's wedding so I got to play chief scrutineer. This gave me a really good look at all the cars. Once again there were a few very ordinary cars, a lot of well built but totally unimaginative designs, and, I was pleased to see, a fair few well thought out, well designed and well built cars. Also, the weather was rather variable, ranging from 90% sun down to 2% sun. This really tested the cars but one thing became even more obvious. Whether bright sunlight or total overcast, the best performing cars were all small, lightweight, low loss designs. Tasmanian teams dominated the event, taking the top three places. Another Tasmanian car missed the finals due to an ill advised motor change but did a lap in 16.62 seconds in 90% sun when the proper motor was fitted. If you think that was impressive, the Queechy High (Tas) car that finished in second place did a lap in 16.24 seconds, also in 90% sun. That's a full second off the old lap record. Yet, these cars, unchanged whatsoever, still ran around the track in less than 5% sun. Tasmania took five cars to the Nationals, all based on our original 2002 design concept. All five had run sub 18 second laps in the Tasmanian competition held in mid October.

P.S. I have since discovered that, despite being very smooth, the new NSW track is not 100 metres but only about 94 metres long, so our old lap record times stand up pretty well.

Adelaide 2007, what can I say. This was the Atlanta Olympics of solar car nationals. If you are too young to know what I am talking about, don't worry. I won't elaborate too much, but... The track was late arriving so no-one got to practice. In the middle of a drought the weather sucked for most of the time, especially on Saturday, and then was all over the place on Sunday. Why is it that it always seems to rain when we go to Adelaide? And they have the hide to make comments about Tasmania. The Saturday time trials were farcical to say the least and the 'seedings' saw the two top Tasmanian cars race each other in the first elimination round on Sunday while other races had two cars that hardly crawled around the track. This trend, and the variable weather, continued all day so the finals were in no way a true indication of the standard of the cars. Given any other weekend I suggest that the final four would have been completely different. For example, the car that was placed fourth did not make the finals in Tasmania and was taken at last minute as a wild card to make up the numbers. Not to say it wasn't a good car, it's just that other cars were better. Once again I was involved in measuring the power of the panels and calculating the weights so I saw all the cars first hand. The car that was awarded first place was very ordinary but by virtue of an anomaly in the rules was able to gain a huge advantage in low light conditions. This effect is now fully understood and I will have more to say later. Probably one of the best cars was from Winthrop Baptist College in WA. This was a small, lightweight car built from this help file by a new school, and, despite some teething troubles and a bad draw, turned in a 16.3 second lap yet was eliminated. The 'winners' didn't crack 19 seconds all weekend. You work it out, I can't.

Hobart 2008 has been declared a success by all who attended. Possibly this was due to the fact that we coerced the National champs from 2005 and 2006 to run the event, with help from yours truly and other long sufferers. Maybe it was because the organising committee have all been directly involved in model solar car teams? Despite the fact that it rained every night it did not actually rain on the event. One of the team had written a seeding programme that took the light level into account and it worked out pretty well spot on. As well we measured all the panels at 50% Sun then doubled it to greatly reduce any advantage from low Fill Factor panels. This caught a few teams by surprise even though it was written into the regs so there was a bit of panel shuffling going on. This won't be allowed any more, you will now have to stick with what you first bring to scrutineering. As a result a number of the 'fancied' teams didn't perform very well. Most of the cars were pretty ordinary to say the least, with only a few stand outs design and construction wise. The Victorian car that won broke lots of the accepted design norms but won due to meticulous preparation and attention to detail. A well deserved win. There was a bit of inventive interpretation of some of the regs, including by the winning car, but this has been tidied up for 2009. Despite the 2nd placed Velox doing 16.18 seconds in 122% Sun (due to the clean dry Hobart air) none of the other cars were particularly fast, unless you count the 3 wheeler built to the 2008 rules by the 2005/6 winner which went 15.75 seconds in a demonstration time trial in 108% Sun. Shows what can happen if you build your car properly in the first place.

Melbourne 2009 was different again. The weather was variable and a lot of time was spent with the selection of the Victorian team and too many wild cards so a number of races were not best of three as they were supposed to be which upset a lot of teams. Marc Iseli's seeding programme was used again and it turned out again to be pretty much spot on. A lot of cars, particularly from Victoria, were allowed to run panels over 12 watts, something that I am not in favour of, and one NSW car ran 13.4 watts! With the ballasting rules in force these cars had a huge advantage over two laps. They all tended to be fairly basic and heavy. The three wheelers have been dubbed JJ cars by some people. Well, I call these other cars FF cars. That's Fred Flintstone. Primitive. Basic four wheels, usually on fixed axles. Perhaps Yank Tank would be more appropriate. No thought to the chassis design, just whack in a huge power plant. A Tasmanian colleague has also pointed out that as well as no design effort, these cars require no effort in making parts, just buy it all from RI and put it together a bit like a kit. Beat us why they need to run classes all year to come up with…what? Despite that, a pair of light weight three wheelers from Tasmania still managed 3rd and 4th. And then Marc ran his 2009 demo car. Scary. Late in the afternoon, 80% Sun. Three caster wheels, eight watts, sixteen and a bit seconds. He easily beat all the major runners Catch me if you can.

So then, if you reckon you already know everything that there is to know about model solar car racing and you couldn't possibly learn anything new by reading on, stop now. It's true what they say, you just can't help some people.

Recommended reading. More than just a good idea.

I used to recommend that all solar car modellers read the book by Stan Woithe from the University of Adelaide, "Model Solar Cars: Optimising their Performance", ISBN 0-7308-7620-9. Stan is also on the National committee, one of the rule makers and is Chief Scrutineer. However, the book is a few years old now and fairly out of touch with the current regulations. I do believe a long overdue update is on the way. Despite saying that, the laws of physics have not changed much in that time. It doesn't say much about what makes a winning car, but it does cover a lot of the dos and don'ts of basic engineering. I don't intend rewriting Stan's book but where he has gone right back to fundamentals I will simply say what we found out works and what doesn't. Ian Gardner (mechanical engineer, Victorian committee) has also written a lot of useful stuff (over 130 pages of it, in fact!) but, again, it tends to be fairly technical so is aimed at the more experienced constructor. Check it out on the Victorian and Tasmanian websites. It gets pretty heavy but is a worthwhile read for the serious competitor.

Bodies. Body building without using steroids.

Once upon a time, model solar cars used to be made from a couple of sticks. Sticks with wheels attached and a solar panel sitting on top. Then the organisers saw reason and brought in bodywork. You can still make your car from sticks but have you looked at how real cars are made? Once upon a time all cars had a separate chassis with the motor and wheels attached and then the body sat on top. So did racing cars. So did trucks. Trucks still do, but now all real cars are monocoque construction. Monocoque means “single shell”. This means the body is also the chassis. So are racing cars, and aeroplanes. This is done to get maximum strength with minimum weight. A tin can, a milk carton, a soft drink bottle and an egg are all examples of monocoque construction. Trucks and four wheel drives (read small trucks) still use a separate chassis. What are you going to build?

Fibreglass is very strong but just too heavy. Carbon fibre is even lighter and even stronger but it also is very brittle. When it does break it shatters and is almost impossible to repair quickly. It can also be fairly difficult to work and join, needing special skills. It’s OK for a stick chassis but not for bodywork, unless of course you work for Ferrari or Lamborghini.

Aluminium is also strong and light but nowhere near as light. It will bend before it breaks. Unless you can get aircraft grade aluminium and all the fancy gear required to work it, it is not really worth using for bodywork. It is ideal for suspension bits and pieces and motor mounts as it is relatively easy to work yet mechanically sound while still relatively light. A couple of 2009 cars had light weight body parts supplied by a specialist aluminium spinning company but not everyone has access to such a facility.

Polystyrene blocks can be used to make complicated body shapes. It is messy to work and can only be glued with things like Liquid Nails. It has very little structural strength and you have to have a separate chassis or at least make up extensive sub frames to attach suspension and motors, etc. You cannot use thin sections and it gets damaged very easily. It is also surprisingly heavy so you have to hollow it out. A 2003 car we made from foam was actually heavier than the same car made from balsa sheets, but nowhere near as strong or robust, requiring a separate chassis. I must admit, in 2006 and 2007 a couple of pretty successful Tasmanian cars were made by laminating thin foam with tissue paper on each side. The result was fairly strong and light, but they were extremely lucky that they didn’t suffer any damage as this construction is extremely brittle and repairs would have been almost impossible. Also, both years were fairly overcast, so, who knows what damage high speed action might have wrought. They didn’t do as well in 2008 or 2009, for some reason. The second placed car in 2009 had a very thin polystyrene body on a carbon fibre stick chassis. It had a monumental crash early on in 119% Sun but they were able to reassemble the body with sticky tape and eventually go on to take 2nd. Lucky for them the crash was in very first race of the day so they had plenty of time to effect repairs. Later on may have been a different story. Anyway, this year the race is not over until the car has been safely stopped and removed from the track so the final results may have been very different.

Good old balsa wood is very light and yet is stronger weight for weight than steel. It does this because it is a maze of hollow cells of cellulose fibre. Cotton and linen are also cellulose fibre and look how strong they can be. Did I mention bamboo? It’s always difficult to beat nature. Now, if only we can work out how to weave spider web! Balsa is readily available in all sorts of shapes and sizes from 1mm thick sheets to 100mm square blocks. You can get sheets 100mm wide and 1000mm long. By carefully choosing you can get some that is extra flexible for bending around curves and some that is quite stiff for structural bits. For extra strength pieces like suspension mounts you can get close grained but lightweight timber such as beech, spruce and radiata from the same model shops.

You could use space frame construction covered in tissue paper or film as you would if you were building a model plane but you then have to be ultra careful when handling the car. Also, racing on the track is pretty rough on the machinery and this form of construction tends to not last the distance. Box construction using 1mm balsa sheets can be very light yet very strong. Use bulkheads as stiffeners and put fillets in all corners. Properly designed and built balsa cars can weigh under 300gm with all running gear except the solar panel and ballast installed.

Balsa can be cut to complicated shapes with simple tools and can be joined in minutes using solvent based glue. You must use very sharp tools such as scalpels or Exacto knives. If it does get damaged repairs are quick and easy, as are urgent modifications. By applying two coats of aircraft dope to all surfaces even thin curved sheets become very rigid as you have effectively made a sandwich. If you don’t apply dope then don’t get balsa wood wet. It works like a sponge and quickly becomes very heavy and soft. The only real drawback with balsa is that it is difficult to make compound curves, but even that is possible by using a steamer. And anyway, you really don’t need to.

Streamlining. Going with the flow.

When cars were made of sticks with a solar panel on top streamlining didn't matter as these cars had a very low frontal area. Back when a minimum 200 square cm frontal area was first introduced streamlining became essential for any reasonably fast car. Tests at Adelaide Uni found that, at 7 metres per second, a streamlined car had only 1.5 times the drag of a stick car while a non-streamlined car had over 7 times as much drag. Later rules have modified the frontal area several times but it can be shown that even at fairly low speeds streamlining remains absolutely essential.

Don't forget that in full sun your car should be doing over 25 kph on the straights (and this is 7 metres per second). I must also point out to those who did not know, wind resistance is proportional to the square of the velocity. Double the speed means four times the drag, three times the speed means nine times the drag! Very serious stuff. That's why even a super streamlined Bugatti still needs over 1300kw to reach 400kph.

For 2004, the single egg and the unspecified can carrying arrangement allowed for a very narrow body with wheels on sticks again, but streamlining was still a benefit as terminal speeds had gone up. It is worth noting that in Melbourne 2005, the cars that came second and third both carried their cans end on and so had very narrow but fully streamlined bodies. The winning car actually had its can sideways but still had a beautifully streamlined balsa body. In 2006, one of the cans had to be carried sideways so the body had to be wider, making streamlining essential again. The successful cars were all very streamlined.

In 2007 the cans were replaced with milk cartons so now the front of the car had to be at least 235 mm wide and 75 mm high. Once again, streamlining was absolutely essential. The 2007 winner didn't actually ever go fast enough to need streamlining, but the fastest laps (low 16s) were done by fully streamlined monocoque cars. The 2008 winner and runner up both used extensive streamlining, although they both bent the interpretation of the rules somewhat in the process. Interestingly, a number of cars went to great trouble using various methods to reduce the weight but had square box shapes. They didn't go very fast. Perhaps someone told them that the sun never comes out in Tasmania?

The 2009 rules called for a 2 litre milk bottle so the car had to be at least 100mm high. You could have the bottle end on or sideways, so the body could be 100mm or 260mm wide. Both ways did have merit but universally the bottle was end on. This equated to a small reduction in frontal area from the previous years. Strangely, many cars still had bodies excessively wide for no apparent reason, well no reason that I can think of.

The 2010 rules call for two bulkheads separated by 200mm, one 200 sq cm and the other 100 sq cm. These must be solid and vertical but you can have either at the front. The obvious thing to do is to take full advantage of the width restriction and make your car the full 320mm wide. Play safe and go a bit less, say 318mm. This means your big bulkhead will be 63mm high. Not bad, nice and low. Now, you can have a tear drop with the second bulkhead 159mm wide or a wedge with the bulkhead 31.5mm high. Who said the new rules were hard? Give me an afternoon and I'll make you a competitive car from scratch.

Don't forget the floor area, either. You have to not only consider the shape looking from above but also looking from the side. For a couple of years the cars had to have a floor with a minimum of 400 sq. cm. and combining this with the area of the solar panel you had a large potential wing. At the speeds a good car was going becoming airborne was a definite possibility. We saw, at first hand, how easy it is to hit a bad join in the track at full speed, get well and truly airborne and fly right off the track. We cured our problem with little wings and front skirts, just like a full sized racing car. This may not have been such a problem with a smaller front and floor, but a bit of aerodynamic down force is not hard to achieve. More importantly, you can still get a lot of lift if you are not careful! With the two bulkheads you are still looking at a fairly large floor area. Combined with the solar panel this can create a serious wing area so it should be taken into account when thinking about body shape. Get too much air under the front of the car and it could be all over until next year. I have it on good authority from a Doctor of Fluid Dynamics (or something like that, he's the son of a friend) that one of these cars at full speed could generate up to 1 kg of lift! Think seriously about where and how you want to arrange the bulkheads to minimise both drag and lift. Unless like a lot of teams your car isn't going to be particularly fast, of course.

Lastly, draw a line between where all the wheels contact the track. Any weight outside this line will increase instability and must be minimised so think about how you are going to arrange things like the solar panel and the ballast weight.

Wheels and tyres. On a roll.

First thing to decide is how many wheels do you want, three or four? The obvious thing is to emulate a road car and use 4 wheels, but this is not the most efficient arrangement. Road cars are practical devices but we are building a specialised racing vehicle. You wouldn't expect to drive a F1 car to work each day, would you? Due to the rough and uneven nature of the track we found it almost impossible to keep all 4 wheels on the track at all times. Complicated suspension is just too heavy and introduces other problems, as we found out to our peril on more than one occasion, so you may often have your drive wheel off the track. Not a good idea. A tripod arrangement is inherently stable, (normally) keeping all wheels on the track. We do have photos of Ewen's three wheeled car taking the corners in Sydney in 2002 while up on 2 wheels, but the drive wheel was still firmly on the track. The moral of the story is to use two wheels at one end and to drive through a single wheel at the other end.

If you still don't believe me, anyone who has been in Adelaide for the finish of the Darwin to Adelaide solar race will have noticed one glaring detail common to all the cars. Without exception, they all have three skinny wheels. Also, one of these cars was in Melbourne during the 2009 event. It had three wheels and I made a point of loudly quizzing the team member attending the car on this matter. His reply? What possible reason could you have for wanting four wheels?

For several years at the Nationals, all the most successful cars were 3 wheelers, some front wheel drive, others rear wheel drive. Changes to the rules somehow created a relapse to 4 wheeled stick cars for 2004, but, 2005 saw sense and bodywork return. The cars that came 1, 2 and 3 at the 2005 and 2006 Nationals all had 2 wheels at the front and a single drive wheel at the rear. I haven't seen an arrangement of 2 wheels on one side like a motorbike and sidecar, but it might work. I don't think I'd bother, though. Also, just like a full size racing car, unless you have four wheel drive with three viscous coupled power splitting limited slip differentials, rear wheel drive is the only way to go. All serious sports cars are rear wheel drive. Could you imagine a F1 car putting 1000HP onto the track through the front wheels? You'd need to be The Governator to steer it! True, the first and second placed cars in 2007 were four wheelers, but, for various reasons which I'm not allowed to talk about, they didn't actually get to race in anything like full sun, and, also for various reasons some of which I have already mentioned, they didn't get to race against any serious three wheelers. I am also not allowed to mention the inappropriate panel weight carried by some of them. The race times still show that the three wheelers were up to 3 seconds faster than the four wheelers, but they didn't necessarily get the chance to show their potential in a fair fight. The 2008 winner was again a 3 wheeler. The 2009 winner was a curious hybrid. It had a pair of front casters but two close together fixed rear wheels, I think.

P.S. I have seen photos of a stunning looking sidecar arrangement model solar car built in Portugal. I have no idea of its performance, but it looked fantastic.

The regulations specify that all wheels must either be at least 1mm wide or 0.6mm radius. Why? It's called rolling resistance. The ideal wheel would have a hard, very narrow rim but this causes serious damage to the track and is therefore banned. Racing bicycles use very thin tyres pumped up very hard. Trains use steel wheels on steel rails. Even drag racing cars use narrow little front wheels. The next time you go for a long car ride get out and feel the tyres. They get hot from the friction in the rubber, so hot in fact that in racing cars the rubber starts to melt and stick to the track, a property they can exploit, but we can't. The power to heat the tyres comes from the car engine, and since we have so little power to start with we simply cannot afford to waste any, no matter how small.

Tyres are only needed to get a road car around corners, for braking and accelerating. Model solar cars use a guide rail to get around the corners, a bit like trains and trams, don't need to have brakes and only accelerate through the drive wheel(s). So, don't use tyres when you don't need to. The rolling resistance may be small but it all adds up and is proportional to the overall car weight. Also, unless you are the world's best model maker, you will probably not get the wheels to track exactly and they will still spend a portion of the time being dragged sideways. You must use something on drive wheels though, unless you want to stay at the start gate or at the bottom of the hill. Very narrow O rings are ideal, but you must glue them to the wheel or they may fly off at high speed. Another option employed by some teams is to use an aluminium wheel with a serrated rim. This may actually work better on a wet track, but I don't know. I like the tiny tyre idea. I personally think that metal wheels should be outlawed, they still damage the track.

You can buy wheels or make your own very easily from 3mm PVC sheet in a lathe. About 50mm diameter seems to work OK. For non-drive wheels turn the edge down to about 1.2mm leaving a central hub to hold the bearing. For drive wheels turn a groove into the rim to take the O ring then turn out the body of the wheel if you like, leaving about 3mm at the rim and a hub for the bearing. Don't drill holes to lighten the wheels as the extra wind drag more than offsets any weight loss. I have seen a number of teams drill out their wheels and then place film on each side. This seems to be a reasonable idea, although how much weight is saved is debatable. You also have to bore a hole in the centre for the bearing. The bearings must be a press fit and a bit of Loctite is a good idea. Don't get Loctite in the bearings, though. It doesn't matter if the wheels wobble a little bit, as long as they spin freely and they are round.

Guides. Keeping it on the island.

Solar cars are guided around the track by an extruded plastic channel. The track builders have finally woken up to the fact that the joins in the track and guide were far from perfect. Now they place strips inside the channel to align the joins. This means you cannot run a guide pin down the middle of the channel. No serious cars ever did, anyway. You must use a guide each side of the channel. The new National track is extremely smooth and well aligned at the moment, but that probably won't last as the rigours of weather and transportation take their toll. It was pretty obvious in Hobart and in Melbourne that the track is starting to distort as some scalloping was fairly evident when it was wet.

If you think about how fast your car will be going then you have to use wheels running on the outsides of the channel for guides. These wheels need to have sufficient diameter to cope with any bad joins in the channel and must be fitted with bearings. They probably will be turning faster than the road wheels and will have quite a load on them to get the car around the bends at full speed, especially if you don't have steering front wheels.

You could just use ball bearings running on the channel but it is easy to make some PVC wheels. We used 6mm PVC and made top hat shaped wheels. This was to get the rim closer to the track yet raise the screw that goes through the bearing. Don't bother with tyres. They just add weight and rolling resistance, and who cares about the noise. Our wheels were 25mm diameter and fitted with the same bearings as the road wheels, the rim was 1.5mm thick.

Make sure that you use good solid mounts for your guide wheels as they will take quite a pounding. I have seen cars with long thin bolts extending down with bearings on the bottom. They invariably fail. This is not the area to save weight at the expense of strength. Remember, even the lightest car is still going to weigh around 1kg when racing and the guides have to push it around the corners at 25kph or more. It can be shown that at full speed on a 5 metre radius the guides can have the full weight of the car pressing on them and allowing for misaligned joins and bumps in the guide rail, the impulsive force can be up to five times the weight of the car! You must at least be able to hold the whole car up by any one of the guide wheels and shake it about. If you aren't game to do this then start thinking again.

You are required by the rules to have guides at the front of the car. Position these just behind the point of contact of the front road wheels. This is to cope with any bad track joins. If the guides are just behind the wheels then the wheels will lift the guides up over the bad joins. The alternative can often be disastrous yet quite spectacular.

If you have a badly designed car you don't need guides at the rear. If it is overcast you may not need rear guides. If you have F1 racing slicks on your car you won't need rear guides. Otherwise you do need rear guides. At any reasonable speed the car will want to slide out. It is called momentum. The car simply wants to keep going in a straight line. Without rear guides either the car will spin out or at best it will drag its rear wheel(s) or worse, its drive gear, along the guide channel. Either is a disaster. All you have to do is decide how far apart they are going to be. If you have fixed rear wheels you must have the guides wide enough apart to let the rear of the car track in on the corners at low speed. Dragging wheels around corners is hard work. At any reasonable speed though, the back of the car will slide out on corners. Setting the guides so the back wheels now point straight ahead, that is, the car is pointing tangentially down the track, will give the best high speed performance, especially if you have rear wheel drive. But there are better ways.

A final word on guides. It can be advantageous to incline the guide wheels so that the inside rim is lower than the outside rim. This has two benefits. It gets the point of contact lower so there is less chance of the car coming off the guide rail and it also means that if the guide wheels bottom out on the track for any reason they will simply take a bit of the weight on the rim rather than being dragged along the track. Trust me, every little bit helps.

Bearings. Putting a spin on things.

You must use good quality ball bearings. Using good bearings means you only need one for each wheel. The smallest readily obtainable industrial ball bearing is 10mm outside diameter, 4mm wide with a 3mm inside diameter. They are available from any industrial bearing supplier. Bearings come in several versions. The open type are low in friction and are easy to clean out but they also pick up dirt easily. Those fitted with rubber seals to keep dirt out cannot have the grease cleaned out easily and also have relatively high friction levels. Those fitted with shields can be fairly easily cleaned out, have low friction levels yet also keep out most dirt. They can have shields fitted to both sides and this is what we want. The bearings we used were type 623-2Z. The ‘2Z’ (or sometimes ‘ZZ’) means shields both sides. Only use first quality reputable brand name bearings as they will last for many years even without lubrication. Quality bearings are not cheap but you only get what you pay for.

Before you use them in you solar car you must wash out all the grease using white spirit or dry cleaning fluid. It takes several goes to get all the grease out. Don’t use petrol as it leaves a residue and never use WD-40 or similar as these intentionally leave behind a sticky residue. Once the bearings are clean you must wrap them up and keep them dry because they can rust. They may make a lot of noise but they should spin freely. They must be washed out on a regular basis, especially after a lot of use on the track, but it is worth it. You should wash them out, dry them and then use a little sewing machine oil before long storage, washing again before racing. It can be worth having several sets of wheels with clean bearings fitted so they can be quickly changed between races if needed. Every time your car comes off the track you must check out the bearings and a wet track can be a worry. Methylated spirits or pure alcohol will remove water and dirt once all the grease and oil have been removed. Alcohol and water mix readily and evaporate together.

P.S. We have our old 2002 cars that still get dragged out for demonstrations. The bearings cost around $10 each but have not been looked at, oiled or cleaned for several years. Despite the noise they can still beat all but the best new cars.

Steering. Going around the bends without going around the bend.

Even with smooth front wheels, unless they steer, your car might not get around the corners in low light. This also means that even in high light you are still wasting energy. The problem is even worse if you use front wheel drive because you probably need a tyre and if the drive wheel is not pointing straight down the road you are wasting lots of energy. Front wheels must steer into the corners. This can be achieved using complicated guide systems with tie rods etc., but it is almost impossible to get them to track absolutely correctly. The best way by far is to allow the front wheels to caster like shopping trolley wheels. Simple, low weight, effective.

Under the subject of guides I talked about dragging the rear wheel across the track with close guides or allowing the rear to slide at speed. Dragging is to be avoided at all costs. If you have rear wheel drive and the back of the car is sliding then you have already broken traction and are losing drive potential, even if you do have a tyre fitted. It’s called limiting friction. So the resistance has gone up and the drive has gone down. A total lose-lose situation. There is a simple way around all these problems. Use close guides at the rear as well and allow any rear wheels to caster.

The cars that came 1st and 3rd in 2005 had two castering front wheels and a single castering rear drive wheel. The car that came 2nd also ran two front wheels and a single rear drive wheel but all wheels were on fixed axles. The 1st and 2nd cars both cars used the same 10 Dick Smith Electronics panels and the same Engelec maximiser. The 2nd car had the better motor and was noticeably faster in a straight line, but the 1st car actually caught and overtook it around the outside of the last corner, due no doubt to the much lower drag of the caster wheels. I rest my case.

A big word of warning. If you use a castering rear drive wheel you must either offset the drive wheel or offset the guides to prevent the wheel or worse, the drive gear, running into the guide track. Either method is OK but we always preferred to offset the guides as this kept the car better balanced.

An even bigger word of warning. I have lost count of how many cars I have seen fitted with casters where no effort has been made to correctly align the wheels. It is absolutely critical that the wheels are directly in line with their pivots. Haven’t any of you ever pushed a supermarket trolley with a bent or misaligned caster? I get continually asked why car XYZ has fixed wheels but beats car ABC which has caster wheels. It’s simple. The car with fixed wheels has lots of drag on the corners but very little on the straights whereas car ABC with its badly aligned casters has drag on both the straights and the corners. Properly set up and aligned casters have little or no drag on the entire track. If you aren’t prepared to properly align all the wheels then don’t bother, stay home.

Motors. Speaking motivationally.

Are you serious about this competition? Anyone (well, I used to think almost anyone but now I’m not so sure) can build a car that will go around the track in bright sunlight. Not fast, but it will go. Just attach a cheap hobby motor to your solar panel and it will go, maybe, if the sun is bright. A lot of people have used motors recovered from VCRs etc. but you don’t know anything about them and they tend to be built for long, smooth, silent operation rather than efficiency. If you want to compete seriously and win races you must use a precision motor. These motors use very powerful magnets, precious metal brushes and precision wound ironless rotors. They are actually built inside out compared to normal motors. They are designed for industrial applications which call for small size, low weight, high efficiency and predictable performance. These are the things they use for medical tools and space exploration.

Probably the most successful motor for solar cars is the Faulhaber Minimotor. Full motor data is available for download from <www.minimotor.ch>. No, that's not Chile or China, it's Switzerland.

Without going into too much detail the pick of the motors used to be the Type 2233, either 4.5 or 6 volt. We always used the 4.5 volt version because it had a lower DC resistance, a slightly higher efficiency and a slightly higher power rating. You must ask for the 2mm shaft because this fits the pinion gear that you should use. They cost about $100 each. Even though it is only rated at 3.9 watts you can safely connect it to up to 10 watts of panel because it will last for thousands of hours at 3.9 watts and probably several hundreds of hours at 10 watts. Each race is much less than 30 seconds so that's a lot of races. (A good race is under 20 seconds.) Don't even think about using brushless motors.

Now, however, without a shadow of a doubt, there is a better motor. It is the Type 2232 6 volt. This is almost the same motor as the 2233 but fitted with rare earth magnets. It boasts a power rating of 11 watts, has an even lower resistance so has an efficiency of 87%. More importantly it has three times the torque. It has a lower speed constant (revs per volt) so it was thought that the gearing may need changing, but this hasn't seemed to be the case. This is the motor used by the 2nd car in 2005 and explains its performance despite the non-steering wheels. Of course, it costs more but it is worth having. I simply replaced the 2233 in Kent's old 2002 cars with a 2232. The results were amazing. This very tired old car was 1metre faster over the Tasmanian track than the 2005 National champion car! When one of these motors was then fitted to the champ car it was now 1 metre in front! Needless to say, all 2006, 2007, 2008 and 2009 Tasmanian cars ran these motors. In Sydney 2006 at least the top 4 cars used this motor. In Adelaide 2007, the top 14 cars all used this motor. Hobart 2008, apart from the 2 Taiwanese entries, 28 cars ran this motor. If you don't want to use one of these motors, then save your money and stay at home. The other 2 cars ran a Maxon 118740 motor. This motor is supposed to be very good but it also is very big, very heavy and very expensive. In Melbourne 2009 only one car ran the Maxon motor, the rest ran the Faulhaber.

The next question is, do we use one or two motors? Easy, just the one. No two motors are exactly the same, even the precision ones. Even if you buy lots of motors and do lots of testing to get two almost the same they will still fight each other and you will not get twice the value. You will have twice the weight, twice the gear losses, twice the cost, but slightly less power. If you connect them in parallel they will have the same voltage applied but it is highly unlikely that they will want to run at exactly the same speed, so one will get dragged down by the other. If you put a motor on each side of the car then when it goes around a corner the wheels will want to go at different speeds but the motors will try to go at about the same speed. It just doesn't work. If you wire them in series they will operate a bit like a differential and let the wheels go at different speeds around corners but you still have twice the weight and twice the losses, and you will now need twice the voltage or some very strange gearing.

Anyway, why would you bother? If you had a 10 watt panel and two 3.9 watt 86% efficient motors you would have 8.6 mechanical watts to play with, not 7.8 watts. If you only use one 3.9 watt motor you will still have 8.6 mechanical watts to play with, not 3.9 watts. Electric motors do not create energy, they simply convert the electrical energy to mechanical energy. The motor just won't last as long, that's all. Anyway, the motor that we are all going to use now is rated at 11 watts. End of story. By the way, using an 11 watt motor also doesn't mean we need an 11 watt panel. It just means that if we use less than 11 watts it will last for more races than you can possibly comprehend.

The only advantage of two motors and two drive wheels is that it can reduce torque steering, but that's yet another story.

Gears. Setting the wheels in motion.

It would be possible to fix a wheel straight on to the motor shaft but our motors spin too fast for this to be successful. If we were using a stepping motor or a pancake motor then it could be possible but we're not. You need to use something to reduce the speed. This also increases the available torque and therefore the tractive force and acceleration. Power is proportional to torque (turning force) times rpm. Like all things in real life you get nothing for free so you are going to loose a bit of the available power in the process. What we have to do is keep this to a minimum.

I have seen it all. Rubber bands and O rings used as belts, Lego chain drives, Lego gears, rubber idler wheels running on the road wheels, idler wheels running on the top of the guide channel, you think it up it's probably been tried. A high quality, micro-miniature roller chain and sprockets would probably work OK. However, unless you are very rich you're not likely to get one.

Bevel and bevel cut gears are quiet but too inefficient. Hypoid gears can transmit a lot of power but that is not our concern. Two and three stage gearboxes are also too inefficient. By far the most efficient and the simplest form of transmission is a single set of straight cut spur gears. Leonardo da Vinci knew that hundreds of years ago. Don't play around with cheap gears. You must use good quality gears or this can be a serious source of losses. You can get instrument quality precision moulded plastic gears from Purgon in Melbourne or Farnel Electronic Components in Sydney. These are about 98% efficient.

The ones to use are 0.5mm pitch and come in sizes from 12 to 80 teeth. The 12 and 15 teeth have a 2mm bore to press fit onto the motor shaft. (Remember to get a 2mm motor shaft). A drop of glue helps to keep the gear on but makes it hard if you have to replace it. I have a gear puller left over from my misspent youth as a slot car racer which is extremely handy. Do not get glue on the teeth! You can come up with all sorts of methods to work out what size of gears you need but if you start with a 12 tooth and a 72 tooth you won't be too wrong and you can go from there.

These gears are made from a fancy plastic and are self lubricating so the worst thing you can do is to oil them. This only makes them pick up dust and that quickly wears them out. You must allow a bit of play in the gears, they must never mesh tightly. You can attach the big gear straight to the drive wheel but then you must be accurate. Make sure the small gear doesn't rub on the wheel. We have always fitted a separate bearing into the gear to allow the gears to be meshed properly before fitting the road wheel. We put pins through the gear to loosely engage holes in the road wheel. This allowed for quickly changing either the gear or the wheel if needed.

It is most important to use a good solid mounting for the motor and wheel. The motors have threaded holes for 2mm screws in the end plate and that is how they should be mounted. Farnell sells packs of 2mm screws. Make sure you use screws that are the correct length. If they are too long they can irreparably damage the motor or leave the motor loose. Any movement will chew out the gears and you might as well go home. If you have the misfortune of having the gears come out of mesh while running they will quickly destroy each other and must be replaced. You can practice with damaged gears but don't bother racing with them. Bear this in mind if you go gluing gears onto shafts, etc. A spare set of gears is a must.

P.S. Hobart Nationals, 2008, one team dared to be different. They used a Maxon 118740 motor with direct drive to the wheel. This required a wheel around 30mm diameter to clear the motor so the motor still ran quite slowly, around 4400rpm for 25kph. The data for this motor shows that it has a speed constant of 1200rpm/V, or it does 5360rpm at 4.5 volts This meant that the motor voltage was always relatively low and, as a consequence, the current high. This can be a problem with higher maximiser and motor losses at low output voltages. Also, the side loading on the motor shaft may be too high. Whether all this offsets the 2% gear loss is debatable. They tried this again in 2009, yet again without success. These motors are very heavy and expensive so I don't think I'd bother going down this path, but is an interesting concept.

Solar Panels. You've got the power.

When this competition first started there where no suitable panels available, so a company in Melbourne made the 8 watt APSYS panels. These provided 4 rows of 3 volts each that could be connected as desired. Everyone used them but they started to break down after a couple of years. Solar car racing is pretty hard on the equipment. There are still a few of these being used and while some are almost as new, most are well past their use by date.
The only readily obtainable alternatives were the BP Solar 12 watt and the Solarex 10 watt. These were both expensive and very heavy as they were intended for a long life out in the elements. We chose a Solarex at this time, even though it weighed 1.4kg and you weren't allowed to modify the panel in any way. Next year you were allowed to remove the frame as the required weight was calculated from the surface area. The Solarex still weighed almost 1kg but needed more ballast.

One of the WA Colleges had imported some small panels from the USA and convinced the powers that be to allow measuring the active area of each individual panel when calculating the weight. We exploited this by using 14 Dick Smith panels which produced more power than the old APSYS panel but were required to weigh considerably less.

Never to be outdone, the committee changed the rules to require the power of the panel be measured and the weight calculated according to the formula: Weight = (Power in watts – 4) x 220gm. This meant our 14 DSE panels had to weigh about 970gm.

If you take car weights (all up and including the egg but not including the solar panel) from 250gm to 600gm and then use panel powers from 4 watts to 12 watts, you can calculate the overall power to weight ratio for the car. You can do this manually or use Excel to plot graphs. Either way you would quickly discover that the best power to weight was with a 4 watt panel. Unfortunately you cannot make a panel with zero weight. Using 9 DSE panels meant the panel was over weight while 10 DSE panels still required a small amount of ballast. This equated to a bit over 6 watts, using the DSE panels of the time. This car took 2nd place and held the lap record for the next 4 years. The car that beat it used imported cells and chicanery.

Next year, 2003, to get closer to the ideal, we trimmed all the excess off the panels and glued them to balsa wood. This way we found 8 DSE panels to be overweight and 9 DSE to be just underweight. We used these in the Tasmanian races but to get even closer we imported bare solar cells from the USA and used double-sided sticky tape to attach them to 15mm polystyrene sheet. We had panels that weighed less than 50gm. However, the National committee didn't agree with our power figures and we had to carry 400gm of lead in each car which played havoc with our spring suspension settings. We should have removed cells and had them re-assessed, but if you'd seen the circus that was National scrutineering you'd understand why we didn't. The car that beat Ewen out of 3rd place supposedly only ran 4 watts, but the panel size and the car speed told a different story and in fact, this car and panel were not allowed to race in Perth the next year, much to the chagrin of the team.

From 2004 they changed the rules yet again. The formula was now: Panel Weight = (Power– 6) x 175 + 600gm, with the proviso that the minimum panel weight was 600gm.

Now doing the calculations for power to weight showed that for an all up car weight of 450gm (no panel) the power to weight was constant for any panel power above 6 watts. If your car weighed less than 450gm then a 6 watt panel gave the best power to weight. If your car weighed more than 450gm then the more power the better, you're going to need it, hauling all that unnecessary bulk around. Or was it? With a 6 watt panel you will always get a bigger gain for any reduction in car weight. Then there is the extra friction in wheel bearings and the increased rolling resistance from carrying all that weight around. 6 watts was easy to get. We just used 10 DSE panels. These were relatively cheap, are quite robust and easy to attach.

There have been a number of successful panels made up this way. We used a narrow PCB to which we attached the panels using their own bolts, fitted balsa sheets beside the PCB and then ran tape around the edges, taking care not to cover the cells. This has proved to be very reliable and we have panels many years old. Other teams have simply used Corflute sheeting or balsa or polystyrene and wired the panels together. Whatever fits your car is the best for you, just make sure you have good connections. Do not try soldering directly to the panels as you will probably melt the solder inside and you cannot fix it. Also, don't over tighten the nuts as you can turn the bolts, fracturing the tracks inside, also unrepairable. As in all things, a little care required. Once you've made it, don't fiddle. We have home made panels many years old. We don't touch them. Ever.

N.B. I have found that there were at least five different solar cells sold by DSE. The original dark blue monocrystalline that produced around 550mA, a blue polycrystalline that also produces around 550mA, a grey monocrystalline that can produce over 660mA and a light blue polycrystalline that only produces 430mA. All four styles deliver the same voltage, but, you must be aware that they will produce vastly different power figures. However, they have now changed the design so the present ones produce more current but they are also much larger and heavier. Also, you should never, never, never, ever mix up different cells in a panel.

Jaycar are advertising that they sell the same panels as the old DSE but this is not so! These modules are quite large and unwieldy and I could never recommend them. I also tried a supposed 6 watt panel from Oatley Electronics. Very cheap but oh so big and heavy. Forget it.

After countless requests for where to buy solar panels I have had panels made to specification in China. These have proven to be very popular and successful. They are the same size as the original DSE panels but have large solder pads instead of bolts for the terminations. They are three cell modules made from high quality Taiwanese cells with a FF of about 0.75. They produce more current than I would have liked, around 800mA, which makes them about 0.8 watts each but even so a 10 module car goes very well. Full details are on the Tasmanian web site. If there is enough interest I am looking into a four cell module which will be 2 volt and maybe 600mA. This would mean 8 modules would seem the go, with a lower ballast weight but a higher Vpmax and potentially a higher top speed. Watch this space.

Don't forget that since 2008 you are not allowed to have anything on your panel. That includes the On/Off switch and series/parallelling switches.

A few teams who purchased the APPSYS panels years ago have been stripping them down but they are still quite large and as they produce over 8 watts they have to carry a fair bit of ballast. Also a lot of them appear to have internal faults.

Some teams have been using the full 12 watts allowed, but the all up car weight can be too much. I know of one 11 watt powered car that had a habit of breaking its wheels. Any crash can become a nightmare, especially if they hit another car, as happened several times in Melbourne 2009. The situation has been made worse over the last couple of years with Victorian cars, in particular, 'legally' using two nominal 6 watt panels that produce over the 12 watt limit and one NSW car ran in 2009 with 13.4 watts! This situation was never intended by the scrutineers and now such panels will have to carry an additional weight penalty

The other cell worthy of comment is that obtained from the Tech Ed centre. There seems to be a huge variety of cells from this source, also of widely varying performance. Many of these seem to be either reject or surplus cells. There are some that have an unusually low and normally unacceptable Fill Factor. The Fill Factor is the ratio of the maximum power to the product of the open circuit voltage and the short circuit current. It is an indication of the quality of the cell. The laws of the universe limit the maximum FF to about 0.85 and normally commercial viability limits the useful minimum to about 0.7. It seems that at least one batch of cells from Tech Ed have a FF of around 0.5. These cells give normal open circuit voltage and short circuit current but the maximum power and the maximum power voltage are both well below what you would expect. A panel made from these cells will seriously under perform. However, it can be easily shown that the loss of output is much less at lower light levels and it is easy to build a large panel that only registers around 6 watts when measured on a light box, yet performs the same as a 10 watt (or more) panel in 50% light. This can give a huge boost in car performance in anything below 100% sunlight, as observed by everyone in Adelaide in 2007. From 2009 the rules have been amended to take this into account.

Note. It is extremely easy to artificially create this effect in any panel and this practice has been outlawed as well. Not only that but it is also possible to modify any panel to give an advantage in very bright light, as often happens. This is because the panels are measured at AM 1.5 but this is often exceeded at midday on very clear days. AM stands for Air Mass. The molecules in the air block some of the radiation. In outer space there is no air so it is AM 0. At midday in the tropics the sun can be directly overhead so that is the shortest path through the atmosphere or AM 1. This happens very rarely so a more useful figure of AM 1.5 has been adopted as the universal test condition for solar panels.

There was a 20% increase in the required panel weight in 2009 if you chose to use electronics. I said that this would change nothing in the overall scheme of things since the only 2 cars without electronics in Hobart came from Taiwan and they would have fitted electronics on the spot except that their panels did not produce a high enough voltage. All cars in Melbourne ran electronics. One team opted to not use electronics for one race but the car stalled on the hill and could not be coaxed into restarting. End of story.

The weight formula has been changed for 2010. It now is: Panel Weight = (Power– 6) x 200 + 500gm, with the proviso that the minimum panel weight is 500gm. The rules no longer have a 20% penalty for electronics but allow a 30% reduction in panel weight if you do not use electronics. This means the break even total car weight has gone up from 450 gm (or 540 gm with electronics) to 700 gm (490 without electronics), in a further attempt to discourage high powered cars. Both weights will be recorded on the car and teams can elect which way they will go before each race.

I think you would be very brave to go down the non-electronics path. In the days before electronics, even with the simple solar panels on wheels cars, if you could crack 22 seconds you were really quick. Now, if a Tasmanian car can't do a 20 second lap we won't send it to the Nationals.

Car Weight and Performance. Anorexia on wheels.

Tests by Adelaide Uni, done some years ago, also showed where the power goes in a solar car. For the particular car tested, from the total power developed by the solar panel, 15% was lost in the motor, 3% in the gears, 13% in rolling resistance, 11% in air resistance and 58% in accelerating the car.

We have chosen the most efficient motor and we have perfectly meshing gears. We have clean bearings in our three narrow wheels fitted to perfectly aligned casters. Our body is beautifully aerodynamic. How can we further improve the performance?

As in any vehicle, the biggest power consumer is simply accelerating the car. To get up to speed and to go up the hills you have to accelerate the car. Plus you have the extra drag due to rolling resistance and convincing it to go around the corners.

A quick lesson in some basic physics.

Force is needed to accelerate a mass. F = ma.

Work is done by applying a force through a distance. W = Fs = mas

Power is the time rate of doing work. P = W/t = Fs/t = mas/t

The mass in this case is the mass of the car. We have to accelerate it up to speed, drag it along the track and around the bends and get it up the hill. We have to do this over the length of the track. The time we take determines how much power we use. Perhaps now you see why power to weight is so important?

Doctor Who may be able to change time and distance but we can't. What we can do is change the mass of the car.

At this point the more astute among you will have started to protest that I have forgotten wind resistance. No I haven't. I have already said that our car is beautifully aerodynamic. What, yours isn't? That's just too bad.

The really clever will now point out that if the car starts on top of the hill it will convert the potential energy to kinetic energy and then use it to climb back up again at the end of the lap. Nice in theory, but we live in a real universe and this energy gets used up in the inefficiencies of the system and even in a really well built car is lost in about half a lap. True, on the old track the steep hill meant even rubbish cars could appear to accelerate away from the start, but these cars usually couldn't coast around the first bend. The new track has a much gentler hill so the 'advantage' is not so evident.

Now you might see why I mentioned power to weight calculations when discussing solar panels. You can decide the solar array power (and therefore weight) and you can reduce the car weight. Weight is the force exerted by gravity trying to accelerate a mass. Reducing the mass (weight) has the biggest gain in performance of anything you can do to your well built car. If your complete car, without its solar array and ballast, but including the egg, weighs more than 500gm then you just simply aren't trying hard enough. 300gm and you are getting really serious. Yes, it can and has been done, many times. The best performing cars in 2005, 2006 and 2007 all weighed less than 1100 grams all up in full racing trim. Former Champion and now AIMSC committee member Marc Iseli has a car built to the 2009 regs that weighs around 300gm complete except for the panel. In full race trim it did demo laps in Melbourne in a bit over 16 seconds in 80% Sun with about 8 watts on board. He reckons he could probably get it down to 270gm if he put his mind to it.

Power Maximisers. Things that go bump in the night.

There has been a lot said about the use of electronics in model solar car racing. The simple fact of the matter is that it works. It is true to say that, if you could build the perfect car, for the conditions prevailing at the time, because of the smaller losses, you will go faster without electronics than with electronics.

Some of the well funded teams used to turn up at the Nationals with an array of components that had to be seen to be believed. They'd have a choice of 4 or 5 different motors and a choice of 20 or more gears to play with. Plus they had years of test data at their disposal. Provided the conditions didn't change during the course of a race they were very hard to beat, but it was possible, as we have proved. If conditions change during a race, such as when a cloud crosses the sun, then these cars can be in real trouble. Yet they still rarely cracked 20 seconds!

Over the years, being fully self-funded, we have always had to keep the cost to a minimum. Running 2 teams meant doubling up on everything and buying lots of motors was out of the question. We have also had very limited access to a track to do serious testing. Usually our cars have only been run across the driveway at home before going on to take out the Tasmanian race and to shake up the Nationals. Testing gear ratios at the Nationals is normally not possible. Kent did get to try his quick-change gearbox in Adelaide one year and this proved to be invaluable.

Why does anyone need to change motors and gears? In simple terms you have to match the source of energy, in our case the solar panel, to the load, in our case the car. There is a thing called The Maximum Power Transfer Theorem which students of electronics will learn about, but, trust me, it applies to everything. In simple terms this states that, for maximum power to be transferred from the source (solar panel) to the load (motor) the impedance (resistance) of the load must be the same as that of the source.

Electrical power is found by multiplying the voltage and the current. A solar panel not connected to anything except a voltmeter develops an open circuit voltage. There is no power being produced because there is no current flowing. An ammeter connected directly across the panel will cause the panel to produce a short circuit current but again no power is being produced because there is no voltage. (Any power being produced is all being lost in heating up the panel). We know that the panel does supply power in between these two points, but in varying quantities. Somewhere in there is the point at which the panel supplies the maximum power possible to the load.

An electric motor has unusual and dynamic properties. In its simplest form it can be likened to a resistor in series with an adjustable battery. The resistor value is the resistance of the windings and brushes, etc. The battery voltage varies directly in proportion to the RPM of the motor and is created by the motor acting as a generator when it is turned. It is generally referred to as the back EMF, or electro-motive force. This is found in motor data sheets as the voltage constant.

Ohm’s Law states that the voltage across a resistor is directly proportional to the value of the resistance and the current flowing through the resistor, $V = IR$. So, if we connect a battery to a motor the current drawn will be limited only by the resistance of the motor. This will be quite a high value and is known as the starting current, or stall current. This high current through the windings will produce a high force in the rotor so the motor will try to accelerate quickly.

As the motor speeds up it will generate an increasing back EMF. This opposes the applied battery voltage so the current will decrease. This process will continue until the difference between the battery voltage and the back EMF causes just enough current to flow to overcome the losses in the motor. This is the no-load current. These losses include bearing friction, brush friction and wind resistance. The biggest loss is called the I^2R loss, or the loss due to the winding resistance. This is why a motor gets hot. A perfect motor would have zero resistance, maybe by using superconductors.

If a load is now connected to the motor it will slow down, the back EMF will reduce so the current will increase until it is sufficient to supply the losses and the load. The combined losses are what determine the overall efficiency of the motor. The motor we have chosen has very low bearing friction, very low brush friction and virtually no wind resistance. It also has a very low winding resistance and is therefore the most efficient that is affordable.

All this means that the motor presents a very complex and changing load to the solar panel as the car changes speed going around the track and up and down the hills. That is, the voltage across it varies continuously. However, the solar panel produces maximum power at only one particular voltage. At all other times it produces a current proportional to the light level and the motor load then determines what the voltage will be.

Back in the olden days teams tried connecting their panels in series/parallel to get different voltages. Different motors have different voltage/speed characteristics and different gear ratios will also alter the back EMF. As I said, this is all great just as long as conditions don’t change. What we need is something to automatically change the parameters of the motor and gears so they match what the panel would like.

Changing the motor and gears during a race is beyond most of our capabilities. A mechanical continuously variable ratio drive would be far too inefficient and I have yet to see an automatic gear change system used on a model solar car. By using an electronic circuit between the solar panel and the motor we can make the solar panel think that the motor is a near perfect match, all the way from stalled at the start to going at several times its rated speed. It can never be a perfect match because of this thing called entropy, which basically means you never get anything for free. You will still never beat the perfectly set up car and occasionally the opposition will fluke it. However, for most of the time you will get a big advantage.

Basically, all maximisers/optimisers, whatever, work the same way. They switch the current on and off at a high frequency to maintain the correct maximum power voltage on the solar panel. The switching is usually done with a MOSFET and the energy stored in a small inductor. Capacitors smooth out the switching pulses. How they do it varies from simple circuits using operational amplifiers to those using micro-controllers. I have tested some of these circuits and found that they all work to some extent but have drawbacks. Simple op-amp circuits tend to be free running so the frequency varies greatly with load. Also, they tend to switch too slowly between on and off and so can be quite inefficient. They are easy to set up and adjust, though. Most micro controller circuits are extremely efficient, but, they often seem to be overkill and often do not lend themselves to simple adjustment. Some also have been shown to have potential problems at low light levels and they can stop working for no apparent reason if the programme gets lost, something that can easily happen in this type of application.

We have developed our own design which uses a dedicated switch mode power supply integrated circuit and a high speed driver stage. It is extremely easy to set up. It is so effective that the cars will spin their drive wheels at the starting gate. The circuit allows for a micro switch to be placed at the front of the car to inhibit the operation when the gate is down, then accelerate smoothly away. It also allows for dynamic braking at the end of the race. Cars fitted with these maximisers will operate in fully overcast and rainy conditions at less than 5% sun and still do full laps of the track, yet when the sun is shining do a standing lap in well under 17 seconds. This equates to an average speed of well over 20kph with a finishing speed of well over 25kph. No changes need be made to the cars to go between these two extremes. These cars may still be beaten by cars perfectly set up for either of the two extremes but we didn't have to change our cars between races, ever.

I am pleased to say that the first three cars in Melbourne in 2005 all used these maximisers and the top three cars in Sydney 2006 also used them. The top 4 cars in Adelaide 2007 all used maximisers, although not all mine. In 2008 only 2 cars out of 32 did not use a maximiser of some sort. Melbourne 2009 all cars used maximisers except for one car in one race as mentioned earlier. There were at least 5 different designs used. I think the case for maximisers has been settled, once and for all.

Calculations. Additional things.

What motor do I use?

This one's easy. You must use a precision motor, like the Faulhaber Minimotor. The most efficient one used to be the 2233 series 4.5 volt. It is 86% efficient. This is still a good motor but the newer 2232 6 volt is 87% efficient and has 3 times the torque while retaining the low series resistance. It does however rotate slower because, as I said, you get nothing for free. Despite that this is now the only motor to use. I have been assured that the Maxon is also a good motor but it costs over twice as much, is big and it weighs bucket loads more.

How many watts do I use?

First you have to decide whether you are going to use electronics or not. Don't bother asking me, you know what my answer will be. Now, sit down and work out the power to weight ratio (watts/kg) for panel powers from 6 to 12 watts and car weights from 300gm to 700gm. If you are using electronics it looks like this.

Panel power	6	7	8	9	10	11	12
Panel weight	500	700	900	1100	1300	1500	1700
300gm car wt	800	1000	1200	1400	1600	1800	2000
Power/weight	7.5	7.0	6.67	6.43	6.25	6.11	6.0
400gm car wt	900	1100	1300	1500	1700	1900	2100
Power/weight	6.67	6.36	6.15	6.0	5.88	5.79	5.71
500gm car wt	1000	1200	1400	1600	1800	2000	2200
Power/weight	6.0	5.83	5.71	5.63	5.56	5.50	5.45
600gm car wt	1100	1300	1500	1700	1900	2100	2300
Power/weight	5.45	5.38	5.33	5.29	5.26	5.24	5.22
700gm car wt	1200	1400	1600	1800	2000	2200	2400
Power/weight	5.00	5.00	5.00	5.00	5.00	5.00	5.00

And it only gets worse from here on.

If your car, complete with all running gear and egg but without solar panel and ballast, weighs less than 700gm then use as close as you can get to, but not less than, 6 watts. If it weighs more than 700gm then use whatever you like, you really can't be serious.

If you decide to not use electronics the required solar array weight will be decreased by 30%. The formula then becomes Weight = [(Power – 6) x 200 + 500] x 0.7. I'm not going to bother working this all out but you will find that the break even car weight is 590gm. If you can't get your car weight below this you shouldn't even be considering running without electronics, and if you are over, well……

There is a further complication this year. Because you now must have a bigger cross section your car will be pushing a lot more air so perhaps a bigger panel is called for. Not so if you build a decent streamlined body. Back in 2002 cars were required to have a 200 sq cm cross section. Both our 2002 cars would comply with the 2010 rules with very little modification and they ran under 7 watts but did 100 metre races in a bit over 17 seconds with the old motors. What they could do a 95 metre race with the new motors is anybodies guess, but it wouldn't be slow. One was a teardrop and one was a wedge so there is plenty of design scope available.

What panel voltage do I use?

Experience shows that you will need at least twice the rated motor voltage and perhaps not more than three times the rated voltage. A lower voltage will give you more current for hill climbing and low light operation while a higher voltage will give you more high light speed. If you are using a maximiser you want 2-3 times the rated motor voltage and the maximiser will compensate for all conditions. (See later for actual calculations. It depends on gearing and wheel size.) With a maximiser you will probably need at least 8 volts to ensure the circuit works properly, especially in low light conditions.

What size wheels do I use?

You have to compromise between getting enough ground clearance and not making the car unstable. You need at least 25mm under the middle to clear the guide channel when you go over the bridge and if you have an overhang at the front or back you will need about the same. Also, your drive wheel has to be bigger than the drive gear. Basically, 30mm is getting too small and 100mm is way too big. We originally used 65mm wheels because we had them but when we made our own we made them 50mm because it seemed like a good size. The tyre made the drive wheel 52mm. A number of fast cars in 2006 used narrow commercial 65mm wheels. The wheel size will combine with your gear ratio to determine the overall final drive ratio so you could have fixed gears and change wheel sizes but this also affects ride height so then you would also have to adjust the height of your rear guides.

What gear ratio do I need?

This is tied into the motor you are using, your panel voltage, the diameter of your drive wheel and the weight of your car. It may be anywhere from 3:1 to 10:1. We tried them all, even using a quick change gearbox one year. We found that using a maximiser the gear ratio isn't as critical. We settled on 6:1 many years ago. That is a 12 tooth motor gear driving a 72 tooth wheel gear and a 52mm wheel. If you use the new motor the ratio may need to be different. Hobart College tried from 6:1 to 5:1 with very little effect. Queechy ran 6:1 with a 65mm wheel and took second place but also smashed the track record.

To be a really serious contender your car will need to be able to do a 100 metre lap in much less than 20 seconds. The top cars are now taking under 16 seconds to do a 95 metre lap. A 16 second lap means an average speed of 22.5kph but the finishing speed is more likely 25 or even 30kph. A 50mm wheel has a circumference of 157mm. To do 25kph the wheel has to turn 25,000,000/60/157 per minute, or 2655rpm. With 6:1 gears the motor must do 15,930rpm. With 6 volts applied your 2232 motor has a no load speed of 7,100rpm. So, to do 15,930rpm at full load, you need to have over 13.5 volts available. To have the best power to weight you will use a 6 watt panel. At 13.5 volts this is 444mA and you will have trouble getting a solar panel to suit. 10 DSE panels produce something over 6 watts at about 15 volts and about 400mA, so you could change the gear ratio or the wheel size, and it might even work. Or use a maximiser like everyone else. With the 2232 motor it might be worth going for perhaps a 5:1 gear ratio. This would mean a motor speed of 13,275rpm and an applied voltage of over 11.2 volts. To get closer to 30kph may need a lower gear ratio or a bigger wheel or a higher voltage. Also, I haven't included the motor IR losses. That is, the voltage drop due to the current flowing in the motor resistance. Or the maximiser losses. Then you have to allow for the panel heating up and the voltage dropping. What you have to do is make sure that at top speed the motor voltage is at, or, if you have a maximiser, just below, the maximum power voltage of your panel. Obviously, if you are not running the panel at its maximum power point then your car could be going faster. This is where maximisers come into their own.

Conclusions. The sum of all fears.

Basic four wheel stick chassis cars are easy. Anyone can build them. And a well built one usually goes fairly well. I could name certain schools that have taken basically the same cars to the nationals for several years.

Three wheeled monocoque cars can be harder to build and even harder to build properly, but the results are well worth while. And they look better and give you a much greater sense of achievement. They win a lot of Best Engineered Car awards as well.

If you think this is all too difficult, have a look at the top three cars for 2005 and 2006, and the fastest cars from 2007, 2008 and 2009. Different schools, different constructors, but all based on our original three wheel concept. It can be done, it's not that hard. I can name several schools that have never competed before but have followed this line of thinking and made it to the Nationals on their first attempt.

Why didn't they win in 2007, 2008 and 2009? Simple, forget 2007, it was a total furphy. The seeding was a nightmare and enough has been said about the winning car. Three wheelers still came 3 and 4 and totally creamed the fastest lap when they were given their chance. The 2008 winner was also a 3 wheeler and although not completely to this formula it won simply because of the meticulous way it was prepared and maintained and the unfortunate lack of serious well designed and built competition. The 2009 winner was a semi three wheeler. It had castering front wheels but a pair of close together rear drive wheels. 3rd and 4th were three wheelers. A demo three wheeler blew everything else off the track.

So, happy racing, you too are going to upset a lot of people. Believe me, rattling cages is contagious.

Any questions, just ask. I long ago ceased having favourites, I'll help anyone.

Oh, one last thing. In case you haven't caught on yet, the grey NSW track is not 100 metres long. It is in fact only 85 metres for a lap with 9 metres more to the finish line, a total of 94 metres. This means that Ewen's old lap time of 17.5 seconds for 100 metres on the rough old track, with the old motor and a 200 sq cm cross section, set back in 2002, still stands up pretty well against the new motors doing 16 seconds with less frontal area on the new, smooth, 94 metre, short course track.

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