©

MODEL SOLAR CAR

DESIGN GUIDE

REVISION 10 JANUARY 2012

BY: IAN GARDNER ©
FOR VICTORIAN MODEL SOLAR VEHICLE COMMITTEE

MODEL SOLAR CAR DESIGN GUIDE

CONTENTS

MODEL SOLAR CAR DESIGN GUIDE
REVISION 10 JAN. 2012

This document raises in general terms some of the factors to be considered in the design and construction of model solar cars. The information provided will be of assistance to first time entrants while providing ideas on future directions for the more experienced. Part A of the document covers in general terms the basic topics which should be considered in any model solar car design. Part B gives additional detail in many specific areas supplied in the form of appendices.

Most of the performance data and behaviour characteristics quoted in this document have come from the extensive testing performed at Box Hill High School. As they are the result of tests with specific cars and equipment, the accuracy and relevance to other cars cannot be guaranteed. Use them as a guide and an inspiration to begin your own test program. Do remember the car performance quoted in this document is based on cars built to the regulations at the time of testing. Use it as a guide but be aware there will be quite different performance profiles for cars built to different regulations.

IMPORTANT COMMENT: This year 2012 the Car Regulations have been changed only slightly from the 2011 regulations. Ballast remains the same and only the drag plate has been varied. The area has been reduced to 200 square cm and any shape is now allowed but the plate must be aluminium with a minimum thickness of 1.2 mm.
Do read and understand these regulations before designing and building your car.

Additional information can be obtained from:

Victorian Model Solar Vehicle Challenge at contact@modelsolar-vic.net

WRITTEN FOR THE VICTORIAN MODEL SOLAR VEHICLE COMMITTEE BY IAN GARDNER.

PART A GENERAL SOLAR CAR DESIGN

INTRODUCTION: ("Roadmap to success")

Firstly obtain a copy of the current regulations, read and understand them, then design and construct your car to conform to the regulations. In the past many non conforming cars have been presented for scrutineering. Even minor non-conformities slow up the scrutineering process, delaying everyone and reducing the practice time available while the car is modified to conform and passed through scrutineering again.
NOTE: The Victorian regulations are based on the National Regulations which are changed every year. Your car must conform to the National regulations if you wish to compete at that level for details go to www.modelsolaraustralia.org for the latest National regulations.

The key point to remember in designing a model solar car is that you have very little power available from your solar panel. For the shortest race time you must use all the power available at the highest efficiency possible to propel your car.

We shall begin with a brief description of the basic elements that make up a "good car and successful project.

BASIC REQUIREMENTS FOR BUILDING A GOOD CAR:

A. PROJECT MANAGEMENT

This item is not at the top of the list by accident. You can have the best resources and car design in the world but poor or no management of the project will assure failure.
Following are some critical items to consider.

- Define the project: Exactly what is involved in the total project.
- Feasibility study: Have you got or can you get whatever is required to successfully complete the project. Some of the things to consider are listed below.

  Time
  Funding
  Equipment
  Skills
  Sufficient personnel
  Materials for construction

  If you cannot say yes to the above it is time to stop.
- Time line: Produce a timetable detailing the start date finish date and duration of every section of the project. Work backwards from the event date to ensure completion in time. Note, in many instances activities can overlap, for example car construction can be progressing before all materials are available. Some of the things to consider are listed below.

  Car design
  Material & equipment procurement
  Manufacture of car

Testing & modifications as required
Poster

- Detail car design: This area is critically important. It is imperative you know exactly what you are going to build and what materials you need.
  Do produce drawings and sketches of components and an overall assembly drawing of the car and draw it to scale. Many hours of work and much material is wasted remaking components that did not initially fit into the car as intended. All because it was not clear exactly what the components were to look like and the actual dimensions required to assemble into the complete car.

  Firstly I suggest looking at photographs and video of cars at previous events, then check the various State solar car web sites for additional data and ideas.

  Some of the sub assemblies / design areas to consider are listed below.
  Overall dimensions
  Wheel details, number and placement, drive wheel?
  Motor
  Electronics
  Solar panel
  Guiding, placement & dimensions of guides
  Gears
  Track clearances
  General conformance to regulations
  Body shape (aerodynamics) & material
- Materials & equipment procurement: Be certain to order and obtain any materials or items needed for your construction in plenty of time, so they will be available for use when you need them. As an example Faulhaber motors are in limited production in only one factory in Europe. Quantities held here in Australia are limited. Should the local stocks be exhausted in about May it could be late August or early September before more motors are available. The reason is simple the factory in Europe closes down for summer vacation over the June / July time span, if there are no stocks of this motor on the shelf in the factory we must wait for a run of these motors to be scheduled down their production line.
- Decisions & action: Regularly review your position and make decisions and take action as required to maintain progress.
- HELP !!!! Remember the Model Solar Vehicle Committee here in Victoria run workshops from time to time. However technical advice is always available, contact the committee chair at the email address on the regulations.

  Box Hill High School have an active Model Solar Car programme and are willing to provide assistance to other schools or students. They have a test track which is erected from time to time particularly near the event date. Any students are welcome to come and make use of the track at these times.

B. LOW WEIGHT TO POWER RATIO

A weight to power ratio of about 160 gm per watt used to be typical on top cars in the past. The new ballasting formulas for introduced in 2011 will allow lower ratios than this on well designed and built cars. We will have to wait and see what competitors achieve. (The test car Photon Cruncher MK IV (see page 45 for details of this car) has weight to power ratio about 220 gm/watt and outperforms many cars with better ratios only because it is accurately built)

C. BUILD ACCURACY
Poor build accuracy can easily cost 5 seconds. (Axles 3mm out of parallel has about the same effect as adding about 700 gm to the car weight on a 4 wheel car without steering) Ensure axles are parallel, steering if fitted is free to move but does not shimmy, test to ensure your car is not "crabbing" down the track pushed hard on the guide rail. The car must run smoothly with no wheel wobble or bouncing.
Correct clearances in bearings and gears, bearings lubricated with light oil never run bearings unlubricated. The chassis must be strong & stiff enough to maintain clearances and alignment if good performance is to be achieved.

D. AERODYNAMICS (See section 17, Appendix K & L)
Good aerodynamics, by which I mean a car with low aerodynamic drag is critical if your car is to have the best performance possible. (a car with excellent aerodynamics can be 22 M ahead of the same car with poor aerodynamics at end of 2 laps in high sun level.) Aerodynamic drag is the largest retarding force acting on an average car by the time it exits the first corner. It varies with velocity squared so is high for all the second lap of a 2 lap race. Typically the aerodynamic drag is about twice the rolling resistance as the car crosses the finish line.

E. TESTING
Testing is critical to obtain a car that runs well. It shows up any bad design and poor build quality, allowing you to rectify any faults before the event.

F. ENERGY UTILISATION (See section 8 Electronics & Appendix E)
It is important to use as much as possible of the energy collected by your panel to drive the car. The use of electronics is strongly advised for new starters, as it will assist in this. Ensure you have selected the best gear ratio. (Use of the mathematical simulation will give a starting point.)
By knowing where the energy is used you can take steps to use it effectively.
Energy is used in the following areas. The factors influencing energy use are in brackets.

- Overcoming air drag (shape and frontal area)
- Giving the car Kinetic Energy (car mass and velocity)
- Electronics (unit efficiency and correct adjustment)
- Motor (motor characteristics and operating point)
- Rolling resistance (use of tyres, bearings fitment and lubrication, axle alignment and use of steering)
- Driving of car (tyre on drive wheel and gear reduction, is the reduction ratio correct? Are the gears correctly meshed and in alignment)

G. SOLAR PANEL

The ballasting formula in use this year means that provided panel power output is between 6 and 10 watts there is little or no advantage or disadvantage, provided the car is well designed and constructed. has

It is more important to use a good quality solar panel. Solar cells have internal resistance both series and parallel, the ratio of series and parallel resistances within the cells and ultimately when assembled, the panel, can give a ballasting disadvantage or advantage depending on the ratio. Low quality panels are more likely to have an undesirable ratio of resistances. See the section on solar panels for details.

H. RELIABILITY

Your car must function correctly every time you place it on the track to race.

Testing will show up any problem areas, be sure to correct them.

REGULATIONS & IMPLICATIONS FOR PERFORMANCE:

The regulations are changed every year primarily to force teams to build a new car, the changes are carefully chosen to ensure cars built previously are easily identified as "old design" and if possible disadvantaged in performance by the new regulations.

The regulation changes for 2012 are minimal. Only the drag plate has been changed, its area reduced to 150 cm sq and must be aluminium over 1.2 mm thick.

The 2012 regulations still allow much simpler cars to be constructed, in the simplest format they could be a ladder type frame chassis with a solar panel on top and the 150 square cm drag plate. This type of car is very simple to build and will have good performance due to its light weight. However a more complex heavier car employing a body with a good low drag aerodynamic shape would be expected to have even better performance.

What power Solar Panel should you choose? Significant effort was expended by members of the National committee in evaluating different ballasting formulas, the computer modelling performed indicated there was no significant difference from 5 Watts upwards, provided the car was of excellent design and build quality and correctly set up.

Electronics or not? The new ballasting formula is generous for cars not using electronics. Again computer modelling indicates that for a car without electronics a slight advantage exists. Remember this is only true for a top car correctly set up. The correct set up for a non electronics car is significantly more difficult and must be adjusted if Sun levels vary by more than about 5%.

Overall the secret to a winning car is just build a really good car put in plenty of practice to iron out all the bugs and pay attention to detail during preparation and racing.

WARNING !!! A top car built to the current regulations will be running very fast in high Sun conditions. On the Victorian track take off over the hill will occur ** and roll over or dislodgment of guides in the corners is highly probable. You may need to consider slowing the car down in high Sun conditions. There are many options for slowing the car, including adding a plate or similar to form an air brake, changing gear ratios or partly shading the Solar Panel. Which is best for your car?

** Calculations indicate take off will occur at speeds over about 6.5 metres per second, do not fall for the trap of thinking adding extra weight will hold the car down it will not. Check the Physics texts. The only way extra weight helps is that it slows the car due mainly to rolling resistance increase.

1. WHEELS

Diameter is important. Large diameter wheels traverse bumps better than small diameter wheels. However, larger wheel diameter will increase weight and require a larger reduction ratio between motor and drive wheel, possibly making the design and construction of the transmission more difficult.

Remember, the track is constructed from sections and there will inevitably be some mismatch at joints, very small wheels can tend to trip on these bumps.

To reduce friction, wheels should run on ball bearings shielded to reduce dirt ingress, but not sealed. Seals add friction.
A word of caution here, the small ball bearings normally used in this application have a low load rating , it is adequate for normal operation but a crash or improper handling during installation can apply loads high enough to permanently damage a bearing. Typically the damage takes the form of permanent deformation of the balls and races. That is the balls have flats on them and the races have dents in them. The result of this damage is that the bearing then runs rough with significantly increased friction. Be especially careful to lubricate bearings with light oil, the urban myth that running bearings dry decreases friction is totally wrong it is against all sound engineering practice and in any case tests have proven that bearings run dry and clean have about 250% more friction than lubricated bearings. See Appendix I for handling tips and other bearing data.

Many cars have been constructed with wheels at around 40 mm diameter and appeared to perform without problems.

Tyres increase rolling resistance and hence act to slow the car but may be required on the drive wheel(s) to provide friction to drive. A wet track may cause wheel slip even with a tyre. Tests indicate that a single 1/16”section O ring used as a tyre on a wheel of 70 mm diameter increased rolling resistance by 0.07 Newton. To keep rolling resistance to a minimum never use tyres on any wheel except the drive wheel. And only then if wheel slip is a problem.

Observation has shown that an aluminium or plastic drive wheel has sufficient friction to drive without a tyre once the car is up at speed. However at high Sun levels with an electronics system wheel slip will almost certainly occur during starting. (NOTE: The plastic drive wheel has about 15% less friction than the aluminium wheel so will require a tyre at a lower Sun level if slip is to be avoided or minimised.)

Track testing has shown that the high torque output of the 2232 motor when driven through an electronics unit results in appreciable wheel slip on initial take off in high sun conditions.
At 90% Sun actual track testing of Photon Cruncher MK IV has shown this wheel slip resulted in a single lap time 0.6 seconds slower than that obtained when a tyre was fitted. (to the drive wheel only) Obviously as the Sun level drops there is a break even point where a tyre begins to slow you down again this is because of the increased rolling resistance a tyre causes.

2. DRIVE TRAIN

The car should have its gear ratio very carefully chosen to operate the motor and solar panel combination at their most effective point for the prevailing conditions . (See section 8 ELECTRONICS for operating point description.)

You need to reduce motor speed which can be in the order of 20000 RPM down to the wheel speed required typically in the area of 1000 to 3000 RPM depending on wheel diameter.
Gears are the most common speed reduction system in use. Remember the power loss in the drive train can be high if it is not accurately made and adjusted.
On a conventional axle set up i.e. a transverse axle with a wheel each end, normally only one wheel is driven and the other allowed to run free to give differential action. If you have both wheels locked to the axle, large power losses will be experienced during cornering.

Refer to Appendix B, Transmissions for Solar Cars, for more details on reduction systems.

3. SOLAR PANEL

A: General

NOTE: All data and references to Solar Panels or cells in this document are to SILICON CELLS, as these are the only type of cell approved for use in this event. (See regulations)
Maximum dimensions and power output of your panel must conform to the requirements detailed in the Regulations.

If you are not using an electronics system it is critically important to consider the motor and panel in conjunction with each other to ensure the best voltage and current match from panel to motor in order to obtain optimum performance. As Sun level varies you will need to make adjustments to maintain the motor and panel match.
SEE SECTION 8 ELECTRONICS for a detailed description.

Some factors to consider when making your decision on which solar panel to use on your car are:

* Voltage, Current and consequently the Power you require.

* Can you obtain a commercial panel to suit your requirements?

* Should you manufacture a panel from commercial cells that are already mounted on a backing and protected by encapsulation?
  (such as the cells available from Dick Smith Scorpio , Engelec and others)

* Should you manufacture a panel from un-mounted cells cut to suit you requirements
  (Caution: un-mounted cells are brittle, require careful handling are extremely difficult to solder to and must be mounted on a stiff backing to prevent breakage. They may require some protective covering.)

* Weight of your panel
  Is the panel heavier than the panel plus ballast weight required by the regulations, resulting in a weight handicap?
  Effect of panel & ballast weight and centre of gravity on car stability.

Maximum power is developed from a panel when light strikes it at right angles. This is virtually impossible to achieve on a model solar car, as the position of the Sun relative to the car changes as the car traverses the track.
Shading even one element on a panel will drop the output significantly. Take care when mounting your panel to avoid shading and remember to keep the panel clean.

Solar panel power output falls as the panel temperature increases so do not leave your panel laying around in the sun cooking, some competitors cool their panels prior to racing. With panel power dropping by about 0.5% per degree C temperature rise, a 25 degree C temperature reduction results in a worthwhile power increase. Be cautious the panel will heat quickly to a quite high temperature when placed in the sun. (we have measured panel temperature of 60 deg. C after ½ hour on a cloudless day of 20 deg C)

B: Ballast & your Solar Panel
To ensure a fair competition the power output of all solar panels is measured then based on this measured power the minimum weight of ballast plus solar panel required by the

regulations is calculated. For panels lighter than this required minimum ballast will be required to bring the weight up to the minimum required
The ballasting formula and a full explanation is available in the regulations.
It is important to know the approximate power output of your panel so you can arrange any ballast required before the event, as you are required to provide your own ballast.

To obtain the approximate panel power either check its power output from the label (probably this will be within 10% of the power that will be measured on the light box at the event) or if it has no label measure its power output.

NOTE:

If you cannot measure your panel's power output an approximation can be obtained by measuring Open Circuit Voltage (OCV) and Short Circuit Current (amps) (ISC) in full Sun, then by multiplying these together and multiplying the answer by the cells fill factor (FF)

That is Approx. Power in Watts = OCV x ISC x FF

If the fill factor for your panel is unknown (probably the case) use 0.75 as the expected fill factor for a good quality panel.

For stability, any ballast required is best secured as low down in the car as possible. Be VERY careful and secure ballast properly. The forces acting when a car stops suddenly from high speed (for example a crash) can be extremely high. Loose ballast flying around inside your car can damage other components.

C: Fill Factor (Sometimes called Form Factor)

What is Fill Factor you ask? It is the panels actual power output divided by the product of open circuit volts and short circuit current. (You may like to consider fill factor as a sort of guide to panel efficiency or quality.)
See appendix F Photovoltaic cells and panel power testing page 71 for an explanation of fill factor.

D: Panel Quality

Over the past few years at scrutineering at both the State and National events I have noticed cracked cells in some panels refer to Appendix Q for more details.

4. CHASSIS

The chassis should be as light as possible but must be strong enough to hold together during handling and running. It must also be stiff enough to hold everything in alignment and position (consider the possibility of rough handling & accidents).

Take care that your chassis is not so stiff that the car tends to lift the drive wheel off the track as the car moves over undulations in the track. We have observed this on several occasions. Some form of suspension, or packing the drive wheel down lower than the other wheels may be required.

We have observed that in general, cars with some flexibility have better track holding characteristics than stiff cars. Obviously 3 wheel cars will always have all wheels on the track.

It is not mandatory that a separate chassis is used, a well designed and constructed body can perform the same functions as a separate chassis and in our modern motorcars does just this.

5. MOTOR

The regulations allow the use of any motor or motors. Generally, permanent magnet brush type direct current (DC) motors are used as they are common, readily available and well suited to this application.
Inexpensive motors can be used successfully to power a car but in general their performance is inferior to the high quality motors used in the most competitive cars.

For example a “TOY” motor can require about 0.30 Amps to just run without driving a load. This is equivalent to about 50% of the maximum current available from a typical cars solar panel in full sun light. The high quality high efficiency motors typically require only about 0.020 Amps to just run. This is only equivalent to about 3.5% of the maximum current available from a typical cars solar panel in full sun light.

Most cars use the FAULHABER 2232 6 Volt motor (FAULHABER motors are distributed in Melbourne by Erntec Australia – see Buying Guide on Web site). Another commonly used high quality motor is MAXON which also offers a large range of motors which just like the Faulhaber are expensive. (Maxon motors are available from Maxon Motor Australia in Sydney www.maxonmotor.com.au)

CAUTION: When using Faulhaber motors never exceed the manufacturers limit of 20 Newton (2kg.) end load on the shaft or motor destruction is probable. Consequently I strongly advise never to push gears onto the motor shaft. If you intend to use push on gears seriously consider the use of tooling to support the shaft.

The following is a general overview of the characteristics of small Permanent Magnet DC Motors.

POWER:

- The motor has a nominal output power stated by the manufacturer.
- More power can be obtained from the same motor simply by increasing the supply voltage.
- Note that running a motor above its nominal power will reduce its life.

RPM :

- As a general rule, RPM is proportional to voltage, double the voltage and the RPM will double.

TORQUE:

- Motor torque is directly proportional to current, double the current and the motor torque will double.

EFFICIENCY:

- At nominal supply voltage, maximum motor efficiency (of around 82%) occurs at about 1/3 of maximum power output (refer to manufacturers data). At other operating points efficiency is lower, down to about 55% at full power and down to zero if the motor is stalled. Check the manufacturers specifications for your particular motor.

OPERATION AT OVER-VOLTAGE:
Operation at Over Voltage is common it gives the following general advantages;

- At over voltage the motor is capable of producing more power than possible at nominal voltage. We tested a Faulhaber 2224 6 Volt motor nominal 4 Watts at 12 Volts with 14 Watts input and obtained 9 Watts output at 14000 RPM. The motor failed after this test. Note the efficiency at this point was only 64%.
- In general, operation at over voltage tends to hold motor power output and efficiency up at high levels over a much wider RPM range than obtainable when operated at nominal voltage. This means in practice that selection of gear ratio and frequent gear ratio changes to keep the motor operating at near maximum power and efficiency are not required as frequently.

EXTREME CAUTION: Remember any overload will reduce motor life and have the potential to cause permanent motor damage or destruction.
Handle your expensive motors carefully.

CRITICALLY IMPORTANT : NEVER TEST A MOTOR AT OVER VOLTAGE USING A POWER SUPPLY THAT IS NOT CURRENT REGULATED SIMILAR TO A SOLAR PANEL.
A solar panel is a constant current device so is in effect power limited and can therefore not supply unlimited power to the motor, consequently the chances of burning out the motor is reduced compared to a battery or power supply which can supply very high current .

The book 'Model Solar Cars: Optimising Their Performance' by Mr. Stan Woithe contains a lot of useful data on motors and their performance. This publication is currently out of print but an updated version is being prepared and when completed will be published on the SA web site.

6. WEIGHT

For best performance, keep weight to a minimum. But remember, a super light weight vehicle that falls apart and does not finish is no good at all. (See Appendix C on materials for some strength to weight data for materials sometimes used in model solar car construction).

Remember, while weight may not be as important as some other areas such as build accuracy, aerodynamics and effective power utilization, it does have a significant effect on performance. On a car capable of a 20 second run in 100% sun, an extra 200 gm will slow the car by about 0.8 seconds over a one lap race, while 200 gm extra at 20 % sun will slow the car by about 2.5 seconds over the one lap race and may even prevent it from climbing the hill.

At the end of a race a significant proportion of the energy provided by the motor will be stored by the car in the form of Kinetic Energy. Lower weight means less energy is stored in this form and more will have been available to overcome other losses during the race. Weight also directly influences wheel rolling resistance as well as the side forces acting on the guide system when cornering. Lower weight reduces these forces.

7. GUIDING

Guiding on the outside of the U channel is now MANDATORY as there are joining pieces placed inside the "U" to improve horizontal alignment. Remember there can still be some mismatch at the joints so any guiding system used must be able to cope with this. (The mismatch can be both vertical and horizontal.)

To keep friction low, use ball bearings either alone or supporting a roller wheel. Remember a car capable of a 20 second run will be experiencing a side force up to about 80% of the car's weight while traversing the last corner in high sun. Consequently guide rollers deserve as much consideration as wheels.

Mounting the guide rollers is important as they are subjected to quite high side forces plus impact loads as they pass over the guide channel joints. The rollers, their support shafts, and the section of car they are mounted to, all must have adequate strength to survive the pounding they will experience during the course of racing. As a rule of thumb the side forces on a fast car can be equal the car weight and that is not counting the impact loads as the guides traverse the joints in the guide.

A word of caution: ensure whatever guides you use are high enough above the track not to catch on the track mismatch at the joints. Rollers have been ripped off cars when this has happened. As a rule of thumb 3 mm clearance between the guide rollers and the track has been found to work well.

What appears to be a good idea for guide rollers was seen at the 2008 National event in Hobart. It is shown in the photograph below.
It is simply to cant the rollers so that they run on the guide rail down close to the track surface. This allows the car to bounce upwards nearly the full height of the guide rail before becoming disengaged.
This angle on the guide roller reduces the probability of catching on any step that may be present at the track joints. The angle tends to assist the guide roller to ride up and roll over the step instead of catching on it and bringing the car to a dead stop, with the probability of significant damage.

CANTED GUIDE ROLLS

It is suggested you mount the guides to the rear of and as near to the axles as possible to maintain maximum clearance over humps, hollows or mismatch in the track. It is disasterous if rollers are mounted too high and become disengaged from the guide allowing the car to run off the track out of control.

As for spacing between guide rollers, 45 mm clear between the rollers is a good starting point. Too close and the rollers are in contact with the guide channel for a longer time, in the extreme all the time. A guide roller touching the guide wastes energy. This distance between guides improves the chances of your car landing back down with the guides still over the guide channel after it has taken off when cresting the hill at high speed.

The photograph below taken at the 2009 Victorian event by Mr. Witney is proof of take off.

Calculations predict take off at around 6 Metres per second. Remember take off is controlled by car speed and radius of hill curve. The common suggestion of adding weight will not help except that it tends to slow the car down.

8. ELECTRONICS

In 2009 most of the cars used an electronics system of some sort. The question has now become.

ELECTRONICS: To use it or not?????

The regulations have been changed in order to remove the disadvantage that cars not using electronics have. Hopefully this change will encourage more teams to operate cars without “the magic black box”.

The changes allow significantly reduced ballast for a non electronics car.

The reason behind this change is simple. Since electronics has come into universal use at the National level (and probably most states) the interviewing panel has noted a significant drop in teams understanding of the effect on car performance of motor, solar panel configuration, gear ratio and wheel size. Total reliance is being placed on the

electronics “black box” to take care of everything. To make matters worse there is no understanding of how the electronics functions.
As one of the aims of this competition (and our major sponsors) is to foster and improve technical understanding it is hoped this regulation change will assist in achieving this. Since running without electronics requires significantly more knowledge and ability I expect that only more experienced teams will opt for this. Inexperienced teams and particularly new starters would be advised to initially run with electronics then consider deleting it as their experience and competence increases.

CAN A CAR WITHOUT ELECTRONICS BE COMPETITIVE??? YES

At the 2009 Victorian event a car without electronics was only narrowly beaten into 4th place. When car design is taken into consideration this result could easily have been different. The 4th placed car had a larger frontal area than the other cars. Frontal area increases aerodynamic drag. Low aerodynamic drag is critical for good performance. My expectation is that had this car been constructed with the minimum frontal area possible it would have won. The even more generous ballast allowance for this year will give cars potential for even higher speeds. Mathematical modeling predicts well designed, constructed and correctly set up cars without electronics will generally be slightly faster than cars with electronics.

FIRSTLY -- WHY IS ELECTRONICS SO POPULAR ??:
Examination of the graphs below will show why electronics has become so popular. These graphs depict results of actual tests on a Solarex SX 10 panel illuminated by a light box powering a Faulhaber 2232 6 Volt motor. The accuracy of these results is limited by the difficulty of measuring the low motor torque. Heating of the solar panel on the light box and consequent power variation adds further error. Note the downward kink in the motor power output with electronics graph from about 14000 RPM onwards this is due to the significant increase in power needed to overcome motor friction and flywheel air drag at high RPM. Obviously it is also affecting the motor power output direct on panel but is not obvious on that graph. See graph 3 for details of power consumed as RPM increases.
However the general trends shown by these graphs are obvious and not in any doubt.

GRAPH 1 : Power vs RPM (test at 82% Sun equivalent)

Examination of graph 1 above shows,

- Maximum power output through an electronics unit is slightly lower than the maximum panel power. This is expected as no electronics can be 100% efficient.

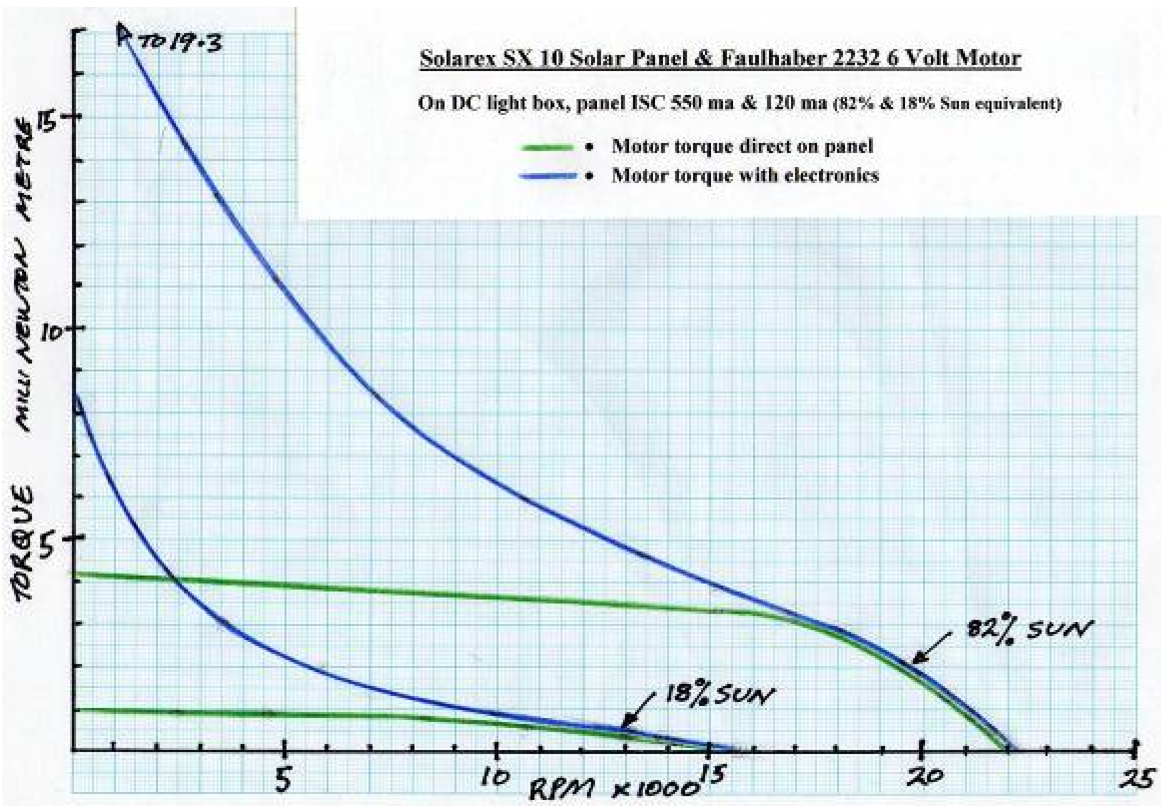
- The electronics unit, holds its maximum power output constant down to about 6 volts and drops out at about 4 volts. By this stage the power from a motor connected directly to the panel power has fallen significantly.

- Maximum motor power with electronics is slightly higher than without. (With a high efficiency electronics unit in use.)

- The power obtained from a motor connected directly to the panel falls in a similar manner to the panel power. No one would choose to operate at below 5 watts which gives an operating RPM band between about 15000 and 19000 RPM. A range of 4000 RPM.

- The motor output power when it is powered through an electronics unit generally follows the power output of the electronics. For the same 5 watts operating power as used above the RPM range would be between about 4000 and 19000 RPM a range of 15000 RPM.

- This wide maximum power RPM range makes gear changes unnecessary in many cars, no matter what changes occur in Sun level. Car set up and operation is consequently simplified. Once the correct gear ratio is established and fitted to the car and the electronics unit correctly adjusted it is truly a matter of placing the car on the track and switching it on. Note: unless sun levels fall below 20% there in not even a need to readjust the electronics set point.
- Take care operating your motor above about 16000 RPM as motor losses increase rapidly significantly reducing output power available.



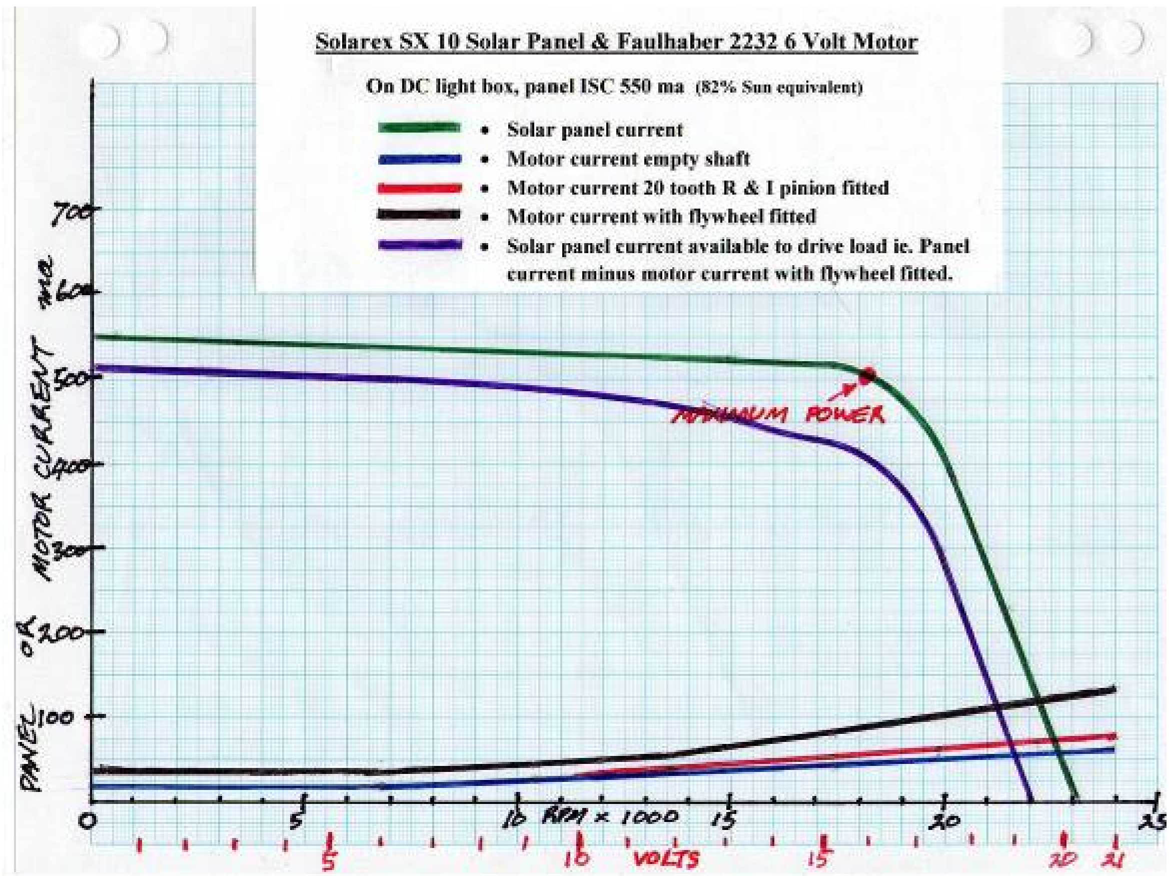
GRAPH 2 : Torque vs RPM

Examination of graph 2 above shows,

- At high sun levels motor stall torque with an electronics unit is about 450% higher than the stall torque of a motor wired direct on the panel, this figure rises to about 800% at low Sun levels.

- The torque increase we see from the electronics powered motor as RPM drops has the same effect as a constantly variable gear ratio resulting in better acceleration on initial take off together with improved hill climbing ability.

Considering the advantages offered by the use of an electronics unit, particularly that the use of electronics will make a poorly designed and constructed car run when otherwise it would not, there is little wonder that all cars now are now fitted with electronics units.



GRAPH 3 Current consumed in motor losses

CAR SET UP REQUIRED TO OPERATE WITHOUT ELECTRONICS:

For a car to run effectively without an electronics unit what is required?
Firstly some basic data.

- Power is the time rate of doing work. The unit of power is the Watt which is equal to 1 Joule per second or a force of 1 Newton operating over a distance of 1 metre in 1 second. For a motor, power is calculated by multiplying torque by shaft speed (RPM). For a car the power required to drive it can be calculated by multiplying the drive force applied to the car by the cars velocity. (When the car is moving at a constant speed the retarding force is the sum of aerodynamic drag, rolling resistance which includes wheels and guides and any gravity force such as when on the hill.)

- Ignoring friction losses the power from a motor can be converted into the same power at any nominated RPM by the use of gearing. (Note the torque will be altered)
- For the DC motors we are using torque varies directly with motor current (amps).
- For the DC motors we are using RPM varies directly with voltage.

To obtain the best performance from any car we need to take the maximum amount of energy available from the solar panel and use as much of it as possible to drive the car. To achieve this, a high efficiency motor used in conjunction with a solar panel whose output current and voltage suits the motor characteristics is essential. A gear ratio that matches the available motor power to the power required to propel the car at the highest speed possible is just as important.
The statement above while accurate, is of little help unless we understand the implications and know what to do in order to achieve the requirements. I hope the following explanation which is broken down into each major section will make it clear.

Maximum energy from solar panel: Refer to Graph 1 where the power output from the panel is shown. The maximum power point is clearly visible. This is where we need to operate.

High efficiency motor: Firstly let us be clear about what we mean by efficiency. For a motor the efficiency is the power delivered by the motor shaft divided by the input power to the motor. There is no point in using a motor that is say 50% efficient when at best we will only get out 50% of the power we put in. We are throwing away all this power without even having a chance to use it.
Motors of around 85% efficiency although expensive are readily available. But do remember the motor will not always be operating at its maximum efficiency point.

Panel voltage and current match to motor: Remember power (P) is voltage (V) multiplied by current in amps (I). Example a power of 10 watts can be obtained from 10 amps at 1 volt or 0.1 amps at 100 volts. Neither of these combinations is of the slightest use to drive our solar car.
Let me elaborate. Assuming the use of a Faulhaber 2232 6 volt motor which has a rotor resistance of 0.8 ohms. (this motor type was used by every car in the 2009 Victorian competition.)

With 10 watts available in the form of 10 amps at 1 volt, the motor at stall will only take 1.25 amps at 1 volt which is only 1.25 watts input to the motor. (Ohms law) This current will drop as the motor speeds up reducing the power input to the motor. Let us assume absolute best case conditions of 1.25 watts input to the motor and motor efficiency of 100%. The best we can achieve is 12.5% of the available panel power being delivered by the motor shaft.

With 10 watts available in the form of 0.1 amps at 100 volts the motor would like to take 125 amps but the current is limited to 0.1 amp, when we deduct the 0.030 amps needed to just run the motor we only have 0.07 amps available to drive the load. The next question is how fast will the motor run? With a 125 volt supply the motor would like to theoretically run at 148,750 RPM which would destroy the motor. In fact testing has shown that the motor would use all the 0.10 amps to just run the motor itself at 28,000 RPM. If we assume the motor is running at 15,000 RPM it would produce 0.875 Watts. This is only 8.75% of the available panel power.

Compare the above with actual test results from a Solarex SX 10 panel configured to give 10.5 volts open circuit and capable of delivering 8 watts. When connected to this panel the motor to produced 6.25 watts output on its shaft. This is 78% of the available panel power being delivered by the motor shaft.

From the above it is obvious just how important the choice of solar panel voltage and current output is.

Gear ratio to match motor power to power to run car: To make best use of the power available from the motor shaft it is imperative we choose a gear ratio that just fully loads the motor.

To better explain this look at graph 5 and in particular the power vs RPM graph of motor direct on panel switched in parallel OCV 10.5 V (blue power graph) Maximum power occurs at about 6200 RPM. If we aim to run in the power range above 1.1 watts there is only a 2000 RPM wide band to operate in before power falls below this level.

We must use a gear ratio that reduces the 6200 RPM motor speed to a wheel speed that pushes the car to the particular speed that just uses the 1.1 watts available.

Great you say, but what is this gear ratio? A good idea of the required ratio can be obtained by running the "Mathematical Simulation" (See appendix H).

For this though it is essential to have the critical car parameters ie. weight, aerodynamic drag characteristics and resistances for wheel and guide rollers. Track testing the car is another and far better option.

Remember when sun level changes so does the required gear ratio.

Extreme care is needed in choosing these components if maximum performance is to be achieved.

Overall for best car performance the following points must be considered

- Good power to weight ratio
- Low aerodynamic drag
- Accurate construction
- Lots of testing and tuning

- Solar Panel voltage, current and ability to easily reconfigure them, compatibility with motor

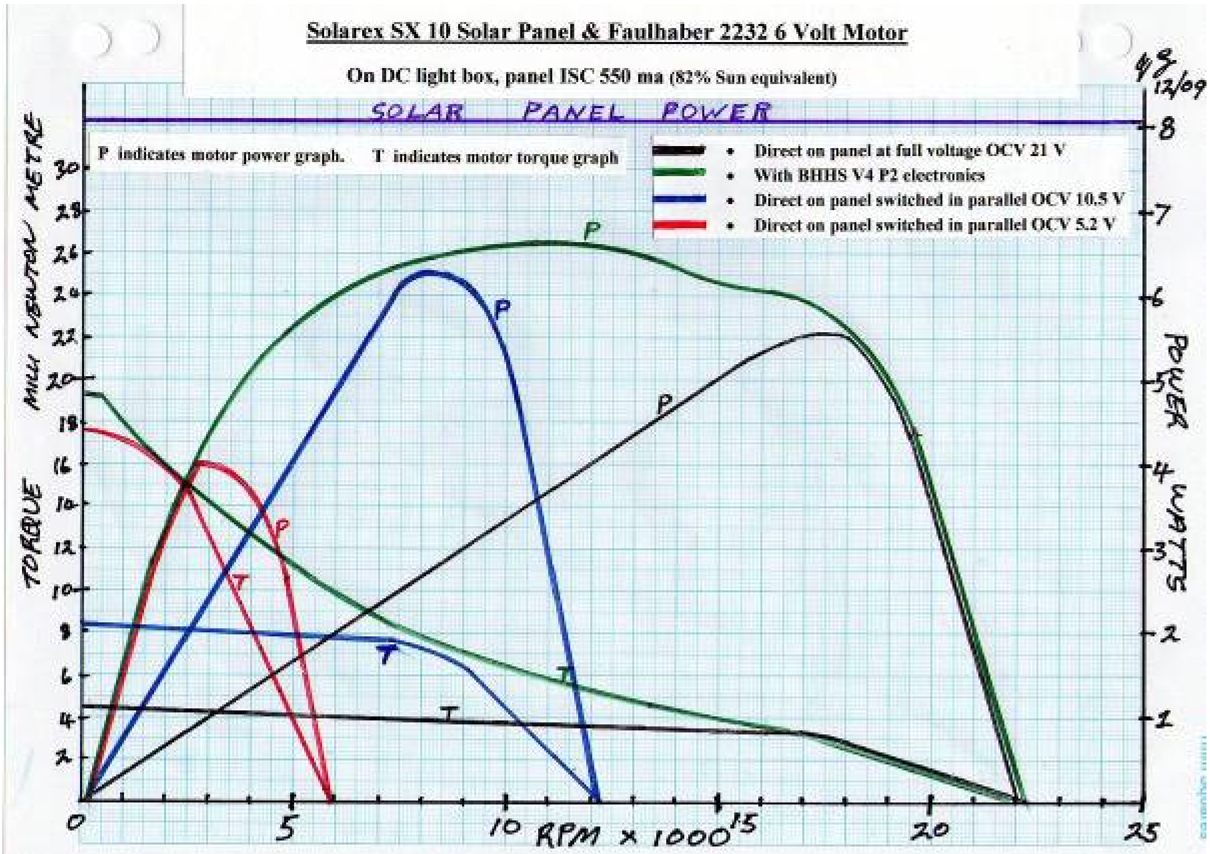
- Motor characteristics required. Voltage, RPM range, efficiency, power and compatibility with solar panel

- Correct gear ratio to match loads, and the ability to quickly change ratios as sun levels change

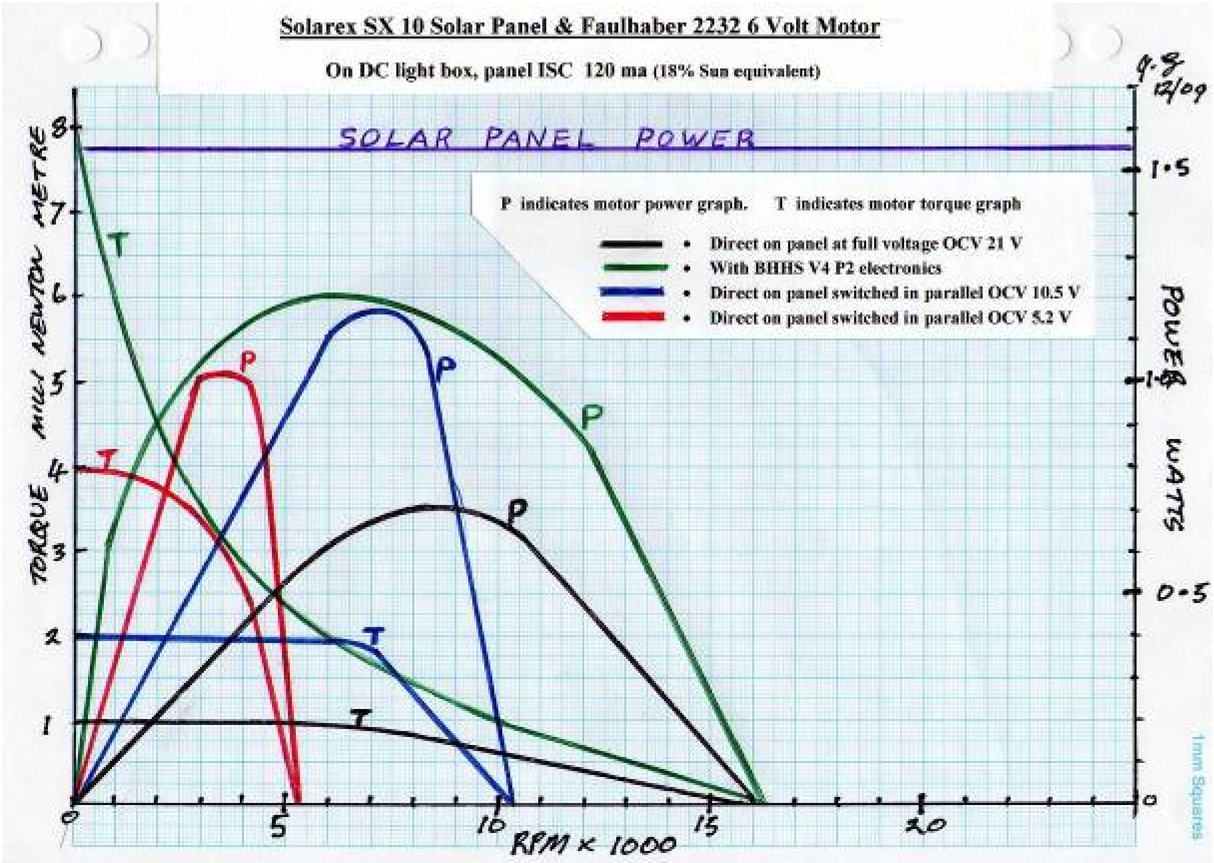
A few words on gear ratios:
Sometimes it may not be possible to obtain the exact gear ratio required by changing gears alone. There is always the option of arranging your solar panel wiring so it can be reconfigured in series and parallel to change the output current and voltage. This will change motor torque and RPM . This change can be accomplished quickly by the flick of a switch.
Do not forget changing wheel diameter, this is commonly used as an alternative method to changing gears, it achieves the same result as changing gear ratios. Remember to readjust the guides to suit the new ride height.

DYNAMOMETER TEST RESULTS:

Below are graphs of dynamometer test results. NOTE: All Sun levels referred to are based on full Sun in December here in Melbourne NOT AM 1.5 which will be the 100% Sun level used in future ie. Feb 2010 onwards.
The tests were conducted with a Faulhaber 2232 6 volt motor powered by a Solarex SX 10 panel configured either with all cells in series, 2 lots of 2 strings of cells in series then paralleled and 4 strings of cells in series paralleled. These configurations giving exactly the same power but at different voltage and current levels.



GRAPH 4 Motor power vs RPM at 82% Sun equivalent



GRAPH 5 Motor power vs RPM 18% Sun equivalent

Examination of these graphs shows the narrow RPM band we must work within to stay near maximum power when electronics is not used.

Other interesting and important observations:

- Solar panel configuration ie. voltage and current available to the motor can have a significant effect on maximum power output available from the motor. (Up to about a 35% variation)
- The power output of the motor when an electronics unit is used is always greater than the power output without electronics.

Do remember an electronics unit will probably make a poorly constructed car move. But it will NEVER turn this car into a winner.

There are several electronics units on the market produced specifically for use in model solar cars. They all operate by switching power to the load (the motor in this case) on and off rapidly to maintain the solar panel output voltage within a narrow pre selected range, around the maximum power point voltage. Generally you must select the required voltage and adjust the circuit to operate at this selected voltage. Ensure you follow the instructions provided with whichever unit you select but remember, if any doubt exists as to voltage setting to use it is safer to set slightly on the low side. This is based on the fact that as your panel heats up the maximum power point voltage will drop. Also the slope of the panel power curve is not as steep on this side of the power peak, meaning any errors in setting results in a smaller power loss.

Be careful to set operating voltage correctly (ie. slightly below the maximum power point of your panel)

Mr Stan Woithe has tested the electronics systems available and concluded there is very little difference between them. I expect his report will be posted on the South Australian web site by now.

SETTING YOUR ELECTRONICS:
It is possible to select a compromise voltage setting that will keep your panel power within about 3% of maximum over light level variations from 20% to 100% provided you maintain the same panel temperature at the start of each race.
This means effectively (provided you are prepared to accept a small power drop) you can preset your electronics and not need to re adjust it over the course of a days racing.
See Appendix N for details.
Since November 2010 the Automax electronics unit has been commercially available It automatically sets to the maximum power voltage and tracks that voltage as it changes. This totally removes the need to ever adjust the electronics.

HOW DO THE ELECTRONICS SYSTEMS FUNCTION:

The following description of the electronics systems typically in use is only a simplistic overview. The various manufacturers have detailed descriptions of their particular units, refer to these for full details.
This description only covers the units I have measured. There are others out there that I have not either seen or tested. Listed below are the units I have tested

Engelec Max 4
Scorpio
Easymax III
Automax (became available late 2010)
Box Hill High School versions 1,2,3 and 4.

The best general description for the units that I can give is **Input Controlled DC to DC down Converter.**
What does this really mean?
It means that the input voltage is controlled, that is held constant at the value you have set which should be just below the maximum power voltage of your panel. An electronics unit that automatically tracks the solar panel`s maximum power voltage was put on the market in November 2010.
By holding the solar panel at its maximum power voltage all the power available from the solar panel is being fed to the motor at all times irrespective of sun level motor speed or load. Whereas without an electronics unit the power fed to the motor is often below the

maximum available and varies significantly with changes in sun level, motor speed and load.
The DC to DC down convertor means the unit takes in DC power and converts it to DC power at a lower voltage. The voltage out of these units is always lower than the input voltage.
How is this all done?
All the units function in a similar manner. They store energy from the solar panel in a small capacitor (the capacitor behaves somewhat like a small battery) this capacitor is charged by the panel until it reaches the voltage that the electronics unit has previously been set to. (Just below the panels maximum power voltage). The electronics unit then switches power to the motor on till the capacitor discharges slightly (typically by about 1 volt) it then switches power to the motor off till the capacitor charges up again, when the capacitor has charged to the set voltage the unit again switches power to the motor on till the capacitor discharges. This switching process continues.
The output section of the electronics unit includes an inductor and an electrolytic capacitor for energy storage and smoothing of the nominal square wave DC being sent to the motor. There is also a diode or field effect transistor in this output section which allows the current to continue to flow in the motor during the time the electronics unit has switched off and is waiting for the input capacitor to recharge. It is the action of this inductor, capacitor, field effect transistor or diode that enables the current in the motor to greatly exceed the panel current but at a lower voltage.

There are detail differences between units which effect their operating efficiency and ease of set up and operation. I strongly suggest you check data from the manufacturer for specific details of any particular unit.
NOTE: In late 2010 the Automax unit became available, it automatically selects and tracks the maximum power point of the panel making adjustment unnecessary. This unit has identical electrical performance to the Easymax III unit.

9. STEERING

Many cars seem to perform very well without steering. However a car without steering will be dragging the wheels sideways on the corners and consequently wasting some energy. Tests performed at Box Hill High School indicate that for a 1200 gm car with aluminium wheels and no steering there is an additional drag force of 0.25 Newton while cornering. This translates into about an extra 1.2 seconds race time in full sun on a car capable of a 20 second race.
We expected a car fitted with plastic wheels which have a lower coefficient of friction than aluminium would have lower drag losses.
Another car without steering was tested. This car has standard R & I Instrument Gear Company wheels and guides made from acetal, only the drive wheel was aluminium. Its car weight during these tests was 2500 gm. The test was performed on the Box Hill High School track by pushing the car around the corner and measuring the force required to just keep it moving.

Ten gm extra force was required to keep the car moving around the corner (same radius as the Victorian track) compared to along the straight, this is an extra 0.1 Newton. As we suspected significantly below the force measured with a car having all aluminium wheels. CAUTION: We have in the past seen problems with cars when steering systems have not tracked straight holding the car hard onto the guide rail thus increasing drag. We have also seen wheels that have gone into and maintained a serious shimmy type motion, causing significant increase in wheel drag.
Remember everything you add to the car increases weight, take care that any steering system is not too heavy.

Consider the possible problems and gains then make your own decision on steering.

10. STABILITY

The main form of instability is the car tending to roll over while cornering. It does not require a complete roll over to give you trouble, as soon as the guide system becomes disengaged the car will run out of control.

A low centre of gravity increases stability, this becomes more important as speed rises. A light weight panel with ballast carried low down will lower the centre of gravity.
Remember the forces trying to roll your car over while cornering vary with velocity squared; consequently if you have a high speed car take care in your design.

Wheel positioning can influence stability, with stability increasing as the wheels are moved further out from the centre line. A wheel at each corner will be more stable than a tricycle wheel arrangement.

As a guide, calculations indicate that a car with its centre of gravity 80mm above the track will not roll or disengage the guides on cornering below a velocity of 9.9 metres per second . This assumes a smooth track as a bump in the track can upset the cars stability and initiate guide disengagement or a roll over at a lower velocity.
For comparison a car with a race time of 18.3 seconds has a final velocity of about 7.2 M/sec. Remember car mass does not influence stability (except by slowing the car down). The height of the cars centre of gravity above the track, car velocity and the radius of corner are the main factors that influence roll over stability.

11. SUSPENSION

Suspension systems are not in common use in the competition, but a well designed and constructed suspension system could be of great help in increasing stability and making sure your drive wheel(s) are in contact with the track at all times. Is it worth the effort and weight?

Remember any suspension must ensure the guide system remains engaged and does not hit the track.

On a smooth track such as the New South Wales track I doubt that suspension would make any difference except to add weight and consequently slow the car down.

12. CONSTRUCTION MATERIALS

The regulations allow the use of any materials. Some important considerations in material selection are: cost, availability, workability, toxicity, stiffness, durability and strength to weight to stiffness ratio. (See Part D on material specifications for data on some suitable materials). Do not overlook common materials. Some very good cars have been constructed from balsa wood, plywood and common plastics.

Caution: We have seen very well made car bodies in balsa wood that fell apart after racing in wet conditions, only because they were not sealed and soaked up water.

13. BODY

A body can improve the looks of your car, but take care that it does not weigh too much. Clever design can produce a body with sufficient strength to hold everything together without the need for a separate chassis. Effective streamlining of a body can significantly reduce aerodynamic drag. This is more important the faster the car goes as drag varies with velocity squared. In 2 lap races the car runs the second lap at near maximum speed making aerodynamic drag a very significant factor in these races. Do not ignore the underside of the car a significant amount of drag can occur in this area.

Remember a body can be as complex as a carbon fibre shell or as simple as a sheet of plastic or cardboard folded into a body.

Regulations for 2011 require a drag plate of 200 square cm area, this plate if not contained within an aerodynamic body will create significant drag. There is however a trade off between reduction of drag obtained by using an aerodynamic body and the reduction in performance due to the extra weight of bodywork. Mathematical modelling indicates that a lightweight aerodynamic body cleverly designed to contribute to the cars structural strength will give a significant performance increase compared to a car without aerodynamic bodywork.

14. TRACK

The Victorian track consists of sections of painted plywood joined up to form a figure of 8 with a bridge at the crossover point (see the Regulations for details). There will be some mismatch at the joints of both ply sheets and guide rails. Be sure you allow for this in your design.

Car design should allow for vertical mismatch up to 2 mm at the joints between track sections and dips (undulations) of up to 10 mm over the length of a section (2400 mm approximate length of full straight section). Mismatch of the guide rail of 1mm horizontally and 3mm vertically would be the maximum expected.

Another important but seldom considered aspect of the track is its surfaces frictional characteristics. Who cares you say, everyone should. Wheel slip due to lack of surface grip will significantly slow your car down. (See section on wheels where tyres are discussed) Here in Victoria where the track is painted with a flat acrylic paint, the friction is fair. However the New South Wales track has a smooth plastic surface with the frictional characteristics of a sheet of glass. This track is sometimes used for the National event so you may encounter it. I have no information on other tracks but do not expect any to be worse than the NSW track.
See Appendix P for track friction test results.

15. CONSTRUCTION (BUILD ACCURACY)

For the best possible performance it is critical to construct your car accurately, with sufficient strength and rigidity to maintain alignments and clearances particularly in the critical areas of drive train, wheels and guides. A poorly constructed car WILL perform poorly.

For example, we have data from 2 similar cars, both about the same size, used the same motors, gears, panel, electronics, wheels and guide system. Both had similar layouts i.e. rear wheel steering and the same aerodynamic drag coefficient. The only difference was weight, about 100 gm which should only give a difference of about 0.4 second in full sun. The actual difference in full sun was 5.3 seconds. The slower car was slightly out of alignment and could be observed “crabbing down the track”.

To help quantify the importance of accuracy consider the following. Two similar cars being track tested at the same time. Both cars using similar motors, panels, electronics, running gear and with similar aerodynamic drag characteristics and no steering, but one car was running without ballast and was consequently 800 gm lighter. The lighter car was noticeably slower. Subsequent examination revealed its axles were 5mm out of parallel.
The lesson here is that build accuracy is critical.

In the construction process, do not neglect the electrical systems. Many problems are due to wiring, it should be colour coded, neatly laid out and secured to prevent damage due to vibration and handling. This will make fault finding significantly easier if it is required. All joints should be soldered then insulated if there is any possibility of shorting out.

16. TESTING

You cannot do too much testing. You can however do too little as shown by the high numbers of cars that will not complete the course or will not even run at all.

Remember testing has two main aims. One is to determine the settings that result in transfer of maximum energy from the panel to the drive wheel and consequently give maximum speed. The other is to prove your construction is satisfactory, strong enough correctly aligned etc.
A third and possibly more important reason for testing is to evaluate new design ideas.

Firstly, test for the obvious:

- Examine the car visually – does it look straight and square, are all components securely fastened, alignments and clearances correct?
- Will the car's guide system fit the guide channel on the track – remember there will be some mismatch of the guide channel at the joins?
- Will the car clear the track as it traverses the hill? Check for clearance on approach when cresting and when departing the hill. Ensure your guide system remains engaged during this test.
- Next check that the car rolls straight and smoothly on the ground (choose a smooth surface). When satisfied the car is rolling acceptably, roll it down a ramp 1260 mm long and 160 mm high onto a flat smooth surface. The ramp and surface should have a guide rail on them the same as on the track. As you will be guiding on the outside of the guide (now mandatory) a piece of timber can be used as a guide secured to the floor with double sided adhesive tape. Our tests have shown that a 1200 gm car when released down the ramp described above, starting with the car's centre of gravity 160 mm above ground level, will roll about 6000 mm along the flat before stopping. This is with no tyres and the motor engaged. If your car will not roll this far, investigate why and correct the problem.
- Run the motor free i.e. not driving anything and record the current drawn. Then run the motor with the gears or drive belts in place and driving the wheel(s) with the car off the ground. Again record the current drawn. The difference between these two current readings will be a good indication as to the losses in your drive system. If the difference is more than about 20% start looking for faults. NOTE: the car 'Enigma' described in part F when tested as described above gave 63ma free and 72 ma when driving the wheel (6 Volt 2224 motor was supplied with 12 Volts for this test).

Undertake as much track testing as possible. The Melbourne Museum event normally held in September presents an opportunity for significant track testing prior to the Victorian Event. (See Victorian web site for details). Box Hill High School have a track which is frequently erected at Box Hill for testing of their cars, they welcome teams from other schools to come and undertake testing on this track. Remember there is normally an opportunity for testing cars on the competition track during the course of the event.
From our past experience, fine tuning your car during an extensive test program usually results in an improvement of between 1.5 to 5 seconds in race time at full sun.

Do not forget to test your electrical systems, verify that all switches and any electronics are operating as intended.

As part of testing do a trial scrutinering of your car to ensure it meets the regulations. Check all the items listed in the **CURRENT** regulations, as the regulations change every year.

17 AERODYNAMICS

Air drag has a much larger effect on car performance than most people realise.
Wind tunnel testing of 2 models, one a simple box the other an aerofoil shape gave us aerodynamic drag figures for these shapes. When these drag figures were used in the Mathematical Simulation to obtain predicted race results indications were that simply changing the car shape from the box to the aerofoil shape all other parameters remaining the same would result in a win for the aerofoil shape by about 8 meters over a 1 lap race and about 23 meters for a 2 lap race.
See Appendix L for complete test results.

Aerodynamics is a complex subject so all we will do is give a simple overview to point you in the right direction. Refer to texts and other publications for a more detailed analysis.
The aerodynamic drag force is trying to slow your car, the drag force can be calculated using the formula below.
Drag Force = ½ x Air Density x Drag coefficient x Area x Velocity squared

There are only two parameters in this formula that you can work on. They are:

- Drag coefficient, which is related to the shape of your car. Typically smooth rounded curves with an aerofoil type shape will give a low drag coefficient. Refer to texts for details but remember it takes a lot of effort and attention to detail to produce a car with a low drag coefficient.

- Area, which is frontal area. The area that is pushed through the air as the car runs forward. (We will ignore the effect of wind which could be coming from any direction) Frontal area is relatively easy to control. Just make your car as small as possible within the regulations. If you can halve the frontal area you will halve the drag force.

For a single lap race aerodynamic drag is a significant retarding force by the end of the race when the car velocity is high. For a two lap race the whole of the second lap is run at high speed making the aerodynamic drag even more important.
See Appendix K for photographs of some cars and their drag coefficients for use in the Mathematical simulation. And Appendix L for Car Shape and Aerodynamic Drag.

I am often confronted with the suggestion that useful lift to reduce wheel load and hence rolling resistance or down force to hold the car onto the track can be generated aerodynamically. It is true these forces exist and are used to great effect on formula 1 and other race cars, but I question the usefulness of them in Model Solar Car racing. For a normal car considering car area together with the maximum expected velocity these

forces will generally be below 50 gm. Not significant and counter productive in my opinion.
See Appendix M for calculations and more discussion.

PART B: APPENDICES

APPENDIX A: PERFORMANCE OF MOTOR AND PANEL

The following information relates to the performance of a solar panel when connected to an electric motor. Its main purpose is to assist in explaining the importance of selecting the correct gear ratio to suit the prevailing light conditions.
NOTE: The explanation is somewhat simplistic so the basic ideas can be understood more easily. See appropriate Texts for complete and accurate descriptions.

* PANEL PERFORMANCE (SILICON CELLS)

The solar panel produces electricity from the energy in the light which falls on it. The current it produces varies directly with the intensity of the light which falls on it. Low light levels give low current and high light levels give high current. At a given light level, the panel behaves like a constant current source.

At a particular light level, the panel can deliver current UP TO the maximum current available at that light level.

Assume a high resistance electrical load on the panel, the current drawn will be low (Ohms law applies V = R x I).

If the load resistance is lowered more current will flow through the load. If the resistance is lowered to a value that would allow more current flow than the panel can provide at that light level, the panel provides its maximum current and the voltage at the panel output drops very rapidly.

Because the voltage is reduced, so too is the power reduced in the load (i.e. the car motor).
In the extreme, if you place an ammeter directly across the panels output you will read current but the voltage will have fallen to near zero.

This means the POWER output from the panel is near ZERO.
(Power = Volts multiplied by amps)
The onset of this voltage drop occurs suddenly with practically no warning, the voltage dropping to near zero almost instantly.

In this discussion, we will call this situation "Panel Stall"

* MOTOR PERFORMANCE (DC brush type)

The motor when at rest has very low electrical resistance across its input terminals .
As an example consider the commonly used Faulhaber Minimotor type 2232 006S with 0.81 Ohms rotor resistance. For this motor the instantaneous current when connected to a 15 Volt supply would be 18.5 Amps according to Ohms law, providing the power source is capable of supplying this current.

Assume the motor is connected to a Solarex MX 10 panel (10 Watts output) capable of supplying only 0.6 Amps at 100% sun. The motor starts up with lower torque and runs up to speed more slowly than it would if the power supply was capable of supplying the higher initial current that the motor would like to draw

What is really happening here? Hopefully the following explanation will help understanding.
When the motor is connected to an electrical supply, it initially appears as nearly a short circuit across the supply, and will draw a large current (provided the electrical supply is capable of providing the large current required).

As the motor begins to rotate it generates a back EMF (voltage). The faster it spins, the higher the back EMF becomes (this can be demonstrated by spinning a motor by hand with a voltmeter across its output). When the motor speed has stabilized there will only be a small voltage difference between the supply and the motor back EMF. This small voltage will drive a small current through the motor producing the power lost in friction and electrical losses. (In the above description, the motor is running free i.e. not driving any load.)

When the motor is loaded, the load slows the speed of rotation of the motor. This reduces the back EMF, resulting in a larger difference between the supply voltage and the motor voltage. This increase in voltage drives more current through the motor which increases its power output. The motor speed will stabilize at a new balance point.

* MOTOR AND PANEL IN COMBINATION

A motor that wants more current to drive its load than the panel can supply will pull the panel voltage down and reduce the power available to drive the car. The car will then run slower. Depending on the magnitude of the load, the panel voltage could be pulled to near zero and the panel "STALLED". The panel and motor will stay in this state till the motor load is reduced or the panel produces sufficient current to get the motor moving again. (Increasing current will increase the torque produced on the motor shaft.)

Conversely, if the load on the motor is low, it will not take all the current the panel is capable of producing and will not be using all the power available from the panel to drive the car. The car will be running slower than its potential. This is why it is critically important to match the motor load to the panel output.

In real life this means that for a particular light level and car speed there is a gear ratio from motor to wheel that allows the use of all the power produced by the panel.

Consider a car running at exactly this power matched position:

- an increase in light level means that more current is available from the panel at a very slightly higher voltage. The very small voltage increase will cause a very slight increase in car speed and air drag. However the majority of the extra current available has not been used. To use this extra available current we need either to increase the motor RPM which requires more voltage which we do not have or to increase the motor load by changing the drive ratio ie. a higher ratio. If we do not change the gear ratio there will be more power available from the panel than is being used. This "available" extra power that is not being used is effectively wasted. If this extra power was used the car would go faster.

- A decrease in light level or increase in load such as a head wind or climbing the hill will mean the motor will not have sufficient current available from the panel to provide the power required to drive the car. The panel voltage will drop causing the available power to drop. The car will then slow down or stop depending on the magnitude of load increase or light reduction. The car will remain in this condition until the panel output increases or the load is reduced. Changing drive ratio ie. a lower ratio will reduce the motor load and restore balance.

This description above is for a motor connected directly to a solar panel.

To get maximum performance from the car it is essential that ALL the available power from the panel is used all the time, but this requires exactly the correct gear ratio for the conditions prevailing at every instant. To achieve this would require an infinitely variable gear ratio constantly changing to match panel output to motor load. To achieve this mechanically is not yet practical for a model car. The only practical mechanical option is to be able to change gear ratios and choose the correct ratio for the conditions prevailing at the start of the race.

The Electronics systems now available operate in a way that gives very similar results to an infinitely variable gear box as suggested above. Losses within the electronics make it slightly less efficient than the exactly correct gear ratio but its ability to instantly maximise energy transfer from the panel to the motor for the entire duration of the race more than makes up for this

APPENDIX B: TRANSMISSIONS FOR SOLAR CARS

The following is a simplified resume of transmissions typically used in model solar cars. It had previously been limited to gear and belt drives, as they were and still are the most commonly used systems in model cars, but has now been expanded to include direct drive.

Please refer to standard Engineering texts for more detailed information.

BELTS:

Belts are used extensively for various drives in industry, automobile and domestic applications. Power transmitted can be high with the use of multiple belts.

SOME ADVANTAGES OF BELTS:

- High efficiency up to 97% possible (Marks Handbook for Engineers) though may be difficult to obtain when scaled down to model solar car sizes and powers.
- Large centre distance between shafts possible.
- Will tolerate misalignment much better than gears. (Consequently ratio changes are easier than gears).
- Pulleys much easier and cheaper to make than gears (meaning that many ratio changes can be available at lower cost).

SOME DISADVANTAGES OF BELTS:

- Always run with some slip or creep so will not guarantee constant angular velocity or angular velocity ratio equal to the pulley diameter ratio.
- Can slip significantly if overloaded.
- Can break.

BE CAREFUL: Belts on model solar cars present some special problems. When scaling down to the very small sizes and powers in the model car we cannot use ordinary belts. Our tests have shown that belt material is critical to success.

- We tested ‘O' rings and found they are very poor belts. The strength is great but efficiency is low, probably because of their stiffness, they waste a lot of energy in flexing the ‘O’ ring.
- Tape recorder drive belts were better but preliminary tests show they are only about 82% efficient.
- Rubber bands when tested gave poor efficiency apparently because of creep they stretch easily and this stretch represents lost energy.

Remember, belts drive by friction, so tension is important. Our tests showed very little difference in losses as belt tension was increased. Keep belts tight. Pulley material and contamination with oil, water, etc. will change frictional coefficients and consequently degrade power transmission.

We have not tested toothed belts but expect them to be similar to “O” rings because of their stiffness.

GEARS:

Gears too are extensively used in industry, automobiles and domestic applications. Efficiencies can be similar to belts, in the order of 97% for a single reduction provided alignment, bearings, gear tooth form and lubrication are good. To keep losses low and efficiency high the teeth of mating gears MUST be parallel, clean and the backlash (clearance between engaged teeth) correctly adjusted. If not accurately set up, gear losses can be very high. The correct backlash for the precision gears commonly used in model solar cars is in the order of 0.08 mm. Operating with less backlash than this will increase losses. Operating with slightly more has very little effect, but too much more will increase losses. To maintain high efficiency your design must ensure accuracy is maintained when gear changes are made. Do not forget that during competition, gear changes must be made in the field quickly while the team is under pressure.

To reasonably match panel output power to motor power requirements as the sun level changes, several ratios will be required. If you want a close match at every operating point as many as 8 or more ratios may be required which can be expensive if precision gears are used. If cheaper, non-precision gears are used, take care the power losses are not too high and the gears have sufficient strength. Many cars have stripped gears during racing.

NOTE: The use of an electronics system probably removes the need for gear changing.

DIRECT DRIVE:
Direct drive whilst always a great method has not been included in previous design hints due to the lack of appropriate hardware. It now appears to be a viable option and has been added.
Direct drive ie. a wheel mounted directly onto the motor shaft has always been worthy of consideration, but difficult to execute. I first saw a car using this system on a car at the 2008 Hobart National event.
With a small diameter wheel, a good electronics system, a motor capable of supplying the high torque required and a solar panel with characteristics that suit the electronics and motor, (See Solar Panel) direct drive is now a real possibility.
After seeing this car run in Hobart I entered appropriate data into the Mathematical Simulation which predicted very competitive times from a car using that set up.
The gains from using a direct drive include, an approximate power increase of 6% due to elimination of gear losses, reduction in weight and complexity by eliminating gears and simplified construction of chassis. There may be a weight penalty involved in using a suitable motor. You as designer must consider

APPENDIX C: DATA ON MATERIAL PROPERTIES

NOTE: The data shown below is typical for the material but should be used as a guide only, as properties can vary greatly depending on manufacturing and subsequent treatments.

CARBON FIBRE TUBE	4.32 mm DIA	10 Gm	750 mm long
	5.84 mm DIA	20 Gm	780 mm long
	6.45 mm DIA	30 Gm	840 mm long

Outside Diameter given, inside Diameter not known.

METALS	DENSITY % Based on Alum.	MPa
Aluminium	100	69-- 550
Brass	318	235-- 413
Steel	289	517--2000
Magnesium	64	275
Titanium	166	345-- 430
Lead	503	27
TIMBER		
Birch	26	69
Oregon	20	45
Spruce	16	59
Red Cedar	16	38
Balsa	6.5	?
PLASTICS		
Carbon Fiber	6.5	103--2400

APPENDIX D: SPECIFICATIONS OF YOUR CAR

Following are some questions / points you need to consider when designing your car.

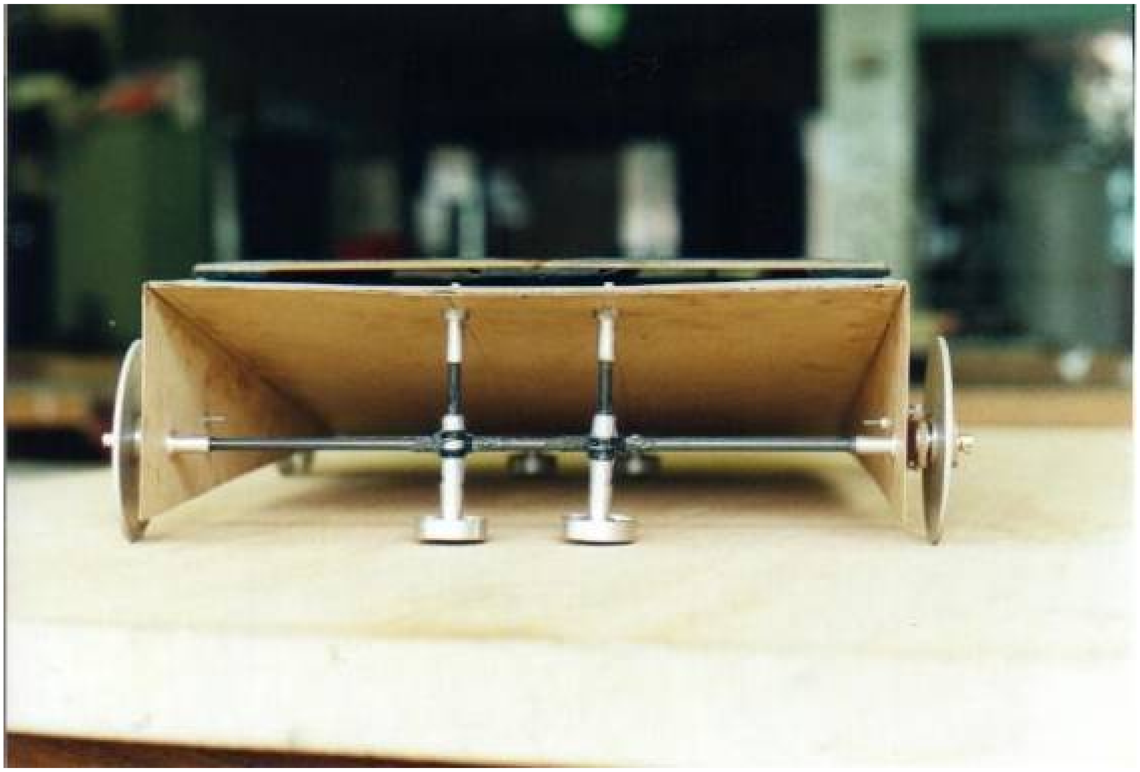
* PURPOSE OF CAR:
  - Build a winning car?
  - Build to complete the course reliably.
  - Other.
* PERFORMANCE REQUIRED:
  - Fastest track time required 20 sec. ??
  - Minimum sun level you require the car to run in.
* PANEL:
  - Type   Power output   weight
  - Ballast required
* MOTOR:
  - Manufacturer   Type   Voltage
* WHEELS:
  - Diameter   Material   Bearings
  - Tyre on drive wheel ?
* CHASSIS:
  - Material   Configuration
* GUIDE SYSTEM:
  - Roller diameter   Bearings
  - Positioning (front/rear)   Height adjusting method (if applicable)
* TRANSMISSION:
  - Belts   Gears
  - Ratios required (see performance required)
* STEERING:
  - Required or not?
  - If required, type & which wheels?
* OVERALL LAYOUT:
  - Panel height
  - Ballast position
  - Driver & passenger
  - Signage panels
  - Drag plate
  - Motor position
  - Drive wheel/s
  - Clearance on approach , exit and cresting hill.
* BODY:
  - Required or not
  - If required, style and material
* STRENGTH
  - Adequate to survive rough handling , accidents such as coming off the track, collisions and crash barrier stopping if applicable

APPENDIX E: CAR PERFORMANCE

DETAILS OF 2 CARS, **ENIGMA** AND **PHOTON CRUNCHER MK IV** ARE PRESENTED IN THIS SECTION

ENIGMA, the second placed car at the 2002 Melbourne event, was capable of a 20.2 second run in 100% sun and able to complete the course in 18% sun. This car weighed 1200 gm and used a panel made up of cells from Dick Smith Electronics producing 6.2 Watts at 13 Volts. It also used an electronics system.

ENIGMA SIDE FRONT VIEW (DRIVE WHEEL SIDE)



ENIGMA REAR VIEW

PREDICTING CAR PERFORMANCE

From on-track testing and computer modelling, the following generalizations on factors affecting a car's performance have been prepared for ENIGMA.

AT 100% SUN:

Increase car weight by 200 gm	+ 0.8 seconds race time
No steering	+ 1.2 seconds race time
Tyre on (1 tyre on drive wheel only)	+1.0 seconds race time
Inaccurate build (slight misalignment)	+5.0 seconds race time
Halve air drag	- 0.5 seconds race time

AT 20% SUN:

Increase weight by 200 gm	+2.5 seconds race time

You can predict the performance of your own car and see what effect a proposed change to your car will have without going to the trouble of building and testing by using the MODEL SOLAR CAR MATHEMATICAL SIMULATION.

The simulator predictions have been within 5% of the actual times recorded on the track. Using it will enable you to get a feel for the effect of various changes. For predictions to be relevant to your car, you MUST first test your car and enter its parameters into the simulator.

How can car performance be improved? Where should effort be expended for the best results? Before these questions can be answered it is necessary to know where the small amount of power available is being used.

A convenient way to evaluate power use during a race is by considering energy use. As energy is the product of power multiplied by time, this approach gives a view of the "amount" of power used over the race. By considering the breakdown of energy use the most significant areas are easily identified. The areas that should be considered are Air Drag, Rolling Resistance, Losses in Transmission and Power used to accelerate the car. By graphing power used against time for each of these over the course of a race the energy is easily determined, it is represented by the area under the power versus time graph.

The TOTAL ENERGY available over the course of a race is easily determined, it is simply the POWER available from the solar panel multiplied by the race time.

This energy will be used in the following:

Overcoming air drag
Overcoming rolling resistance
Giving the car Kinetic Energy
Losses in motor and transmission

Data from the Mathematical Simulator can be used to calculate some of these energies.

Air Drag:
From the simulator air drag and velocity can be read at 0.1 second intervals. For ease of calculation take these values at say ½ second intervals, multiply them together to obtain the power (in Watts) used to overcome air drag. Then plot a graph of power versus time, the graph clearly shows power usage variation as the race progresses. The energy used in overcoming the air drag is depicted by the area under the graph ie. Power x Time = Energy (Joules)

Rolling Resistance:

As for air drag above read rolling resistance and velocity and multiply them together to obtain the power used. Graph power against time and again the area under the graph is the energy used in overcoming rolling resistance.

Kinetic Energy:
Can be calculated using the cars final velocity and its mass
Kinetic Energy = ½ x Mass x Velocity squared

Losses in Motor & Transmission:
These are difficult to obtain on their own but are taken care of "automatically" if you like in that the data on motor performance inputted into the simulator was actual motor power output for the sun level tested so the motor efficiency was already taken into account (ie. motor losses) the transmission efficiency is also inputted into the simulator so the Motor drive force and Velocity from the simulator output multiplied together and graphed as in Air Drag above give the power to the drive wheel after losses . Losses and unused energy will make up the difference between the energy used to drive the car and the total energy available from the panel.

Consider ENIGMA configured with a 6 Volt 2224 Faulhaber motor no electronics and powered by a solar panel producing 6 Watts. Using the Simulator and data from the Dynamometer testing of motors the following has been calculated for a race.

Total Energy available from the Panel over the race duration 114.6 Joules

Total energy the motor could have delivered to the drive system if it had been fully loaded at its most efficient operating point for the entire duration of the race. (presently impossible) 87.8 Joules
Which is only 76.6% of the total energy available from the Panel.

Energy actually delivered by the motor during the race 59.0 Joules
Which is only 51.4% of the total energy available from the Panel.
And only 67.2% of the total energy available from the motor if it had been fully loaded at its most efficient operating point for the total race duration.

The energy the motor delivered was split up in the following way expressed as % of total panel energy available over the race duration

Air drag	13.0 Joules	22%
Rolling resistance **	18.3 Joules	31%
(Split 10.3 J to wheels and 8 J to guide rolls)		
Car Kinetic Energy **	27.7 Joules	47%

** Both increase with increasing car Mass

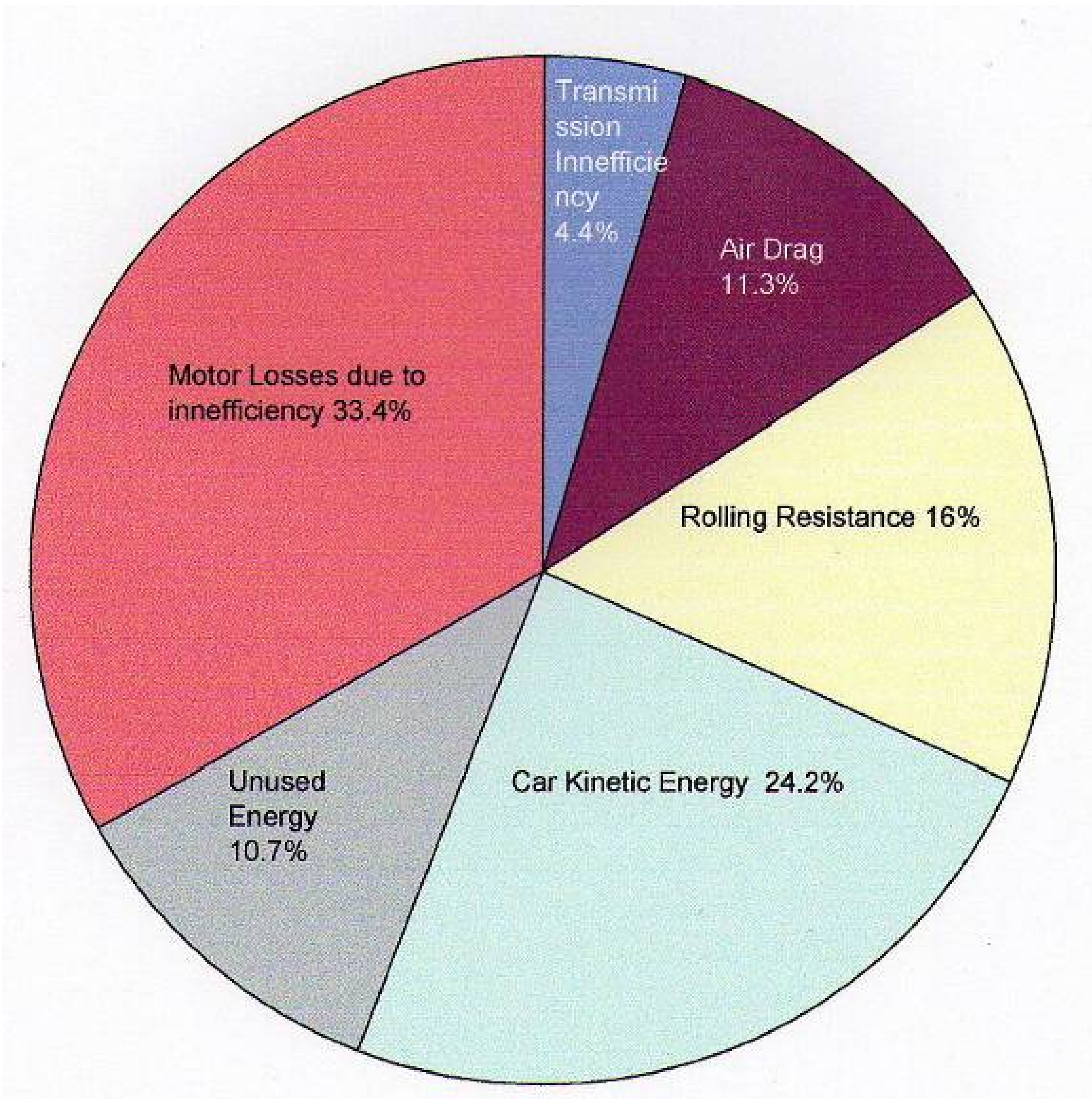
SUMMARY:

Based on total available panel energy as 100% usage over the whole race was as follows. (NOTE: without electronics active) TOTAL ENERGY USED TO DRIVE CAR 51.5%

Split up as follows	Air Drag	11.3%
	Rolling resistance (Wheels 9% Guide rollers 7%)	16.0%
	Car Kinetic Energy	24.2%

TOTAL ENERGY NOT USED TO DRIVE CAR 48.5%

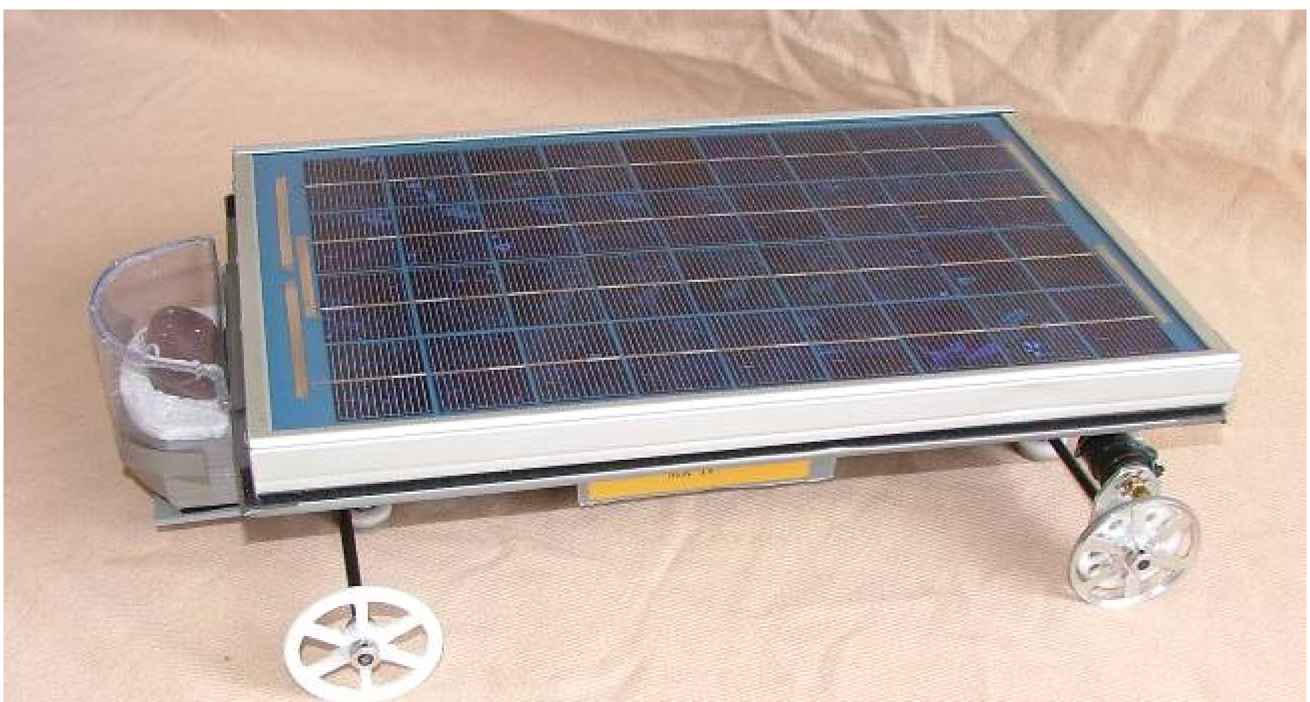
Split up as follows	Motor losses	37.8%
	Drive losses (gear)	4.4%
	Available energy not used	10.7%



PHOTON CRUNCHER Mk. IV 8/05

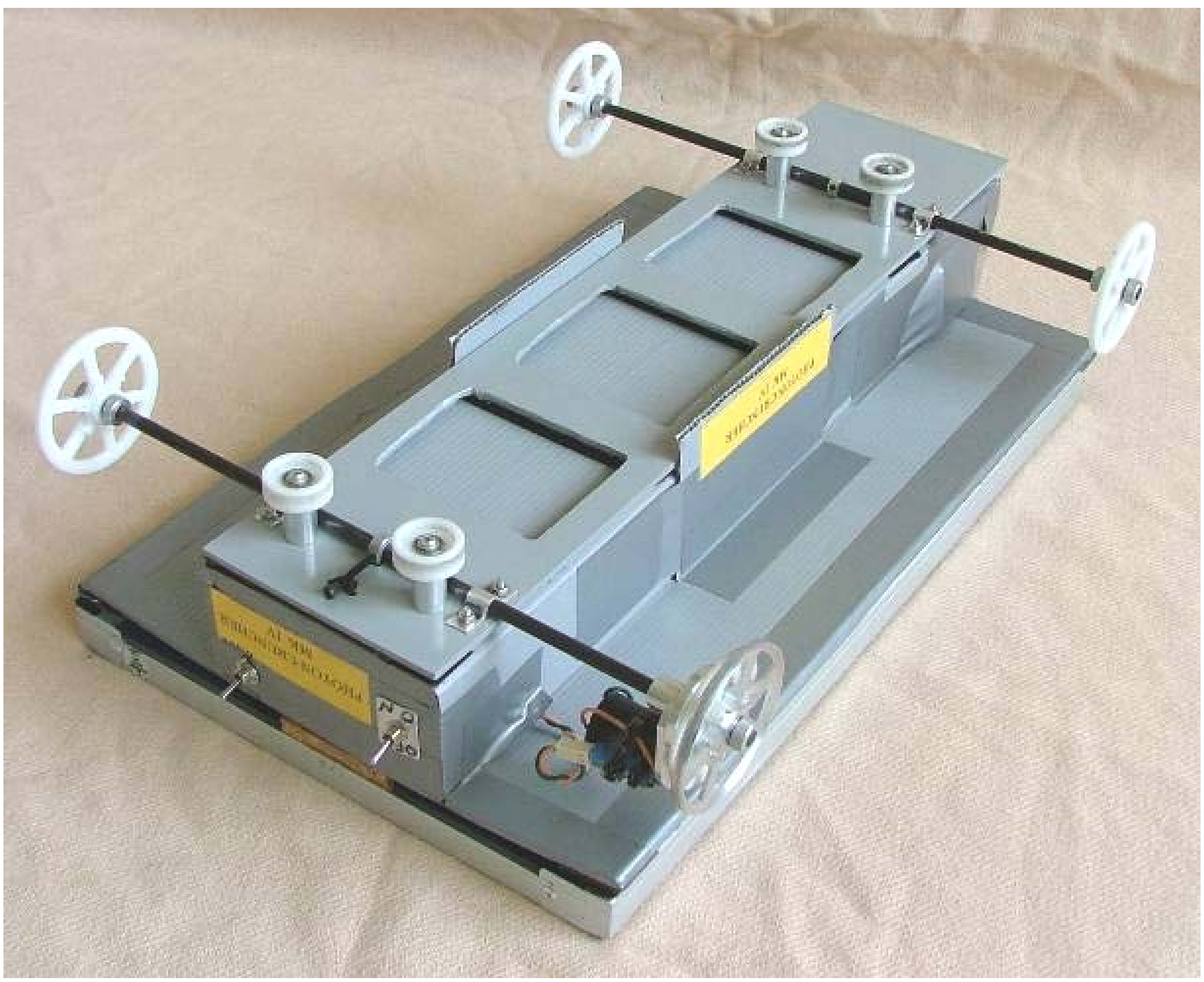
This car was specifically constructed for use at workshops to demonstrate how easily a "good car" could be made from commercial off the shelf components. A car similar to this can be constructed using only basic hand tools so can be made at any school.
The simulator detailed laterin Appendix H is loaded with data for this Car
"Photon Cruncher MKIV".
You should run the simulator with this cars data to get a feel for how it works and what use it will be to you as a design aid.
To help you we have Included test results giving actual times recorded by this car on the track, together with data on motor Dynamometer tests.
A list of components used in construction of this car together with photographs at various stages follows. More details of construction and parts lists follow the photographs.
REMEMBER THE PURPOSE OF THIS SECTION WAS ONLY TO SHOW HOW A CAR COULD BE BUILT NOT TO GIVE DETAILED CONSTRUCTION INSTRUCTIONS.

THE FOLLOWING SERIES OF PHOTOGRAPHS SHOW
PHOTON CRUNCHER MK IV IN THE CONFIGURATION TESTED FOR THE DATA
ENTERED INTO SIMULATOR (CARBON FIBER AXLES ALUMINIUM DRIVE WHEELS AND CHASSIS LIGHTENED)



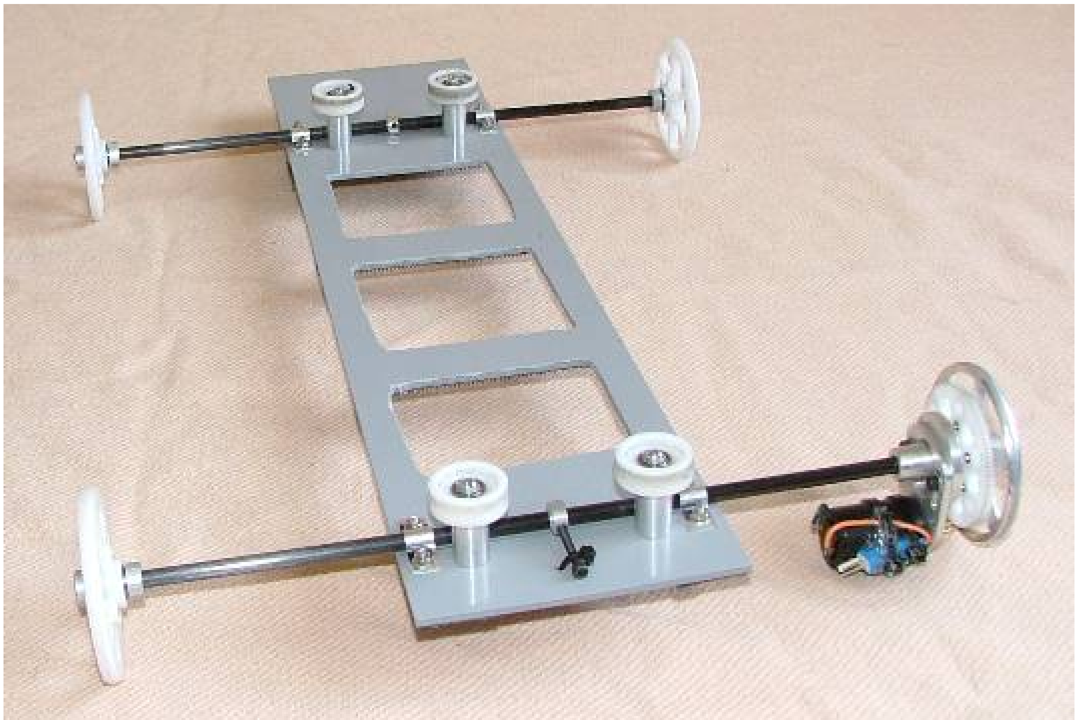

PHOTON CRUNCHER
MK IV


OFF
ON
PHOTON CRUNCHER
MK IV



TOP VIEW SOLAR PANEL REMOVED

UNDERSIDE VIEW OF BODY (FOLDED CORFLUTE) SHOWING VELCRO USED FOR FIXING BODY TO CHASSIS NOTE: BODY IS ONLY REMOVABLE FOR DEMONSTRATION PURPOSES AT WORKSHOPS



CHASSIS UNDERSIDE VIEW

CHASSIS TOP VIEW

PHOTON CRUNCHER MK IV SIDE VIEW
WITH STANDARD DRIVE WHEEL FITTED WITH “O” RING TYRE
Note : the Engelec Electronics is mounted in the cockpit so it is visible

PHOTON CRUNCHER MK IV REAR VIEW
Note: The drive wheel (left hand side) is the plastic version with an O ring tyre not the Aluminium drive wheel the test results are for.

MATERIAL LIST AND DESCRIPTION
PHOTON CRUNCHER MK IV

The intention was to design a basic car that would be easy to construct using only common hand tools and equipment typically available in all schools. Reasonable performance, and obviously meeting the VMSVC regulations was essential.
(CAUTION DESIGNED TO CONFORN TO 2005 REGULATIONS)
To achieve simple construction with only basic tools off the shelf components have been used wherever possible.
From observations made at the Victorian Event, typically the biggest problems faced by the competitors relate to constructing an accurate chassis with effective running gear then achieving good energy transfer from the solar panel to the motor and track.
Consequently we concentrated on these areas and chose components we considered were easy to use reliable, readily available and likely to give the best results.
No attention was paid to minimising cost, weight saving , aerodynamics or body design. All efforts were concentrated on producing a design that is easily assembled using what we consider to be the best simplest and most reliable running gear together with effective energy transfer. Having been given a head start with these critical components we expect the students to take it from there come up with improvements and modify the design to produce their own car.

This basic car consists of :
A 3mm thick PVC chassis fitted with wheels axles, guide rollers, motor mount and gears from R&I Instrument and gear Co.
Power is from a Solarex SX-10 panel fed to a Faulhaber 2224 or 2232 6 Volt motor via an Engelec Max-4 maximiser.
A body folded up from Corflute has been provided so the prototype car can be test run and meets the regulations. Our intention is that students will take these concepts , modifying them to produce a unique original car of their own.
If assembled accurately the car detailed here will give excellent performance , in the order of 20 seconds race time (one lap) in 90% sun is predicted by the simulator**.**
Photographs and sketches showing construction details will be added when available.
Preliminary material lists are included

A student designed and built car using these components recorded the following performance in the Melbourne event 2005.

SUN LEVEL %	RACE TIME Sec.
60	21.9
53	38.6

This car had a lower frontal area and weight than the Photon Cruncher.

POSSIBLE MODIFICATIONS TO IMPROVE PERFORMANCE:

- **General weight reduction , in particular use carbon fibre axles which give a weight saving of 120 gm.**
- **Reduce frontal area and improve shape to reduce air drag. (Drag figures of 0.48 N at 8.4 M/s and 1.91 N at 16.94 M/s were measured in wind tunnel tests)**
- **Use an aluminium drive wheel to reduce rolling resistance due to the "O" ring tyre.**

R & I COMPONENTS:

R&I Instrument And Gear Co. (Aust) Pty. Ltd. Has supplied quality model solar car components to schools for many years. They stock a wide range of components both suitable for use in , and manufactured specifically for model solar cars.

Remember R & I have many more components available than we have selected and listed here. You should check their website for a complete list.

The R&I part numbers are listed below.

FRONT AXLE ASSEMBLY (NON DRIVE AXLE):

- Wheels SCCW-RAD 2 No
- Bearings SMF 106ZZ 4 No
- Retaining bush 6mm bore SCCRB06 5 No
- Axle 6mm silver steel 320mm long 1 No

REAR AXLE ASSEMBLY (DRIVE AXLE):

- Wheel SCCW-RAD 1 No
- Wheel (drive) SCCW-OR 1 No
- Bearings SMF 106ZZ 4 No
- Gear 100 tooth SCCMO50-100-BL 1 No
- Pinion gear to your selection SCM050-0?? 1 No
- Retaining bush 6mm bore SCCRB06 4 No
- Socket head cap screw 25mm long 1 No
  (rear axle anti rotation)
- Screw M3 by 12mm long + nuts and washers 2 No
  (gear to drive wheel)
- Axle 6mm silver steel 320mm long 1 No
- Motor mount plate SCCMMP 1 No
- Motor mount flange SCCMMF 1 No
- Motor mounting screws M2 by 5mm long Csk Hd 6 No
- M3 by 8mm long Skt Hd Cap Screw + washers 2 No
  (flange to mount plate fastening)

GUIDE ROLLER ASSEMBLY:

• Guide rollers	SCCGR-25	4 No
• Bearings	SMF 106ZZ	8 No
• Sleeve Guide roller	SCCSL06	8 No
• M3 washers 2 fitted between bearings (to hold sleeves apart so no end load is carried on bearings due to retaining screw)		8 No
• Stand off (18mm long)	SCCGRSO	4 No
• Large top washer 12mm Dia.	STAND OFF WASHERS	4 No
• M3 or 1/8" Whitworth screw with nuts and washers to secure assy to chassis. Length to suit your chassis thickness to be provided by you.		4 No

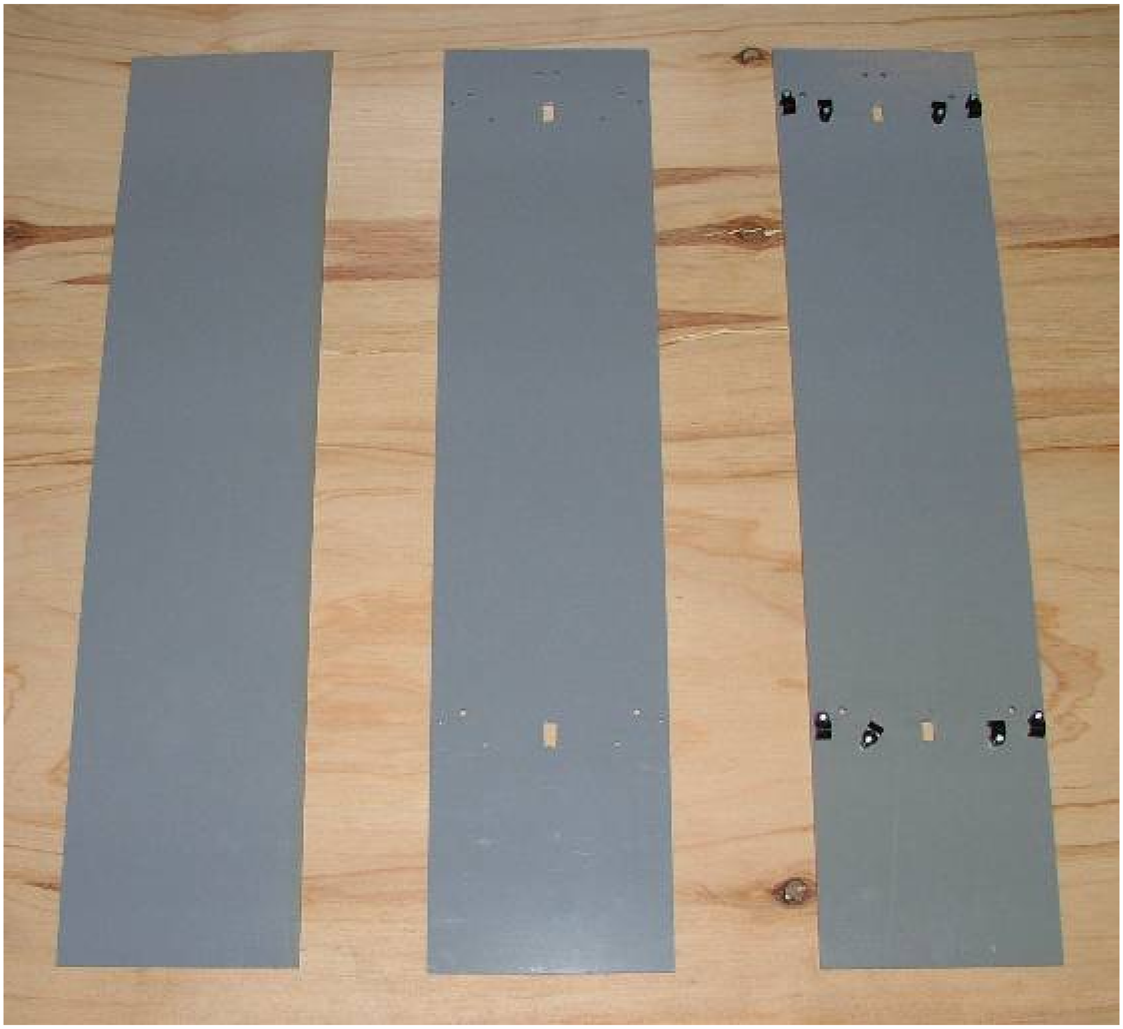
OTHER COMPONENTS:

* Solar Panel SOLAREX SX-10 plus plastic edging as reqd (NEED TO STRIP ALUMINIUM EDGING OFF PANEL TO REDUCE WERIGHT)	1 No
* Velcro for panel attachment to body self adhesive	700 mm
* Corflute for body 450 by 600	2 No
* Double sided tape and duct tape	as required
* Switch (plus wire as required)	1 No
* Electronics ENGELEC Max 4	1 No
* Faulhaber 2232 or 2224 6 Volt motor	1 No
* Plastic chassis PVC ,110mm by 490mm by 3.0 mm	1 No
* Saddles axle mounting 6mm cable clips	8 No
* Screws M2 by 12mm long + nuts and washers	8 No
* Other components as required	

PERFORMANCE OF THIS CAR:

In order to enable you to evaluate this design the parameters for use in the Mathematical Simulation for this car are entered into the simulator detailed later in this document . NOTE: the details entered in the simulator refer to a car with some modifications to improve performance. Also the air drag coefficient listed is for this car which has a frontal area of 15800 square mm and a very poor aerodynamic shape. You can ratio this drag figure based on areas to obtain a representative figure for your car. It would be difficult to build a car with worse aerodynamics so you will be looking at somewhere near worst case aerodynamic drag coefficient by using this method.

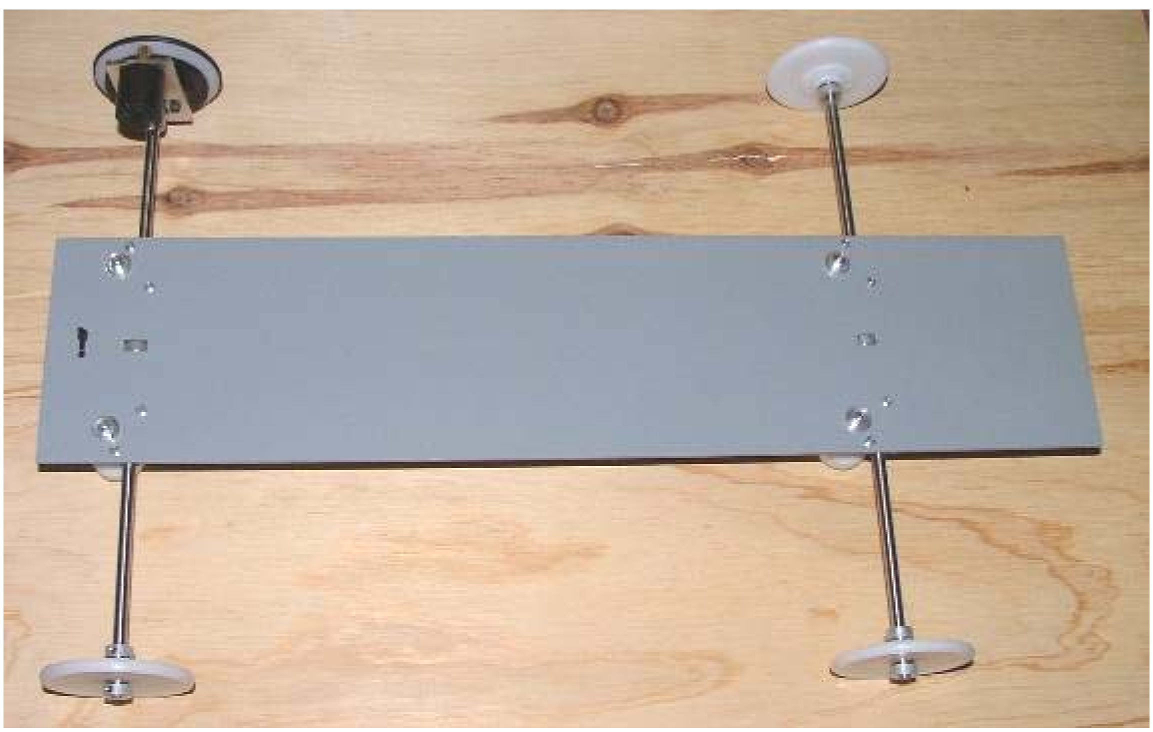
THE PHOTOGRAPHS FOLLOWING SHOW DETAILS OF THE COMPONENTS AND THEIR ASSEMBLY.



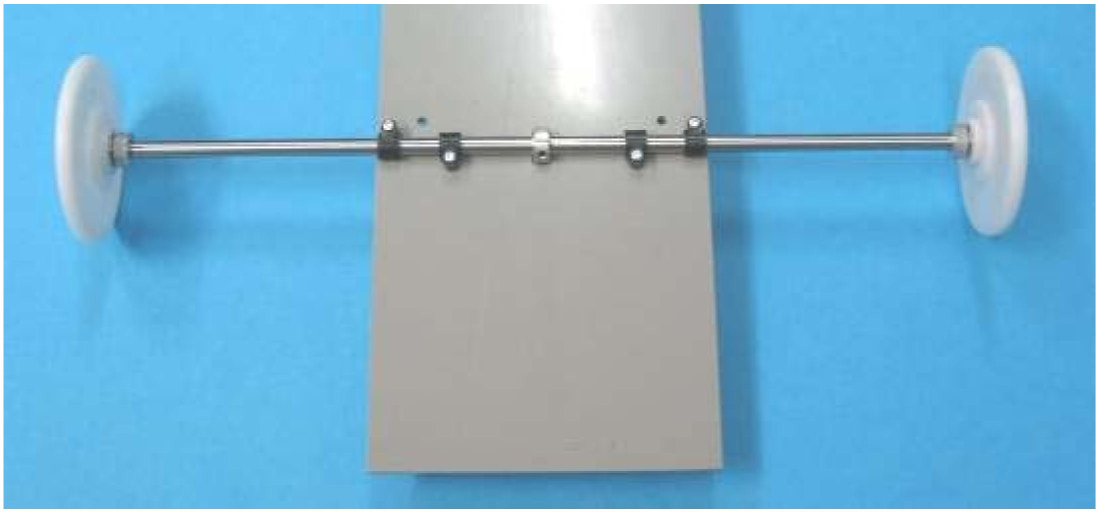
CHASSIS FROM LEFT TO RIGHT:

BLANK PVC SHEET
PVC SHEET DRILLED
PVC SHEET DRILLED WITH AXLE CLAMPS IN PLACE

CHASSIS UNDERSIDE VIEW



CHASSIS TOP VIEW



FRONT AXLE FITMENT TO CHASSIS (GUIDES NOT IN PLACE)
NOTE THE USE OF A RETAINING BUSH SCCRB 06 IN CENTER OF AXLE AND LOCATED INTO SLOT IN CHASSIS TO PREVENT LATERAL MOVEMENT

REAR AXLE ASSEMBLY UNDER SIDE VIEW NOTE THE LONG BOLT IN THE LATERAL MOVEMENT PREVENTION RETAINING BUSH IN THE AXLE CENTER
LASHED DOWN TO PREVENT AXLE ROTATION

FRONT AXLE DETAIL EXPLODED VIEW OF WHEEL ASSEMBLY SHOWING BEARINGS AND RETAINING BUSHES

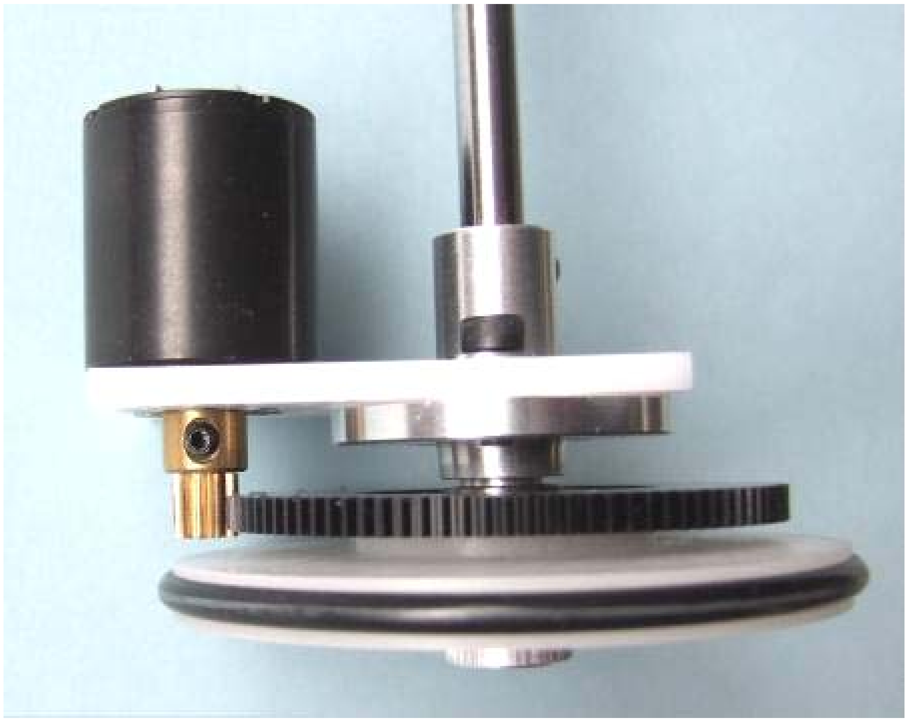
REAR AXLE EXPLODED VIEW TOP COMPLETE ASSEMBLY BOTTOM

AXLE RETAINING CLAMP (6MM CABLE CLAMP)

NON DRIVE WHEEL SCCW –RAD
BEARINGS SMF 106ZZ

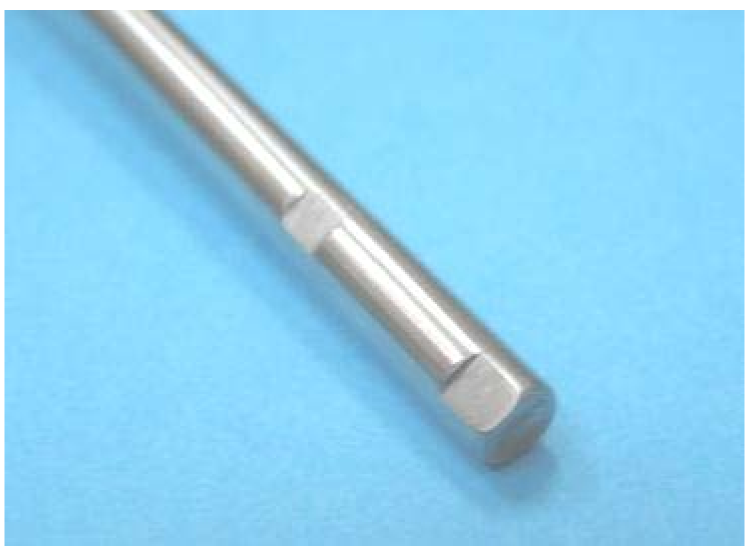
BEARING SMF 106ZZ CLOSE UP

RETAINING BUSH 6MM BORE SCCRB06
THE SMALL LIP IS ASSEMBLED FACING THE BEARING



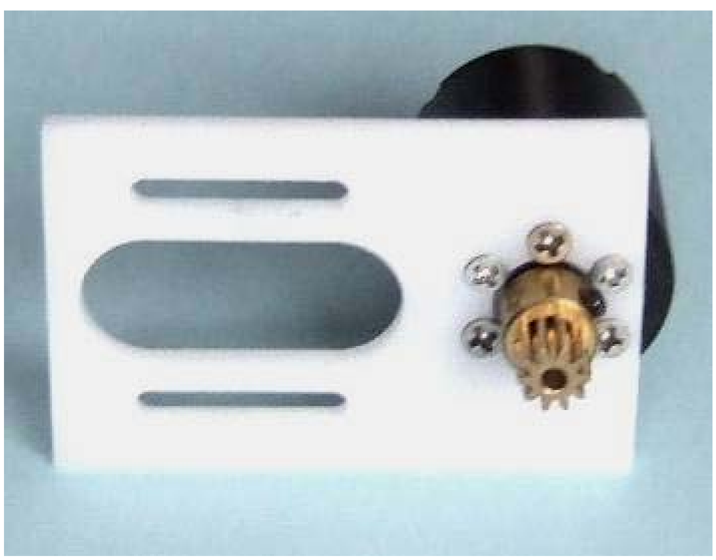
.

MOTOR MOUNT DETAIL CLOSE UP



HINT: FILE FLATS ON AXLES WHERE GRUP SCREWS BITE TO ALLOW EASY DISASSEMBLY LATER (THE BURRS CAUSED BY GRUB SCREWS BITING INTO SHAFT WILL STOP SLIDING BEARINGS PAST THIS DAMAGE)

MOTOR MOUNT FLANGE SCCMMF INSIDE VIEW



MOTOR MOUNTED ON MOTOR MOUNT PLATE SCCMMP

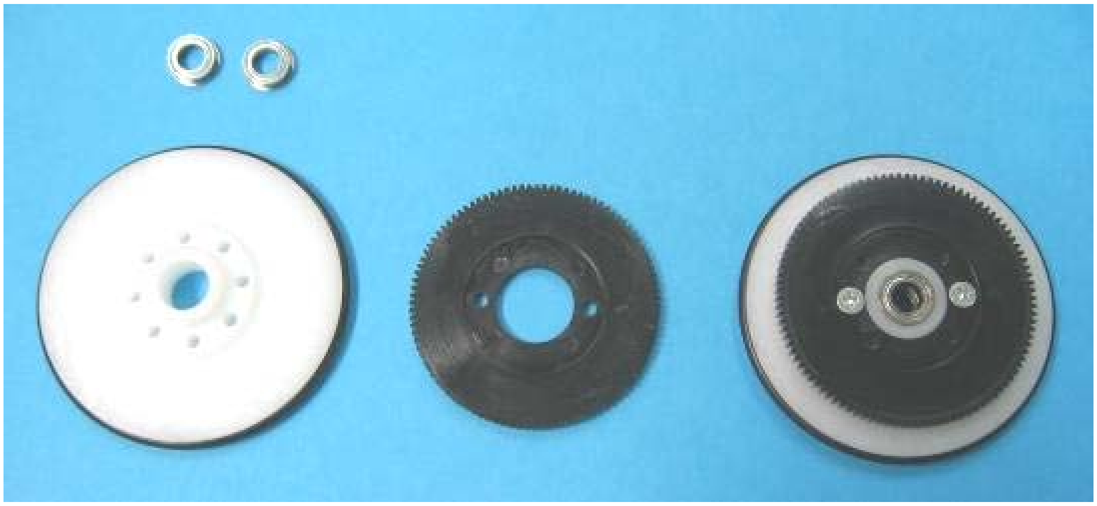
MOTOR MOUNT PLATE AND MOTOR MOUNT FLANGE ASSEMBLY
WHEEL SIDE VIEW

MOTOR MOUNT ASSEMBLED TO AXLE MOTOR SIDE VIEW

MOTOR MOUNT ASSMBLY MOTOR SIDE VIEW

MOTOR MOUNT ASSEMBLY WITH AXLE FITTED WHEEL SIDE VIEW

DRIVE WHEEL SCCW-OR WITH GEAR SCCM050-100-BL FITTED



LAYOUT DRIVE WHEEL GEAR AND BEARINGS BEFORE ASSEMBLY

GUIDE ROLLER ASSEMBLY ROLLER WHEEL SCCGR-25 THE ASSEMBLY IS PACKED DOWN WITH LARGE WASHERS BETWEEN THE CAR BODY AND GUIDE ROLLER ASSEMBLY TO OBTAIN DESIRED CLEARANCE BETWEEN ROLLER AND TRACK

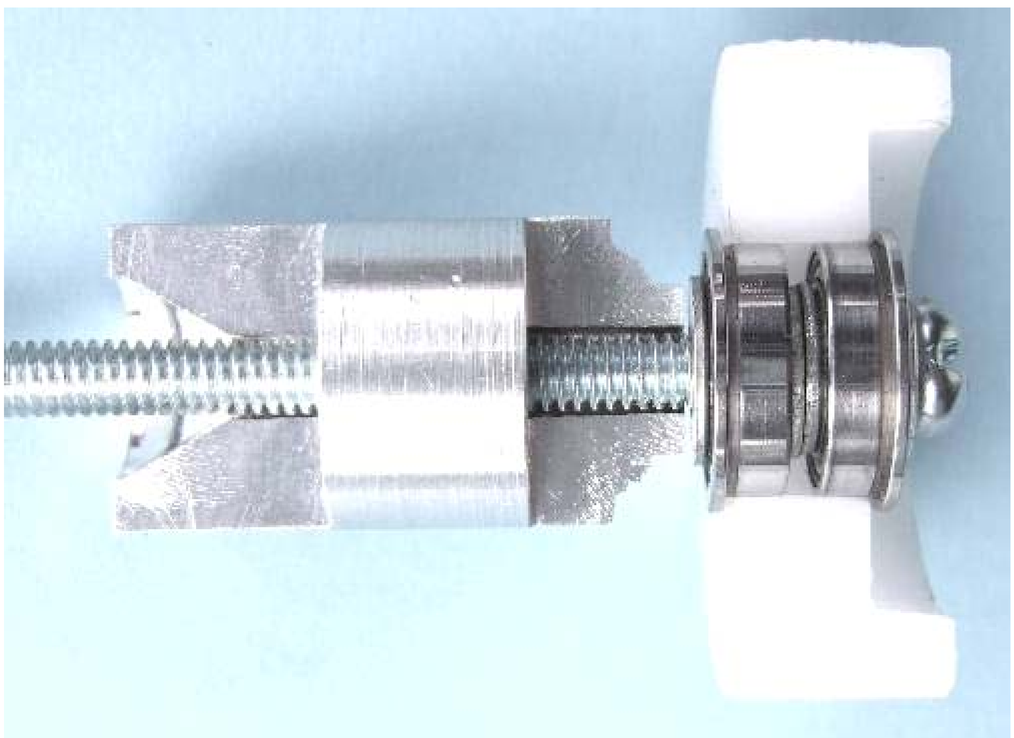
GUIDE ROLLER STAND OFF SCCGRSO VIEW OF BOTTOM END (LEFT) AND VIEW OF TOP END (RIGHT)

WASHERS FOR USE INSIDE THE CAR BODY TO SPREAD THE GUIDE LOADS FROM LEFT TO RIGHT

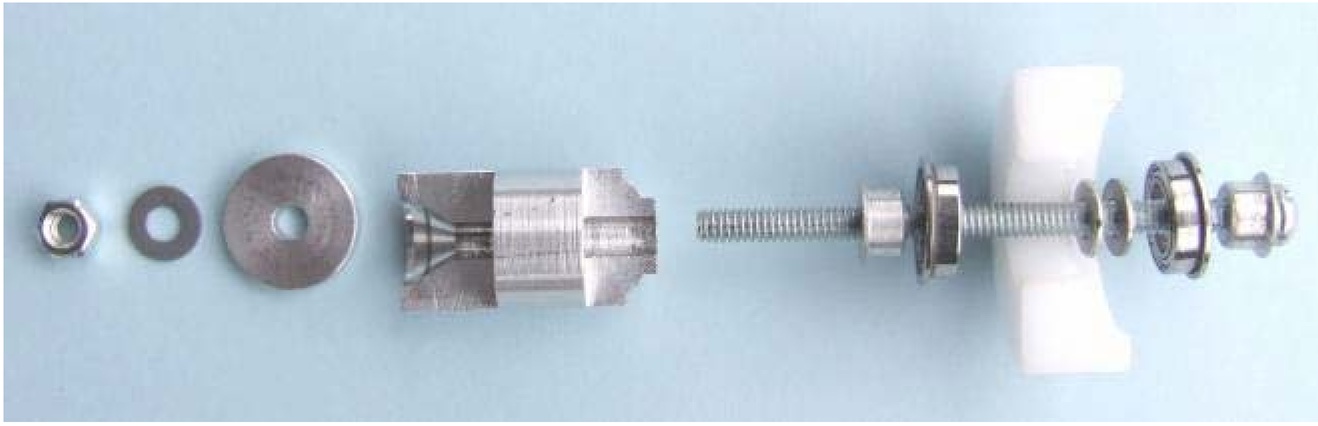
3MM NUT
3MM WASHER
LARGE ALUMINIUM WASHER SCCGR W

EXPLODED VIEW SLEEVES BEARINGS AND WASHERS

SLEEVES ASSEMBLED INTO BEARINGS



SECTIONED GUIDE ROLLER AND PART SECTIONED STAND OFF ASSEMBLED TO SHOW SEQUENCE. NOTE: THE TWO 3mm WASHERS BETWEEN THE BEARINGS TO ENSURE THERE IS NO AXIAL LOAD ON THE BEARINGS WHEN THE SECURING BOLT IS TIGHTENED. AN AXIAL LOAD CAN DAMAGE BEARINGS OR INCREASE FRICTION BOTH ARE HIGHLY UNDESIRABLE.



EXPLODED VIEW OF PART SECTIONED COMPONENTS OF GUIDE ROLLER AND BEARING ASSEMBLY

FROM LEFT TO RIGHT

STANDARD 3mm NUT
STANDARD 3mm WASHER
LARGE SPECIAL 3mm WASHER SCCGR W
STAND OFF (PART SECTIONED) SCCGR SO
SLEEVE SCCSL O6
(adapts 6mm bearing bore to 1/8” or 3mm retaining screw)
BEARING SMF106ZZ
STANDARD 3mm WASHERS (TWO REQUIRED)
GUIDE ROLLER SCCGR25
BEARING SMF106ZZ & SLEEVE SCCSL06
3 mm SECURING SCREW

APPENDIX F

PHOTOVOLTAICS (SILICON SOLAR CELLS & PANELS)

Solar cells are solid-state semiconductor devices which convert light energy directly into electrical energy. Their construction is basically similar to transistors and other solid state devices, in that they are predominantly silicon doped with small quantities of different material to create the semi-conductor effect.
There are several different types of cells, amorphous, mono-crystalline and poly-crystalline.
Let us consider a polycrystalline cell (a very common type) the base material is silicon doped with boron to give it positive or p-type characteristics , a thin layer on the front of the cell is doped with phosphorous to give it negative or n-type characteristics. We have now created an n-p junction where these two layers join. When photons (light) hit the cell and are absorbed in the junction region, their energy (if sufficient) will free electrons in the silicon crystal giving them sufficient energy to break free of the electric field at the junction and travel through the silicon crystal to be conducted away by wires connected to the silicon so they can then perform useful work as electricity.
A solar cell is a low voltage device typically about 0.45 Volts per cell , cells are connected in series to increase voltage.
Similarly if larger currents are required more surface area is required in the cell, this may be a larger cell or smaller cells in parallel
As with most solid state devices output will vary with temperature.
Typical variations are in the order of

-80 mV per deg C on open circuit volts.
+0.065% per deg C on short circuit current

-0.5% per deg C on power

POWER TESTING OF SOLAR PANELS

You need to know the maximum power output of your Solar Panel in order to prepare any ballast required before the race day.
Your Panel may have the maximum power it can produce on it's label otherwise testing the power output will be required. In Victoria the official panel testing during scrutineering is performed on a calibrated light box using a micro processor based power measuring meter. (NOTE: this power measuring meter was designed and constructed by Mr Tony Bazouni specifically for power measuring of solar panels, these meters are in limited production see Buying guide for contact details for Mr. Bazouni.)
ENGELEC has a similar meter, again in limited production. Refer to buying guide for contact details.

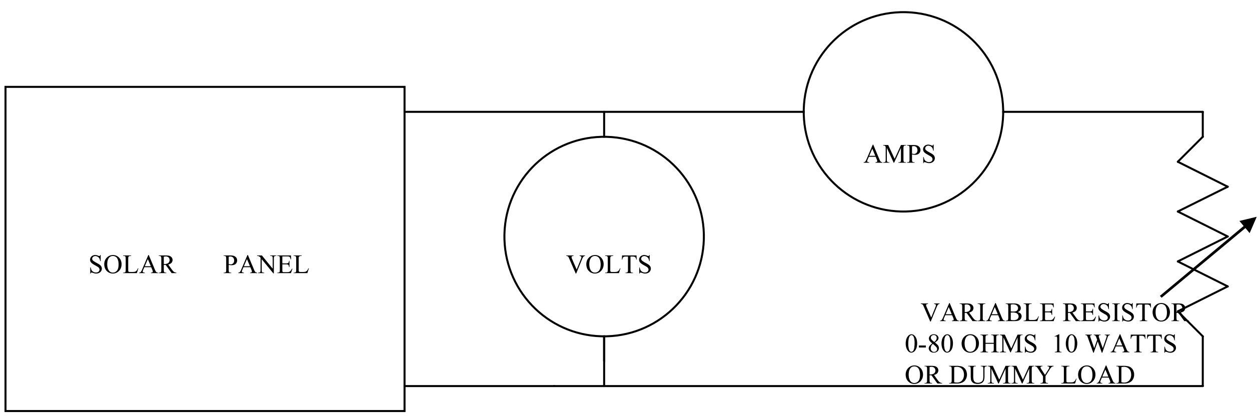
You can however undertake power measuring with basic equipment needing only an ammeter, voltmeter and variable load. This method while slower than the previously mentioned methods will give good accuracy within the limits imposed by panel heating. During the time taken to gather and record data panel heating will have reduced the power reading you obtain to a figure below that which would be obtained by the other much faster methods mentioned above.
Remember panel power falls by about 0.5% per deg C temperature rise of the panel. A power reading about 10% below that obtained at scrutineering is possible.

Test your panel in full sun about midday, preferably between October and March (December is best) as the sun strength is lower during the winter period.

Set up the circuit as shown below, place panel in the sun with the sun striking it at right angles and take readings of voltage and current as the variable resistor is changed from zero ohms to about 40 ohms. The intervals between readings required to accurately determine the maximum power vary depending on the voltage and current characteristics of your panel. Initially aim to take readings at current intervals of about 1/10 of your panels short circuit current. Calculate the power.

Power (Watts) = Volts multiplied by Amps.

Graph the results with Power on the Y axis and Volts on the X axis. Read maximum power from the graph. Take extra readings if required to increase accuracy.



If equipment is not available to you here is an approximate method of calculating panel power. With your panel directly facing the sun at around midday preferably in December or January measure the Open Circuit Voltage (OCV) and the Short Circuit Current (ISC) you also need to know the panels Fill Factor (FF) for accurate power estimation. If FF is unknown use 0.75 see below for an explanation of fill factor.

The approximate power is given by OCV x ISC x FF in watts.

PANEL TESTING : POWER DATUM

If you have a commercial solar panel the label will most probably specify the power at AM 1.5. What does this mean? (Caution: The power listed on your panel is probably only nominal not an actual measurement.)

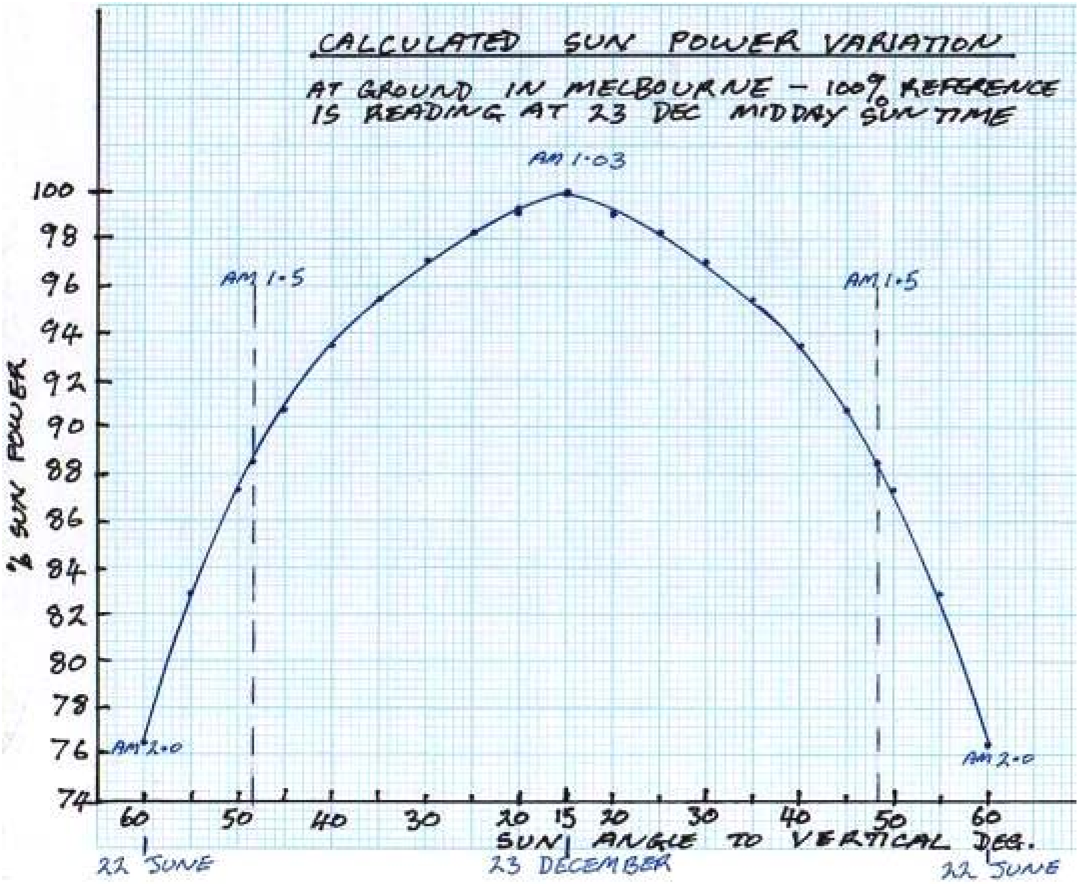
AM 1.5 refers to the energy and spectrum of Sunlight after it has passed through a distance of 1.5 times the thickness of the atmosphere. (Note 1.5 times the atmospheric thickness occurs when the angle between the vertical and the sun is 48.2 Deg.) The actual energy striking the earths surface at AM 1.5 is 970 Watts / square metre but it is rounded up to 1000 Watts / square metre in the standard.
For full details see: Applied Photovoltaics Second Edition by Stuart R Wenham, Martin A Green, Muriel E Watt and Richard Corkish.

Previously (prior to 2010) solar panel power at the Victorian Model Solar Vehicle Challenge was not measured to this standard. We used the maximum Sun power expected here in Melbourne as the 100% Sun datum for our measurements. The light box we (and all other states) use is fitted with quartz halogen globes, these do not have the same spectrum as Sunlight introducing a slight error.

To better align us with international standards, the National regulations now specify 100% Sun to be AM 1.5 In Victoria and Nationally all solar panel power measurements will be referred back to this datum.

CALCULATED SUN POWER VARIATION:

The following graph was produced as an aid to understanding. It shows the calculated power variation in Melbourne over the course of a year.
It's 100% is based on the power measured at midday Sun time 23 December, this is the power previously used as the 100% Sun datum for setting the light box at the Victorian Model Solar Vehicle competition.
NOTE: It is only calculated and assumes that power losses are linear with distance travelled through the atmosphere, which is not strictly accurate particularly as the Sun angle becomes large.


CALCULATED SUN POWER VARIATION
AT GROUND IN MELBOURNE – 100% REFERENCE
IS READING AT 23 DEC MIDDAY SUN TIME
AM 1·03
AM 1·5
AM 1·5
AM 2·0
AM 2·0
% SUN POWER
100
98
96
94
92
90
88
86
84
82
80
78
76
74
60
50
40
30
20
15
20
30
40
50
60
SUN ANGLE TO VERTICAL DEG.
22 JUNE
23 DECEMBER
22 JUNE

FILL FACTOR:

AN excellent explanation of fill factor was written by Mr. J Jeffery and has been condensed for inclusion here. The unmodified original is available on the Tasmanian web site.

A Short Explanation of the Effect of Low Fill Factor on Model Solar Car Performance.

By Mr J. Jeffrey MSV Tas. (edited by Mr I Gardner MSV Vic.)

When exposed to light solar panels produce an open circuit voltage (Voc) and a short circuit current (Isc). These are easy to measure with a multimeter. The maximum power produced by the solar panel is not equal to Voc times Isc but is something less than that figure. The ratio of the actual maximum power to Voc x Isc is called the Fill Factor. Good quality commercial panels have a FF of around 0.75 Most of this missing power is dissipated in the internal series and shunt resistances inherent in the manufacture of the cells.

Many of the hobby cells used in model solar car racing are sourced from off-cuts and surplus stock but are still usually of normal commercial quality, with a FF of around 0.72 Occasionally though, a hobby cell will turn up that has been made from wafers that would normally have been rejected.

In simple terms, cells produce a current that is proportional to the light that is falling on them and generate a voltage determined by the number of cells and the properties of the silicon atom, around 0.6 volts per cell open circuit. The internal parasitic (both series and parallel) resistances chew up some of this so the real world results are a little bit different.

The question is this, what would be the effect on a model solar car if the panel used had a lower than normal Fill Factor?

(* Fill factor is controlled by both series and parallel resistance series resistance has been used for our testing since it is easier to add to a panel. Series resistance lowers the output current while parallel resistance lowers voltage.)

Imagine if you will, a large solar array comprising 48 cells each capable of (say) 500mA in full sun, connected in series/parallel to give 14.4 volts open circuit and 1 amp short circuit. By all normal reasoning, this panel should deliver around 10.5 watts when tested on a light box.

Now, consider what happens if we artificially lower the FF by simply placing 4 ohms in series with the output. The open circuit voltage will not change as there is no current flowing so no voltage is lost across the resistor. The short circuit current will not change since the cells generate current proportional to the light falling on them. (Actually they will both drop a little bit, but not enough to raise suspicion.) We can only detect that something is wrong when we measure the maximum power output of this large panel and we only get a figure of 6.5 watts! The missing 4 watts are going up in the resistor. (P =

I^2R) Not only that but the maximum power voltage is not around the expected 11.5 volts but is several volts lower.

Let's see what happens when the light level falls below 100%? At 50% the current will drop to 0.5 amps and the power from our panel will drop to 3.25 watts. No it won't!!! In a perfect world the power from the unmodified panel would drop to 50% or 5.25 watts but the power lost in the extra series resistor is not halved. The power in the resistor equals the resistance times the SQUARE of the current so the loss is now 0.5 x 0.5 x 4 or only 1 watt not 2 watts, meaning the resulting power output is 4.25 watts, a gain of 1 watt or 31% over a 'standard' panel. And it only gets worse at lower light levels.

At 25% the expected power would be 6.5/4 or 1.625 watts. However, our modified panel delivers 10.5/4 – 0.25 x 0.25 x 4 = 2.625 – 0.25 = 2.375 watts!!!! This is a theoretical gain of 46% and you can see that this can be a huge advantage. In fact, at all light levels below 100%, which is most of the time, a car equipped with such a panel will have a significant advantage over other cars.

At very low light levels it performs like a 10.5 watt panel but only carries the weight of a 6.5 watt panel. You don't need to be Einstein to work out which car will go better in low light.

Because of this performance anomaly and the ease with which the fill factor of a solar panel can be modified simply by inserting series resistance, the regulations have been changed.

If you think that you know it all after reading the above think again!

The above article concentrated on the effect of series resistance we must not forget parallel resistance. Please continue and read the following to obtain an overview of panel performance including the effect of low parallel resistance.

SOLAR PANEL SELECTION

The Solar Panel you fit to your car can have a very significant effect on performance. In fact it could easily mean the difference between winning and losing.
Let me explain. I am not thinking about the power output of the panel as all the modeling done indicates that with the ballasting formulas now in use there is virtually no performance difference between a low wattage and high wattage panel as long as they are fitted to a "GOOD" car.
I am referring the characteristics of the panel. To understand this, consider the ballasting formula prior to 2011. Ballast was calculated based on the panel power measured at ½ Sun and doubled. This means that any panel with a low Fill Factor FF (or if you prefer Form Factor as used in some texts), due primarily to high series resistance will end up carrying ballast weight for which there is no actual power available from the panel.

Conversely a panel with low FF due primarily to low parallel resistance can in fact be advantaged. I must point out here that we have only seen a few panels like this at scrutineering for power testing. I do have such a panel in my possession, its test results are included in the table below.
Examination of the table below will hopefully clarify this for you. The table shows light box test results of panel test, the column 'Ballast With No Panel Power' shows the ballast weight carried (calculated from the 2010 formula) for which there is no actual power produced by the panel. This is because ballast is calculated on power taken at 50% Sun and doubled.

PANEL POWER WATTS		FILL FACTOR	BALLAST WITH	COMMENTS
100% Sun	2 x 50% Sun		NO PANEL POWER	
9.14	**10.20**	**0.65**	**212**	
10.20	**10.16**	**0.71**	**8**	
8.20	**8.64**	**0.59**	**88**	
10.56	**10.56**	**0.75**	**0**	**Victorian master**
9.62	**9.44**	**0.76**	**36**	
9.81	**8.62**	**0.57**	**minus 238**	**ie. an advantage**
11.19	**11.38**	**0.76**	**38**	

Clearly whilst panels with a high fill factor always perform well it is possible for a panel with a low fill factor to perform even better from the ballast point of view. The secret is in the panel characteristics namely the split between series and parallel resistance of the panel. Who would want to use a panel with the characteristics of the first panel shown in this table? However the panel second from the bottom would be great.
The regulations have been changed for 2011 to reduce the effect of the anomaly shown above. The change made is to measure panel power at a Sun level nearer to that expected to prevail during the course of racing, then ratio up to expected power at 100% and use that value for ballasting purposes. This means we will hopefully be conducting our ratio over a narrower band with resulting lower errors.

APPENDIX G

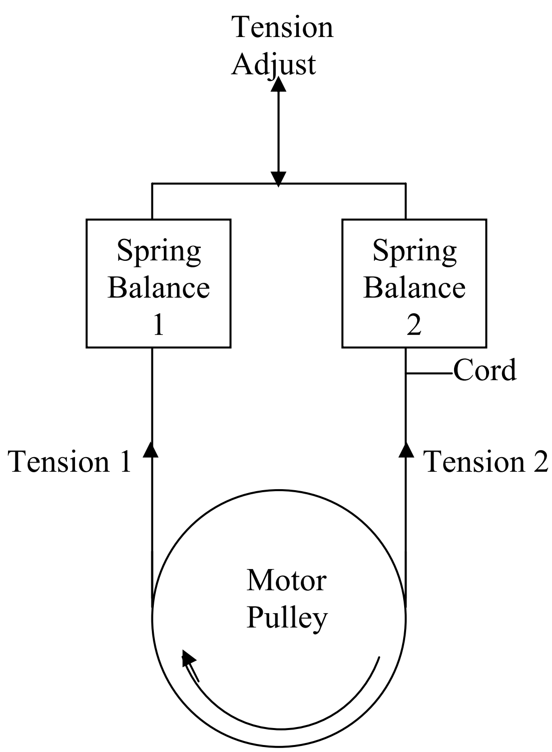
DYNAMOMETER TESTING

A dynamometer is a device used to measure power. Commonly they are used to measure the power output from motors (although not exclusively). They are used extensively in industry and sometimes for familiar things such as power output of motor car engines during tuning operations (particularly for competition)

In the application of measuring power output from motors, normally the rotating output shaft of the motor drives a variable load. The torque and RPM are measured as the load is varied and the power calculated from them. Commonly the results are depicted in a graphical form, with torque and power graphed against RPM.

Measuring the low power output of the motors used for model solar cars presents some difficulties. With output power in the range of 0.5 to 8.0 Watts, small unaccounted for losses significantly degrade the accuracy.

A very basic dynamometer was constructed see, sketch below for the concept.



This dynamometer is very basic but overcomes the problem of unaccounted for losses , as all the loads are taken directly on the motor with no additional bearings used . The motor is simply fitted with a pulley on its output shaft , a cord is taken around the pulley and supported on two spring balances (balance one 50 gm and balance two 100 gm). The rotation of the pulley tends to drag the cord around thus reducing the load on one spring balance and increasing the load on the other. To increase the load on the motor both (or one) spring balances are moved up to increase the total load on the cord. Conversely the load is reduced by lowering one or both spring balances. (the construction we used for this unit moves both spring balances together initially we used a quick action clamp then later a screw thread).The difference in tension from one side of the cord to the other multiplied by the pulley radius gives the torque. The RPM is measured with a Laser tachometer from Jajcar Electronics. (Digitech QM 1448)

Power is calculated by using the formula below

$$\text{Power (Watts)} = \frac{\text{Torque (mNm)} \times \text{RPM} \times \Pi}{30 \times 1000}$$

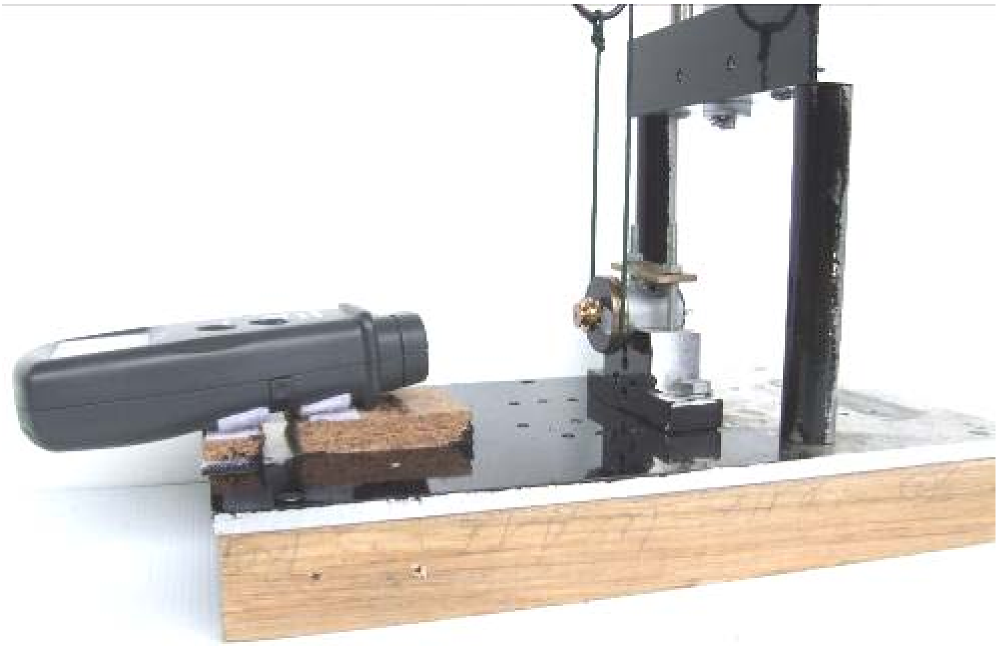
The standard pulley we use is 34 mm Diameter.
Multiplying the difference in tensions of the cord around the motor pulley (T1-T2) by 0.1666 gives torque in mNm.

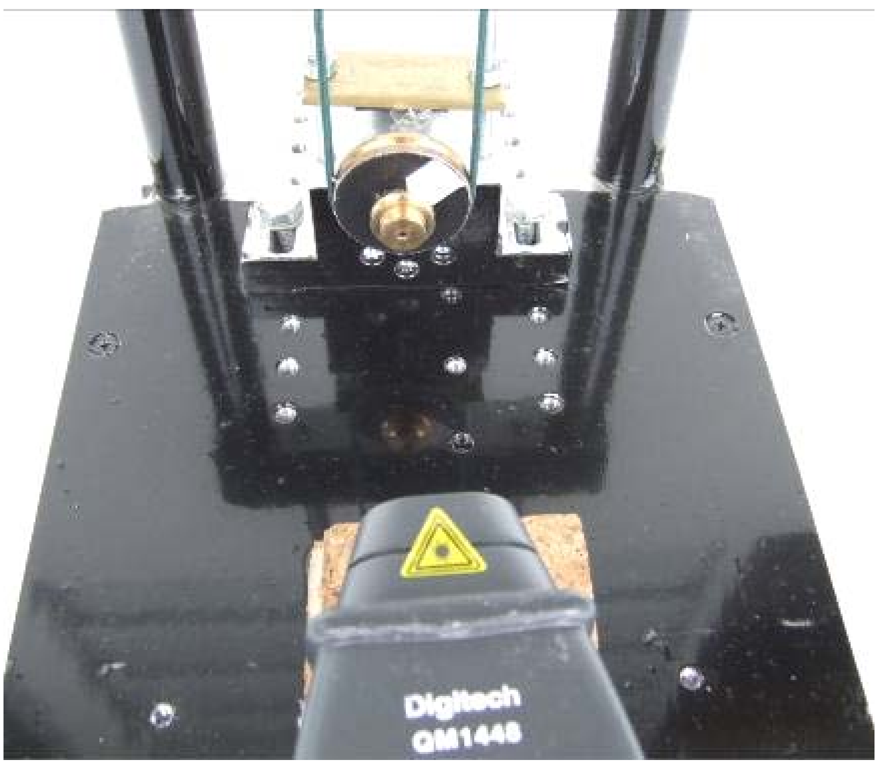
TESTING THAT CAN BE UNDERTAKEN USING THE DYNAMOMETER

- Optimum over voltage of motors.
- Electronics package, how good is it? is it worth using?
- Panel characteristics required for best match of electronics to motor
- Motor efficiencies
- Gear and other drive system efficiencies
- Power output at car drive wheel ie. configure unit as a chassis dynamometer simply by placing the load cord in a groove in the cars drive wheel.
- Motor characteristics for use in the Model Solar Car Mathematical Simulation

The actual Dynamometer with Laser tachometer in place is shown below.

Because of the use of a laser system for safety, the operating area is shielded and the inside of the shields are painted black to reduce reflections. The view above has shields in place. Shields have been removed to show the details in subsequent photographs.





View of motor and laser tachometer (From Jajcar Electronics) note the reflector on flywheel.

APPENDIX H
MODEL SOLAR CAR
MATHEMATICAL SIMULATOR

MODEL SOLAR CAR

MATHEMATICAL SIMULATION

EXCEL VERSION 1.5 DEC 06
TEXT REVISED JAN 08

BY
ROSS PERRY
&
IAN GARDNER

MODEL SOLAR CAR SIMULATOR INSTRUCTIONS

This mathematical model of a Model Solar Car is intended to be used by students as an aid to designing model solar cars. It allows students to vary characteristics of a proposed car and see what probable effect this has on the performance.
NOTE: The accuracy achieved depends on many things but particularly important is the accuracy of the coefficients used for air drag and rolling resistance (which need to be determined by the students experimentally) and the power output versus RPM data for the proposed motor. A power curve obtained from Dynamometer testing using a solar panel or a power supply with similar characteristics to a solar panel is essential for accuracy. Use of a battery or power supply without similar voltage & current characteristics to a solar panel will yield inaccurate results.

The model uses only basic mathematics and Newtonian Mechanics so students should be able to understand and modify it to suit their individual requirements. It is laid out on a standard EXCEL spread sheet.

Remember this is only a simple model of a very complex system, only the main forces have been considered and simplifying assumptions have been made to keep the programme manageable. However it has given better than 95% correlation to the performance of the 3 cars we have tested. The results should prove to be very useful particularly when the simulation is used to determine what effect a change is likely to have, say car weight, streamlining, motor (type, power output or torque / RPM characteristics), gear ratio, or sun level changes.

IMPORTANT: ACCURATE INPUT DATA IS CRITICAL FOR OUTPUT ACCURACY

SECTION 1

DEVELOPMENT OF THE MATHEMATICAL MODEL:

Consider the main forces acting on the car, see sketch below.

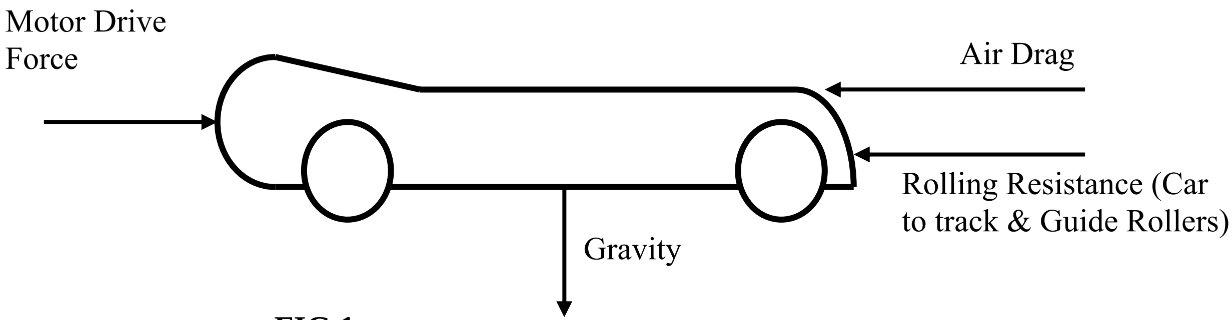


FIG 1

1 GRAVITY

Gravity acts vertically down, the gravity force in Newtons is determined by multiplying the Mass (M) of the object in Kilograms by the gravity constant 9.81 m/s/s. However when the car is on a slope a component of the gravity force will be acting down the slope. The magnitude of the gravity force component acting down the slope depends on the angle of the slope. This gravity component will provide a force accelerating the car down the slope. When the car is travelling down the slope this force will tend to speed it up, conversely if the car is going up the slope this force will tend to slow it down and may even stop the car if the car does not have sufficient speed or drive force to overcome this gravity component.

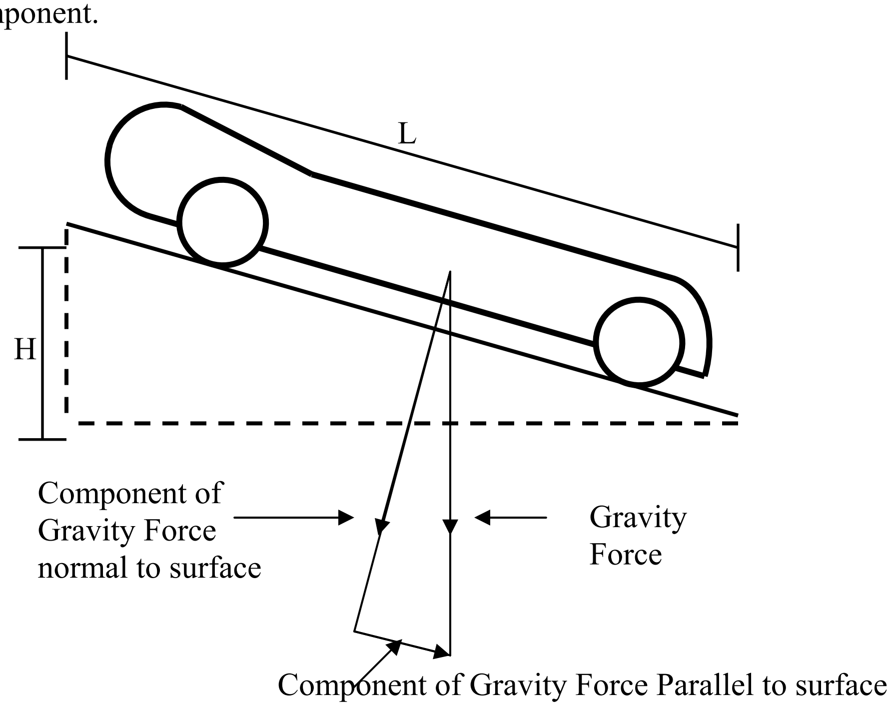


FIG 2

Component of Gravity Force Parallel to surface

$$= \frac{(9.81 \times M \times H)}{L}$$

2 AIR DRAG

Air drag is due to the passage of air over the car, it can be due to the car moving through the air or air passing over the car such as a prevailing wind. This force acts parallel to the air flow and in the same direction as the air flow.

In this simulation we have ignored any prevailing wind, as the wind velocity is low close to the ground due to the drag effect of the ground surface and the many objects normally close to the ground which tend to block the wind eg. buildings, fences, trees, shrubs, etc. As the track is a figure 8 layout, any wind would be a tail wind for about the same time as it was a head wind and so the effects tend to cancel out.

For a complete explanation of air drag refer to standard fluid dynamics texts, but simply put:

$$\text{Air drag} = \tfrac{1}{2} \times \text{Air density} \times \text{Drag coefficient} \times \text{Frontal Area} \times \text{Velocity}^2.$$

Drag coefficient depends on the shape of the car, an aerofoil shape will have a drag coefficient many times lower than a flat plate. Wind tunnel testing is normally used to determine drag coefficients. For large items such as aircraft accurate scale models are normally used for wind tunnel testing.
Model solar cars are small enough to allow testing of the actual car, the coefficient we are using in our simulation is based on this assumption .

Consider the elements of the air drag formula:

- Air density changes with temperature and pressure. As we are operating at sea level we will ignore the small changes that take place and treat density as a constant.
- Frontal area is the projected area facing the air flow, since we are testing the actual car this is also constant
- Drag coefficient is dependant on the shape of the car. Again as we are testing the actual car this remains constant.
- Velocity is the only element that changes

Since we are testing our actual car, with air density, drag coefficient and frontal area all constant for simplicity we will combine them together into one constant which is called **Air Drag Coefficient** in the simulation.

So $$\text{Air Drag(Newtons)} = \text{Air Drag coefficient} \times \text{Velocity}^2\text{(m/s)}.$$

Therefore to obtain the air drag coefficient for a car perform wind tunnel tests on that car at a known air velocity and measure the drag force, transpose the above equation and use it to calculate the air drag coefficient to be used in the simulator for the car tested.

NOTE: You MUST do wind tunnel testing of your car to determine its air drag coefficient. (Values in the order of 0.03 for a flat plate of 200 cm square area to 0.003 for a low drag aerofoil shape of 200 cm square area would be typical.)

If you cannot perform wind tunnel testing you can make an estimation of air drag coefficient by taking the 0.03 drag coefficient for a flat plate of 200 cm square area and calculate the air drag coefficient for your car with a simple ratio calculation based on your cars frontal area compared to the 200 cm square.
This will give a worst case drag figure as it is based on a flat plate.

3 MOTOR DRIVE FORCE

As our motor performance data will be from Dynamometer tests, we will have torque and RPM data available.
See 5 DETERMINATION OF MOTOR TORQUE

Drive force is calculated from the motor torque as follows.

Motor torque × Gear ratio × Transmission efficiency = Wheel torque,

where:

Motor torque is the torque on the motor shaft.

Gear ratio is the ratio of motor RPM to wheel RPM. It is normally a reduction ratio (must be a reduction in this simulator) but does not have to be gears, it can be belts or any other form of reduction device. Note this simulation allows for a one shot gear change from an acceleration gear to a running gear.

Transmission efficiency allows for the losses in the reduction device. For a single step gear reduction 95% (0.95) would be about right. Testing will be required to determine the efficiency of your particular drive system.

Knowing the torque on the wheel and the wheel diameter you calculate the force on the wheel required to produce this torque.

Wheel drive force = Wheel torque ÷ Wheel radius

The motor torque measured in our dynamometer testing was in mNm so the wheel force in Newtons will become:

$$\text{Wheel drive force} = \frac{\text{Wheel Torque (mNm)} \times 2}{\text{Wheel Dia. (mm)}}$$

$$= \frac{\text{Motor torque (mNm)} \times \text{Gear ratio} \times \text{Efficiency} \times 2}{\text{Wheel Dia.(mm)}}$$

NOTE: The maximum force the wheel can transmit to the track before wheel spin occurs is limited by friction. When using an electronics system it is possible to have wheel spin for a short time during take off from the start line. Obviously when wheel spin is occurring the drive force accelerating the car is lower than calculated above.
The addition of WHEEL SLIP COEFFICIENT in the simulation takes care of this. You must measure the force required to cause wheel slip, use this force to calculate the wheel slip coefficient. Within the excel programme the Wheel Slip Coefficient is used to calculate the force required to cause wheel slip this is compared to the wheel drive force and the lower value used to calculate the cars acceleration.

4 WHEEL SLIP COEFFICIENT:

This was added to the simulator when it was observed that the 2232 Faulhaber Motor coupled to an Electronics unit could produce sufficient torque to spin an aluminium wheel on take off.
All we have done is written some logic that limits the drive force on the wheel to the slip value.
However you must determine the slip value for your particular car. This is easy just lock the drive wheel and measure the force required to drag the car along, this is the wheel slip force. (In Newtons)
To obtain the wheel slip coefficient use the following formula

Wheel Slip Force (N) = Wheel Slip Coefficient x Car Mass (kg)

NOTE: It will be different for a wheel with a tyre compared to a wheel without a tyre.
CAUTION: If you change the weight on the drive wheel the slip force will change.
To maintain the best accuracy if significant weight changes are made to the car retest it, if only minor changes are made and the C of G is not changed it will be all right.

5 DETERMINATION OF MOTOR TORQUE

The motor torque is determined by testing, see Dynamometer Testing. For a car using an electronic system testing is critical as the current multiplication the electronics provides greatly increases the available torque at lower RPM. Because of the difficulty in determining the formula to a curve, the curved graph of Torque vs RPM is arbitrarily broken down into 3 straight line sections. Coordinates defining these sections are entered in the simulator and the approximate Torque at the motor RPM we are considering is obtained by interpolation. See FIG 3.
(For a motor operating without an electronics system it is possible to calculate the torque RPM curve, you may wish to research this avenue.)
Refer to the typical straight line split up of a graph of torque vs RPM shown below.

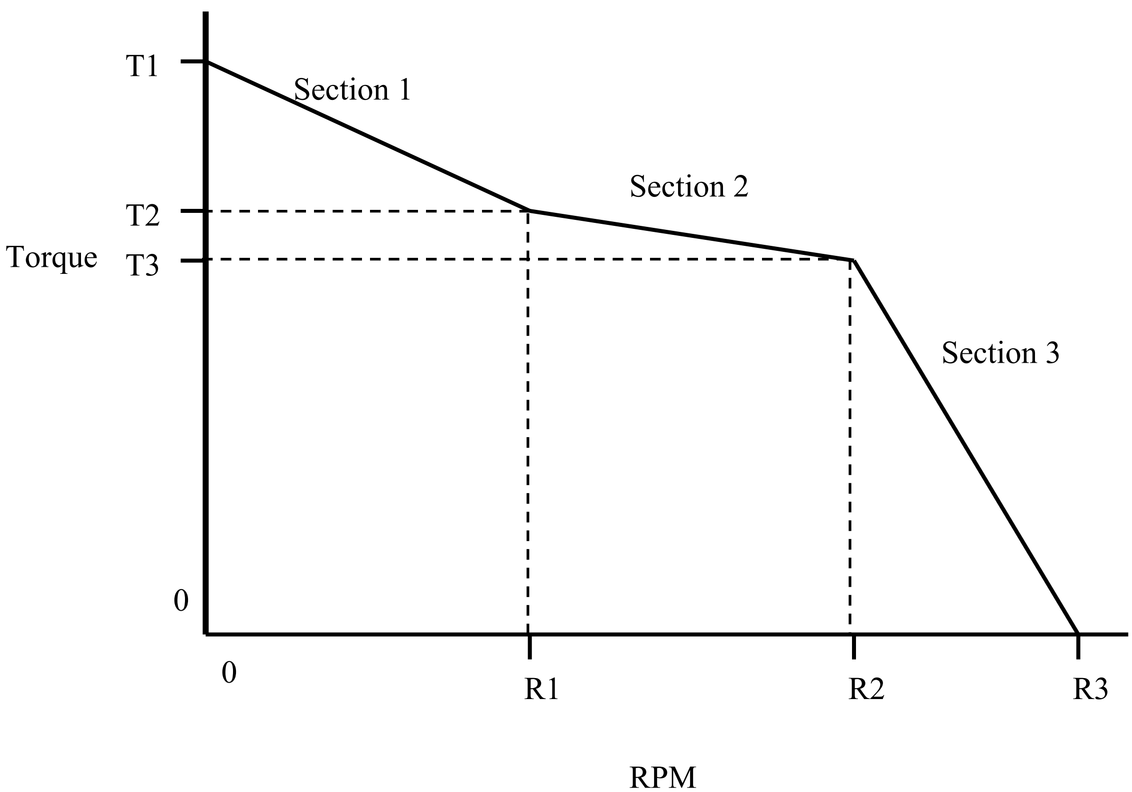


FIG 3

For section 1 of the graph the formula for calculating torque at a given RPM is

Torque = T1- (T1-T2 ÷ R1-0) × RPM

For section 2

Torque = T2-(T2-T3 ÷ R2-R1) × RPM

For section 3

Torque = T3-(T3-0 ÷ R3-R2) × RPM

These formulas are the equation to the straight line sections of the graph. In conjunction with logic statements to select which formula is to be used based on motor RPM they are used in EXCEL to calculate the torque at any given RPM.

(To enable realistic evaluation of this simulation some motor test data is included later in this section but also see Appendix J for more motor test results.)

If you have a power curve for your motor (graph of power vs RPM) it will be necessary to construct a torque vs RPM graph to allow you to input the data to the simulator. Torque can be calculated by transposing the formula

$$P = 2 \times \pi \times N \times T$$

N= Revs / Second
T= Torque Nm
P= power watts

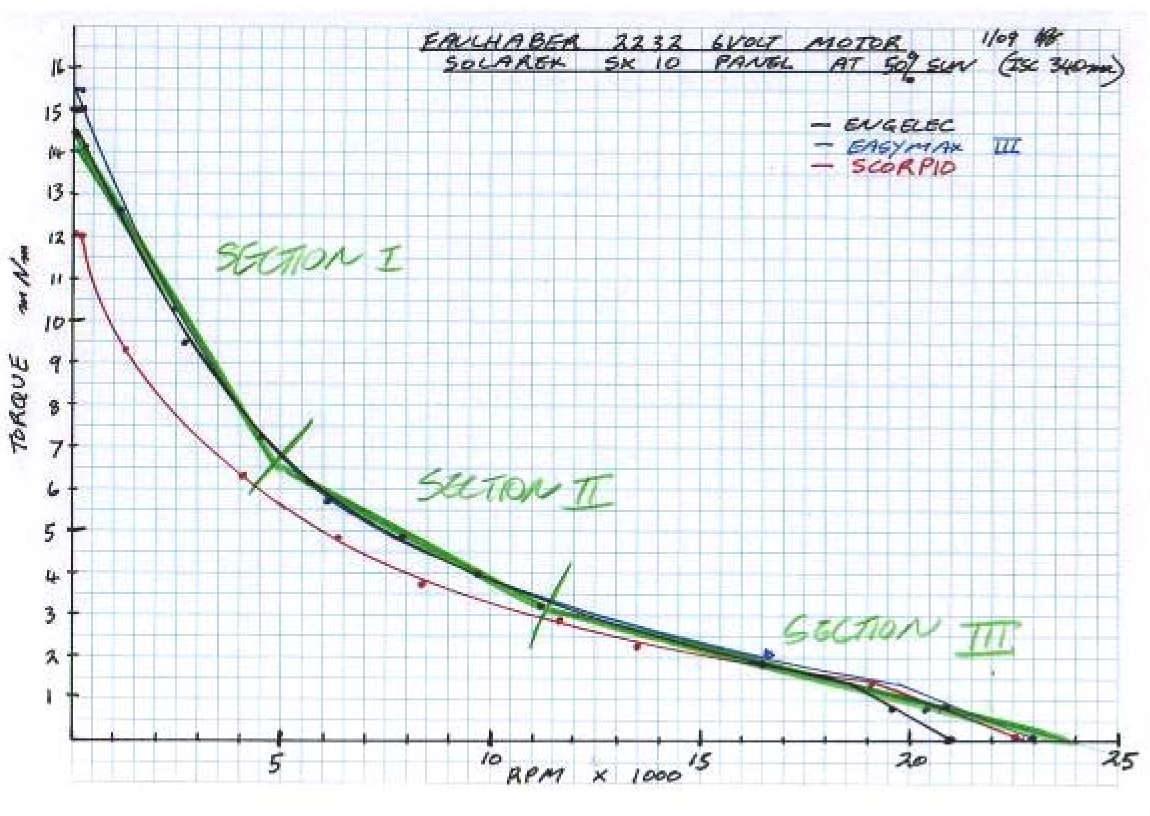
Into $$T = \frac{P}{2 \times \pi \times N}$$

Remember testing the motors at different sun levels is required as this is the only method provided for inputting different sun levels into this mathematical model.

HINT TO IMPROVE ACCURACY:
Using 3 straight line sections derived from a curved graph to input the data to the EXCEL model leads to inaccuracies. If you have good curve fitting software you could obtain the formula to the curve and input this formula into the EXCEL model. This would give virtually perfect results.

However sticking with the current 3 section method a significant improvement in accuracy can be easily obtained by extrapolating the graph section 2 to cross the axis thus effectively eliminating section3. This allows an additional section to be inserted in the middle portion of the graph.

See the marked up copy of a real dynamometer test below showing how it is done. The important thing you MUST remember is that you cannot in fact operate in the extended area as it is imaginary. The chances of this are very remote.



Graph of torque vs RPM with modified third section to improve accuracy. The new sections are shown in green. The imaginary section you must not Allow car operation in is from 20000 RPM upwards.

5 ROLLING RESISTANCE

Rolling resistance in the case of our model solar car comes from 2 sources. One is the wheels the other is the guide rollers. It has been assumed that rollers of some sort are used for guiding as using a guiding system without rollers would have significantly higher friction due to rubbing on the guide rail.

Firstly consider the rolling resistance due to the wheels on the track. This is made up of two components, friction in the bearings, and the resistance to the wheels rolling on the track surface. The component due to the wheels is the most significant; it increases significantly for wheels with tyres or wheels that are running on a soft surface. The reason is that tyres when loaded will have a flat spot on the bottom causing an effect similar to running up a slight hill, while a soft track will effectively allow the wheel to sink into a hole making this up hill effect even greater – imagine this as riding a bicycle on sand. Both these effects mean your wheel is constantly trying to climb a small hill.

Additional weight on the wheel will increase the resistance due to this effect.
For the low loads we are working with the bearing friction is not expected to alter significantly with weight change so we expect the total resistance to be a small constant due to bearing friction plus the additional wheel to track resistance which varies with wheel load.

The coefficient for the simulator is obtained from testing of your car.
Testing is simple place the car on a flat level surface and measure how much force is required to just start it rolling. Repeat this test at different car weights (ie. Add weights to the car.) take care to place the weights over the cars centre of gravity to maintain the wheel and bearing loads in the same ratio. (motor disconnected from drive wheel we wish to measure rolling resistance due to wheels and bearings only)
Graph the results of your test, car weight on the X axis and force to roll on the Y axis.
The slope of this graph in Newton per kg is the Roll CoEf: in the simulator.
(NOTE: depending on tyres and bearings the graph may not pass through the zero point but cross the Y axis up from zero this is not common but the **Wheel Roll RS: in the simulator is this crossing value.**)

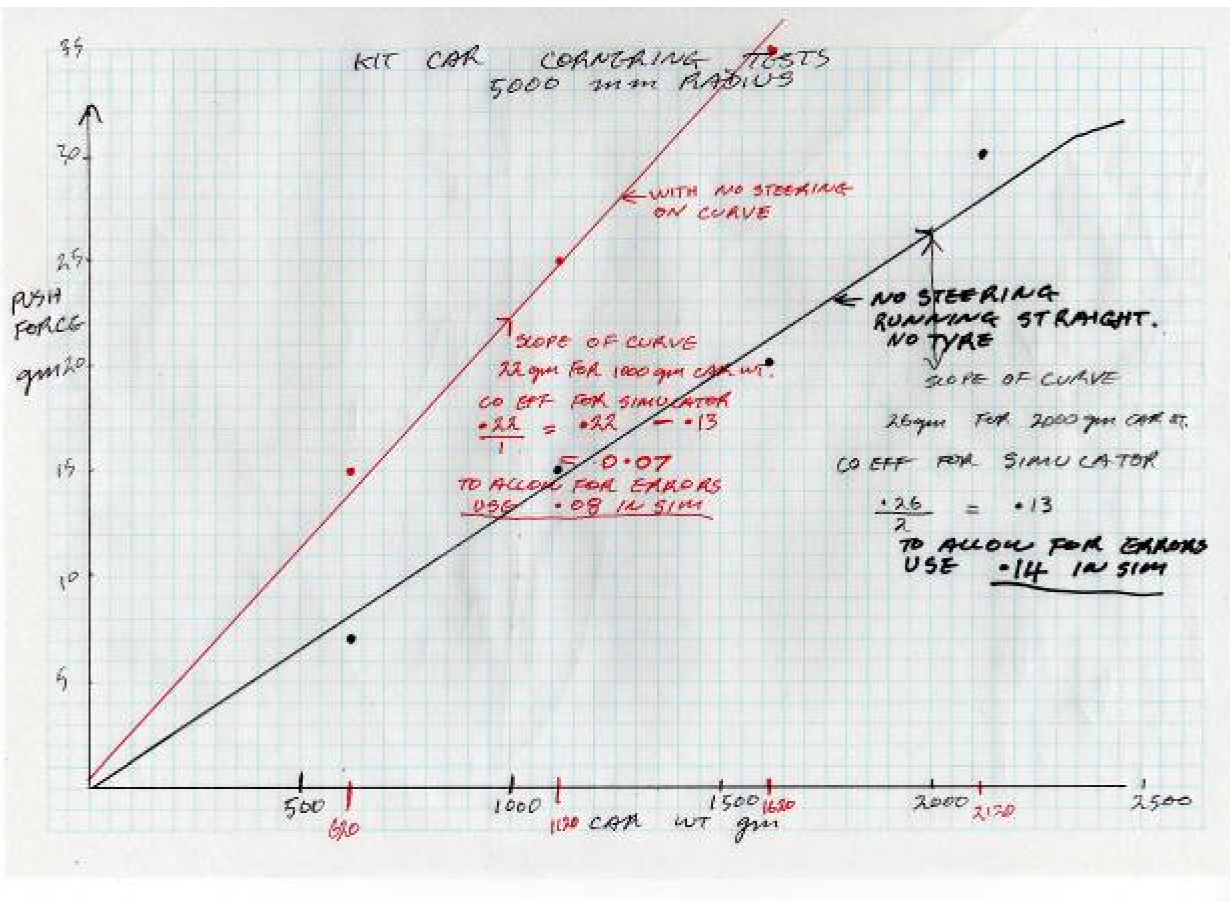
The Steering Drag , the additional drag which occurs when a car without steering is cornering (there is some side slip of wheels happening which increases the drag) is determined in the same way as the rolling resistance above except that the car is pushed around a corner of 5000 mm radius for the test.
Again graph the results on the same set of axes as the rolling resistance. **The difference between the slope of the graph for straight rolling resistance and the resistance around the curve is the Steering Drag: in the simulator again it is in Newton per kg.**

As a guide the results from testing the Sheridan Kit Car and associated graphs are shown below.

SHERIDAN KIT CAR ROLLING TEST RESULTS

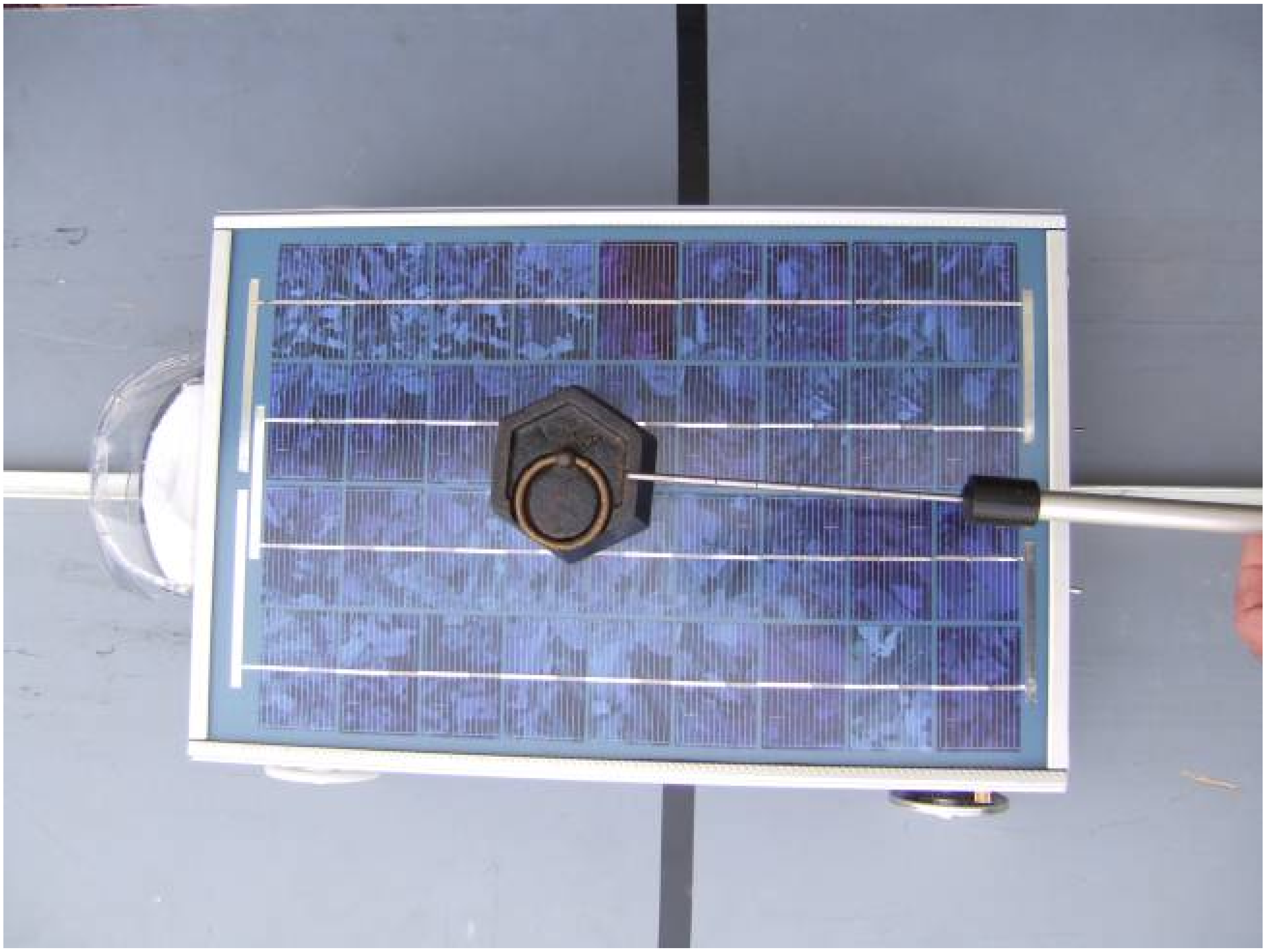
CAR WEIGHT gm.	FORCE TO ROLL gm.	
	ON STRAIGHT	AROUND CORNER
620	7	15
1120	15	25
1620	20	35
2120	30	40

GRAPHS OF THESE RESULTS ARE SHOWN IN GRAPH 2 BELOW.



GRAPH 2

To further assist understanding the photograph below shows testing set up on the car Photon Cruncher MK IV.



PHOTON CRUNCHER MK IV BEING PUSHED ON STRAIGHT TRACK SECTION NOTE ADDITIONAL WEIGHT ON SOLAR PANEL.

Determining the force to roll can be done with a spring balance , but take care that the balance you use maintains accuracy when horizontal. Otherwise a cord around a pulley to keep the spring balance vertical will be required. An option is tilting the surface the car is on, measuring the height it is lifted to just roll and calculating the force acting down the ramp due to gravity.

You should note that for this model we have assumed the wheel load to be constant as the car runs around the track. This is not exactly true. The wheel load is determined by the component of the gravity force which is normal to the track surface. This changes depending on position on the track – when the car is on a slope it is reduced slightly (see FIG 2). Since the hills are short compared to the track length and the slope fairly gentle we did not go to the trouble of including this change in the model.
There is also weight transfer to the outside wheels when cornering this too has been ignored.

The second portion of rolling resistance is due to the guide rollers on the guide rail. This force is acting mainly when the car is cornering, a well made car when running straight will have almost no contact with the guide rail.

Consequently we have considered this force to act only while the car is cornering.
The sideways force on the guide rollers can be quite high, we will assume the guide rollers take all the centrifugal force of cornering and none is taken by the wheels, (probably a reasonable assumption as the aluminium and plastic wheels have low friction on the track).

Centrifugal force (N) = Mass (kg) × angular velocity^2 (Radians) × Radius (m)

The force calculated above is the force acting on the guide rollers the force that is trying to slow the car down is due to the guide rollers rolling on the guide, just the same as wheels on the track. Except the force on the rollers is not just due to the cars weight the angular velocity around the corner together with the cars mass creates it .
Just as for the car on the track we will find the rolling coefficient of the guides on the guide rail and use it to calculate the retarding force.

Retarding Force = Coefficient × Mass × angular velocity^2 × Radius

Angular velocity is calculated from the velocity of the car and the radius of the curve.

$$\text{Angular velocity} = \frac{\text{Car velocity (m/s)}}{\text{Radius (m)}}$$

Substituting this angular velocity back into the previous formula the rolling resistance force due to the guide rollers on the guide rail becomes,

$$\text{Retarding Force (N)} = \frac{\text{Coefficient} \times \text{Mass (kg)} \times \text{Car Velocity}^2 \text{ (m/s)}}{\text{Radius of curve (m)}}$$

This coefficient is determined in the same way as the rolling resistance of the car on the track except it is for the guide rollers not the wheels. Consequently the test needs to be somewhat different. The test is conducted with the car hanging on its guide rollers on a nearly vertical section of track, this removes most of the effect of wheels on the track and the small wheel to track force is ignored.
Again graph the force to roll against weight, the slope of this graph is the Guide Roll CoEf: in the simulator. (it is a dimensionless quantity in the simulator)

PHOTON CRUNCHER MK IV IN POSITION FOR GUIDE ROLLER COEFFICIENT TESTING.

The Total Rolling Resistance is obtained by adding the resistance for the car on the track, the steering and the guide rollers together.

CALCULATING THE CAR'S PERFOMANCE

Having defined the main forces acting on the car, the performance can be calculated. By vector addition of the forces trying to drive the car forward and hold it back we obtain the resultant force acting in the direction of motion. This may be a positive force accelerating the car or a negative force decelerating the car.

This force is used in conjunction with the Newtonian Mechanics formulas to calculate the cars acceleration, velocity and distance travelled after a specified time. Remember the force acting varies with car velocity and position on the track, while the formulas used here assume the force is constant over the time interval chosen. Consequently our calculated results will be inaccurate, as the forces acting on the car are constantly changing, but for a short time interval the changes will be very slight. The inaccuracy will increase the longer the time interval used. We have chosen a short time interval of 0.05 seconds so reasonable accuracy is achieved.

At the end of each time interval the forces acting on the car are re-evaluated and used to calculate the performance for the next time interval. This iterative process is continued until the car has travelled the track length.

THE CALCULATIONS

The following method is used to calculate the car's performance.

1 DETERMINE THE RESULTANT FORCE ACTING ON THE CAR

Resultant force = Gravity + Air drag + Motor drive force + Rolling resistance
(the gravity force is the component acting up or down the hill see FIG 2)

NOTE: Standard Newtonian mechanics formulas are now used to calculate accelerations, velocities and distances travelled. Refer to standard texts for derivations and full explanations of their use.

2 CALCULATE THE ACCELERATION OF THE CAR

From Force (Newtons) = Mass (kg) × Acceleration (m/s^2)
Transforming this we get

Acceleration = Force / Mass

3 CALCULATE THE DISTANCE TRAVELLED
(This is the distance travelled in the time interval.)
We now substitute the acceleration calculated into the formula for distance travelled.
Distance travelled = Initial velocity × Time + 0.5 × Acceleration × Time^2

4 CALCULATE THE FINAL VELOCITY OF THE CAR

(This is the velocity at the end of the time interval.)

Final velocity squared = Initial velocity squared + 2 × Acceleration × Distance travelled

5 CALCULATE MOTOR RPM

(RPM at the end of the time interval)

Using the final velocity obtained from above the motor RPM is calculated

$$\text{RPM} = \frac{\text{Velocity (m/s)} \times 60000 \times \text{Gear ratio}}{\pi \times \text{Wheel Diameter (mm)}}$$

6 CALCULATE MOTOR DRIVE FORCE

Using the motor RPM from above and the Torque vs RPM graph for the motor at the sun level being considered, determine the motor torque as detailed previously.
Use this torque to calculate motor drive force as detailed previously. NOTE: the drive force is limited to the value determined in wheel slip testing by comparing the wheel slip force to the motor drive force and using the lower value.

7 CALCULATE AIR DRAG

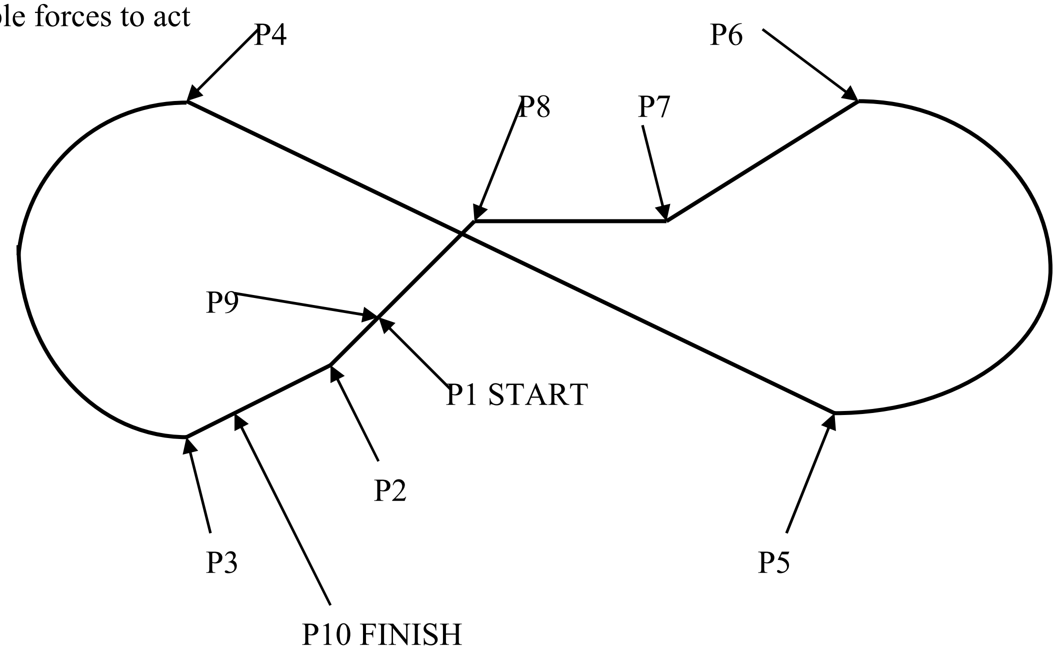
Use the final velocity to calculate the air drag as detailed previously.

8 REPEAT CALCULATIONS

Using the data calculated above, update the all the forces acting and re-evaluate the resultant force acting on the car. Repeat the calculations for the next specified time interval. Continue this cycle until the car has completed the course. By keeping a running total of time and distance travelled we know exactly where we are on the track at any time. Since the track is defined, logic statements based on distance are used to modify the gravity forces as we go up and down the hills and add the rolling resistances due to the corners. This process of calculating the conditions and position at the end of each short time interval is continued until the total distance travelled = track distance. The race is then over and the total of the time intervals is the time taken to complete the race.

TRACK LAYOUT

Below is a sketch of the track showing the distances over which we have allowed the variable forces to act



Position on track		**Cumulative distance from start (Meter)**	
		LAP 1	**LAP 2**
P1	Start	0.0	
P2	Bottom of start ramp	6.7	
P3	Start of first corner	14.0	100.42
P4	Finish of first corner	3 7.0	123.42
P5	Start of second corner	49.0	135.42
P6	Finish of second corner	72.0	158.42
P7	Base of hill	76.72	163.14
P8	Top of hill	84.92	171.34
P9	Start position distance after I lap	86.42	172.84
P2	Bottom of start ramp	92.12	178.54
P10	Finish line	100.03	186.45

FIG 4

NOTE: From version 1.2 onwards modifications are included to make the slope on the hill reflect the track as it is now after the 2005 upgrade. For simplicity the hill has been assumed to be formed by two straight sections meeting at the crest where in fact there is radius (of approximately 3.625 Metre) over the top section. The height of the hill is 445mm and it is 8500mm long on both sides of the crest.

SECTION 3

CONVERTING THE MODEL INTO EXCEL

A standard Excel spread sheet was created to perform the above calculations. Refer to the spread sheet: we will now detail each column of calculations.
The formulas and calculations used in the spread sheet are all detailed in the previous section. They have been transcribed into the format required by Excel and had the appropriate logic statements added to ensure the correct data is used in calculations.
The detailed formulas for each column can be viewed on the spreadsheet if desired.

Column A : A running total of elapsed time in 0.05 second intervals

=IF($B20>=100,A20,A20+0.05)

Column B : A running total of distance travelled in Meters

=IF(B20>100,B20,$B20+$C20*0.05+0.5*0.0025*$K20)

Column C : Velocity of car Meters / second

=SQRT($C20*$C20+2*$K20*($B21-$B20))

Column D : Motor RPM

=$C21/(3.1416*$B$10)*IF($L21>=1,$B$12,$B$11)*60000

Column E : Motor drive force Newtons. This section allows for 2 different gear ratios to be used – one lower ratio for initial acceleration then a change to a higher ratio at a nominated motor RPM. The logic statements in the Excel formula and the register column L allow this change to occur only once on initial rising motor RPM.
There is also a logic statement that limits the motor drive force to the value of the wheel slip force. (this added in Dec 06 see column M)

=$I21*2/$B$10*IF($L21>=1,$B$12,$B$11)*($B$13/100)

Column F : Air drag force Newtons

=B$9*$C21*$C21

Column G : Rolling resistance Newtons. This is the sum of car to track and guide roller resistance. It varies according to position on track ie. Guide roller resistance only operates during cornering. The effect of having steering active or not is included in this by adding the additional drag force which occurs during cornering when a steering system is not active.

```
=IF(OR(AND(B19>14,B19<37),AND(B19>49,B19<72)),$B$6*($B$7*C
19*C19)/5+$B$8+$D$8*$B$7+IF($D$9="Yes",0,$D$10*$B$7),$B$8+$
D$8*$B$7)
```

or the a two lap race a second sheet has been added, with logic statements to apply cornering resistance for the second lap at the appropriate distances, which is very similar to that shown above.

```
=IF(OR(AND(B2>100.42,B2<123.42),AND(B2>135.42,B2<158.42)),Sheet
1!$B$6*(Sheet1!$B$7*C2*C2)/5+Sheet1!$B$8+Sheet1!$D$8*Sheet1!$B$
7+IF(Sheet1!$D$9="Yes",0,Sheet1!$D$10*Sheet1!$B$7),Sheet1!$B$8+Sh
eet1!$D$8*Sheet1!$B$7)
```

Column H : Gravity force Newtons. This also varies according to position on track. It is positive while going down hill and negative when going up hill.

```
=IF(B20<6.7,0.445/8.5*B$7*9.81,IF(AND(B20>=6.7,B20<=76.72),0,IF(
AND(B20>76.2,B20<84.92),0.445/8.5*B$7*-
9.81,IF(AND(B20>=84.92,B20<=84.92),0,IF(AND(B20>84.92,B20<92.1
2),0.445/8.5*B$7*9.81,IF(B20>=92.12,0))))))
```

Similar to the rolling resistance formula this has been slightly modified for the second lap calculations and is shown below.

```
=IF(AND(B2>=92.12,B2<=163.14),0,IF(AND(B2>163.14,B2<171.34),0.
445/8.5*Sheet1!B$7*-
9.81,IF(AND(B2>=171.34,B2<=178.54),0.445/8.5*Sheet1!B$7*9.81,IF(
B2>=178.54,0))))
```

Column I : Motor torque milli Newton meters. This is calculated from the data entered detailing the torque vs RPM graph (see previous section).

```
=IF($D21<=$B$15,$C$15-$D$15*$D21,IF($D21<=$B$16,$C$16-
$D$16*($D21-$B$15),IF($D21<=$B$17,$C$17-$D$17*($D21-
$B$16),IF($D21>=$B$17+1,0))))
```

Column J : Acceleration force Newtons. This is the resultant force acting on the car (the vector addition of the forces acting in the direction of motion). It will cause acceleration if positive or deceleration if negative.

= $M20+$H20-$F20-$G20

Column K : Acceleration in m/s/s this is the acceleration caused by the force above.

=$J20/$B$7

Column L : A shift register created to allow the logic statements to control only one change of gear ratio.

=IF($D20>=$D$11,1+L20,0+L20)

Column M: Wheel slip drive force, this is the force at which the drive wheel slips on the track we compare the motor drive force to this force and use the lower value in determining the acceleration force in column J.

=IF(E20>=($D$6*$B$7),($D$6*$B$7),(E20)

SECTION 4

USING THE MODEL

The model is simple to use. Just enter your car's characteristics in the Parameters section. The results will be displayed in the Results area. For details of the cars performance as the race progresses just scroll down the spread sheet.

If you wish to use only one gear ratio set this ratio into both acceleration and run ratio areas.

When entering data to the motor torque and RPM section fill in all areas i.e. if you have a graph with only 2 straight line sections, divide one straight line section into 2 sections so you have data to enter into each area of the motor torque-RPM section.

You can customise the spread sheet to suit your own requirements. Full details of the calculations are detailed above which should allow you to perform modifications.

Below is a copy of the input output section of the simulator so you can see the layout, the data here is for a real car (PHOTON CRUNCHER MK IV) constructed from commercially available components.
Faulhaber motor, R&I Instrument and Gear Co. Gears ,wheels ,guides, bearings and retaining components, Solarex SX10 Solar Panel and Engelec Electronics.
Full details of this car are published earlier in this document.

Model Solar Car Simulator

Parameters				**Results**	
Car Name:	PC IV MODIFIED FOR WHEEL SLIP			**1 LAP RACE**	
Sun Power:	88% Sun Solarex SX 10			**Time:**	19.5
Motor Type:	Faulhaber 2232 6Volt Engelec Electronics			**Velocity:**	6.897
Guide Roll CoEf:	0.015	**Wheel Slip Coeff**	0.9	**Mtr RPM:**	14694
Mass(kg):	2.1			**Air Drag**	0.333
Wheel Roll RS:	0	**Roll CoEf:**	0.097	**Rolling R:**	0.2037
Air Drag Coefficient:	0.007	**Steering(Yes/No):**	NO	**Mtr Torque:**	4.008
Wheel Diameter(mm):	64	**Steering Drag(N):**	0.13		
Acceleration Gear Ratio:	7.14	**Change RPM:**	0	**2 LAP RACE**	
Final Gear Ratio:	7.14			**Time:**	31.9
Transmission Effy:	92			**Velocity:**	7.373
Motor Tourque:	**Finish RPM:**	**Start T(mNm):**	**Formula**	**Mtr RPM:**	15710
Section 1:	5600	17.8	0.001429	**Air Drag**	0.381
Section 2:	10300	9.8	0.00083	**Rolling R:**	0.2037
Section 3:	24000	5.9	0.000431	**Mtr Torque:**	3.570

ABOVE IS SIMULATOR INPUT OUTPUT PANEL FOR PHOTON CRUNCHER MK IV USING AN ALUMINIUM DRIVE WHEEL,NO TYRE.

Model Solar Car Simulator

Parameters				**Results**	
Car Name:	PC IV MODIFIED FOR WHEEL SLIP			**1 LAP RACE**	
Sun Power:	88% Sun Solarex SX 10			**Time:**	19.1
Motor Type:	Faulhaber 2232 6Volt Engelec Electronics			**Velocity:**	6.851
Guide Roll CoEf:	0.015	**Wheel Slip Coeff**	1.67	**Mtr RPM:**	14597
Mass(kg):	2.1			**Air Drag**	0.329
Wheel Roll RS:	0	**Roll CoEf:**	0.11	**Rolling R:**	0.231
Air Drag Coefficient:	0.007	**Steering(Yes/No):**	NO	**Mtr Torque:**	4.049
Wheel Diameter(mm):	64	**Steering Drag(N):**	0.13		
Acceleration Gear Ratio:	7.14	**Change RPM:**	0	**2 LAP RACE**	
Final Gear Ratio:	7.14			**Time:**	31.55
Transmission Effy:	92			**Velocity:**	7.319
Motor Tourque:	**Finish RPM:**	**Start T(mNm):**	**Formula**	**Mtr RPM:**	15594
Section 1:	5600	17.8	0.001429	**Air Drag**	0.375
Section 2:	10300	9.8	0.00083	**Rolling R:**	0.231
Section 3:	24000	5.9	0.000431	**Mtr Torque:**	3.620

ABOVE IS SIMULATOR INPUT OUTPUT PANEL FOR PHOTON CRUNCHER MK IV USING AN ALUMINIUM DRIVE WHEEL WITH A TYRE. (Tyre used is "O" ring BS032 fitted in a groove 0.050 inch deep)

DETAILS OF PARAMETERS ENTERED

Car Name, Sun Power, and Motor Type, identify the test conditions for future reference.

Guide Roll CoEf : this is the Coefficient determined empirically in Section 1 Part 4. Used to calculate the rolling resistance of the guide rollers.

Mass: The Mass of the car in kg.

Wheel Roll RS: Determined empirically see Section 1 Part 4 for details. Used to calculate the wheel rolling resistance on the track.

Roll CoEf Determined empirically see Section 1 Part 4 for details. Used to calculate the wheel rolling resistance on the track. (in conjunction with Wheel Roll RS above)

Air Drag Coefficient: Determined empirically see Section 1 Part 2 .Used to calculate the air drag on the car.

Wheel Diameter : The drive wheel diameter in mm .

Acceleration Gear Ratio: This gear ratio will be used in the calculations until the nominated motor RPM (Change RPM) is reached. The Final Gear Ratio is used thereafter. The ratio is a reduction ratio and only the reduction ratio number is entered. That is 9.5 to 1 reduction is simply entered as 9.5. If a gear change is not to be used this ratio must be set the same as the final gear ratio if best possible accuracy is to be obtained. (NOTE: even with the change RPM set at zero the first calculation will use the acceleration ratio.)

Change RPM: The motor RPM at which you nominate the gear change from the acceleration ratio to the Final Gear Ratio to take place. Once this change has occurred the car is locked into that ratio for the rest of the race simulation, no further gear changes are allowed for.

Final Gear Ratio: This is the gear ratio used for the remainder of the race after the change RPM has been reached. It is entered in the same format as the acceleration gear ratio.

Transmission Effy.: The efficiency of your transmission system between the motor and the drive wheel , an efficiency of 95% would be entered as 95. This efficiency must be measured by test if accuracy is to be achieved. Efficiencies in the order of 90% to 95% can be expected for a well adjusted single step gear reduction using precision gears.

Motor Torque: The torque vs RPM curve for the Faulhaber motors can be approximated to a graph with 3 straight line sections. The 3 Sections listed under this heading correspond to these sections. The RPM and Torque values entered allow the calculation of torque at any given RPM. Motor torque is used in calculating the motor drive force.

Wheel Slip Coefficient: Used in calculating the force at the wheel periphery at which the wheel slips on the track. IE. it is the maximum drive force the wheel can exert before wheel slip occurs. Determined by tow testing the car with the drive wheel locked and measuring the force required to cause the wheel to slip.
Caution it varies with wheel load, the calculations in the Simulator are based on the ratio of drive wheel load to total car weight remaining constant as car weight is changed. (This feature was added to the simulator because the electronics systems in use can result in motor torque values which cause wheel spin with consequent loss of drive.)

Steering(Yes/No): This sets the additional drag force which occurs during cornering when there is no steering either on or off.

Steering Drag(N): The amount of additional drag force in Newtons which occurs during cornering when the car has no steering. The magnitude of this additional drag force must be determined for your car by testing.

DETAILS OF RESULTS DISPLAYED

Results are displayed for both a single and two lap race.

Time: The total time in seconds taken for the car to complete the course.

Velocity: The velocity of the car in Meters per Second as it crosses the finish line.

Mtr RPM: The motor RPM as the car crosses the finish line.

Air Drag: The air drag force in Newtons acting on the car as it crosses the finish line.

Rolling R: The rolling resistance in Newtons acting on the car as it crosses the finish line.

Mtr. Torque: The torque in mNm being produced by the motor as the car crosses the finish line.

All the above results are displayed for both a single lap and two lap race . Remember the final series of races are two lap.

DATA TO ENABLE YOU TO USE THE SIMULATOR FOR EVALUATION

The simulator is loaded with data for the Car Photon Cruncher MKIV. This car was specifically constructed for use at workshops to demonstrate how easily a "good car" could be made from commercial components.
You should run the simulator with this cars data to get a feel for how it works and what use it will be to you as a design aid.
To help you we have Included here test results giving actual times recorded by this car on the Track.
Further results from Dynamometer testing are given in Appendix J.

PHOTON CRUNCHER MK IV SIDE VIEW

Note : the Engelec Electronics is mounted in the cockpit so it is visible.

PHOTON CRUNCHER MK IV REAR VIEW

Note: The drive wheel (left hand side) is the plastic version with an O ring tyre not the Aluminium drive wheel the test results are for.

TESTS ON PHOTON CRUNCHER MK IV

24/11/05 ON VICTORIAN TRACK AT SCIENCEWORKS

CAR CONFIGURATION:

MOTOR: Faulhaber 2232 6 Volt
DRIVE WHEEL : Aluminium no tyre.
ELECTRONICS: Box Hill V4.0 Programme 1.6
SOLAREX SX 10 Panel
FULL RACING WEIGHT : 2100 gm with wooden egg on board

SUN LEVEL %		TRACK TIME SEC.	
90		19.62	
80	Oct 08	20.27	
80	Oct 08 2nd lap ie flying 86 M	14.0	
62	Panel Covered	21.84	
		37.58	2 LAPS
30		28.2	
20	Panel Covered	36.98	

Additional information;

Tests performed on Victorian track as set up for the 2005 Nationals using the official timing system and solarometer.

The panel was covered with mylar drawing film to reduce sun levels for some tests (solarometer was also covered)

REVISIONS OF SIMULATOR AND DOCUMENTATION

Version 1.1: Steering option added
Version 1.2: Track parameters altered to reflect new shape hill after 2005 track upgrade.
Results now given for both a single and two lap race.
Version 1.3: Calculation time interval reduced from 0.1 sec to 0.05 sec.
Version 1.4 Modified to account for wheel spin.
Version 1.5 Additional mods for wheel spin. December 2006
January 08 Documentation revision (reflecting wheel slip coefficient changes)

APPENDIX I

HANDLING TIPS FOR BALL BEARINGS

While they are tough the small bearings typically used in Model Solar Cars are not indestructible. And in fact the general information presented here holds for large bearings as well. In ball bearings rolling of the balls carries the relative motion of the inner section of the bearing to the outer. Whereas in a sleeve type bearing this is a sliding action of two surfaces relative to each other. The rolling action has lower friction provided the surfaces are smooth. Typically bearings are produced with very fine tolerances and smooth operating surfaces.

If the loads being carried by the balls onto the races are too high the races and or balls will be damaged permanently by denting of the races and by producing small flats on the ball surface. The bearing will then run rough and friction will have gone up significantly. This type of damage can occur due to incorrect handling, usually during installation, or as the result of the car crashing. When mounting or dismounting bearings onto shafts or into housings NEVER push on the bearing in such a way that the assembly forces are carried through the balls. That is when mounting bearings into a housing only push on the outer. When mounting bearings on a shaft only push on the inner. If necessary make pushers to ensure the loading is correct. Mounting and dismounting forces are often high enough to damage bearings by denting the balls or races.
Be careful not to mount bearings into a housing that is too small or on a shaft that is too large, excessive forces on the bearings will deflect the bearing and reduce clearances which will increase bearing friction. I have seen a bearing mounted in a nylon wheel so tightly that the bearing had deformed to the point that it would not rotate.

Cleanliness and lubrication are also important. Cleanliness is obvious, shielded bearings will normally not suffer with dirt ingress in the relatively clean area of the track. Even open bearings give no trouble so long as a little care is taken in handling.
Lubrication is a little more tricky. Bearings are commonly supplied lubricated with grease (they may be ordered oil lubricated if required) .
We devised a test to give an indication as to the losses due to lubrication, it entailed mounting the bearings under test in a test wheel then spinning the wheel with a known amount of energy input. By counting the number of revolutions the wheel did before stopping a relative measure of the friction due to the lubricant was obtained. To input the energy the wheel had a pin on its periphery, the pin was aligned horizontally a 10 gm weight hung from it and the wheel let free to rotate. This always gave about the same energy input.

Two new bearings were tested and the following results obtained

As supplied	1.5 revolutions
Lubed with light clock oil	9 revolutions
Lubed with WD 40	26 revolutions initially
	12 after 20 minutes
Lubed with INOX	24 revolutions initially
	23 after 6 weeks

(INOX manufactured by Candan Industries distributed by Consolidated Bearing Co.)

From these results it is obvious that lubricant is important to bearing friction, but we need to be careful not to trick ourselves. Grease lubed bearings after some use will have spun the grease to the outer edges and give better results than shown here.
However having a known performance from the start is best for our Solar Car. The energy saving when comparing as supplied lubrication to INOX lubrication as measured by the technique described above is about 3 Joules over a complete race which for the car Enigma mentioned in Part F Car Performance represents about 3% of the total energy the panel could supply over the duration of a race in full Sun.

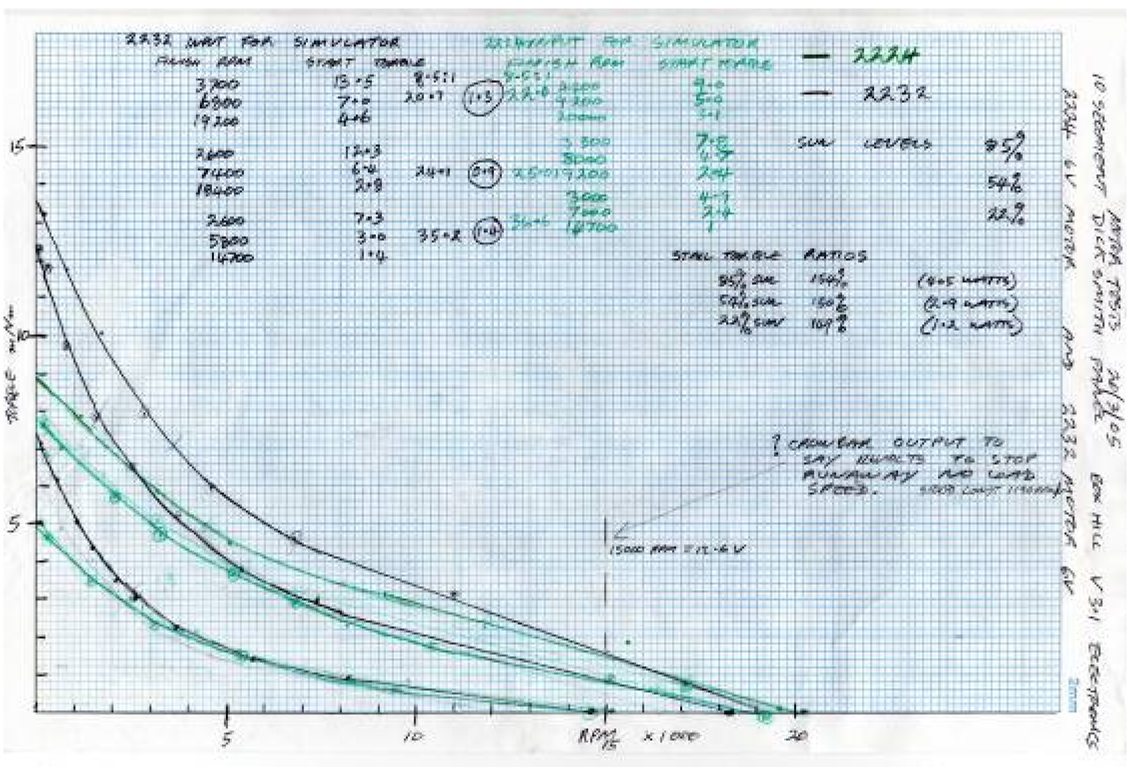
APPENDIX J

MOTORS & ELECTRONICS & DYNO 12/06

The purpose of this file is to gather all the basic current data on Motors , Electronics and Dynamometer testing of motors together.
The data presented here is relevant to new car design.

1 MOTORS:
Current thinking is, the best motor available is the Faulhaber 2232 6 Volt.
This is a 10 Watt motor with the same shaft size and mounting detail as the 2224 series which had previously been very popular. The 2232 however has a rotor resistance that better suits the characteristics of the typical electronics units being used , consequently its torque at low RPM is significantly higher resulting in better acceleration and faster race times.

Below is the graph of Torque vs RPM for both these motors.
These graphs were produced from data obtained in is the initial tests we performed to evaluate the suitability of the then new 2232 motor.
2224 6 Volt Motor Green graph   2232 6 Volt Motor Black graph
When these results were entered into the Mathematical Simulation, predictions were that by just changing motors from 2224 to 2232 a significant reduction in race time occurs.



Technical Data for these motors follows. These are copies of the manufacturers data sheets.

DC-Micromotors

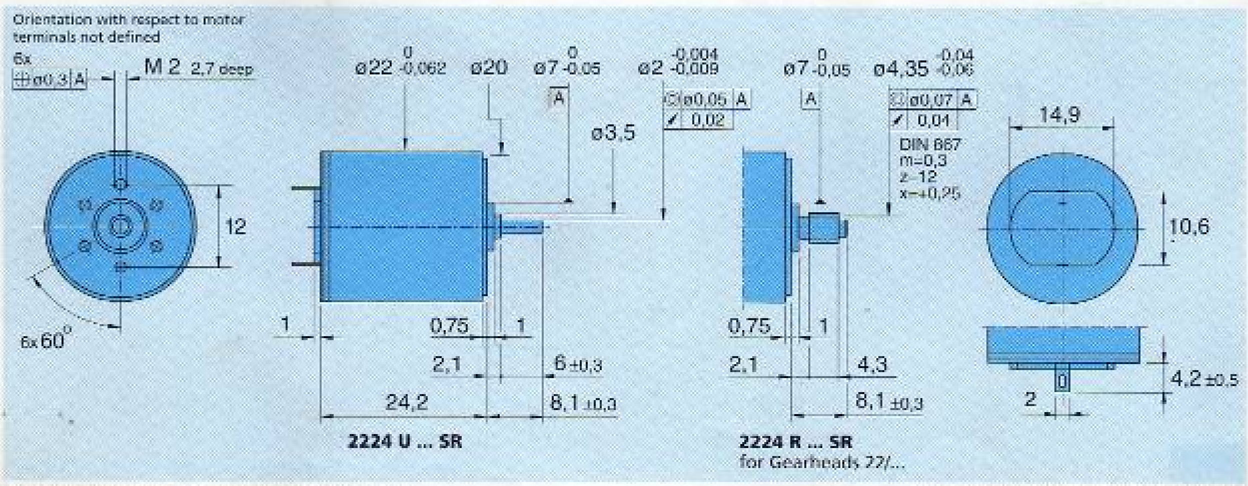
Precious Metal Commutation

4,2 Watt

For combination with:
Gearheads: 20/1, 22E, 22/2, 22/5, 22/6, 23/1, 38/3
Encoders: IE2

Series 2224 ... SR

		2224 U	003 SR	006 SR	012 SR	018 SR	024 SR	036 SR	
1	Nominal voltage	U_N	3	6	12	18	24	36	Volt
2	Terminal resistance	R	0,56	1,94	8,71	17,50	36,30	91,40	Ω
3	Output power	$P_{2\ max.}$	3,92	4,55	4,05	4,54	3,88	3,46	W
4	Efficiency	$\eta_{max.}$	80	82	82	82	81	80	%
5	No-load speed	n_o	8 100	8 200	7 800	8 100	7 800	7 800	rpm
6	No-load current (with shaft ø 2,0 mm)	I_o	0,066	0,029	0,014	0,010	0,007	0,005	A
7	Stall torque	M_H	18,5	21,2	19,8	21,4	19,0	16,9	mNm
8	Friction torque	M_R	0,23	0,2	0,2	0,21	0,2	0,22	mNm
9	Speed constant	k_n	2 730	1 380	657	454	328	219	rpm/V
10	Back-EMF constant	k_E	0,366	0,725	1,520	2,200	3,040	4,560	mV/rpm
11	Torque constant	k_M	3,49	6,92	14,50	21,00	29,10	43,50	mNm/A
12	Current constant	k_I	0,286	0,144	0,069	0,048	0,034	0,023	A/mNm
13	Slope of n-M curve	$\Delta n/\Delta M$	438	387	394	379	411	462	rpm/mNm
14	Rotor inductance	L	11	45	200	450	800	1 800	µH
15	Mechanical time constant	τ_m	11	11	11	11	11	11	ms
16	Rotor inertia	J	2,4	2,7	2,7	2,8	2,6	2,3	gcm²
17	Angular acceleration	$\alpha_{max.}$	77	78	74	77	74	74	·10³rad/s²
18	Thermal resistance	R_{th1} / R_{th2}	5 / 20						K/W
19	Thermal time constant	τ_{w1} / τ_{w2}	6,8 / 440						s
20	Operating temperature range:								
	– motor		– 30 ... + 85 (optional – 55 ... + 125)						°C
	– rotor, max. permissible		+125						°C
21	Shaft bearings		sintered bronze sleeves		ball bearings		ball bearings, preloaded		
22	Shaft load max.:		(standard)		(optional)		(optional)		
	– with shaft diameter		2,0		2,0		2,0		mm
	– radial at 3000 rpm (3 mm from bearing)		1,5		8		8		N
	– axial at 3000 rpm		0,2		0,8		0,8		N
	– axial at standstill		20		10		10		N
23	Shaft play:								
	– radial	≤	0,03		0,015		0,015		mm
	– axial	≤	0,2		0,2		0		mm
24	Housing material		steel, black coated						
25	Weight		46						g
26	Direction of rotation		clockwise, viewed from the front face						
Recommended values									
27	Speed up to	$n_{e\ max.}$	8 000	8 000	8 000	8 000	8 000	8 000	rpm
28	Torque up to	$M_{e\ max.}$	5	5	5	5	5	5	mNm
29	Current up to (thermal limits)	$I_{e\ max.}$	2,200	1,200	0,570	0,400	0,280	0,180	A



2224 U ... SR

2224 R ... SR
for Gearheads 22/...

FAULHABER

NEW

DC-Micromotors

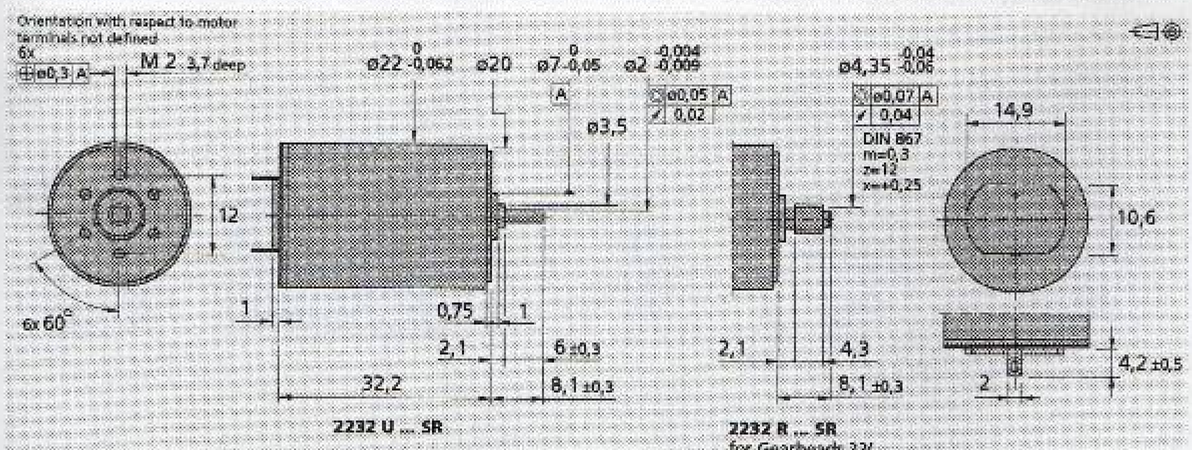
Precious Metal Commutation

10 mNm

For combination with
Gearheads:
20/1, 22E, 22/2, 22/5, 22/6, 23/1, 26A, 38/3
Encoders:
IE2 – 16 ... 512

Series 2232 ... SR

No.	2232 U		006 SR	009 SR	012 SR	015 SR	018 SR	024 SR	
1	Nominal voltage	U_N	6	9	12	15	18	24	Volt
2	Terminal resistance	R	0,81	2,14	4,09	6,61	9,04	16,4	Ω
3	Output power	$P_{2\,max.}$	11,0	9,35	8,70	8,41	8,86	8,68	W
4	Efficiency	$\eta_{max.}$	87	86	86	85	86	86	%
5	No-load speed	n_0	7 100	7 400	7 100	7 100	7 100	7 100	rpm
6	No-load current (with shaft ø 2,0 mm)	I_0	0,0350	0,0241	0,0175	0,0139	0,0116	0,0087	A
7	Stall torque	M_H	59,2	48,3	46,8	45,2	47,6	46,7	mNm
8	Friction torque	M_R	0,28	0,28	0,28	0,28	0,28	0,28	mNm
9	Speed constant	k_n	1 190	827	595	476	397	298	rpm/V
10	Back-EMF constant	k_E	0,84	1,21	1,68	2,10	2,52	3,36	mV/rpm
11	Torque constant	k_M	8,03	11,5	16,0	20,1	24,1	32,1	mNm/A
12	Current constant	k_I	0,125	0,087	0,062	0,050	0,042	0,031	A/mNm
13	Slope of n-M curve	$\Delta n/\Delta M$	120	153	152	157	149	152	rpm/mNm
14	Rotor inductance	L	45	90	180	280	400	710	µH
15	Mechanical time constant	τ_m	6	6	6	6	6	6	ms
16	Rotor inertia	J	4,8	3,8	3,8	3,8	3,8	3,8	gcm²
17	Angular acceleration	$\alpha_{max.}$	120	120	120	120	120	120	$\cdot 10^3$rad/s²
18	Thermal resistance	R_{th1} / R_{th2}	4 / 13						K/W
19	Thermal time constant	τ_{w1} / τ_{w2}	7 / 340						s
20	Operating temperature range:								
	– motor		– 30 ... + 85 (optional – 55 ... + 125)						°C
	– rotor, max. permissible		+ 125						°C
21	Shaft bearings		sintered bronze sleeves (standard)		ball bearings (optional)		ball bearings, preloaded (optional)		
22	Shaft load max.:								
	– with shaft diameter		2,0		2,0		2,0		mm
	– radial at 3 000 rpm (3 mm from bearing)		1,5		8		8		N
	– axial at 3 000 rpm		0,2		0,8		0,8		N
	– axial at standstill		20		10		10		N
23	Shaft play:								
	– radial	≤	0,03		0,015		0,015		mm
	– axial	≤	0,2		0,2		0		mm
24	Housing material		steel, black coated						
25	Weight		62						g
26	Direction of rotation		clockwise, viewed from the front face						
Recommended values									
27	Speed up to	$n_{e\,max.}$	8 000	8 000	8 000	8 000	8 000	8 000	rpm
28	Torque up to	$M_{e\,max.}$	10	10	10	10	10	10	mNm
29	Current up to (thermal limits)	$I_{e\,max.}$	1,87	1,30	0,94	0,74	0,63	0,46	A



For notes on technical data and lifetime performance refer to "Technical Information".

Specifications subject to change without notice.

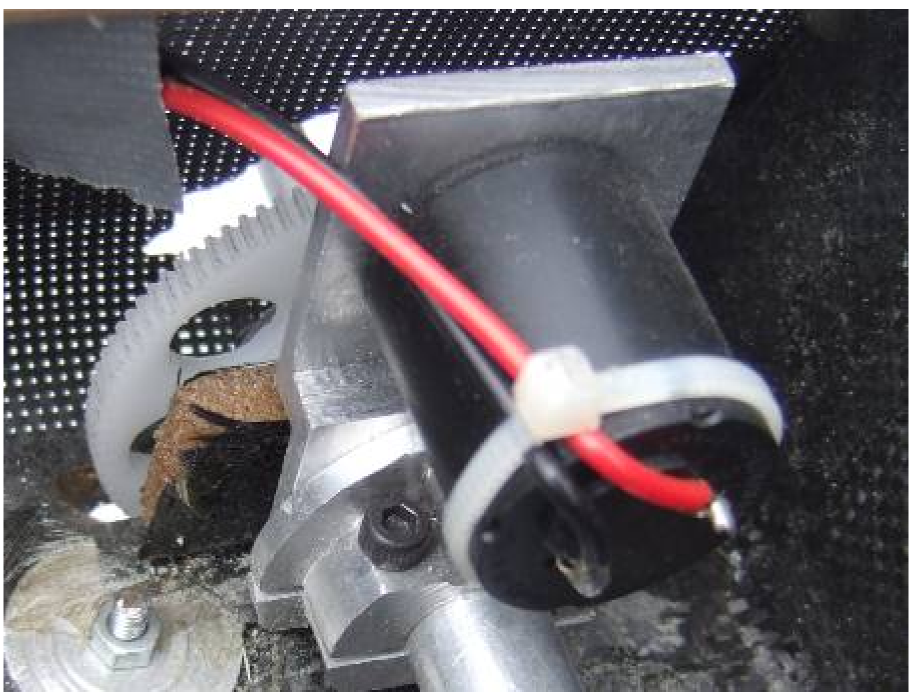
Edition 05.11.2008

PHOTOGRAPHS OF THE MOTORS FOLLOW

FAULHABER 2232 MOTOR

FAULHABER 2232 MOTOR DISASSEMBLED

SIZE COMPARISON 2232 LEFT & 2224 RIGHT



TYPICAL IN CAR MOUNTING 2224 MOTOR SHOWN

You MUST take some precautions when handling these motors. They are expensive high quality precision equipment. Careless handling can damage or destroy them. In particular :

- **Do not drop the motor.**
- **Take care connecting wires to the motor terminals they are small and thin and can be easily broken off if they are wobbled around. I suggest securing the wires as in the photograph above "Typical in car mounting"**
- **Do not push on the end of the motor shaft. Refer to the manufacturers data an axial load on the shaft must not exceed 20 Newton or motor damage is probable. The shaft is retained by the small brass ring which is pressed onto it. A load of over 20 Newtons and this ring will slip allowing the rotor to move back in the motor and destroy the brushes. SO DO NOT USE PUSH ON GEARS UNDER ANY CIRCUMSTANCES.**
- **Motor mounting screws must not be too long. There is only 4mm between the front face of the motor and the magnet inside (2232). If the mount screws enter too far and push on the magnet displacing it serious damage will result.**

2 ELECTRONICS:

There are a number of electronics units produced for model solar cars available on the market.
In 2006 Mr Stan Woithe in Adelaide had students test most of the units then available.
A report was written, I believe it is titled

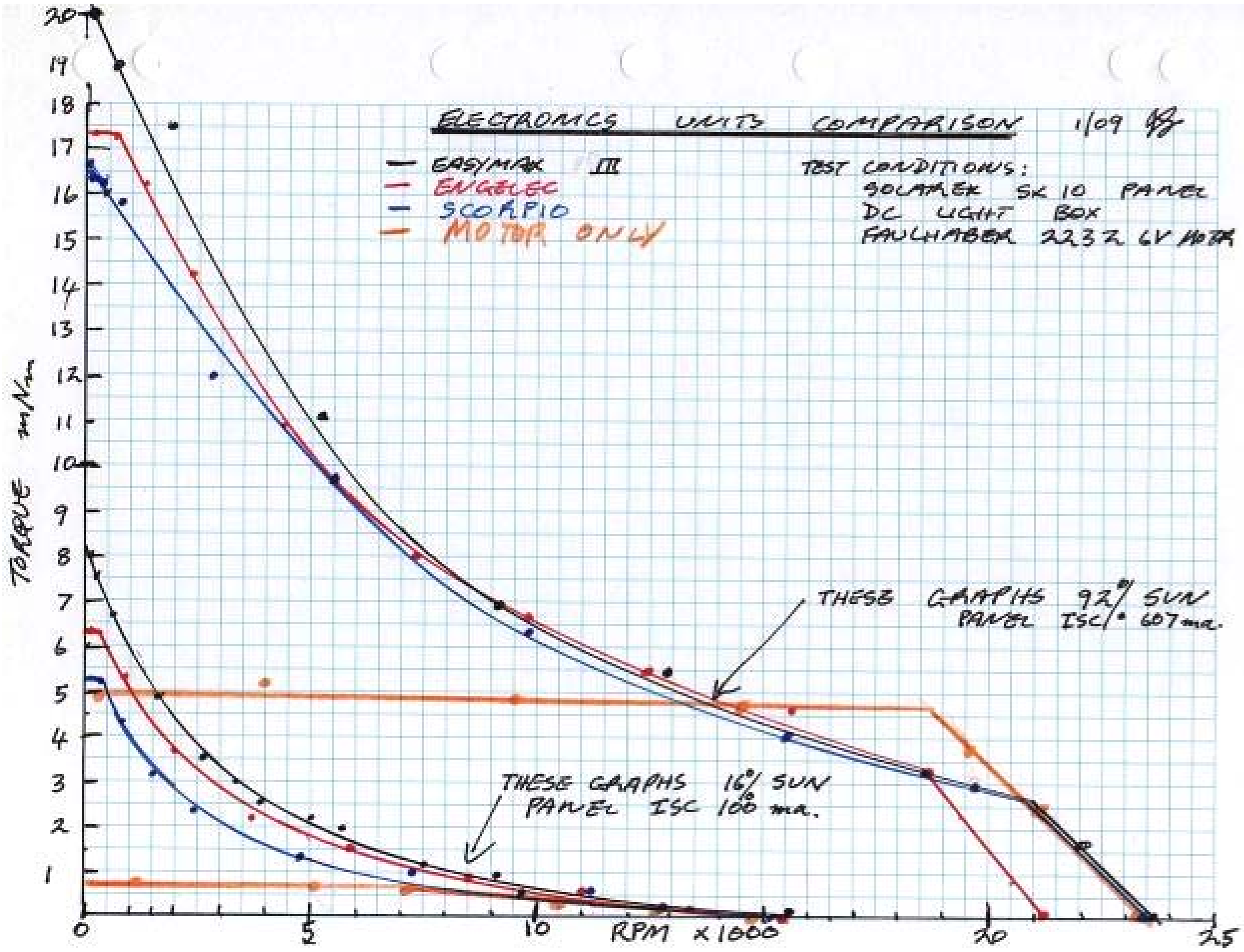
Solar Panel Power Controllers for Model Solar Cars

In the report conclusion it states----

The inclusion of a PPC unit on a model solar car is certainly worthwhile. However, the type of unit selected does not appear to be critical. All the units tested should perform satisfactory, provided they are properly made and correctly adjusted. Its more important to build a mechanically sound car with low chassis weight, low rolling resistance, good electrical wiring and low wind drag, than to be overly concerned about which PPC to use.

Refer to Section 8 ELECTRONICS for more details.
To compare some of the commercially available units I conducted Dynamometer tests on a Faulhaber 2232 6 Volt motor powered by each electronic unit in turn. The power source for the testing was a Solarex SX 10 solar panel illuminated with a DC light box. The load was a Faulhaber 2232 6 Volt motor.

The graphs below depict the Torque vs RPM data obtained from these tests



From examination of the graphs it can be seen that for this motor, allowing for experimental error in obtaining torque and RPM values, at 92% Sun there is little difference between units at speeds above about 7000 RPM.

The Easymax unit however gives the highest torque output when RPM is below about 7000 RPM.

At 16% Sun the Easymax III unit gives consistently higher torque output.

As from late 2010 the Automax became available it has the same performance characteristics as the Easymax III but automatically selects the operating point for maximum power.

When it became obvious that there is only a slight difference between the performance of the different electronics systems it was decided to put together a set of Dynamometer test results for a variety of solar panels. This would allow students to have immediate access to data that is fairly representative for initial use in the Mathematical Simulator without having to perform testing.

DO REMEMBER YOU MUST TEST YOUR PANEL MOTOR AND ELECTRONICS UNIT TO OBTAIN ACCURATE DATA FOR THE MATHEMATICAL SIMULATOR THIS DATA IS SUITABLE ONLY FOR PRELIMINARY INVESTIGATION.

These test results were compiled into a document which is copied below.

DYNAMOMETER TEST RESULTS --- GENERIC

Extensive testing of different ELECTRONICS systems for Model Solar Cars has indicated that there is only a small difference between them in terms of motor output so long as they are correctly adjusted according to the manufacturer's instructions.
NOTE: Unless otherwise noted this testing has been conducted with a FAULHABER 2232 6 VOLT motor , using the Solar Panels nominated.
Results for other combinations are unknown but we suspect they will be similar.

Based on the above tests and observations the following tables of motor output for various solar panels has been assembled.
The intent was to produce a set of tables giving motor output data that can be inputted to the Mathematical Simulator allowing initial predictions of car performance to be made without having to perform motor tests.
For more accurate predictions of performance you **MUST** have test results that are **specific to your particular motor and solar panel**. Just as **you MUST have tested your car** to obtain the other parameters such as rolling resistance etc. if you want the best possible accuracy in your predictions.

I strongly suggest that you do not use the results in the tables below but go to the original graphs that these figures were taken from and determine the torque and RPM data yourself.
When determining the figures to use you should use the revised technique for selecting RPM and torque values described in section 5 of the Mathematical Simulation Instructions. This will increase accuracy of the results.

ELECTRONICS UNITS TESTED:

ENGELEC MAX 4
EASYMAX III
SCORPIO
BOX HILL HIGH SCHOOL
V 2
V 4.1 Programme 1.6

RESULTS FOR SOLAREX SX 10 PANEL: (9.8 W at 100% Sun)

PANEL ISC	SUN %	SECTION 1 START	SECTION 1 FINISH	SECTION 2 START	SECTION 2 FINISH	SECTION 3 START	SECTION 3 FINISH

		TORQUE	RPM	TORQUE	RPM	TORQUE	RPM
600	88	17.8	5600	9.8	10300	5.9	24000
500	74	16.6	4800	9.0	10300	4.8	24000
400	59	15.1	4200	8.0	9600	3.8	23500
300	44	12.5	4900	5.0	10200	2.4	23500
200	28	10.0	2600	5.0	7200	2.0	18000
100	14	5.4	1500	2.8	6100	0.8	12000

RESULTS FOR 9 DICK SMITH SEGMENTS:

(6.16 W at 100% Sun)

PANEL ISC	SUN %	SECTION 1 START TORQUE	SECTION 1 FINISH RPM	SECTION 2 START TORQUE	SECTION 2 FINISH RPM	SECTION 3 START TORQUE	SECTION 3 FINISH RPM
450	80	15.3	3600	8.4	9000	4.2	18200
280	50	12.0	5000	4.5	10300	2.1	17200
110	20	7.2	2900	2.6	9200	0.6	15200

RESULTS FOR 10 DICK SMITH SEGMENTS:

(6.86 W at 100% Sun)

PANEL ISC	SUN %	SECTION 1 START TORQUE	SECTION 1 FINISH RPM	SECTION 2 START TORQUE	SECTION 2 FINISH RPM	SECTION 3 START TORQUE	SECTION 3 FINISH RPM
450	80	16.0	7500	6.0	16500	2.5	20500
		3.6	10000	3.0	16500	2.6	20500
280	50	12.5	8500	3.0	16600	1.0	19500
		2.3	10000	1.7	16500	1.2	19500
110	20	6.5	4000	2.0	11000	0.5	16200
		0.9	5000	0.7	10500	0.65	16200

Figures in RED are for NO Electronics.

RESULTS FOR 11 DICK SMITH SEGMENTS:

(7.56 W at 100% Sun)

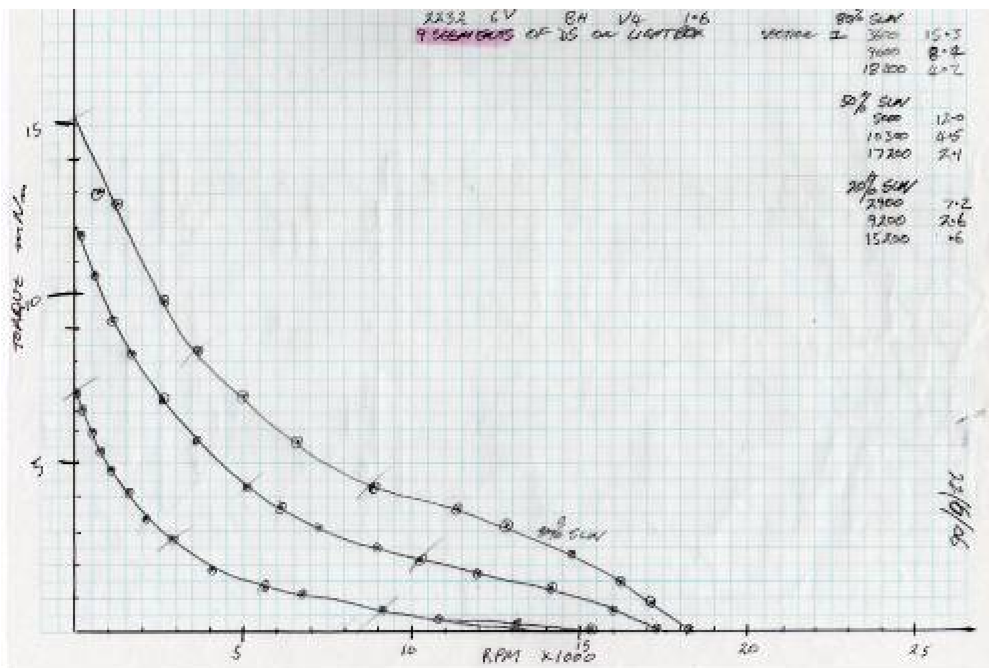
PANEL ISC	SUN %	SECTION 1 START TORQUE	SECTION 1 FINISH RPM	SECTION 2 START TORQUE	SECTION 2 FINISH RPM	SECTION 3 START TORQUE	SECTION 3 FINISH RPM
450	80	16.0	7500	6.0	18000	2.0	22200
280	50	13.5	6300	4.0	19000	1.0	21500
110	20	8.0	3500	2.0	13000	0.6	16800

RESULTS FOR 12 DICK SMITH SEGMENTS:

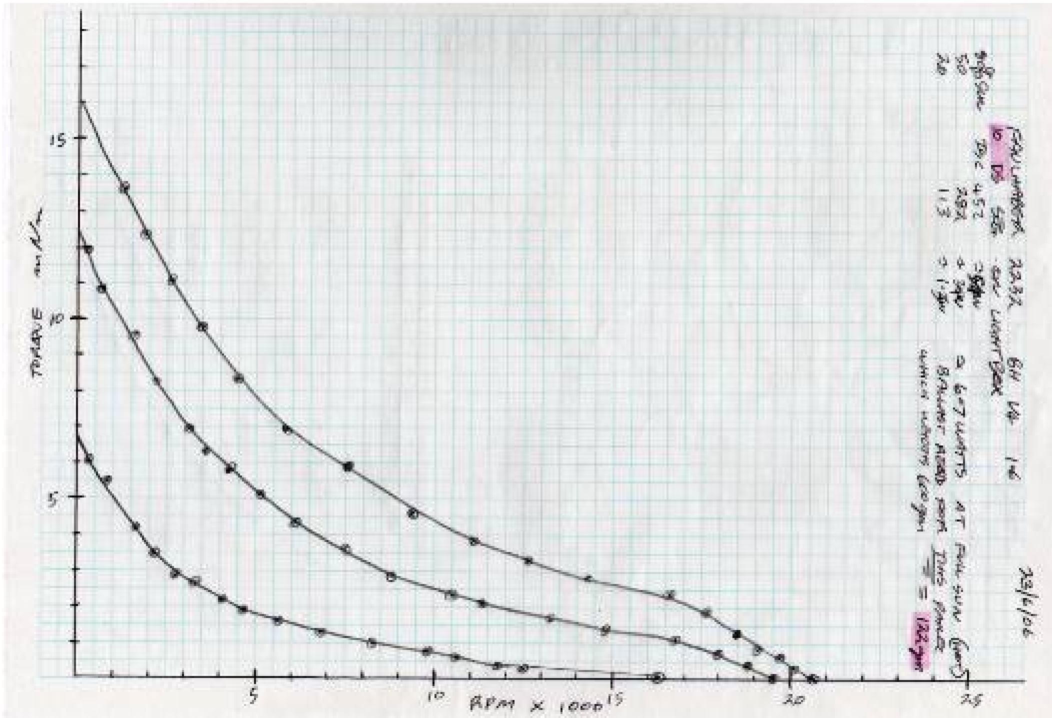
(8.26 W at 100% Sun)

PANEL ISC	SUN %	SECTION 1 START TORQUE	SECTION 1 FINISH RPM	SECTION 2 START TORQUE	SECTION 2 FINISH RPM	SECTION 3 START TORQUE	SECTION 3 FINISH RPM
450	80	18.0	9000	5.0	20000	2.0	23500
280	50	14.5	8000	4.5	19500	1.0	22500
110	20	8.0	5000	2.0	12000	0.6	16500

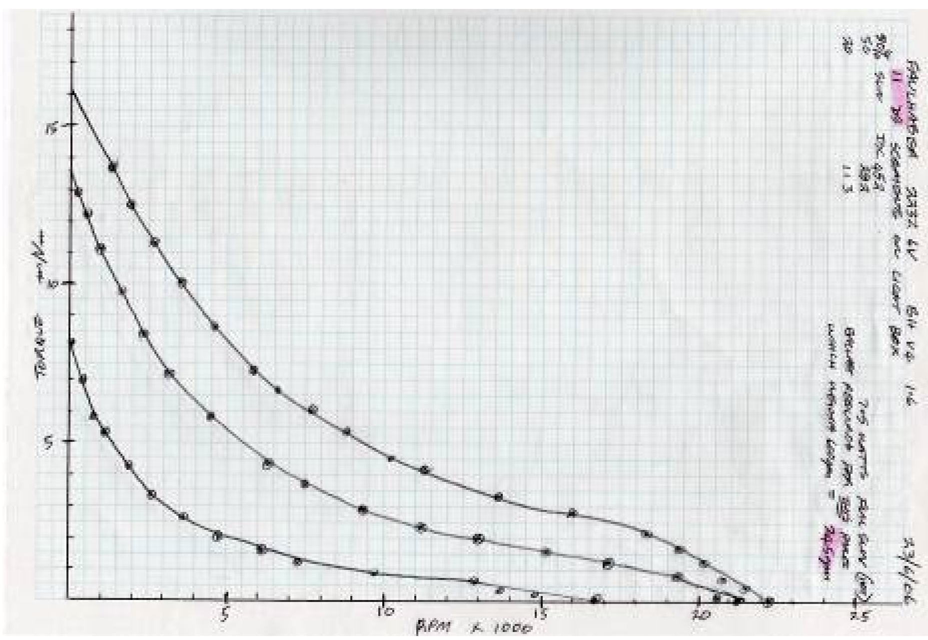
THE ORIGINAL GRAPHS OF TORQUE VS RPM THE ABOVE DATA WAS TAKEN FROM ARE COPIED BELOW FOR INFORMATION.



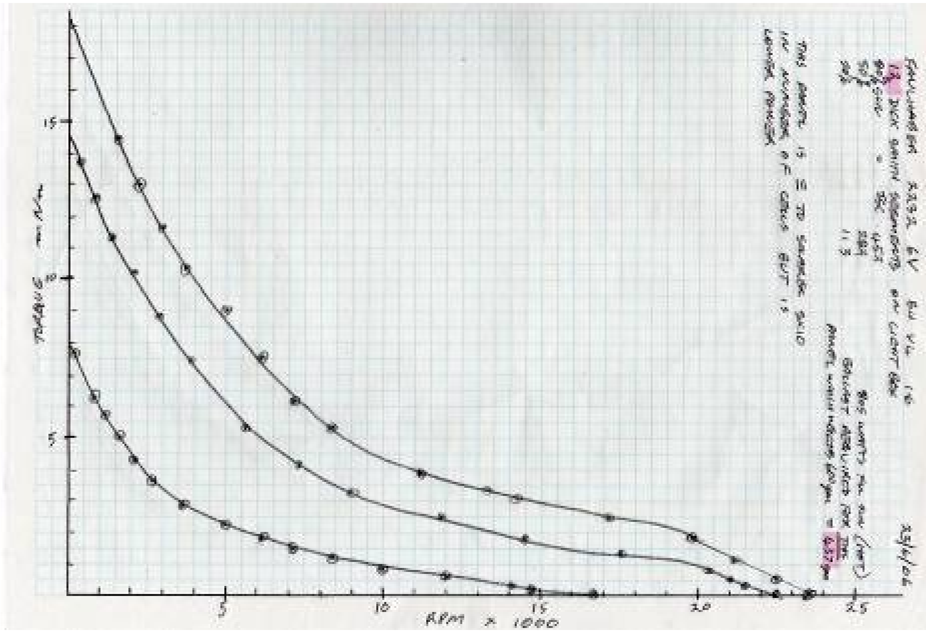
9 Dick Smith Segments



10 Dick Smith Segments



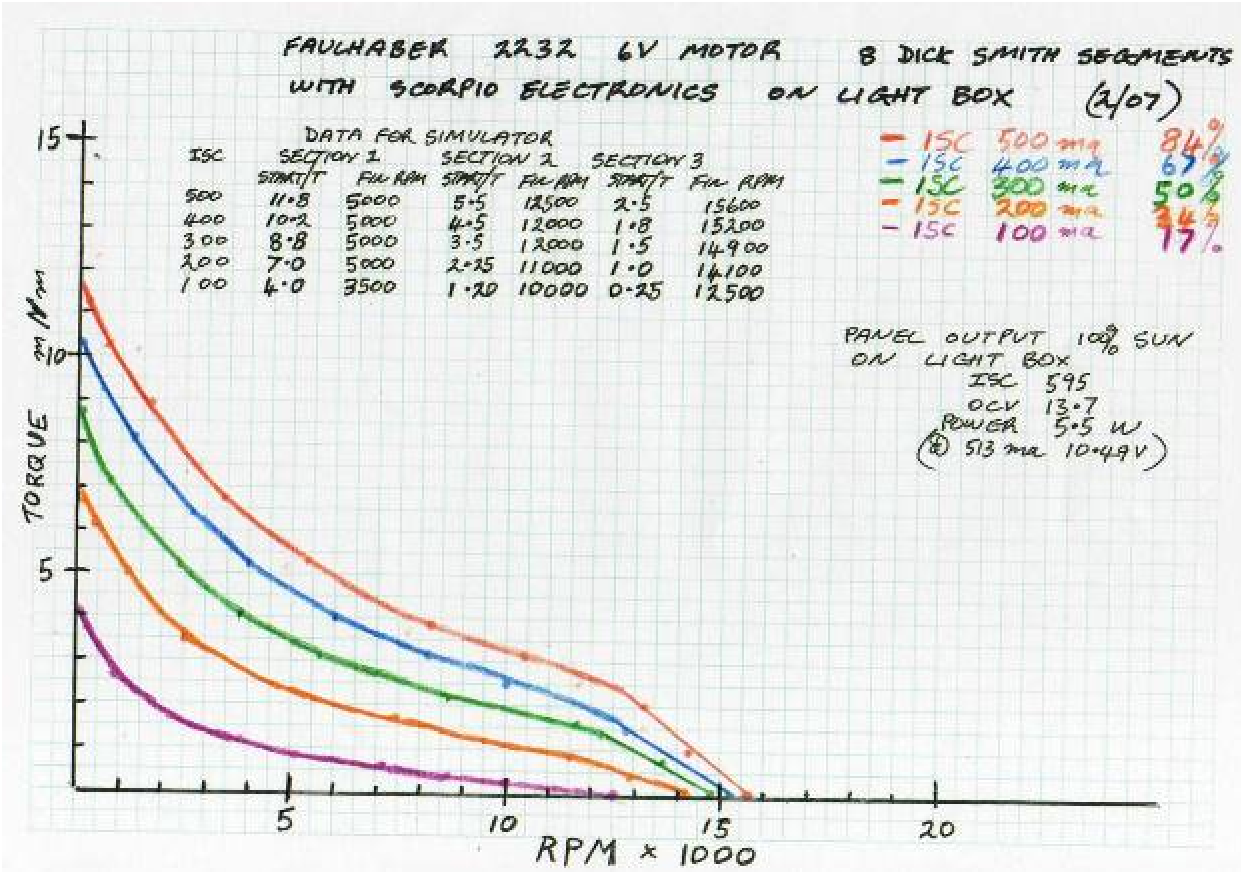
11 Dick Smith Segments



12 Dick Smith Segments

NOTE: The Dick Smith Segments used in the above tests were the 3 cell type with a nominal 1.5 Volt and 500 mA output in full sun Dick Smith Cat. No. and O 2015
For rough calculations you can use the following—Power output per 3 cell segment in full sun 0.7 Watts at a voltage of 1.38 Volts per segment.
As segments vary in performance you MUST test your own panel to obtain accurate data.

ADDITIONAL TESTING:
To provide data for Kit Cars 8 Dick Smith Segments were tested with a Scorpio electronics system. The results are shown below.


FAULHABER 2232 6V MOTOR 8 DICK SMITH SEGMENTS
WITH SCORPIO ELECTRONICS ON LIGHT BOX (2/07)
DATA FOR SIMULATOR
ISC SECTION 1 SECTION 2 SECTION 3
START/T FIN RPM START/T FIN RPM START/T FIN RPM
500 11·8 5000 5·5 12500 2·5 15600
400 10·2 5000 4·5 12000 1·8 15200
300 8·8 5000 3·5 12000 1·5 14900
200 7·0 5000 2·25 11000 1·0 14100
100 4·0 3500 1·20 10000 0·25 12500
ISC 500 ma 84%
ISC 400 ma
ISC 300 ma 50%
ISC 200 ma
ISC 100 ma 17%
PANEL OUTPUT 100% SUN
ON LIGHT BOX
ISC 595
OCV 13·7
POWER 5·5 W
(@ 513 ma 10·49V)
TORQUE
15
10
5
20
RPM × 1000

ADDITIONAL DYNAMOMETER TEST DATA

The following dynamometer test data was gathered during testing of electronics systems undertaken in December 2008. I have not yet produced graphs but present the data here for anyone who may wish to make use of it.
Note: There may be a few rogue readings where I misread or incorrectly recorded data these will be obvious when you graph the data, just ignore them. This data is all from a Solarex SX 10 panel.

DYNAMOMETER TEST RESULTS 12/08
ENGELEC MAX 4

These tests were performed to evaluate the performance of various electronics units.
Test set up used:

- SOLAREX SX 10 Solar Panel.
- DC Light Box to illuminate panel.
- Electronics unit under test.
- Dynamometer with Faulhaber 2232 6Volt motor.
  (See details in Design Hints)

Test conditions:

Sun Level % 92 %
Panel ISC 607 ma.
Electronics set Voltage 16 Volts
Short Circuit Current into Fluke Meter 3.82 Amps

Torque mNm	RPM
	21060 Running Free
0.8	20500 Start Temp 26 Deg C
2.2	19400
3.2	18600
4.7	15600
5.5	12400
6.7	9800
7.3	8000
8.0	7000
10.8	4400
14.3	2400
16.2	1350
17.3	700
17.8	300
17.3	73
17.5	60 Finish Temp 45 Deg C

Test conditions:
Sun Level % 50 %
Panel ISC 341 ma.
Electronics set Voltage 16 Volts.

Torque mNm	**RPM**
	21000 Running Free
0.7	19600 Start Temp 23 Deg C
1.8	16500
3.3	11200
4.8	7800
6.2	5600
7.2	4500
9.5	2680
12.7	1200
14.2	270
14.5	90 Finish Temp 32 Deg C

Test conditions:
Sun Level % 16 %
Panel ISC 99 ma.
Electronics set Voltage Automatic 15.7 Volts.

Torque mNm	**RPM**
	15400 Running Free
0.2	13150 Start Temp 23 Deg C
0.6	11000
0.9	8500
1.5	5850
2.2	3680
3.6	2000
5.3	980
6.3	350
6.3	150
6.1	100 Finish Temp 31 Deg C

DYNAMOMETER TEST RESULTS 12/08
FAULHABER 2232 6 VOLT MOTOR

The tests were carried out in exactly the same way and using the same equipment as the previous tests on the Faulhaber Motor. This test was with the motor direct on panel with NO electronics .

- SOLAREX SX 10 Solar Panel.
- DC Light Box to illuminate panel.
- Electronics unit. NONE USED DIRECT ON PANEL.
- Dynamometer.

Test conditions:

Sun Level % 92 %
Panel ISC 607 ma.

Torque mNm	**RPM**
	23400 Running Free
2.5	21200 Start Temp 30 Deg C
3.6	19600
4.6	14500
4.9	9500
5.2	4000
4.9	250

Test conditions:

Sun Level % 50 %
Panel ISC 350 ma.

Torque mNm	**RPM**
	22000 Running Free
0.2	22000 Start Temp 30 Deg C
0.5	21500
1.0	20800
1.4	19900
2.0	17800
2.2	12000
2.6	8600
2.7	4000
2.9	900 Finish Temp 40 Deg C

Test conditions:

Sun Level % 16 %

Panel ISC 100 ma.

Torque mNm	RPM
	14600 Running Free
0.2	13300 Start Temp 26 Deg C
0.3	12800
0.4	10500
0.6	7100
0.65	5600
0.8	1200 Finish Temp 34 Deg C

DYNAMOMETER TEST RESULTS 12/08
4.5 VOLT MAXON MOTOR

This test was performed to evaluate the performance of the 4.5 Volt MAXON Motor compared to the Faulhaber 2232 6 Volt Motor.
The tests were carried out in exactly the same way and using the same equipment as the previous tests on the Faulhaber Motor. This test was with the motor direct on panel with NO electronics .

- SOLAREX SX 10 Solar Panel. **** Not the same panel as used for all other tests, this panel can be configured in series and parallel and for these tests was set up with two sections paralleled to give ½ the voltage and twice the current when compared to a standard panel.
- DC Light Box to illuminate panel.
- Electronics unit. NONE USED DIRECT ON PANEL.
- Dynamometer with MAXON 4.5Volt motor. (Motor free running current 0.040 Amps.)

Test conditions:

Sun Level % 92 %

Panel ISC 1200 ma. OCV 10.39 V

Note: During testing of this motor extreme care was taken so as not to damage the Motor, RPM was limited to < 12000 and long cool down periods were allowed between tests.

Torque mNm	**RPM**
	11600 Running Free
0.3	11400 Start Temp 25 Deg C
2.5	10800
8.3	8500
Motor stalled with slight load increase	Finish Temp 32 Deg C

Test conditions:

Sun Level % 50 %

Panel ISC 707 ma.   OCV 9.79 V

Torque mNm	RPM
	11100 Running Free
1	10800 Start Temp 28 Deg C
3.5	9920
6.0	7300
7.0 Slowed Down to Stall	

Test conditions:

Sun Level % 16 %

Panel ISC 200 ma. OCV 8.88 V

Torque mNm	RPM
	9480 Running Free
0.3	8900 Start Temp 29 Deg C
0.8	8150
1.2	6300
1.8 Motor Stalled	

DYNAMOMETER TEST RESULTS 12/08

SCORPIO

These tests were performed to evaluate the performance of various electronics units.
Test set up used:

- SOLAREX SX 10 Solar Panel.
- DC Light Box to illuminate panel.
- Electronics unit under test.
- Dynamometer with Faulhaber 2232 6Volt motor.
  (See details in Design Hints)

Test conditions:

Sun Level % 92 %
Panel ISC 607 ma.
Electronics set Voltage 16 Volts
Short Circuit Current into Fluke Meter 2.89 Amps

Torque mNm	**RPM**
	23400 Running Free
3.0	19700 Start Temp 26 Deg C
4.0	15500
6.3	9900
6.7	9000
9.7	5500
12.0	2800
15.8	740
16.0	420
16.5	127
16.8	70 Finish Temp ? Deg C

Test conditions:

Sun Level % 50 %
Panel ISC 341 ma.
Electronics set Voltage 16.0 Volts.

Torque mNm	**RPM**
	22500 Running Free
0.8	20900 Start Temp 25 Deg C
1.3	19100
2.2	13500
2.8	11600
3.7	8400
4.8	6400
6.3	4100
9.3	1340
12.0	227
12.2	70 Finish Temp 34 Deg C

Test conditions:

Sun Level % 16 %
Panel ISC 99 ma.
Electronics set Voltage 16.0 Volts.

Torque mNm	**RPM**
	15200 Running Free
0.2	12800 Start Temp 26 Deg C
0.6	11000
1.0	7300
1.3	4750
2.4	2400
3.1	1500
4.3	850
5.2	400
5.5	230
5.5	100
5.5	60 Finish Temp 33 Deg C

DYNAMOMETER TEST RESULTS 1/09
EASYMAX III

These tests were performed to evaluate the performance of various electronics units.
Test set up used:

- SOLAREX SX 10 Solar Panel.
- DC Light Box to illuminate panel.
- Electronics unit under test.
- Dynamometer with Faulhaber 2232 6Volt motor.
  (See details in Design Hints)

Test conditions:

Sun Level % 92 %
Panel ISC 607 ma.
Electronics set Voltage Automatic 17.6 Volts

Torque mNm	RPM
	23700 Running Free
1.7	22000 Start Temp 22 Deg C
3.3	18600
5.5	12900
6.8	9200
11.2	5300
17.5	1800
19.0	780
21.2	240
20.0	190
	34 Finish Temp 32 Deg C

Test conditions:

Sun Level % 50 %
Panel ISC 341 ma.
Electronics set Voltage Automatic 17.8 Volts.

Torque mNm	**RPM**
	23000 Running Free
0.7	20400 Start Temp 15 Deg C
2.2	15600
4.0	9700
5.7	6170
10.2	2400
15.5	200
15.5	96 Finish Temp 22 Deg C

Test conditions:

Sun Level % 16 %
Panel ISC 99 ma.
Electronics set Voltage Automatic 14.6 Volts.

Torque mNm	**RPM**
	15600 Running Free
0.5	9700 Start Temp 24 Deg C
1.0	9300
1.2	7500
1.3	7300
2.0	5700
2.2	5050
2.5	3900
3.0	3400
3.5	2600
4.8	1600
6.7	650
7.5	250
8.0	80 Finish Temp 26 Deg C

DYNAMOMETER TEST RESULTS 1/09

EASYMAX

These tests were performed to evaluate the performance of various electronics units.
Test set up used:

- SOLAREX SX 10 Solar Panel IN PARALLEL .
- DC Light Box to illuminate panel.
- Electronics unit under test.
- Dynamometer with MAXON 4.5 Volt motor.
  (See details in Design Hints)

Test conditions:

Sun Level % 92 %
Panel ISC 1234 ma. OCV 10.44 Volts
Electronics set Voltage Automatic 8.9 Volts

Torque mNm	**RPM**
	11300 Running Free
4.2	10380 Start Temp 24 Deg C
9.2	7100
15.5	3780
20.7	2270
25.7	1240 Finish Temp 34 Deg C
29.6	940
32.1	540
34.6	180
34.9	105
35.3	40 Finish Temp 32 Deg C

Test conditions:

Sun Level % 50 %
Panel ISC 691 ma. OCV 10.4 Volts
Electronics set Voltage Automatic 8.96 Volts.

Torque mNm	RPM
	11200 Running Free
3.5	9650 Start Temp 17.5 Deg C
4.8	7380
6.8	5500
7.5	4520
11.0	2902
15.3	1800
17.8	1180
20.3	860
21.7	635
23.0	450
23.4	320
24.6	184
25.3	80 Finish Temp 28 Deg C

APPENDIX K

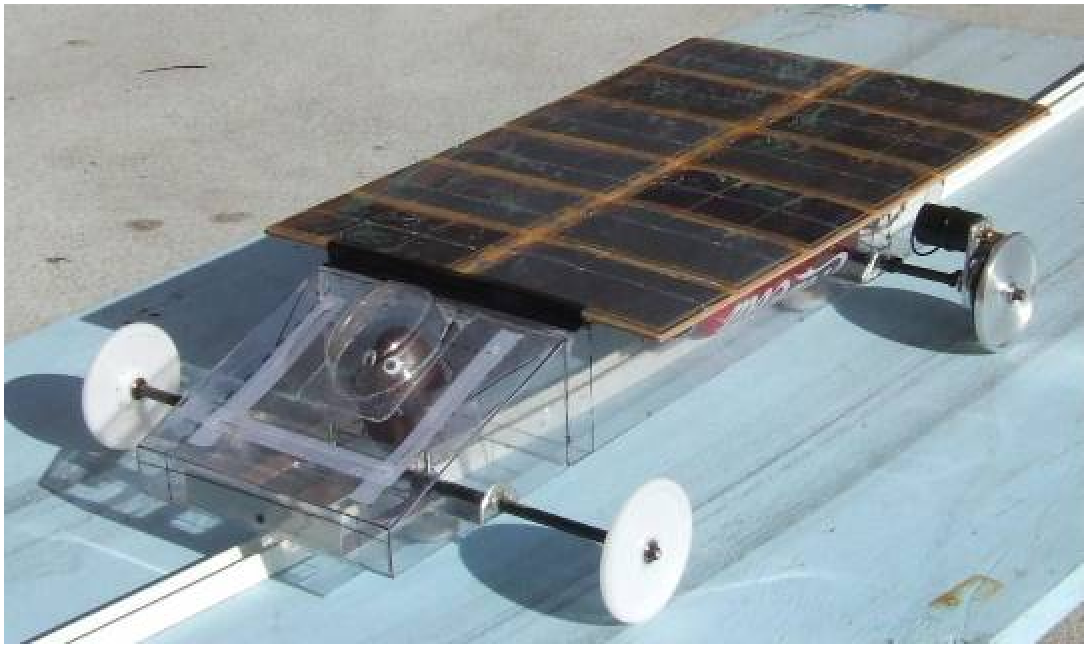
PHOTOS OF CARS & AIR DRAG COEFFICIENT

NOTE: You MUST do wind tunnel testing of your car to determine its drag coefficient. (Values in the order of 0.03 for a flat plate of 200 cm square to 0.003 for a low drag aerofoil shape of 200 cm square would be typical.)

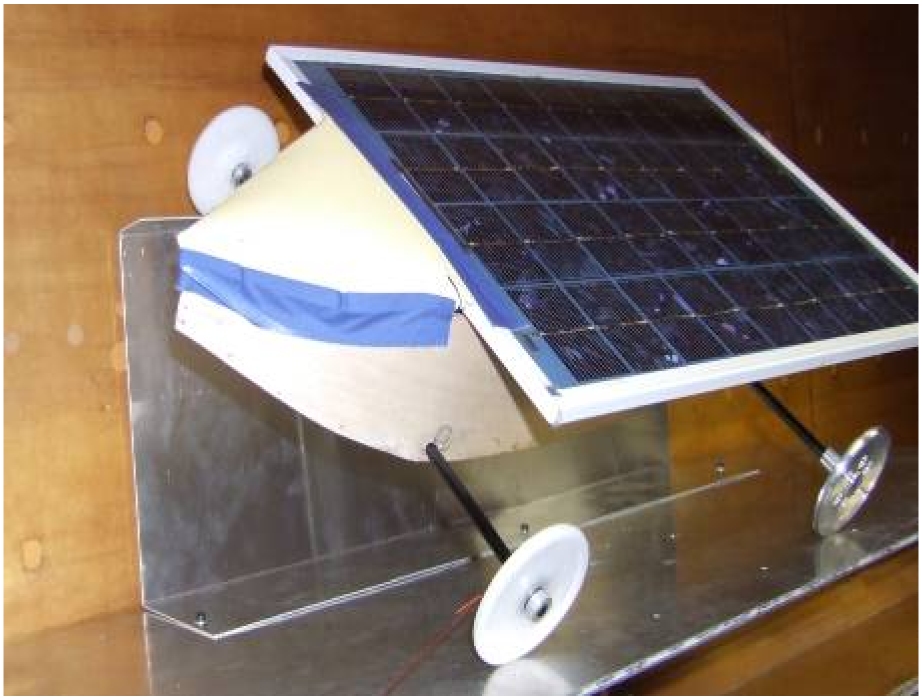
If you cannot perform wind tunnel testing you can make an estimation of drag coefficient by taking the 0.03 drag coefficient for a flat plate of 200 cm square and calculate the drag coefficient for your car with a simple ratio calculation based on your cars frontal area compared to the 200 cm square.
This will give a worst case drag figure as it is based on a flat plate.
As a help to determining your drag ratios some drag ratios of actual cars that have been tested in a wind tunnel are given below.

CAUTION: The air drag coefficients listed here are not cd values or Drag Coefficient values as normally seen. They are derived from testing of a particular car and the coefficient includes cd values as well as frontal area and air density all rolled into the one coefficient. Consequently we cannot compare the aerodynamic performance of different cars without considering their frontal area.
(See section on air drag in Mathematical Simulator earlier in this document for more details)

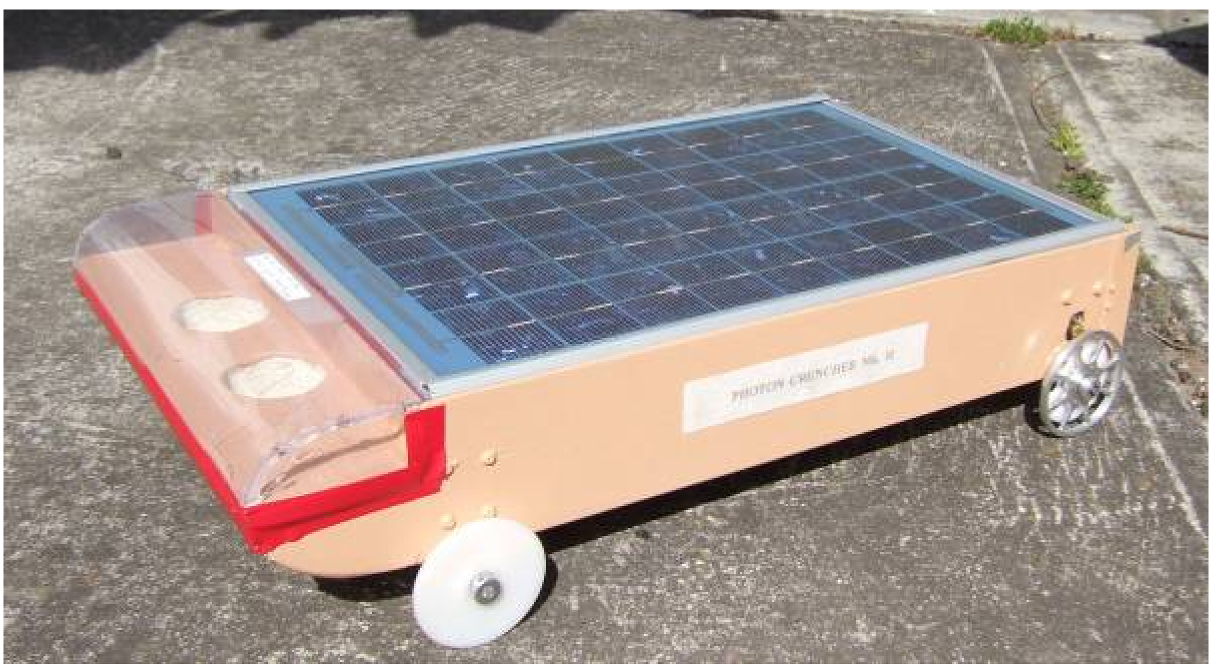
PHOTON CRUNCHER MK IV : SIMULATOR AIR DRAG COEFFICIENT 0.007



PHOTON CRUNCHER MK V : SIMULATOR AIR DRAG COEFFICIENT 0.0045



SYNDAL SOUTH 2006 CAR : SIMULATOR AIR DRAG COEFFICIENT 0.0045



PHOTON CRUNCHER MK II : SIMULATOR AIR DRAG COEFFICIENT 0.012
(Note:This car designed to meet the 200 sq.cm. transverse panel requirement.)

ENIGMA : SIMULATOR AIR DRAG COEFFICIENT 0.012
(Note:This car designed to meet the 200 sq.cm. transverse panel requirement.)

HELIOS : SIMULATOR AIR DRAG COEFFICIENT 0.004
(Note: This car designed to meet the 200 sq.cm. transverse panel requirement.)

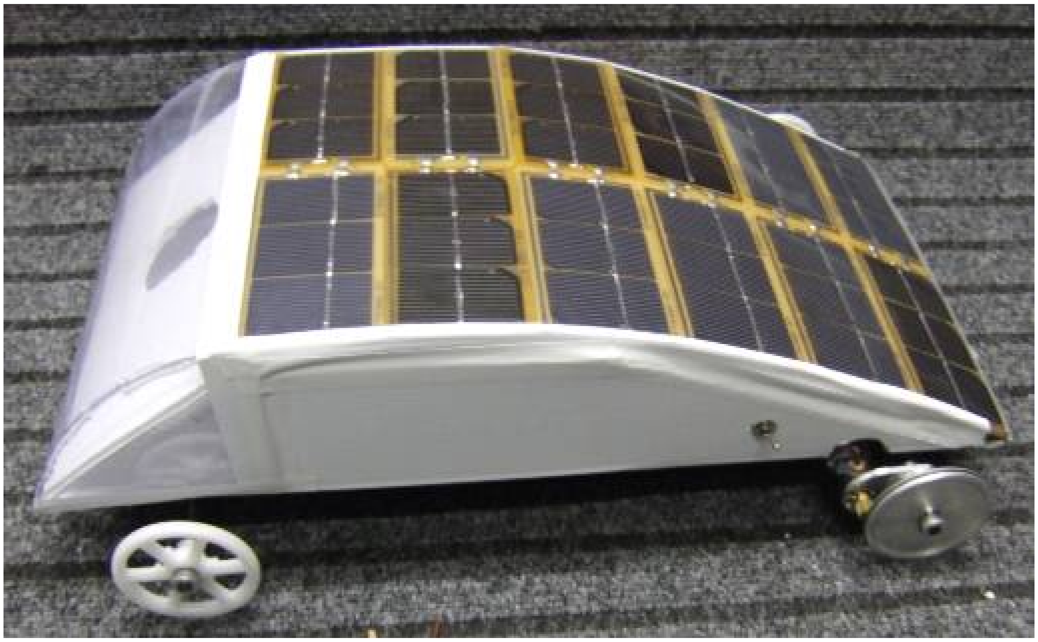
CARBO TRUDIS: SIMULATOR AIR DRAG COEFFICIENT   0.0039

NFG : SIMULATOR AIR DRAG COEFFICIENT 0.007
(Note:This car won the 2008 National event. Designed for transverse milk carton.)

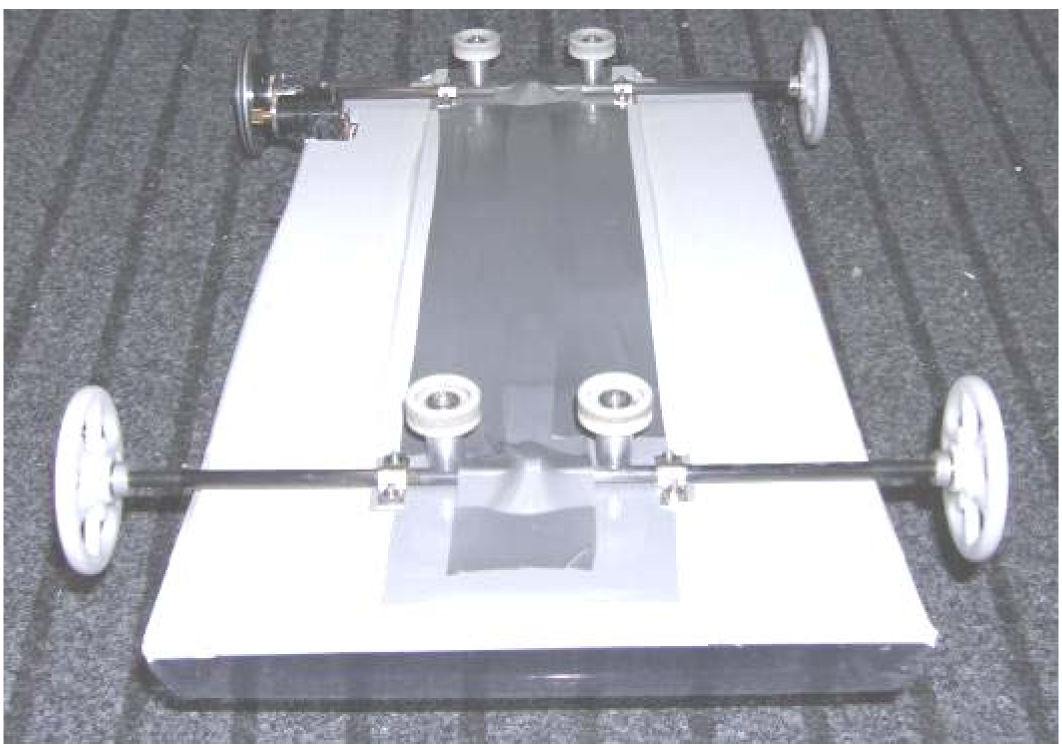
EFFECT OF WHELLS AND GUIDES ON DRAG

In order to show how important apparently small items can be when it comes to air drag, wind tunnel tests were carried out on a car to evaluate the effect exposed motor, wheels and guides has on air drag. A sample car made for workshop demonstrations was tested as a body only then as a complete car. Please note the chassis is that from PC IV so is shown in detail in the Design Hints.
NOTE: This car was designed to meet the transverse milk carton regulation.

BODY ONLY : SIMULATOR AIR DRAG COEFFICIENT 0.0035



COMPLETE CAR : SIMULATOR AIR DRAG COEFFICIENT 0.008



CHASSIS ONLY (SHOWN HERE STILL ATTACHED TO CAR)
: SIMULATOR AIR DRAG COEFFICIENT 0.0045

APPENDIX L: CAR SHAPE AND AERODYNAMIC DRAG

To evaluate the importance of aerodynamics to car performance, two models were constructed for wind tunnel testing. One was intended to have bad aerodynamics the other to have good aerodynamics.
A basic box was chosen as the bad aerodynamic shape model.
For the good aerodynamic model an airship shape was selected.
The requirement to carry cargo in the form of milk cartons means that a pure airship shape cannot be used. To accommodate the milk cartons the shape was stretched in length by adding a parallel section in the middle, and stretched in width by adding a wing like section between the sides to enable the specified cargo to fit. This stretching also allowed room for the solar panel.

The models were designed and constructed to have similar frontal areas and wetted surface area, making them virtually identical except for shape. Both models were constructed at ½ scale.

To evaluate the performance of these car shapes, wind tunnel testing of the models was undertaken and the drag results obtained used in the mathematical simulator to predict performance of full size cars manufactured with these body shapes.

<u>WIND TUNNEL TESTING OF MODELS:</u>
The models are pictured below in the wind tunnel for testing.

Stretched airship shape
(Frontal area 7016 mm sq.)

Block shape
(Frontal area 6848 mm sq.)

Test results obtained are detailed below.

Air Speed	Drag readings Newtons		Coefficient for simulator *		Cd	
M/sec	Stretched Airship	Block	Stretched Airship	Block	Stretched Airship	Block
8.4	0.0599	0.209	0.0034	0.0119		
11.3	0.1018	0.3887	0.0032	0.0122		
16.94	0.2336	0.855	0.0033	0.0119	0.1902	0.738

Note: The drag figures shown are the actual drag in Newtons on the model. The coefficient for the simulator is obtained by scaling the drag up to the expected drag for a full size car ie. multiply by 4 then dividing by the air speed squared. The Simulator * is the one written by Ross Perry & Ian Gardner.

CAR PERFOMANCE IMPLICATIONS:

To see in general terms how air drag influences car performance the air drag coefficient obtained was used in the mathematical simulator. For all simulator runs the same car parameters except for air drag coefficient were used.
The basic parameters used are those of the car PC IV (Photon Cruncher MK IV which is fully detailed in the Design Hints) the main parameters are listed below.

Mass 2.1 kg
Solarex 10 Watt panel 88% Sun level
Engelec electronics
No Steering

AIR DRAG COEFFICIENT	RACE TIME SECONDS		DISTANCE DIFFERENCE METRES	
	1 LAP	2 LAPS	1 LAP	2 LAPS
0.012	20.3	34.3		
0.0033	18.85	30.9	10.0 *	23.0 *

* Approximate distance this car is ahead at the end of the race due only to the lower aerodynamic drag.

NOTE: To achieve the same performance increase by weight reduction alone it would be necessary to reduce the weight from 2.1 kg to 1.4 kg.

Calculation & Comparison of Cd:

$$Cd = \frac{\text{Drag Force}}{!/2 \text{ x Air Density x Car Speed squared x Frontal Area}}$$

(The following data was used for calculations:
Standard air density 1.22 kg/m cubed
Standard air viscosity 1.78 by 10 to the minus 5 kg.m/sec squared)

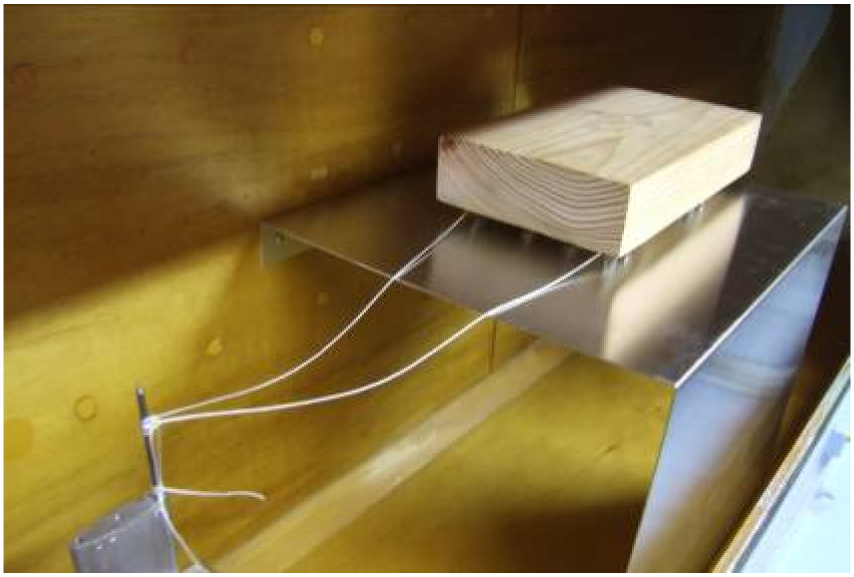
VEHICLE	TYPICAL Cd	MEASURED Cd
Bicycle rider upright	1.1	
Large truck	0.95	
"The Block"		0.738
		0.682**
"Ute"	0.5	
"Modern Car"	0.3	
Stretched Airship		0.190
		0.242**
GM Sunraycer (Well known experimental solar car)		0.12

** Average of CD measured with the model resting on a floor

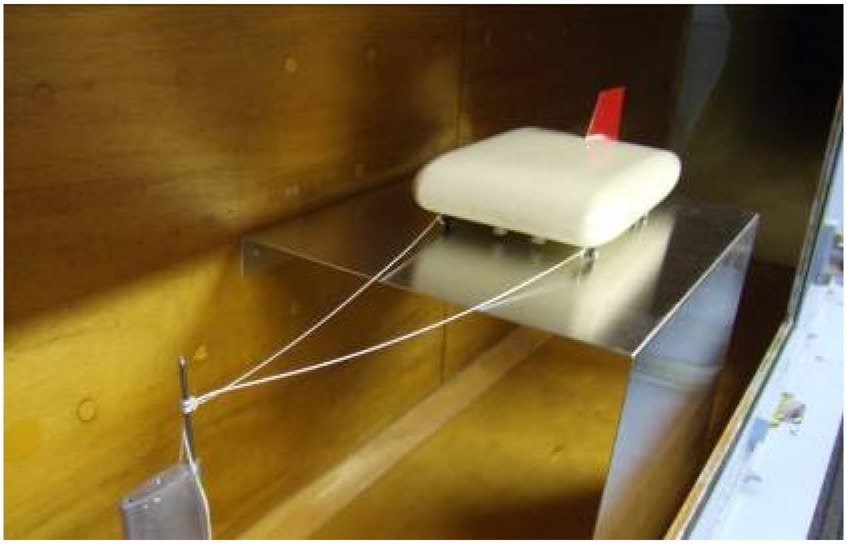
FURTHER TESTING:

The previous tests were performed with the models on a "stick" well above the floor of the wind tunnel. This is not an identical situation to a car on the track. The relevance of results obtained when testing like this have been questioned. The general suggestion being that drag would increase when the car is on the track. To answer these questions both models were tested resting on a floor located about ½ way between the floor and roof of the wind tunnel. The floor was placed here so it was in an area where the airflow is least effected by the wind tunnel walls.

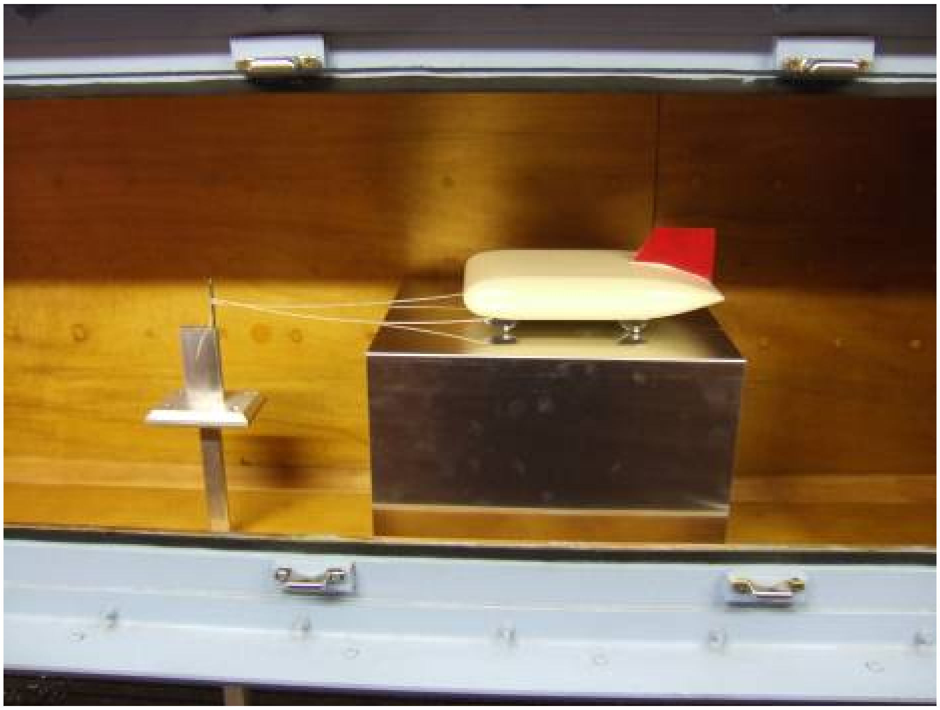
This is still not exactly the same as a car running on a track but is the best we can do with the equipment we have.



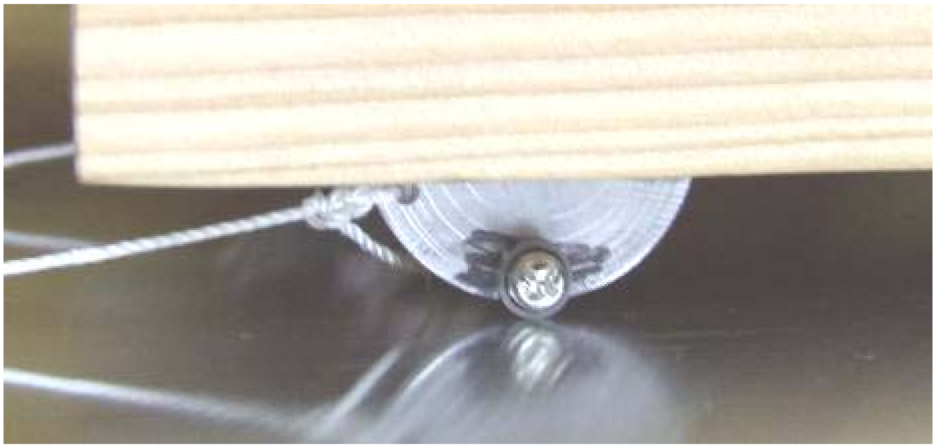
The BLOCK on wheels ready for testing



The AIRSHIP on wheels ready for testing



Overall view of wind tunnel set up



Detail of bearing fitted to wheel

In order to perform testing with the models on a floor, the fixed wheels on the models had small (7mm OD. By 3mm Wide) ball bearings fitted on the bottom to allow the car to move freely in the air stream. The model was tethered by thin nylon cord to the wind tunnel measuring arm.
Testing was carried out exactly as before. The results obtained follow.

Air Speed	Drag readings Newtons		Coefficient for simulator *		Cd	
M/sec	Stretched Airship	Block	Stretched Airship	Block	Stretched Airship	Block
8.4	0.0792	0.2073	0.0045	0.0118	0.2622	0.7033
11.3	0.1341	0.3536	0.0042	0.0111	0.2454	0.6629
16.94	0.2632	0.6842	0.0037	0.0095	0.2195	0.6976

Note: The drag figures shown are the actual drag in Newtons on the model.
The coefficient for the simulator is obtained by scaling the drag up to the expected drag for a full size car ie. multiply by 4 then dividing by the air speed squared. The Simulator * is the one written by Ross Perry & Ian Gardner.

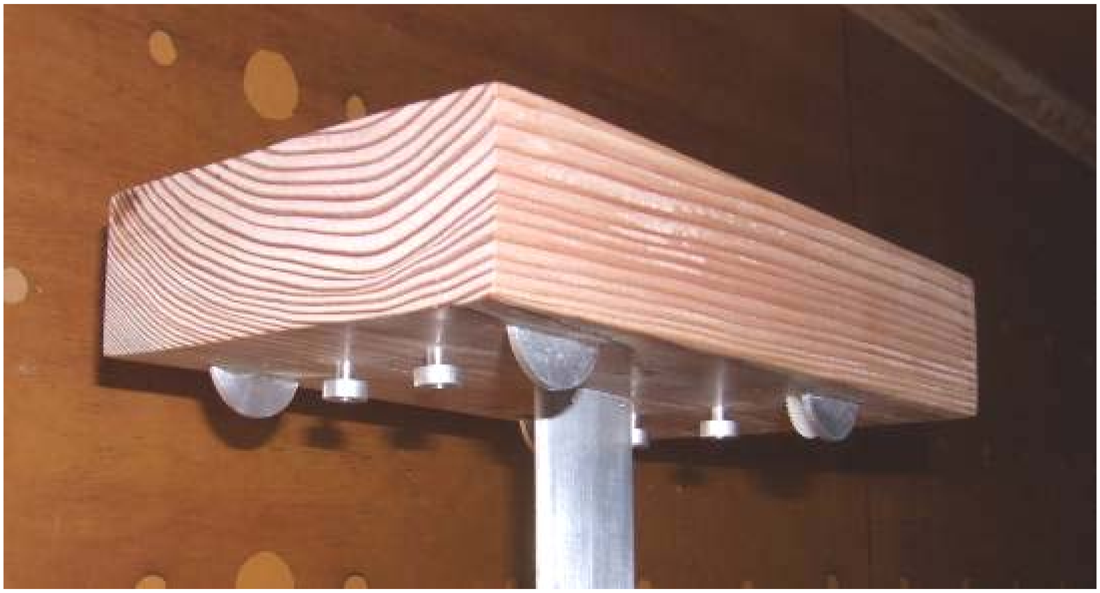
These results show a slight increase in drag when the airship shape car is tested on a floor as opposed to on a "stick". This is in line with expectations.
However the lower drag recorded on the Block model was unexpected, it is possibly due to the bluff front close to the ground acting like a deflector skirt (as seen on most racing cars) limiting the airflow under the model as well as modifying the flow over the top.

In conclusion there is a difference in drag when tested on "a stick" and "on the track", but these tests results indicate there may not always an increase. Caution is required and in fact the testing of your car is the only certain way of getting accurate drag figures.
Using the air drag coefficients obtained above for the cars on a floor in the mathematical simulation the following predictions were obtained.

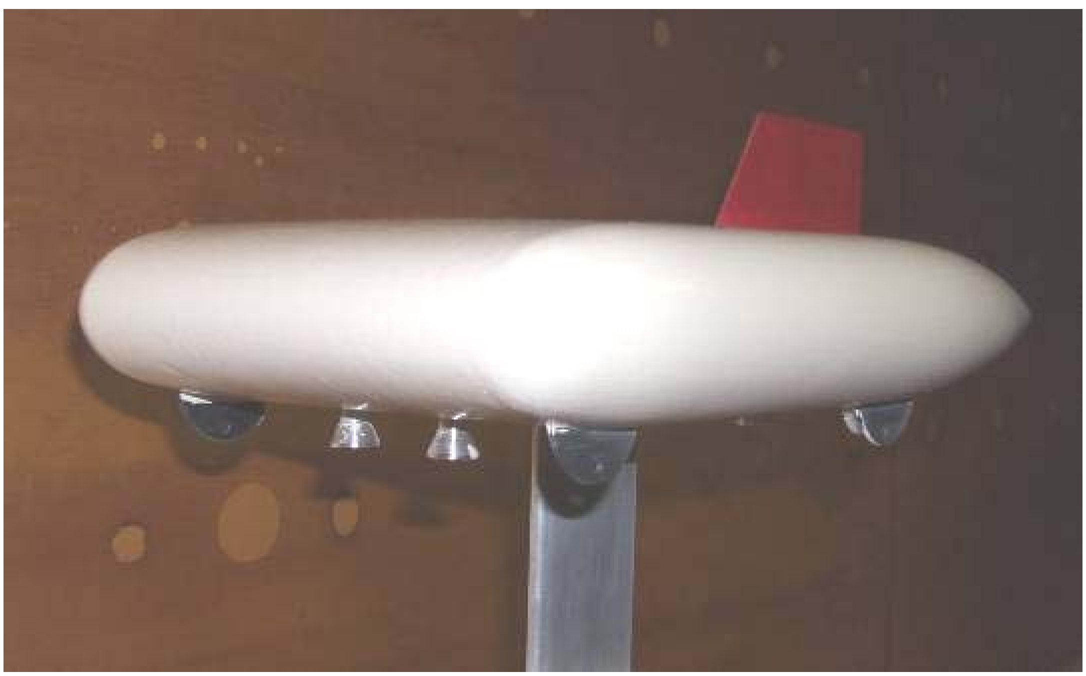
AIR DRAG COEFFICIENT	RACE TIME SECONDS		DISTANCE DIFFERENCE METRES	
	1 LAP	2 LAPS	1 LAP	2 LAPS
0.0114	20.2	34.1		
0.0042	19.05	31.3	8 *	23 *

Approximate distance this car is ahead at the end of the race due only to the lower aerodynamic drag.

ADDITIONAL PHOTOGRAPHS:



THE BLOCK



STRETCHED AIRSHIP

APPENDIX M:

MODEL SOLAR CARS AND AERODYNAMIC LIFT

Over the years I have often had the suggestion made to me that significant lift or down force can be generated aerodynamically. In order to clarify this proposal I decided to take "a quick look" at this topic and publish the results.

Firstly down force, why would I want it? Yes it will help hold the car down onto the track around corners and over the hill **but.** Down force will increase the wheel loadings and consequently raise rolling friction slowing your car. As very fast cars without any deliberately generated aerodynamic down force have managed to win races for years, why do you need it. Design and build your car properly. Remember too that there is always a drag force generated in conjunction with lift, or down force (down force is just lift turned upside down) this additional drag will only assist in slowing your car down, not a particularly good idea.

Secondly lift can reduce wheel loads thus reducing rolling resistance, as well as the most undesirable effect of increasing the tendency to take off over the hill and disengage guides when cornering. Sounds like a great idea, gain a slight reduction in rolling resistance and crash out in the corners or over the hill.

There have even been suggestions that cars could become airborne due to unintentionally generated lift. So how much lift can we reasonably expect to be generated? I will assume insanity runs in your family and you have produced a car with a body in the shape of a wing designed to generate lift instead of the more sensible non lift low drag strut shape. I will though, credit you with sufficient intelligence to orient your wing for zero angle of attack. Well how much lift can we expect?

Using data from Marks Standard Handbook for Mechanical Engineers Eighth Edition section 11 AERONAUTICS with characteristics for a NACA 4415 wing section at a velocity of 8 m/sec. (ie. a 16 second lap) and a wing of dimensions 300mm by 400mm. Calculated lift generated at zero angle of attack for this wing .

Lift = Lift coeff x 0.5 x air density(slugs/ft cubed) x velocity squared (ft/sec) x area (ft sq)

= 0.2 x0.5 x 0.002378 x 25 x 25 x 1.3

= 0.1932 lb. (british units used in calculations as text is from USA)

= 87 gm lift

Re calculated for angle of attack which gives maximum lift coefficient (ie. 20 deg.) and I assume only a total lunatic would build a car with a high lift wing section set at a 20 deg angle of attack if lift force was not intended.

= 1.54 lb lift

= 700 gm lift, still a lot short of taking off as the minimum reasonable weight of a car powered by a 6 watt panel is 900 gm and for a 12 watt panel is 2100 gm. This much lift however, is more than enough to cause instability problems

Yes I can hear the cries of: but you ignored Reynolds number and ground effect. Yes I did I also ignored the fact that any wing you produced would most probably have such a rough surface and imperfect shape due to the solar cells that performance anywhere near to that of a standard wing is all but impossible. While we are about it you must also consider that a 20 deg angle of attack is possible within the 180 mm allowed car height but things are getting tight and while we are about it do not forget the massive increase in drag associated with such a high angle of attack will certainly slow the car significantly with consequent reduction in available lift. I will leave research and evaluation of all this to you.

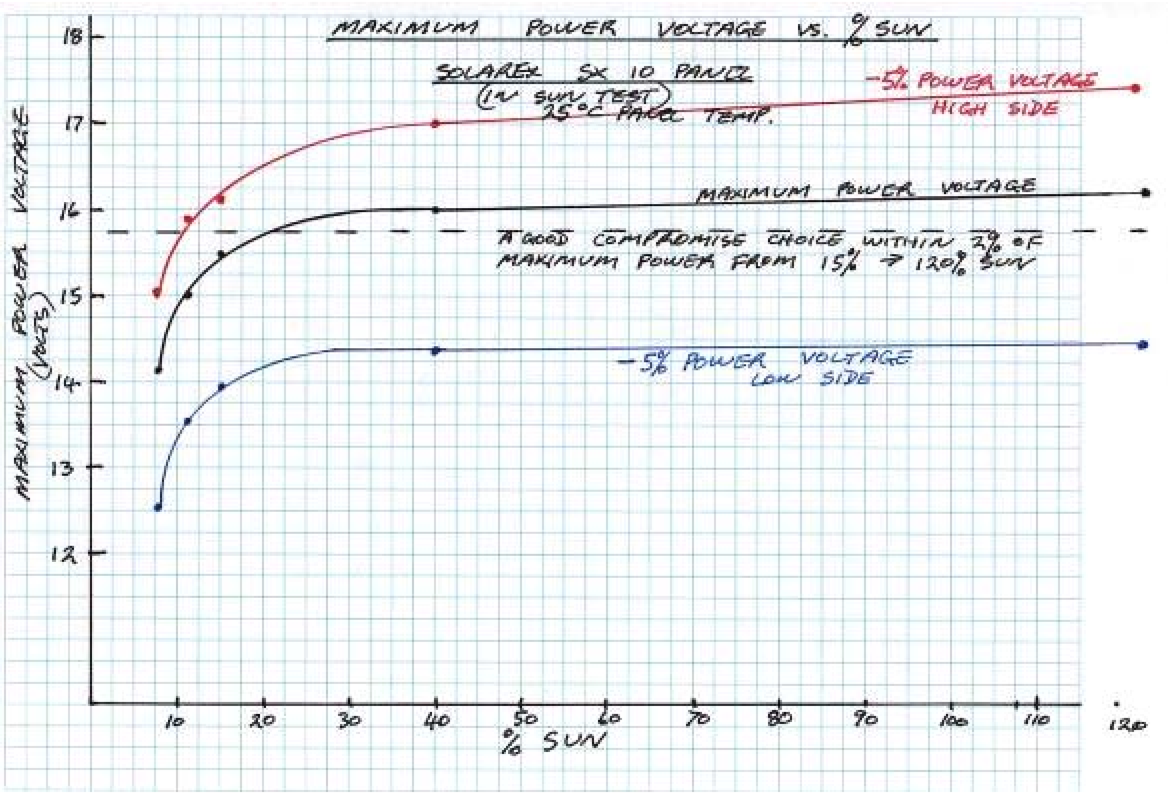
My advice is, design and build your car with a low drag shape but forget about obtaining significant lift or down force by accident. And why would you design it into your car.

APPENDIX N:

MAXIMUM PANEL POWER VOLTAGE VARIATION WITH

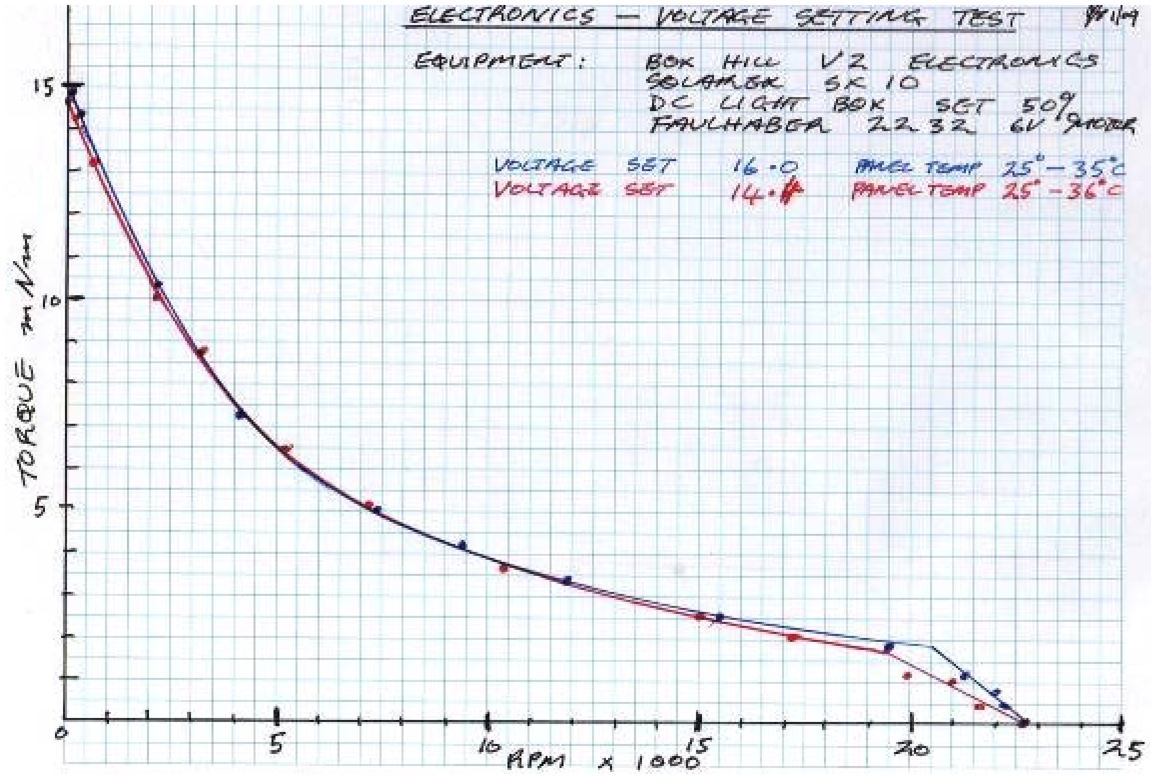
TEMPERATURE AND LIGHT LEVELS

In support of the suggestion in section **8. ELECTRONICS** that an electronics unit can be set at a compromise voltage and only be a few % off maximum power. The following data has been prepared.
Firstly how does maximum power voltage change with light intensity.
A Solarex SX 10 panel was tested at constant panel temperature of 25 Deg C but at various light levels, the results are graphed below. (Tests conducted in sunlight)



From the graph it is apparent that it is possible to set your electronics unit to a compromise voltage and not change it unless the Sun level drops below 15%, or your panel heats up. With the Solarex panel characteristics graphed above and the correct compromise setting chosen you need only be a couple of % off maximum power setting.

To further add confidence to the argument that being a little bit off the exact voltage setting only makes a small difference to performance, a dynamometer test was performed with the same Solarex SX 10 panel an electronics unit and a Faulhaber 2232 6 Volt motor. The voltage settings for the tests differed by more than "a little bit" see the graphs below.



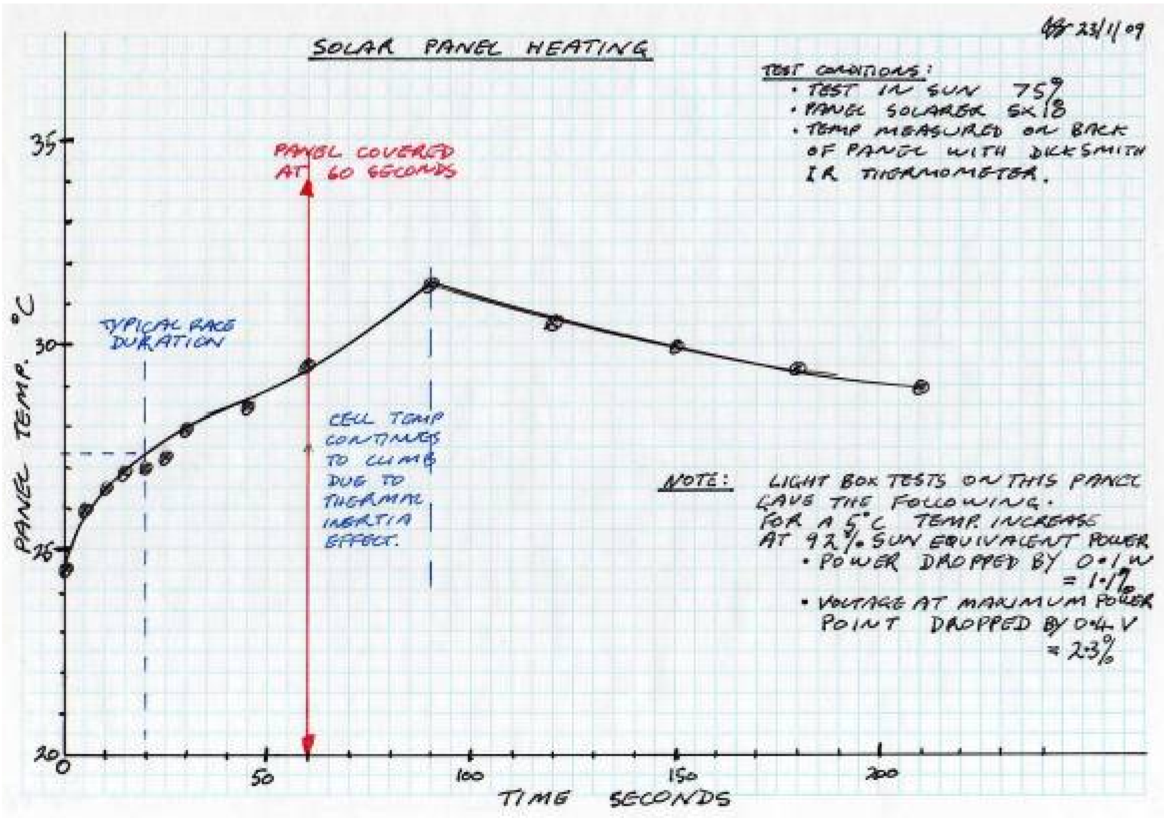
(While the graph above depicts Torque vs RPM and within this article I talk about power, you probably think I am crazy, but Torque x RPM = Power To calculate power in Watts using Torque of mNm the actual power in Watts = Torque x RPM x 0.0001042)

When the graphs are carefully examined the torque at the lower voltage setting tends to be fractionally lower than the other. There is very little in it and the voltage difference is not just a small amount it is a massive 1.6 Volts. Importantly the variations are at a minimum over the RPM range of between 3000 and 13000 RPM which is the general operating range during a race.
Remember the power difference for a small voltage variation will be greater at higher and lower sun levels. It will also be influenced by panel temperature variations, as the panel heats the maximum power voltage point drops markedly.

I assume that no competitors will leave their panel out in the sun baking, in fact most actively cool their panels and during a race which lasts only about 20 seconds, the panel only heats up a few degrees. Consequently under these conditions temperature variations can be ignored. (Can they really.)
Even if we cannot ignore panel heating during a race there is not much we can do about it, put a solar panel out in the Sun and it is bound to heat up.

To convince you that panel heating during the course of a race is not critical, consider the following results obtained from testing.

Firstly the same Solarex SX 10 Panel was placed in 75% Sun and its temperature measured every 5 seconds up to1/2 a minute then every 15 seconds up to 1 minute. Results are graphed below.



The question is how much does a panel heat up during a race?
Consider the graph, after the panel is covered the temperature continues to rise. This lag effect is due to the time it takes for the heat to travel from the front of the cell to the back of the panel.
At worst case condition the cells will be hotter by this temperature, so if we add this temperature rise to the temperature we recorded at the time of interest say 20 seconds for an average race time. We will have a fair indication of actual cell temperature at that time.
What is the temperature rise after 20 seconds?
Probable total temperature rise = temperature rise after 20 seconds + thermal lag temperature rise, ie. 2.5 + 2 = 4.5 Deg C.
Panel testing has shown that a temperature rise of 4.0 Deg C results in an approximate fall in maximum power point voltage of 0.54 volts. This leaves us with the option of setting the electronics unit about ½ a volt below the maximum power point and only being within a few % of the maximum power point at the end of a race.

APPENDIX O:

BIOGRAPHY OF A WINNING CAR
Syndal South Primary School car “SCORPION” 2009

This article was written to show just how easy it is to build a good competitive car for the **Model Solar Vehicle Challenge.**

The car is pictured below on the track, it surprisingly managed first place at the Victorian event by beating the car that eventually finished second at the Australian International Model Solar Challenge.

Syndal South Primary School car “SCORPION” on right.

The car “SCORPION” was one of the 2 cars constructed by the students at Syndal South in 2009. In practice and previous races there was practically no difference between these cars they had incredibly similar performance. The second Syndal South car “Lean Green Speed Machine” finished in third place.

Both the Syndal South cars were very basic there was no other option as they had to be constructed on a table top using only the most basic of hand tools. Consequently the simplest of construction techniques and off the shelf components were used.

The big question is why was this team so successful? There is no simple answer but the following points all contributed to the success.

- The School has been very supportive of this program for the past 12 years. This includes financially and by releasing students from normal classes for about 1.5 hours each week from the start of term 2 to participate in this program. The teacher and parents have made also made themselves available to take the students to the Museum Event ** and to Box Hill High to both work on their car in the technology area as well as to test the car on the test track.
- There is a long history within the school of car manufacture and many sample cars from previous years.
- A succession program is in place where each year at least one year 5 student is included in the team to gain experience and expertise and become a team leader in year 6.
- The first few weeks of the project are spent in workshop type sessions where the students learn about the basic components and functioning of model solar cars. Particularly important is the discussion and understanding of the regulations governing the car design. Emphasis is placed on build accuracy as this is critical for good car performance.
- The students produce a timetable to allow for car completion before the Museum event. This gives plenty of time for producing their poster and testing their car before the Victorian event in October.
- A car design sketch is produced and this is used to manufacture a cardboard model of the car which in turn is used as a guide for manufacturing the actual car.
- The one thing that has the most influence on success is practice. The cars from Syndal South are always completed to the stage that they can participate in the Museum event and are brought to Box Hill High School in the September holidays for another 2 full day's practice and tuning on the practice track there. I cannot stress enough how important practice and tuning are, we have in the past regularly seen improvements in race time in the order of 5 seconds after only a few hours of practice. The practice also improves the cars reliability while giving the students the skills and confidence to operate their car effectively and autonomously.

** Museum Event: this is an event run by the Victorian Model Solar Vehicle Committee at the Melbourne Museum each year about 4 weeks before the actual event. It is conducted as a pursuit race on a single lane track the main purpose of this event is to give students an aiming point to finish cars before the last minute, plus provide an opportunity to practice in a race type environment

THE CAR:

Because of the limited manufacturing facilities available at Syndal South Primary the car construction had to be simple and utilize as many off the shelf components as possible. Body construction used is high density polystyrene foam, hot wire cut and glued to a 0.8 mm thick plywood base. Axles are arrow shafts secured to the body with standard ¼ inch pipe saddles.. Wheels, gears, motor mount and guide rollers are all off the shelf components from R & I Instrument and Gear co. steering is not used. The motor is a Faulhaber 2232 6 Volt unit which is in almost universal use here in Victoria for model solar cars. The Solar Panel is from Scorpio Technology being 2 Number 6 Solar Panels connected in series and mounted on an aluminium base plate. The solar Panel is secured to the car body with Velcro. An electronics unit is used to control the panel power, there are several units commercially available but the unit used in this car was assembled by students in a previous year. Ballast required was lead sheet wrapped in tape and laying on the floor.

The car was designed to meet the 2009 regulations a synopsis of the requirements is given in appendix A.

BASIC CAR DIMENSIONS:

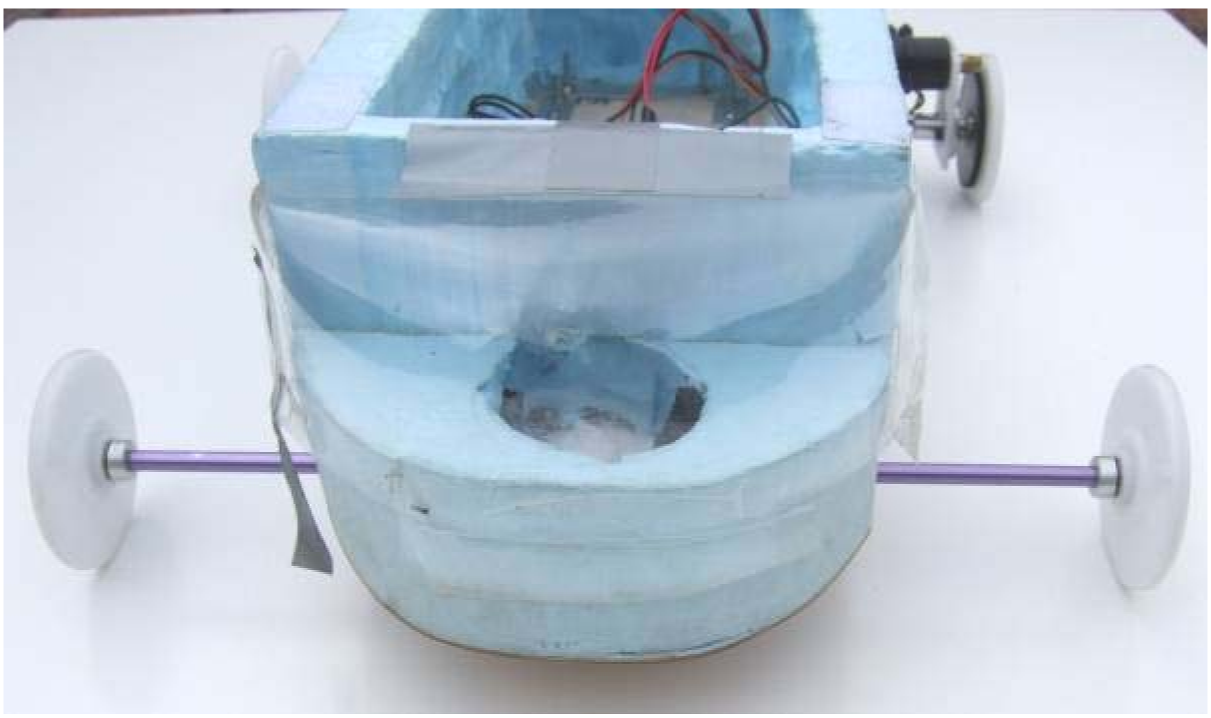
- Body dimensions, length 520 mm maximum width 155 mm height 100 mm.
- Body weight 525 gm with electronics but no egg.
- Solar panel 173 mm wide by 500 mm long
- Solar panel power 12.16 Watts (At Vic. 100% Datum not AM 1.5 as now required)
- Axle length 320 mm.
- Distance between axles 250 mm.
- Forward body overhang ie. distance from front axle to front of body 80 mm.
- Rear body overhang ie. distance from rear axle to rear of body 185 mm.
- Distance between guide roller centers 60 mm.
- Guide roller clearance to track 3 mm.
- Wheel diameter 64 mm. Guide roller diameter 25 mm.
- Gear ratio, main gear 100 tooth pinion gear 14 tooth.

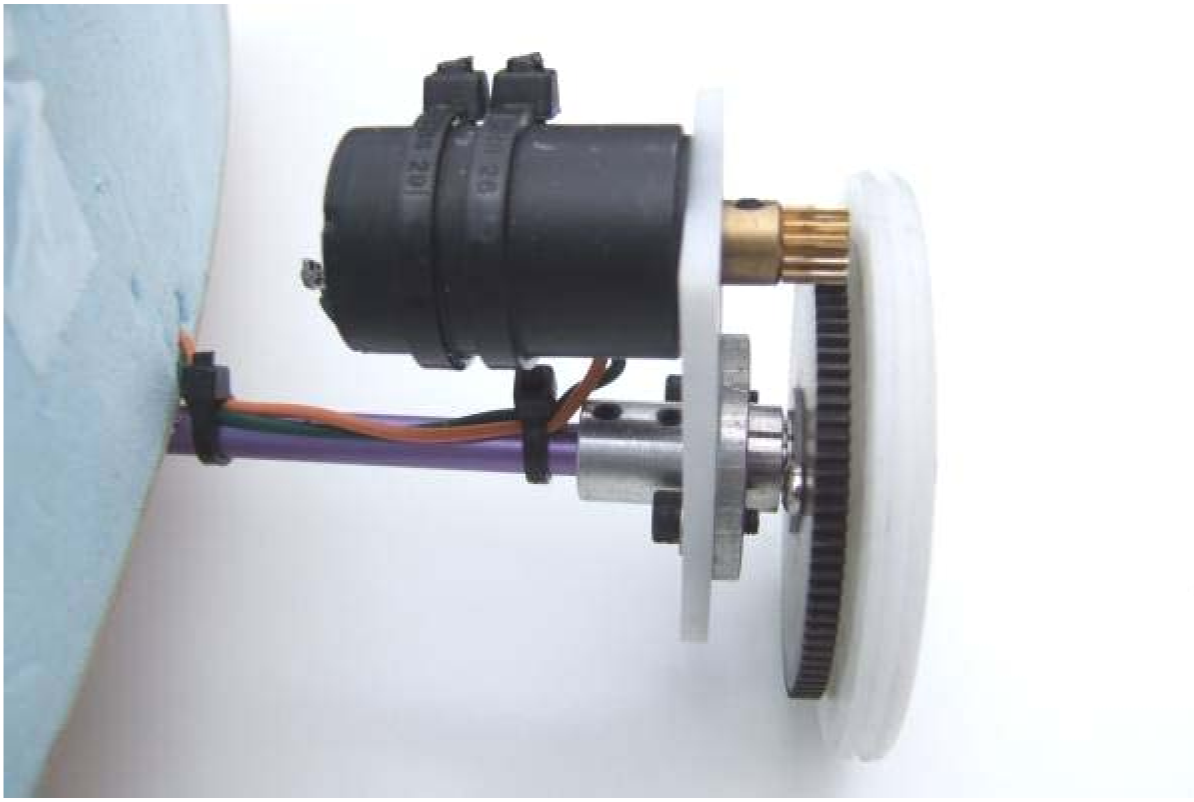
NOTE: The Design Guide contains full details of R & I components and assembly details used in the construction of Photon Cruncher MK IV. The same components and construction techniques, except for the body construction are used on the Syndal South cars car.

Detailed photographs of the car Scorpion follow:

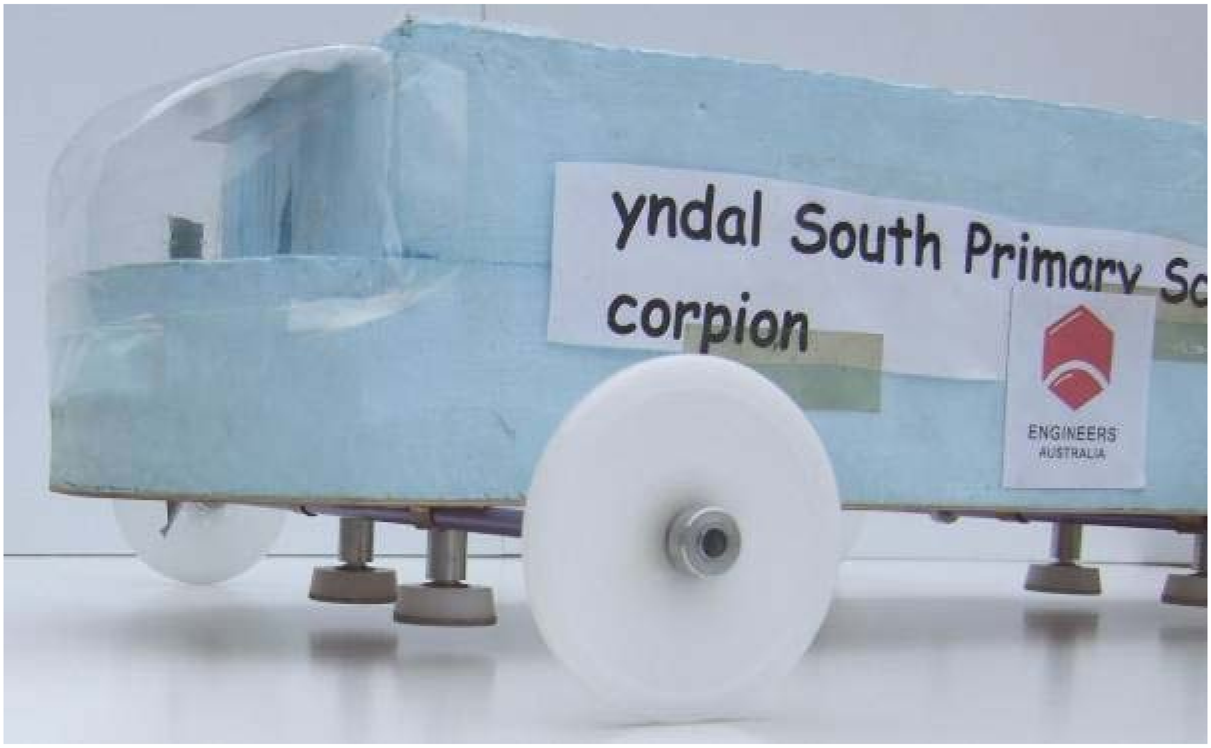

yndal South Primary School
corpion

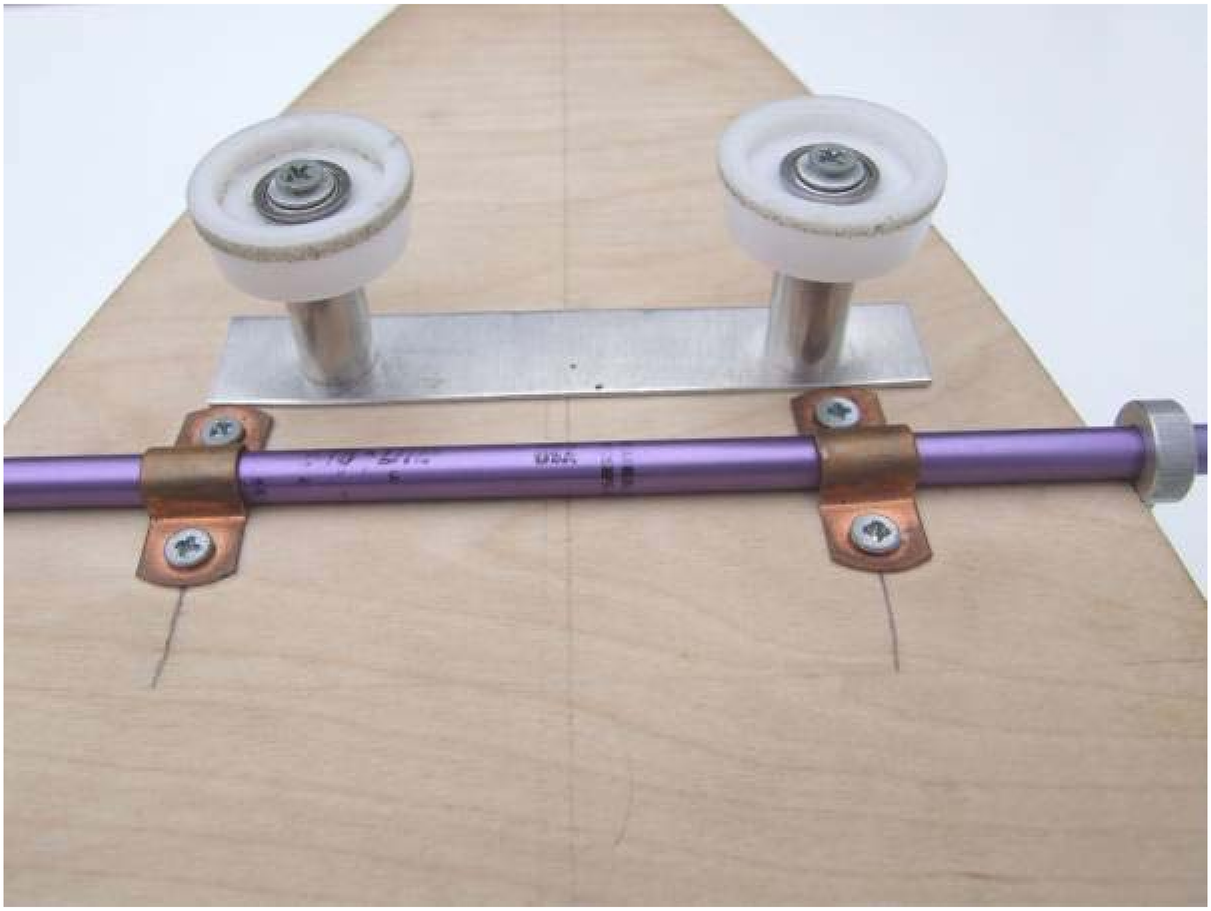

16

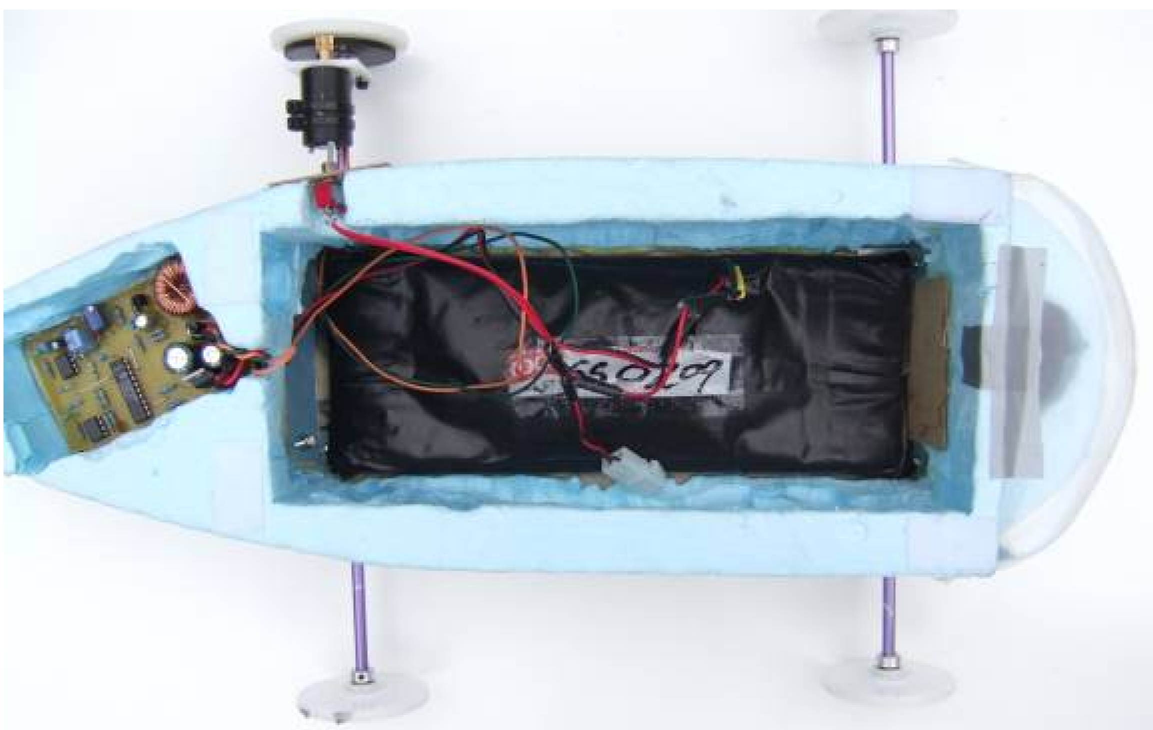


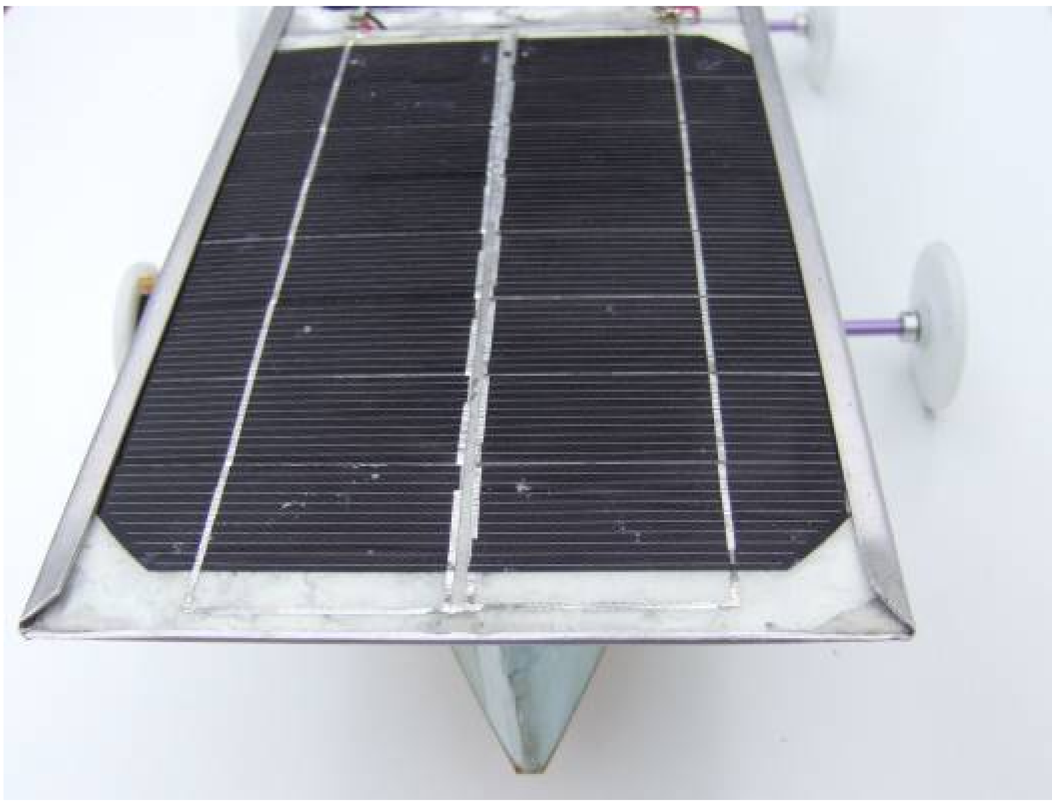


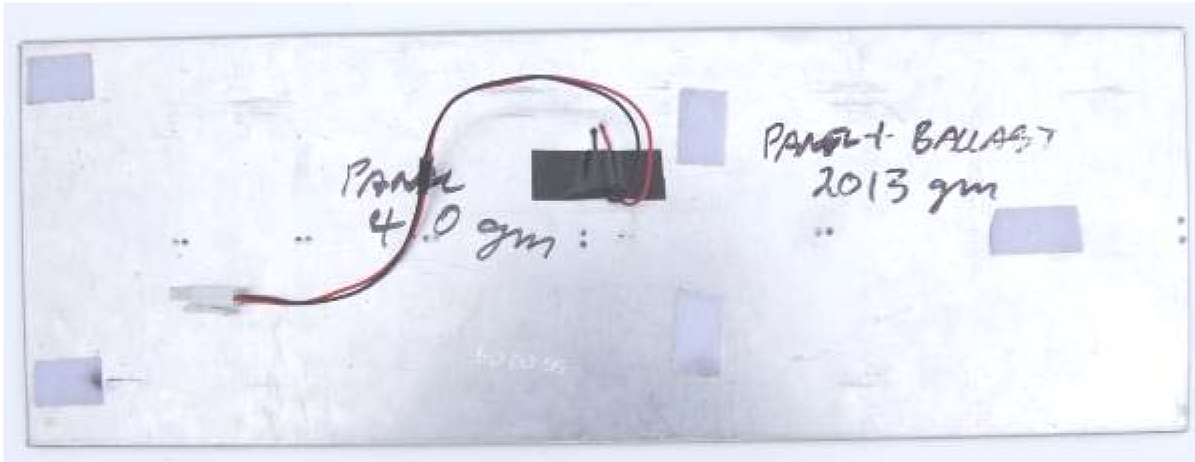

16 Syndal South PS Vic
Scorpion
2720
Syndal South Primary School
Scorpion


yndal South Primary Sc
corpion
ENGINEERS
AUSTRALIA









APPENDIX A: The specifications this car was designed to meet.

MODEL SOLAR VEHICLE 2009
SYNOPSIS OF CAR SPECIFICATIONS

The following is intended to be used as a quick reference guide only. It contains the important basics but does not cover all the detail. YOU MUST REFER TO THE REGULATIONS FOR FULL DETAILS.

Changes for this year are shown in bold type.

MAXIMUM OVERALL DIMENSIONS :

550mm long
320mm wide Less than 200mm from centre line of guide rail. **At no time may any part extend more than 250mm from the centre line of the guide rail.**
180mm high

DRIVERS CABIN:

Must be a fully enclosed and sealed compartment at the front of the vehicle.
Have room for a 60 g egg driver.
The top 25mm of the egg must be visible from straight ahead to 90 degrees each side.
The windscreen must be transparent and have minimum 10mm clearance to the egg over the 180 degree visibility arc
3mm minimum clearance is required over the top of the egg.
Two 4mm wide frames are allowed in the visibility arc.

WHEELS:

Minimum width 1mm or 0.6mm radius at contact point with track.

GUIDING:

Must be on the outside of the guide rail.

CARGO SPACE:

An enclosed space behind the driver and beneath the Solar Panel large enough to hold **1 standard 2 litre plastic fresh Milk bottle. (Any orientation is allowed.)**
The floor must be capable of supporting **the full 2 litre plastic milk bottle** standing vertically anywhere on your designated cargo area and the car capable of rolling without the panel attached. Only ballast is allowed to be in this designated space.

SIDE PANELS:

One each side, minimum 75mm high by 120mm long..
Allowed curvature 20mm vertically, 15mm horizontally.\

SCHOOL & CAR NAME:

In letters 10mm high visible when racing. Not on the side panel.

SOLAR ARRAY:

Must be fully removable from the car.
Maximum power 12 Watts.
Only commercially available silicon cells are allowed.
For power measuring at scrutineering a positive and negative lead with 10mm of bare wire must be provided.
Must not have any devices mounted on it including the ON/OFF switch.
Panel power measured will be standardized to 25 Deg C.

WIRING:

All wiring and electronics must be reasonably visible.
If wiring enters sealed areas a circuit diagram and explanation will be required.

ON—OFF SWITCH:

An on off switch visible to the starter (ie. Left hand side or top) is required.
Switch must have on and off positions clearly marked.

ENERGY STORAGE:

No batteries allowed.
Capacitors up to 0.2 Farad allowed but must be discharged before the race. Inductors to 1mH allowed.

BALLAST:

The required weight of the solar array and support structure plus ballast (TOTAL WEIGHT) is given by the formula.

TOTAL WEIGHT = 175(P-6) +600 gm.
Where P is Panel power (standardized) in Watts

Ballast weight required can be calculated simply.
BALLAST WEIGHT = TOTAL WEIGHT – SOLAR ARRAY & SUPPORT

STRUCTURE WEIGHT

Any ballast required can be carried anywhere in the car. Bring the ballast you require to scrutineering NO ballast will be provided by the scrutineers.

USE OF ELECTRONICS:

If teams elect to use electronics the total BALLAST + SOLAR ARRAY WEIGHT required will be INCREASED BY 20 % over the value as calculated above.

TEST CRITERIA **All references to car behaviour and measurements assume** The car is on a flat level section of track in full racing configuration.

****

SOME OF THE FACTORS THAT INFLUENCE CAR PERFORMANCE:

While we are thinking of how a winning car is built, we should take time for an overview of the factors which influence car performance. Below is a list of areas of car construction and design that can have a significant influence on performance. The influence can vary from slight all the way up to stopping the car from running depending on the severity of the defect.

MOTOR:

- Voltage, power, torque constant and voltage constant must suit solar panel selected.
- Should be high efficiency & preferably lightweight
- Not worn or damaged

BEARINGS:

- Clean and undamaged
- Correctly installed with no preload.
- Lubricated with light oil (we have found INOX to be best) we have measured bearings running without lubrication to have 250% more friction than lubricated bearings.

ELECTRONICS:

- High efficiency at operating point

- Correctly set to panel power point. Caution: the maximum power point voltage drops rapidly with increasing panel temperature.

SOLAR PANEL:

- Good quality, that is ballast neutral.
- Panel cooled, panel power drops by nearly 0.5% per Deg C temperature rise. (Caution electronics set point)
- Voltage suitable for both the motor and electronics unit.
- Able to be configured to suitable voltage and current if it is intended to run without electronics.

WHEELS:

- Must run true especially radially.
- Be in correct alignment particularly if steering is not used.
- A tyre on the drive wheel(s) can improve performance by reducing wheel spin on take off, but a tyre will increase rolling resistance. There is a cutoff point where a tyre will not improve performance but in fact reduce performance. (At 90% sun on the test car Photon Cruncher MK IV a tyre reduced race time by 0.2 seconds.)
- The number of wheels and their position has a significant effect on car stability.

STEERING:

- The use of steering reduces drag while cornering thus improving performance.
- Steering if used must be stable, we have seen cars where the steering mechanism goes into a wobbling mode shaking the car from side to side wasting a lot of energy.

GEARS:

- Good quality with properly formed teeth.
- Adjusted for correct mesh.
- Correct ratio chosen for the car.
- The main gear is best if manufactured from plastic, this allows satisfactory operation without lubrication even if the pinion gear is metal. The use of lubrication on open gears holds dirt and consequently increases wear and power losses.

BUILD ACCURACY:

- It is important to manufacture your car with its critical components correctly aligned and with the required clearances. Your car must be strong and stiff enough in critical areas to maintain these clearances.

AERODYNAMICS:

- Is critical to car performance. As a general rule the rear of the car is often neglected but is quite important as a poor shape here will lead to high drag in the wake.

WEIGHT:

- While it is not the only or most important parameter that controls car performance it does have a significant effect. Every effort should be made to keep chassis weight to a minimum. This not only improves acceleration and allows the car to reach full speed more quickly but reduces rolling resistance and loads on other components such as axles, wheels and guides.

- Any ballast required should be carried as low down in the car as possible to increase stability. The best location for any ballast will be influenced by the number of wheels and their position. For example a 3 wheel car with the single wheel offset from the center line will tend to roll over more easily in one direction. Placement of ballast can help reduce this effect.

GUIDES:

- Are subjected to high forces when the car is cornering at speed. The side forces acting on the guides when cornering at speed can exceed the weight of the car. Consequently the guide anchor points and the guide rollers and their bearings deserve as much attention as the wheels.

- Must be properly aligned and positioned.

STABILITY:

- At speeds in excess of 6.5 m/sec calculations indicate that on the Victorian track a car will take off over the crest of the hill. If the car is not stable and running straight it will probably not land with the guides engaged on the guide rail and consequently crash. (We have photographs of a car about 20 mm off the track with the guide rollers clearly visible above the guide rail.

- Again at high speed when cornering, a car with a high center of gravity can either roll far enough to disengage the guide rollers from the guide rail or in fact roll over completely.

WHEEL SLIP:

- When using an electronics system it is possible and in fact common to experience wheel spin on takeoff in high Sun. This will cost race time.(We have measured 0.2 seconds in testing.) Either increasing the weight on the drive wheel or fitting a tyre which unfortunately also increases rolling resistance can improve this situation.

APPENDIX P:

TRACK FRICTION - DRIVE WHEEL MATERIAL & THE USE OF TYRES

When using an electronics unit most cars exhibit wheel spin on takeoff from the start line, particularly in high Sun conditions. This costs race time, in fact the addition of a tyre even with its slight increase in rolling resistance will give a lower race time.

One suggestion to reduce the need for a tyre, is to use an aluminium drive wheel which has a higher friction coefficient than a plastic wheel. Aluminium though is significantly heavier than plastic.

To evaluate this suggestion a test was conducted to determine the difference in friction coefficient between plastic (acetal) and aluminium.
The test was conducted on a section of Box Hill track (blue track) using the test car Photon Cruncher MK II. For testing the car was placed on the track which was angled up slightly to ensure a constant load on the force measuring equipment.
The car was towed up this ramp and the force required to pull it with all wheels free was measured at 65 gm.
The downward force on each rear wheel due to gravity was measured at 840 gm.
The rear drive wheel was then locked and the towing force measured. This test was conducted with both an aluminium and a plastic wheel with no tyre fitted.
With the aluminium wheel locked the force to tow the car was measured at 340 gm.
With the plastic wheel locked the force to tow the car was measured at 295 gm.

By subtracting the 65 gm. required to tow the car with wheels free the actual force required to overcome the locked wheel is obtained, this force is the maximum possible drive force at this loading condition.

Test conditions	Towing force gm.	Coefficient of Friction
No Tyre Aluminium wheel locked	**275**	**0.327**
No Tyre Plastic wheel locked	**230**	**0.273**

The measured difference in maximum drive force is only 20% lower for the plastic wheel. Since a tyre is probably required anyway on an aluminium wheel at high Sun levels this difference in friction only suggests that a tyre would be required on a plastic wheel at a slightly lower Sun level than for the Aluminium wheel.

There is no really significant drive force gain from using an aluminium wheel, certainly not sufficient to enable running without a tyre in all conditions. Consequently a plastic wheel which is lighter, cheaper and easier to make seems the obvious choice. Just fit a tyre at a slightly lower Sun level than required with an aluminium wheel.

The next question is when should a tyre be fitted? This can be answered by using the Mathematical Simulation, simply run the simulation set up for your car with and without a tyre at different Sun levels and note the race time. The Sun level cut off point for using a tyre will be obvious from the results.

To make an accurate determination of the Sun level at which to use a tyre it is necessary to know the friction characteristics of the actual race track. I have not conducted tests on the Victorian track but expect its frictional properties to be similar to the Box Hill track as they are both constructed from plywood and painted with a flat water based paint. This suggests the results of the testing detailed above can be used for the Victorian track.

The NSW track which is normally used at the National event is also constructed from plywood but has a form of plastic coated surface not paint. We can expect this surface to have significantly different frictional properties to paint.

To determine the difference if any, testing was undertaken during the 2009 National event held in Melbourne. On a flat section of track a car (Syndal South Primary School car “Lean Green Speed Machine”) was towed with and without a tyre fitted and with and without the single drive wheel locked. The results are recorded below. Note: This car was fitted with standard R & I acetal wheels, consequently an aluminium wheel was not tested. Total car weight was 2580 gm. with a load of 663 gm. on the wheel being tested.

Test conditions	Towing force gm.	Coefficient of Friction
No Tyre wheel locked	**47**	**0.070**
Tyre wheel locked	**170**	**0.256**
No tyre no wheels locked	**1**	**N/A**
Tyre no wheels locked	**2**	**N/A**

These results above from testing on the NSW track have some significant implications.

Firstly: The low coefficient of friction for the acetal wheel with no tyre fitted suggests that on many cars wheel slip could be a problem for a significant portion of the race. The use of a tyre for Sun levels above about 30% is indicated. Do ensure you check this for your car if you gain a place at the National Event.

Secondly: The low coefficient of friction for the acetal wheel with no tyre fitted suggests that having steering may not be quite as important on this track as previously thought. The low friction coefficient will reduce the losses incurred in dragging a fixed wheel around the corner making the energy loss due to fixed non steering wheels much lower than on a painted track.

NOTE: The tyre used in testing was a standard 1/16 inch section "O" ring fitted into a groove 0.050 inch deep.

While it is all very well to know the coefficient of friction of the NSW track how can you test your car before actually getting to the track. In order to solve this problem, I have conducted testing using the same car ie. Syndal South Primary car Scorpion.
Tests were conducted in exactly the same way and using the same equipment as was used for the on track tests. Many different surfaces were tested in an attempt to find a common surface that would give a similar friction coefficient to that obtained on the NSW track. Eventually a surface that gave exactly the same results was discovered. Luckily it is a very common surface which is available to everyone.
It turned out to be a glass table top, consequently any glass top table or indeed any sheet of glass can be used to test wheel grip expected on the NSW track. Be very careful these results are for a plastic wheel constructed from acetal (Delrin) tested with and without an "O" ring tyre.
These results are only accurate for this specific material and configuration.

APPENDIX Q:
COMMENTS ON SOLAR PANEL CRACKING

Over the past few years it has become apparent that some types of solar panels have a far greater tendency to cell cracking than others.

This year at the 2011 Australian-International Model solar Challenge during panel power testing we observed a significant number of car panels exhibiting cell cracking, (at least 11 of the 32 panels tested) some with very significant cracks. In general the competitors were not aware of the cell cracking in their panel.

Cell cracking does not always result in a drop in power output, but often will, the wicked part is power drop due to cracking can be intermittent depending on how slight movements within the panel position the crack edges. Consequently the power output of a cracked panel often varies in a random way. I have seen panel power of 8.5 watts drop to 6.75 watts due to cracking. A crack in a critical location can reduce power to zero.

What causes this problem? In the panels typically used in model solar applications there are two major causes, one being straight out mechanical stress due to deflection (bending) of the panel and the other being thermal stress created by the differential expansion of the materials used in panel construction.
Mechanical stresses can be managed by careful handling, but thermal stress is another matter. In order to produce power the panel must be exposed to sunlight and consequently will heat up causing thermal stress. The practice of cooling panels with ice can increase the thermal stress.

What type of panel is most at risk of thermally induced cracking? From my observations any panel with hard front cell encapsulation is likely to be at risk. The Dick Smith three cell modules have a soft front encapsulation, I have never seen any of these crack due to thermal stress, and have tested them by cycling them from a freezer to full sun many times without inducing any cracking. However just by exposing panels with hard front encapsulation to the sun I have observed moderate levels of cracking, testing from the freezer to sunlight produces significant levels of cracking.
The fibreglass encapsulated car and boat panels from Scorpio Technology while having a hard front encapsulation do not suffer from thermally induced cracking due to the fact that the front and rear encapsulation are both fibreglass which has similar thermal expansion rates to the silicon solar cells so there is little or no differential expansion occurring to cause thermal stress and crack the cells.
Commercial glass fronted panels such as the Solarex type also do not suffer cracking, yes they have a hard front but the cells are embedded in a soft flexible plastic material that lets them move without significant stress being generated.

APPENDIX R:

MODEL SOLAR CAR BUYING GUIDE

List of some possible suppliers of components used in Model Solar Car manufacture. I have limited it to suppliers of specialized components that are not widely available.

NOTE: This is not an exhaustive list of all possible suppliers, it is only a list of the suppliers known to me. The list of items supplied does not cover all items available from the listed suppliers it only lists the few that I think are the most important.

If you know of other suppliers not listed here please tell me so they can be included in future lists.

SUPPLIER

CAM art/craft and technology
Ph (03) 9802 4200 www.camartech.com.au
FOR: **Faulhaber motors, R & I Gears and components, Solar panels, Engelec electronics, general tools and materials.**

ERNTEC PTY LTD
15 Koornang Rd. Scoresby Vic. 3132
Ph (03) 9757 4000 www.erntec.net
FOR: **Australian agents for Faulhaber Motors**

MAXON MOTOR AUSTRALIA
Ph (02) 9476 4777 PO Box 1961 Hornsby Westerfield NSW 1635
www.maxonmotor.com
FOR: **Australian supplier of Maxon motors.**

R & I INSTRUMENT AND GEAR CO. (AUST) PTY LTD
385-391 Lower Dandenong Rd. Dingley Vic. 3127
Ph (03) 9551 0956 Fax (03) 9551 0958
Email: rigear@hardmanbros.com.au
FOR: **Gears, wheels ,axles , bearings, fasteners etc.**

SCORPIO TECHNOLOGY Vic Pty Ltd
Ph (03) 9802 9913 Fax (030 9887 8158
www.scorpiotechnology.com.au
FOR: **Electronics units, wheels, bearings, gears, axles, solar panels.**

Tony Bazouni (Mr.)
Ph 0403 665 577
admin@solarfreaks.com
FOR: **Automax electronics unit. Faulhaber motors & other components.**