MODEL SOLAR CAR

DESIGN GUIDE

REVISION 14 27/03/2017

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REVISION 14 JAN 2017

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, 2017 the Car Regulations have been changed significantly from all previous regulations. The solar panel to be used for all races and time trials will now be provided by the organizers. These panels will be calibrated to provide 5.5 watts at full sun. This change allows a significant reduction in the ballast previously required. In fact no ballast will be required if electronics are not used and a standard ballast of 150 grams will be required if electronics are used. This change greatly simplifies the scrutineering required previously by eliminating panel power testing and ballasting. This significant change does not alter the basic principles or the way in which components are utilised. Cars built to these regulations are predicted to have performance at least equal to those built to previous regulations.

Do read and understand the current 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 aspect 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 (Provided by the organisers for racing.)
  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, use the contact form on the Victorian web site.

  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 190 g/ watt is typical on cars utilising electronics and 160 g/watt for cars not using electronics. As with all motorsport maximum power and minimum weight are the goals to aim for.

C. BUILD ACCURACY

Poor build accuracy can easily cost 5 seconds.
Ensure axles are parallel, this is particularly important on a car without steering, if fitted steering must be 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

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 many metres 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 as it exits the first corner. It varies with velocity squared so is high for all the second lap of a two lap race. Typically, the aerodynamic drag is much greater than the rolling resistance as the car crosses the finish line.
For a car built to the 2017 regulations in high Sun a win by up to 7 metres is to be expected by a car with excellent aerodynamics when compared to a car with poor aerodynamics, assuming all other features are the same.
Most important is the option of the National event being run as a pursuit event. This means that many laps will be conducted at high speed with the consequence that good aerodynamics if far more critical than ever before.

E. TESTING

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

F. ENERGY UTILISATION

It is important to use as much as possible of the energy collected by the solar 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 appropriate 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 solar panel to be used in all races will be provided by the organisers it will be issued just before each race and collected for use by the subsequent competitors immediately on the completion of the race.
The panels that will be provided are fully detailed in the regulations. Your car must be designed to function with a panel having the electrical characteristics of these panel as well as the physical size and mounting method.

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 current regulations still allow simple cars to be constructed, in the simplest format they could be a ladder type frame chassis with a solar panel on top and the required cargo mounted in a suitable manner. This type of car is very simple to build and will have good performance due to its light weight. However, a more complex slightly heavier car employing a body with a good low drag aerodynamic shape would be expected to have even better performance.

Electronics or not? The ballast required for electronics equipped cars is intended to give the non-electronics car an advantage as reward for the extra difficulty. 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 10%.

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. While the hill shape of the Victorian track has been improved to increase the take off speed cars will still be running fast enough to take off over the top of the hill. Irrespective of track condition roll over or dislodgment of guides in the corners is highly probable as the cars are now running at near the theoretical roll over speed. 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?

MAJOR COMPONENTS

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, (Inox is good.) 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 later 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.)

Do test and evaluate whether your car needs a tyre, and if required, at what Sun level it should be fitted.

Now to number of wheels and positioning. There have been many three wheel cars over the years. Is there an advantage in using only three wheels on your car? The answer is yes but there is also a disadvantage. The advantage is a slight reduction in power used in the guide system.
A typical four wheel car with one wheel driving will be experiencing a torque effect due to the one driving wheel pushing the car trying to drive it in a circle. This effect is counteracted by the guide rolls pushing on the guide rail. Calculations indicate that this costs about 2% of the energy used by the car.
A three wheel car with the drive wheel near to the centreline has significantly reduced torque effect with consequent reduction in energy used in the guides leaving more energy to drive the car.

There is a way to run a four wheel car without this torque effect and that is to drive two wheels one each side this removes the torque effect. This set up however requires a differential to reduce the losses that would otherwise occur when cornering.
Differentials can be quite inefficient so care is needed if using one.
About two years ago a student came up with a good idea that worked well. He drove the axle and fitted one way bearings into each wheel on that axle. This gives differential action without the losses with the advantage of a four wheel car.

In 2016 the winning car used a geared differential designed and built by the student.

The main advantage of a four wheel is stability. When cornering at speed a four wheel car is in the order of 35% more resistance to rolling over than a three wheel car.

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.

(Note: It is assumed that a gear reduction will be used in preference to belts. Belts when used in large installations can have efficiencies as high as gears, but when scaled down to the size required for a model solar car cannot match gears for efficiency.)

You need to reduce motor speed which can be in the order of 8000 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

3. SOLAR PANEL

General:

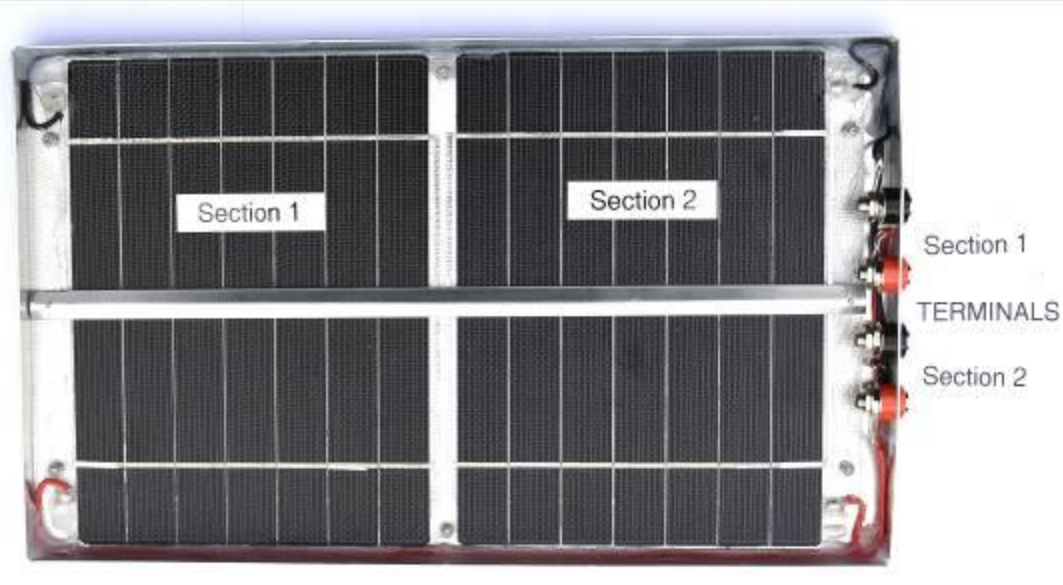
The regulations for 2017 have changed significantly. The solar panel to be used for all racing and time trials will be provided by the organisers. The panel will be issued immediately before the trial or race and collected immediately on completion of the trial or race. **Refer to the regulations.**

This means that for any practice the competitor must provide their own panel. This should not present any significant problems as most competitors are already using the Scorpio no. 26 panel which is the panel that will be supplied by the organisers.
Details of the panels supplied taken from the regulations are given below.

8.4 Source of power
In all races the car must only use the solar array provided by the organisers and must operate only on the energy provided by the solar array during the course of the race. Details of this unit are included below. As this array will be provided immediately before a race and collected immediately after, car design must allow for installation and removal in less than 30 seconds.

Practice will be conducted with a solar array provided by the competitor. It is strongly suggested that this array have a maximum nominal power of 6 watts and similar characteristics to the panel which will be provided for racing.

The array provided by organisers is a Scorpio Number 26 solar panel mounted on an aluminium backing for protection see below for details.



Dimensions:
Overall dimensions, length 276 to 280 mm not including the terminals, width 165 to 170

mm maximum height of sides 20 mm at terminal end other sides 12 mm.
Weight 240 plus or minus 15 grams.

Terminals:
Jaycar banana chassis sockets catalogue PS-0406 (red) PS-0408 (black) are mounted on one end.
The two sections of the panel have their positive and negative terminals brought out to these banana sockets allowing for connection in either series or parallel as desired by the competitors.

The banana sockets are spaced at a nominal 20 mm (+ or – 2mm) apart.

Mounting:

Velcro loop tape 25 mm wide is available all around the outer edge.

Array - typical electrical output at AM 1.5 25 Deg. C: (In series)

Volts open circuit	*8.64*
Volts at maximum power	*6.88*
Current at maximum power amps	*0.808*
Current short circuit	*0.9*
Maximum power watts	*5.56*

Solar panel motor and electronics performance

The following graphs have been included to provide motor performance data when powered by a solar panel conforming to the 2017 regulations.
This data is intended to be used in the mathematical simulation to aid in car design evaluation.
The test results were carried out using a Scorpio No. 26 solar panel a Faulhaber 2232 6 volt motor, Automax and Scorpio electronics units, as these are the components most commonly used in car construction. Data for the motor without electronics is also included.

The tests were all conducted with the motor driving a "wheel" using R & I gears at a reduction of 4:1. Torque and RPM values were measured on this "wheel" then converted to the values on the motor shaft which were used to prepare the graphs.
The torque versus RPM graphs are the values on the motor shaft.
Consequently, **when using this data in the simulator you must insert the gear reduction ratio you are using but the transmission efficiency should be set at 100% as the gear losses are already included in these test results.**

Data from graph 1 below for Automax Electronics to be used in simulations:
Faulhaber 2232 6 volt Motor- on One Scorpio No.26 Panel 4:1 R & I reduction gears.

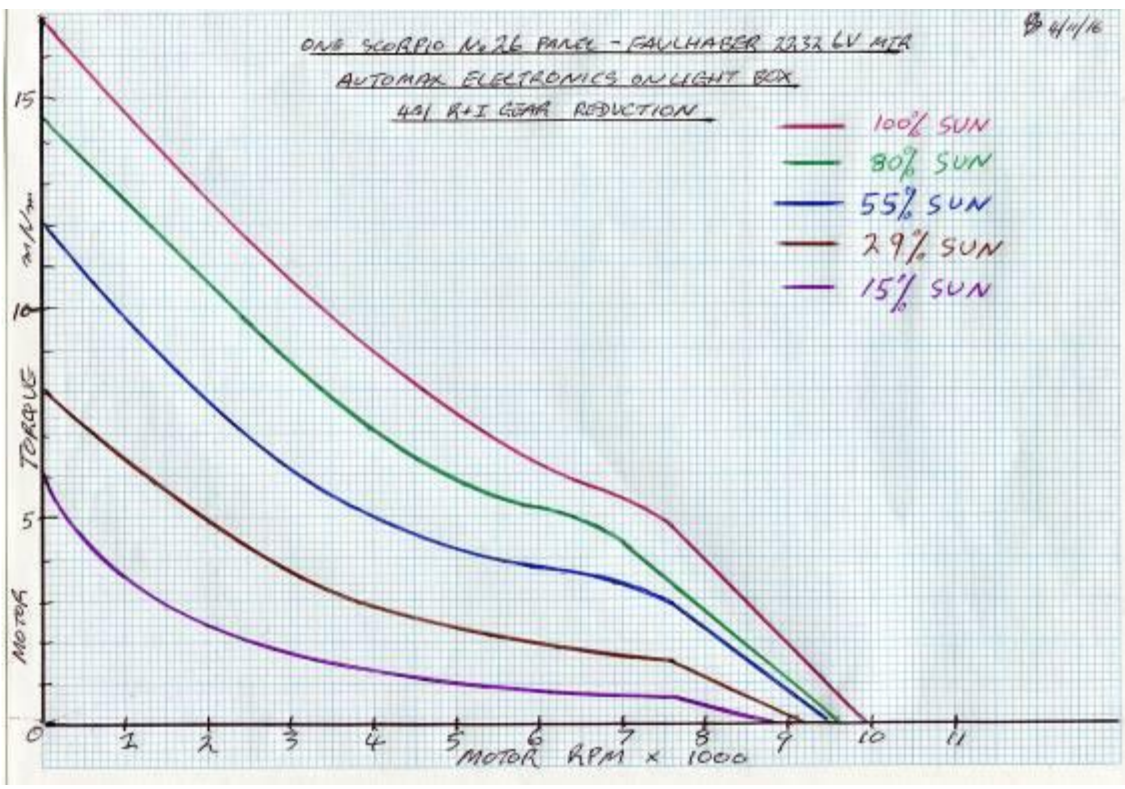
100% Sun	Finish RPM	Start Torque mNm
Section 1	4700	16.0
Section 2	7500	7.6
Section 3	10000	5.0

80% Sun	Finish RPM	Start Torque mNm
Section 1	4000	14.5
Section 2	7000	6.8
Section 3	9700	4.4

55% Sun	Finish RPM	Start Torque mNm
Section 1	3200	11.5
Section 2	7700	5.5
Section 3	9500	2.9

29% Sun	Finish RPM	Start Torque mNm
Section 1	3300	7.8
Section 2	7700	3.0
Section 3	9200	1.4

15% Sun	Finish RPM	Start Torque mNm
Section 1	2500	5.5
Section 2	7200	1.6
Section 3	8900	0.7



Graph 1 Automax electronics.

Data from graph 2 below for no electronics Panel connected in Series to be used in simulations: Faulhaber 2232 6 volt Motor- on One Scorpio No.26 Panel 4:1 R & I reduction gears.

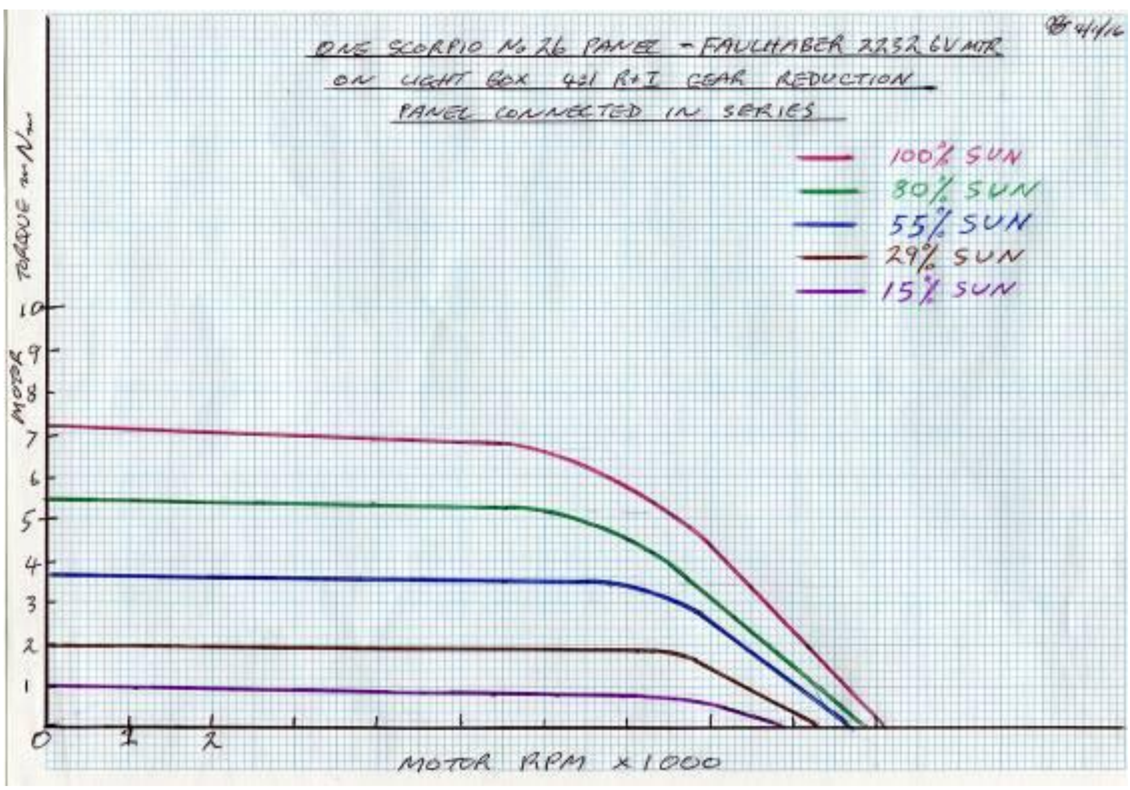
100% Sun	Finish RPM	Start Torque mNm
Section 1	5600	7.1
Section 2	7600	6.7
Section 3	10200	5.0

80% Sun	Finish RPM	Start Torque mNm
Section 1	5800	5.4
Section 2	7400	5.2
Section 3	9900	4.0

55% Sun	Finish RPM	Start Torque mNm
Section 1	6300	3.6
Section 2	7700	3.5
Section 3	9700	2.8

29% Sun	Finish RPM	Start Torque mNm
Section 1	4000	1.95
Section 2	7600	1.9
Section 3	9300	1.8

15% Sun	Finish RPM	Start Torque mNm
Section 1	4000	1.0
Section 2	7700	0.8
Section 3	8900	0.7



Graph 2 no electronics panel connected in series.

Data from graph 3 below for no electronics panel connected in parallel to be used in simulations:

Faulhaber 2232 6 volt Motor- on One Scorpio No.26 Panel 4:1 R & I reduction gears.

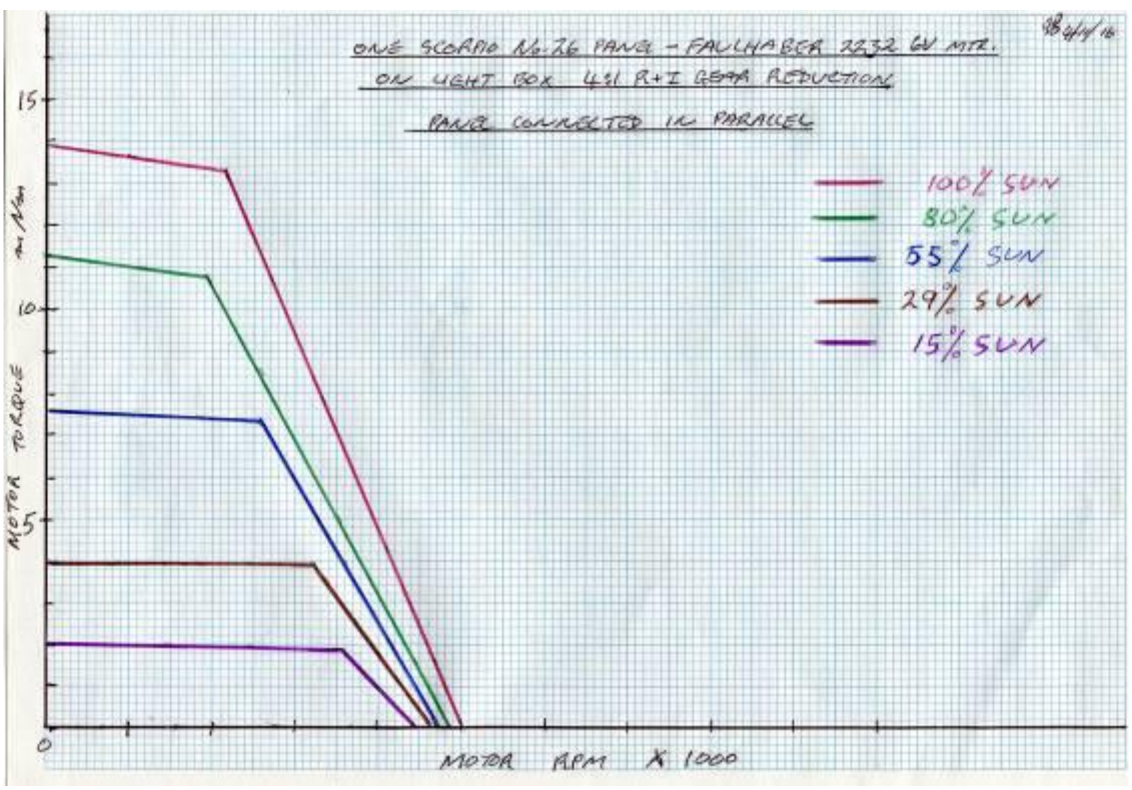
100% Sun	Finish RPM	Start Torque mNm
Section 1	2100	14.0
Section 2	2900	13.4
Section 3	5000	10.0

80% Sun	Finish RPM	Start Torque mNm
Section 1	2000	11.2
Section 2	3000	9.7
Section 3	4900	7.0

55% Sun	Finish RPM	Start Torque mNm
Section 1	2300	7.6
Section 2	2800	7.4
Section 3	4800	6.8

29% Sun	Finish RPM	Start Torque mNm
Section 1	2000	4.0
Section 2	3200	3.95
Section 3	4700	3.9

15% Sun	Finish RPM	Start Torque mNm
Section 1	2000	2.0
Section 2	3600	1.9
Section 3	4400	1.8



Graph 3 no electronics panel connected in parallel.

Data from graph 4 below for Scorpio Electronics to be used in simulations:
Faulhaber 2232 6 volt Motor- on One Scorpio No.26 Panel 4:1 R & I reduction gears.

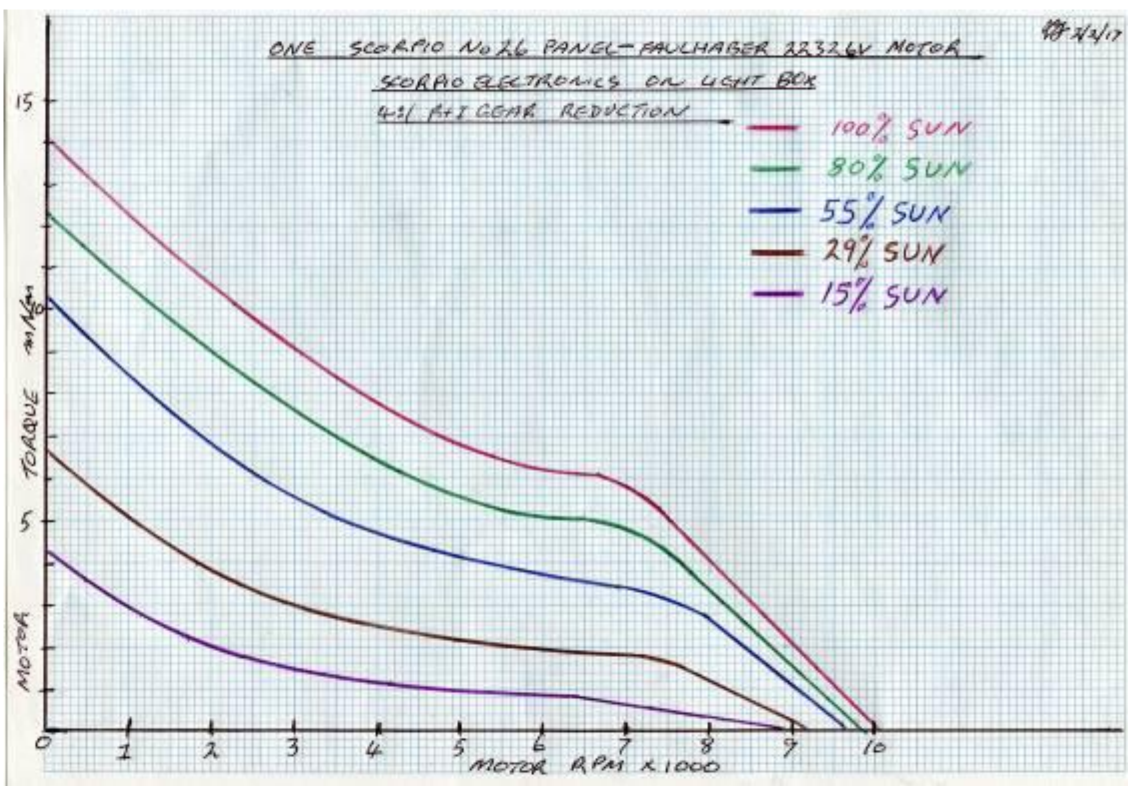
100% Sun	Finish RPM	Start Torque mNm
Section 1	4300	14.8
Section 2	7050	7.3
Section 3	10000	5.9

80% Sun	Finish RPM	Start Torque mNm
Section 1	4400	12.0
Section 2	7200	5.7
Section 3	9850	4.8

55% Sun	Finish RPM	Start Torque mNm
Section 1	3850	9.6
Section 2	7650	4.6
Section 3	9650	3.1

29% Sun	Finish RPM	Start Torque mNm
Section 1	3200	6.0
Section 2	7400	2.6
Section 3	9200	1.7

15% Sun	Finish RPM	Start Torque mNm
Section 1	2600	4.0
Section 2	6500	1.5
Section 3	9000	0.8



Graph 4 Scorpio electronics.

NOTE:

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 the panel to avoid shading.

Solar panel power output falls as the panel temperature increases so do not leave the panel exposed to the Sun for longer than necessary prior to the race starting.

Ballast & your Solar Panel: Only required if electronics are used.
For stability, 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.

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 35% 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 2% of the maximum current available from a typical cars solar panel in full sun light.

Most cars (over 90%) use the FAULHABER 2232 6 Volt motor These motors are available in Melbourne from Scorpio Technology and Erntec Australia. Another 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)

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:

- The Faulhaber 2232 6 volt motor has a maximum efficiency of around 86%. Do note that this efficiency varies depending on the operating point, efficiency will often be lower, zero if the motor is stalled. Check the manufacturer's specifications for your particular motor.

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

CRITICALLY IMPORTANT:
Avoid stalling the motor for any length of time (more than a few seconds), this is particularly important at high Sun when using an electronics unit or if testing with a battery as the high current through one section of the commutator will cause overheating. The overheating can quickly damage or destroy the motor.

Basic data for the Faulhaber 2232 6 volt motor:

The Faulhaber 2232 6 volt motor is used by most car teams and by the majority of advanced boat teams.

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 lower rotor resistance and higher torque constant resulting in lower losses, better acceleration and faster race times.

Manufacturers data for this motor follows.

P

FAULHABER

NEW

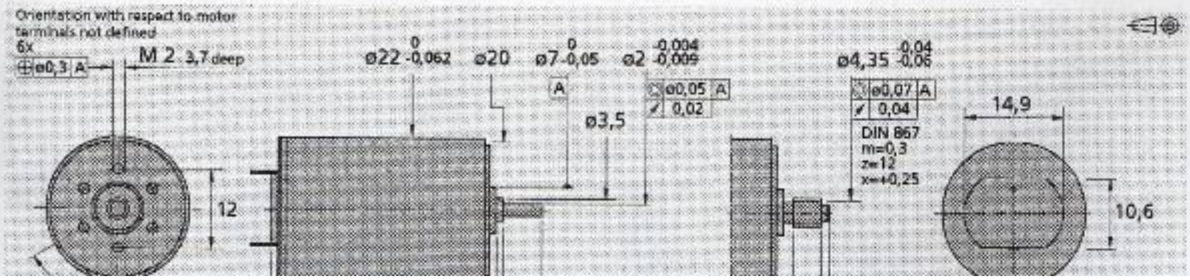
DC-Micromotors — 10 mNm

Precious Metal Commutation

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

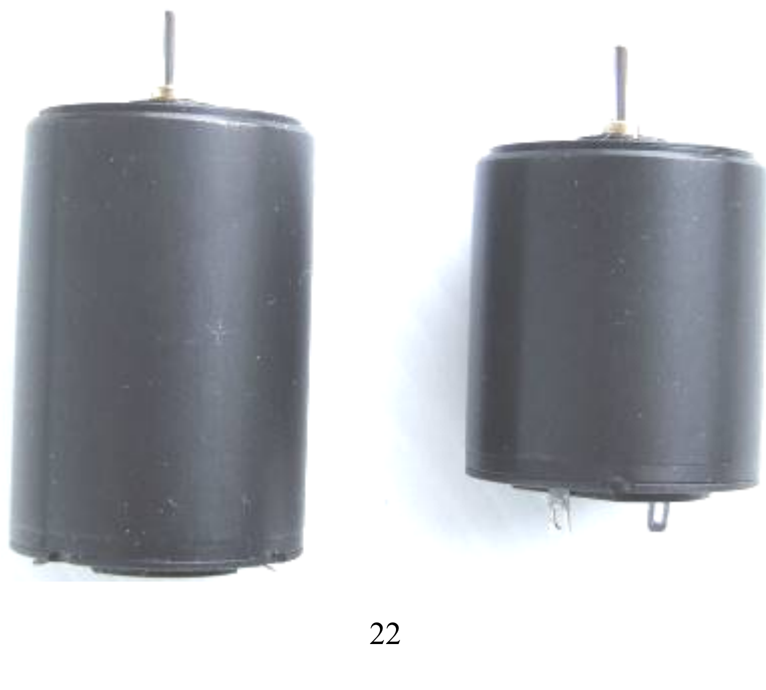
Series 2232 ... SR

		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	10^3rad/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

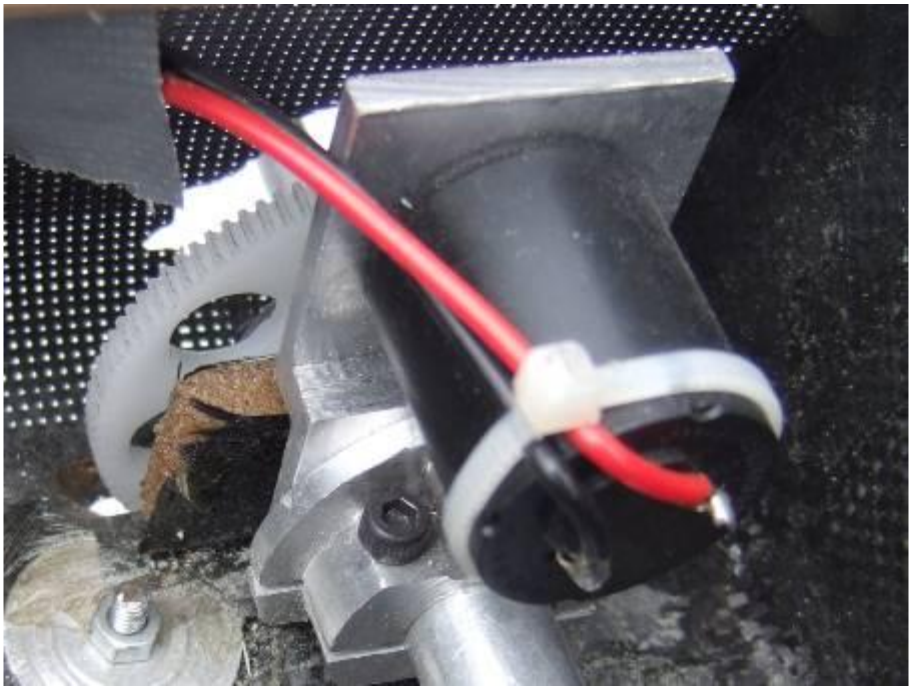


FAULHABER 2232 MOTOR

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 manufacturer's 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.

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.
Remember, weight has a significant effect on performance. In terms of consuming energy produced by the solar panel.

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 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.)
The guide channel is nominally 16mm wide by 13mm high, it is clearly visible in the photograph following as is an orange joining piece in the channel.

To keep friction low, use ball bearings either alone or supporting a roller wheel.
Remember a car capable of a sub 20 second run will be experiencing a side force close to the car's weight while traversing the corner in high sun. The guides consume about the same amount of power as the wheels do over the course of a race. 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. There will be impact loads acting on the guides as they 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 disastrous 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 7 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.
The hill has been modified since this photograph was taken to increase take off speed, however take off is still probable on the fastest cars.

8. ELECTRONICS or NO ELECTRONICS

Typically, most cars use an electronics system of some sort. The question is.

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

The regulations give a car operating without electronics a slight advantage. The purpose of this is to encourage more teams to operate cars without "the magic black box".

Inexperienced teams and particularly new starters would be advised to initially run with electronics then consider deleting it as their experience and competence increases.

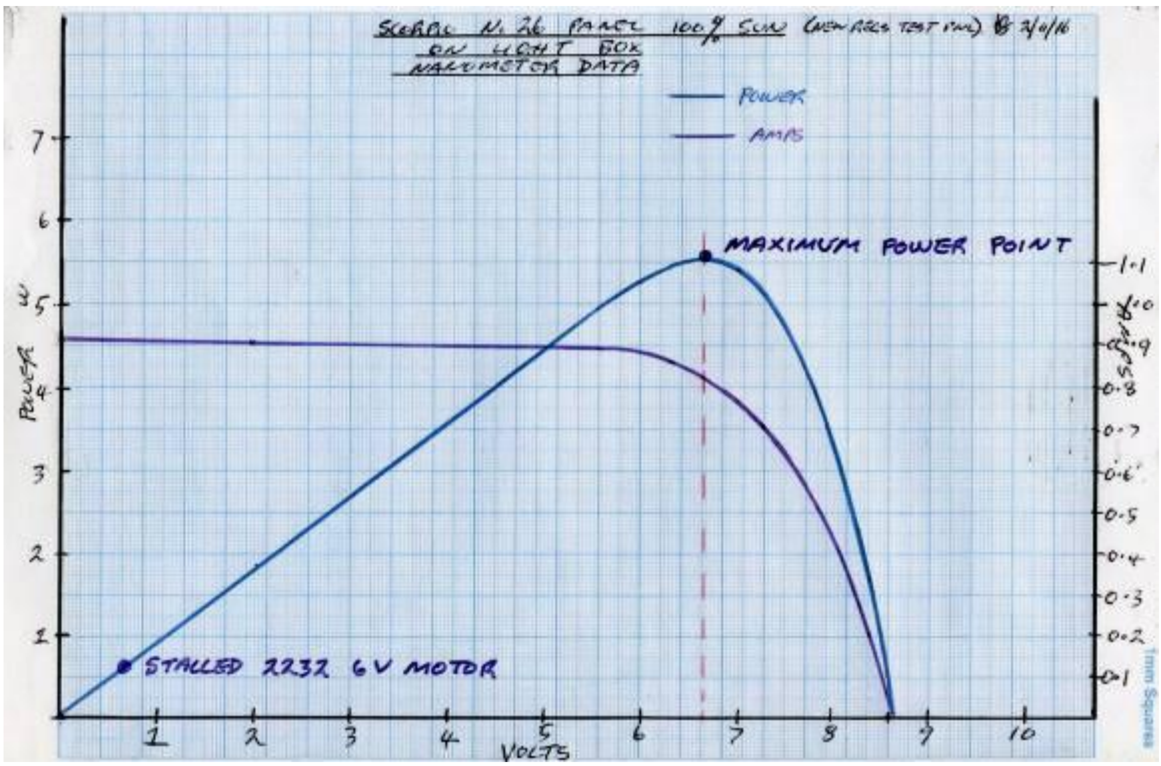
OPERATING WITH ELECTRONICS:

There are only two readily available electronics units, both are distributed by Scorpio Technology. One unit, the Automax is plug and play, it automatically finds and holds the solar panel at its maximum power point. The other unit is supplied in kit form and requires assembly. This unit requires manual adjustment to obtain the solar panel maximum power point. You should consult Scorpio Technology for detailed information.

A good general description of an electronics unit is. **Input Controlled DC to DC down Converter.**

Why do I want to control the input voltage?

Examine the graph below.



Output from a single Scorpio No. 26 panel ie. that specified in the 2017 regulations.

The maximum power point of the panel and the point where a stalled Faulhaber 2232 6 volt motor will be are depicted on the panel power graph. This is without electronics. The stalled motor is taking only about 10% of the available panel power due to the fact that it has pulled the panel voltage down to less than one volt. Power = Volts × Amps.

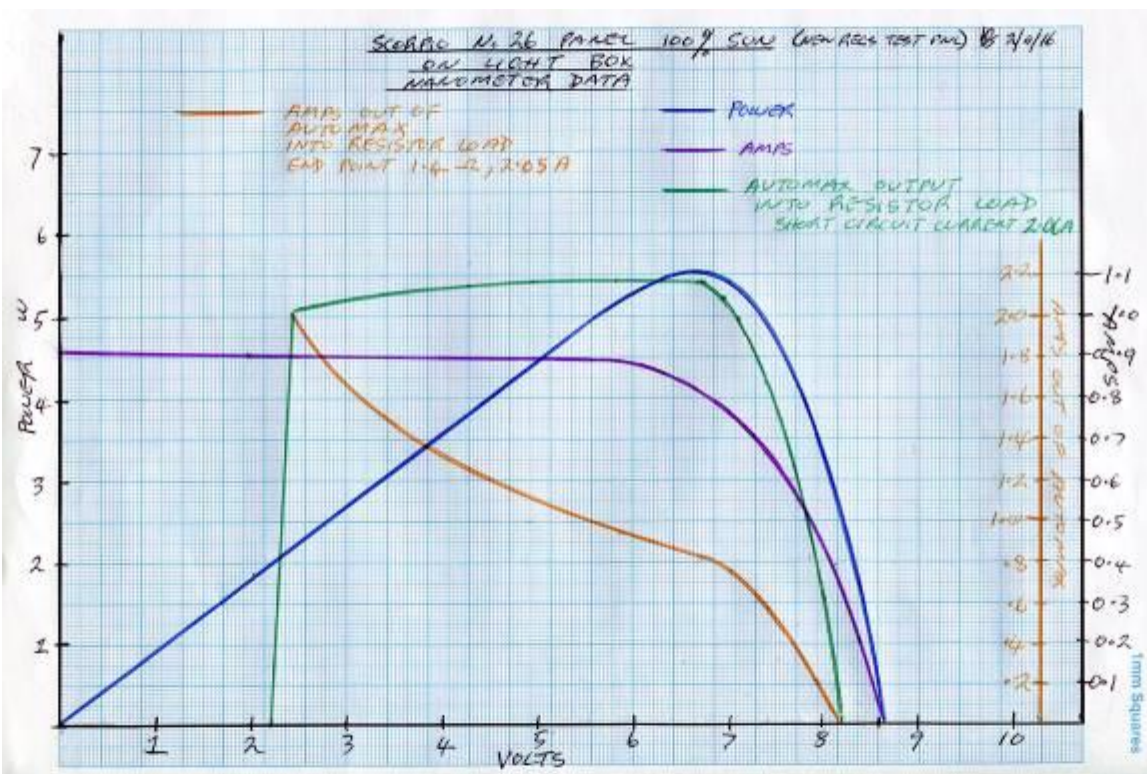
As the motor RPM increases so does its effective terminal resistance** allowing its operating point to move up the power curve till it reaches the maximum power point, that is provided the load on the motor shaft will allow this.

** The effective terminal resistance rises because the motor behaves like a generator additional RPM causes the back EMF (voltage) to rise making the motor appear to have a higher resistance.

A load that is too high will hold the motor to an operating point below the maximum power point, a load that is too low will allow the motor to operate to the right of the

maximum power point, again below the maximum power point.
The motor load must exactly match the power available from the solar panel at its maximum power point if all the power available from the panel is to be transferred to the motor.
A change in Sun level results in a different maximum power being available from the solar panel, the motor load must be adjusted to this new available power. The adjustment if not using electronics is accomplished by changing the gear ratio between the motor and drive wheel(s).
This requirement to frequently change gears to maintain power match, and what is more, to know what gear ratio should be used makes operating without an electronics unit difficult.

The Automax electronics being fully automatic in operation finds the maximum power point of the panel irrespective of Sun level and maintains this point by varying the power to the motor using pulse width modulation.
That is, it switches the load on and off at a rate of about 35,000 times per second, varying the on time to limit the power sent to the load to the maximum power available from the panel. This ensures the panel is always at the maximum power point and sending this maximum power to the motor, provided of course the gear ratio from motor to wheel provides sufficient load to use all the power.
The circuit operation also maintains the power it sends to the load at near panel maximum power value over a wide voltage range. See graph below.



The green plot depicts the power sent to the load by the Automax electronics. The orange

plot depicts the current sent to the load by the Automax electronics.
What this means for your car is that as the motor RPM drops the torque increases due to the current increase. At the same time, close to the maximum power available from the panel is sent to your motor over a very wide voltage range, remember voltage = motor RPM so a wide RPM range is available to your car, reducing the need for gear changes when compared to a car running without electronics.
The negative is that as the motor voltage drops so does its efficiency, so not all the power shown in the green graph is available as power to drive your car as the voltage drops.

A word of caution, while operation with electronics reduces the need for frequent gear changes it is still necessary to change gears in order to obtain maximum performance. Indication from simulations suggest 2 or so gear changes will be required.

OPERATING WITHOUT ELECTRONICS:

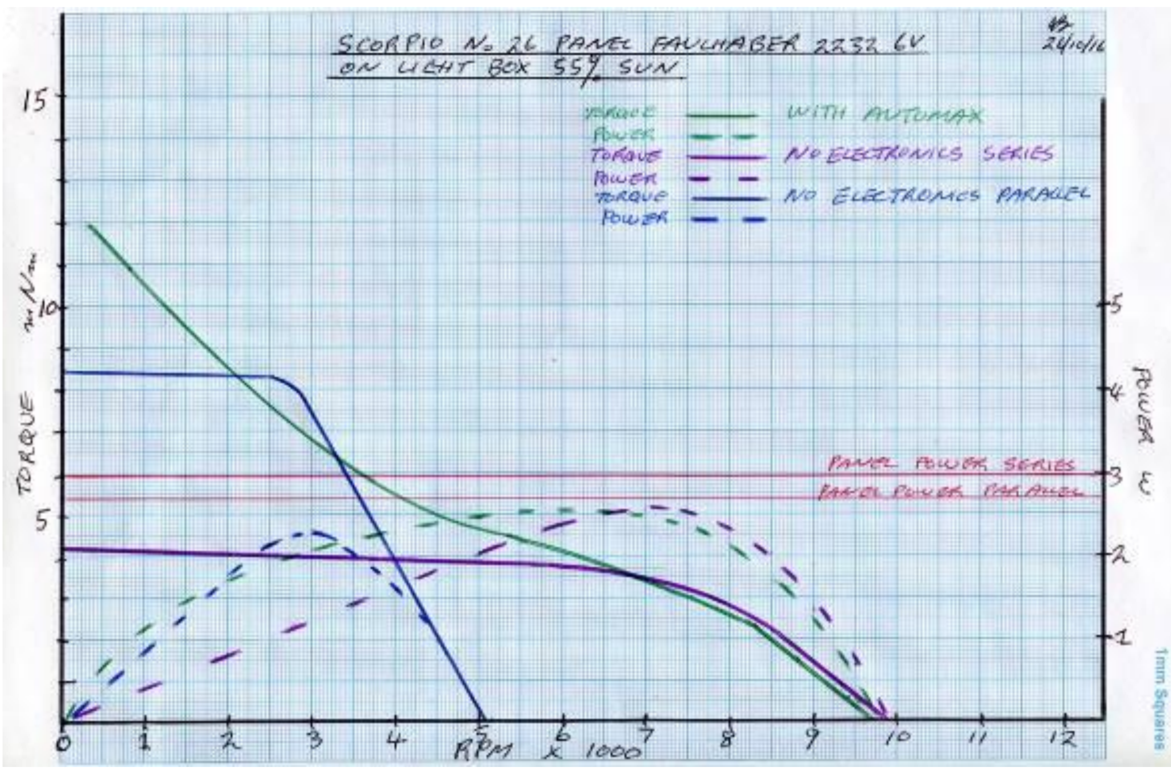
As indicated previously operation without the use of electronics requires more frequent gear changes.
There is the option of changing the solar panel wiring configuration from series to parallel which by halving the voltage halves the motor RPM, effectively a 2:1 reduction. Use this technique with caution as when operating at lower voltage the motor efficiency drops as well as the power available from the solar panel, due to the increased current causing resistive losses to increase significantly, they vary with current squared.

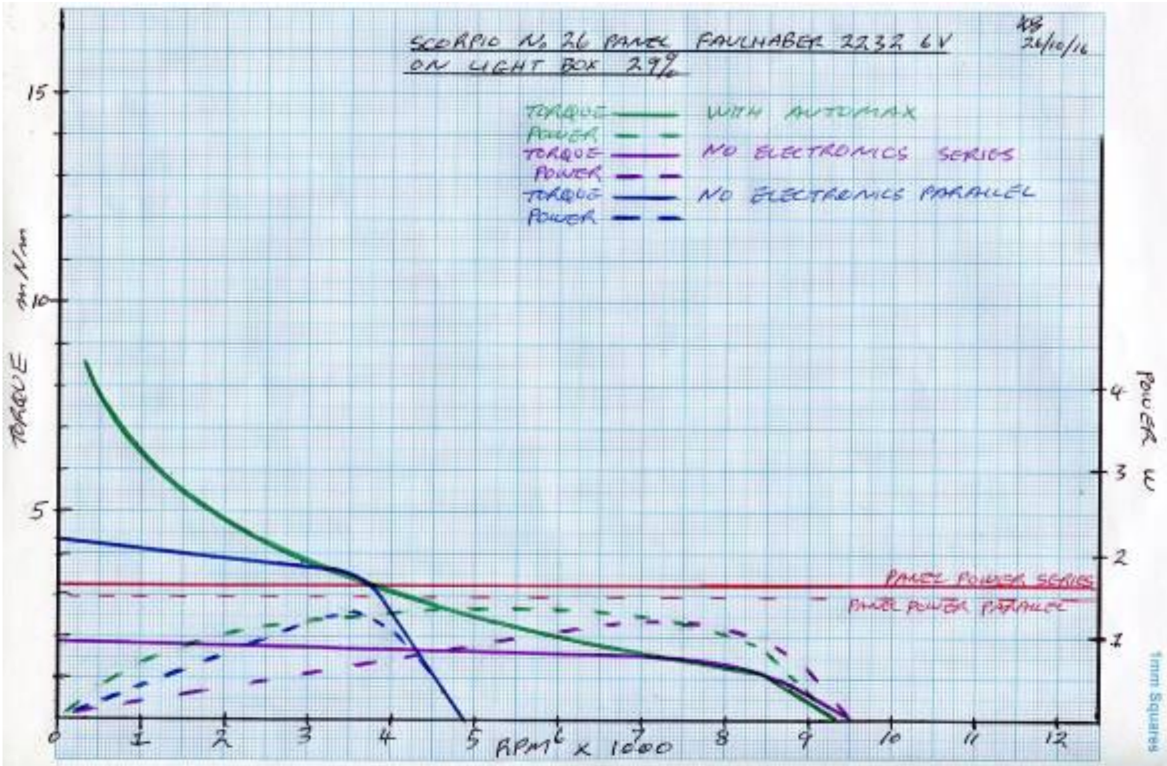
Except at low Sun levels it is best to change gears instead of wire the solar panel in parallel.
The graphs below show how the power out of the motor and the solar panel vary when the panel is connected in series or parallel.

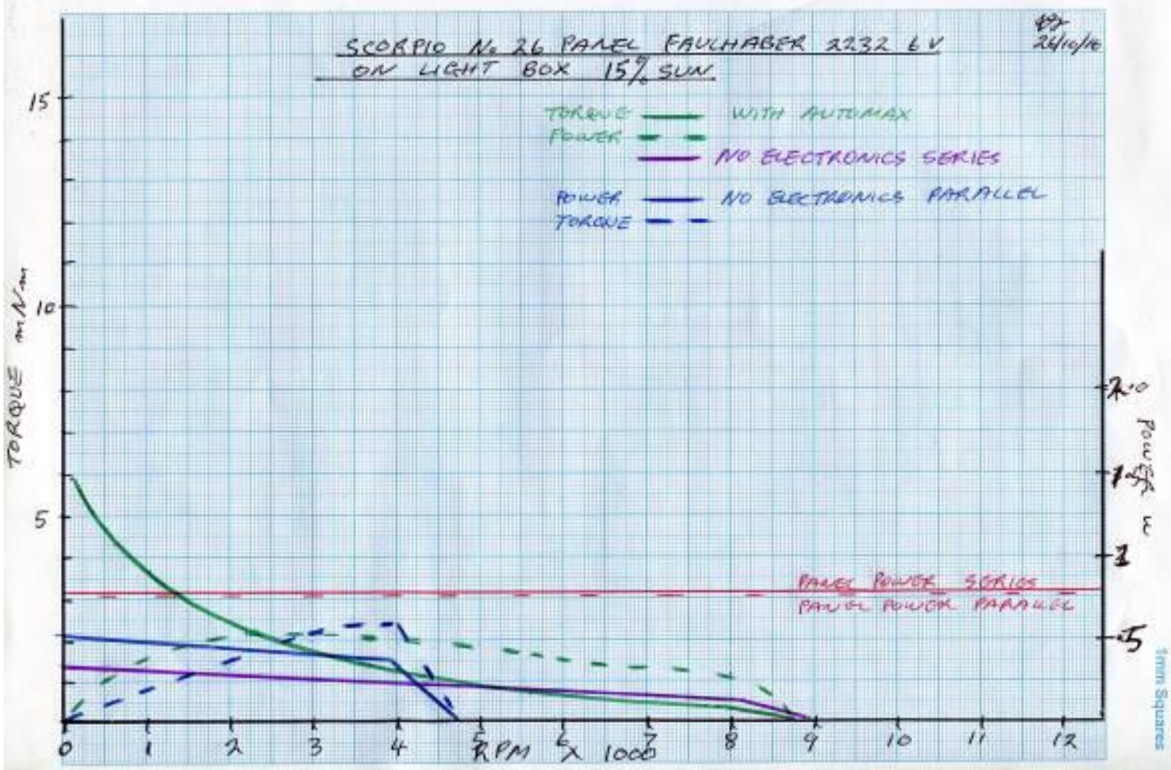
Note these graphs do not include the gear losses as do the graphs in the solar panel motors and electronics performance section previously. Use the previous data in the simulator.

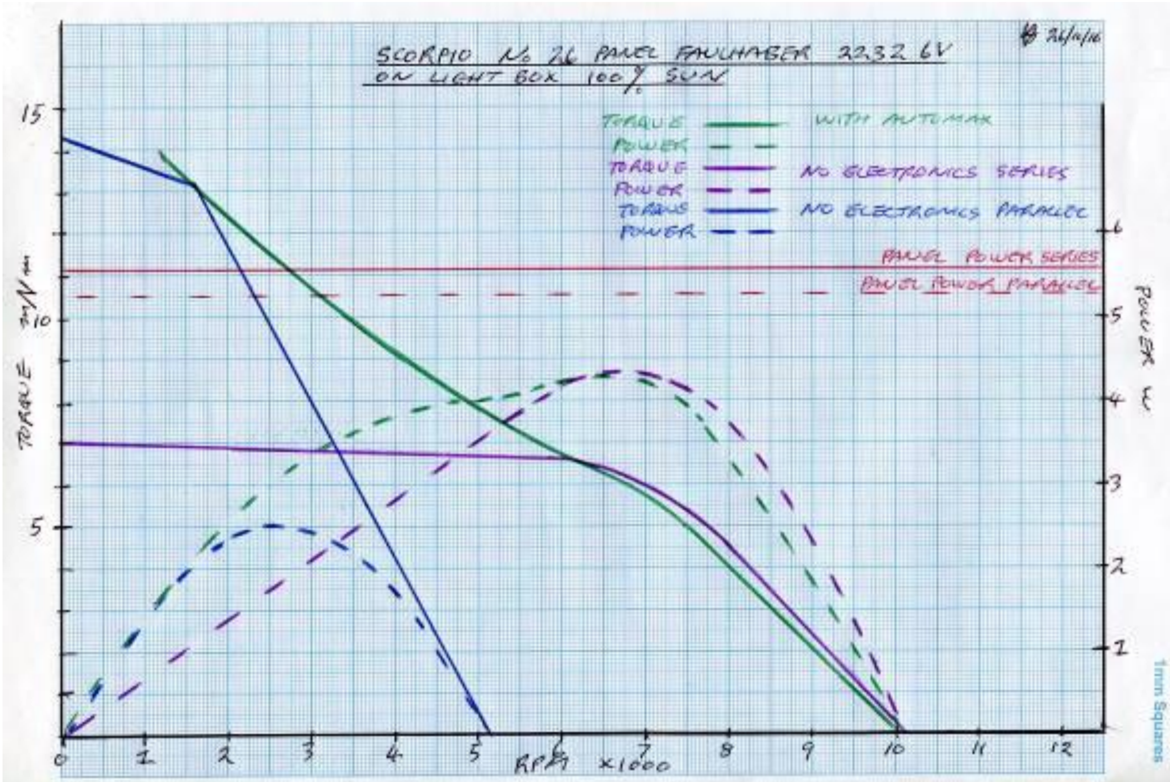
The second important feature shown on these graphs is the motor RPM at maximum power. With the panel configured in series this RPM value is around 7000 RPM at all Sun levels.
What does this mean for your car?
A simple view of the setup requirement when running without electronics is the need to select a gear ratio that holds the motor as near as possible to this RPM value for the maximum time possible during a race. Either above or below this number the maximum available power will not be driving the car.
At a particular Sun level this gear ratio as well as letting the motor run at this 7000 RPM point must also be driving the car at a speed which just uses all the available power.
Once the car has accelerated up to maximum speed and is running on the flat the power is used to overcome air drag and rolling resistance of the wheels, guides and their bearings.

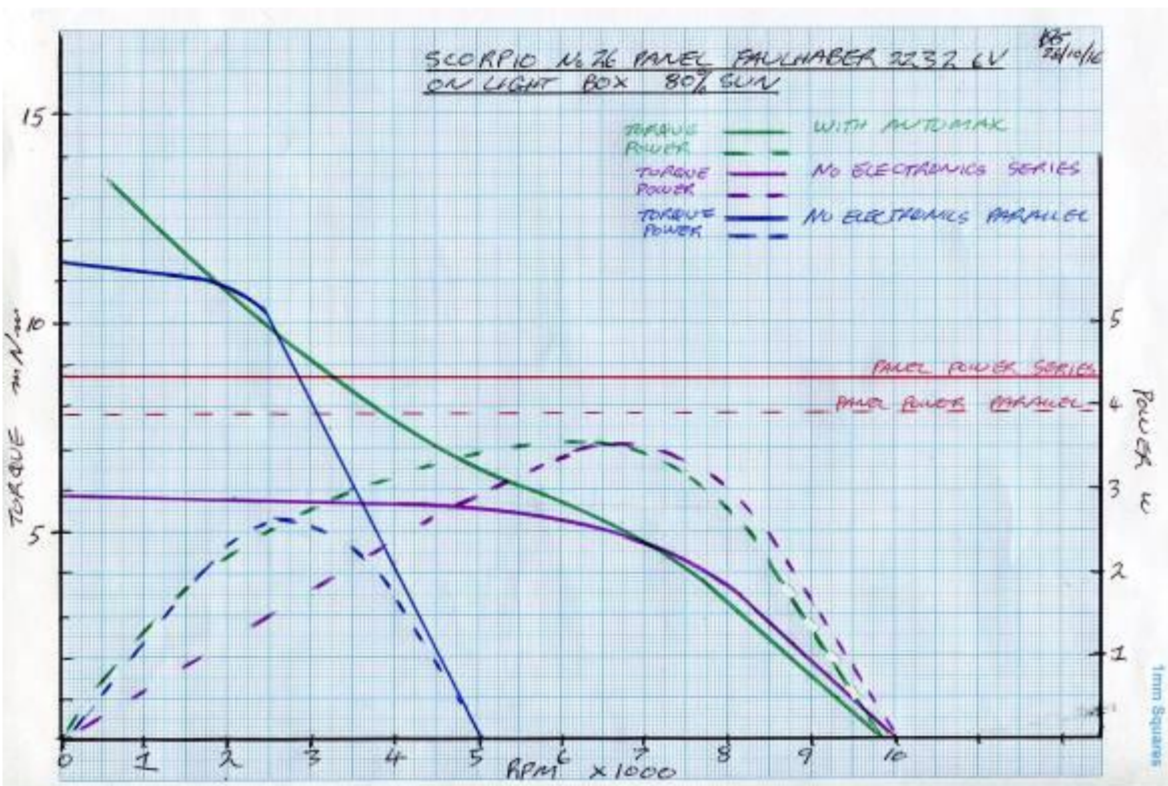
The rolling resistance of the wheels depends on car weight so can be considered constant. The rolling resistance of the guides is practically zero when the car is on a straight section of track, but when cornering varies with angular velocity squared, meaning the faster the gar goes the greater is this drag force. Double the car speed and this force increases fourfold.
The air drag also, is speed dependent and varies with speed squared as does the cornering drag described above.
Selecting the gear ratio that meets these requirements at each particular Sun level is difficult.
Using the excel simulation is the best way to obtain an indication of the best gear ratio to use but track testing of your car to determine the optimum gear ratio is essential.




SCORPIO No 26 PANEL FAULHABER 2232 6V
ON LIGHT BOX 29%
26/10/16
TORQUE — WITH AUTOMAX
POWER
TORQUE — NO ELECTRONICS SERIES
POWER
TORQUE — NO ELECTRONICS PARALLEL
POWER
TORQUE mNm
POWER W
RPM x 1000
PANEL POWER SERIES
PANEL POWER PARALLEL
1mm Squares


SCORPIO No 26 PANEL FAULHABER 2232 6V
ON LIGHT BOX 15% SUN
26/10/16
TORQUE — WITH AUTOMAX
POWER
NO ELECTRONICS SERIES
POWER — NO ELECTRONICS PARALLEL
TORQUE
TORQUE mNm
POWER W
RPM x 1000
PANEL POWER SERIES
PANEL POWER PARALLEL
1mm Squares


SCORPIO No 26 PANEL FAULHABER 2232 6V
ON LIGHT BOX 100% SUN
TORQUE
POWER
WITH AUTOMAX
NO ELECTRONICS SERIES
NO ELECTRONICS PARALLEL
PANEL POWER SERIES
PANEL POWER PARALLEL
TORQUE mN m
POWER W
RPM x1000
1mm Squares


SCORPIO No 26 PANEL FAULHABER 2232 6V
ON LIGHT BOX 80% SUN
TORQUE
POWER
WITH AUTOMAX
NO ELECTRONICS SERIES
NO ELECTRONICS PARALLEL
PANEL POWER SERIES
PANEL POWER PARALLEL
TORQUE mN m
POWER W
RPM x1000
1mm Squares

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 g 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 g. 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 lightweight 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. Typically an average three wheel car is about 35% less stable in roll over while cornering compared to the four wheel car with wheels at each corner.

As a guide, calculations indicate that a car with its centre of gravity 80mm above the track will roll or disengage the guides on cornering at about 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 car's 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.

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. 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 require a cargo to be carried if it is not contained within an aerodynamic it 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.

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 g 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 you are happy 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. Start with the car's centre of gravity 160 mm above ground level, the car should 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 that is not driving anything and record the current drawn, the voltage applied to the motor should be 6 volts. 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.

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 scrutineering 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 aerodynamic 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 significant win for the aerofoil shape car.

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 × 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.

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 typical car considering car area together with the maximum expected velocity these forces will generally be so low as to be ineffective. There is always some drag force associated with lift.   Not significant and potentially counter-productive.

18 MATHEMATICAL SIMULATION

A mathematical Simulation for a model solar car has been written in Excel. It uses Newtonian mechanics to calculate the predicted performance of a car.

Providing accurate input data is used the predicted performance has been found to be within 3% of that measured in track testing.

The simulator is particularly useful in playing the what if of solar car design. It allows designers to evaluate the probable effect of design changes without building a car and conducting tests.

It is also invaluable in predicting the approximate gear ratio required.

The Excel spreadsheet and a full description of the operation of the simulation is available separately.

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 $V = R \times I$).

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 rapidly dropping to near zero.

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 6 Volt supply would be 7.4 Amps according to Ohms law, providing the power source is capable of supplying this current.

Assume the motor is connected to a Scorpio No. 26 panel (5.5 Watts output) capable of supplying only 0.9 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 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. 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: CAR ENERGY USE

Knowing where the car uses the energy provided by the solar panel can be an invaluable tool in determining which aspects of the car design should be improved in order to achieve optimum performance.

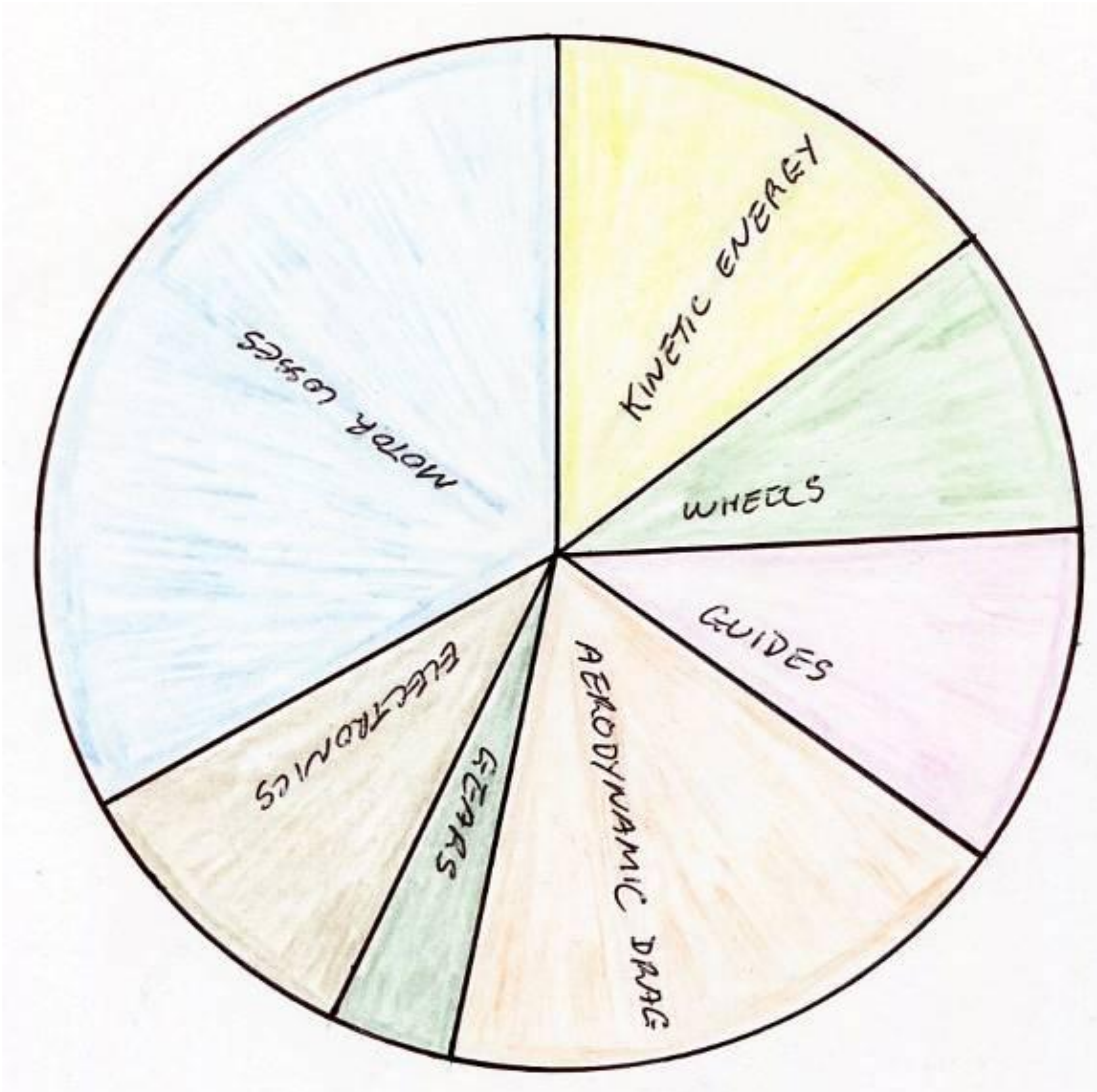
The following energy calculations are based on a car having the characteristics shown in the data entry area of the Simulator below at full Sun. Obviously, the energy use distribution will vary depending on the cars individual characteristics, however the data shown below can be safely used as a guide to energy usage in a typical car with electronics and powered by a single Scorpio No. 26 panel as described in the 2017 regulations.

Model Solar Car Simulator

Parameters				Results	
Car Name:	Standard Evaluation Car			1 LAP RACE	
Sun Power:	1 panel 100% Sun			Time:	17.4
Motor Type:	Faulhaber 2232 6 volt BHHS V4.1 electronics	Automax		Velocity:	7.628
Guide Roll CoEf:	0.015	Wheel Slip Coeff	1.2	Mtr RPM:	7967
Mass(kg):	0.95			Air Drag	0.233
Wheel Roll RS:	0	Roll CoEf:	0.097	Rolling R:	0.09215
Air Drag Coefficient:	0.004	Steering(Yes/No):	NO	Mtr Torque:	3.994
Wheel Diameter(mm):	64	Steering Drag:	0.13		
Acceleration Gear Ratio:	7.14	Change RPM:	0	2 LAP RACE	
Final Gear Ratio:	3.5			Time:	29.25
Transmission Effy:	92			Velocity:	7.694
Motor Tourque:	Finish RPM:	Start T(mNm):	Formula	Mtr RPM:	8036
Section 1:	4900	15.5	0.0015714	Air Drag	0.237
Section 2:	7200	7.8	0.001	Rolling R:	0.09215
Section 3:	10000	5.5	0.0019643	Mtr Torque:	3.857

The areas where the energy available from the solar panel is used are depicted in the following pie chart.

Note this is for a car using electronics for a car without electronics the car mass is lower as ballast is not required so the kinetic energy will be slightly lower, the electronics losses will be gone but the motor losses will increase somewhat as it will be operating for a longer time away from its most efficient point.


KINETIC ENERGY
WHEELS
GUIDES
AERODYNAMIC DRAG
GEARS
ELECTRONICS
MOTOR LOSSES

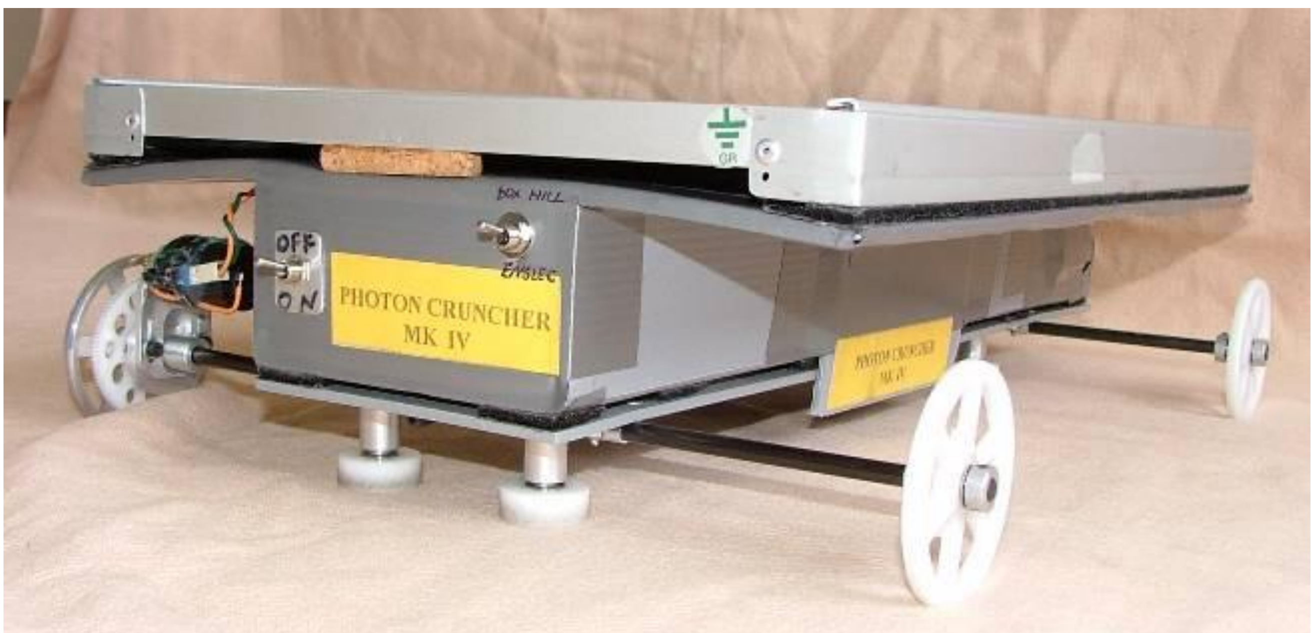
APPENDIX C: ASSEMBLY OF R & I COMPONENTS

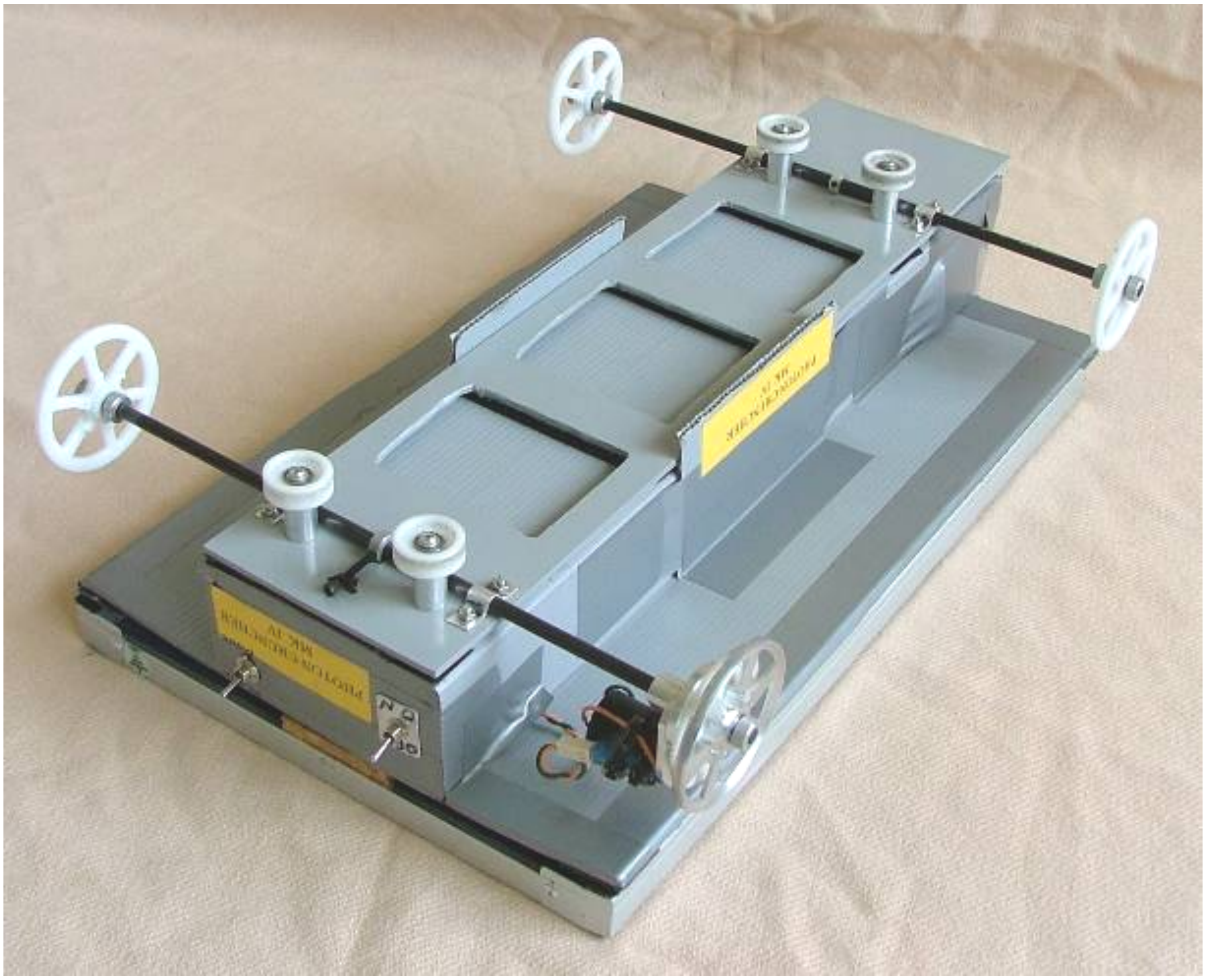
PHOTON CRUNCHER Mk. IV 8/05

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 later in 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)

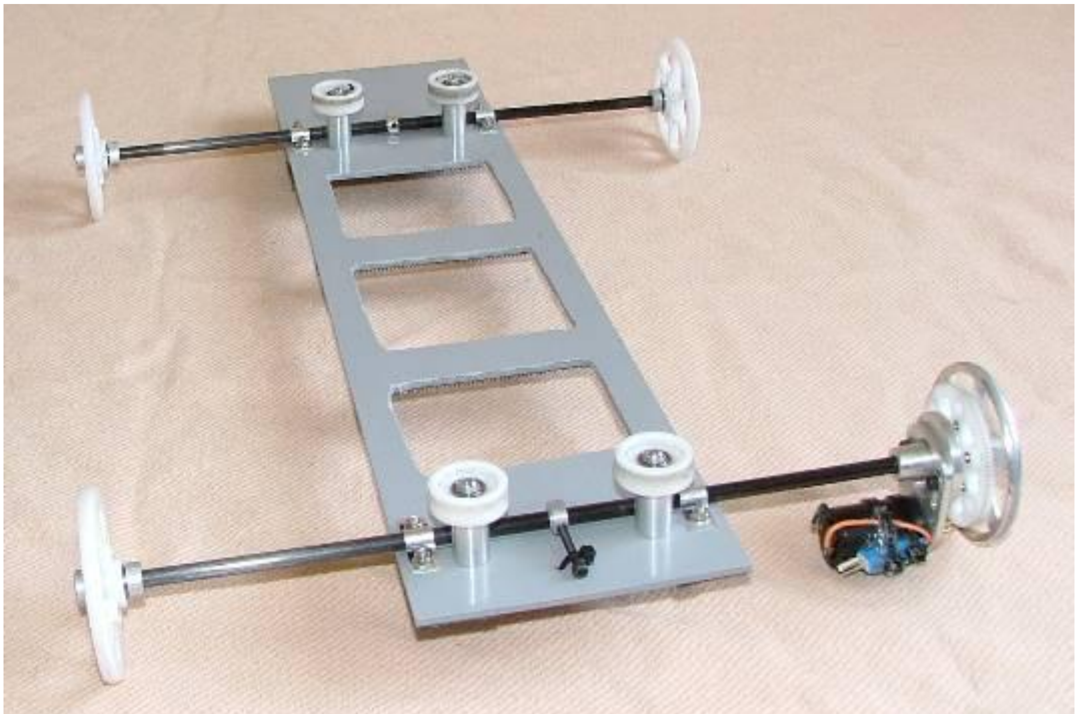

PHOTON CRUNCHER
MK IV


OFF
ON
PHOTON CRUNCHER
MK IV

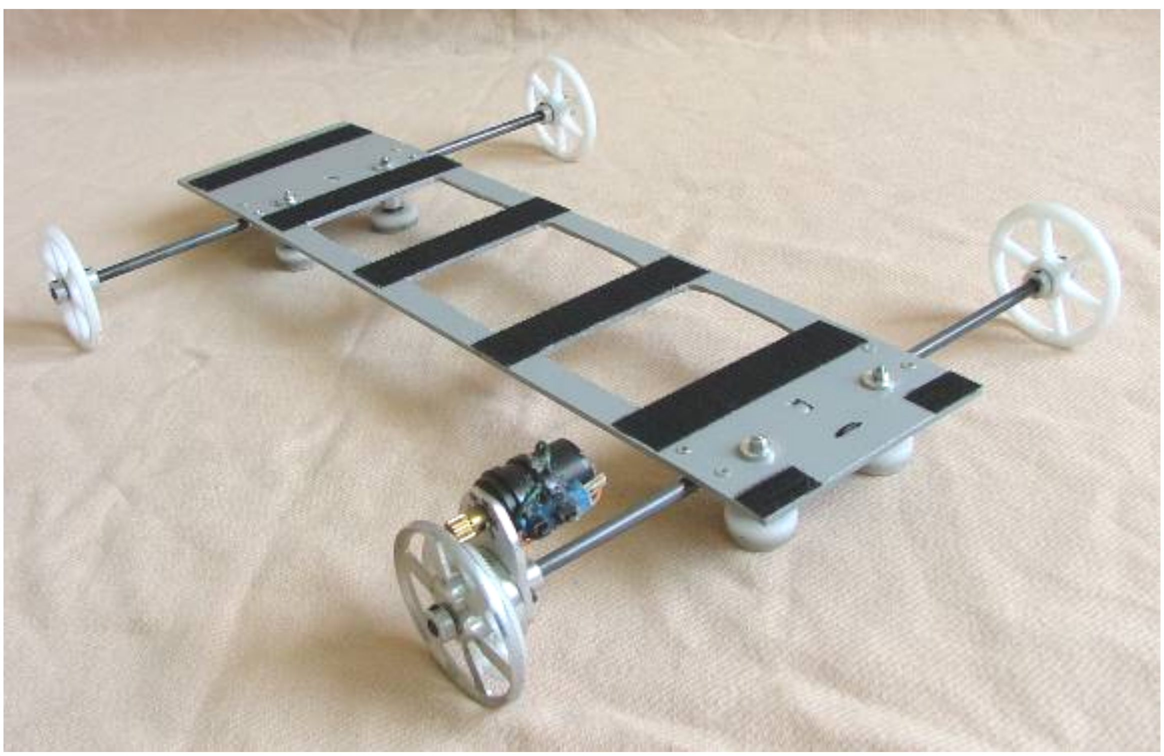


TOP VIEW SOLAR PANEL REMOVED

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 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

Please note that this car was designed to the 2005 regulations, the method of using all the components described here are still completely relevant to the 2017 regulations.
The race time predictions etc. are not relevant due to the significant change to the solar panel requirements in the 2017 regulations.

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 CONFORM 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 g.**
- **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 (rear axle anti rotation)		1 No
● Screw M3 by 12mm long + nuts and washers (gear to drive wheel)		2 No
● 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 (flange to mount plate fastening)		2 No

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		8 No

bearings due to retaining screw)

- 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 4 No
  to secure assy to chassis. Length to suit your chassis
  thickness to be provided by you.

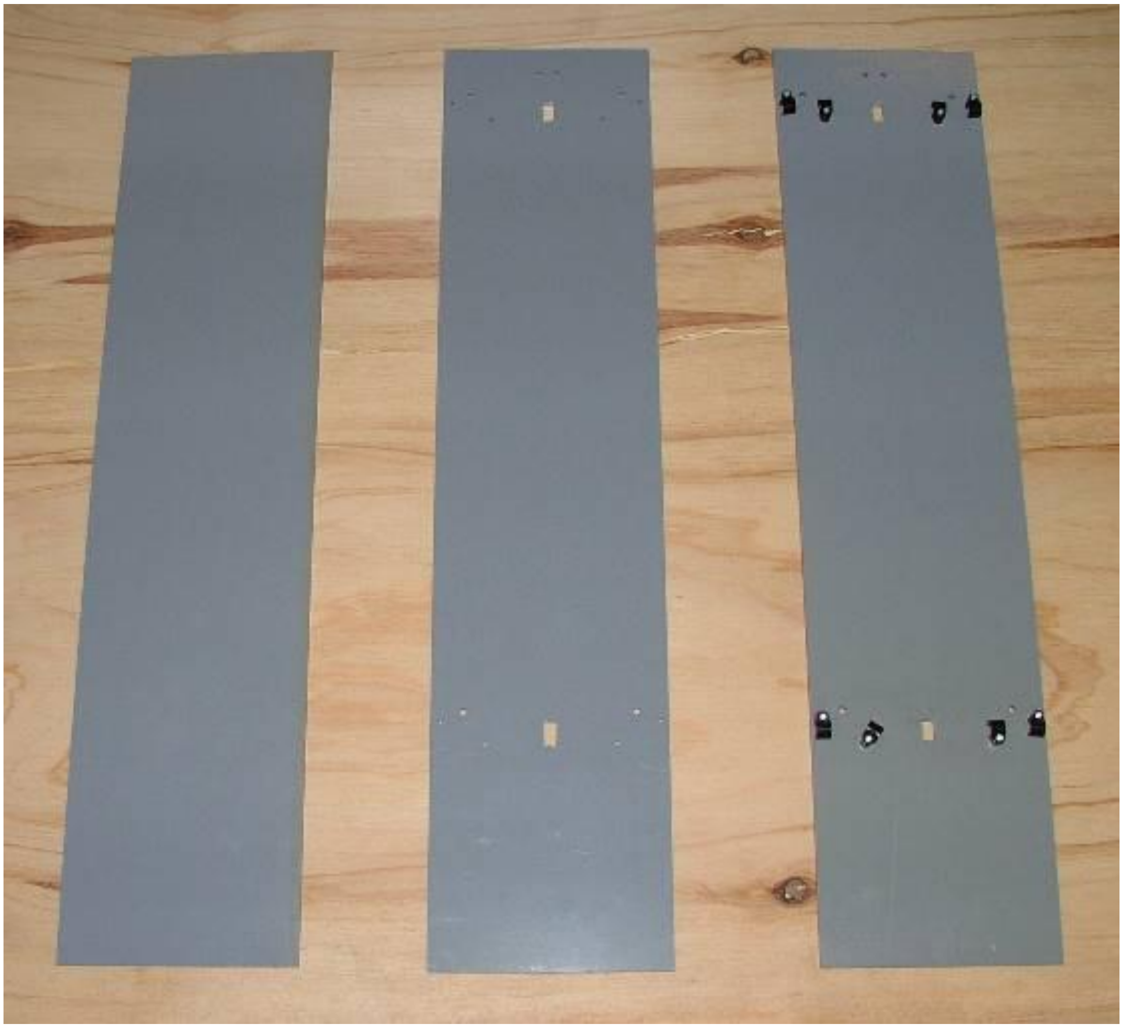
OTHER COMPONENTS:

* Solar Panel SOLAREX SX-10 1 No
  plus plastic edging as reqd
  (NEED TO STRIP ALUMINIUM EDGING
  OFF PANEL TO REDUCE WERIGHT)
* 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:

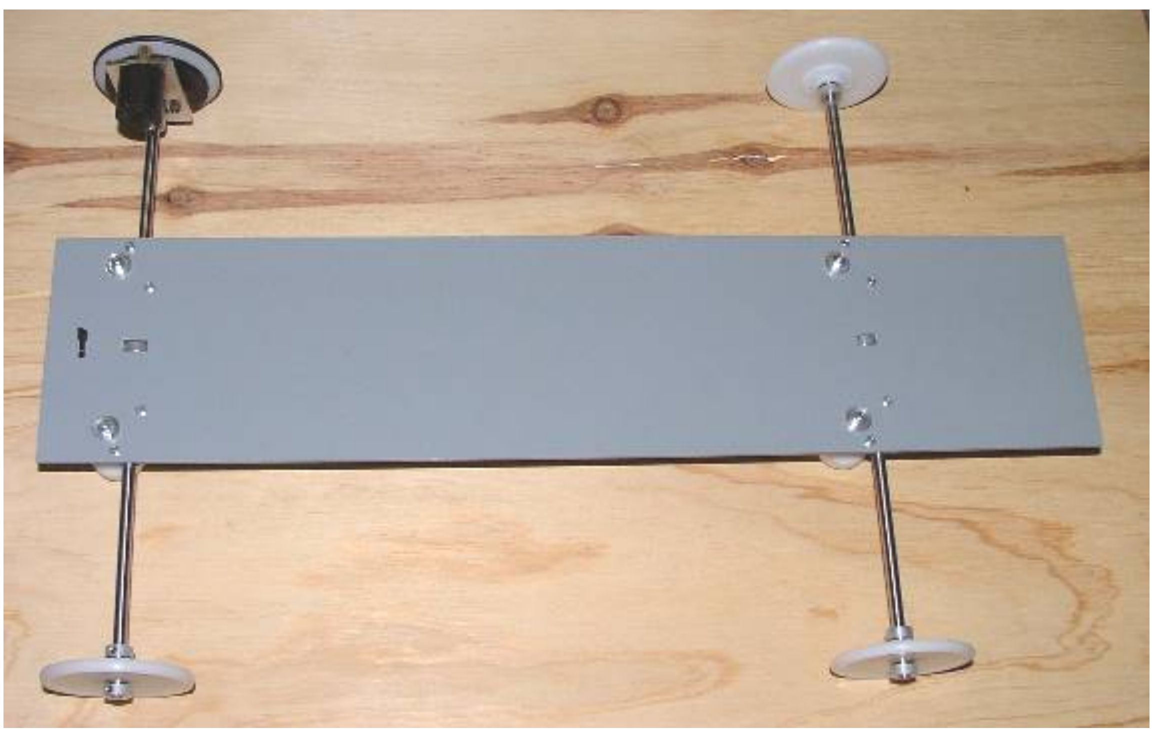
In order to enable you to evaluate this design the parameters for use in the Mathematical Simulation for this car are entered into the simulator detailed later in this document. NOTE: the details entered in the simulator refer to a car with some modifications to improve performance. Also the air drag 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.

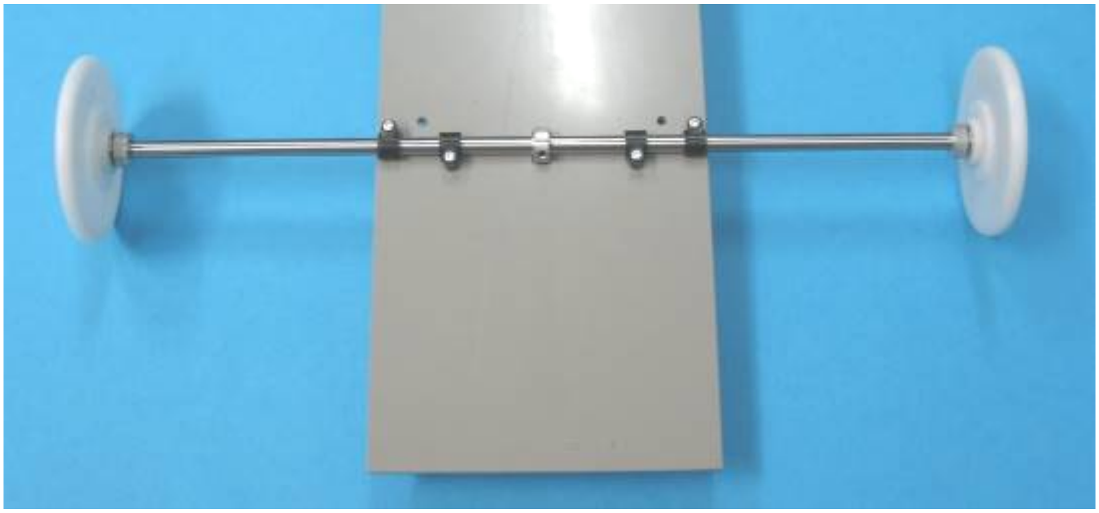


CHASSIS FROM LEFT TO RIGHT:
BLANK PVC SHEET
PVC SHEET DRILLED
PVC SHEET DRILLED WITH AXLE CLAMPS IN PLACE

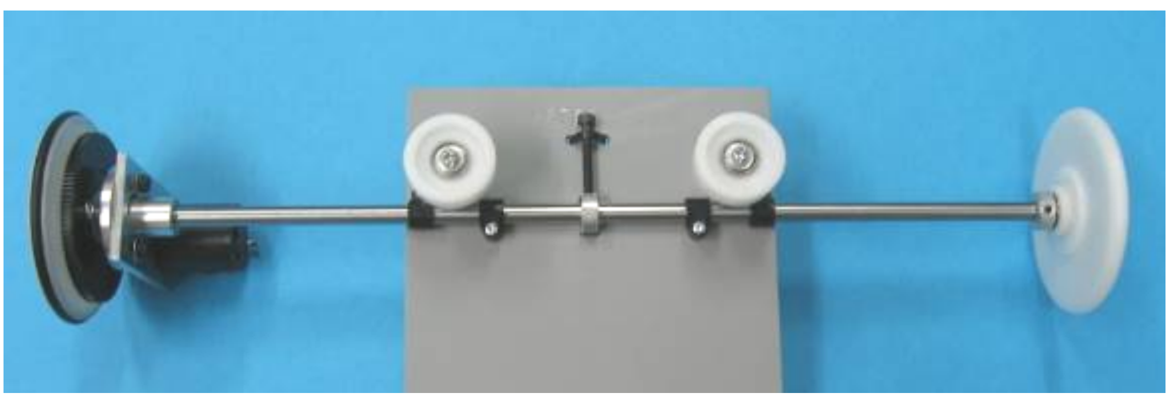
CHASSIS UNDERSIDE VIEW



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

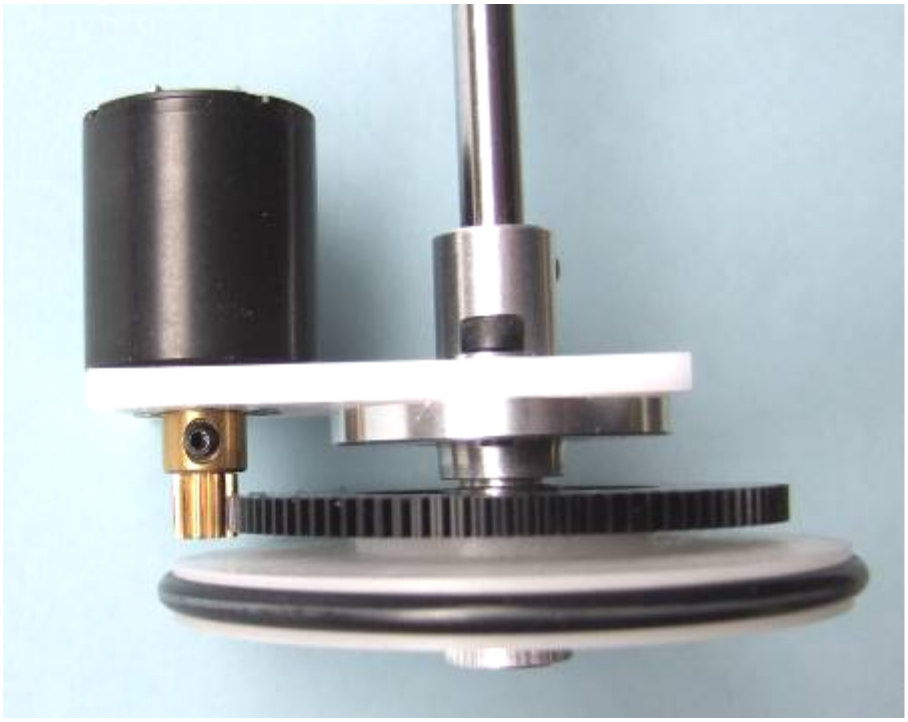
AXLE RETAINING CLAMP (6MM CABLE CLAMP)

NON DRIVE WHEEL SCCW –RAD

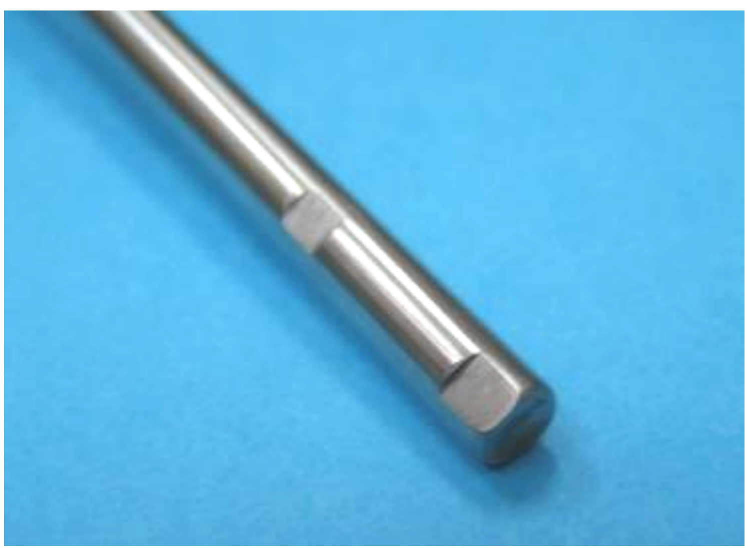
BEARINGS SMF 106ZZ

BEARING SMF 106ZZ CLOSE UP

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

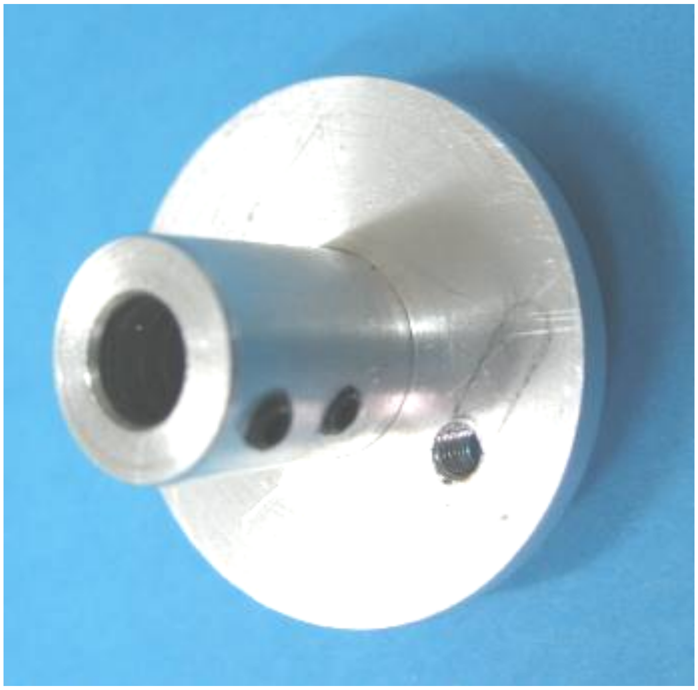


MOTOR MOUNT DETAIL CLOSE UP



HINT: FILE FLATS ON AXLES WHERE GRUB 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

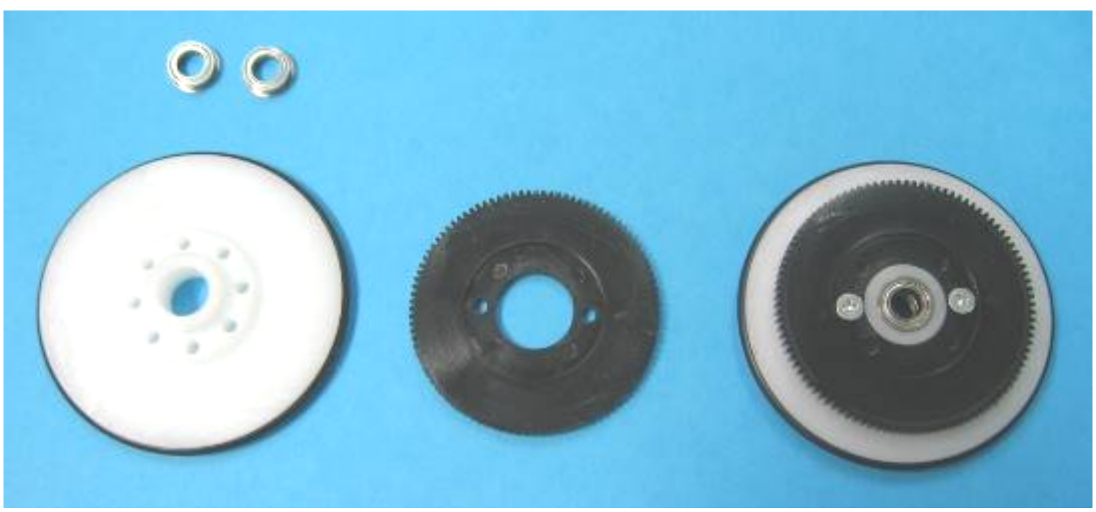
MOTOR MOUNT PLATE AND MOTOR MOUNT FLANGE ASSEMBLY
WHEEL SIDE VIEW

MOTOR MOUNT ASSEMBLED TO AXLE MOTOR SIDE VIEW

MOTOR MOUNT ASSEMBLY MOTOR SIDE VIEW

MOTOR MOUNT ASSEMBLY WITH AXLE FITTED WHEEL SIDE VIEW

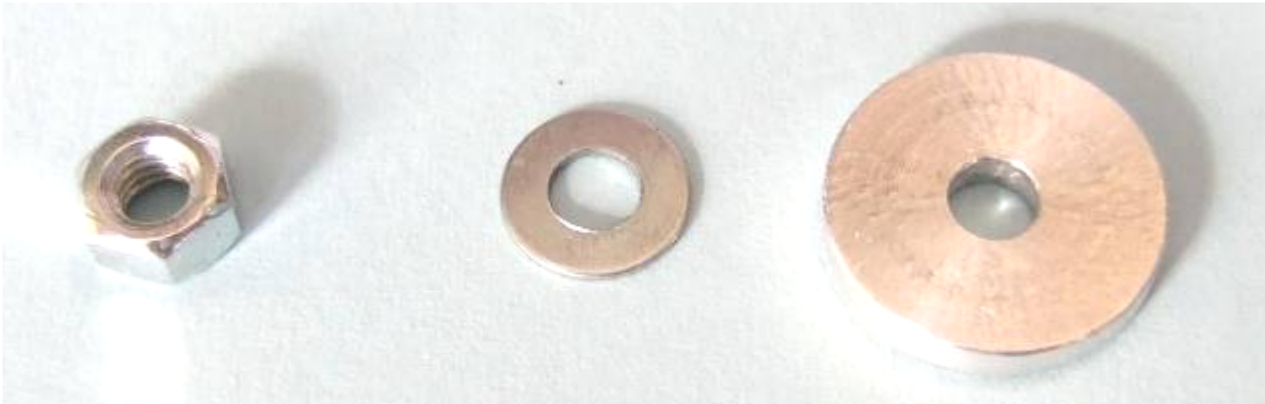
DRIVE WHEEL SCCW-OR   WITH GEAR SCCM050-100-BL FITTED



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

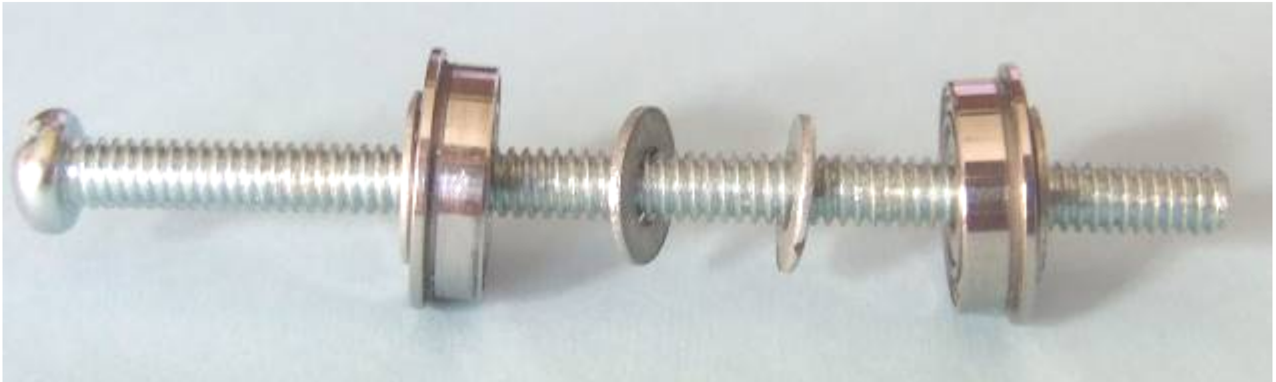
FROM LEFT TO RIGHT

3MM NUT

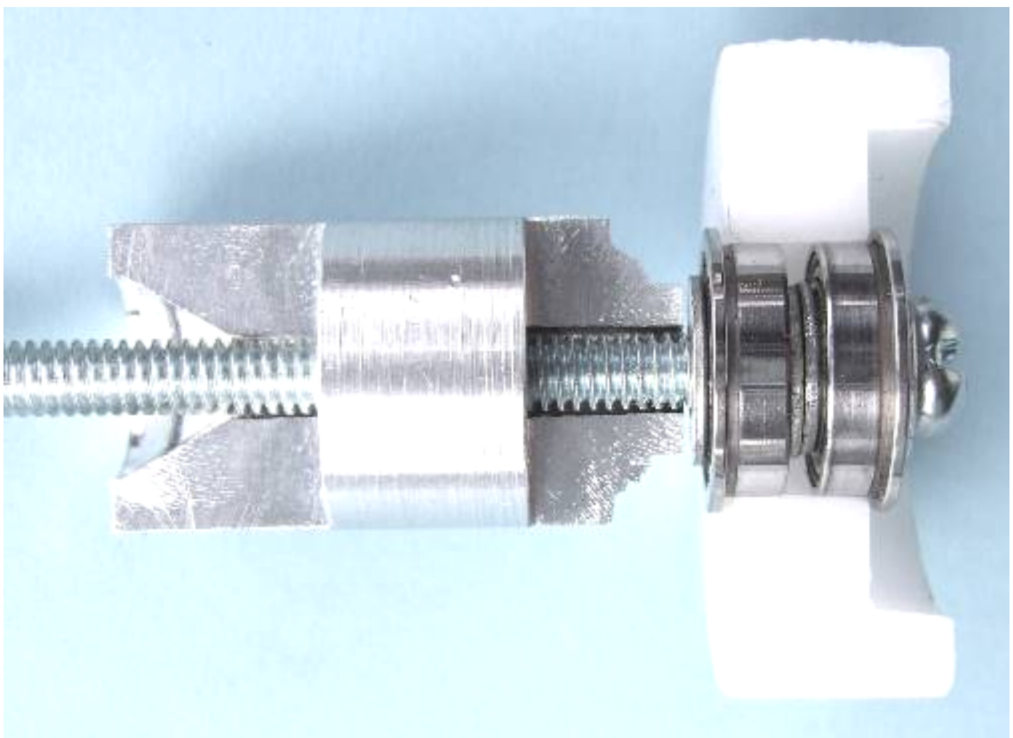
3MM WASHER

LARGE ALUMINIUM WASHER SCCGR W

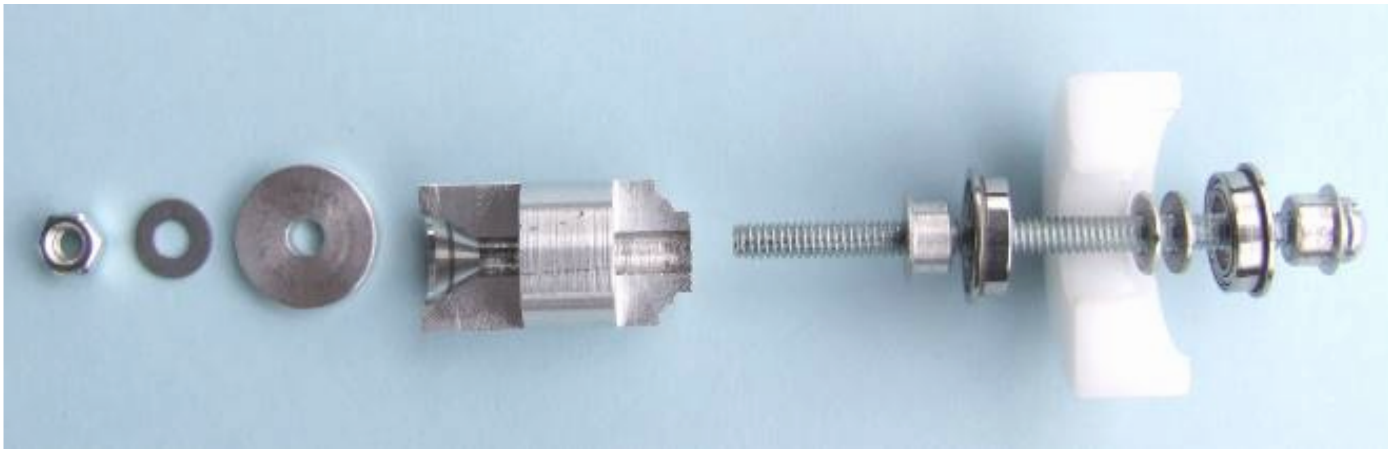
EXPLODED VIEW SLEEVES BEARINGS AND WASHERS



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 D: SIMPLE CAR USING SCORPIO CLAMP BLOCKS AND MOTOR MOUNT 2015

Scorpio Technology has just introduced some new components into their Solar Catalogue.
They are a motor mount kit for the Faulhaber motor (FAUMMK) and an axle bracket kit (AXBKTK) these components allow the quick easy assembly of a "ladder" type carbon fibre tube chassis. Scorpio also have the 6 mm diameter carbon fibre tube (CFT) in 650 mm lengths.
These components have been utilised along with R & I wheels, guides and gears in the construction of a sample car.
This car was deliberately kept as simple as possible so is neither, pretty or aerodynamic. It does meet the 2015 regulations and with only slight dimensional changes meet the 2017 regulations. As shown here does not have the side panels or ballast included.
The time taken to assemble the rolling chassis was about four hours and the only tools and equipment required were a screwdriver, hacksaw, rule, spanner (supplied in the Scorpio kit), a hexagon key and some epoxy adhesive.

Note the performance detailed below is for a solar panel comprising 2 Scorpio panels, you will need to run the simulation with data for the single Scorpio panel in order to get data relevant to the 2017 regulations.

The title block from the Mathematical Simulation of this car is included.

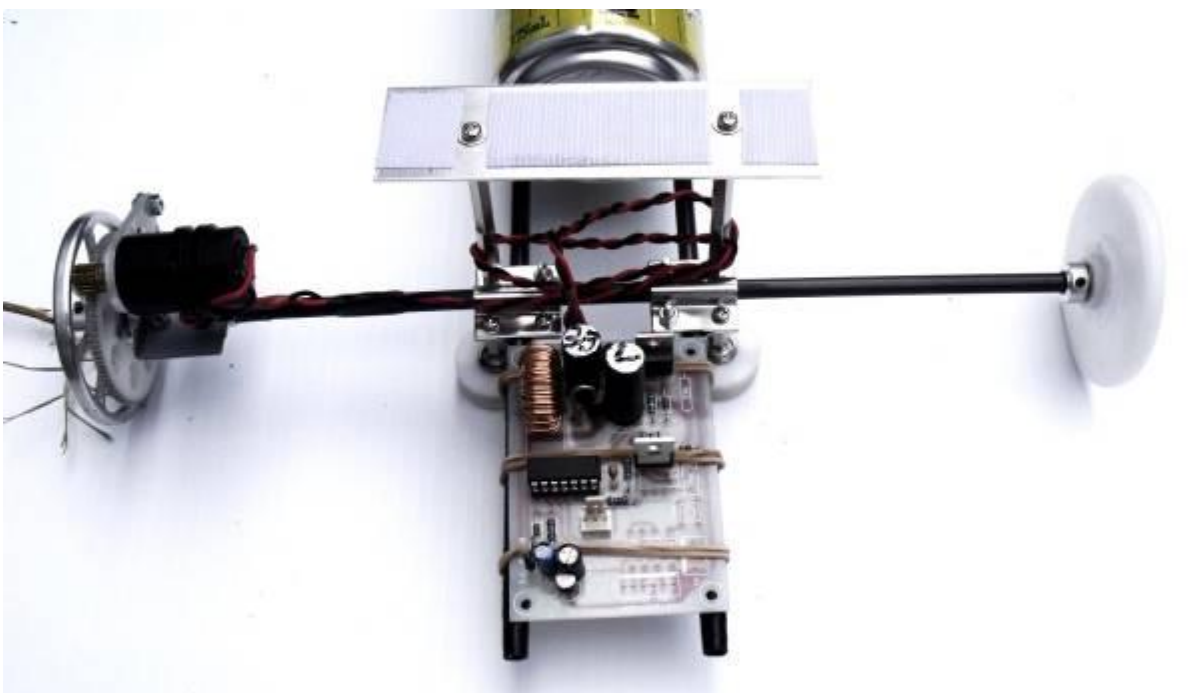
Predicted performance is:	92% Sun	16.5 seconds	for 1 lap
	50% Sun	20.75 seconds	for 1 lap
	15% sun	39.0 seconds	for 1 lap

Note at high Sun the predicted speed (a 16.5 second race time) will result in instability when cornering, action must be taken to slow the car down under these conditions otherwise a crash is inevitable.

Complete car top view

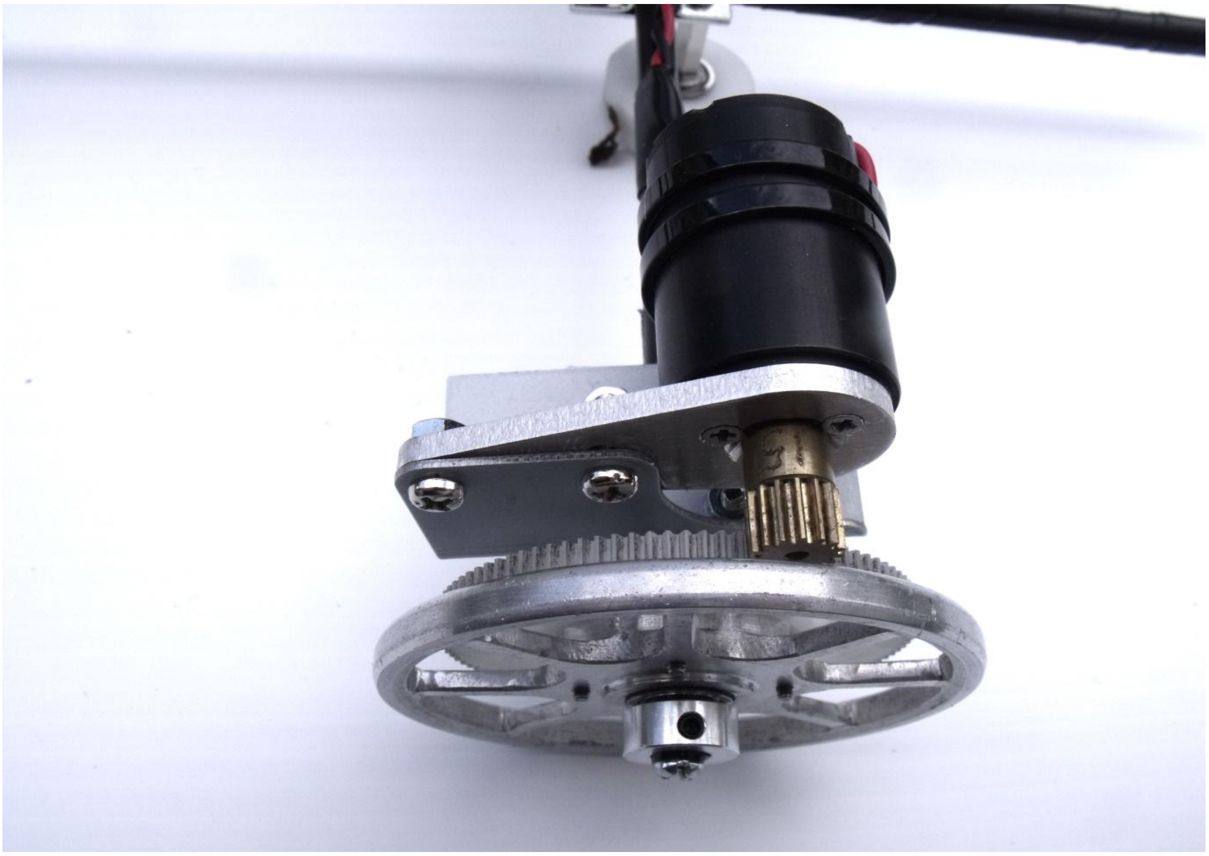
Front view

Top view solar panel removed



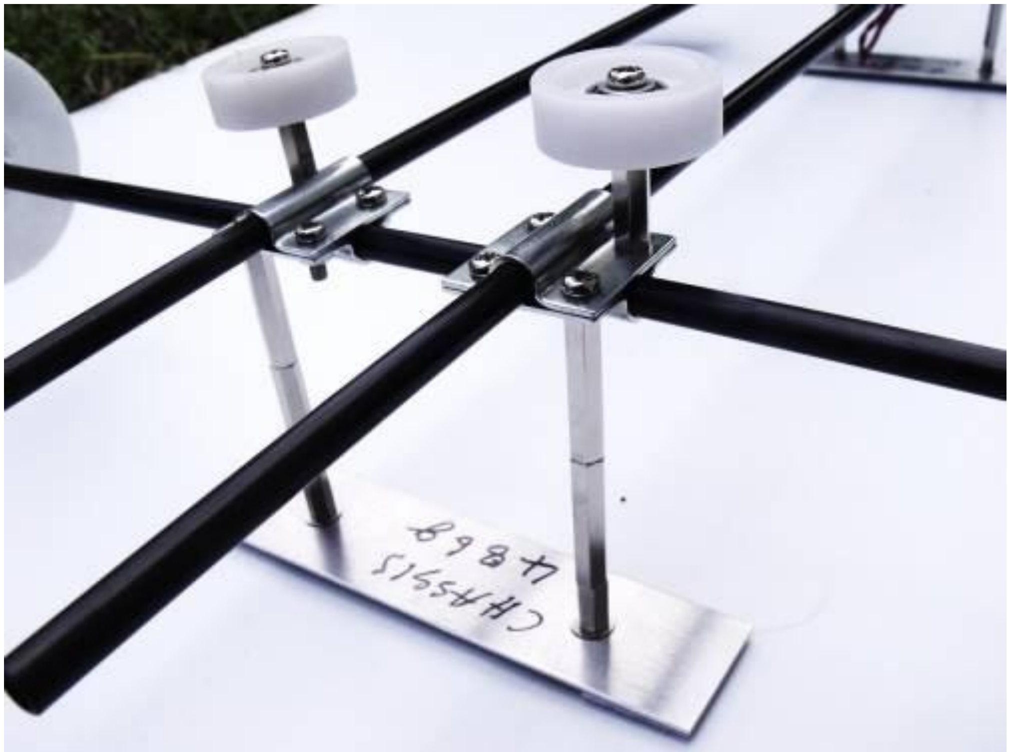
Rear view solar panel removed showing electronics mounting.

Caution: Not easily visible in this photograph is the insulation tape wrapped around the carbon fibre to prevent shorting. Remember carbon fibre is conductive.



Motor mount close up

Chassis underside view



Close up of axle brackets on carbon fibre chassis and axles.

Note: The stand offs supporting the guide rollers and solar panel are circuit board stand offs from Jaycar. They are brass and have an M3 thread which screws directly onto the M3 screws supplied in the axle bracket kit.

An M3 screw is secured in the hollow carbon fibre axle with 5 minute araldite, this helps resist the axle crushing when the M3 grub screw securing the clamp ring is tightened.

Model Solar Car Simulator

Parameters				Results	
Car Name:	Ians simple car 2015			1 LAP RACE	
Sun Power:	92% Sun 2 No 6 Scorpio			Time:	16.5
Motor Type:	Faulhaber 2232 6 V BHHS V4 P1.6			Velocity:	7.958
Guide Roll CoEf:	0.015	Wheel Slip Coeff	4	Mtr RPM:	18261
Mass(kg):	2.056			Air Drag	0.380
Wheel Roll RS:	0	Roll CoEf:	0.11	Rolling R:	0.22616
Air Drag Coefficient:	0.006	Steering(Yes/No):	NO	Mtr Torque:	4.052
Wheel Diameter(mm):	64	Steering Drag:	0.13		
Acceleration Gear Ratio:	7.14	Change RPM:	0	2 LAP RACE	
Final Gear Ratio:	7.69			Time:	27.7
Transmission Effy:	92			Velocity:	8.125
Motor Torque	Finish RPM:	Start T(mNm):	Formula	Mtr RPM:	18645
Section 1:	4500	21.5	0.001889	Air Drag	0.396
Section 2:	9200	13	0.000745	Rolling R:	0.22616
Section 3:	25000	9.5	0.00060	Mtr	3.821

	1	Torque:

Model Solar Car Simulator

Parameters				Results	
Car Name:	Ians simple car 2015			1 LAP RACE	
Sun Power:	50% 2 Scorpio No 6			Time:	20.75
Motor Type:	Faulhaber 2232 6 V BHHS V4 P1.6			Velocity:	6.236
Guide Roll CoEf:	0.015	Wheel Slip Coeff	4	Mtr RPM:	16915
Mass(kg):	2.056			Air Drag	0.233
Wheel Roll RS:	0	Roll CoEf:	0.11	Rolling R:	0.22616
Air Drag Coefficient:	0.006	Steering(Yes/No):	NO	Mtr Torque:	2.603
Wheel Diameter(mm):	64	Steering Drag:	0.13		
Acceleration Gear Ratio:	7.14	Change RPM:	0	2 LAP RACE	
Final Gear Ratio:	9.09			Time:	35.25
Transmission Effy:	92			Velocity:	6.378
Motor Torque	Finish RPM:	Start T(mNm):	Formula	Mtr RPM:	17300
Section 1:	4000	16	0.001813	Air Drag	0.244
Section 2:	10300	8.75	0.00069	Rolling R:	0.22616
Section 3:	26500	4.4	0.000272	Mtr Torque:	2.499

Model Solar Car Simulator

Parameters				Results	
Car Name:	Ians simple car 2015			1 LAP RACE	
Sun Power:	15% 2 Scorpio No 6			Time:	38.95
Motor Type:	Faulhaber 2232 6V BHHS V4 P1.6			Velocity:	3.368
Guide Roll CoEf:	0.015	Wheel Slip Coeff	4	Mtr RPM:	6281
Mass(kg):	2.056			Air Drag	0.068
Wheel Roll RS:	0	Roll CoEf:	0.11	Rolling R:	0.22616
Air Drag Coefficient:	0.006	Steering(Yes/No):	NO	Mtr Torque:	1.877
Wheel Diameter(mm):	64	Steering Drag:	0.13		
Acceleration Gear Ratio:	7.14	Change RPM:	0	2 LAP RACE	
Final Gear Ratio:	6.25			Time:	71.15
Transmission Effy:	92			Velocity:	3.370
Motor Torque	Finish RPM:	Start T(mNm):	Formula	Mtr RPM:	6286
Section 1:	3000	8.6	0.001633	Air Drag	0.068
Section 2:	7500	3.7	0.000556	Rolling R:	0.22616
Section 3:	19300	1.2	0.000102	Mtr Torque:	1.875

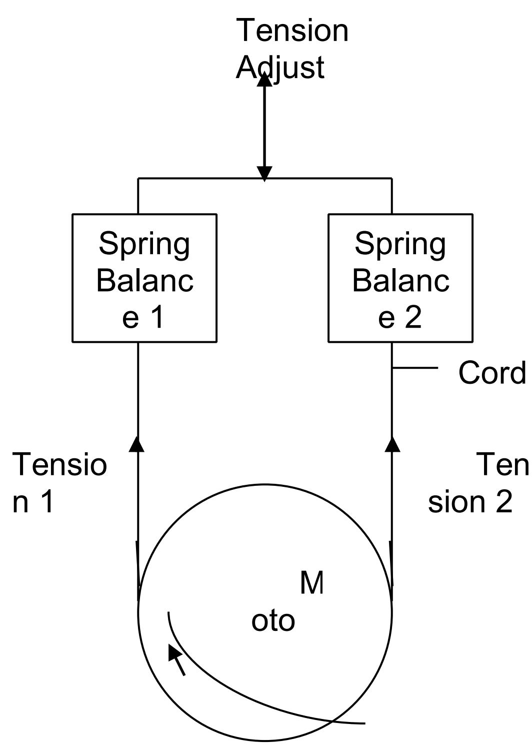
APPENDIX E: DYNAMOMETER TESTING

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

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

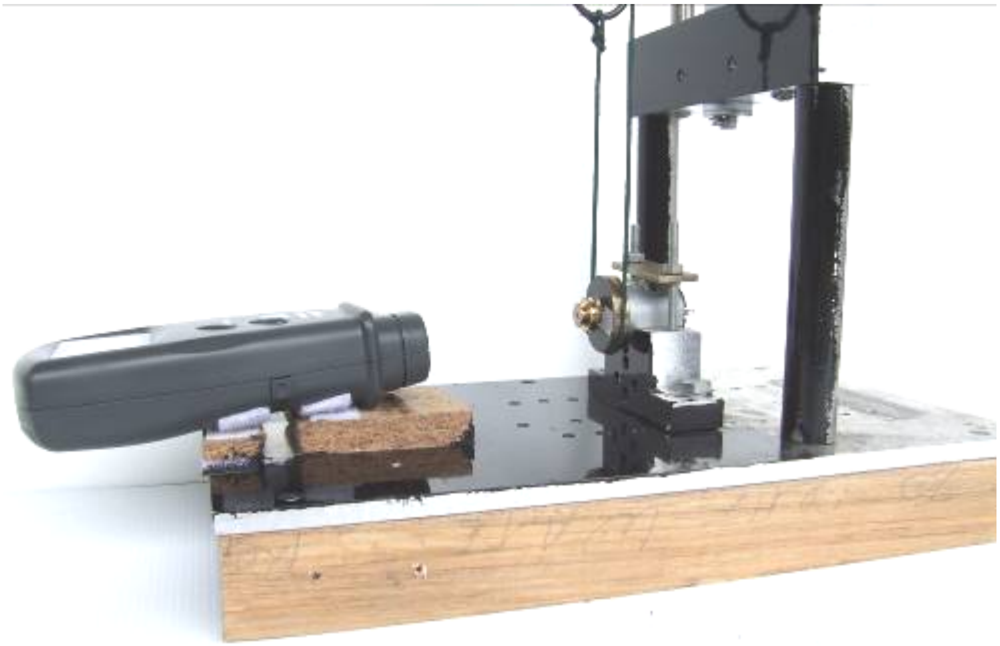
The standard pulley we use is 34 mm Diameter.
Multiplying the difference in tensions of the cord around the motor pulley (T1-T2) by 0.1666 gives torque in mNm.

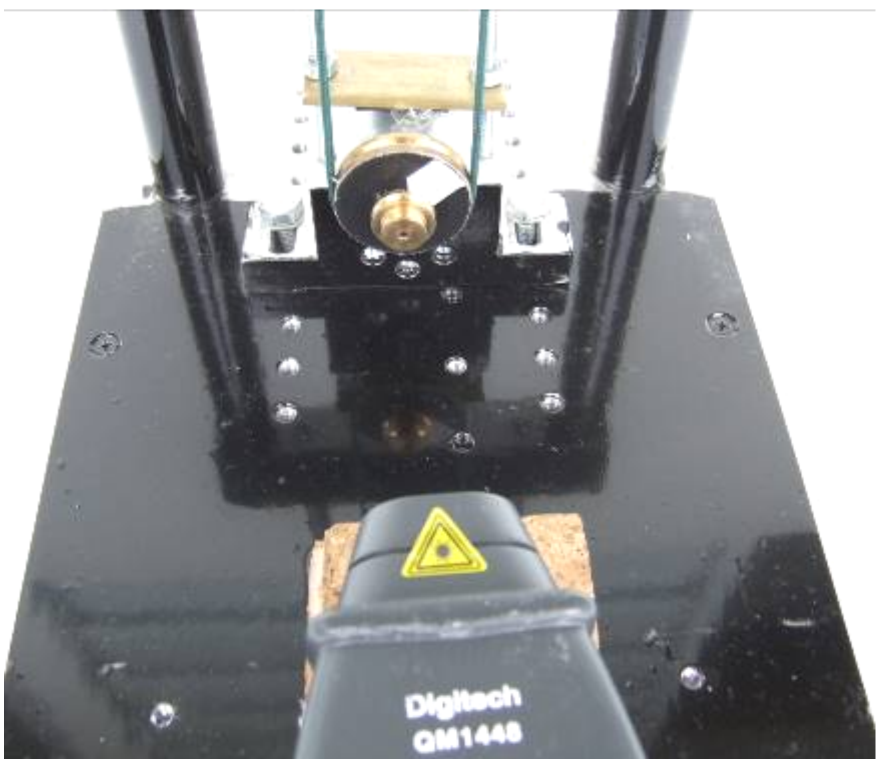
TESTING THAT CAN BE UNDERTAKEN USING THE DYNAMOMETER

- 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 the 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 F: 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 complex. 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 g weight hung from it and the wheel let free to rotate. This always gave about the same energy input.

Two new unused bearings were tested the following results obtained

As supplied	1.5 revolutions

Lubricated with light clock oil	9 revolutions
Lubricated with WD 40	26 revolutions initially
	12 after 20 minutes
Lubricated with INOX	24 revolutions initially
	23 after 6 weeks

(INOX manufactured by Candan Industries distributed by Consolidated Bearing Co., Jaycar, Bunnings and others)

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.

Beware of the urban myth which suggests completely clean unlubricated bearings run with lower friction. This is not true. I have conducted tests on clean unlubricated bearings and recorded friction 300% greater than that obtained with bearings lubricated with Inox. There are two things happening in totally clean bearings. Firstly totally clean steel in contact with totally clean steel will cold weld. In a bearing the rolling action breaks this weld leaving surface damage which quickly builds up to result in bearing destruction. Secondly while most of the bearing load is taken by the balls rolling on the inner and outer races however there is still some sliding friction between the balls their cage and the inner and outer races, requiring lubrication to reduce friction.

APPENDIX G: PHOTOS OF CARS & AIR DRAG COEFFICIENT

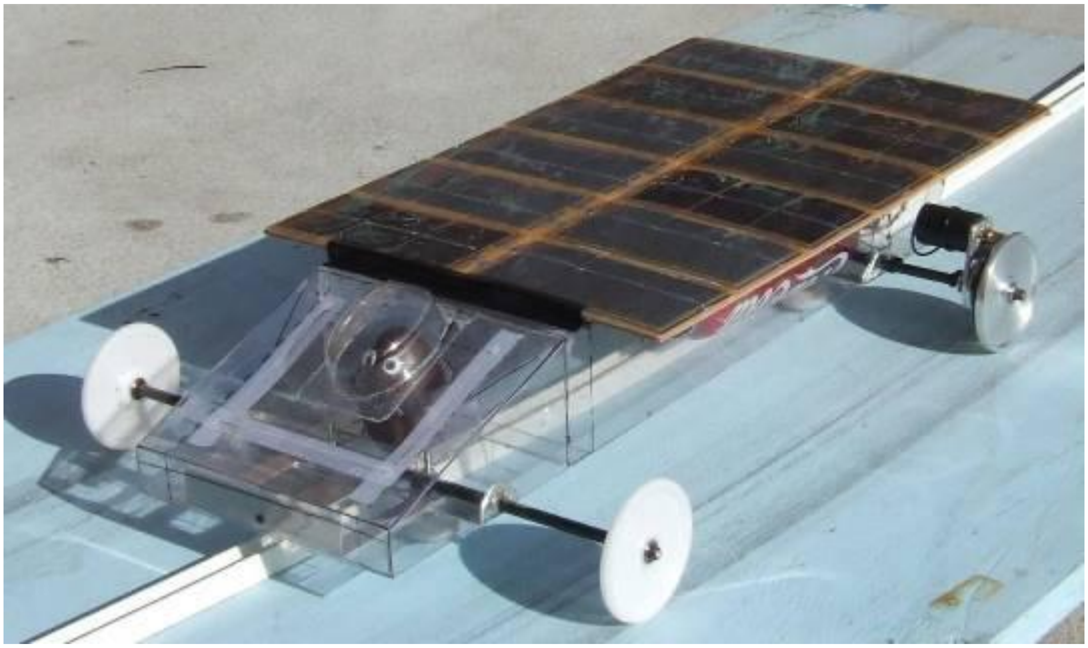
NOTE: You MUST do wind tunnel testing of your car to determine its drag coefficient. (Values in the order of 0.03 for a flat plate of 200 cm square to 0.003 for a low drag aerofoil shape of 200 cm square would be typical.)

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)

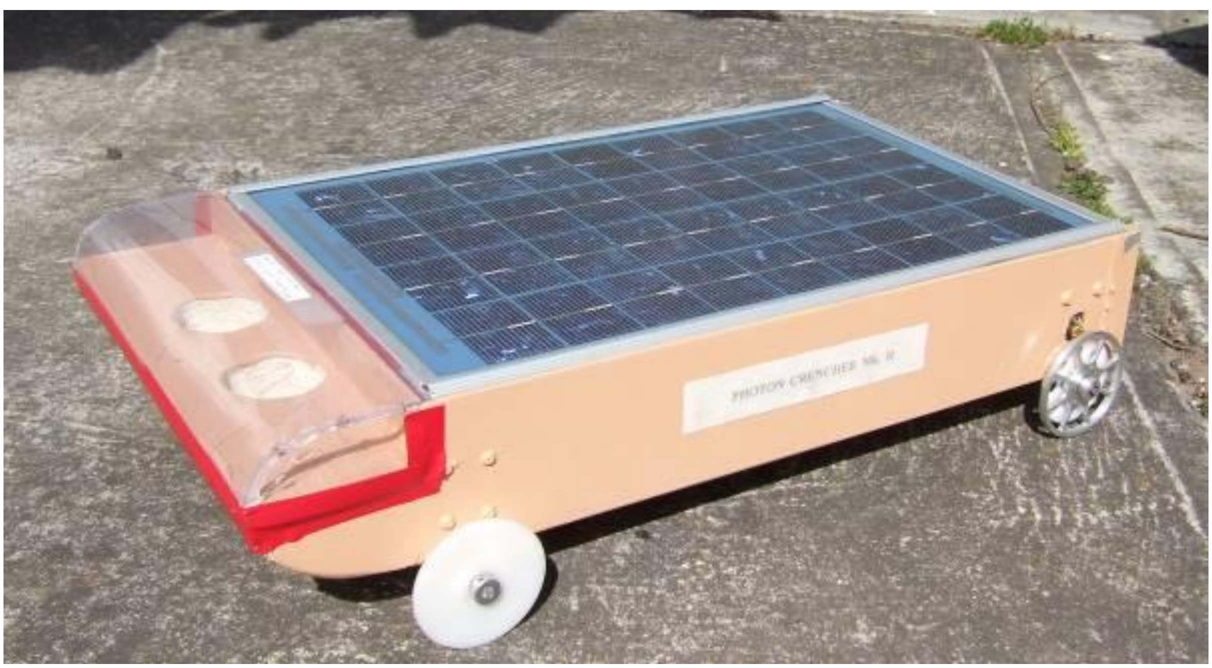
PHOTON CRUNCHER MK IV : SIMULATOR AIR DRAG COEFFICIENT

0.007

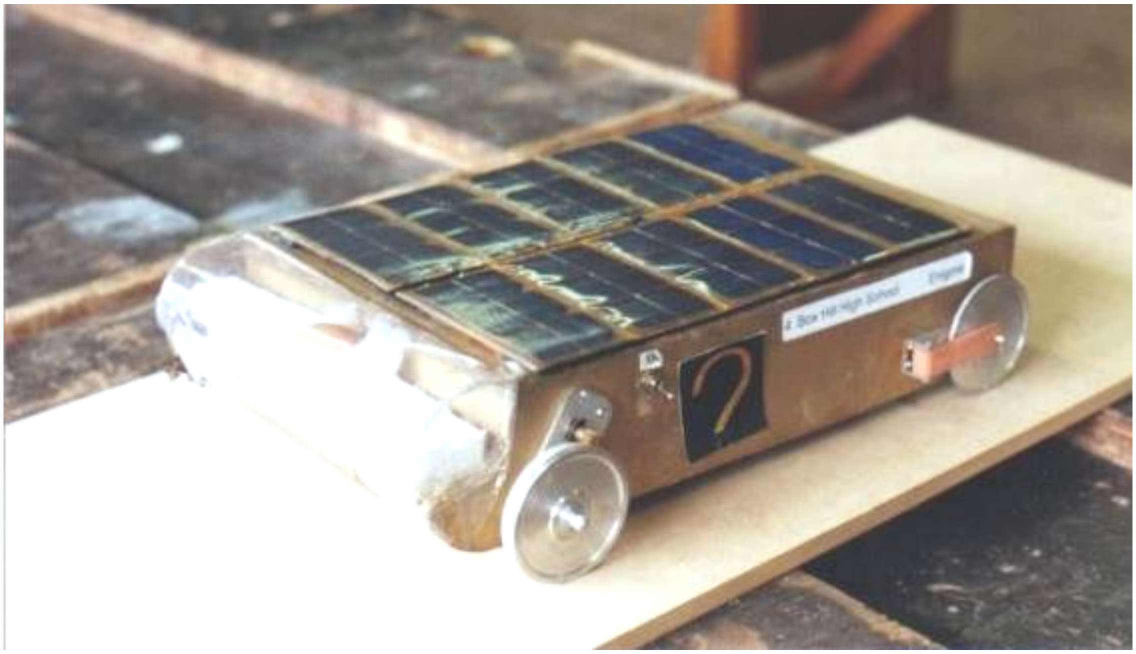


PHOTON CRUNCHER MK V: SIMULATOR AIR DRAG COEFFICIENT 0.0045

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.)

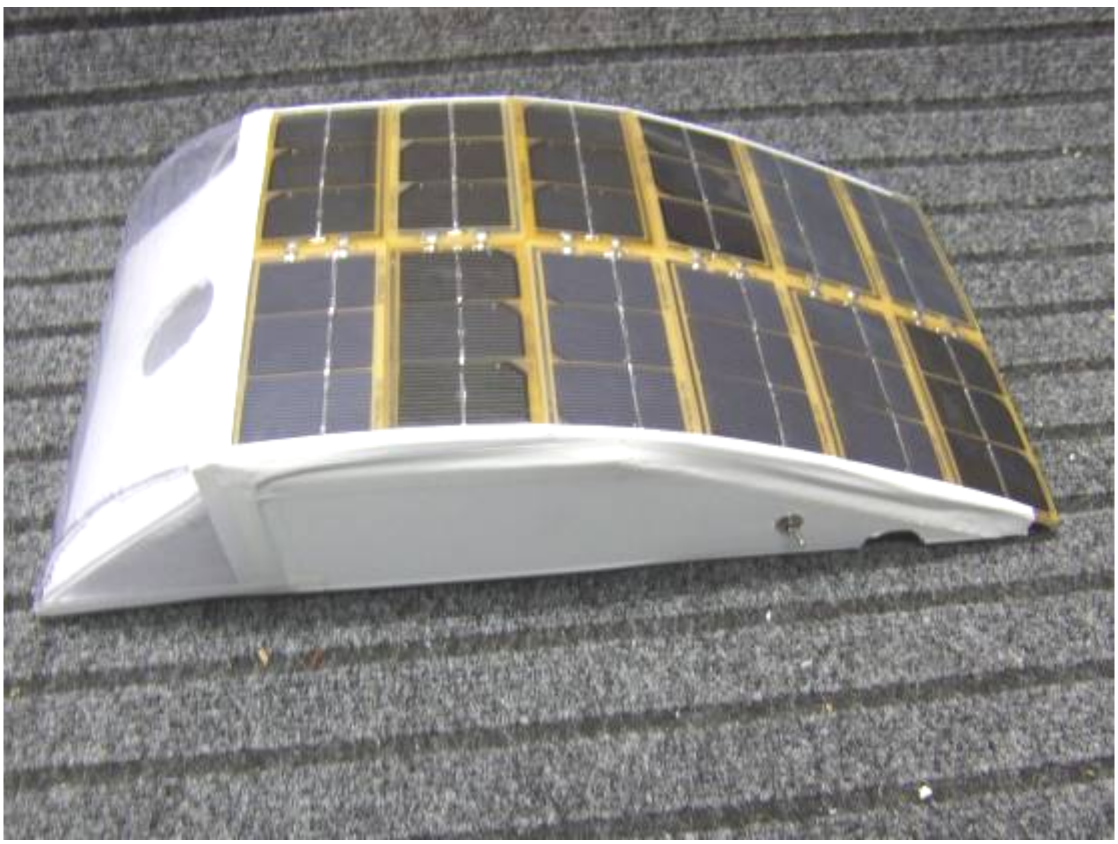
HELIOS: SIMULATOR AIR DRAG COEFFICIENT 0.004
(Note: This car designed to meet the 200 sq.cm. transverse panel requirement.)

CARBO TRUDIS: SIMULATOR AIR DRAG COEFFICIENT 0.0039

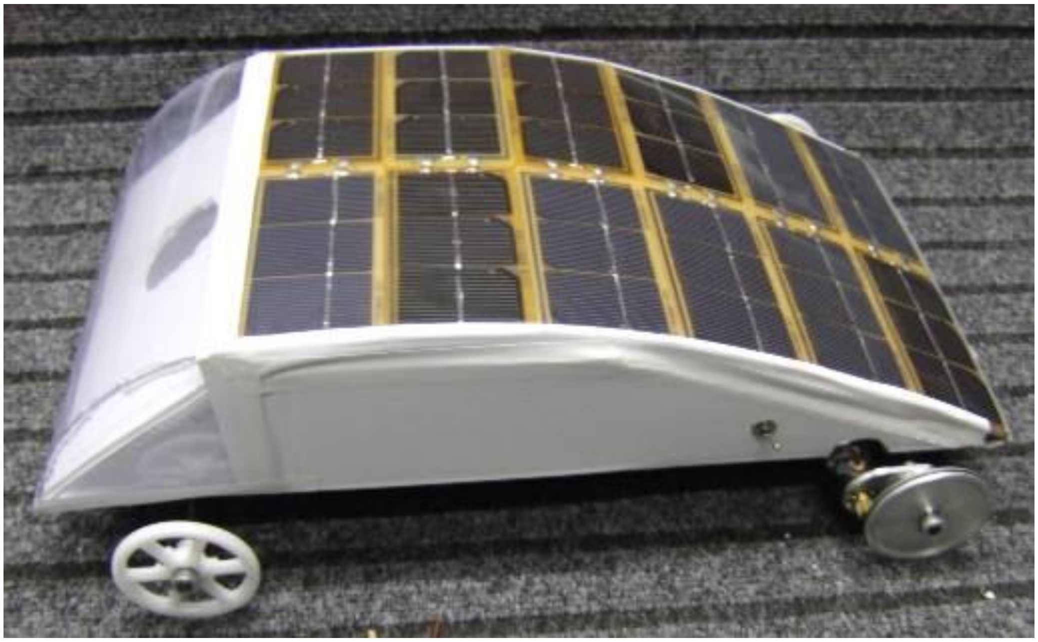
NFG: SIMULATOR AIR DRAG COEFFICIENT 0.007
(Note: This car won the 2008 National event. Designed for transverse milk carton.)

EFFECT OF WHEELS AND GUIDES ON DRAG

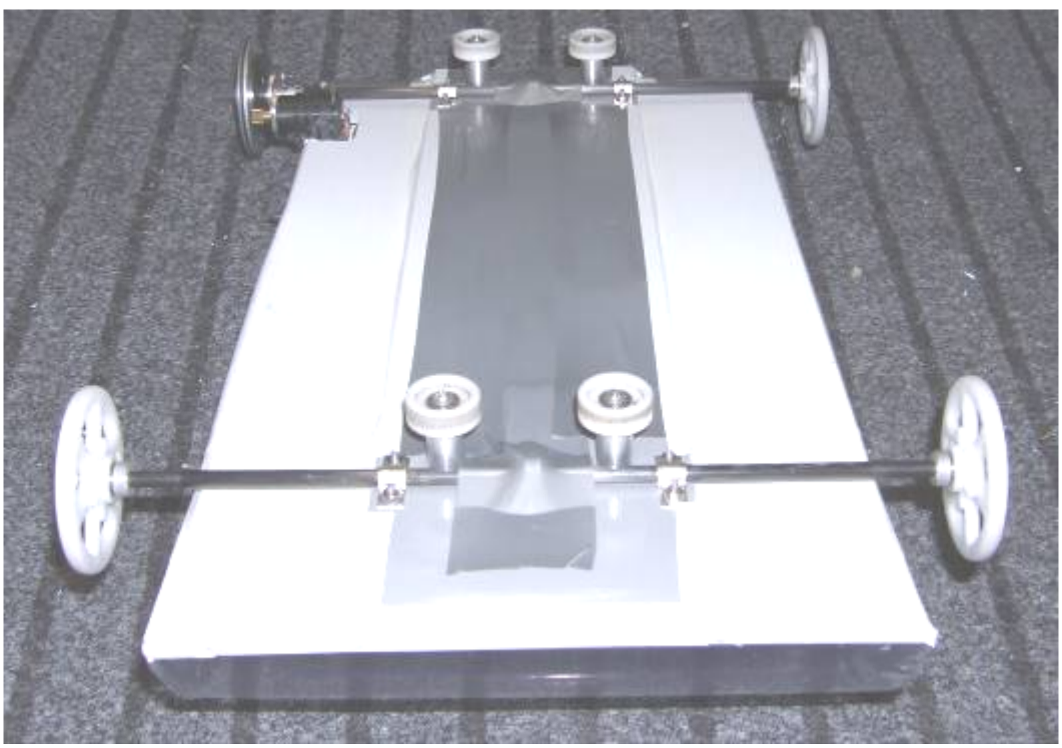
In order to show how important apparently small items can be when it comes to air drag, wind tunnel tests were carried out on a car to evaluate the effect exposed motor, wheels and guides has on air drag. A sample car made for workshop demonstrations was tested as a body only then as a complete car. 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 H: 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.

WIND TUNNEL TESTING OF MODELS:
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 PERFORMANCE 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 for a car that conforms to the 2017 regulations, the main parameters are listed below.

Mass 0.7 kg
! Scorpio No. 26 panel at full Sun.
No electronics
No Steering

AIR DRAG COEFFICIENT	RACE TIME SECONDS 1 LAP	RACE TIME SECONDS 2 LAPS	DISTANCE DIFFERENCE METRES 1 LAP	DISTANCE DIFFERENCE METRES 2 LAPS
0.012	**19.4**	**33.4**		
0.0033	**16.75**	**28.0**	**21.1 ***	**43.0 ***

* 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 is not possible.

Calculation & Comparison of Cd:

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

(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

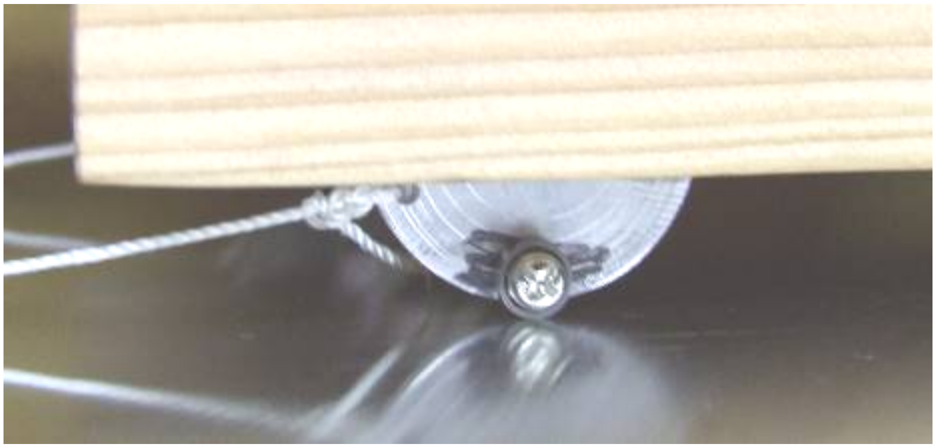
FURTHER TESTING:

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.

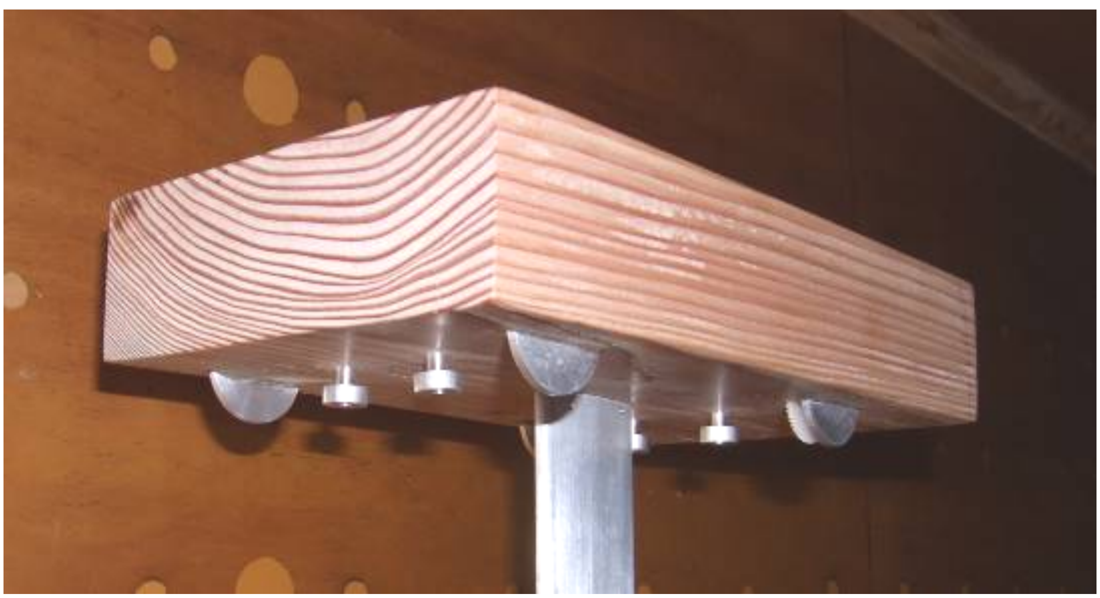
In conclusion there is a difference in drag when tested on "a stick" and "on the track", but

these tests results indicate there may not always be 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.

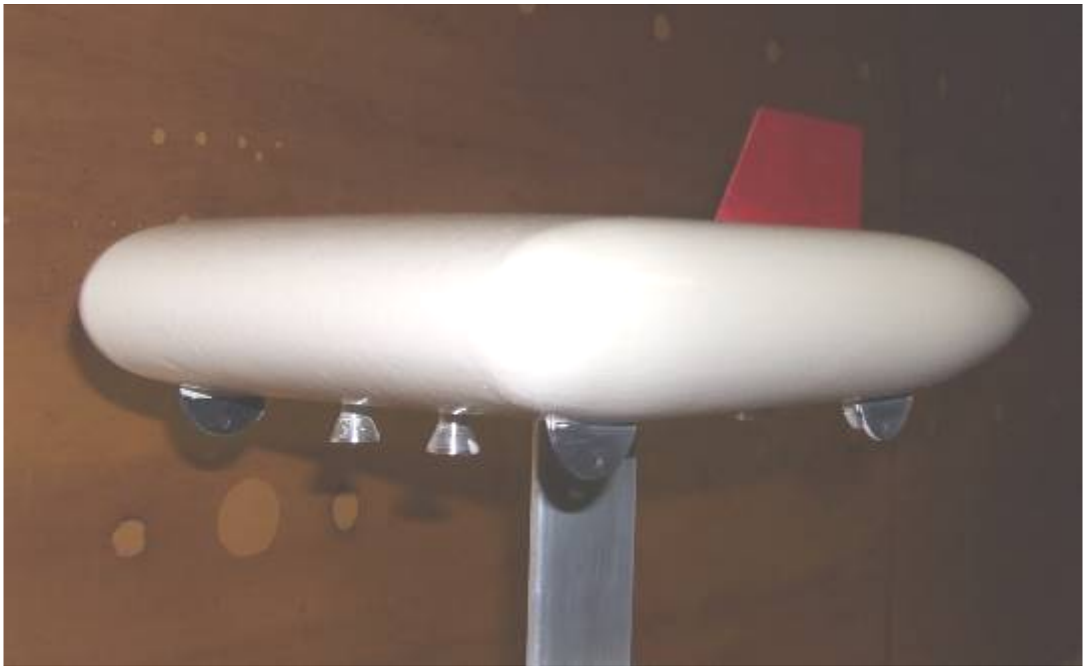
AIR DRAG COEFFICIENT	RACE TIME SECONDS		DISTANCE DIFFERENCE METRES	
	1 LAP	2 LAPS	1 LAP	2 LAPS
0.0114	19.15	32.95		
0.0042	16.95	28.5	17 *	35 *

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 I: MODEL SOLAR CARS AND AERODYNAMIC LIFT

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, but comes with 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. To evaluate this theory, how much lift can we reasonably expect to be generated?
Using data from Marks Standard Handbook for Mechanical Engineers, Eighth Edition section 11 AERONAUTICS. Using the 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 is.

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.
Lift force = 1.54 lb lift
= 700 gm lift, still a bit short of taking off as the minimum reasonable weight of a car under the 2017 regulations is 850 grams. 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. True, 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 whether a 20 deg angle of attack is possible within the 180 mm allowed car height. 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 J: BIOGRAPHY OF A WINNING CAR

This car while designed to the 2009 regulations could with slight modifications meet the

2017 requirements and still have reasonable performance. It is worth consideration even if only from the perspective of construction technique.

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:

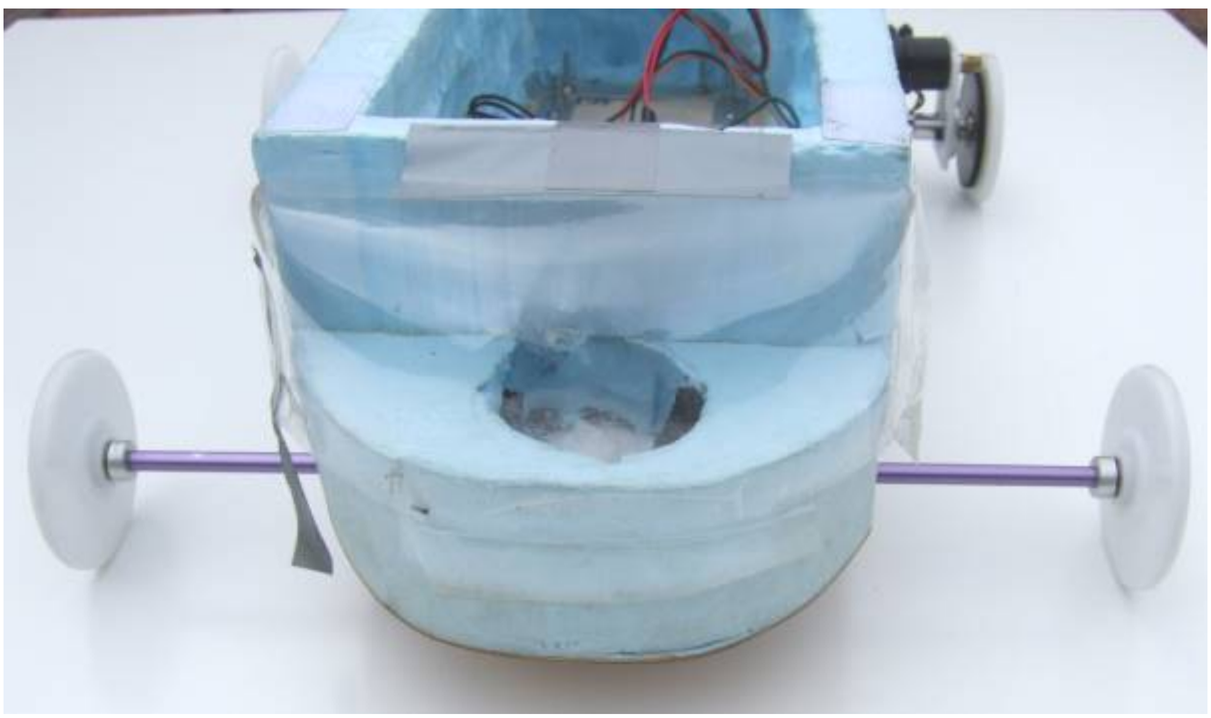
- Body dimensions, length 520 mm maximum width 155 mm height 100 mm.
- Body weight 525 g with electronics but no egg.
- Solar panel 173 mm wide by 500 mm long
- Solar panel power 12.16 Watts (At Vic. 100% Datum not AM 1.5 as now required)
- Axle length 320 mm.
- Distance between axles 250 mm.
- Forward 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.

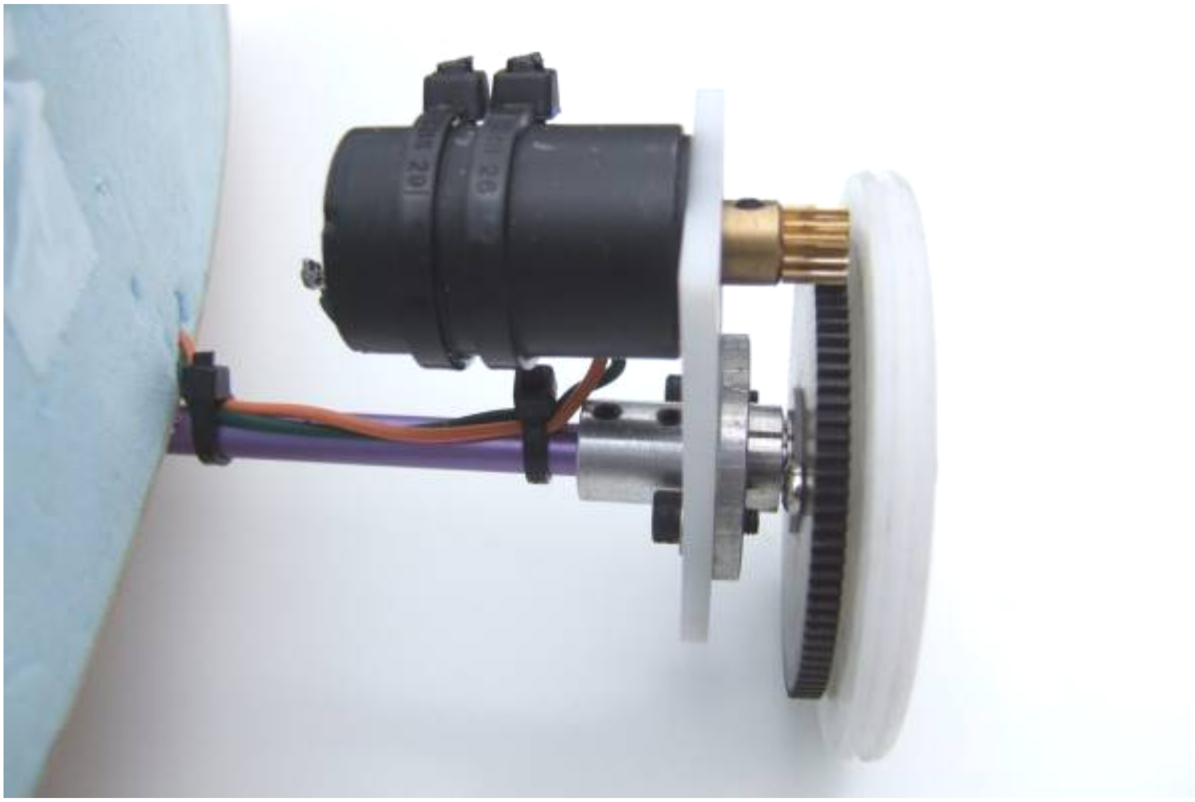
NOTE: The Design Guide contains full details of R & I components and assembly details used in the construction of Photon Cruncher MK IV. The same components and construction techniques, except for the body construction are used on the Syndal South car.

Detailed photographs of the car Scorpion follow:

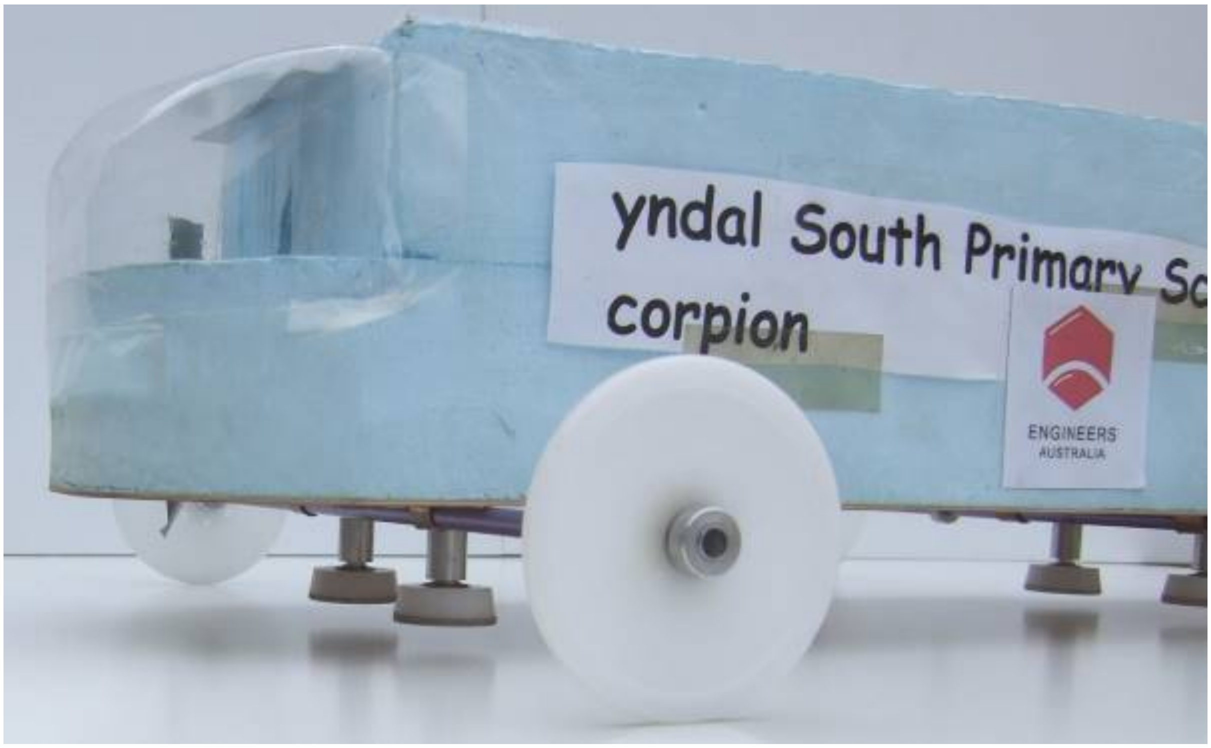

yndal South Primary School
corpion


16






Syndal South Primary School
Scorpion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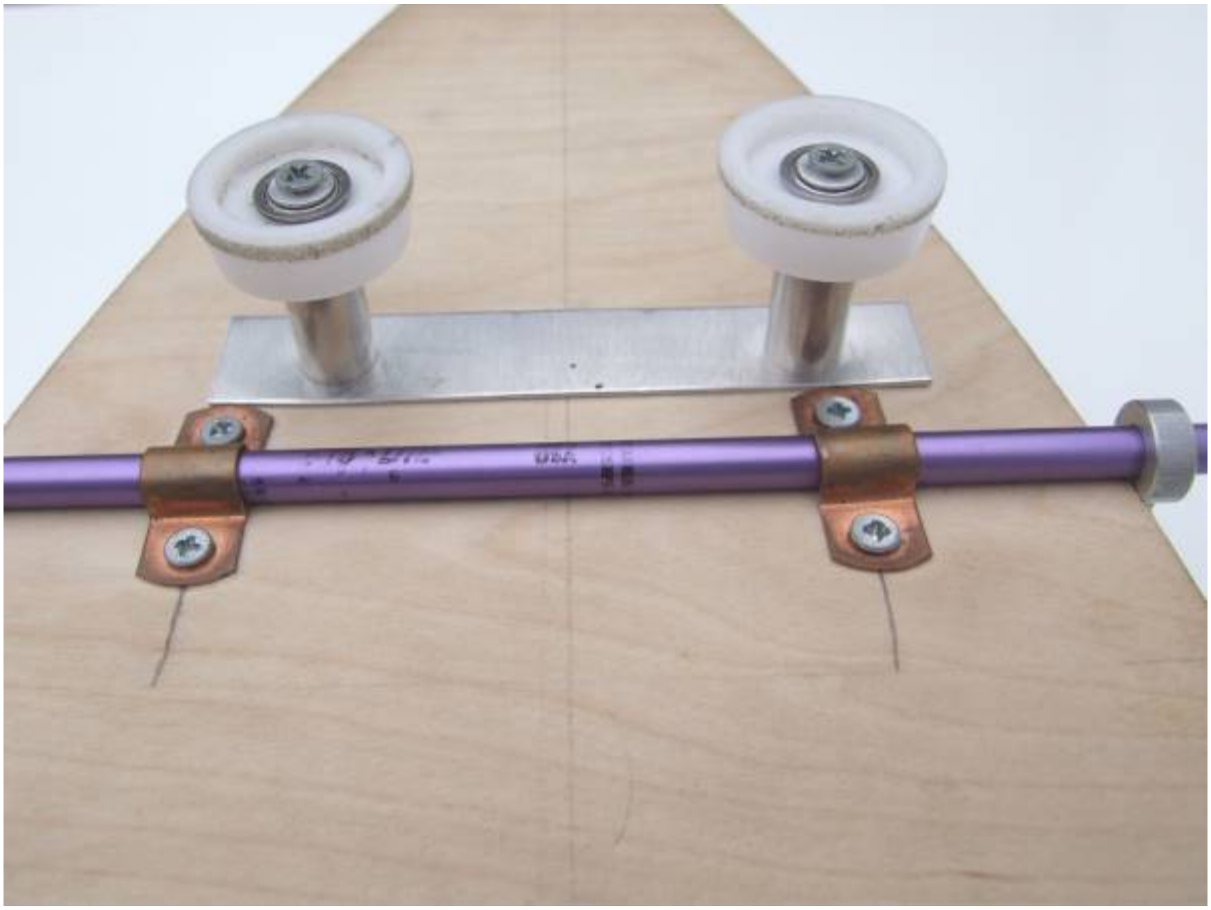
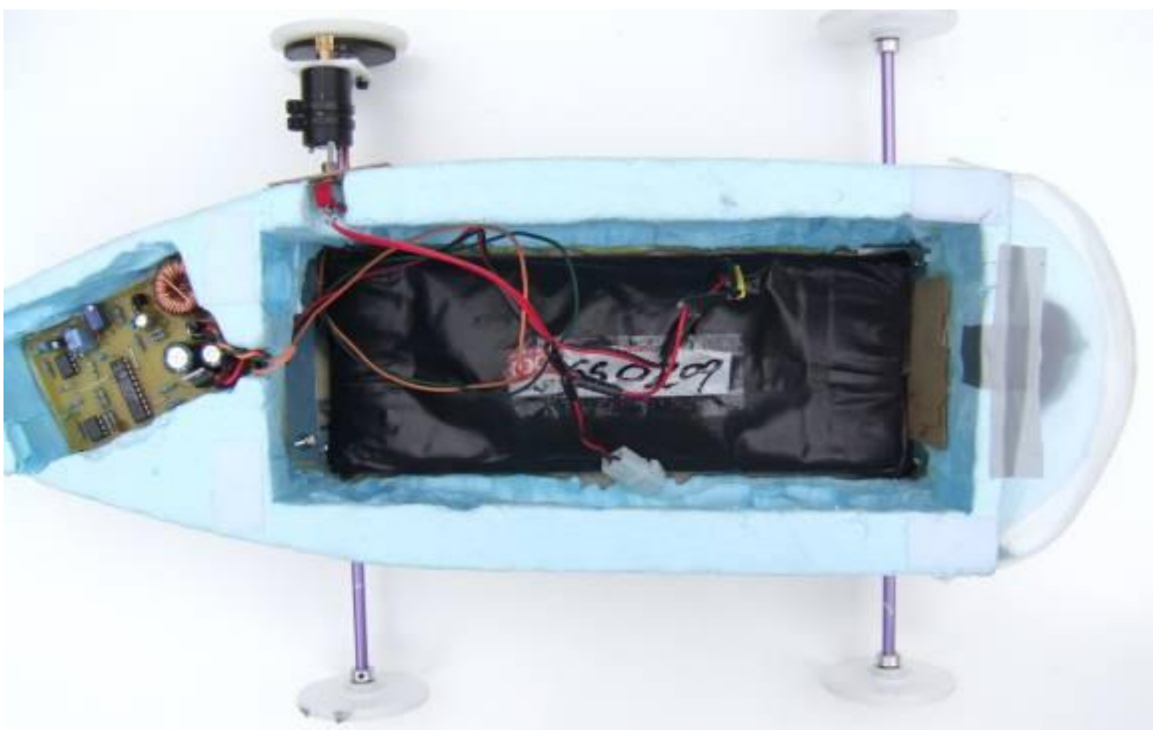
ENGINEERS
AUSTRALIA



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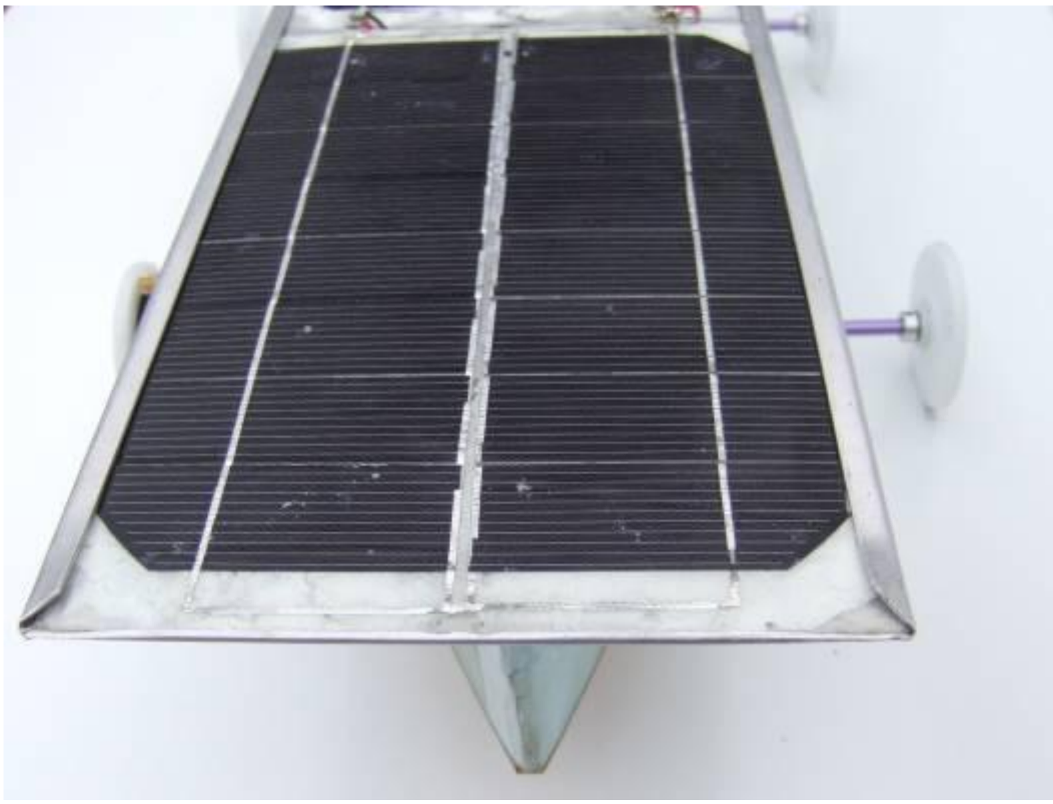

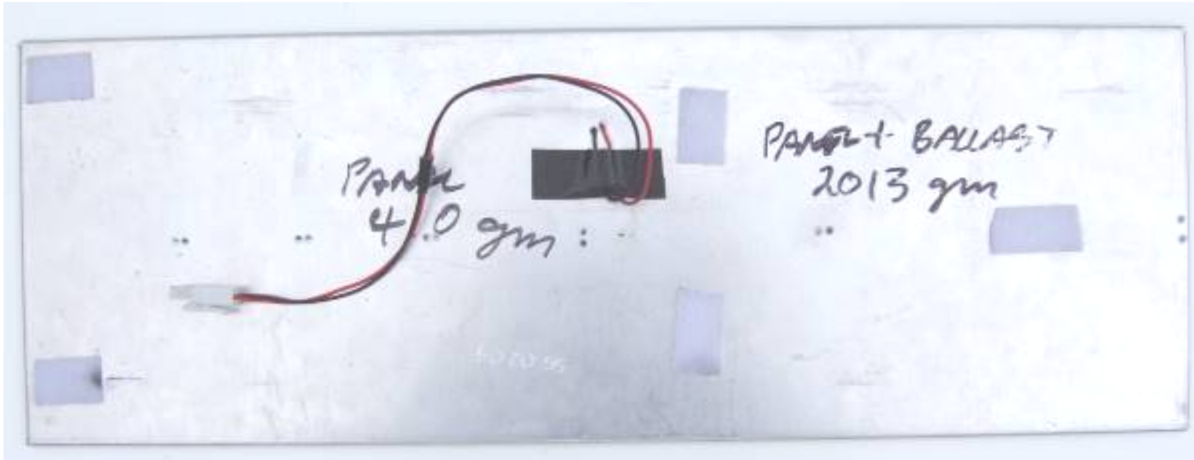

APPENDIX A: The specifications this car was designed to meet.

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 K: 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 g.
The downward force on each rear wheel due to gravity was measured at 840 g.
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 g.
With the plastic wheel locked the force to tow the car was measured at 295 g.

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 sometimes 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 g.**	**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 commencing at quite low Sun levels is indicated. Do ensure you check this for your car if you expect to race on this track.

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 L: GEAR MESH ADJUSTMENTS

Correct adjustment of gear tooth engagement is important to avoid wasting power in the gears, or even worse damaging the gears.
When correctly adjusted, there should be a small clearance between the teeth of mating gears. This clearance is usually referred to as "backlash". See photographs below.

No backlash teeth touching. **Backlash clearance between teeth.**

These photographs are of much larger gears than used on the model solar car so the backlash is easily visible. The backlash shown in the right hand photograph is greatly exaggerated over what is normal in order to make it obvious.

The backlash or clearance you should aim for in your solar car gears is 0.01mm (or 0.004 inch) this is the thickness of a single sheet of normal paper (80 GSM).

Adjust your motor mount to obtain this backlash. Slightly more is acceptable but too much will have just the gear tips engaged, this will lead to stripping the tops off the gear teeth destroying the gear. Gear teeth touching with no clearance will greatly increase power losses in the gears. Moving the motor further away from the large gear increases backlash, closer decreases backlash.

<u>How to check backlash:</u>
The suggested method is, with the drive wheel free (not on the ground or touching anything) place one finger on the motor pinion gear to stop it rotating, then with the other hand gently rotate the wheel back and forward. You will be able to feel the free movement as the gear teeth on the wheel gear move back and forward between the locked teeth of the motor pinion gear.
Because the diameter of the wheel is about 1.7 times that of the gear the movement at the wheel outer diameter should be about 1.7 times the movement at the gears. (It is just a simple lever.)

You are looking to get the thickness of just less than 2 sheets of paper movement. With practice this is easily achieved.
Remember be gentle in your movement of the wheel holding it lightly with one finger gives the best feel.

APPENDIX M: 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

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: **Faulhaber motors, Electronics units (incl. Automax), Solar panels, wheels, bearings, gears, axles, chassis components, motor mounts, fasteners, wire, etc.**