Model Solar Car Racing

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Designing and building a model solar car at school

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Introduction

This book is designed to be a practical resource for teachers of Science and Technology Studies, with implications for teachers of Maths, English, Media, Graphics and Computer Studies. It is suitable for teachers of students from yr 7 – 12 depending on the degree of complexity with which the project is explored.

Although the word ‘racing’ suggests that winning is the principle objective, model solar car design and construction has provided focus and educational experience for girls and boys of far more lasting value than simply winning or losing a particular contest. It can be an extremely powerful activity, providing (often inescapable) practical applications for many ideas and concepts.

In addition, team involvement and responsibility combined with a broad curriculum approach to the project can lead to the development of personal qualities in students in a way not possible in the classroom.

1. The development of solar powered vehicles

Hans Tholstrup and Larry Perkins built the first solar powered car in 1980 which they drove from Perth to Sydney in 1981.

The first solar powered vehicle race, the Tour de Sol was held in Switzerland (of all places) in 1985 and has since been held annually. One month after the first Tour de Sol, Hans Tholstrup announced the first World Solar Challenge which was to be run between Darwin and Adelaide in 1987.

The art of solar car development was given a major boost when General Motors decided to enter the 1987 race. GM launched a major research and development effort throughout the organisation, costing many millions of dollars and involving such luminaries as Dr Paul MacCready the designer of the famous human powered aircraft, Gossamer Albatross and Gossamer Condor.

GM took no chances in the first Darwin to Adelaide race bringing two Sunraycer vehicles (one as a spare), arguably the finest terrestrial human transport vehicles ever built. They comprehensively won the first race in 44 hours and 54 mins averaging an extraordinary 67 Km/h for the journey.

GM decided not to contest the second World Solar Challenge in 1990 but remained an important supporter of the contest sponsoring a number of teams including 3 university teams from the United States. The 1990 race was a more closely fought event in which Sunraycer would have struggled to defeat the eventual winner, the University of Biele, Switzerland. The Biele car completed the course in 46 hours and 8 minutes only one hour slower than the 1987 GM car in less favourable weather conditions.

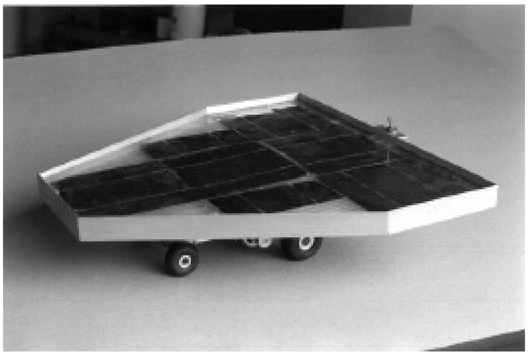
The World Solar Challenge is now established as a triennial event attracting competitors from all over the world.

2. Model solar car racing

Paul Wellington, a lecturer at Chisholm Institute of Technology (now Monash University) and driving force behind the Chisholm and later Monash University (full size) solar cars, led teams which competed in the 1987 and 1990 Darwin to Adelaide races. Ted Mellor, a teacher of Technology Studies at Warrigal Technical School in Victoria had led a team of students in constructing and then driving a large scale solar car across Australia from north to south in 1986, the first group to achieve this feat. Ted also took his team on the 1987 Darwin to Adelaide trek.

As experienced educators and solar car racers, Paul and Ted, became interested in the idea of a model solar car competition for secondary schools which was first mooted by Alan Pears from the Victorian Government’s Renewable Energy Authority, Energy Victoria in 1985.

It is not known if miniature solar powered cars had been built anywhere in the world prior to the model built by Mick Harris and Bob Keeley of the Alternative Technology Association in 1986. The model was commissioned by Alan to demonstrate the feasibility of a schools competition.



The first model

Energy Victoria became the major sponsor of the Victorian Secondary Schools Model Solar Car Challenge in 1990. With the support of Energy Victoria and championed by Paul Wellington and Ted Mellor, 75 Victorian schools were provided with solar panels and other resource materials.

The world's first model solar car race was held on a sunny Sunday in May 1990 at the Exhibition Buildings in Melbourne. Thirty five schools were able to reach the starting line in this first event with Lynall Hall Community School, Wodonga Technical School and Assumption College topping the first field.

Educators, particularly in the Technology Studies and Science areas have been quick to appreciate the value of the project with its high motivational value requiring minimal technology resources and facilities and providing opportunities for the development of many skills.

The event has now become an established annual event on the Victorian school calendar and has rapidly spread to all Australian states. Australian national championships commenced in 1994 and are to be held annually. The 1994 event was won by a girls team from Perth College WA.

International events are to be held triennially to coincide with the World SolarChallenge. The first International competition was held in Adelaide in November 1993. The only non Australian competitor in that race was from New Zealand. It was won by Eastern Hills High School from WA. Interest in model solar racing is growing internationally and it is expected that future internationals will attract competitors from further abroad.

3. The relevance of MSC design in the curriculum

Our experience at Lynall Hall Community School has shown us many ways in which the model solar car project can be developed beyond the core related areas of science and technology. With sufficient commitment from the students and support from other teachers, related work requirements can be found and negotiated in many curriculum areas.

Examples at our school have included

3.1. Technology Studies

The project is essentially a design and construction project, the stuff from which technology courses are made. Since a solar car has many elements and possible construction techniques and materials, the project may be used in technology courses which are media specific such as electronics, metal work, fitting and machining, plastics and composites and wood.

3.2. Mathematics

Mathematics can be used in making sense of and working through the many graphs and formulae which can be generated in component testing. Another important potential use of maths is in developing mathematical models of car performance. (See Mathematical Modelling)

3.3. Science

Science and Physics in particular can play a very important role in the design process. A number of very practical experiments and activities designed to test and compare components and design approaches are outlined here. In the most meticulous approach to solar car design the results of the experiments are vital in preparing data for mathematical modelling.

3.4. Computer Studies

Computers are almost essential in modelling vehicle performance if this detailed approach is to be taken. Spreadsheets or languages such as Basic can be used.

3.5. Communication Studies

Our school has developed work requirements in English and Graphics which support the model solar car project. Team members are responsible for writing to potential sponsors for donations and for the various follow up activities. Communicating with other groups about the project has also formed an assessment task as has publicity and media work.

Work in graphics has included team emblems, T- shirt design and technical drawing of the models.

3.6. Environmental Studies

The car provides a perfect illustration of the application and use of energy from re-usable sources and can be used as a starting point for further investigation or comparison such as of transport modes.

4. The team approach

For such a potentially comprehensive project usually involving out of school activity, it is advisable to adopt a team structure. This is the approach we have taken at our school. A team identity has been developed and students are encouraged to assume ownership of the project.

A Team Manager is selected from among the group. This student is required to work with the teacher/co-ordinator in guiding the project and monitoring the various tasks and timelines. The team manager also acts as representative of the group at official functions and in liaising with the press.

Other students assist the Manager and undertake such tasks as seeking sponsors, developing vehicle design and in conducting tests and experiments. Our teams have typically numbered between 5 and 7 students with two teachers working on a single vehicle.

Team meetings are held frequently so that members are kept abreast of developments and can each participate in developing the work program. The team approach has proven very successful with students developing a high level of commitment to the project and a healthy sense of ownership and comradeship.

5. Financing the project

5.1. Budgeting

A dedicated pool of money must be allocated for the project. Depending on the amount of component testing and prototype building undertaken, solar car development can be costly. Materials alone could cost up to $600. High performance electric motors may cost around $150. On the other hand, low power motors used in other hobby models cost $10. It is worth noting that Assumption College's two excellent cars in 1990 used cheap motors and were the second fastest cars on the day. Some schools have achieved excellent results using pirated motors from video machines. The very fast champion South Australian car of 1992 and the 1991 Victorian runner-up from Swan Hill Tech had pre-loved VCR motors. The degree of subsidisation of solar panels is also a factor, the unsubsidised cost of a panel is around $150.

The cost of bearings, gears, wheels and other construction materials does add up.

Various other team costs can also be anticipated. The cost of team uniforms is an example. At Lynall Hall we have always endeavoured to pay for team member's meals during out of school hours work. Team morale is seen to be important and deserves consideration in the budget.

5.2. Sources of funds

While it is reasonable to expect a school to commit funds from within its educational program budget to such a worthwhile project, reason does not always prevail or the school's priorities may not accord with those of the solar car team.

External sources of funding are often available. A variety of authorities may be interested in extending grants for the project. Local Government can be an important source of funding, especially councils with youth welfare departments. A number of other government and community service organisations also make funds available for youth projects. Often such organisations are eager to fund innovative and socially worthwhile projects and need only be asked.

Another source of funds is sponsorship. This would normally come from businesses with an interest in education or in the particular application of technology. Local energy supply authorities, especially those who promote energy conservation may be interested in associating with the project.

Submissions to these organisations may be as simple as a brief letter from your team manager outlining the project and making a specific funding request. The letter should offer to meet with the business and discuss the project further. Personal telephone follow-up by the team manager or teacher is **very** important.

Other potential sponsors are your suppliers of parts and materials who will often respond favourably to the request of assistance, particularly because the free supply of materials is often inexpensive to them.

Team uniforms are an excellent way of acknowledging sponsors and of building team spirit. Extra t-shirts can be sold to other teachers, students and supporters as fund raisers. With an attractive design, several hundred dollars can be raised quite easily.

5.3. Publicity

The other side of the funding coin is publicly acknowledging your sources. You may get assistance in one year from organisations but unless there is some recognition of their support the assistance may not be continued in future years. Recognition of sponsors and funding agencies may include: badges and stickers on vehicles, names and logos on team uniforms (usually t-shirts), and a sign acknowledging the assistance wherever the solar car is displayed such as on race days.

If funding is received from community organisations, they will be eager to involve the group in community days and local exhibitions. Participation in these sorts of activities builds team spirit and promotes the school's educational program in the community as well as raising the level of awareness of re-usable energy alternatives.

General promotion of the school in the community (including the education community) can have a very tangible pay back to the project in terms of funding from within the school budget and in teacher release time for solar car activities.

At least one photo opportunity should be arranged with the local press usually just before the annual race. Remember to seize all opportunities to acknowledge your sponsors.

6. Race regulations and the design brief

The design brief for the project is essentially to design and construct a solar powered vehicle which will complete the stated course in the fastest possible time. The course and constraints on the vehicle design are outlined in the race regulations. The 1995 Australian Model Solar Car Challenge race regulations are given in Appendix 3. You may wish to introduce your own constraints such as cost and time limits.

The course and track construction are of fundamental importance and will have a large bearing on the design. For example, track curves of 10m radius will probably not require a steerable front end but 2m curves certainly will. The type of guiding system to be used whether it be by guideway attached to the track or radio control (as used in New Zealand in 1992) is specified and critically effects design. Track surface is also important.

Limits on the type and size of panel permissible and the overall dimensions of the car will be specified as will ground clearance and provision for a model driver.

7. Design approaches

There are two possible approaches to the design problem.

1. *To build a car which will move in sunlight*. This is a very satisfying objective in itself and may be sufficient achievement in the first year of involvement in the project. This can be achieved largely by **trial and error** without much component testing and I would refer those intending to adopt this approach to the construction tips contained below.

2. *To build a high performance racing car.* The essential of this approach is component **testing and performance modelling**. This can be approached with more or less vigour. Sufficient information is provided here for a very thorough approach however hints and ideas can be gleaned from these notes which will allow a competitive car to be built with less test work.

Note: A high performance vehicle can be constructed by trial and error however it would require the construction of a full size track on which to conduct accurate trials. Such an approach would also be very time consuming requiring the construction of a number of test vehicles. In addition, not all possible race day conditions can be simulated.

In practice many schools will adopt a combination of both approaches. At Lynall Hall Community School we have used an almost entirely test and model approach to the extent that we have not had a vehicle in going order until the day before the race in three of the four years in which we have won the Victorian contest. (While this is triumph for theory it is not to be recommended as it relies on an element of luck.absent in our fourth year)

So component testing and performance modelling is described here.

8. The design principles

Isaac Newton set out the ground rules for model solar car racing.

In general – to win a race the vehicle must ***accelerate*** *as much as possible for as long as possible.*

1. The car should be as light as practicable, otherwise acceleration is reduced. This fundamental trade off between weight and strength is well understood by the 1995 *One Australia* America's Cup yachting syndicate!

$$F = m \infty a$$

F = force (Newton)

m = mass (kg)

a = acceleration (m/s/s)

$$a \propto 1/m$$

Acceleration varies inversely with mass.

2. The car should have as little wind drag as possible because wind drag increases as the square of wind speed.

$$F_w \propto v_w^2$$

v_w = wind speed = Vehicle track velocity

(v) + head wind speed, (m/s)

F_w = wind drag, (N)

3. The car should have as little rolling resistance as possible. This is the resistance to wheels and bearings rotating and tyres moving along the track. Rolling resistance seems to have two parts. One is a preload or static resistance to movement no matter what the velocity and the other part is a dynamic resistance (F_f) which increases with velocity, probably linearly

$$F_f \propto v$$

F_f= rolling resistance, (N)

v = track velocity, (m/s)

Wind and rolling resistance effect acceleration because they reduce the forward force acting on the car.

$$F_r = F_m - F_w - F_f$$

F_r = resultant forward force, (N)

m = force from motor through dri

F_w = wind drag force (N)

F_f= rolling resistance, (N)

Note: When $F_w + F_f = F_m$ acceleration of vehicle ceases. This occurs at the terminal velocity.

4. The motor and solar panel combination should provide as much power as possible (a motor search is often necessary). Forward force delivered by the motor through the wheels is related to (i) the power coming from the motor at that instant, and (ii) the instantaneous velocity of the car.

$$F_m = P/v$$

F_m = force from motor via drive wheels, (N)

P = Power delivered by motor, (Watt)

v = track velocity, (m/s)

Note: Typically, power from motor is low as car starts off, increases as speed increases until it reaches a maximum and then reduces as motor speed increases beyond it's optimum.

5. Both selection of the appropriate gear ratio connecting motor to drive wheel/s and the drive wheel diameter effect the motor speed at any given car velocity

$$M_s = vR/\Pi d \infty 60{,}000$$

M_s = motor speed (RPM)

d = drive wheel dia, (mm)

R = gear ratio, (drive axle gear:motor gear)

6. Bearings in which axles are mounted should be low friction, firmly fitted to body (or wheels in the case of wheels mounted on fixed axles) and accurately aligned (so the axle is not required to bow between the bearings).

7. Front and rear axles should be parallel.

8. Wheels should be round and have solid tyres (on smooth track) to minimise rolling resistance. A test can be made to see if wheels develop sufficient traction for acceleration.

9. On tracks with tight curves steering mechanisms and differential drive to drive wheels may give increased performance.

10. The guide assembly for steering should be low friction.

9. Component testing

Component testing has two functions:

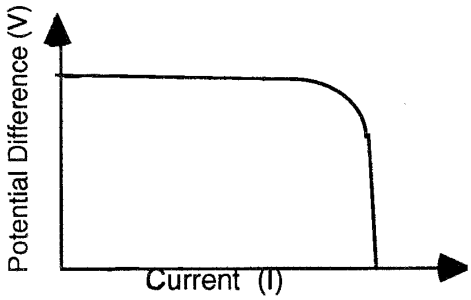
1 to compare components such as motors and body types so that the best selection can be made;

2 to prepare data for mathematical modelling to further refine component selection and gear selection for race day conditions

9.1. The photovoltaic panel

The panel is specified by the race organisers to avoid expensive world wide best technology hunts. GM spent $2 million on the satellite grade cells on Sunraycer. The polycrystalline panels used in Australian and New Zealand model races to date are approximately 10% efficient, ie. 10% of the sun's energy striking the panel is converted to electricity. The best in the world are about 25% efficient and are hugely expensive.

The electrical output of the panel will reach a maximum at a certain load or resistance. By connecting the panel to a variable resistor, and measuring current coming from the panel with an ammeter and the potential difference across the resistor with a voltmeter, you can plot a graph of potential difference vs current or a graph of power output vs resistance. Power output is given by the formula Power = Potential Diff x Current or P= V ∞ I (Watts = Volts ∞ Amps)



Output characteristics of P-V panel

Graphs plotted in this way are not necessarily of much use for modelling but do give a better understanding of the behaviour of the panel and may assist you in selecting a motor which matches the panel's power output (if you don't believe it's power rating).

The cell area of the panels approved for Australian races is approximately 0.1m^2. They are suposed to deliver power outputs in full sunlight of between 8 and 12 Watts.

Most of the approved panels have a set ouput voltage of 6 or 12 volts. The APPSYS panel is constructed of 4 independent strings of cells. The potential difference across each string in light is approximately 3 volts. The panel can be thought of as four 3 volt cells and just as battery cells can be connected in parallel, giving a 3 volt supply; in series, giving a 12 volt supply; or in a combination of series and parallel giving 6 volts so can the panel. Note that power outputs are not effected by these configurations. With low voltage connection you will achieve a relatively higher current output. Some **motors** however will have a preference for one configuration over another. Some schools have exploited this ability to use different output voltages to advantage by changing voltage during a race.

Treat the panel with great care, especially if conducting tests under artificial light which is relatively much hotter than sunlight. The protective cover will soften and deform if it gets too hot. Be gentle, the cells are extremely brittle and are easily cracked. The protective plastic cover should be kept in good order to maximise its optical clarity. If you are soldering electrical connectors to terminals on the panel try not to get things too hot as the heat may effect soldered connections on the cells themselves.

9.2. Motors

There are two ways of testing and comparing motors described here: the dynamometer and the winch method.

A **dynamometer** is a device for measuring the power output of rotating shafts such as those in model solar cars or in electric motors. I don't know of any commercially available dynamometers but they can be built by the electronics enthusiast.

The Winch Method. The simplest method for testing motors (unless you have a dynamometer) is to construct a winch powered by your test motor and lift weights. There is a diagram of the winch in appendix A2.

The weights are lifted a measured distance (say 2m) and the time for the lift recorded. With this information the power output from the motor during the lift can be calculated.

$$P_O = wd/t$$

P_O = Power output of motor (Watt)

w = weight (Newton)

d = length of timed part of lift (m)

t = time for lift (s)

Note. Allow the weight to accelerate to a constant velocity before measuring time t over distance d.

Students may also wish to measure the power **input** to the motor during the lift by measuring potential difference across, and current through the motor/s.

$$P_i = VI$$

P_i = power input to motor (Watt)

V = potential difference (Volt)

I = current (Amp)

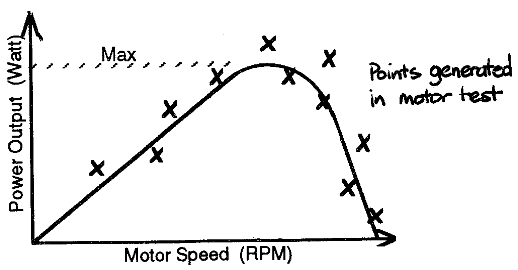
The percentage efficiency of the motor can then be calculated

$$e = P_O/P_i \infty 100$$

By varying the weight being lifted the motor is forced to operate at different speeds, generating a range of power outputs, indicating that it does not work very well when forced to go very slow or when lightly loaded and going very fast.

9.2.1. Graphing the power output of the motor.

As the weights being lifted by the motor are varied from say 50g to a weight which stalls the motor (probably 200–400g), the motor speed varies accordingly. By recording the power output and motor speed for each lift a characteristic curve of power output vs motor speed can be generated for each motor.



Motor Output Characteristic

Motor speed can be calculated by counting how many turns of the motor (T) are required to lift the weight distance d. Or count the number of loops of string on winch axle for lift d and calculate the engine rotations using the gear ratio.

Knowing the number of turns of motor (T) to lift weight distance (d) simply divide by time (t)

$$M_S = T/t \times 60$$

M_S = Motor Speed, (RPM)

9.2.2. Power supply for motor tests.

The power source for the motor tests could be a constant power supply but since the solar panel does not behave like a constant power supply, a better approach is to use the actual solar panel. Additionally the panel and motor behave as a unit where the panel output varies with the speed of the motor, so the panel behaviour can not easily be simulated by a constant voltage supply (the panel output voltage under load does not stay constant).

9.2.3. The solar panel as test power supply

Using the panel as power supply you are in fact measuring the mechanical power output of the panel and motor combined which is the real situation. If you do use the panel you can either illuminate it using the Sun (which may vary in intensity during the tests), or artificial light which can be held constant.

9.2.4. Artificial light

1. To illuminate the panel for tests use a 2Kw halogen light (available from theatrical lighting hire) or use 2 ∞ 1kW portable halogen video lights.

2. Measure the intensity of light on the panel by measuring the closed circuit current coming from the panel (the panel serves as a very accurate light meter for this purpose). Compare this to the values measured in bright sunlight and adjust your light/s accordingly by moving them closer or farther away from the panel.

3. **BEWARE! Do not** leave lights illuminating panel for longer than **1 minute** without a cooling off period. The lights are much hotter than sunlight and the panel will be damaged by excessive heat. A fan can be used to aid cooling.

4. If time permits conduct a range of experiments on each motor at varying light

intensities so that you will be prepared for race days in less than full sunlight. For example, at full sunlight, 1/2 full sunlight and 1/4 full sunlight. Plot graphs of power vs speed for each luminosity.

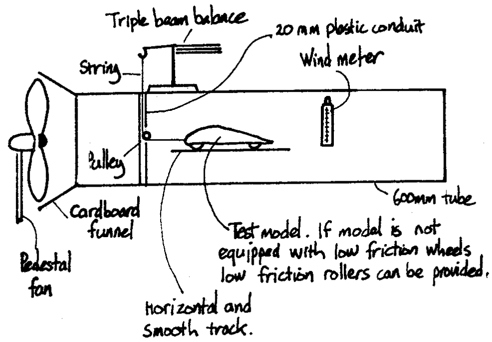
9.3. Wind drag

Speeds of over 25km/h have been achieved with these cars. At these speeds wind drag does become significant, especially when compared to the tiny forward force being provided by the motor at high speed. Body streamlining usually means extra mass though which reduces acceleration especially in the early part of the race.

To evaluate the wind drag of different body shapes, students can build full size mock ups of body shapes and test them in a home made wind tunnel. The Aeronautical Research Laboratory has a tunnel but it costs $2000 per hour to use.

A 600mm dia cardboard tube of the type used for display purposes in carpet stores (not the inner tubes of cardboard rolls) makes a suitable tunnel. A high powered pedestal fan makes a suitable wind source and can be hired from plant hire places. Wind speed in the tunnel can be measured by a Venturi effect wind speed meter available from boating suppliers for about $30. Wind drag on the model can be measured using a triple beam balance mounted on top of the tunnel with a string replacing the pan and running from the end of the beam through a hole in the top of the tunnel, down a plastic conduit around a small low friction pulley (also available from boat shops) and connecting to the test model.

Students performing wind tunnel tests



Wind Tunnel

The model must be mounted in a level position on very low friction runners. The higher the wind speed the less significant will be the effects of poor runners.

A wind drag factor can be calculated for each model as follows:

$F_W \propto v_W^2$

F_W = wind drag, measured by beam balance, (N)

v_W = wind speed, measured by wind meter, (m/s)

$F_W = k_W v_W^2$

k_W = Drag factor, (m/kg)

$k_W = F_W / v_W^2$

Note: 1. As drag varies with v_W^2, drag becomes much more significant at high speeds.

2. Normally drag is given by a dimensionless constant called the drag coefficient much more suited to the application of wind tests on scale models to the real thing. For our purposes k_W is fine.

9.4. Rolling resistance

Rolling resistance is proportional to velocity and is effected by the track surface, the wheel diameter, wheel bearings and guide peg assembly.

The way in which rolling resistance relates to velocity is not clear to the author (on the basis of experimentation) but **may** be something like this

$$f_r = k_r \infty v + f_{rs}$$

f_r = Rolling resistance (N)

k_r = rolling resistance factor

v = Velocity (m/s)

f_{rs} = static rolling resistance(N)

k_r and f_{rs} are clearly difficult variables to quantify and present an interesting challenge to the model solar car designer. If the vehicle is well made with quality bearings, accurate axle alignment, a low friction guide peg assembly and firm tyres, wind resistance seems to be more important and rolling resistance can be ignored in the mathematical model.

Tests of comparative rolling resistance of different vehicles or rolling components can be devised using an inclined track or other means of applying a constant force.

10. Motor selection

Motor selection requires more research and testing than any other part of the process. As mentioned in the budgeting section, motors can cost $150, $10 or nothing (when salvaged from wrecked machinery). Specialist suppliers of scientific or electronic equipment carry the expensive motors which can be up to 80% efficient (at converting electrical energy to mechanical energy), hobby shops have the cheap motors usually less than 50% efficient (but may work better than an expensive motor poorly matched to the panel) and free motors can be from videos, cassette players or any other low power machine with DC (not AC) motors.

What ever your source of motors it is fun to get hold of a few and compare them.

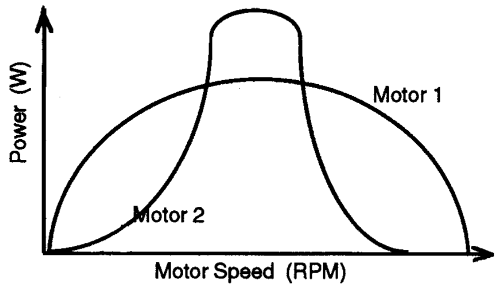
10.1. Approaches to motor selection.

1. Approach a recommended supplier of quality motors and purchase a motor which is designed to match the power you expect the panel to deliver.

2. Purchase, borrow or pirate a selection of motors with likely characteristics and test and compare them.

10.2. Comparing motors

Once Power vs RPM graphs are produced for each motor, a judgement can be made as to the most effective motor for each level of sunlight. The maximum power obtained gives a good guide to the best motor, but not always. In the diagram, Motor 1 will probably be the best option even though Motor 2 has a higher maximum power, because motor 1 will deliver more power through a larger range of motor speeds from the beginning of the race to the end. (The curve for motor 2 is not typical.)



Comparing Motor Characteristics

The use of a mathematical model will provide the most accurate way of comparing motors but usually inspection of the power vs RPM curves will suffice.

11. Gear ratio selection

In the ‘classical’ model solar car, the drive motor has a little gear which meshes with a big gear on the drive wheel or the drive wheel’s axle.

A correct judgement as to the best motor available should be possible with simple examination of the Power vs RPM graphs, however selection of the best gear ratio to use between motor and drive wheels is more difficult.

In practice only a limited number of off the shelf gear sizes will be available to you, so trial and error gear selection is possible provided you have access to a race track. A calculated guess approach to gear selection may also be successful.

The most accurate way to select a gear ratio (without access to a full length test track) is by mathematical modelling.

The relationship between vehicle road speed, v(m/s) and motor speed, M_S (RPM) is effected by two factors:

1 the drive wheel diameter, d (mm) and

2 the gear ratio, R between the drive wheels and the motor

$$M_S = vR/\Pi d \infty 60,000$$

Since R and d can both be varied, we are able to adjust the relationship between M_S and v.

11.1. Estimating a gear ratio

Ex. If you think your best bet is to make your motor hit its top speed of (say)12,000 RPM when the car velocity reaches (say) 5 m/s then, transposing the formula above:

$$d/R = v/\Pi M_S \infty 60000$$

therefore

$$d/R = 5/12000\Pi \infty 60000$$

$$d/R = 7.96$$

For drive wheels with d = 50 mm

$$50/R = 7.96$$

$$R=6.3$$

R = 6.3 could be achieved with a 12 tooth gear on the motor and a 76 tooth gear on the drive wheel axle.

In practice your motor test will tell you the maximum speed you can hope to achieve from the motor and past model solar car races will enable you to make a reasonable estimate of a maximum v for a model vehicle. With this knowledge a value for d/R can be obtained.

Wheels must be large enough to give adequate ground clearance to the car body but can be varied somewhat. R can be varied by changing the size of gears or pulleys on the motor and drive axle.

Note: A low value of R say 30:15 = 2 will give slow early acceleration but more power later.

A high value of R say 100:10 = 10 will give high early acceleration but less power later.

12. Mathematical modelling

Mathematical modelling is where all the test information can be brought together to give accurate predictions of such things as the best gear ratio to use, the best motor to use and the time you can expect to run the race in under a range of light and wind conditions.

Modelling car performance is an excellent application of problem solving through the creation of a mathematical model and is ideally suited to project work in Calculus or ‘Change and Approximation’. The work also presents many possibilities in the study and application of Physics.

The reason for creating a model is to provide a means by which students can test various options in the set up of the car without having to build a large and expensive race track. The crucial output from the model is gear ratio selection but the effect of varying other parameters can also be assessed. Eg. See “Additional uses of information obtained in the model” .

The need for input parameters to the model provides the impetus for a number of tests which may be performed on the vehicle and its mechanisms.

The model can be approached at various levels of complexity and student involvement:

1. A model could be created by a teacher or in a teacher led process to allow students to test changes in parameters. (eg. changes in: mass, power, wind drag, rolling resistance, gear ratio).

2. The model may be very accurate and run on a computer (for which it is ideally suited) or it could be a more approximate and simpler process worked on a manually computed table.

3. The model could be developed by senior students as a project work requirement in Maths or Physics or elements of the model could be developed in this way.

12.1. Input parameters

The factors effecting vehicle performance which should be included in the model are:

12.1.1. Essential

1. Vehicle mass (kg)

2. Power output vs motor speed information (Watts vs RPM)

3. Diameter of drive wheels (mm)

4. Gear ratio (Wheel gear:motor gear)

5. Starting ramp height (m)

6. Starting ramp length (m)

7. Race track length (m)

12.1.2. Optional (for increased accuracy)

8. Wind drag factor (kg/m)

9. Rolling resistance factors

10. Head wind speed (m/s)

11. Location of curves in track and information on increase in rolling resistance on curves

Note. Provided that wind drag and rolling resistance are kept to a minimum these parameters can be ignored and although the time given for the race will be inaccurate, the best gear ratio given will probably be pretty close.

12.2. Output

The principle output will be **time** to complete race (s)

Once the model has been established, input parameters (mainly gear ratio) can be manipulated to achieve the smallest possible time for a race.

12.3. An approach to constructing the model

Because forward force being delivered by the motor, motor power, rolling resistance and wind drag are all functions of velocity and because velocity is constantly changing, the best way to model the behaviour of the vehicle is by considering the race as a sequence of small time increments and computing the power, forward force, acceleration, velocity and distance travelled at each progressive time increment.

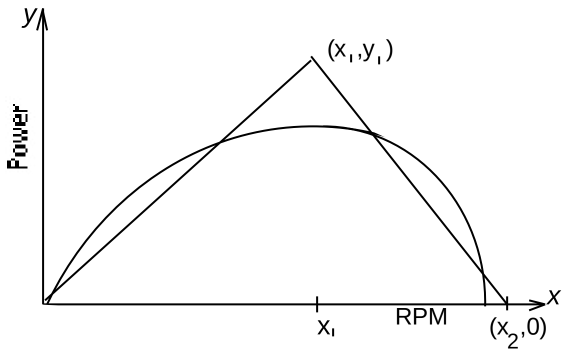
The procedure at each time increment is as follows:

1. Calculate the motor RPM based on the velocity (v_0) reached in the previous time interval.

$$RPM = 60000 \infty v_0 \infty R/\Pi d$$

(Design Principles 4)

2. Calculate the Power output of the motor from the Power vs RPM curve obtained in motor tests. A simple mathematical description of the curve should be developed and the details stored in the model as an input parameter. The simplest model of the curve would be 2 straight lines which could be described in two pairs of ordinates (plus the origin). Equations for the lines and therefore values of power at the given motor speed can be easily computed.



Simplified power output curve for modelling

Calculation of power.

For RPM< x_l For RPM > x_l

$$P = X \times \frac{y_l}{}$$

$$P = X \times \frac{y_l}{x_l - x_2} + \frac{x_2 y_l}{x_2 - x_l}$$

A more accurate approximation can be created using more than 2 straight lines.

3. Calculate forward force of motor using power (from 2 above) and vel (v_0 from prev. time interval).

$$F_m = P/v_0$$

(Design Principles 3)

4. Calculate wind drag force by multiplying wind drag factor by v^2.

$$F_w = k_w \infty v_w^2$$

(Design Principles 2)

$v_w =$ vel from prev. time interval (v_0) plus head wind velocity.

5. Calculate rolling resistance force F_f if the relationship between F_f and v has been established. Otherwise ignore.

6. Calculate resultant forward force on vehicle

$$F_r = F_m - F_w - F_f$$

(Design Principles 3)

7. Calculate acceleration due to F_r by dividing by mass of vehicle

$a_r = F_r/m$

a_r = acceleration due to F_r (m/s^2)

(Design Principles 1)

8. If distance travelled along the track at the previous time interval (s_0) was less than the length of the starting ramp (ie. the end of the starting ramp has not been reached) acceleration due to gravity must be added.

a_g = Ramp height /ramp length ∞ g

(ie. slope ∞ g)

9. Calculate total acceleration a.

$$a = a_r + a_g$$

10. Calculate increase in velocity during time increment by multiplying acceleration by the time increment

$$\delta v = a \infty \delta t$$

(Time increment, δt may be set between 0.1 and 0.5 sec depending on degree of accuracy required. δt may be made an input parameter and varied as desired).

11. Calculate current velocity by adding velocity in last time interval to δv.

$$v_1 = v_0 + \delta v$$

12. Calculate increase in distance travelled during this time increment by multiplying current velocity by time increment.

$$\delta s = v_1 \infty \delta t$$

13. Calculate current distance travelled by adding distance at last time interval to δs.

$$s_1 = s_0 + \delta s$$

14. Calculate total time elapsed by adding δt to total time elapsed at last time increment.

$$t_1 = t_0 + \delta t$$

15. Check to see if distance travelled is equal to or greater than race track length. If yes, record results (ie, time for race) and try some different input parameters especially for gear ratio R until a minimum time for race is achieved. If not repeat steps 1 to 15 substituting v_1 for v_0 , v_2 for v_1, s_1 for s_0, s_2 for s_1 , t_1 for t_0, t_2 for t_1

12.4. Computer programs

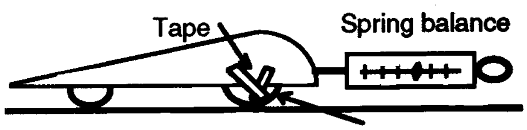
Any spreadsheet program (eg. MS Works or Excel) is suitable for this model and offer the advantage of being able to easily generate graphs, or it could be constructed in BASIC. A manual spreadsheet could be constructed but δt would have to be large (2 or 4 sec) to avoid long and tedious computation. Such a spreadsheet will still give some useful ‘ ball park’ figures.

13. Additional uses of information obtained in the model.

13.1. Drive wheel traction

By scanning the spreadsheet, you will be able to find a point in the race where the value of Force coming from the motor through the drive wheels is at a maximum. A simple test can be made to check whether the wheels develop sufficient traction to transfer this amount of force without slipping (resulting in lost power).

Simply lock up the drive wheels with sticky tape or something and pull the car along a short length of track surface with a spring balance. If the force required to make the wheels slide along, as measured by the spring balance, is less than the max. force in the model, you’re in trouble.



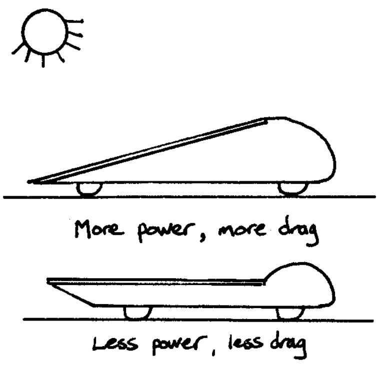
Wheel Traction Test

13.2. To tilt or not to tilt

Tilting the photo-voltaic panel so it is perpendicular to the sun (for most of the race) will give increased power output which can be calculated by measuring the closed circuit current coming from the panel through a range of angles of inclination to the sun. (See power source for motor tests). Conduct motor tests at these reduced or increased power outputs from panel. Prepare Power vs RPM curves.

Use wind tunnel to compute wind drag factors for cars with tilted and flat panels.

Run both sets of parameters through the model and compare results.



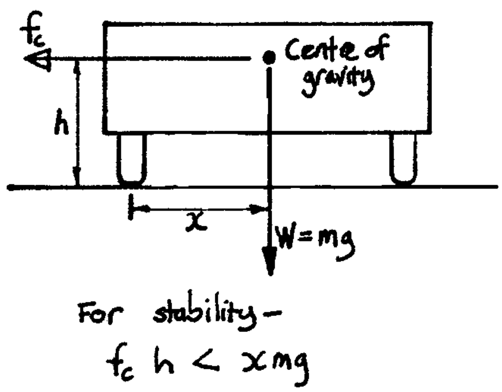
13.3. Stability on curves

Inspect spreadsheet to find velocity of vehicle on curves. Calculate centrifugal force using velocity, curve radius and vehicle mass.

$$f_c = v^2 \infty m/r$$

Estimate the height (h) of the centre of gravity of the vehicle (will be close to the height of the heavy solar panel) and calculate the overturning moment $= f_c \infty h$. The stabilising moment will be equal to the weight of the vehicle ($m \infty g$) times the horizontal distance from the outside wheel to the centre of gravity (usually at the centre of the car). If the overturning moment is greater than the stabilising moment you're in trouble.

Alternatively calculate f_c. Attach a spring balance to the side of the car at C of G height and apply force to the car until it tips over. Compare this force to f_c to determine whether the vehicle will be stable. Allow for some margin of safety.



13.4. Wind faring vs mass

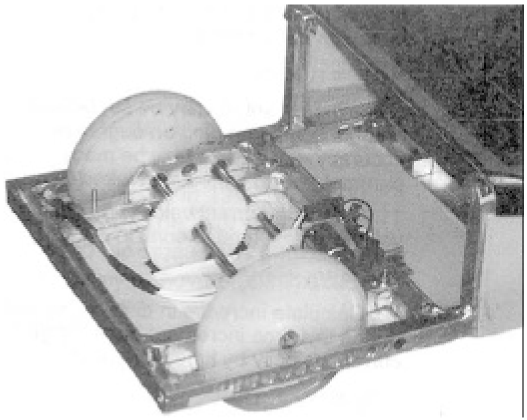
Putting wind faring on the vehicle will be at the cost of increased mass. Measure wind drag and vehicle mass with and without faring. Run the two options on the model and compare. Note: You may find that the vehicle runs faster without wind faring in low light but is better with the faring in bright light.

13.5. To use or not to use steering

In the Australian Model Solar Car Races, steering is achieved by locking the vehicle onto a centrally located guideway by means of a guide peg.

The minimum radius of curvature of curves is given in the race regulations and is usually 5m.

Adding a steering mechanism to the vehicle may reduce rolling resistance on curves but at what cost?



Spur gear drives

14. Construction and materials tips

Model solar car design and construction is well within the resources of most schools. Essential tools are a vice, a vertical press drill (if possible), drill bits, a vernier caliper, screw drivers, pliers, spanners, files, a centre punch, a soldering iron, a pop rivetter and considerable patience and time.

For teachers and students who are shaky about spacial design make a cardboard or a lego model first just to organise your thoughts and get things in the right place. Experiment with wheel diameters using cardboard. Find a likely place to put your motor. If all else fails, find a friendly fitter for advice.

14.1. Body and chassis design

Strength and lightness are, as in all vehicle design, the critical factors to be considered. Provision for streamlining is a third factor.

Model solar cars must be strong enough to support themselves through a race on sometimes bumpy tracks and be able to resist rough handling by enthusiastic students.

Frames and bodies can be constructed of many different materials including balsa, aluminium, fibre glass or other composites, styrene etc.

Probably the simplest approach is to construct a rigid chassis (frame) from aluminium onto which the drive components, solar panel and lightweight streamlining are mounted. Twelve millimetre square aluminium is excellent for the purpose. Aluminium can be screwed, bolted, rivetted or welded together. For assistance with welding, you could approach a local TAFE college.

An alternative approach is to build a lightweight body which provides structural strength, much as a modern auto sedan is built. A sandwich of light foam and fibreglass makes a very strong panel which can be formed to the shape of your choice. Laminated nomex or styrene foam would be suitable for this purpose. Balsa wood might also be suitable for a structural body. One attractive and relatively light car in the 1990 Victorian contest was carved out of a solid block of balsa.

Several W.A. schools have developed very lightweight frames using 4 or 5 mm diameter carbon fibre arrow shafts (as used by archers). These light and very rigid tubes are joined by gluing into specially formed blocks.

14.2. Gearing

A gear step (or two) between motor and drive wheel axle will usually be required because the motor will want to spin much faster than the wheels.

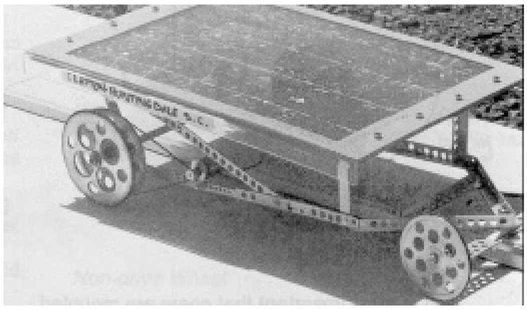
The gear step can be achieved in a variety of ways, but normally pulleys or gears are used.

14.2.1. Pulleys

Pulleys can be turned by students on a lathe or purchased or pirated from toys or electrical equipment.

Small pulley belts can be similarly pirated purchased or a substitute such as rubber bands or O-rings (available from bearing suppliers) can be used.

Pulleys are more easily made than gears but are less efficient at transmitting power than well made gears or roller chains and sprockets.

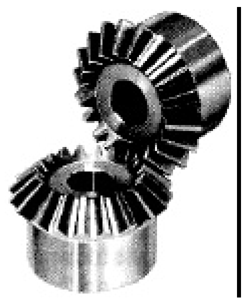


Pulley drive

14.2.2. Gears

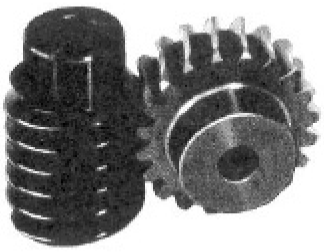
Spur gears are the most common form of gear designed to provide drive between parallel shafts. The advantage of spur gears is that light plastic forms can be purchased cheaply (see list of suppliers) and in quite a large range. Spur gears can also be cut to order in a well equipped school machine shop or cut to your specification by a professional. Spur gears are very efficient at transmitting power. With careful matching of axle and gear sizes it may be possible to find stock plastic gears which can be press fitted onto the axle or motor shaft avoiding further machining of gear internal diameters or the need to provide a fastening mechanism.

Bevel gears are designed to transmit power between shafts aligned at an angle, usually 90 degrees. This type of gear is used in slot cars where the motor is normally mounted with its centre shaft at right angles to the drive axle. Relatively cheap forms can be found in plastic from gear suppliers or from hobby shops. Bevel gears are quite efficient.



Worm gears are suitable for transmitting power between shafts mounted at right angles where a very large reduction gear ratio is required. They are available in plastic.

Worm gears are less efficient at transmitting power than the other gear types although we hear of advances in worm gear efficiency.



It is most important that gears are mounted and engage very accurately. Misalignment or fitting too close causes excess friction which will result in power losses. Belts and pulleys are not so difficult to align but will still require some tension adjusting mechanism.

Spur or bevel gears will be mounted on the motor shaft and either on the drive wheel axle or on the drive wheel itself. This latter arrangement will enable the drive wheel to mounted on bearings which rotate on a stationary stub axle.

3 Small roller chains and sprockets are another possibility offering potentially large gear ratios, light weight and the advantage of allowing the motor shaft and drive shafts to be physically separated as on a push bike. They are relatively efficient.

14.3. Axles, bearings and mountings

The careful assembly and precision fitting of these components is most important to ensure that the maximum amount of power reaches the wheels.

Bronze or polymer bushes may make good and light weight bearings for axles provided they are mounted accurately and that their internal diameter and the external diameter of the axle have the correct clearance.

An excellent ready made solution is to use small ball bearing races designed for hobby models. Hobby shops supply these in a range of sizes. It is important to purchase axle shaft which has a diameter exactly equal to the internal diameter of the bearing races.

Accurately sized shaft materials include piano wire available from hobby shops (in imperial unit sizes only) and 'silver steel' shaft available from engineering suppliers or certain steel mongers. Silver steel is available in imperial or metric sizes, is cheap and is produced to very close tolerances. Very lightweight axles may be formed in aluminium or from carbon fibre arrow shafts.

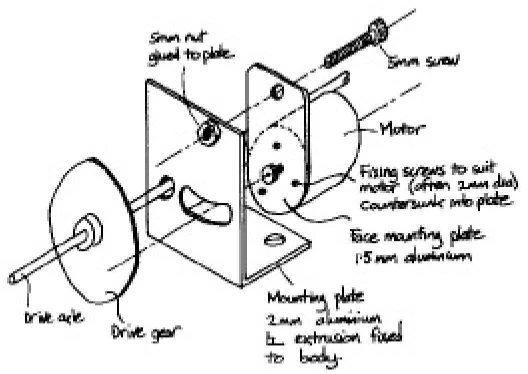
Bearing mountings can be simply produced from aluminium plate. The plates should have a thickness equal to, or slightly larger than the thickness of the bearing or bush being housed. A hole equal in diameter to the outer diameter of the bearing race or bush is then drilled through the plate in the appropriate position. The plates must be mounted very accurately on the chassis of the car. If the bearings are a bit loose in the housing put some centre punch marks on the inside of the hole in the plate. See " Bearing Mounting Plate Detail" in Appendix 2.

14.4. Motor mounting

Motor mounting is the most exacting part of construction if gears are to be used and is the area of construction where poor alignment or fitting will waste a portion of the precious power of the motor. A means must be devised to both solidly fix the motor in place and of being able to make fine adjustments in its position in order to bring the gear on the motor shaft into gentle contact with the gear on the drive axle or wheel. Solid motor mounting should not be compromised for small mass savings.

One of the advantages of using a pulley and belt drive mechanism is that accurate alignment of the motor and drive shaft are less important although some means of moving the motor to tension the belt must be provided.

Different motors will have different provision for mounting. The high efficiency motors tend to be face mounted. A means for mounting this type motor is shown here.



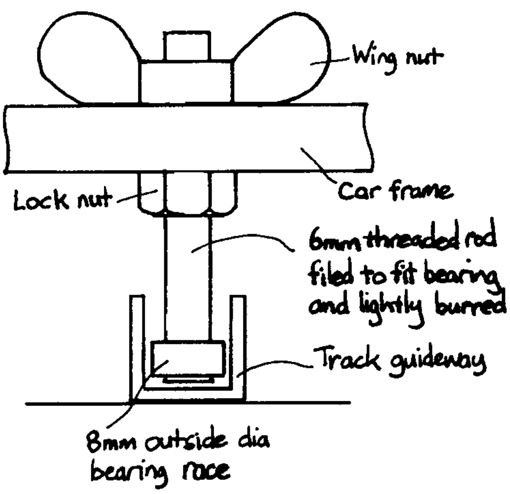
Adjustable Motor Mount (for face mounted motor)

14.5. Guide pegs

A guide peg must be provided in Australian solar car races for steering. The 1992 NZ race used radio controlled steering with a separate battery power supply.

The guide peg is a source of track friction so it should be designed to offer as little friction as possible. A metallic peg extending vertically from the under side of the car will suffice, teflon or another low friction polymer would be better. An approach used by some schools has been to use a small bearing race mounted horizontally on a vertical peg. The bearing race must be of a diameter that will fit into the guideway without jamming. Alternatively more than one guide peg could be set on either side of the guideway. This latter approach may be advantageous if the track or guideway are not accurately layed or aligned.

Which ever system is used, provision for adjusting the height of the guide peg should be provided.



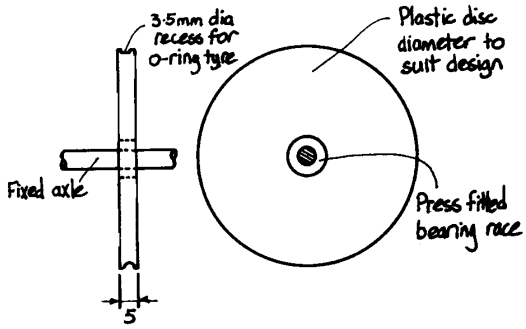
Adjustable Guide Peg

14.6. Wheels

The construction of wheels is up to your group's own ingenuity. There are many possible wheel construction techniques but for nice round wheels with a hole in the centre, you can't beat a lathe. If you don't have one at school see if you can get a friendly local school or TAFE to help or pay a local turner to make them, perhaps as a sponsor. Nylon or Acetal are suitable polymers.

Non drive wheels should be made so that a bearing can fit in their centre so that the axle they mount on is fixed and only the wheel rotates.

Wheels from toys or models may also be suitable.



Non-drive Wheel

Tyres will be necessary at least for drive wheels so that traction is developed. The outside edge of wheels can be formed with a recess to allow an o-ring (available from bearing suppliers) to be stretched onto the wheel.

14.7. Room for improvement

Rolling resistance is not well understood by the author.

The contribution to rolling resistance of cornering without a steerable front end is not well understood although we do know that the winner of the 1993 international championship did not have steering. The second placed car did have a steering mechanism. This same car, however, would not have sufficient power to negotiate a 1m radius curve.

Electronic power maximisers in the power supply from panel to motor would be advantageous as the panel does not deliver power at peak performance through the whole range of engine speeds. Several cars in the 1993 International race (not including the winner) used impedance matching devices (" maximisers"). A number of schools including a finalist in the 1993 International Challenge, have experimented with mechanical gear change devices.

There is a lot of scope to improve the component testing techniques and therefore the accuracy of the mathematical model being used. Schools could develop expertise and more refined processes over a number of years of involvement.

The author would welcome feedback on this publication. Please send comments to Peter Harley, PO Box 5, Brunswick East, Victoria 3057.

Appendices

A1: Sources of parts and materials

A1.1 General

The Technology Education Centre in South Australia produces an excellent catalogue of materials including parts suitable for construction of model solar cars. Included in the catalogue are motors, wheels, gears and various construction materials.

Technology Education Centre
32A Drew St

Thebarton

Sth Australia 5043
Ph 08 8354 4000 Fax 08 8354 4088

A1.2 Photo-Voltaic panels

APPSYS P/L - manufacturer of 8W panel with optional 3,6 or 12V output. Also supply a computer interface for testing panels and other resource materials
Ph or Fax 03 563 7253

Solarex P/L - manufacturers of 10W panels
For nearest distributor Ph 02 727 4455

BP Solar Australia P/L - Manufacturers of 12W panels.
For nearest distributor Ph 02 938 5111

A1.3 Motors

High performance DC motors are available from electronics suppliers.

Eg. Erni Aust Pty Ltd, 12 Monomeeth Dve, Mitcham, Vic 3132
Ph 03 874 8566
Contact – John Hodgson

Distributors of DC – Micromotors. This company will provide schools with a very useful catalogue of motors detailing performance characteristics.

Most hobby shops carry a range of inexpensive low power motors used in model making. Some are even beginning to carry the more expensive high performance motors.

Electronics retailers such as Tandy, carry inexpensive low power motors, which demonstrate quite good characteristics.

A1.4 Gears

Hobby shops carry a limited range of gears deigned for use in RC cars and other hobby machines.

Gear Manufacturers and wholesalers (see Yellow Pages) may carry the small size gears necessary for models although most deal in larger gears and usually heavier metal types. Many gear manufacturers will arrange to have small plastic gears made but this is relatively expensive compared to purchasing stock injection moulded gears.

Purgon Pty Ltd, 5 Lakeside Ave, Reservoir, Victoria 3073
Ph. 03 469 2639
Contact – John Russell

Distributors of NHK Stock Gears.

This range includes spur, bevel and worm gears down to 0.5 Module size (the best metric size for our purpose). A1.5 Bearings

Small ball bearing races are available from most hobby shops which stock radio controlled model cars.

Eg. Victorian Hobby Centre, 21a Swanston St. Melbourne, Vic.
Ph. 03 6504817

A1.6 Axle steel

For ‘silver steel’ look under ‘Engineering Supplies’ in the Yellow Pages.

Eg. A. E. Baker & Co, 1920 Hume Hwy, Campbellfield, Vic
Ph 03 357 8222

E&I Supplies, 665 High St, Preston, Vic
Ph. 03 478 9177

Many hobby shops carry heavy piano wire which may be suitable.

A1.7 Aluminium Extrusions

Alcan outlets (in Australia) are the place to go for this stuff. Look in the phone book.

A1.8 O-rings

See ‘Bearing Suppliers’ in the Yellow Pages

A1.9 Fibreglass and foam

See ‘Fibreglass Materials’ in the Yellow Pages

A1.10 Wind speed meters and low friction pulleys (for tests)

See 'Boat and Yacht Equipment' in the Yellow Pages. A cheap wind meter is made by Dwyer Instruments USA.

A1.11 Plastics machinists (for wheels, gears etc)

Look under 'Plastics – Products – Wholesalers and Manufacturers'

Eg. Alternative Plastics Pty Ltd, 59 Lothian St, Nth Melbourne, Vic. Ph. 03 326 5233

Or try a local secondary college or TAFE college.

A1.12 Bolts, nuts and fasteners.

For special sizes and types look under 'Bolts and Nuts' in Yellow Pages.

Eg. S. Keable & Co Pty Ltd, 185 A'Beckett St, Melbourne, Vic Ph. 03 329 6499

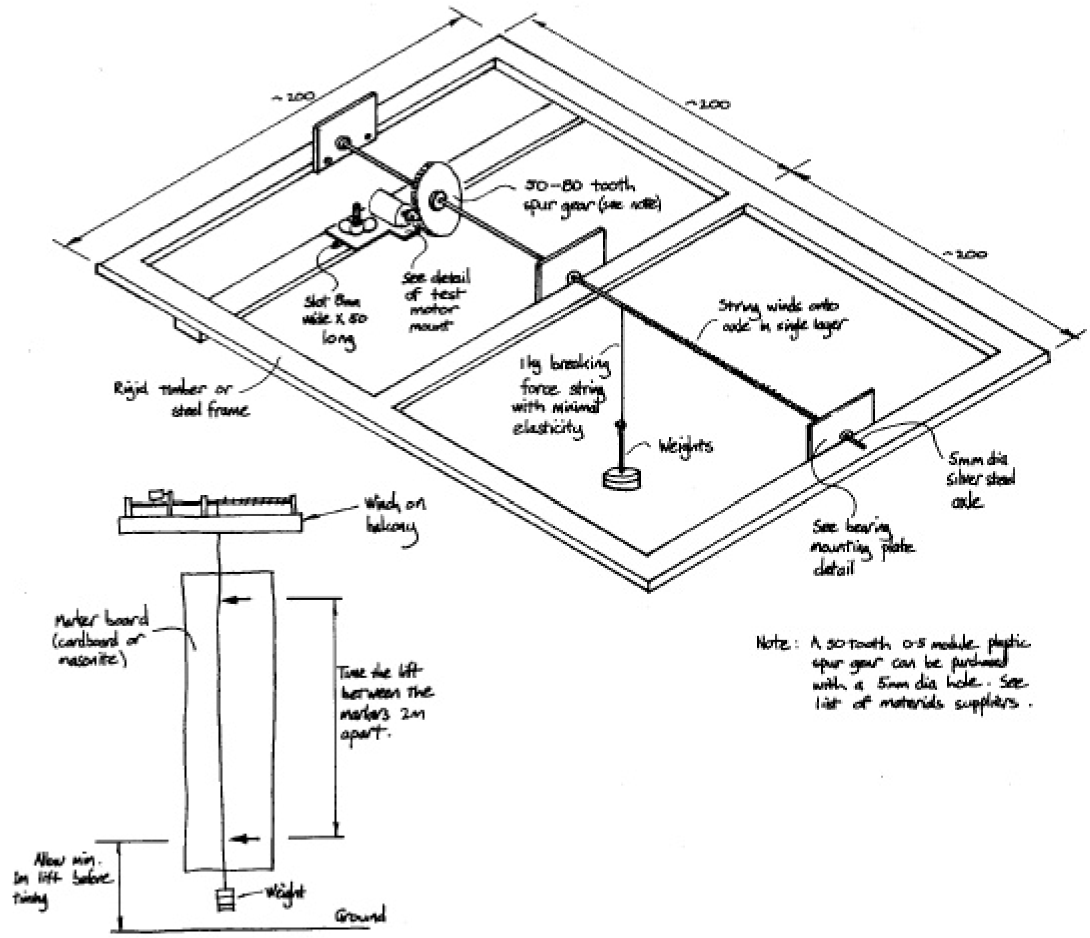
A1.13 Aluminium welders

Try a local TAFE college for help or look under 'Welders' in the Pages or just use 'Pop Rivets' instead.

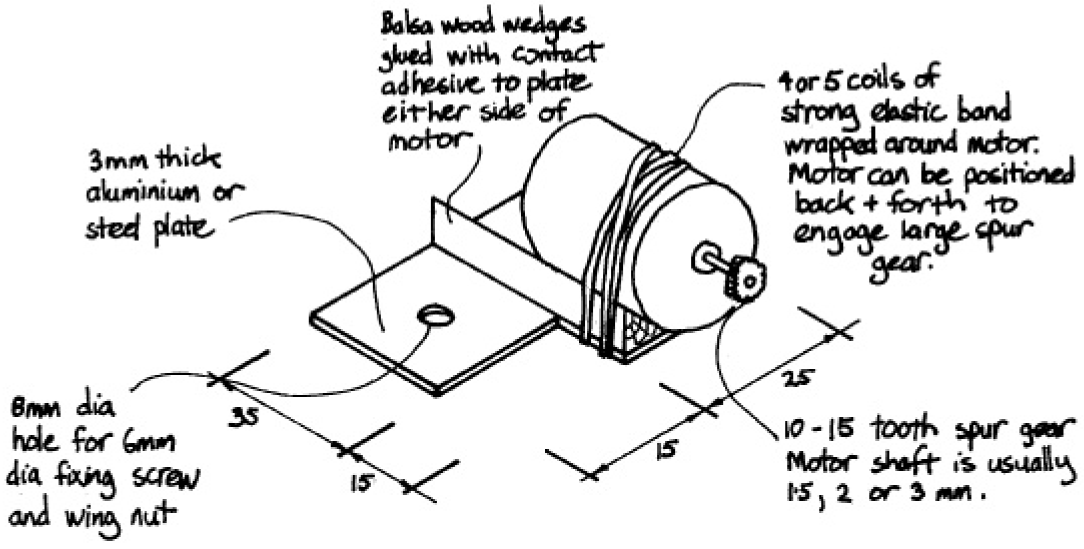
A1.14 Carbon fibre rods

Suppliers of archery equipment have carbon fibre arrow shafts which are suitable for frame building. Look up Sporting Goods retailers.

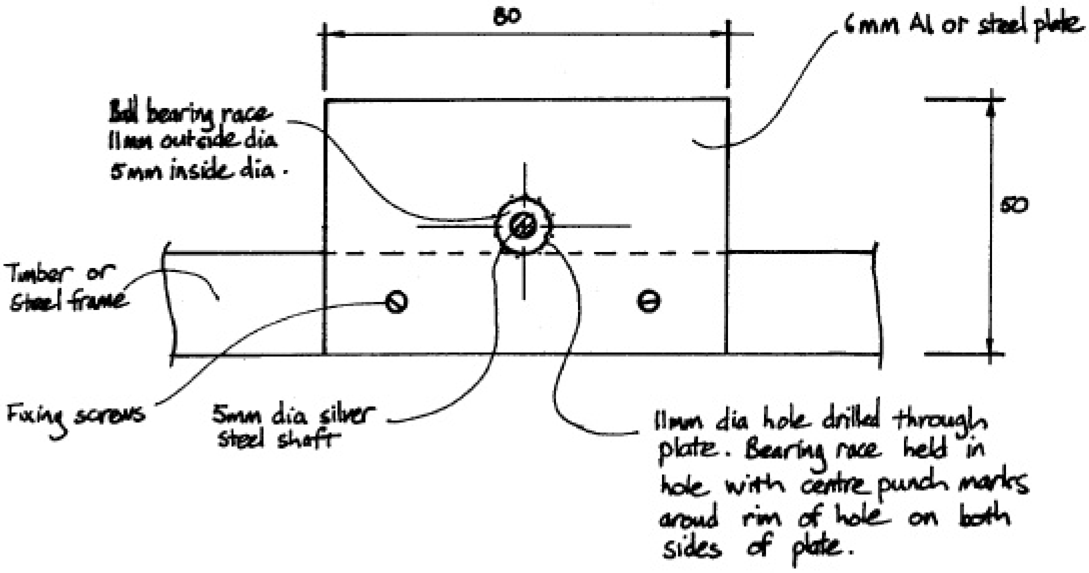
A2: The Motor Test Winch



MOTOR TEST SET-UP



DETAIL OF TEST MOTOR MOUNT



BEARING MOUNTING PLATE DETAIL

A3: Summary Regulations for the Australian-International Model Solar Car Challenge 1999

The regulations for the AIMSCC are extensive . Only rules pertaining directly to car design are summarised here. Intending participants should contact their state organisers and obtain a full set of regulations current for that year.

A3.1 POWER

1 The vehicle is to be powered by direct global radiation only. The collection of this power shall be by photovoltaic cells as described below

2 In very bad weather the organisers may conduct the race indoors under artificial light.

3 PV CELL TYPE - Permissible photovoltaic cells are the lower cost, commercially available mono-crystalline, poly-crystalline or amorphous silicon cells.

4 PV CELL COST AND DISCLOSURE - PV cells used must have a total published retail price of less than $300 Australian. Schools choosing cells other than those listed in (Item 7 here) , must provide a copy of an invoice or receipt of sale for the cells, the brand name and serial number of the cells and the name and address of their supplier. This information will be made public.

5 PV PANEL CONSTRUCTION/AREA - PV cells must be mounted in a rectangular configuration on a flat or moulded panel, which is removable from the vehicle for the purpose of weighing. The area of the rectangle shall be deemed to include gaps between the cells. Where the cells have not been arranged in a rectangle, the smallest single rectangle into which all the cells fit shall be regarded as the total cell area for the purpose of this rule.

A3.2 PV PANEL WEIGHT

6 OPTIMUM SIZE PANELS - Panels whose cell area is close to but not exceeding 864 cm^2 (eg 36 cm x 24 cm) will be advantaged over smaller or larger panels due to a bias in the handicapping (panel weight) system.

7 Panels with a cell area of 778cm^2 - 864 cm^2 which are deemed to include the Appsys and Solarex panels listed below will have a minimum allowed weight of 1200 grams.

APPSYS and Keymac panels

	(Nominal 8 Watt)
SOLAREX	(Model MSX10L)
SOLAREX	(Model MSX10LAM)
SOLAREX	(Model MSX10)

8 OVERSIZE PV PANELS - The maximum PV cell area allowed will be 1,036 cm^2, (ie. 20% greater than the optimum 864 cm^2). A penalty of 125 grams of additional ballast will be imposed for each 5% (or part thereof) by which the cell area exceeds the 864 cm^2.

9 UNDERSIZED PV PANELS - Where the rectangular area of cells is less than 778 cm2 (ie. 10% under size), the panel weight may reduced by 200 grams (to a minimum of 1000 grams).

10 The panel weight may include 1 switch, wires and plugs (if any) but no capacitors, circuit boards or other electronic components. Where a panel weighs less than its required weight, additional ballast must be attached to the panel. Vehicles, which lose any of their ballast during racing, will be disqualified.

A3.3 ENERGY STORAGE SYSTEMS

11 Fuel cells, battery power packs or any other electrical energy storage systems are not permitted in any form on the vehicle. Capacitors are allowed as part of the electrical system but the scrutineer/starter reserves the right to discharge them prior to the start of a race.

12 Mechanical storage systems are allowed provided that they do not contribute to the motive power of the vehicle. (eg. springs to change gears are OK)

A3.4 VEHICLE SPECIFICATIONS

13 Maximum vehicle length 650mm

14 Maximum vehicle height 180mm

15 Maximum vehicle width 320mm including wheels

16 STEERING - Each vehicle must incorporate a means of steering along the PVC channel of the track.

17 Care must be taken to allow for the curve of the track and to allow for some misalignment of the PVC channel.

See item 31 below.

18 SEPARATE CHASSIS AND SOLAR PANEL - The vehicle must be constructed with a chassis and enclosed driver space so that the solar panel may be removed for the purpose of being weighed and the vehicle chassis remain intact.

19 WIND DRAG PANEL - To encourage a more innovative approach to styling, each vehicle must contain a solid flat panel made of a rigid material such as balsa, cardboard or plastic being at least 100 mm high x 220 mm wide x 0.3 mm thick. This panel must be mounted vertically across the width of the car, at 90^{o} to the direction of motion. It must be removable for measurement. (This panel may have small holes or slots in it to allow it to fit over frame members. Excessive holes may have to be covered after scrutineering).

20 SIGNAGE SPACE - The chassis must include panels on each side of the vehicle capable of supporting a sticker measuring up to 100 mm long x 50 mm high over their entire area. The stickers will be provided by the organisers and will incorporate sponsors logos, the school and vehicle names and race number. The panels may be curved but the stickers should be readable from side on.

A3.5 DRIVER(EGG) SPECIFICATIONS

21 Each vehicle must carry a large raw chook egg (>61g) provided by the organisers. The egg must be capable of removal within 1 minute for inspection after a race. If the egg breaks before inspection the vehicle will be disqualified.

22 Each vehicle must have a fully enclosed cabin in which the egg sits.

23 The egg must be placed in an upright position with the pointed end at the top.

24 The driver cabin must be at the front of the vehicle.

25 The cabin must be attached to the vehicle chassis not the solar panel.

26 The cabin must be fully sealed so that if the egg breaks, none of the yolk or white is spilt onto the track.

27 The cabin must have a transparent (not translucent) windscreen at least 25 mm deep (in the vertical direction), which allows at least the top half of the egg to be visible from straight ahead and through a 90^{o} arc on either side when viewed horizontally.

28 The egg must not be covered in a film or painted so as to increase its strength.

A3.6 THE TRACK

29 The outdoor AIMSCC track will be in a figure 8 configuration with a low bridge at the crossover point . The corners will feature curves with an approximate minimum radius of 5 metres. The track length is approximately 86 m with cars completing one full lap plus an extra 14 metres to reach the finish line.

30 Both the uphill and downhill sections of the track at the crossover point will have a maximum slope of 1:8.

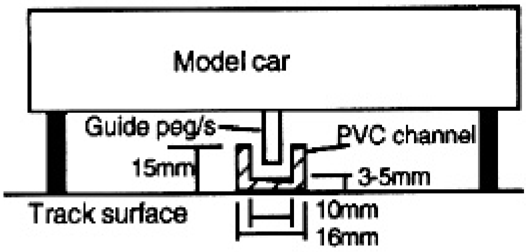
31 The track will have a smooth surface with two parallel guide tracks of PVC channel (see Diagram) such as UM20 or similar screwed to a plywood base. As the track is assembled in sections, there may be minor misalignments. The organisers will endeavor to ensure misalignments both horizontally and vertically will be less than 2 mm.

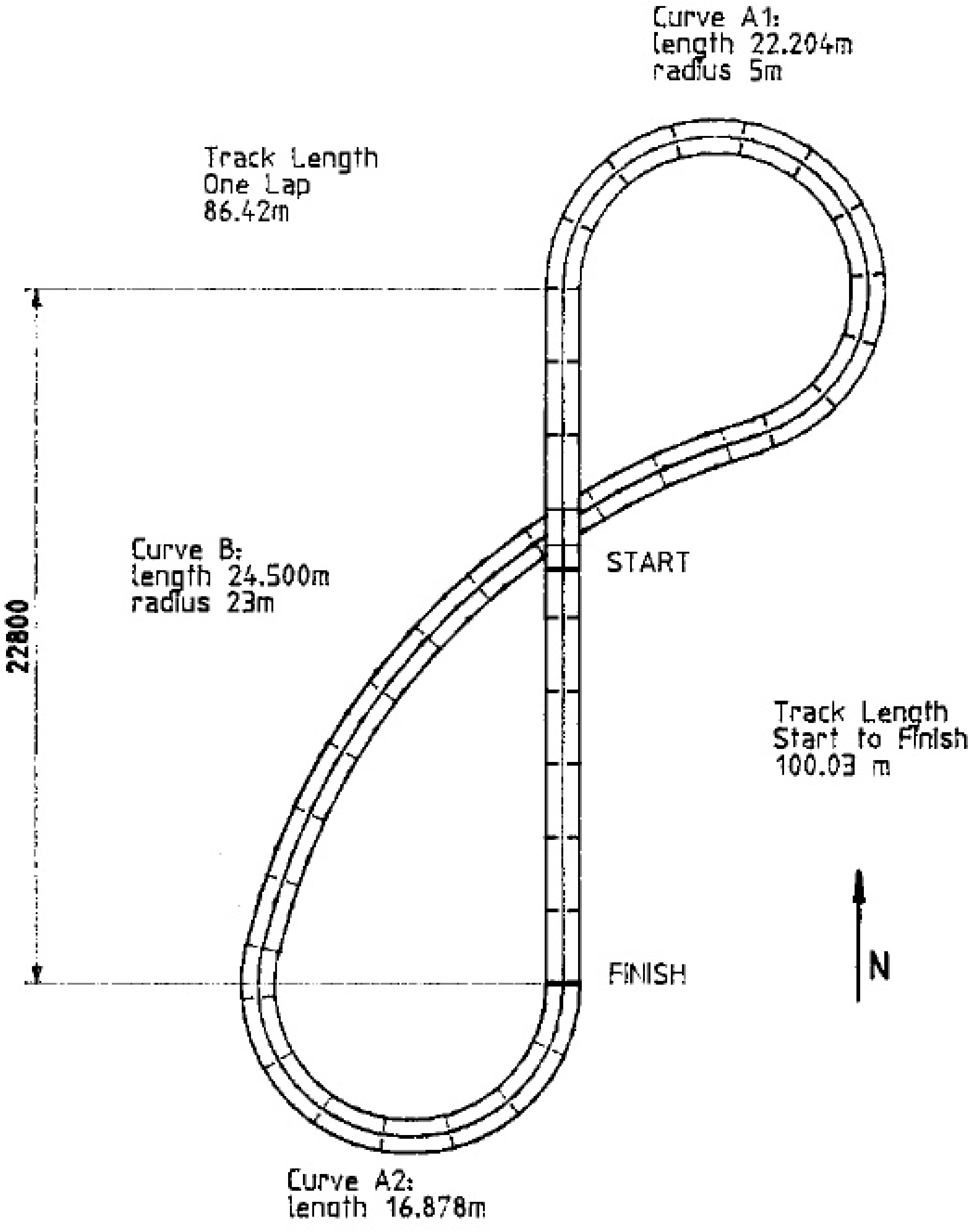
NB. Thin metal (~1mm thick material) channel sections may be

31 ctd. used to align the ends of adjacent plastic guideways if, in the committee's opinion, there is a significant alignment problem. This could lead to a total width of up to

19mm, which should be allowed for if external steering guides are used.

32 STARTING RAMP - Vehicles will start near the top of the downhill section of the track. The starting line on the ramp will be approximately 200mm vertically above the level of the track at the bottom of the downhill section.





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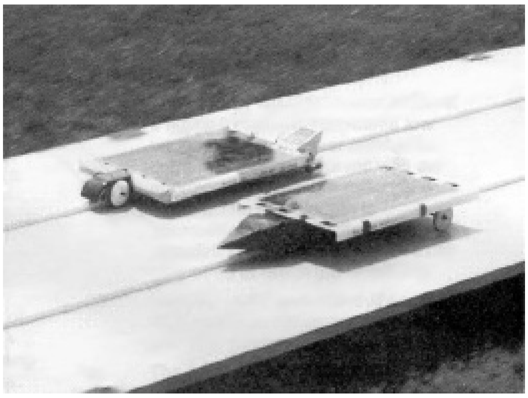

Supplement to the 1999 edition Model Solar Car Racing

Developments in Model Solar Car Design 1990 - 1997

Reprinted from "Solar Times - The newsletter of the Victorian Model Solar Vehicle Challenge" March1998. Written by Peter Harley

The first model solar car race was held in Melbourne in 1990. By 1997 annual races were being held in every state of Australia and the ACT. In addition National and Australian based International championships have been held annually since 1993.

During those eight years there have been no significant rule changes so that the winner of the 1997 Australian International Model Solar Car Challenge could have entered the 1991 Victorian Challenge. The 1997 car would have won but not by a lot.

During the five years since Lynall Hall Community School won the first race with their smart yellow car " The Beast" there have been a few design developments which have added several km/h to car speeds.

The top cars at the 1997 National race displayed the state of the art today and as a teacher in charge of many competing teams in earlier years and a race scrutineer for the past few years I have been in a good position to observe some of the developments.

Ideas that don't seem to have worked (yet).

Mechanical gear change mechanisms - first tried by Swan Hill Technical School in 1992. Beautiful constructions but didn't seem to make the cars go fast enough. Unfortunately both the Swan Hill cars of that year crashed on the old rough track and we didn't see Swan Hill again in spite of their innovative efforts in the first couple of years of the competition.

Electronic power output "maximisers" - Maximisers have been used in photo-voltaic technology for some tie to improve the power output of P-V cells in low light conditions. The DC electric motors which power the cars start off the races requiring power supplied at very low voltage and this requirement gradually increases until the vehicle hits top speed. P-V panels on the other hand work best when they are supplying power at their nominal voltage, usually 6 or 12 Volts. The idea of the maximiser is to trick the panel into thinking it is always supplying power at its favourite voltage and to convert that supply to the voltage that the motor actually wants. The maximisers seem to do the job quite well, the trouble is they are a bit inefficient in that they waste some of the power. The end result is that the cars seem to go faster without them.

Mirrors - Mirrors of various forms have been used since the beginning to try and get a bit more light onto the panels. None of the cars with them have been successful. Although there is a small power gain, the added weight and wind drag seems to slow them down.

Tilted panels - Panels have been tilted since the beginning to match the angle of the sun in the sky. Apart from " The Beast" in 1990 when the rules required that the car be a little higher, all of the successful cars since have minimised their wind drag and maximised their stability by keeping the P-V panel very low. Also with the new figure 8 track in use since 1994 the panel would have to constantly change its tilt depending on the direction of travel. Nobody has had a go at this yet to my knowledge.

Innovations which seem to have worked.

It is very difficult to judge whether a particular innovation has been the telling factor for winning cars because so many factors come into play but we can make some generalisations about successful cars.

Precision engineering - This is probably the most telling factor. The better cars are made to extremely fine tolerances. They roll very well and in a straight line. Gear meshing and alignment is adjustable and accurate. Where steering is incorporated the steering is accurately set. Quality bearings are used and frame connections are carefully designed to give rigidity and light weight.

Light weight - Competing teams have long understood the benefit of mass minimisation. Since the first WA race in 1991 when the fantastic Eastern Hills High School car used a very light weight fibre glass rod frame more cars have been minimising their weight by using glass or carbon fibre stick constructions. We still see fast cars featuring light balsa and aluminium frames but the carbon fibre frames have been very successful.

Ball bearings for wheels - All the fast cars have used small ball bearing races for their wheel bearings since the beginning. Some schools at national races squirt silicon lubricant on their bearings before each race.

Guide peg design - " The Beast" pioneered the use of a ball bearing race for its steering guide peg in 1990 to minimised the drag of a peg in the guide way of the track. The Linalool Hall car of 1992 was the first to mount two guide pegs outside the track rather than inside the track in an effort to improve the track handling ability of the car. That car also pioneered the use of similar guide pegs at the rear of the vehicle to eliminate the fish tailing problems of fast cars. Most of the fast cars now employ this type of stabilising device.

Steering - Most of the successful cars now employ some form of steering. This seems to be less important in bright conditions but in low light when very little power is available steering seems to give a significant edge. Various forms of steering have been tried. The national champion from WA in 1994 was the first to succeed with steering. That was a broad wheel base 4 wheeled car with back wheel drive. It used a delicate steering mechanism in which a single front guide peg mounted slightly forward of the front wheels was attached to a mechanism which moved push rods connected to the independently mounted front wheels. The 1997 national champion used a similar set up. Others have used two in-line front guide pegs to rotate a plate similarly connected to push rods and via push rods to the independently mounted front wheels. Others have tried front wheels mounted on a single axle which pivots about its centre and is turned by two in-line guide pegs.

Several Victorian cars eg. Mentone Grammar, have tried a single front castor wheel running in the guide way behind a guide peg. There is the danger with this that you will get extra friction from the wheel touching the sides of the guide way.

The 1993 Lynall Hall car, second in the first national race, was the only car I know which has attempted front and back wheel steering. The front wheel drive car had independently mounted castor (trolley) wheels on the back which were free to find their own direction. The 1993 race track had only 5m radius curves. The rear guide pegs were set at such a position as to allow the rear of the car to swing out on the curves just enough to allow the front wheels to align parallel to the track at the front of the car. The rear wheels trailed along the line of least resistance. The current race track has two different curve radii so this system has become more difficult to operate.

Wheels - Wheels have become smaller, harder and narrower. Gone are the big soft tyres of yesteryear. Broad soft tyres are not necessary for traction and actually slow the cars down. Most wheels do not have tyres and are very narrow. Some teams have been known to actually sharpen their metal wheels but I'm not sure that this offers any benefit.

Motors - " The Beast" used a high efficiency " DC Minimotor" made in Germany. Virtually every winning car since then have used that brand of motor offering power conversion efficiencies of up to 80%. The Australian distributors have been delighted! The highest efficiency motor they have is rated at about 3.5 Watts output. The P-V panels we use are rated at 8+ Watts. Nonetheless many fast cars use just one of these motors, some use two. The 1997 national champion used just one motor to win the race in low light conditions. Other fast cars use two of these motors including champions of the past. These motors are available from the S.A. Technology Centre.

Panel voltages - The most popular brand of P-V panel used remains the APSYSS 8 Watt module. One advantage that this module offers is that it can be configured to give 3, 6 or 12 volt outputs. Many cars now change voltages according to light conditions, using lower voltages in low light when motors will not run as fast. Some cars have experimented with automatic voltage changing devices which switch voltages during the race to give the effect of a gear change. The Victorian Champion of 1992 was the first to use this type of system. See "Notes on the 1999 Australian regulations" below.

Panel cooling - Many of the successful teams at National races of recent years have cooled their P-V modules by storing them on ice (the winning team even presented to scrutineering with its panel in an Esky) or by spraying them with cold stuff. I'm not sure if this offers much advantage but it's an easy thing to test at school.

Streamlining - The successful Lynall Hall cars of the early nineties all featured streamlined designs enveloping the entire vehicle. The students at the time decided on this as a result of wind tunnel testing of designs. No tests were done on the modern carbon fibre frames which because they are very minimal and low probably do not offer much drag. Still, I wonder if anybody has done the tests because at high speeds with such low power, wind drag is important. See "Notes on the 1999 Australian regulations" below

Summary - the 1997 Australian International Champion from Christchurch Grammar in WA was a good example of the accumulated art in Model Solar Car design. The design was essentially that of the 1994 national champion from Perth College in WA. It featured -

- a very light weight carbon fibre frame
- small narrow hard wheels, 4 wheels in a wide base, standard car configuration
- single rear wheel drive
- front wheel steering controlled by front guide pegs
- a single " DC Minimotor series 2233" motor
- a streamlined driver compartment but no streamlining on the very low body
- rear guide pegs to prevent fishtailing
- beautiful lightweight engineering, high quality bearings and construction that would do a watchmaker proud
- a P-V panel just out of the Esky!

Notes on the 1999 Australian regulations

Two significant rule changes were introduced in 1999

1 Rather than specify a particular **photovoltaic panel** to be used, PV panel design has been freed up. The main constraints on panel design now area Low cost silicon PV cells must be used. The total retail cost of any panel either purchased as an array or built from smaller units must less than $300.

b The optimum panel area is just under 864cm^2. Certain specified panels used in the past are automatically included in this category. Larger panels (>864cm^2) or significantly smaller panels will be disadvantaged by handicap weight penalties. Panels with areas in the range 778cm^2 - 864cm^2 will be required to weigh 1200g so as not to disadvantage those with heavier prefabricated panels, and to simulate a payload.

2 To encourage schools to develop car body styling, cars will now be required to include a flat wind drag panel, 220mm wide x 100mm high mounted vertically across the car. The purpose of the panel is to create significant wind drag. Competitors are free to deflect wind around this panel in any way they choose. They may choose not to.

A third rule introduced in 1998 requires cars to carry a chook egg as a "driver". The egg's driving compartment also has certain requirements.

The PV panel rule - PV panels can now be prepurchased, (10Watt Solarex and BP panels are permissible) or can be built up from smaller panels or individual cells. This broadens the scope for designers and allows for the construction of curved panels. Some electronics suppliers offer small PV panels at a lower cost for the requisite area of cells than the big panel manufacturers. Building your own array of cells also allows the possibility of having a selection of voltage outputs not available with Solarex and BP. Competitors will have to use their imagination to devise ways of determining which type of cell will give the highest power output.(See section 9.1 page 5).

The wind drag panel rule - The wind drag panel makes the successful skeletal car bodies of the 90s look a little less attractive. Although very light, these bodies may not offer sufficient wind protection for this large upright panel. Consequently competitors may be forced to consider using a slightly heavier body construction which gives some wind protection.

What is the answer to the question, less weight or more streamlining? Only wind tunnel tests (see page 7) combined with modelling (see page 9) or extensive track tests will give the answer to this problem.

The egg "driver". Less of a problem is the chook egg driver used in 1998 and 1999. Because a broken egg will result in disqualification, the egg must be kept safe whilst being able to see the track through a window in front and to the sides of its enclosed driving compartment. The egg must also be easily and quickly removed for inspection after each race.

One of Solar car and boat racing's best parts suppliers has moved. **Technology Education Centre** is now located at

32a Dew St

Thebarton S.A. 5031

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About the author

Peter Harley has been involved in model solar car racing both as a teacher and a competition organiser since 1990.

At Melbourne’s Lynall Hall Community School he was teacher of the winning teams in the 1990, 1991 and 1992 Victorian Model Solar Car Challenges.

He has been a teacher of Maths, Science and Technology Studies.