Greenpower
INSPIRING ENGINEERS

supported by
SIEMENS

A-Z Technical Handbook

2011

CONTENTS

INTRODUCTION

The mind is like a parachute, it is only any good if it is open. This handbook does not tell you how to make a car. What it does is give you options and knowledge such that you can make informed decisions.

Back in 1999 when Greenpower started, all the teams were climbing the learning curve together. Nowadays it is difficult for new teams to catch up as they inevitably make the same old mistakes as they go through the learning process. This book is designed to spread experience and information so that teams entering the competition join the learning curve at a higher level.

I also hope there is much in the book that will be of interest to experienced teams. Knowledge is never complete and having an insight into an alternative approach is always useful. There is no one right answer to designing and building a competitive car. Whilst I have done all I can to ensure the content is correct, that does not mean that there are not better ideas or other ways of doing things successfully.

Good luck and happy building.

Michael Joseph

AERODYNAMICS

Aerodynamic drag is enemy number one against the performance of a car. This is because aerodynamic drag increases as the square of the speed. The power to overcome this drag increases as the cube of the speed.

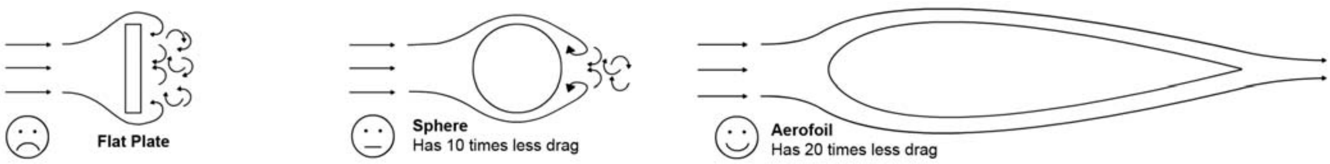
Example: A car doubles its speed from 15mph to 30mph. The aerodynamic drag has gone up 2X2 = 4 times and the power required has gone up 2X2X2 = 8 times.

Furze Platt School provided these figures for their car:

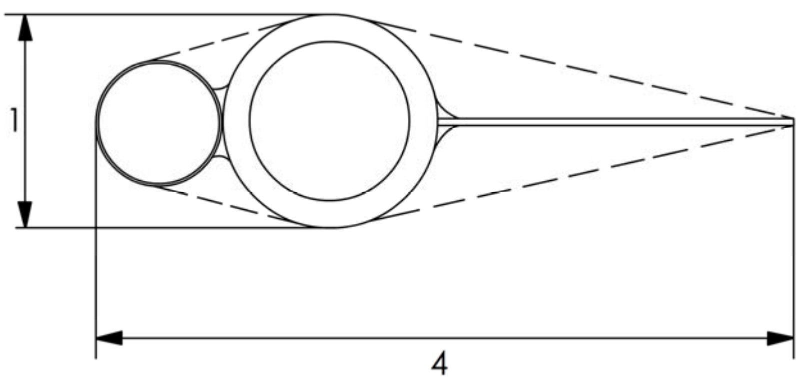
Speed (mph)	Wind resistance (watts)	Rolling resistance (watts)
9	6	26
19	55	55
25	120	72
30	221	88
35	335	101
38	442	111

For low wind resistance you have to move as little air as possible by the smallest possible amount and then carefully put it back where you found it. This means that you need to keep the frontal area to a minimum with an aerofoil shape having a low surface area and good surface finish. Remember the speed of the airflow over the car will be faster than the road speed because it has further to go than the surrounding air. You also need to be aware that if you squeeze air through a small gap, say between the wheels and the bodywork, the local airspeed can be very much higher just where the unaerodynamic brakes are fitted.

How shape affects drag for a given frontal area:



An aerofoil shape around structural components i.e. Axle supports/Roll bars can be achieved like this....



....and then covered in tape.

AXLES

Fork Axles:

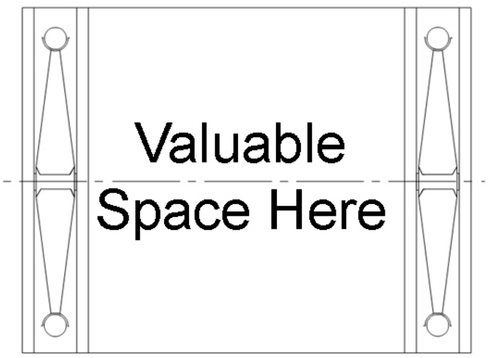
Aerodynamic drag penalty for supporting axle on both sides. This may be mitigated if the extra space this system provides can be used to make a better shaped body. Axles can be lighter, at 10mm or less.

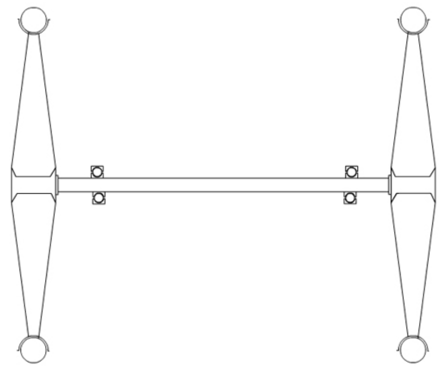
Stub Axles:

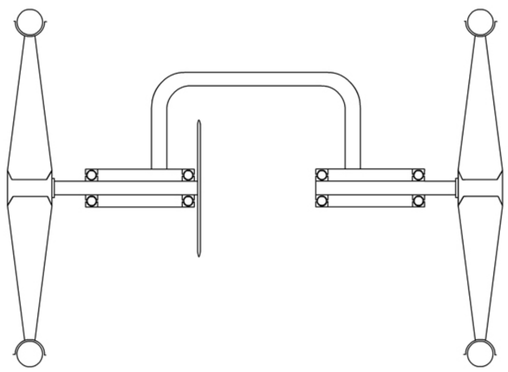
Need to be 12mm diameter or more. Any less and they are prone to bend or break.

Axles should be made from a tough, high tensile steel e.g. EN8 or EN24

Rear Axle Options:







Correct tracking and alignment is essential. Manufacture your chosen system in a jig and check alignment in the event of an accident. To achieve this you will need to work from a datum which will be very difficult if your planform is an aerofoil shape.

One wheel drive is sufficient without the need for a heavy differential.

BATTERY CAPACITY

The capacity of a battery is measured as the amount of current it can supply over time (amp/hours). If you then multiply this by the voltage you get the energy content (watt/hours). The reality is you are unlikely to get the stated capacity because it will vary depending on the temperature, battery condition and the rate current is taken from it.

The MRT35T VRLA (valve regulated lead acid) AGM (absorbed glass mat) battery has a capacity of 35A/hr measured at the 20 hour rate. This means that the battery will deliver 1.75A over a 20 hour period at 20^0C. The efficiency of a battery is lower at higher discharge rates. For this reason, if the battery is discharged at 17.5A it will be discharged well before the expected 2 hours.

Note: *The higher the motor current the lower the battery capacity.*

High Current = Hot motor = less battery capacity = less miles!

The car must have a low enough gear to cope with inclines and headwinds and possibly both at the same time.

Do not be greedy for speed. It is counterproductive. Gear the car to keep the motor revving at high speed/low current. Address car problems of aerodynamics and rolling resistance to make the car faster and go further.

Each battery is 12V. A pair wired in series will give the required 24V. Batteries must be disconnected and loaded/unloaded into and out of the car separately. This is to meet Health and Safety Regulations and to avoid injury. (See page on Manual Handling).

To check the true capacity of a battery it needs to be checked under load. Make up a board with 12V light bulbs of the desired load and plot graphs, timing how long it takes to discharge. Min voltage 10.5V. Less than 10.2V and permanent damage will occur.

The MRT35T battery is designed for optimum performance at 20^0C. Above this temperature, battery life will be decreased. Below this temperature, battery capacity will be reduced.

BATTERY CARE

Treated with care, your batteries will give reliable performance for many seasons. Batteries do not die, teams kill them. This is unnecessary and expensive.

DO:

- Recharge as soon as possible after use
- Remember, AGM batteries must be charged on trickle rate only, at a maximum of 4amps. Any higher and they may vent and reduce battery life
- Keep batteries in a warm place. You will increase their capacity. Keep spare sets in an insulated container. Protect from airflow, wind chill, on the car
- Cycle new batteries a couple of times before a race to bring them up to specification
- Protect them from vibration in the car using some thin strips of closed cell foam under the batteries
- Colour code around the terminals to help pit crew. Red +ve Blue –ve
- Insulate terminals to avoid short circuits
- Use quick release battery clips which are a regulation requirement. Make sure pit crew know how to fit them correctly
- Use a short link when connecting in series so that it is impossible to connect across the terminals of one battery
- Use a battery trolley at all times in the pits and paddock. Batteries should be secured and only stacked one battery high

DO NOT:

- Discharge a 12V battery below 10.2V as irreversible damage will occur
- Overheat batteries as it shortens their life. Optimum 20°C
- Drop batteries on the floor or allow them to fall off trolleys. Internal damage can cause injury
- Stack batteries on top of each other on battery trolley
- Leave discharged
- Leave them on a cold concrete floor

BATTERY INSTALLATION

T2.3 The batteries must be firmly secured to the chassis of the vehicle using rigid fixings – i.e. no webbing or elastic straps, and must not be able to move in any direction in those fixings. Over centre clips must be security pinned.

Any over centre clip must be fitted with a locking pin or device such that it cannot possibly come undone accidentally.

Battery Dimensions: Length 196mm
Width 131mm
Height 161mm

Battery weight: 10.5kg x 2

When designing the car it is worth considering:

- Mounting the batteries as low as possible to lower the Centre of Gravity (CofG)

T4.1 The top of the batteries must be below 360mm from ground level. A 6mm diameter hole should be drilled through any solid floors adjacent to the batteries to allow height measurement.

- Mounting the batteries close to the CofG to reduce the Polar Moment of Inertia.
  (see page on Weight Distribution)

- Positioning batteries close to the motor to reduce the length of cable and the voltage drop losses along them

- Protecting them from cold air by putting them inside insulated boxes

- Ease of access for quick replacement in the pits

- Driver Protection

T2.4 Batteries must be separated from the driver by a bulkhead, or contained in a rigid, covered, ventilated box, which must not be able to short circuit battery terminals. Batteries must be located within the bodywork of the vehicle.

BRAKES

T8.1 The vehicle must have an effective braking system that will prevent it being pushed from standstill with the brakes applied.

Assuming:

Weight of Driver	54kg
Weight of Batteries	21kg
Weight of Chassis and Motor	50kg
Total Weight	125kg

The all up weight of a Greenpower Formula car is considerably more than a bicycle.

Kinetic Energy = $1/2mV^2$

From the formula you can see that an increase in road speed gives an even greater increase in kinetic energy. This inertia needs to be brought to a stop. A heavy car going fast takes some stopping.

- Front wheel brakes are less likely to skid because of the pitching moment onto the front wheels under braking
- If using front wheel brakes, make sure they are set up evenly or the steering will be affected especially if no kingpin angle to give centre point steering
- Hydraulic brakes are more powerful but generally more expensive than cable operated brakes
- Hydraulic brakes can be operated from a single lever using a tee in the pipework. Cable brakes can be operated with two cables from a single tandem lever or by one lever pulling on a balance pulley to the two brakes
- A Drum Brake torque arm and mounting needs to be strong enough to take the loads
- Brake light switch needs to be fitted to brake operating arm, lever or pedal
- Ensure brakes are not rubbing during pre race preparation
- To suit drivers of different height, hand levers are preferred over foot pedals

Calliper or Vee brakes

These are not recommended. They may be adequate in the dry but can be hopeless in the wet

Drum or Hub brakes

Effective and neat where space and aerodynamic drag are considerations

Disc brakes

Very effective and reasonably priced. Tendency to rub when ‘off’

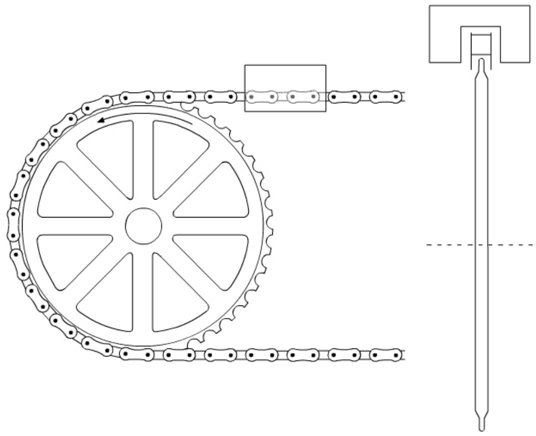
DRIVETRAIN

Health and Safety:

Chains, belts, sprockets and pulleys need to be guarded to protect the driver and pit crew. Guards must cover the top and sides. It is all too easy for the car to roll forwards or motor to inadvertently run when fingers, hair or clothing are in the wrong place at the wrong time.

Reliability:

Tooth belts and gears have been used successfully. Chains have a nasty habit of coming off their sprockets. Even with the correct tension and sprocket alignment, the car will flex, twist and bounce, causing it to come off. A chain begins to come off by riding up the side of the sprocket teeth. It then rides over the top of the teeth and becomes derailed. Prevent this from happening by fitting a guide close to where the chain comes onto the sprocket. Nylon chopping board with a slot just wider than the chain makes an excellent guide and has low friction should the chain rub. Alternatively fit plates either side of the sprocket or chainring.



Sprockets:

The greater the number of teeth, the less likely the chain is to break because the load is spread over more teeth. The drive will be more efficient because the link angular movement is less.

Tension:

Any eccentricity in the sprockets will cause the chain to snatch and flap. Make sure when you check the tension that you do it several times with the chain in different positions. Too tight and it will load the motor, too slack and it could come off.

Chain:

Bicycle chainrings and 1/8 or 3/32inch chain is adequate for a Greenpower car. Having joined a chain with a rivet tool, make sure that you do not have a stiff link and mark it with paint or 'Tipex' in case it needs to be removed again. Re tension and lubricate the chain before every race.
Industrial (3/8 inch) chain and sprockets are heavy but readily available in a wide range of sizes off the shelf and are easy to mount.

GEARING

The trick to performance is to balance the resistance of the car (aerodynamics and rolling resistance) with the characteristics of the motor and the capacity of the batteries. This is achieved through the transmission and/or motor controller. Here are the options, all of which have been used on National Final winners.

Constant Gear Car:

A single gear car makes construction and driving easy. Frictional losses are kept to a minimum. The problem is having a very high current draw when pulling away from a standstill, in a slow corner, climbing a hill or into a headwind. If these are present on the track and the car is over geared, the result is a burnt out motor and flat batteries. On a level circuit without too much speed differential on a lap, the single gear car will perform very well.

Constant Current Car:

Fitting gears will keep the current range within a much narrower band. The closer the ratios the narrower the band. The car will perform efficiently when pulling away, climbing and descending hills, in fast and slow situations or with strong headwinds and tailwinds. The first problem is the installation because the motor rpm has to be reduced into a derailleur or epicyclic gearbox. This can be done with a large chainring on the wheel or through a layshaft. If the revs are too high, gears will jump, be missed, or chains come off. Frictional losses increase with gears. Traction is lost during every gear change unless using a constantly variable transmission. The next problem is knowing when to change gear. Some form of ammeter, rev counter or electronic indicator system is required for the driver.

Constant Speed Car:

The problem with a 'Constant Current Car' is that when it reaches a hill, the indicator system will advise the driver to change down which is all very efficient but in doing so the motor will produce less power and so the car slows down even more. To make up for lost time climbing hills the car has to go faster on other parts of the lap and is then trying to climb up the aerodynamic drag curve. Trading top speed for headwind/hill climbing ability can be done through an intelligent gearbox. Above a target speed the indications go into reversal. i.e. going uphill change up and downhill change down. To protect the motor, the electronic logic needs to include a current limiter. Very complicated.

GEARING CALCULATIONS

Circumference of Tyre = Tyre Diameter x π

$$\textbf{Wheel Speed} = \textbf{Motor Speed} \times \frac{\textbf{Teeth on Motor Sprocket}}{\textbf{Teeth on Wheel Sprocket}}$$

Wheel Speed x Tyre Circumference = Distance travelled per minute

Multiply by 60 and divide by 5280 to get Miles per Hour

Example for 16"wheel, 14T drive sprocket, 50T wheel sprocket.

Circumference = 410mm x 3.143 = 1.289m = 4.229ft

$$\textit{Wheel Speed} = 1850\textit{rpm} \times \frac{14}{50} = 518\ \textit{rpm}$$

(Motor 1850rpm approx equals 15 Amps)

518 X 4.229 = 2190.6 ft/min X 60 = 131437 ft/hr ÷ 5280 = 24.9 mph

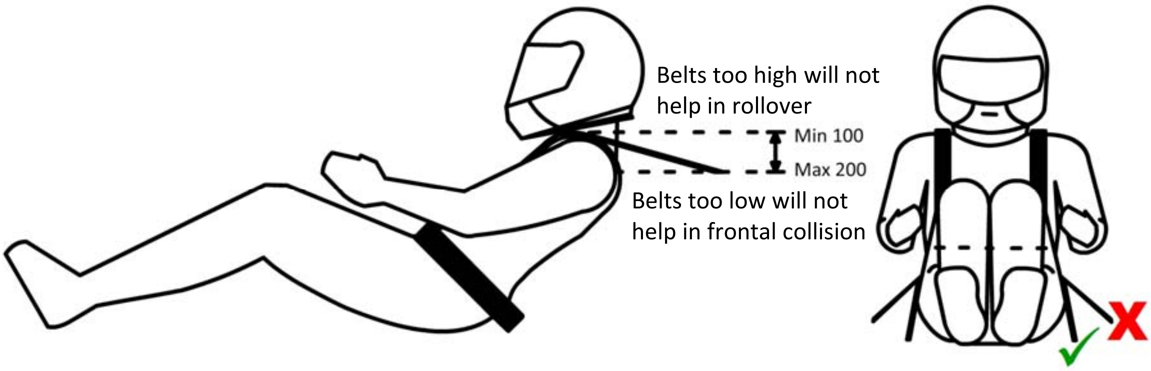
The above example is for a single gear, reasonably aerodynamic car. The car will probably go faster than this with a downhill/tailwind and slower with an uphill/headwind. With this gearing, if the car goes slower than 18mph, for even a short period, it will be drawing 45Amps and in danger of cooking the motor and killing the batteries. Go on the safe side and gear your car for a slower speed (bigger wheel sprocket) which will keep the motor revs high and the current draw low. When you have successfully completed a full race distance on your batteries you can then convert excess energy into a little more speed. Work upwards from a conservative speed. Aiming for an unrealistic top speed will only bring disappointment.

If using a layshaft between the motor and the wheel, multiply the primary gear ratio by the secondary gear ratio to get the overall ratio. E.g. 3:1 + 5:1 = 15:1

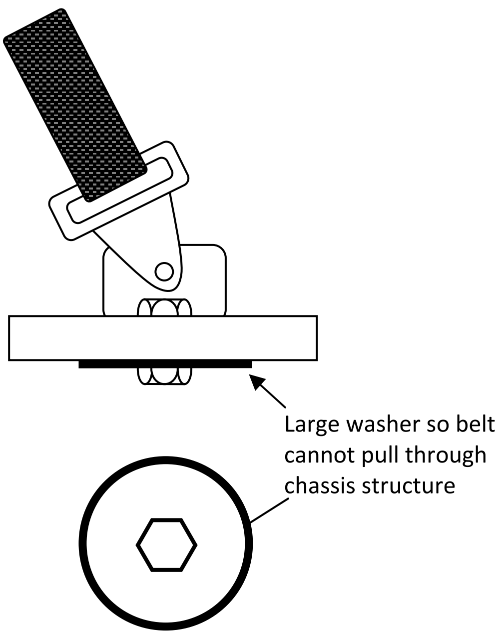
HARNESSES

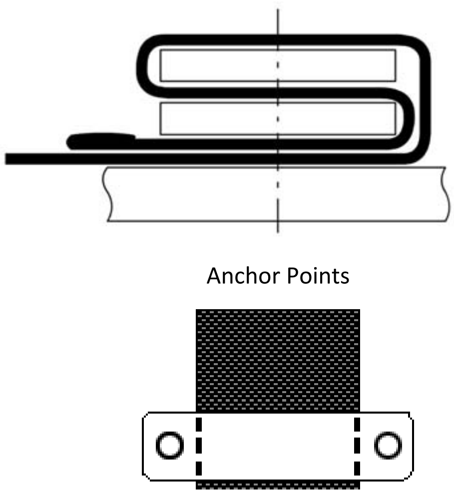
T10.4 Safety Equipment

The vehicle must be fitted with a minimum four fixing point, 50mm width safety harness, with secure fixing points on the roll bar or chassis. Harness shoulder strap fixing points should be close to shoulder height and neck width. Thought should be given to the design of the seat and harness to prevent submarining in the event of frontal impact and lap straps must be able to be fully tightened before shoulder straps. Lap straps must fully tighten around the driver's waist without additional padding in front of the driver.



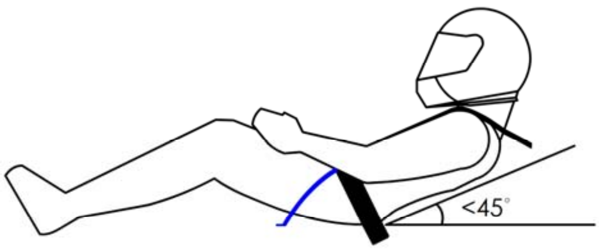
- Lap strap must run across lap near crotch not against stomach.
- Lap strap should run at an angle towards the rear of car.
- Lap strap adjustment needs to be accessible.
- Tighten lap straps **before** shoulder straps.
- Crotch strap or large front lip to seat to prevent submarining.



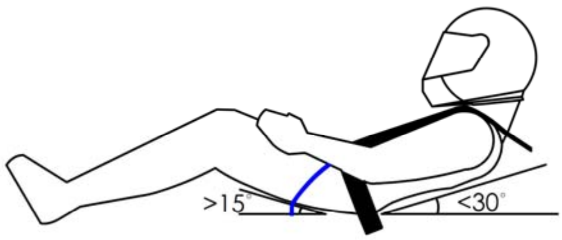


HARNESS SELECTION

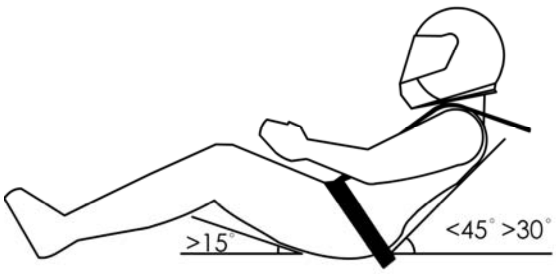
From 2013 a crotch strap (shown in blue) will be required to prevent submarining in the following conditions.



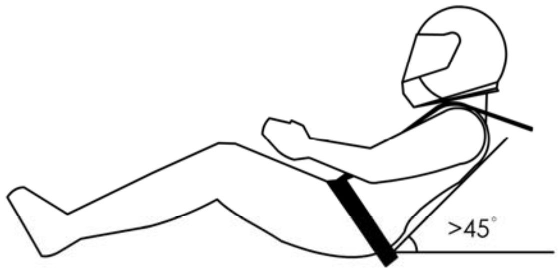
Crotch Strap Required



Crotch Strap Required



Crotch Strap Not Required



Crotch Strap Not Required

IMPACT RESISTANT FOAMS

Suitable flexible impact resistant foams are required both around the cockpit sides to protect a substantial part of the driver's body, from the floor to the cockpit opening and in front of the bulkhead at the front of the car.

Only closed cell types are suitable.

- In **closed cell** foam, the bubbles of gas are all sealed and bonded together
- In **open cell** foams the structure can suck in air or water like a sponge. These provide poor impact resistance.

Suitable closed cell foams:

This list is not exhaustive but would include;

Polyethylene (PE) cross linked foam. Brands include Plastazote ® Alveolen ® Alveolit ® Alveolux Jiffycel ® Stratocell™ Nomapack ® Primafoam ®.

Ethylene Vinyl Acetate Coploymer (EV,VA and EM) cross linked foam. Brands include Evazote ® Supazote ®

Polypropylene (PPA) cross linked foam.

All of the above are CFC,HCFC and VOC free. They are chemically inert and resistant to oils, solvents and dilute acids.

Unsuitable foams:

This list is not exhaustive but would include;
Expanded or extruded rigid polystyrene (EPS), polyurethane (PU), polyisocyanurate (PIR) or phenolic foam. Brands include Styrofoam®, Celotex®, Kingspan® and EcoTherm®.

The above are more commonly used for their insulation properties in construction. They are prone to breaking under impact loads.

Polyurethane Spray foams (from a can). These are available in both open and closed cell variants but neither is suitable.

Polyvinyl Chloride (PVC) foam.

Whilst Greenpower recommend minimum thicknesses in the Technical Regulations, the thicker the foam the better.

MATERIALS

Use appropriate materials depending on the task to which they will be put.

Wood:

- Totally organic, non- toxic, energy efficient, environmentally friendly, biodegradable, 100% useable, recyclable and renewable in your lifetime. Trees absorb CO_2 and produce oxygen.
- Very strong in compression.
- Wood is tough due to the fibres in the grain but prone to splitting if bent too far.
- For bending: soak, steam or laminate.
- Easy to mark, cut and join.
- Join by jointing, glueing, screwing or bolting.

Steel:

- Strong, hard wearing, heavy, bendable, machineable.
- Can be cast into complicated shapes. Grain structure is ball like and brittle.
- Using heat to bend, roll or shape is called forging and maintains the grain structure like bricks in a wall to maintain toughness.
- Join together by solder, braze, welding, bolts or rivets.

Aluminium:

- Lightweight and easy to machine. Three times less strong than mild steel so the material may need to be three times as thick.
- Excellent thermal conductivity.
- Very power hungry to produce.
- Join by bonding, bolts, rivets or welding.

Plastics:

- Vast range of materials from carbon composites to foams.
- Some are good for energy absorption.
- Ideal for making smooth, lightweight, double curvature forms.
- Deforms at low temperature. Can be transparent.
- Bond or bolt together.
- Health and safety considerations.

Fabrics:

- Cotton is a cheap and natural material that can be taughtened with aircraft dope to provide a lightweight skin. Man made equivalents are heat shrinkable.
- Carbon, glass or Kevlar can be combined with resin or PU to form composites.

MOTOR COOLING

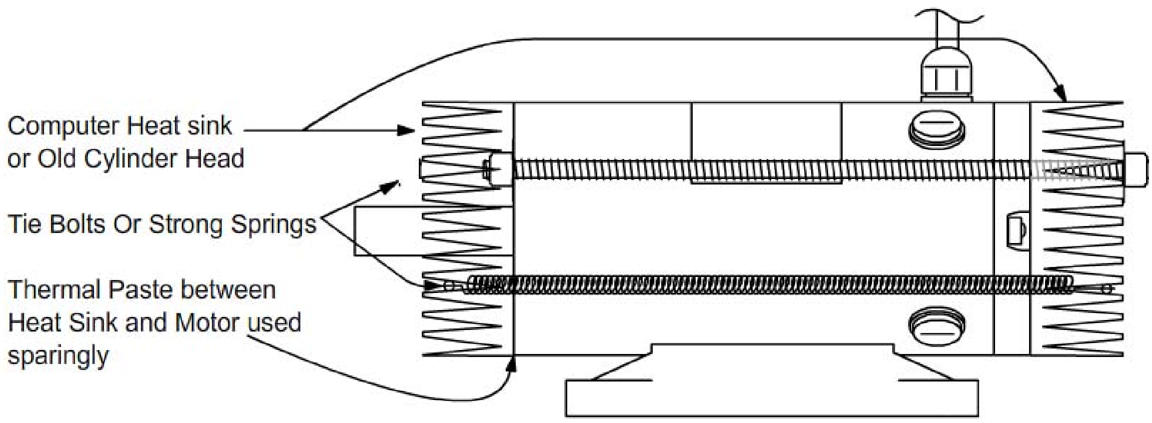
The 24Vdc Fracmo motor is continuously rated at 240W. More power is available but the higher current will increase the resistance in the armature windings, push up the temperature and decrease its efficiency. A cooling system will be beneficial. Before looking at alternative options it is important to thoroughly understand the Motor Graphs (see relevant section). It is much better to treat the causes of hot motors than to treat the symptoms.

You should be able to place your hand on a motor, if it’s too hot to touch, it is overloaded. Continue racing and you will detect an acrid smell as the insulation breaks down followed by the plastic brush holders melting followed by someone reaching for their cheque book.

T1.2 The motor is sealed and must not be opened. No machining or drilling of the casing is allowed.
T1.3 Cooling of the motor is allowed, but not through the use of water or methods using prior energy input (e.g. ice), or power from batteries other than the main vehicle batteries.

Air Cooling:

A cumbersome ram air vent that puts up the aerodynamic drag of the car could increase the motor temperature rather than cool it. Likewise, fan blades fitted to the shaft will simply give the motor more work to do and it will get hotter. Heat sinks fitted to the end plates or to the motor cylindrical casing will dissipate heat in proportion to their surface area.



Computer fans can be used to blow air across the heatsink provided that the power comes from the race batteries

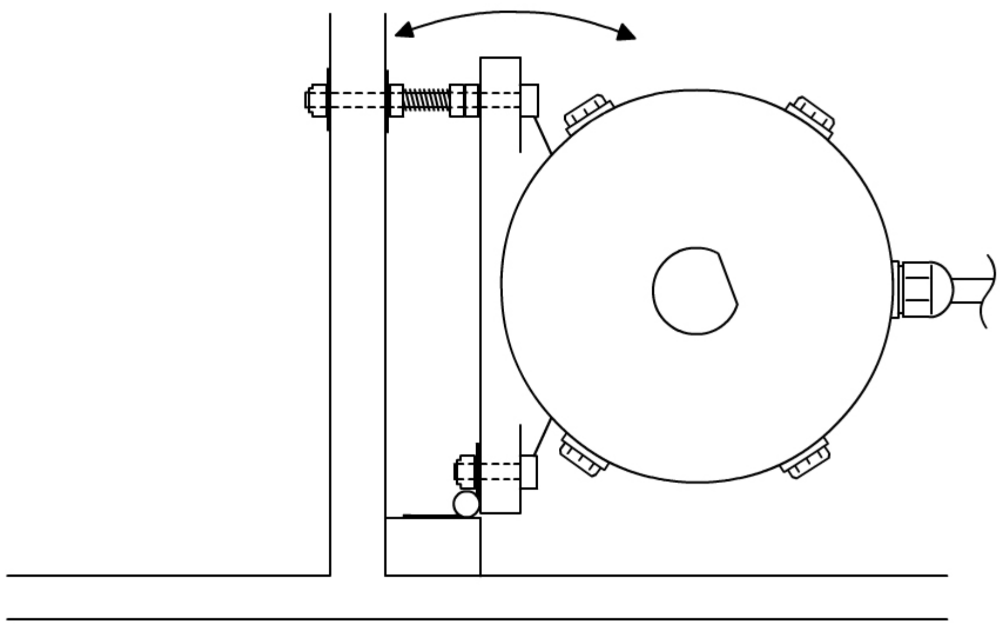
MOTOR MOUNTING

The standard Fracmo motor base plate is attached to the motor by two Allen screws. They have been known to come loose so put them in with a little 'Loctite' on the threads.

For efficiency and reliability, make sure the motor sits horizontal to the chassis and perpendicular to the drive train.

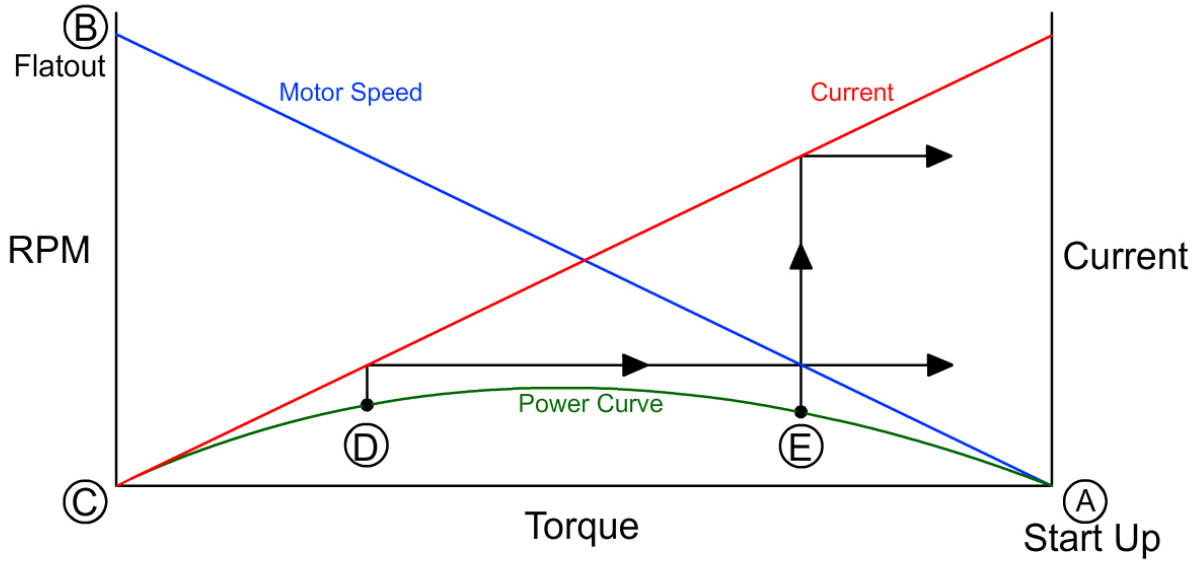
Keep the drive sprocket as close to the motor as possible. If it is on the end of the shaft the moment arm can pull the whole thing out of alignment and load the motor bearings.

Unfortunately the base plate mounting holes are tucked in under the motor casing. This means that the fixing bolts can be difficult to get at if it is attached to the floor of the car. Since the chain or belt tension is often adjusted by moving the motor, consider hinging the motor from a bulkhead. Access to the adjustment nuts is then easier.



MOTOR PERFORMANCE GRAPH

To maximise your car performance and to avoid burning out motors it is important to understand the motor characteristics. The graph is quite simple even though at first glance it looks complicated.



At start-up, position A, the motor will run up to max rpm at B.

Mechanical power output = Angular Velocity (rpm) X Torque.

At start-up the rpm is zero so power is zero.

Flat out the torque is zero so the power is again zero.

Max power is in the mid range at the top of the arc.

Power at D = power at E but the current at E is huge compared to that at D.

At E there will be excessive battery drain and motor overheating. Don't go there.

Operate between D and C for maximum efficiency and a cool motor. Do this by fitting gears, having a current limiter or by using a sensible single gear and keeping the throttle flat out.

Do not be greedy for top speed by over gearing, or you will operate between E and A.

To go faster, improve the car aerodynamics and lower the rolling resistance. (see relevant sections).

For actual values, see the manufacturers' graphs available on the Greenpower website.

PERFORMANCE

Performance = Speed + Efficiency + Endurance

Speed:

The speed of any car for a given power is a function of its rolling resistance and its aerodynamic drag. The latter increases as the square of the road speed. For example: If you double the speed of a car, it will have four times the drag which will require eight times the power to overcome it.
(See Aerodynamics section)

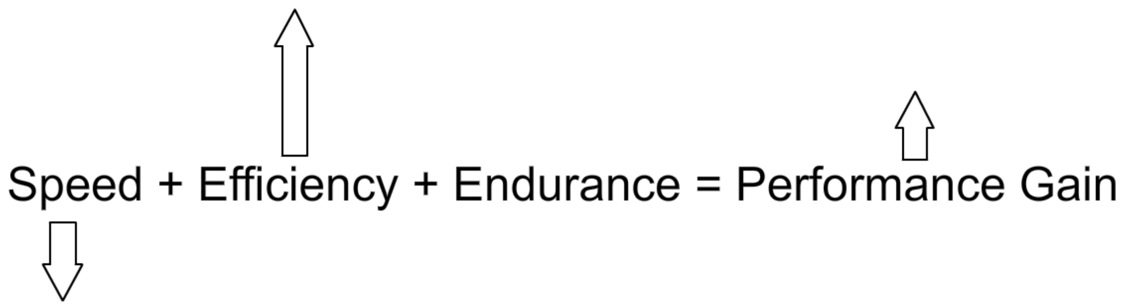
Efficiency:

This is a result of minimising the drag and rolling resistance and then matching the car performance with the battery performance and the motor characteristics through the transmission. Over gear the car and you will not only cook the motor but you will reduce your battery capacity. The car will go slower over the length of a race.

Endurance:

This comes down to reliability, frequency and speed of pit stops and avoiding driver errors. Weeks of work spent shaving off a few seconds a lap can be blown in an instant by a spin or waiting for a recovery truck.

To win you need more performance than your competitors. A small drop in speed will save you a whole load of drag, improve the efficiency and may give you a net performance gain.



Aerodynamic drag and rolling resistance are difficult to measure. Each car will have a best speed. Do not aim for a speed based on other cars. Gear for a low current to finish the race with energy to spare. Measure what is left and work from there. Improve the drag and rolling resistance.

ROLLBARS

The human head is very dense and supported by a strong neck. It is not designed to carry the weight of a car which could be in excess of 150kg. In an accident the impact could easily be 4G = 600kg. Could your roll bar take a load of half a ton?

Kinetic Energy = ½mV^2 where m is mass and V is velocity. The heavier the car and the faster it goes the greater the protection required.

Loads on the structure can be from almost any angle.

Anchor points and mounting are critical. Avoid weakening the structure by drilling holes except at the very bottom. Clamping or welding are preferable.

The greater the triangulation the stronger the structure.

A line between the rollbars must clear the driver's head by 50mm. This is to allow for slack in the seatbelts. The taller the roll bar the stronger it must be.

Rollbars must be able to roll and dissipate the energy gently. Do not have spikes or tee bar extensions that could dig in. Square rollbars are to be avoided for they too will transmit snatch sideways loads on the driver's neck. A square rollbar will not be able to carry the load as evenly.

Cars can and do roll very easily even with a low CofG. Reasons could be hitting or sliding off a kerb, turning into a corner too fast and tight, or if cars touch and climb wheels.

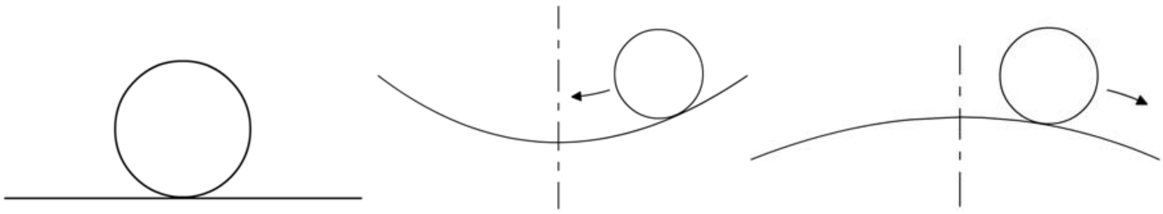
Remember – you are responsible for the safety of your drivers. Do not load your responsibility onto the race scrutineers.

STEERING GEOMETRY

Steering needs to be safe, stable, efficient, free from play and provide positive feel.

Stability:

This means that if the steering wheel is turned and then let go it will return to the straight ahead position of its own accord. To illustrate stability, imagine a ball in a saucer as shown below.



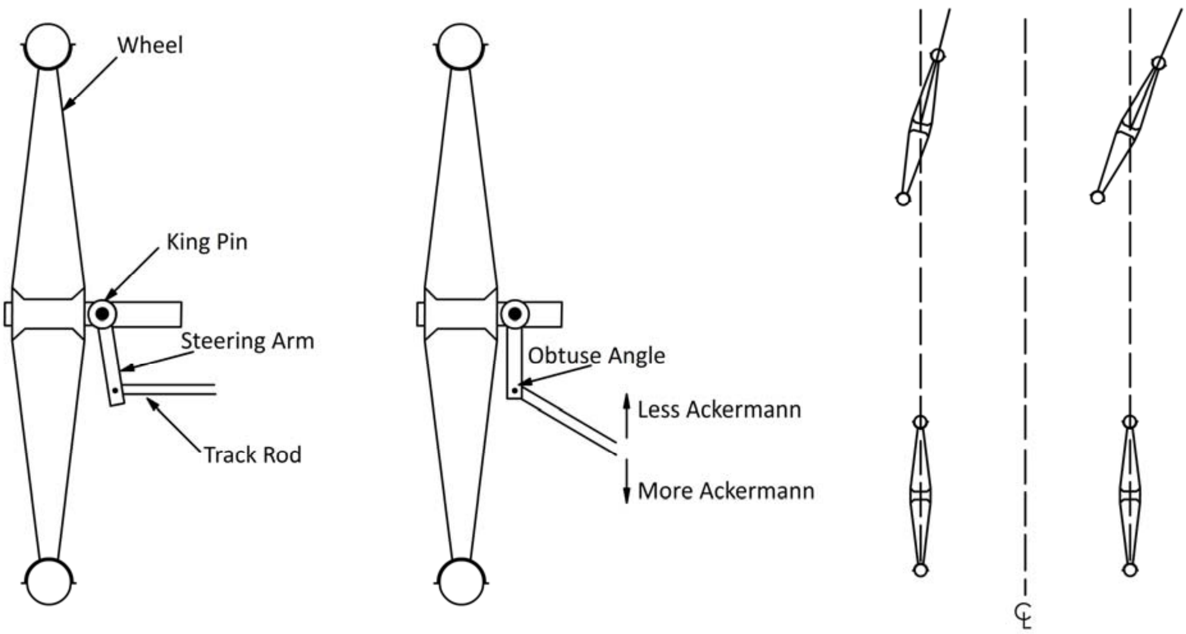
Neutral **Stable** **Unstable**

Caster Angle:

Stability is achieved with caster angle as with the forks on a bicycle angled forwards rather than being vertical. The greater the angle the greater the steering loads. 10^{o} is about right.

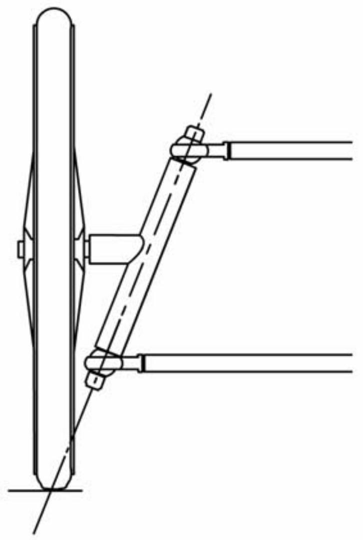
Ackermann Angle:

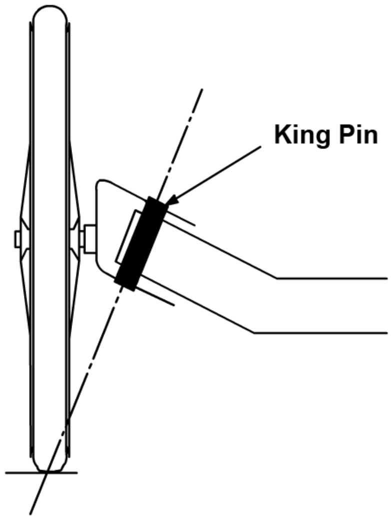
When a car turns a corner the inner wheel needs to turn more than the outer or the tyres will scrub. Ackermann is achieved by pointing the steering rods to the middle of the rear axle or by making the steering arm/track rod angle obtuse.



Centre Point Steering (CPS):

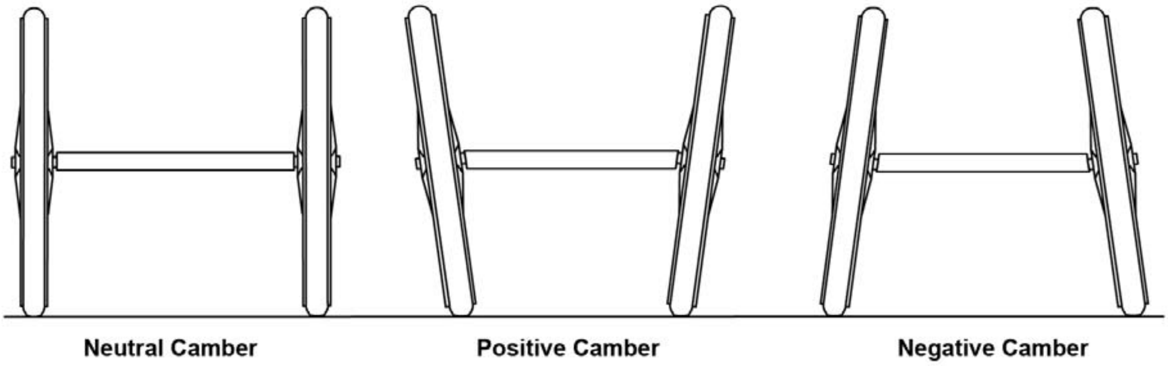
Spoked wheel hubs are wide relative to the wheel diameter. If the hinge axis is to meet the tyre contact point then a hefty kingpin angle is required. With CPS the steering is less affected by bumps in the road or by front wheel brakes.





Camber Angle:

To reduce the kingpin angle, old cars using bumpy roads often had positive camber. Under heavy cornering the tyre tended to roll off the wheel rim. To transfer some of the lateral tyre load onto the spokes, negative camber is employed. Too much and the car will have a high rolling resistance.



Caster angle and Kingpin angle will cause the wheels to camber favourably in a turn. This means they will lean over like a bicycle. Unfortunately the two angles do compound. This means that with a four wheel car with a rigid chassis and without suspension, the outer wheel will lift in a turn. Skipping in a turn will cause tyre wear.

STEERING GEARING

It is important that the gearing is correct for the speed of the car. Too high and it will be far too direct and oversensitive. Too low and it may not have enough lock for tight corners. Greenpower cars with cables attached to the steering wheel or handlebars will have only limited movement available. In this case a simple drop arm or bell crank arrangement will be sufficient. Rack and pinion gearing is an option but can suffer from excessive play.

To lower the gearing and reduce the steering loads:

- Reduce the length of the drop arm
- Increase the length of the steering arm
- Fit a bigger diameter steering wheel

To reduce the play in the steering system:

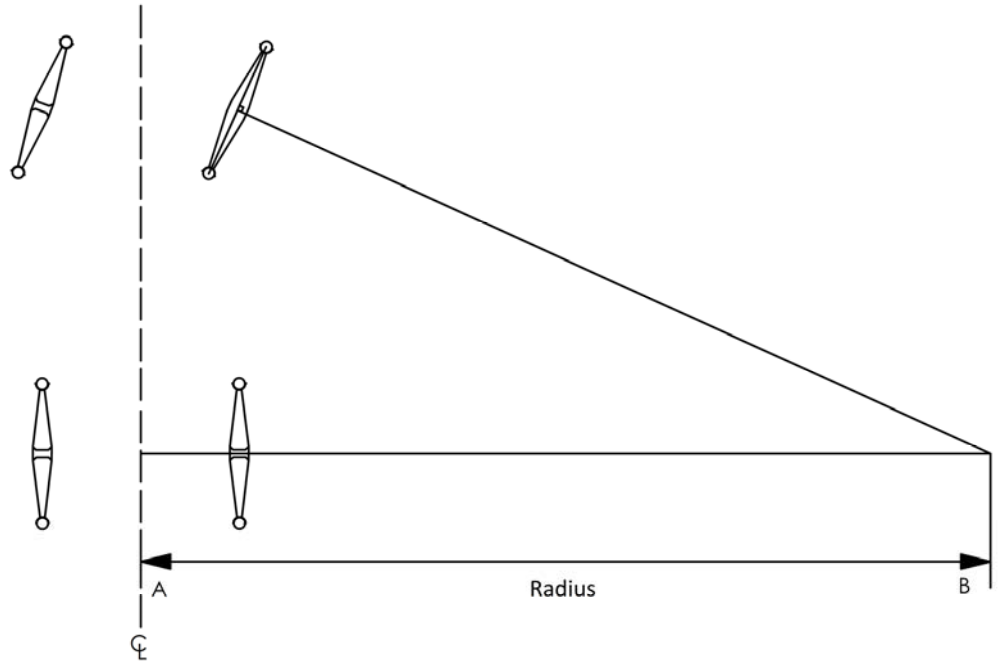
- Design to limit the use of universal joints, splined shafts and the number of rod-end connections
- Use components with lower clearance tolerances

TURNING CIRCLE

Assuming that Ackermann steering geometry is used, calculating the turning circle of a vehicle is relatively straight forward and can prove to be a very useful factor to know whilst in the early stages of design.

It is important to remember that too much steering lock can be dangerous and contribute to a car rolling over. Steering Stops need to be fitted to limit the rate of turn at high speed.

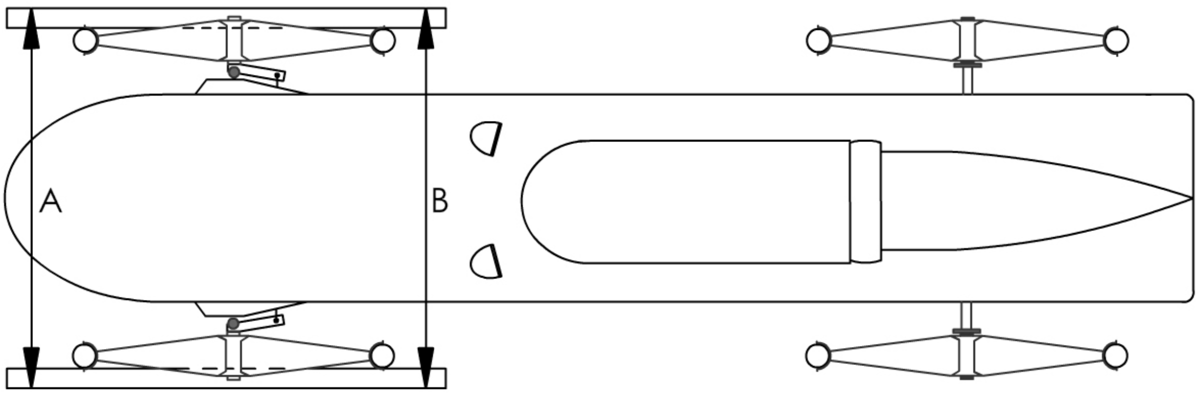
To check the turning circle will be adequate at the design stage. Apply full lock and calculate or measure A-B as shown below, this is the turning radius. By doubling this number you will have calculated the turning circle diameter.



TRACKING

Do not underestimate the importance of correct tracking. Check it before every race. With poor tracking, it is like trying to drive in sand. The rolling resistance increases, dramatically slowing the car, the motor will heat up, and the tyres will wear out.

Track the car fully loaded with driver and batteries as the weight distribution can make a difference. There are many ways to check the wheel alignment but the simplest is to lay two straight edges along the tyres and measure the track ahead and behind the wheel. When A = B the wheels are aligned. If anything err on the side of 'toe in' as the tracking will move towards 'toe out' at speed with rearward steering arms as clearances in the steering mechanism are taken up.



Remember to check the rear wheels even if they are on a common axle.

WEIGHT

A heavy car will have a high rolling resistance, poor acceleration, slower hill climbing ability and greater brake energy. Weight is minor compared to aerodynamic drag because it only increases resistance in direct proportion to speed.

Rolling Resistance:

This is comprised of flexing of the tyre tread and sidewalls, tracking, size of wheels and friction in the wheel bearings. To understand this try pushing a heavy garden roller compared to a lightweight bicycle. Try pushing a car with a flat tyre. All that push and shove comes from the motor taking away precious battery energy.

Acceleration:

The higher the car weight the slower the acceleration rate.

Hill Climbing Ability:

Potential energy = mass x gravity x height

A heavy car will require more energy to push it up a hill for a given speed. Not all this energy is recovered coming back down again because the aerodynamic drag will be greater as the car goes faster.

What difference does it make?

As a guide: At 30mph, a 10kg increase will slow the car down by 0.4mph which over a 4 hour race equals 1.6 miles or just over 3 minutes.

To weigh your car:

Make three blocks the thickness of a pair of bathroom scales. On a level surface measure the load under each wheel in turn, then add them all together. A very light car including motor but excluding batteries and driver will weigh 30kg. A heavy car will weigh in excess of 60kg. Many cars above this weight have won the National Final and the main reason lies in their aerodynamics.

WEIGHT DISTRIBUTION

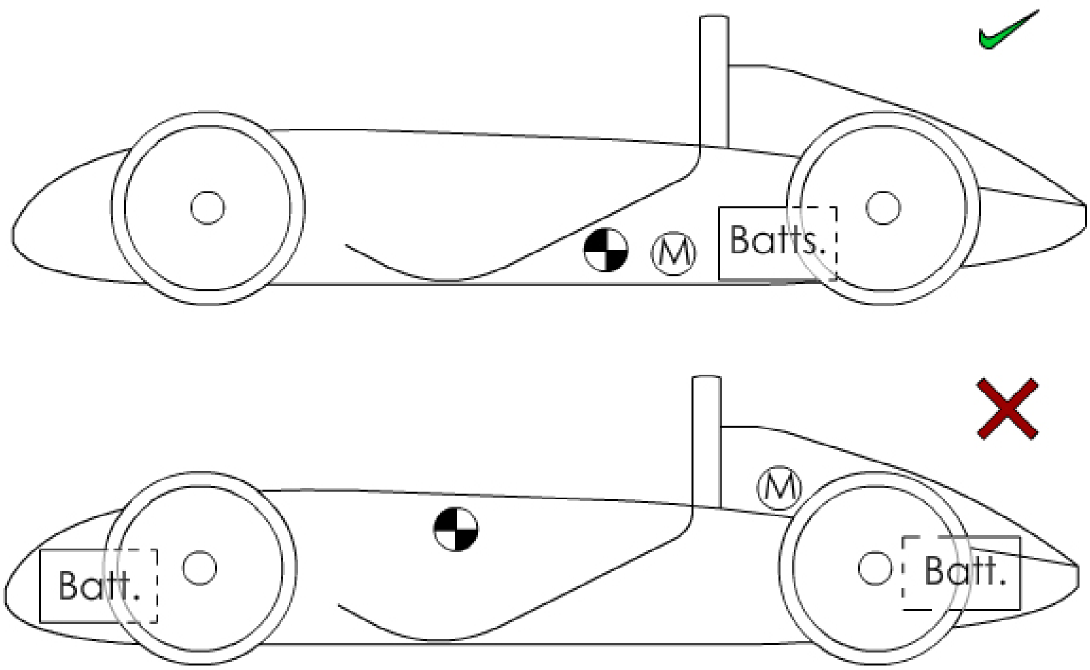
Design the car to avoid: Rolling Over
Spinning
Skidding

40/60 Rule:

For good handling when cornering and braking, aim for 40% of the car weight on the front wheels and 60% on the rear. Under braking there is a pitching moment forwards and some of the 60% will transfer to the front wheels.

Polar Moment of Inertia:

Ideally keep the heaviest items (batteries, driver, motor) as close as possible to the Centre of Gravity and keep the CofG as low as possible.



This car has a high polar Moment of Inertia. It is like a dumbbell and will be inclined to spin when cornering at speed especially on a wet or damp track.

Cars with a short wheelbase will spin more easily.

WHEELS

Bigger Wheels:

Lower rolling resistance
Less tyre wear

Smaller Wheels:

Less aerodynamic drag
Less bending moment on spokes and axles
Require a smaller sprocket

Popular sizes are 16” (349) and 20” (406):

16” (349):

Designed for fold-up Brompton bicycles. Good range of low rolling resistance, high pressure tyres some of which have Kevlar banding to resist punctures.

16” (305):

These are not the same size as the 349s. They are made for children’s bikes. Tend to be cheaper, of inferior quality and have a poor selection of suitable tyres.

20”:

Mainly used on recumbents or BMX bikes. Hubs, steering and brake components can be bought off the shelf and adapted for Greenpower use. Tyre choice is good.

Wheel Skins:

To appreciate the aerodynamic drag from spoked wheels, run the car indoors on a bench and feel the draught created. It is even higher when the car is in motion.

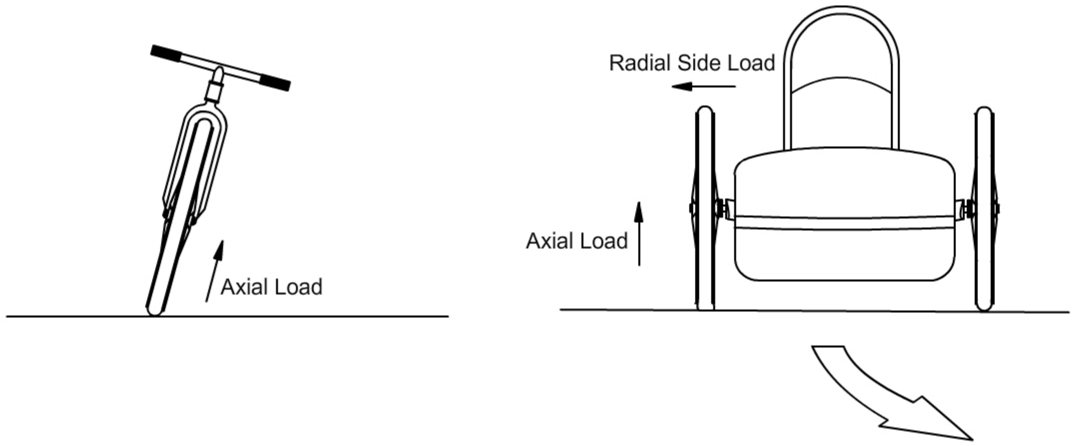
Stiff acetate discs can be cut and cable tied to the spokes. Heatshrink ‘solarfilm’ is neater and available from model shops. This sticks well to wood but not so well to an aluminium rim. For the wheel centre, PU foam glue a thin plywood ring to the spokes. Film can be stuck to the rim with slow setting ‘super glue’ or ‘Prymol’ and tucked over to be held by the tyre.

To cater for the conical shape, make a single cut as a radius and overlap. Gently taughten with a heat gun or an iron. Remember to mark the position of the valve. Check tyre pressure and patch before every race.

WHEEL BEARINGS

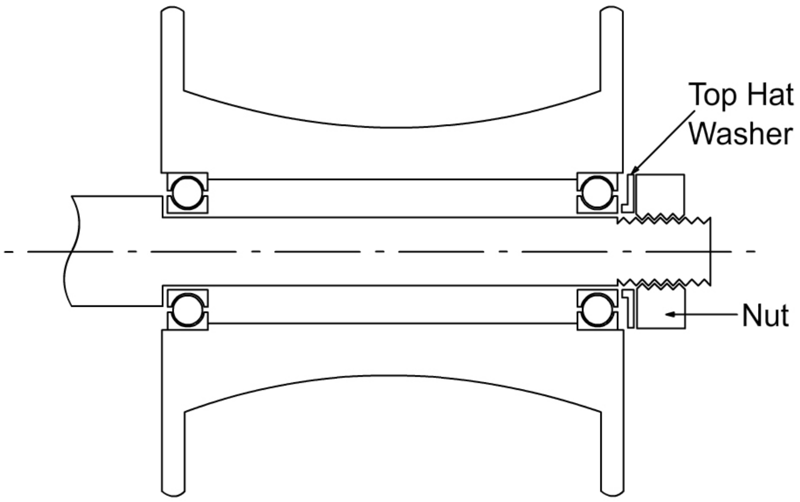
To reduce wear and minimise rolling resistance it is important that bearings are properly adjusted (cup and cone) or set (journal bearings).

Although most Greenpower cars use bicycle wheels, the loads on them are very different. On a bicycle, the hubs are supported on both sides and the axial load is always perpendicular to the spindle. On a car there are additional side loads when cornering and very often the hub is only supported on one side.



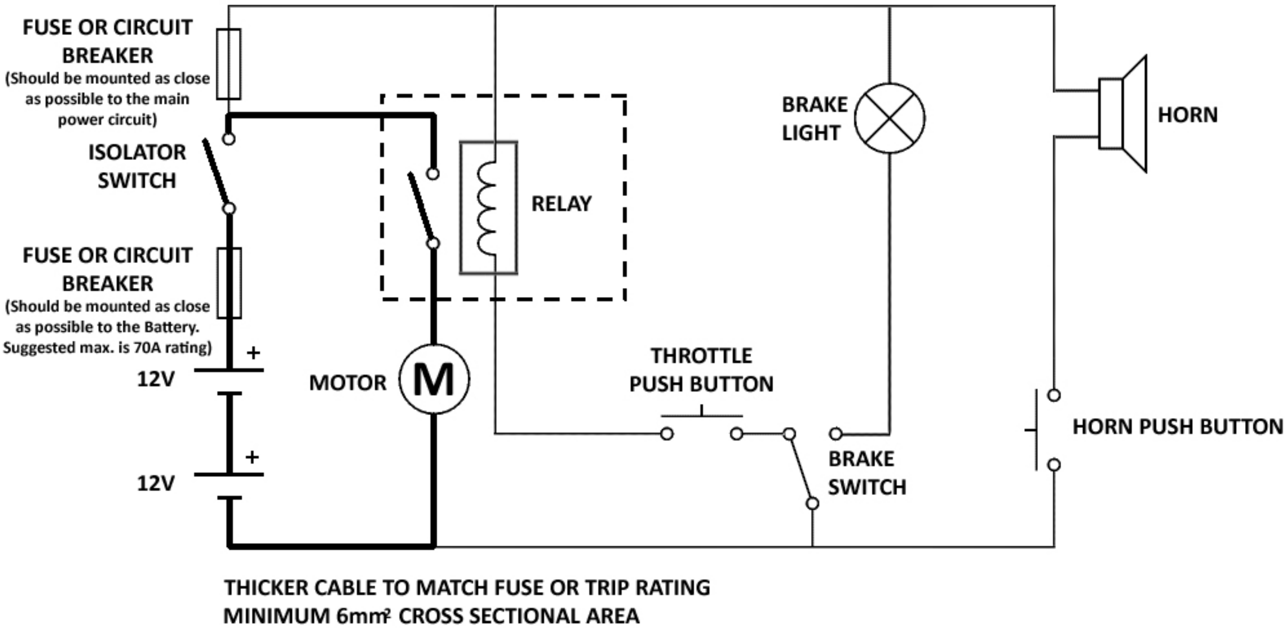
Do not over tighten cup and cone bearings.

With journal bearings, make sure that the hub is spinning about the bearings and not around the axle. The axle should grip the inner ring of the bearing by gently tightening the wheel nut so that the bearings are ‘nipped’ between the axle shoulder and the top hat washer.



Journal bearings come as ‘shielded’ or ‘sealed’. Both are suitable. Beware of removing plastic seals to reduce friction as dirt and dust can soon destroy any advantage.

WIRING DIAGRAM



ELECTRICAL COMPONENTS

Greenpower requires all electrical installations to be "safe". This means:

- Must use a fuse or circuit breaker to automatically and safely disconnect the power in the event of a fault (otherwise the car may catch fire.)
- Cables must be of the correct cross-sectional area
- Cables Properly insulated
- Cables Correctly terminated
- Cables Secured

Fuses or circuit breakers?

You can use either. Higher fuse or breaker ratings mean larger cables, or your wiring will become the fuse. The regulations specify 60 – 100A.. Size depends upon the maximum current you would expect to pull through the load. Starting current is very much larger than the running current. Size your protection device to handle the motor starting current or else the fuse will blow or the circuit breaker will trip. Check the motor characteristic graphs, gearing and the characteristics of your chosen fuse or breaker.

Cables

All cables must be insulated to prevent the conductors from contacting any other metallic parts that would cause excessive currents to flow. The size of the cable (mm^2) must be sufficient to carry the current that will trip your fuse or circuit breaker.

Example from table below. 70A rated trip must be connected with 10mm ^{2} cables that can carry 70A continuously.

Cross sectional area (mm^2)	60C Insulation temperature rating	85-90C Insulation temperature rating
	Maximum Continuous Current (A)	
0.75	6	12
1	8	18
1.5	12	21
2.5	17	30
4	22	40
6	29	50
10	40	70

The ratings shown are for cables in open air at a maximum ambient of 30C.

Terminations

Once you have chosen your cable size (based upon your fuse or circuit breaker rating) then choose suitable terminations. Crimp type connections are very reliable if fitted correctly. Be very careful with the current rating of terminations you choose – they must also carry enough current to blow your trip method if a fault develops.

Security

Make sure all of your cables are mechanically secure and cannot be disturbed by the drivers getting in, or out of, the car. Ensure they cannot chafe on sharp edges.

HOW TO FIND YOUR CRASH HELMET SIZE

Use a tape measure to determine the circumference of your head. Place the tape measure above your ears and about an inch (2.54 cm) above your eyebrows. Try not to wrap the tape too tightly – take your time and take a few sets of measurements to find the common average. Once you have determined your head circumference check the sizing guide below. If your head falls between two sizes, always try the larger size first.

Motorcycle Helmet Size Conversions			
Helmet Size	**Head Circumference (CM)**	**Hat Size**	**Head Circumference (Inches)**
Child SM	49-50	6 1/8 - 6 1/4	19 3/4 - 20 1/8
Child L/XL	51-52	6 1/2 - 6 3/8	21 1/4
Child 2XL	53-54	6 5/8 - 6 3/4	20 7/8 - 21 1/4
2XS	51-52	6 3/8 - 6 1/2	20 - 20 1/2
XS	53-54	6 5/8 - 6 3/4	20 7/8 - 21 1/4
S	55-56	6 7/8 - 7	21 3/8 - 22
M	57-58	7 1/8 - 7 1/4	22 1/2 - 22 7/8
L	59-60	7 3/8 - 7 1/2	23 1/4 - 23 5/8
XL	61-62	7 5/8 - 7 3/4	24 - 24 1/2
2XL	63-64	7 7/8 - 8	24 3/4 - 25 1/4
3XL	65-66	8 1/8 - 8 1/4	25 5/8 - 26

NOTE: These sizes are meant as a guideline only as sometimes manufacturers do interpret sizes differently.

How to Test for a Good Helmet Fit

Once the helmet is on, check for the following:

- The top of your head should be in contact with the helmet interior so that the top pad presses firmly against your head
- The cheek pads should make light to medium contact with your cheeks
- Now try and insert your fingers into the helmet. There should not be any space between your forehead and the helmet interior
- Try and rotate the helmet back and forth and to the right and left. The helmet should move your skin on your head and face as it moves. If the padding is moving over your head, then you need to try a smaller size
- Next, fasten your strap so that it is tight enough around your jaw without suffocating you. Then try and push the helmet off by placing your hands at the back of it. Once you've done this, try the same thing but from the front to the back.
- You should ***NOT*** be able to pull the helmet strap over your chin.
- Lastly, make sure that you are comfortable with your field of vision when the helmet is on.

About the Author:

On leaving school, Michael Joseph did a mechanical engineering apprenticeship with Rolls-Royce Aero Engines before becoming a performance engineer. At this time he learnt to fly light aircraft and subsequently flying became a new career as an airline pilot.

With his own two sons taking an interest in engineering and having seen the very first Greenpower race, Michael persuaded the Weald School to enter under his leadership. With the students, he was responsible for building three cars all of which were primarily made from wood. The Sussex Trug, Super Trug and Slippery Trug were all highly successful over a seven year period culminating in victory at the 2006 National Final.

On retirement as a British Airways Captain and from the Weald School Team, Michael was appointed Greenpower Chief Scrutineer in 2007. He now runs Electroad, designing and building electric motors and components for electric vehicles. Some of these are available through the Greenpower Shop. The Electroad 'Simple Trug' won The Corporate Challenge in 2009.