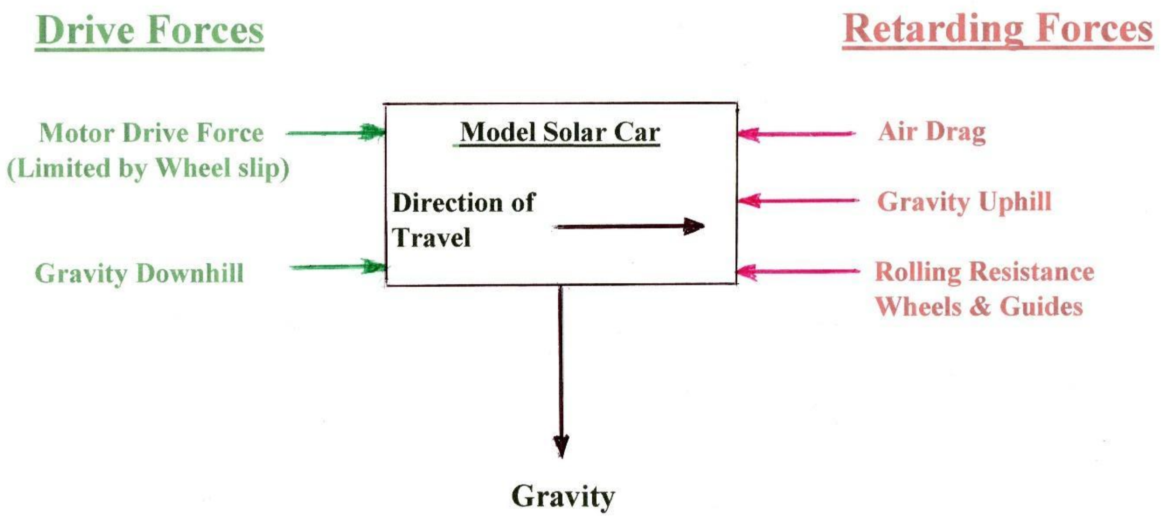
Solar Car Simulator -- How it Works

The diagram below depicts the forces acting on a Model Solar Car.



Determine the resultant force in the direction of motion.

Consider the forces:

Motor Drive Force:
This force varies with motor RPM, Sun level, gear ratio the use of electronics and wheel diameter.
As the motor drive force varies with motor RPM this means it also varies with car velocity.
It is possible to have the drive wheel slip, particularly on initial acceleration away from the start, resulting in a lower drive force than anticipated. The effect of this is incorporated in the simulation via the wheel slip coefficient which is explained later in this document.
The Motor Drive Force is determined using the motor's Torque - RPM curve for the Sun level being evaluated, the gear ratio and wheel diameter.

Gravity Down Hill Component:
When the car is on the downhill section of the track there will be a component of the gravity force acting in the direction of travel, this force is dependent on car mass and hill slope.
Note: for pursuit racing on the flat oval track there is no up or down hill force.

Air Drag:
Varies with velocity squared, car shape and frontal area, as we are operating at Sea level air density is assumed constant. The air drag co-efficient assumes testing of the actual car under consideration so car shape and frontal area and air density is incorporated into this value. An approximate value can be determined by comparison with other cars that have a known air drag value. (See Design Guide). There are also computer programmes that calculate air drag.

Gravity Uphill Component:
When the car is on the uphill section of the track there will be a component of the gravity force acting against the direction of travel, this force is dependent on car mass and hill slope. Note: for pursuit racing on the flat oval track there is no up or down hill force.

Rolling Resistance Wheels and Guides:
Wheel rolling resistance incorporates the resistance encountered when the wheels roll on the track plus, if applicable, the additional resistance that occurs when a car without steering is cornering. The addition of a tyre on the drive wheel increases rolling resistance.

Guide rolling resistance is the resistance the guides contribute when the car is cornering, it varies with angular velocity squared so is speed dependant.

The Simulation Calculations:

The forces described above are used in the Newtonian mechanics formulas within the simulation to calculate the distance travelled and final velocity of the car after a specified short period of time.

The final velocity and distance travelled determined in the previous calculations is used as the start point for the next series of calculations. These calculations determine the velocity and distance travelled for this new short period of time.
The same time interval is used in all calculations.

This process repeated until the distance travelled which is being continuously summed, equals 100 metres at which distance the race is over for a single lap of the figure 8 track and the results displayed in the results area of the excel simulator.
A displayed race time of 90 seconds indicates the car has not completed the race within the total number of calculations allowed. The results for the second lap in the case of a 2 lap race are displayed in the results area with the details of this lap shown on sheet 2.

For pursuit racing on the oval track the distance for one lap is 46.4 metres not 100 metres as for the figure 8 track.

Newtonian Mechanics Formulas Used:

$$F = Ma$$

$$S = Ut + 1/2at^2$$

$$V^2 = U^2 + 2aS$$

$$F = M\Omega^2 r \quad \text{(force on guides when in the corner)}$$

Where F = Force
S = Distance
M = Mass
a = Acceleration
t = Time
Ω = Angular velocity (radians / second)
R = Radius of curve

The Calculations:

1. **Determine the resultant force acting on the car: (in the direction of motion)**
   Resultant Force = Gravity component (either + or -) + Air Drag + Motor Drive Force + Rolling Resistance (Wheels + guides)
   Note: Air Drag and Rolling resistance will be negative, gravity component will be either negative or positive depending on car position on the track. ***The wheel drive force may be limited by slip.***

2. **Calculate the car's acceleration:**
   a = Resultant force ÷ M

3. **Calculate Distance travelled:**
   Using $S = Ut + 1/2at^2$

4. **Calculate final velocity:**
   Using $V^2 = U^2 + 2aS$

5. **Calculate motor RPM:**
   Using $$RPM = \frac{V \times 60000 \times \text{Gear Ratio}}{\pi \times \text{Wheel Diameter (mm)}}$$

6. **Calculate motor drive force:**
   Using On the motor Torque RPM graph lookup the torque corresponding to the RPM from 5 above.

   $$\text{Motor Drive force} = \frac{\text{Mtr. Torque (mNm)} \times \text{Gear Ratio} \times \text{Effy.} \times 2}{\text{Wheel Diameter (mm)}}$$

   Caution: Wheel slip coefficient may reduce Motor Drive Force in the simulation.

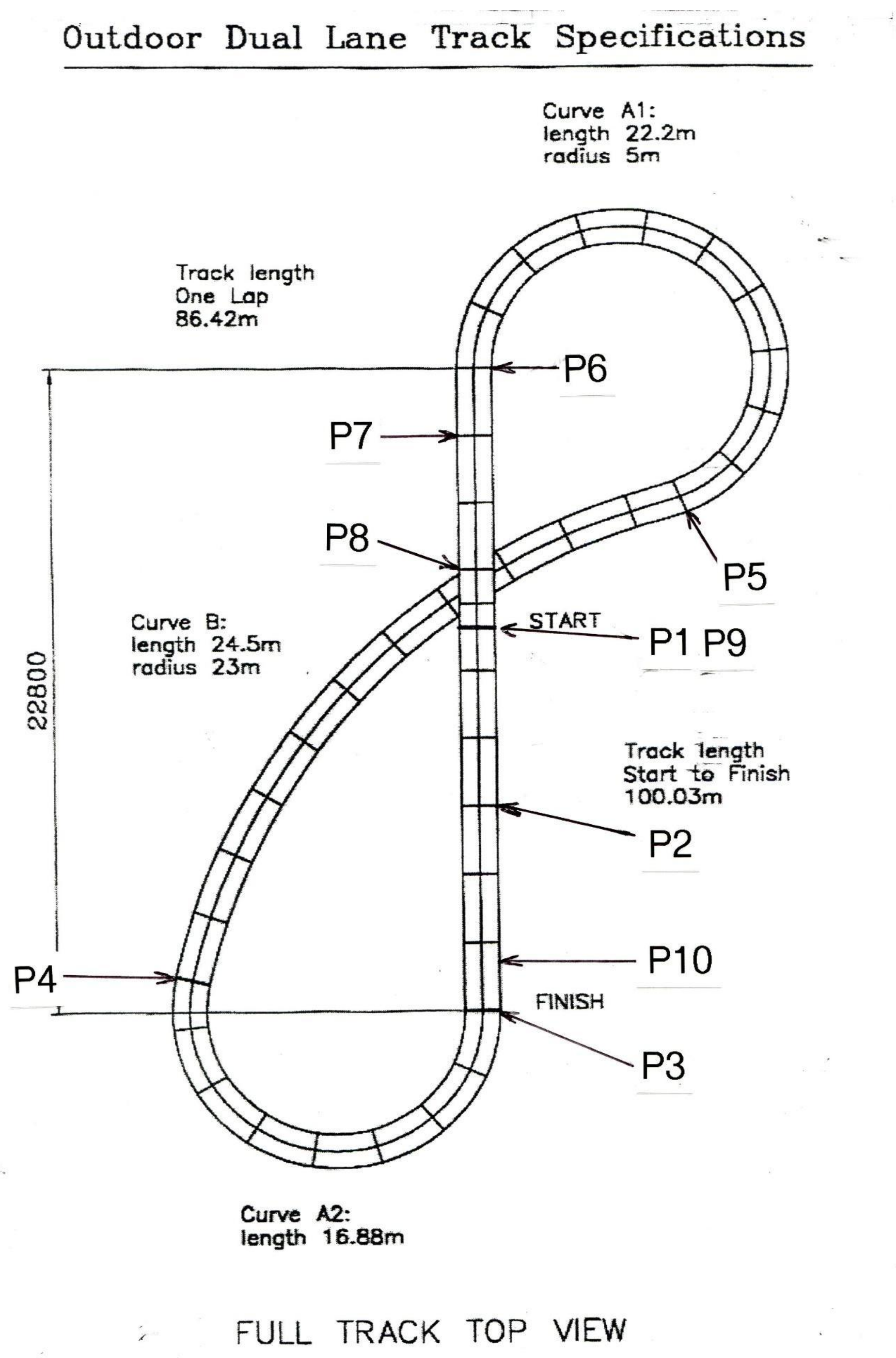
7. **Calculate Air Drag:**
   Using Final Velocity determined in 4 above

Air Drag = Air Drag Coefficient × V^2

Note: Air drag coefficient in simulator combines car frontal area, Cd and air density.

8. **Repeat the Calculations using the parameters determined above as the start conditions. Continue the process until 100 metres travel distance is reached.**

Figure 8 track Dimensions Used in Simulation:



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

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

For racing on the oval pursuit track the following track dimensions are used in the simulation. Corners of 180 degrees with a radius of 5 metres, straight sections joining the corners of length 7.5 metres.

The Simulator Input - Output Panel:

Model Solar Car Simulator Parameters				Results	
Car Name:	Standard Evaluation Car			1 LAP RACE	
Sun Power:	60.4%			Time:	21.2
Motor Type:	Faulhaber 2232 6 volt	08M2 Electronics		Velocity:	5.853
Guide Roll CoEf:	0.015	Wheel Slip Coeff	2.5	Mtr RPM:	7872
Mass(kg):	0.883			Air Drag	0.240
Wheel Roll RS:	0	Roll CoEf:	0.15	Rolling R:	0.13245
Air Drag Coefficient:	0.007	Steering(Yes/No):	NO	Mtr Torque:	2.877
Wheel Diameter(mm):	71	Steering Drag:	0.13		
Acceleration Gear Ratio:	7.14	Change RPM:	0	2 LAP RACE	
Final Gear Ratio:	5			Time:	37
Transmission Effy:	100			Velocity:	5.855
Motor Tourque:	Finish RPM:	Start T(mNm):	Formula	Mtr RPM:	7875
Section 1:	2900	12	0.0020345	Air Drag	0.240
Section 2:	8300	6.1	0.0006481	Rolling R:	0.13245
Section 3:	9700	2.6	0.0018571	Mtr Torque:	2.875

Main input output table of the simulator.

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Version 1.3 Feb 2006 .5 DEC 06 MODIFIED FOR WHEEL SPIN ON TAKEOFF

Denotes for info					
Must be entered	for your car				
Coefficients for	average car				
With Tyre	**Roll Coeff:**	**0.15**			
Without Tyre	**Roll Coeff:**	**0.1**			
SECOND	LAP TIME	15.8	Seconds		

RATIOS AVAILABLE

Gear 80 T	PINION T	RATIO
	9	8.88
	10	8
	11	7.27
	12	6.66
	13	6.15
	14	5.71
	15	5.33
	16	5
	18	4.44
	20	4
	24	3.33

Information area of simulator immediately to the right of the main input output table.

DETAILS OF PARAMETERS ENTERED

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

Guide Roll CoEf : this Coefficient is determined experimentally. It is used to calculate the rolling resistance of the guide rollers. It is turned on during cornering. It is found by using the same method as for the wheels. The difficulty is a test rig to hold a guide while it runs against guide rail material must be constructed.

Guide rollers induce rolling resistance when they contact the guide rail, this is only significant when the car is cornering. This force is turned on and off in the simulation depending on the car position on the track. This force is also velocity dependent, because the force acting on the guides varies with angular velocity squared.

Mass: The Mass of the car in kg.

Wheel Roll RS: Set to zero. It was thought that the friction in the wheel bearings would give some significant initial friction to overcome. Testing proved this was not so. Consequently, this parameter is set to zero.

Roll CoEf Determined experimentally. Used to calculate the wheel rolling resistance on the track.
Wheel rolling resistance remains constant except for the slight variation when the car is on the hill due to the weight transfer caused by the slope, this slight variation is ignored in the simulation.
Note: the use of a tyre will increase rolling resistance.

The coefficient is found by measuring the force required to roll the car at different mass levels and graphing the results, force against mass. The slope of the graph is the coefficient. This is used in the simulation to calculate the rolling force for the car mass entered in the simulation.
For accuracy the test must be conducted on material representative of the track.

Air Drag Coefficient: Determined experimentally. Used to calculate the air drag on the car.

Air drag varies with velocity squared, car shape and frontal area, as we are operating at Sea level air density is assumed constant. The air drag co-efficient assumes testing of the actual car under consideration so car shape and frontal area and air density is incorporated into this value. An approximate value can be determined by comparison with other cars that have a known air drag value. (See Design Guide). There are also computer programmes that calculate air drag.

Wheel Diameter: The drive wheel diameter in mm.

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

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

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

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

Note: recent motor testing has been conducted with a gear reduction between the motor and flywheel on which the measurements are taken. This incorporates the gear efficiency into the motor data. For this data transmission efficiency is set to 100%.

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

Wheel Slip Coefficient: Used in calculating the force at the wheel periphery at which the wheel slips on the track. It is the maximum drive force the wheel can exert before wheel slip occurs. Determined by tow testing the car with the drive wheel locked and measuring the force required to cause the wheel to slip. It works in the simulation by limiting the wheel drive force to this value. The force will significantly increase with the use of a tyre.

The co-efficient in the simulator is a calculated number obtained by dividing the Towing Force (Newtons) by the car weight in Kg. In the simulator the co-efficient multiplies the car weight by the co-efficient to obtain the wheel slip drive force.
Note: any changes in the car that alter the weight distribution on the wheels will introduce errors. A change in car weight so long as the centre of gravity of the car does not change will not affect accuracy.

Wheel Slip Coeff = Towing Force (Newtons) ÷ Car weight (Kg)

Note: *recent tests on wheel friction on the BHHS blue track which is painted plywood similar to the Victorian and Tasmanian tracks, gave the following coefficients of friction* ***(μ)*** *for the drive wheel on this track.*

Acetal wheel	*0.25*
Aluminium wheel	*0.34*
Wheel with "O" ring tyre	*0.75*

The coefficients of friction above can be used to calculate the wheel slip force by using the following formula.

Wheel slip force = μ × down force on drive wheel (in Newtons)

A good indication of wheel slip force on a painted plywood track can be obtained by using the above formula.

However, an actual test on your car is the best option. Preferably on the actual track.

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

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

It is due to the sideways sliding of wheels on the track during cornering.
It is determined by measuring the force to just keep the car moving on a straight level section of track, then measuring the force to just keep the car moving in a corner, again on a level section of track.
The difference between these forces is the steering drag, in Newtons. This force is turned on when the car is in the corners.
It will vary with wheel shape on the running surface, wheel material, and weight on the wheel.
Testing should be carried out at the cars full racing weight.

Note: If you have not tested your car, using the coefficient values in the Input – Output table above, except for air drag, will give reasonable accurate for a well-built car using typically available components.

Air drag will vary greatly from car to car so must be evaluated for your car.

Areas not included in the simulation:

- **The additional loads on the guides due to the "Torque steer" effect of having one drive wheel offset from the car centre line.**
- **The effect of undulations in track sections and mismatch at track joints, causing energy loss.**
- **The effect of ground level variations around the track. (Is the track on flat level ground or been levelled.)**
- **Variation of Sun energy available due to Track orientation or panel orientation on the car and as the car traverses the track. For the figure "8" track, the panel orientation when the car is on the hill.**

DETAILS OF RESULTS DISPLAYED

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

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

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

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

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

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

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

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

Note: the simulation displays the details of the second lap of a two lap race on sheet 2 of the excel spreadsheet.