SSV case 1

Team Apollo

Characteristics of the solar panel

To find the characteristics of the solar panel, an extern light source is directed at the panel. A voltage and an ampere meter are connected, the A-meter in series with an adjustable load and the V-meter parallel. We first measure the voltage for the open circuit, which is 8,72 Volt, and the current for the closed circuit, which is 0,35 Ampère. Before the measurement starts, the load is put to its maximum. The light source is turned on and the multimeters are on. The load is slowly decreased and the voltage and current is measured for different loads. These results are listed here:

Voltage (V)	Current (A)	Diode factor m
0,24	0,349	0,05
1,15	0,346	0,23
1,78	0,344	0,35
3,01	0,340	0,57
4,42	0,340	0,83
5,60	0,330	1,00
6,40	0,324	1,12
7,02	0,310	1,20
7,21	0,260	1,17
7,33	0,230	1,16
7,47	0,175	1,17
7,60	0,140	1,19
7,78	0,115	1,19
7,82	0,101	1,20
7,88	0,092	1,21
7,97	0,071	1,21
8,04	0,057	1,22
8,09	0,049	1,22
8,12	0,043	1,23
8,16	0,035	1,23
8,20	0,030	1,24
8,24	0,027	1,00

Table 1 Characteristics of the solar panel

Because this current is the current generated by a lamp and not by the sun, this current isn't the expected one. Our shortcut current is 0.35A and should be 0.88A. So we multiply everything by (0.88/0.35=2.51) and get this new table.

Voltage (V)	Current (mA)
0,24	0,87599
1,15	0,86846
1,78	0,86344
3,01	0,8534
4,42	0,8534
	0
5,6	0,8283
	0
6,4	0,81324
7,02	0,7781
7,21	0,6526
7,33	0,5773
7,47	0,43925
7,6	0,3514
7,78	0,289403
7,82	0,25351
7,88	0,231924
7,97	0,177708
8,04	0,142317
8,09	0,123241
8,12	0,106675
8,16	0,08785
8,2	0,0753
8,24	0,068021

The third column is the calculated diode factor. This is calculated with the following formula:

$$I = Isc - Is(e^{\frac{U}{m.N.Ur}} - 1)$$

With 'I' being the measured current, 'Isc' is the short circuit current, 'Is' is the saturation current, U the measured voltage, m the diode facter (which needs to be calculated), N Is the number of solar cells in series. Ur is the thermical voltage which is calculated by multiplying the Boltzmann constant with the temperature (K) divided by the charge of an electron. When we rearrange this equation to the unknown factor m, the following equation is received:

$$m = \frac{U}{\ln\left(1 - \left(\frac{I - Isc}{Is}\right)\right) * n * Ur}$$

The constants used in the equation are the following:

Constants	Value
U open circuit (V)	8,72
I closed circuit (A)	0,35
Isc (A)	0,35
Is (A)	1,00E-08
N	15
Boltzmann cte	1,38E-23
Temperatur (K)	298
charge of electron (V)	1,6E-19
Ur (V)	0,0257

Table 2 Constants

We get an average diode factor of 1,00.

To see the characteristics of the solar panel, we must plot the voltage in relation to the current. This plot is shown here:

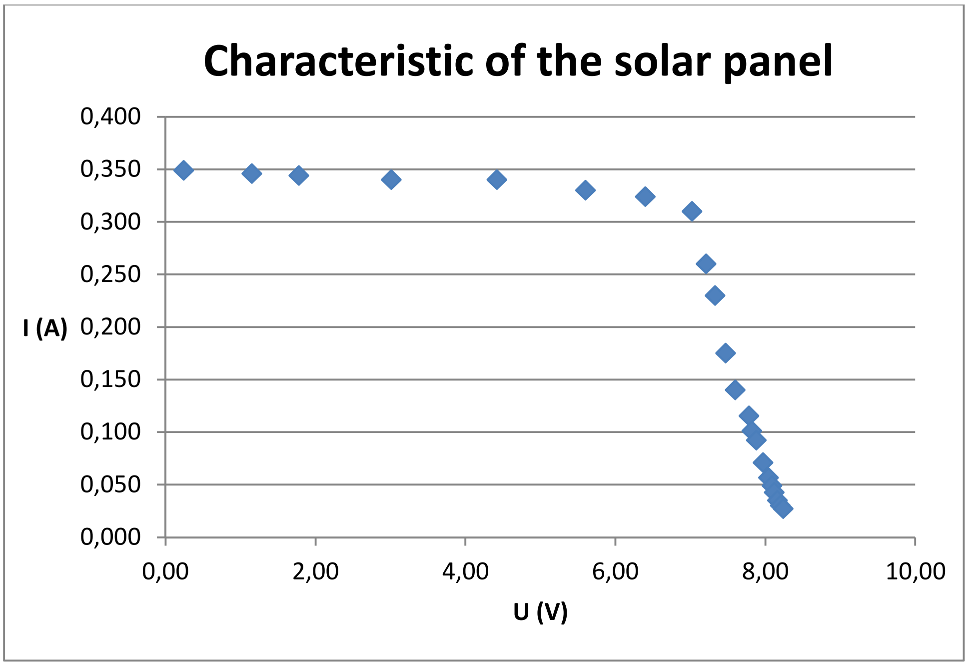


Figure 1 Characteristics of the solar panel plot

The relation is shown quite well. To get the maximum power we take the working point which gives the largest surface under the curve, since power is current times voltage.

Also the power has to be plotted in relation to the current, this plot is can be found here:

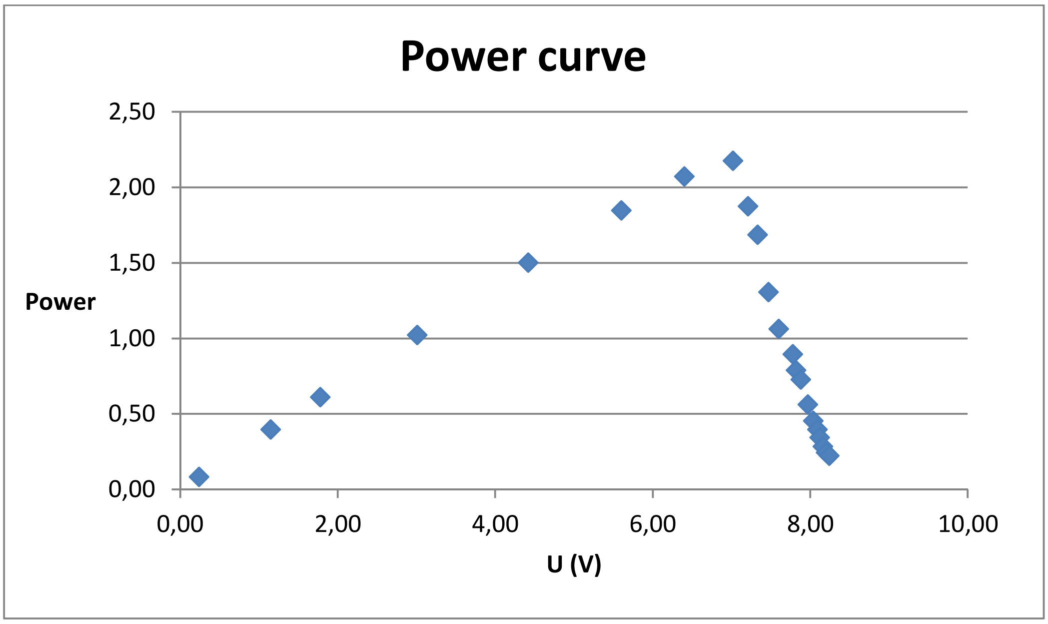
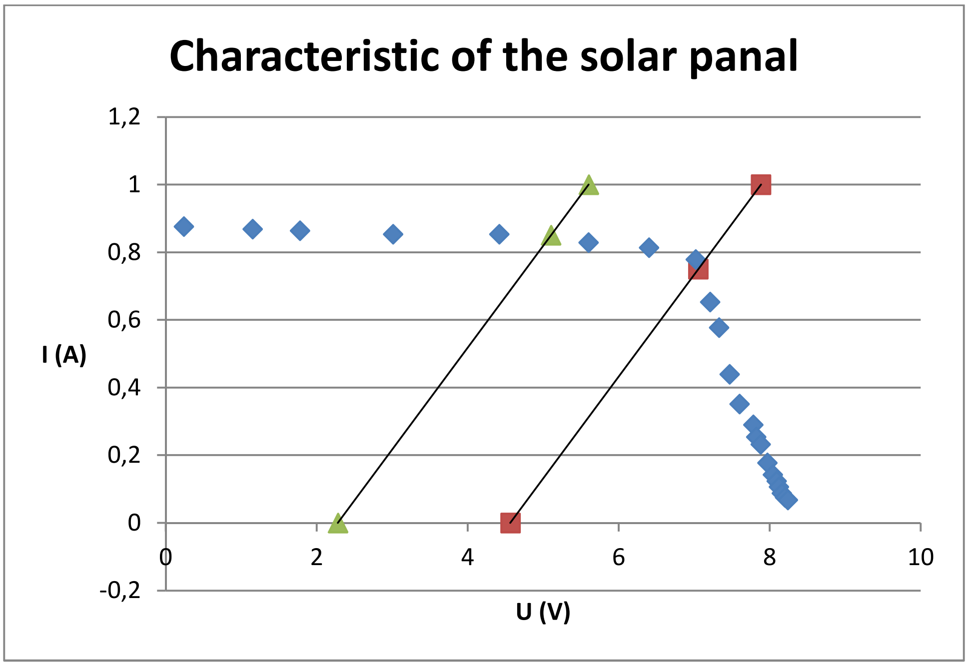
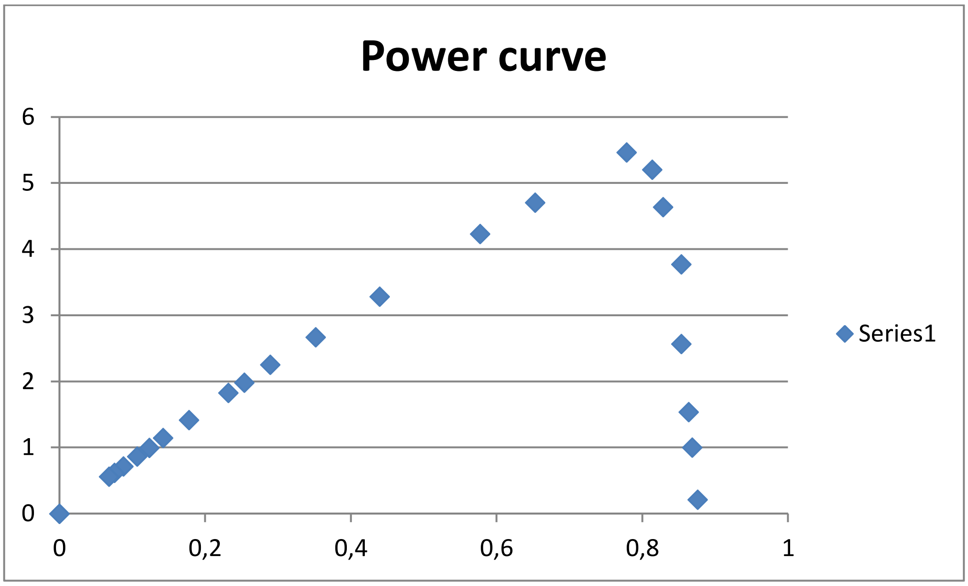


Figure 2 Power curve plot

We find here the optimal working point, this is at around 7 Volt which gives a power of 2,18 Watt.

The same over here. Because our real current is bigger than our measured current, the solar panel characteristic and power curve will change.




Power curve
6
5
4
3
2
1
0
0
0,2
0,4
0,6
0,8
1
Series1

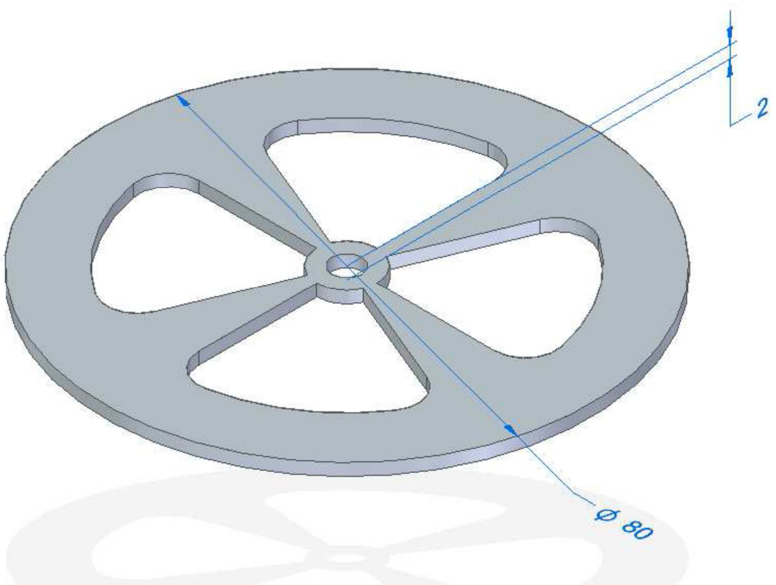
Design SSV

There are various elements in the solar vehicle that must be chosen carefully. The placement of the motor, the choice of wheels, the design of the frame, … , it all contributes to making the solar vehicle faster and must be optimized.

Wheels

The first decision to make are the number of wheels, for we can't design the frame without knowing how to place the wheels.
The most logical choices would be 3 or 4 wheels. To choose the best option we compare the advantages and disadvantages.
4 wheels are more stable, but this is a small advantage because a triangle is also a stable formation.
The difference in the track this year is that there is no guiding system, but walls on the sides instead. So the vehicle must always go straight. 4 wheels are better for maintaining a straight line but again this isn't a big advantage.
The biggest consideration is the rolling resistance. This is proportional with the contact surface with the ground. This is far greater with 4 wheels, so choosing 3 wheels seems the right thing to do.

Since the rolling resistance is mainly caused by the deformation of the object it must be wise to take our wheels from a hard material.
Plexiglas gives several advantages. The biggest advantage is that this is available at Fablab and it can be designed and cut it as wanted. It is a hard material so no deformation will take place.
For the least acceleration drag, the wheels can't be full but rather have areas cut out. The thickness of the wheel will be 2mm. This is optimal for cutting out these areas while still keeping enough strength.
A design for the wheel in SolidEdge is shown here:



Figuur 3 Design wheel

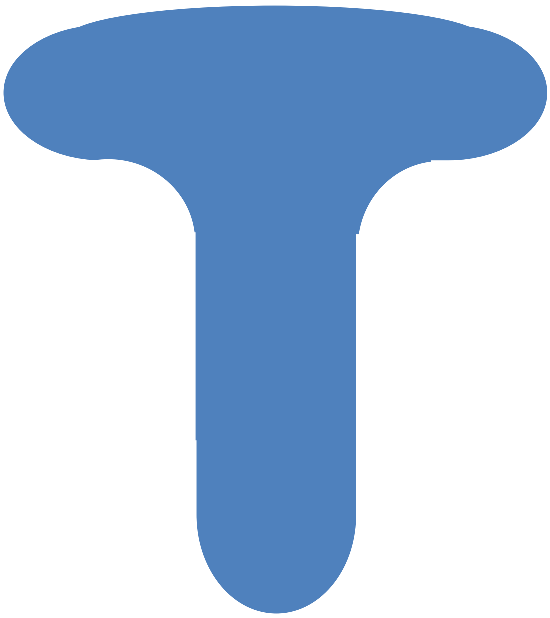
Body

Since the number of wheels is known, the design for the body can be made.
Since the vehicle has 3 wheels, it is obvious to place 2 of them on the same axis and one of them on the front or on the back. We decided to but the axis with the 2 wheels on the front, with the educated guess that the vehicle will go more straight.
There are several chapes that the body can take with 3 wheels. A few of them are summed up here:

Figuur 4 possible shapes for the body

The 2 most important factors for the choice of the shape is the drag coefficient, which is proportional with the shape of the object, and the total weight.

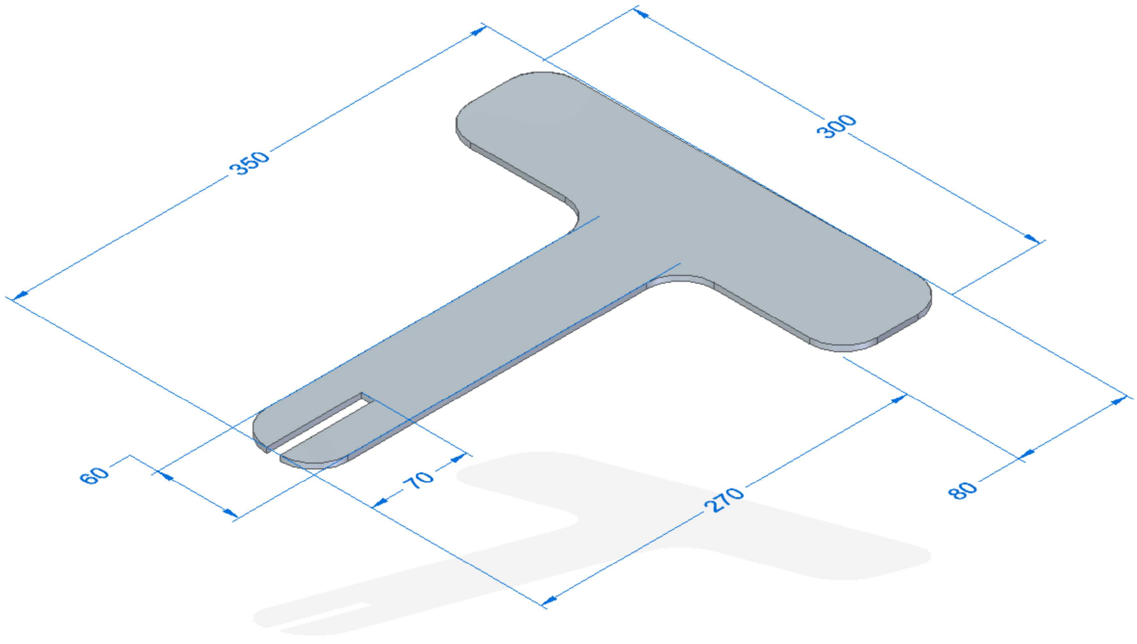
Taking both in consideration, we designed a shape that has low drag and little weight. The shape is showed here:



Figuur 5 shape for the body of the vehicle

The material of which the body is made out off will also be plexiglass. For the same reasons as the wheels, it is at hand at Fablab and easy to cut. It is light but still strong.
The thickness will be 3mm.

A simple design for the body in SolidEdge is as followed:



Figuur 6 Body of the SSV

Motor

Since the motor is given to us, we don't need to take the decision of which motor to take. The biggest decision is where to place the motor. Do we place it on the axis of the front wheels or the back wheel? Do we place it directly on the wheels or do we use gears?

The motor will be placed on the front axis, this is more reliable than placing it on the back wheel. It is fairly obvious not to place the motor directly on the wheels, we need gears to get the optimal ratio so we both have torque and top speed. The calculations for the optimal gear ratio will be discussed in chapter 2.

Collision mechanism

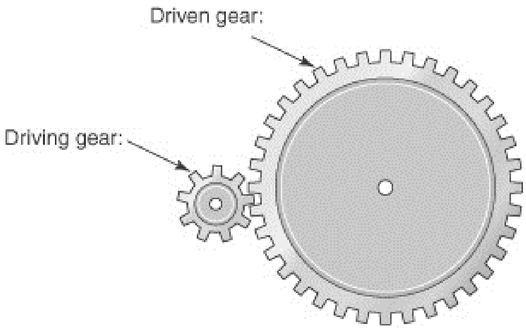
The collision mechanism isn't fully designed yet, for this is not theoretical but must be optimized with practical tests. The idea is to make some kind of shell around our vehicle, transferring the impact force to bounce of the wall in case of collision. Although the plan is to go as straight as possible, we must be prepared if the vehicle does hit the wall.

Optimal gear ratio

The gear ratio is the ratio of the gears between the drive shaft, this ratio is calculated by the following formula:

$$Gear\ Ratio = \frac{\#\,Teeth\ Driven\ Gear}{\#\,Teeth\ Driving\ Gear}$$

Where the driven gear is the gear that is driven by the other gear and the driving gear is the gear that connected directly to the motor axle.



Figuur 7 http://www.education.com/reference/article/firefighter-exam-study-guide-gear-belt-system/

To calculate the ideal gear ratio, MATLAB is used to simulate our vehicle with the characteristics of the solar panel. By simulating the race with different gear ratios we are able to determine the best gear ratio by evaluating certain factors. These factors for the simulation are estimated because we are unable to determine these factors at this given time.

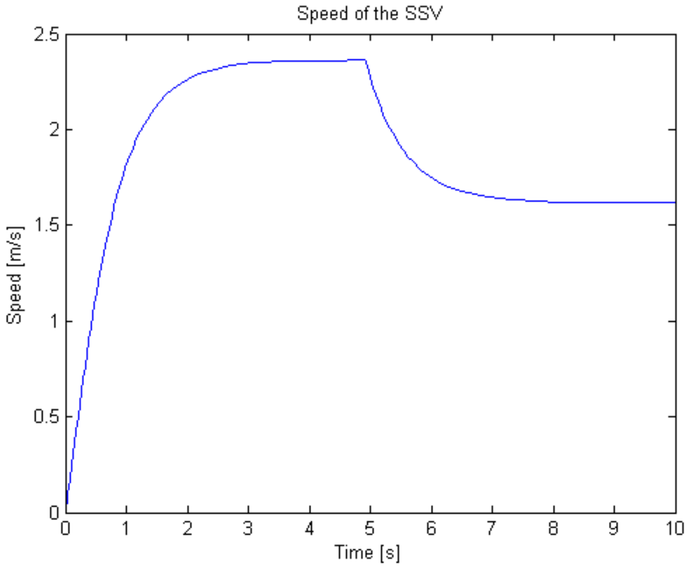
Simulating the gear ratio

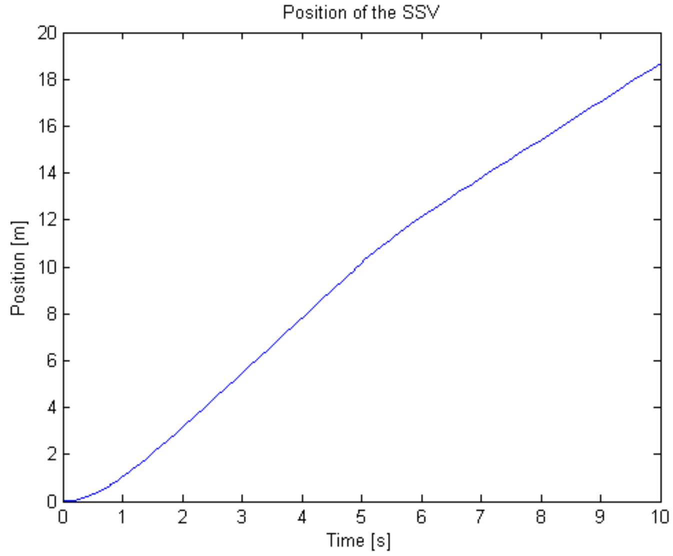
For simulating the track we use the MATLAB file that is made available for us on Toledo. The only thing that we are required to do is to fill in the required parameters and run the files. For the mass of our car we chose to make it as light as possible so chose m= 0.750 kg. Since we want to make our car somewhat aerodynamic we estimated the air resistance coefficient Cw = 0.5 and estimated the rolling resistance to be 0.012. In the design of the wheels we plan on making those 4 cm radius, this gives a parameter of 0.04 m.

After filling in these parameters it was possible for to simulate the race with different gear ratios.

This gave 2 graphs:

- Speed of the SSV
- Position of the SSV



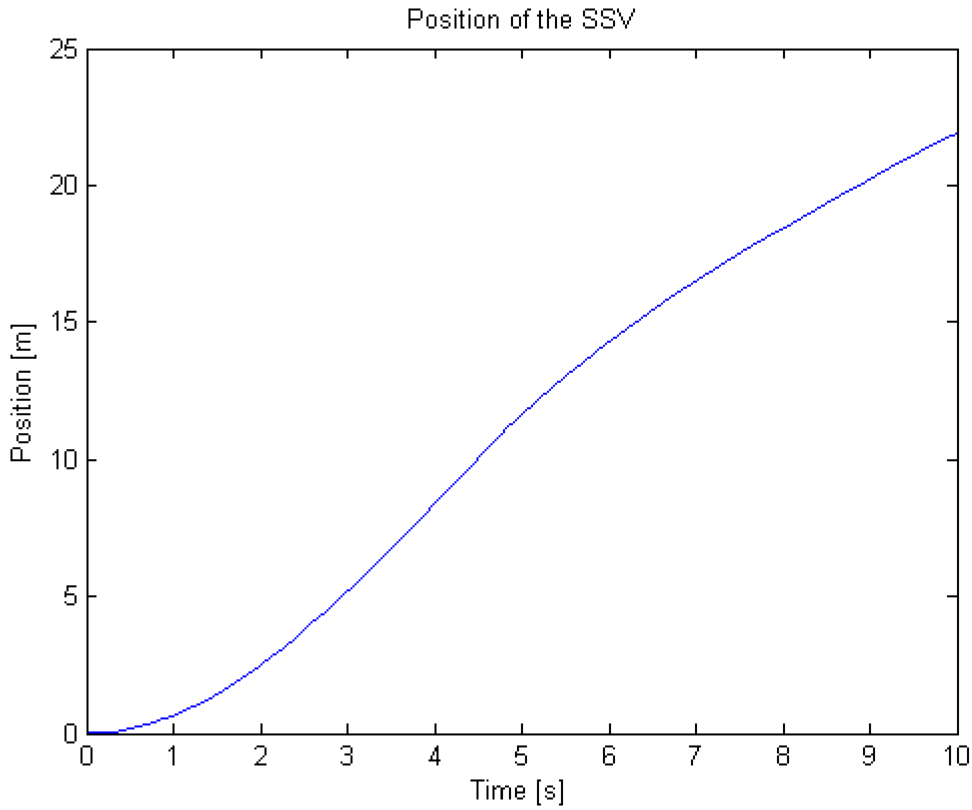


From these graphs we had to decide what gear ratio would be optimal for our SSV. We decided to go for the fastest gear ratio to reach the end distance which is 14 meter. So we redid the simulation several times, the results are in the following table:

Gear Ratio	Time (s)
1	Never
2	Never
3	7,311
4	6,344
5	5,95
5,25	5,912
5,5	5,886
5,75	5,875
6	5,88
7	6,026
8	6,315
9	6,694
10	7,122

Tabel 3 gear ratios

It's clear that a gear ratio of 5,75 is the optimal ratio to reach 14 meters in the shortest time. So we should aim to get a gear ratio around that point. The following graph shows the ideal gear ratio.



Remark: this is the ideal gear ratio without taking the gear power losses into account. If we do, our ideal gear ratio is 3.75. But we used 5.75 as gear ratio in all our calculations.

Numerical method

These calculations were necessary for two time intervals, 0.1s and 0.2s. The results for these calculations were found by substituting the equation of E(t) in the acceleration equation a(t):

$$a(t) = g(\sin(x) - \cos(x) * Crr) + \frac{I(t-1) * E(t-1)}{m * v(t-1)} - \frac{Cw * Ap * v(t-1)^2}{2 * m}$$

$$E(t) = Ce.\Phi * 60 * v(t) * \frac{gear\ ratio}{2\pi * 0.04}$$

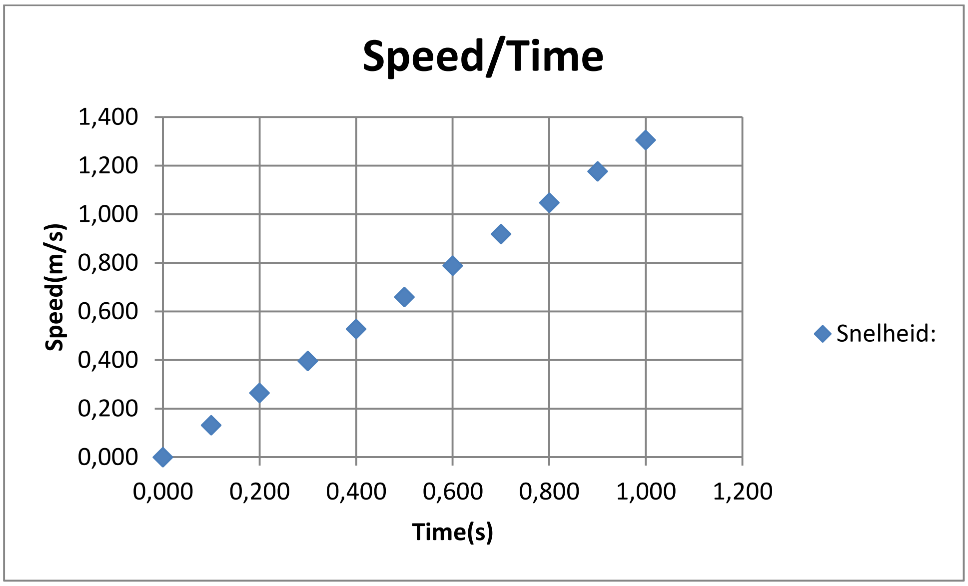
$$=> a(t) = g(\sin(x) - \cos(x) * Crr) + \frac{I(t-1) * Ce.\Phi * 60 * Gear\ Ratio}{m * 2\pi * 0.04} - \frac{Cw * Ap * v(t-1)^2}{2 * m}$$

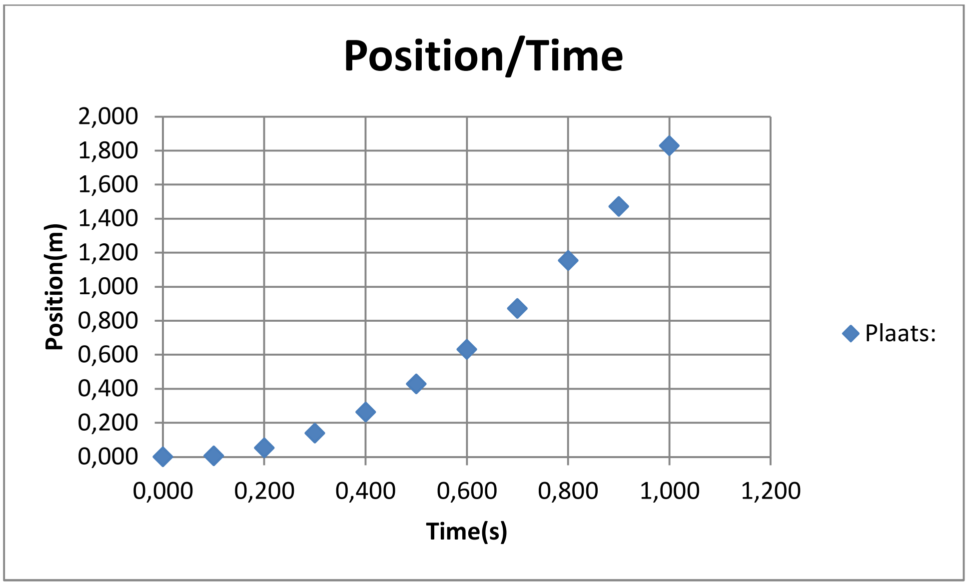
From this formula it is possible to start calculating the speed at the next time interval and position of the SSV at that point. The current was calculated using the bisection method for each interval.

This leads to the following results:

Tabel 4 Results of the calculations by hand for T=0.1s

Time (s)	Speed (m/s)	Position (m)	Current (A)	E (Voltage)	Acceleration (m/s²)
0,000	0,000	0,000	0,880000	0,000	1,320
0,100	0,132	0,007	0,879883	0,162	1,320
0,200	0,264	0,053	0,879883	0,324	1,319
0,300	0,396	0,139	0,880859	0,485	1,320
0,400	0,528	0,264	0,880859	0,647	1,319
0,500	0,659	0,429	0,878906	0,808	1,314
0,600	0,788	0,632	0,878906	0,966	1,312
0,700	0,918	0,873	0,878906	1,125	1,309
0,800	1,047	1,154	0,878906	1,284	1,306
0,900	1,176	1,472	0,879883	1,441	1,305
1,000	1,305	1,828	0,879394	1,599	1,301



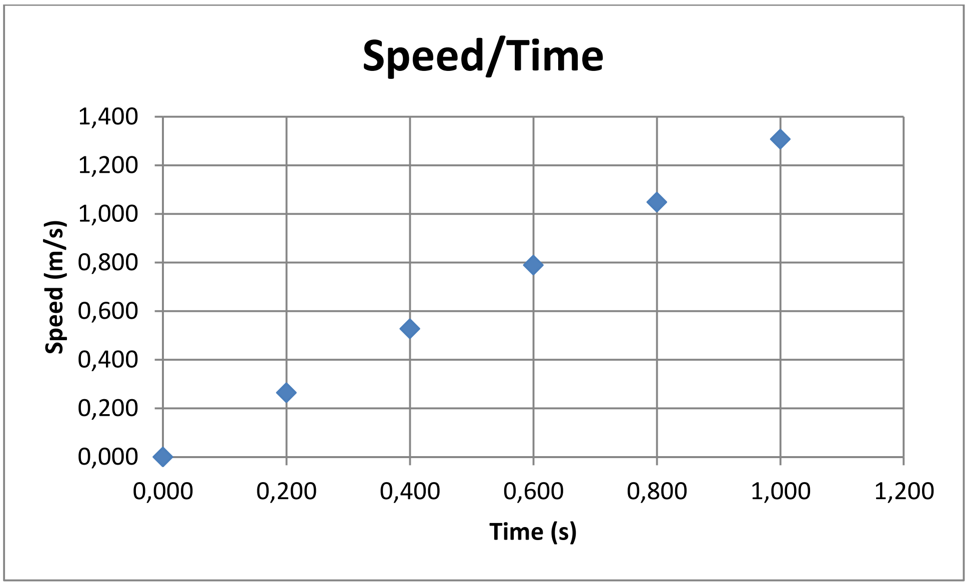


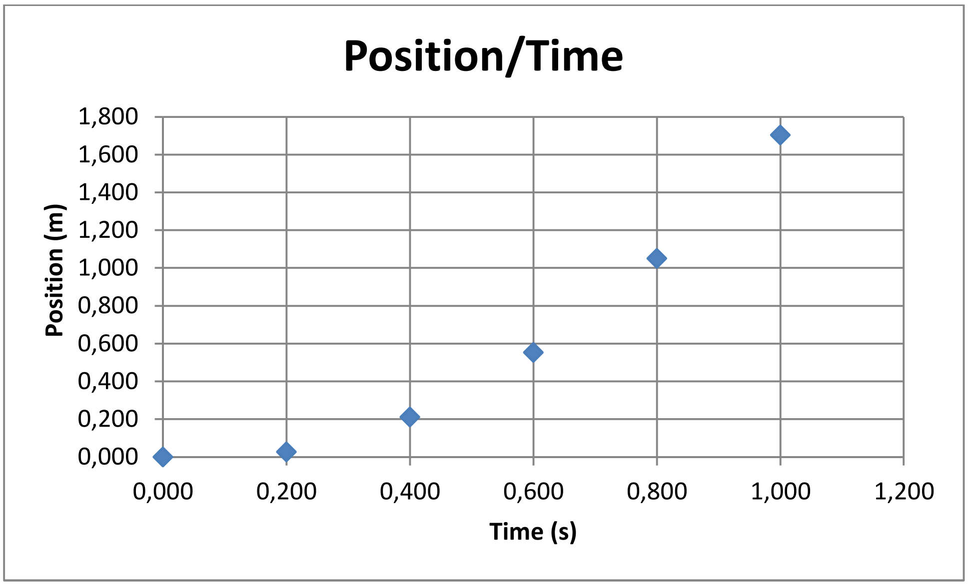
We also did the same calculations for another time interval, T=0.2s. This gave the following results:

Tabel 5 Results of the calculations by hand for T=0.2 s

Time (s)	Speed (m/s)	Position (m)	Current (A)	E (Voltage)	Acceleration (m/s)
0,000	0,000	0,000	0,880000	0,000	1,320
0,200	0,264	0,026	0,879394	0,324	1,319
0,400	0,527	0,211	0,878906	0,646	1,315
0,600	0,789	0,553	0,878906	0,967	1,312
0,800	1,049	1,051	0,879883	1,286	1,308
1,000	1,308	1,703	0,878906	1,603	1,300

If we plot these results in meaningful graphs this gives:





Between the methods there is a slight variation in values, this difference can only be a result of the bisection method since the start values of both intervals were the same. \\

Sankey diagrams

A Sankey diagram is a diagram in which the width of the arrows is shown proportionally to the flow quantity of the energy. For our SSV, we made one for the energy flow when our car is on full speed, and one when our care is driving on the halve of the maximum speed on the slope of 7.2 degrees.

Diagram 1: SSV on full speed

Data

E_{sun} = 800 W/m^2 (remark: In Belgium is the average radiation 800 W/m²)

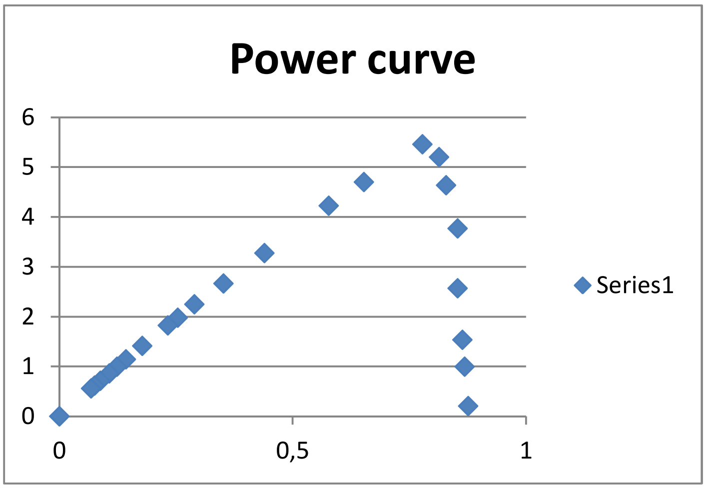
$A_{solar\ panel}$ = (0.03*0.04) * 30 = 0.036 m^2

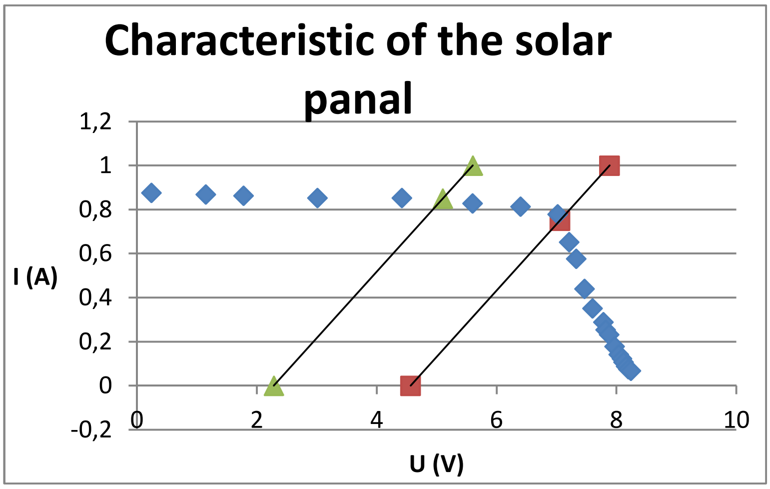
⇨ $E_{solar\ panel}$ = 0.036*800 = 28.8 W

$I_{Short\ circuit\ current}$ = 0.88 A

$U_{at\ workingpoint}$= 7.02 V

→ in the 'Power' diagram, the working point is at 0.7781A. If we put this current in the 'characteristic of the solar panel' diagram, we found $U_{workingpoint}$=7.02V





Calculations

$P_{solar\ panel\ with\ sun}$ = 0.88 * 7.02 = 6.18 W

P_{losses} = 28.8 – 6.18 = 22.62 W -> 78.55 %

$P_{coper\ losses}$ = I^2*R= (0.75)²* 3.32 = 1.87 W -> 6.50 %

$P_{rolling\ resistance}$ = m*g*C_{rr} * v_{max} = 0.750 * 9.81 *0.012 * (3.724)² = 0.33 W -> 1.14 %

$P_{air\ resistance}$ = ½ * A* C_w *v*v^2 = 0.5 * 1.2041 * 0.033 * 0.5 * (3.723)³ = 0.51 W -> 1.70 %

$P_{gear\ losses}$ = 1-0.7855 -0.017 – 0.0114 -0.065 = 0.12 W -> 12.00 %

Diagram 2: SSV on half speed on the slope

Data

E_{sun} = 800 W/m^2 (remark: In Belgium is the average radiation 800 W/m²)

$A_{solar\ panel}$ = (0.03*0.04) * 30 = 0.036 m^2

⇨ $E_{solar\ panel}$ = 0.036*800 = 28.8 W

$I_{Short\ circuit\ current}$ = 0.88 A

$U_{at\ workingpoint}$= 7.02 V →look diagram 1

Gear ratio = 5.75

Calculations

$P_{coper\ losses}$ = I^2*R= (0.85)²* 3.32 = 2.3987 W -> 8.33 %

$P_{rolling\ resistance}$ = m*g*C_{rr} * v_{max} = 0.75 * 9.81 * 0.012 * 1.862 = 0.164 W -> 0.57 %

$P_{air\ resistance}$ = ½ * A* C_w *v*v^2 = 0.5 * 0.033 * 0.5 * (1.862)³ = 0.053 W -> 0.18 %

$P_{slope\ resistance}$ = m* g* (% of slope) *v = 0.75 * 9.81 * tan(7.2) *1.862 = 1.73 W -> 6.00 %

$P_{gear\ losses}$: $P_{max\ speed}$ = T*ω ⇔T= P/ $\omega_{max\ speed}$ with

- P = 0.12*28.8 W = 3.456 W

  (the power losses because of the gear are 12% of 28.8 W at maximum speed (see diagram 1). This is 3.456 W)

- $\omega_{max\ speed/motor}$ [rpm]= 2Π*f*(60/2Π)*gear ratio
  =2Π*(speed/circumference)*(60/2Π)*gear ratio
  =2Π*(3.724/0.08Π)*(60/2Π)*5.75
  =5111.977 rpm

⇔T=3.456W/5111.977=6.76*10^-4

T remains constant → $P_{half\ speed}$=T* $\omega_{half\ speed}$ with

- $\omega_{half\ speed/motor}$ [rpm]= 2Π*f*(60/2Π)*gear ratio
  =2Π*(speed/circumference)*(60/2Π)*gear ratio
  =2Π*(1.862/0.08Π)*(60/2Π)*5.75
  =2555.989 rpm

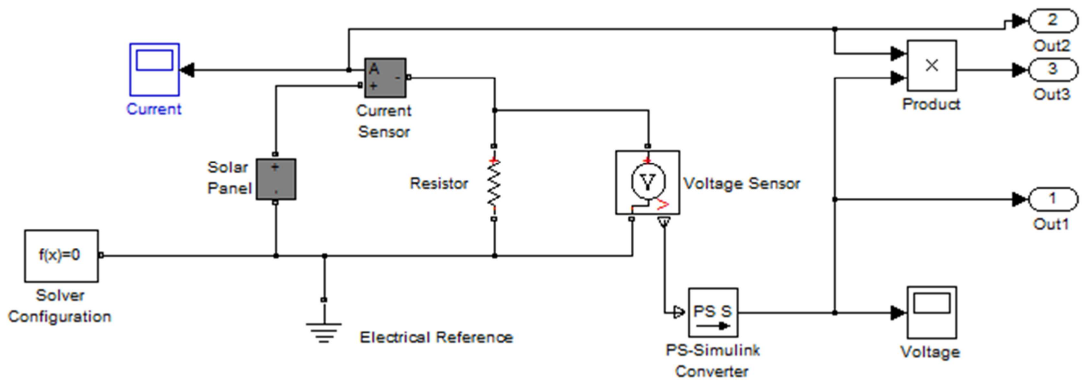
⇔ $P_{half\ speed}$=(6.76*10^-4)*2555.989

=1.73 W →6.00 %

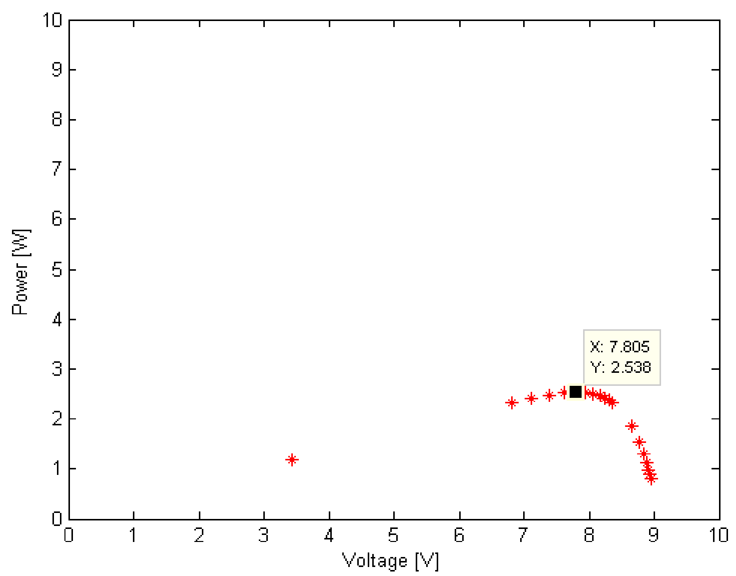
Simulink

Determine the resistor load value (10 to 100 Ohm) that makes the solar panel deliver maximum power

The overview is as followed:

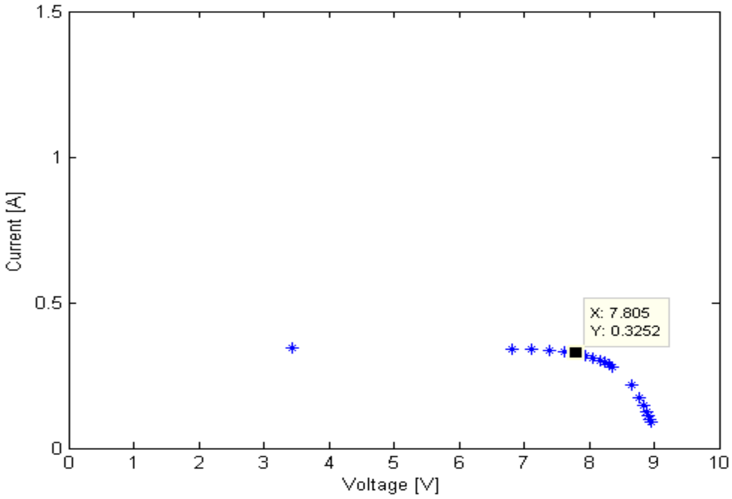


This graph shows the power in function of the voltage.



We see that the maximum power is around 2,5 Watt with a voltage of 7,8V.

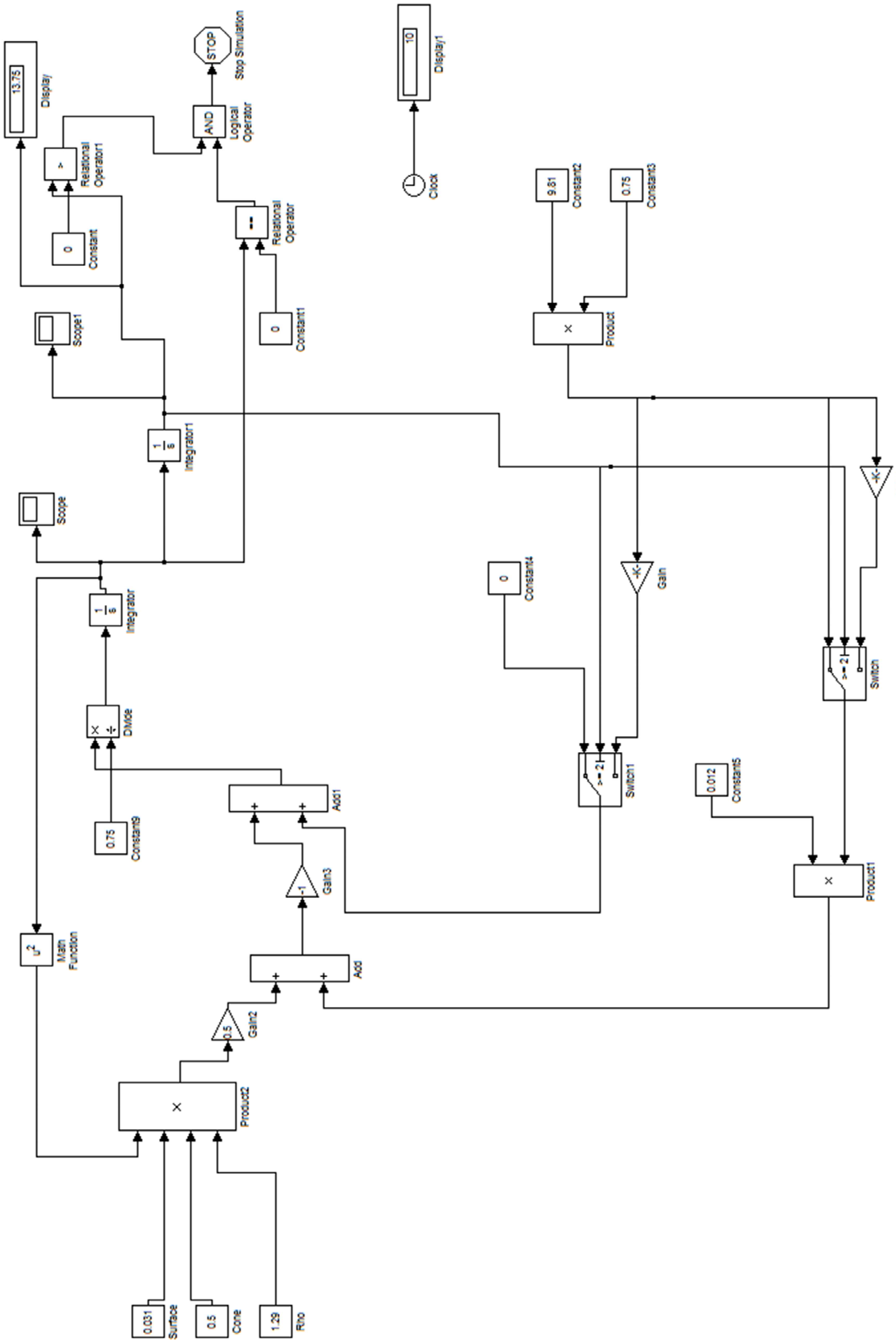
The following graph shows the current in relation to the voltage:



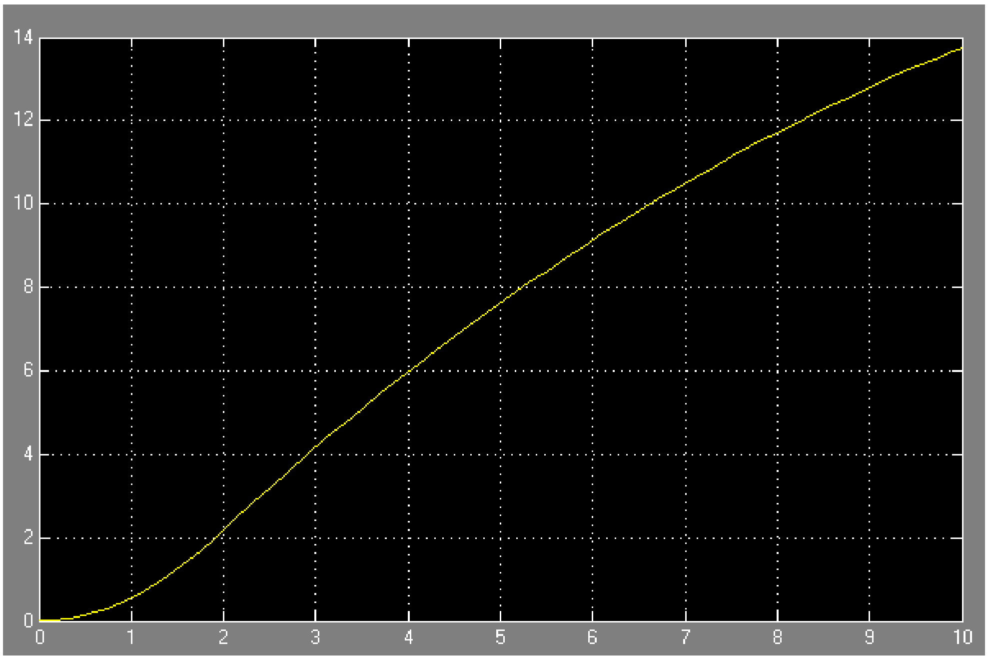
If we take a voltage of 7,8V, the current will be 0,33A. If we use Ohm's law to calculate the optimal resistor value we find 24 Ω (7.8V / 0.33A = 24Ω).

Determine the travel distance when the SVV drives down the slope

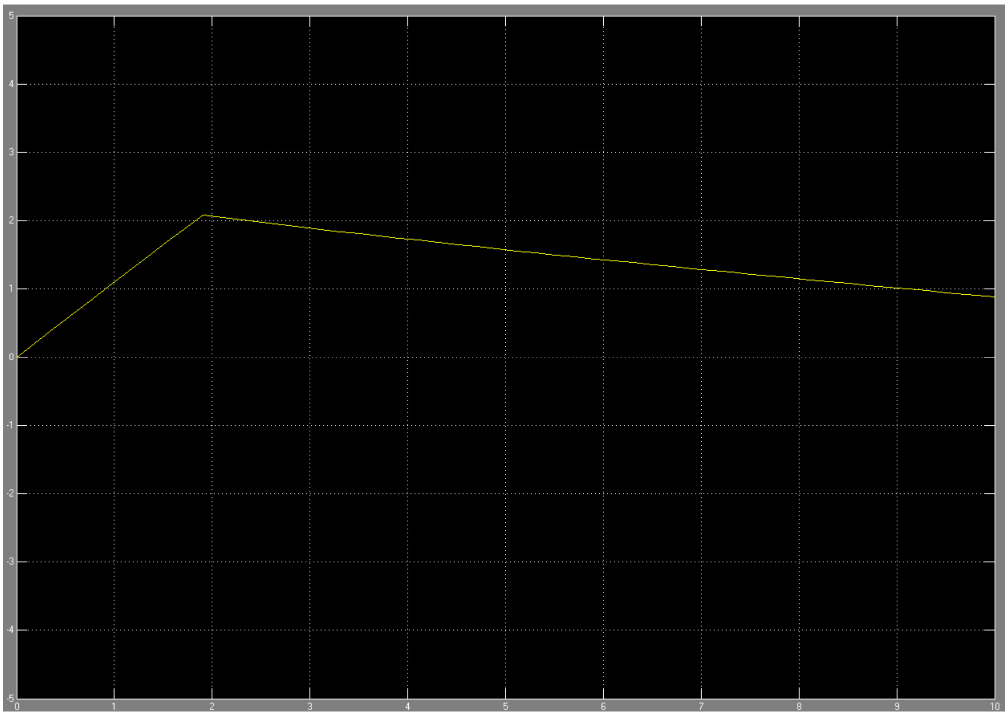
In this first overvieuw we simulate the vehicle being released from a slope of two meter.



The air resistance and the rolling resistance together with the force of the gravity on the slope are all incorporated in this simulation. The force of gravity is the reason our vehicle accelerates on the top of the slope.
If we plot this simulation we see that the vehicle rolls for 13,84m, with the 2 meter from the slope also in this distance. The plot is shown below:

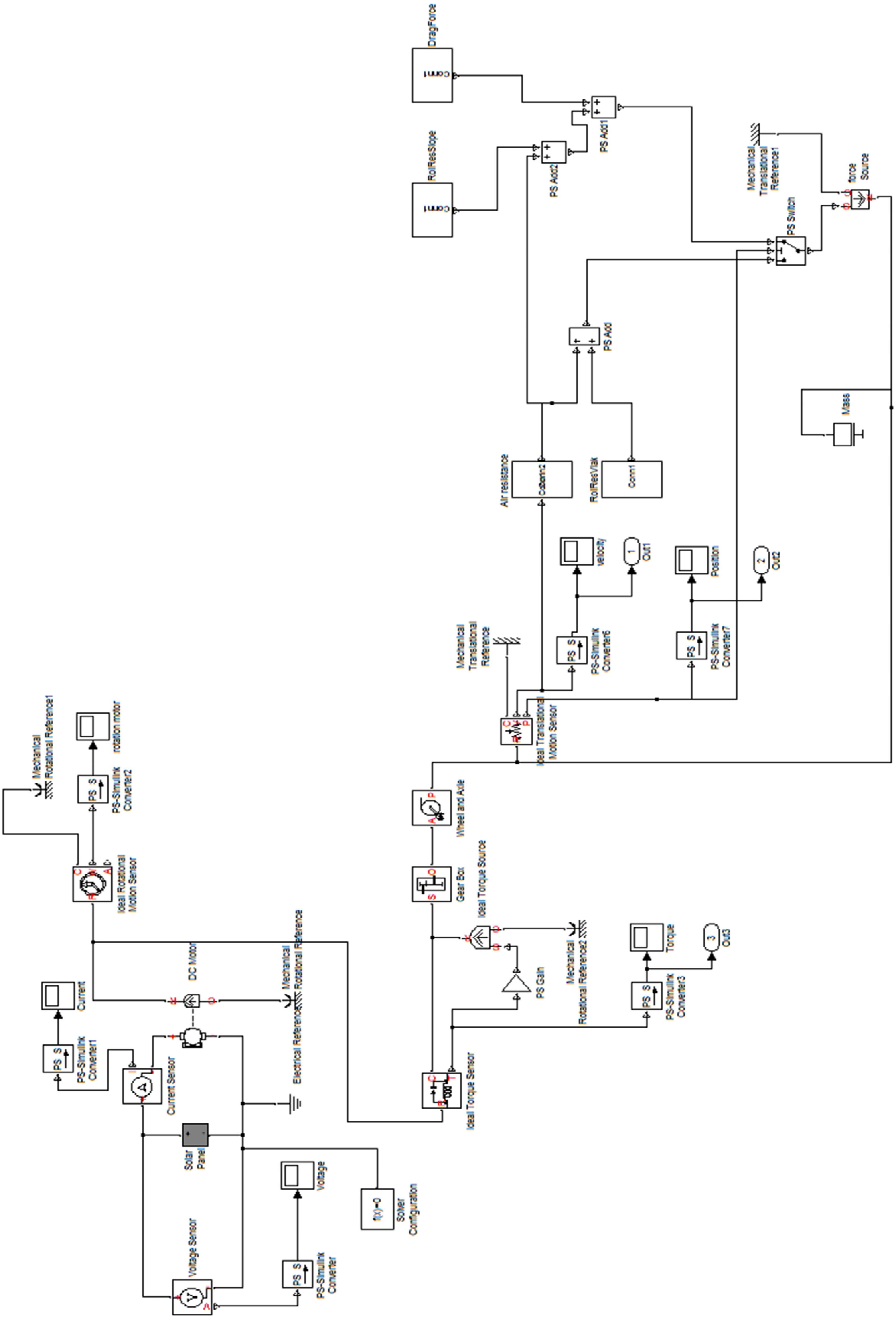


The graph showing the speed of the vehicle in relation to the time is as followed:



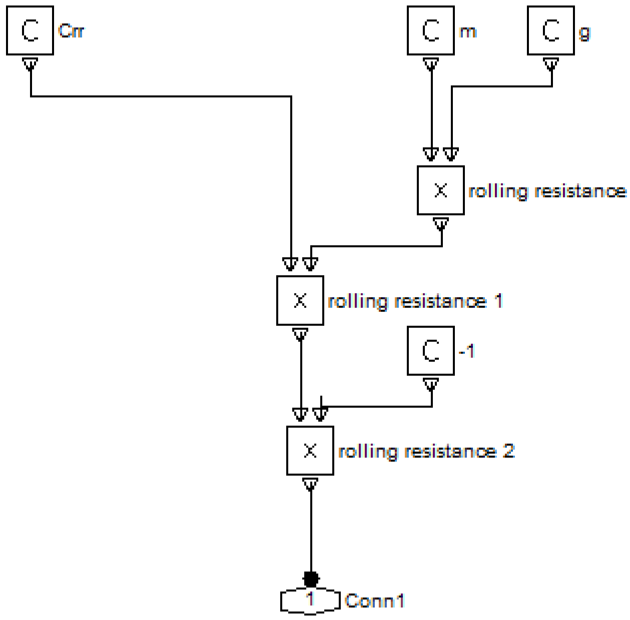
The vehicle goes faster when it descends the slope and slows down when it rolls horizontal. The maximum speed is around 2 m/s.

Simulate the race

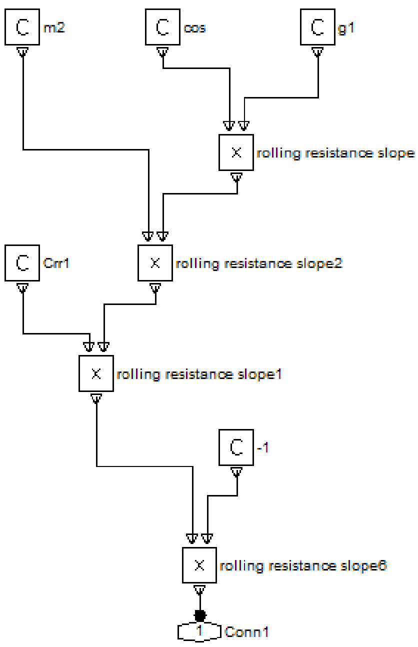


In this simulation we use 4 subsystems to keep a good overview.

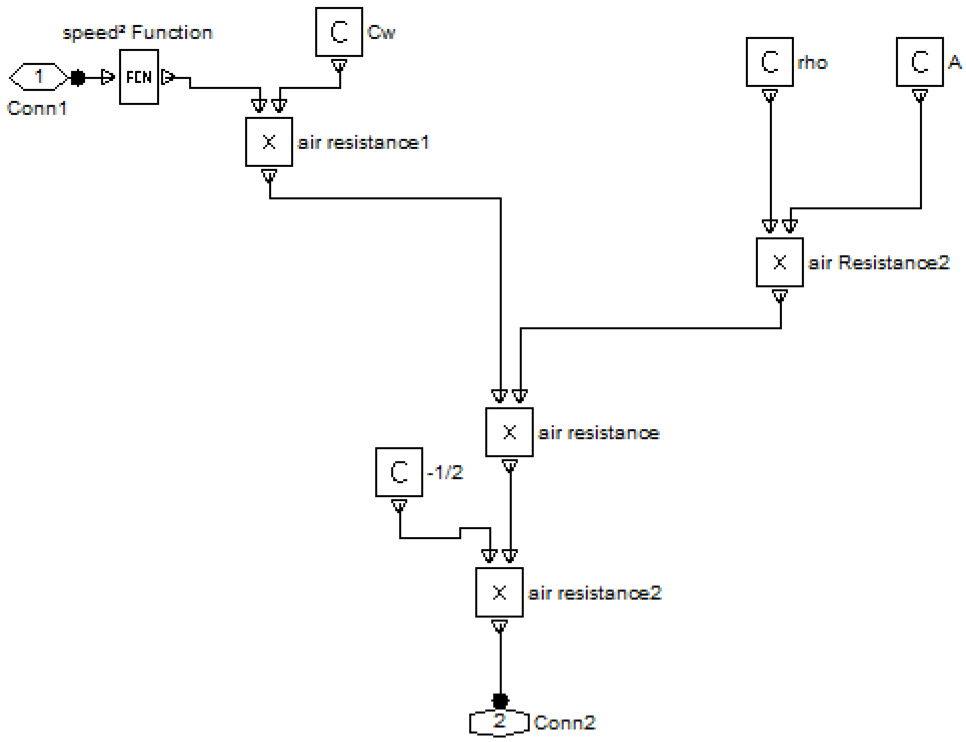
Subsystem 1: the rolling resistance for the horizontal part.



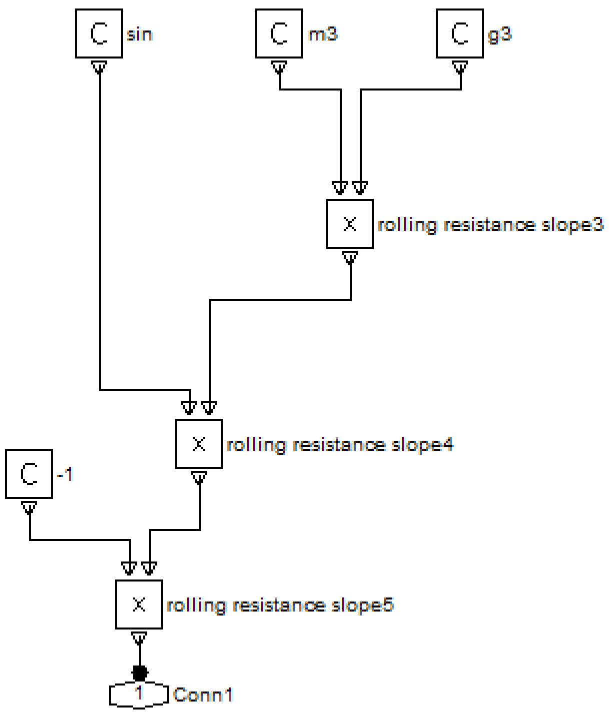
Subsystem 1: Rolling resistance on the slope



Subsysteem 3: Air-resistance.



Subsysteem 4: DragForce



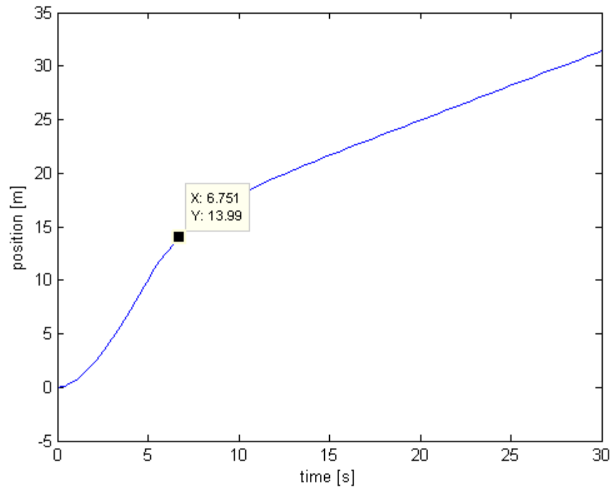
For this simulation we used several parameters that are listed below (file from MATLAB):

```
%%% Solar Power
Ir = 800;    % solar irradiance [W/m^2]
Is = 1e-8 ;    % saturation current [A]
Isc = 0.88;  % short circuit current [A]
Voc = 8.3/15;  % Open circuit voltage [V]
Ir0 = 800;  % irradiance used for measurements [W/m^2]
m = 1.1;     % diode quality factor

%%% Motor parameters
Ra = 3.32;     % ohm
Km = 0.00855;     % Nm/A
L  = 0.00022;     % H
Im = 4.10;     % g*cm^2
Cm = 2.2e-5;     % N*m/(rad/s)

efficiency = 0.84;

%%% SSV parameter
mass = 0.75 ;  % kg
Cw  = 0.5;
A   = 0.031;   % m^2
rho = 1.293;   % kg/m^3
Crr = 0.012;

%%% Wheel radius
r = 0.04; % m

%%% Track

% put parameters track here %

result=[];
tn=[];
for ratio=3:1:6
    ratio
    tn=[tn ratio];   % Extend vector with current ratio
    sim('SSV_model',30);   % Simulate Simulink model for 10 s
    [i,j]=find(yout(:,2)>14);   % find when position of 14 m is achieved
    if isempty(i)
        result = [result 30];  % if not achieved take time = 10 s
    else
        result = [result tout(i(1))];   % put travel time in vector
    end

end

figure(1)
```

For different gear ratios we get different times to finish the race. These can be found in the table below:

Gear Ratio	Time (s)
3	6.81
3.5	6.75
3.75	6.82
4	6.9
5	7.5
6	8.3

For a gear ratio of 3,5 we find the optimal time to finish the race (the shortest time that is).
The graph showing the time in relation to the distance for a gear ratio of 3,5 is shown below:



The graph showing the speed in relation the the position for a gear ratio of 3,5 can be found here: