Group M10

Report

Case SSV part I + Simulink

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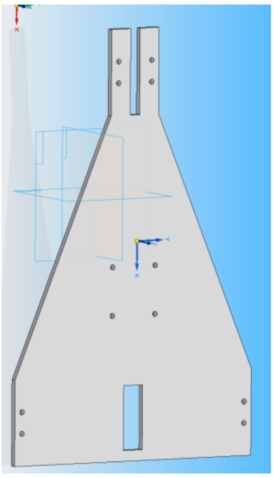
Case SSV part I

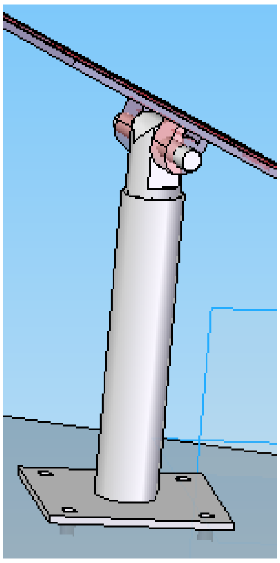
1. Design SSV

1.1 The frame and wheels



The shape of the solar frame was one of the first decisions we made. We chose for a triangular design, because it would give the best stability and still have a light weight. The opening in the front of the frame is there to attach some guiding wheels to guide the SSV on the L-profile on the track. Because of this L-profile on the track we couldn't choose three wheels, because it would destabilize the SSV since one wheel would be on the L-profile. So we decided to go with four wheels. The hole at the wider end of the frame is there for the gear that powers the main shaft. The materials of the frame and wheels will be Plexiglas. The diameter of our four wheels are eight centimeter. How bigger the wheels, how straighter our car will drive.

1.2 The solar panel attachment



The attachment of the solar panel had some demands. It had to be easy to use and there must be a way to move to solar panel to the sun, so we can use the solar cells more efficiently. There were different ways to achieve these demands: with a ball and socket joint, three variable length pipes, ...

The method we chose was something simple. Two cylinders who sit in each other, so the inner one can rotate. On top of the inner cylinder is some type of hinge with the solar panel attached to it, this will allow us to change the angle of the solar panel. This method will allow us to place our solar panel directly to the sun.

The solar panel has no cooling system on the car, but for the beginning of the race, we will keep our solar panel cool to realize maximum efficiency during the race. A ventilation system would handle for more weight and it isn't so necessary because our race isn't so long.

1.3 The motor

We have decided that our solar car will be driven by RWD, so the motor will drive the rear wheels. This should be easy to drive down the 4 meter slope and it will allow to transfer more torque to the rear wheels.

1.4 The shaft and fixation system

In our car, we have two shaft. The shafts will be will be made of steel. One who is driven by the motor and one who connects the two front wheels.
We will also use bearings to minimize the fixation. We will need a total of four bearings, one for each wheel.

1.5 The weight

The density of Plexiglas is 1,20 g/cm³.
The weight of the frame is about

$$A = \frac{30(\,20+4)}{2} = 360\ cm^2$$

$$Weight = 360\ cm^2 * 0.6\ cm * 1.2\frac{g}{cm^3} = 259{,}20\ g$$

The weight of four wheels is about

$$A = \ \pi * 4^2 = 50{,}265\ cm^2$$

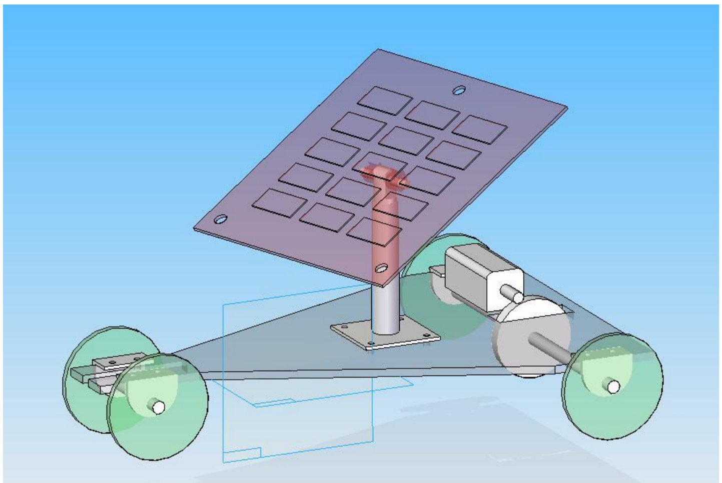
$$Weight = 4 * 50{,}265\ cm^2 * 0.4\ cm * 1.2\frac{g}{cm^3} = 96{,}51\ g$$

The weight of the solar panel is 363 g.

Let's take the weight of the bearings, the shafts and the attachment of the panel about 500 gram.

Then is the total weight of our car about

$$Total\ weight = 259{,}20\ g + 96{,}51\ g\ +\ 363\ g + 500g\ = 1218{,}71\text{g}$$

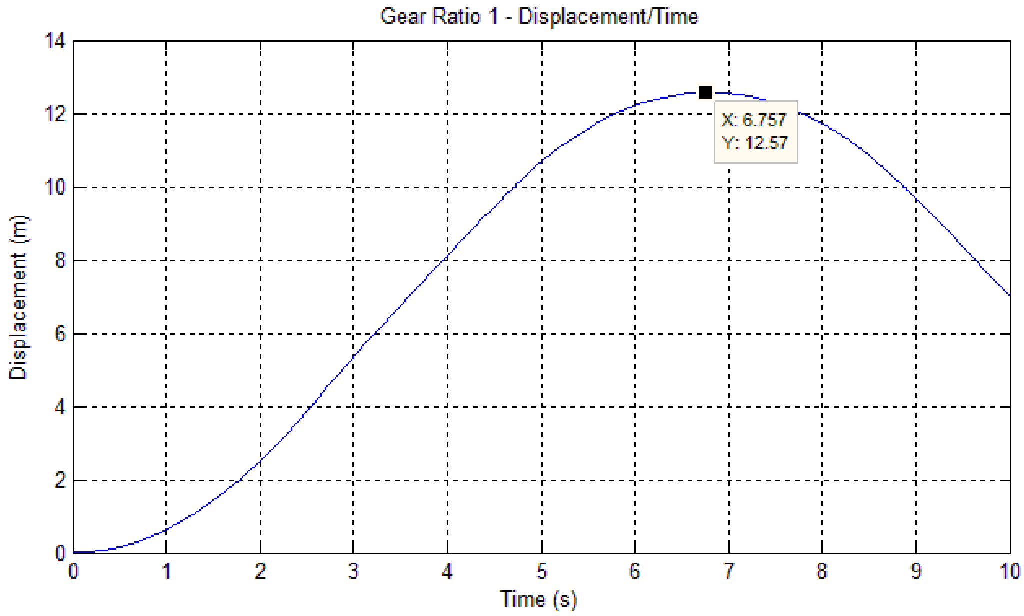


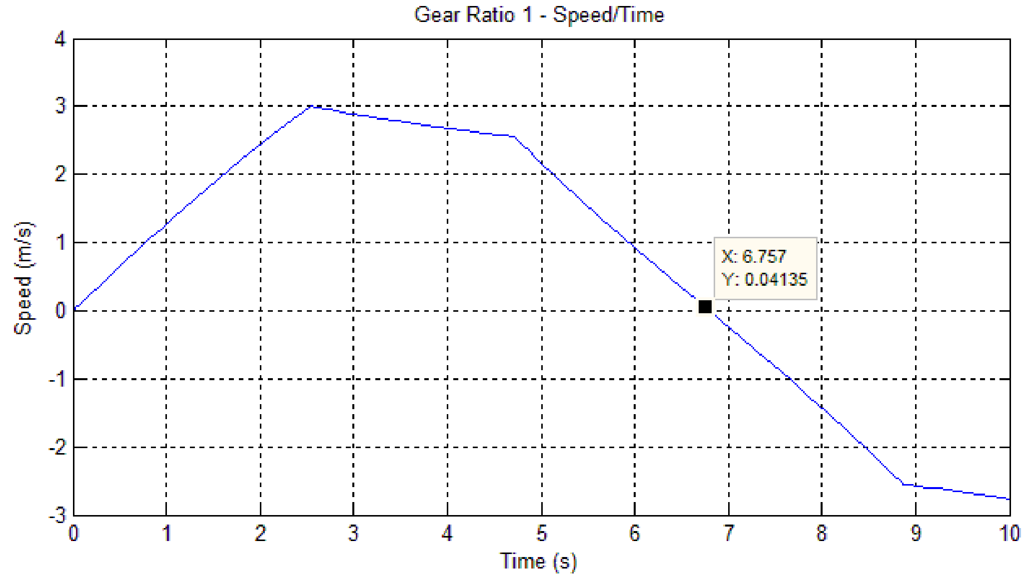
2. Calculation s for the best gear ratio

2.1 Defining optimal gear ratio using Matlab:

We used Matlab to simulate a number of different gear ratios, ten in total. We did this in order to determine the optimal gear ratio for the solar car. We've chosen 10 different gear ratios between 1 and 15. The results, together with the explanations are displayed below.

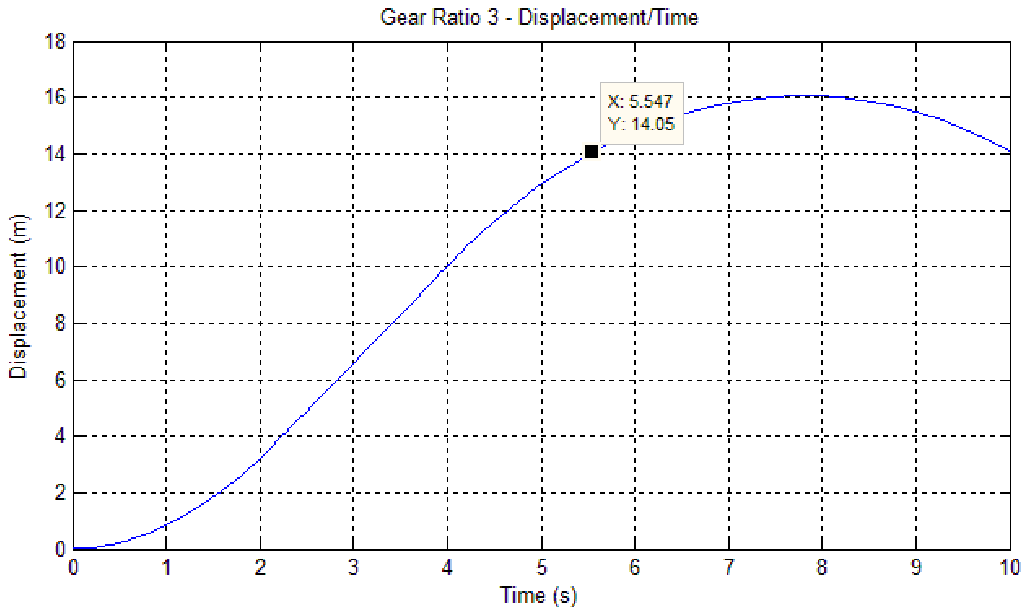
1) Gear Ratio 1

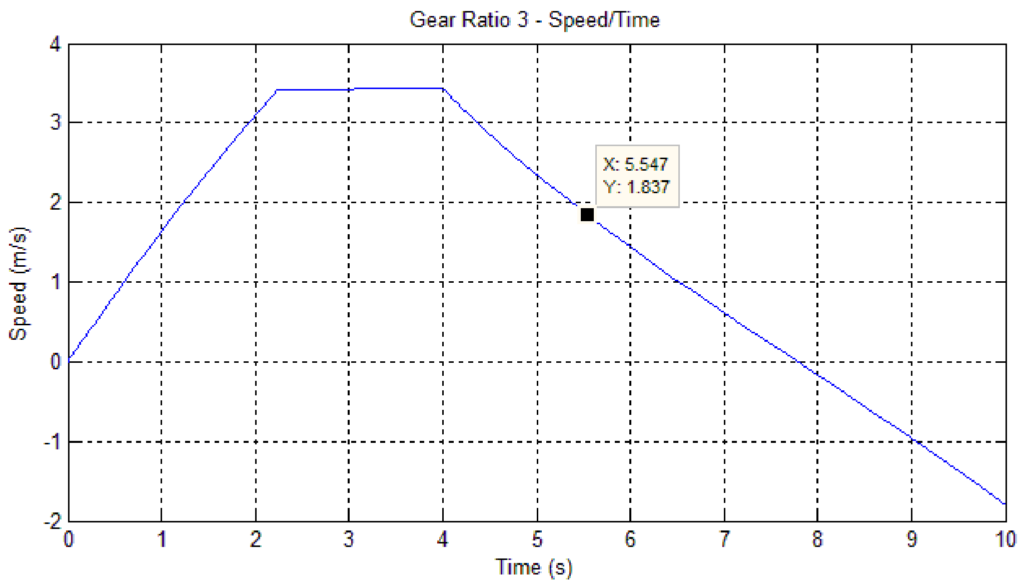




When we look at the displacement curve, we clearly see that the maximum displacement is approximately 12 meters, so with a gear ratio of 1, we won't even get to the finish.

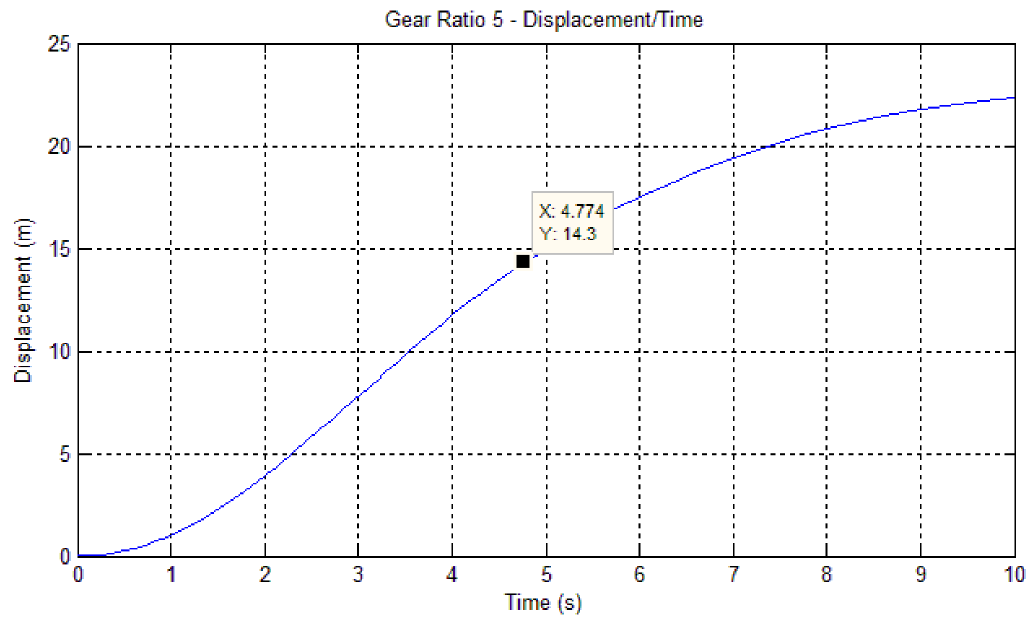
2) Gear Ratio 3

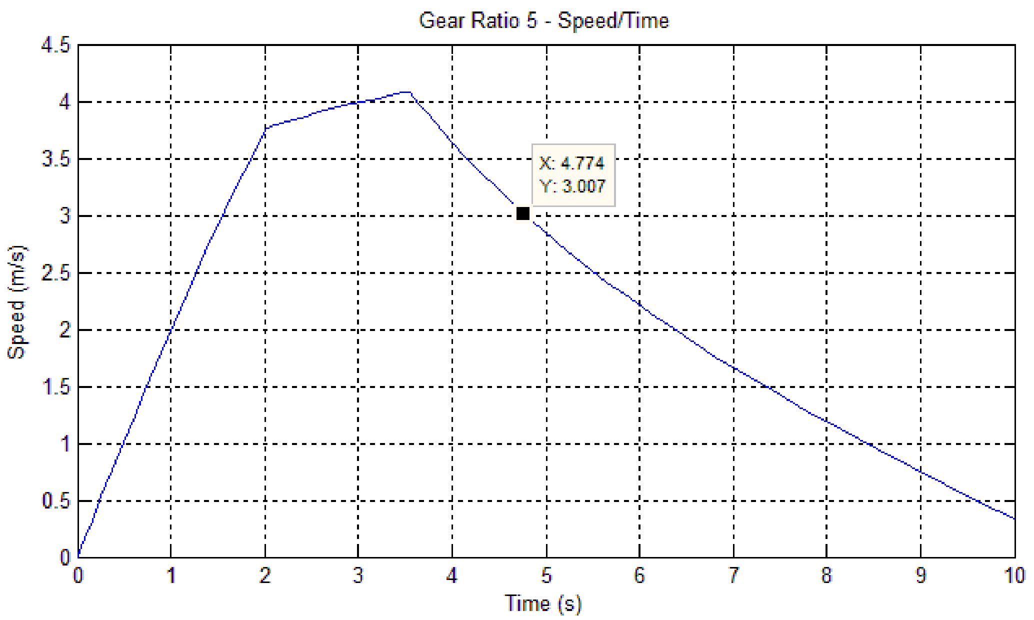




Compared to gear ratio 1, gear ratio 3 is already a little bit better, we are now able to finish (or so to speak, ride more than 14 meters). The solar car will reach the finish after about 5.55 seconds, which corresponds to an end speed of 1.84 m/s. We will now see if there are still other gear ratios, which are faster in time and speed.

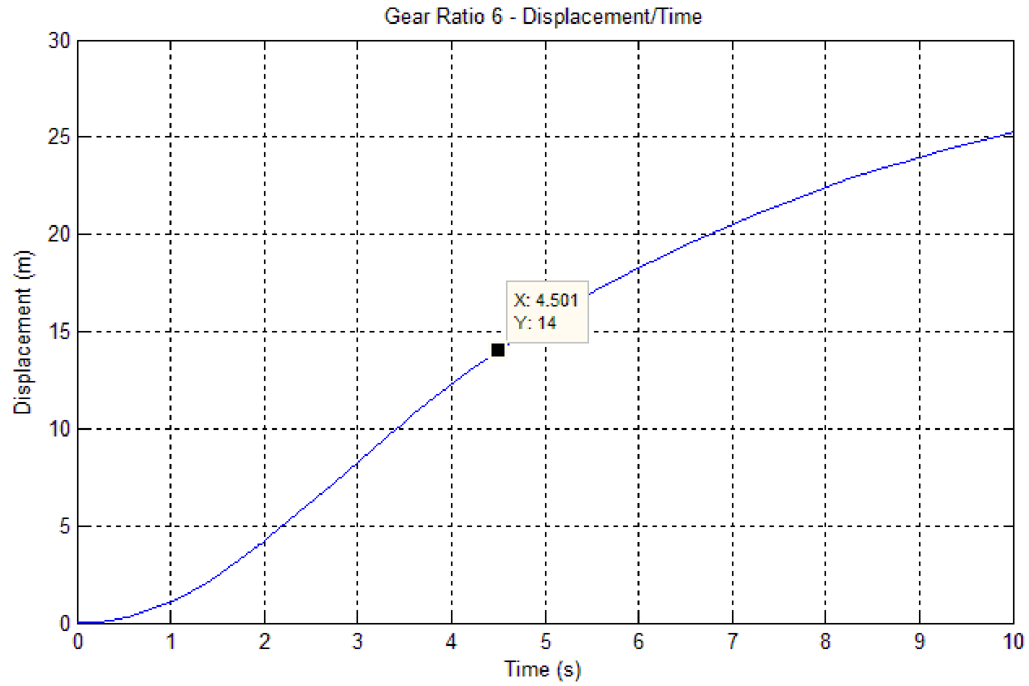
3) Gear Ratio 5

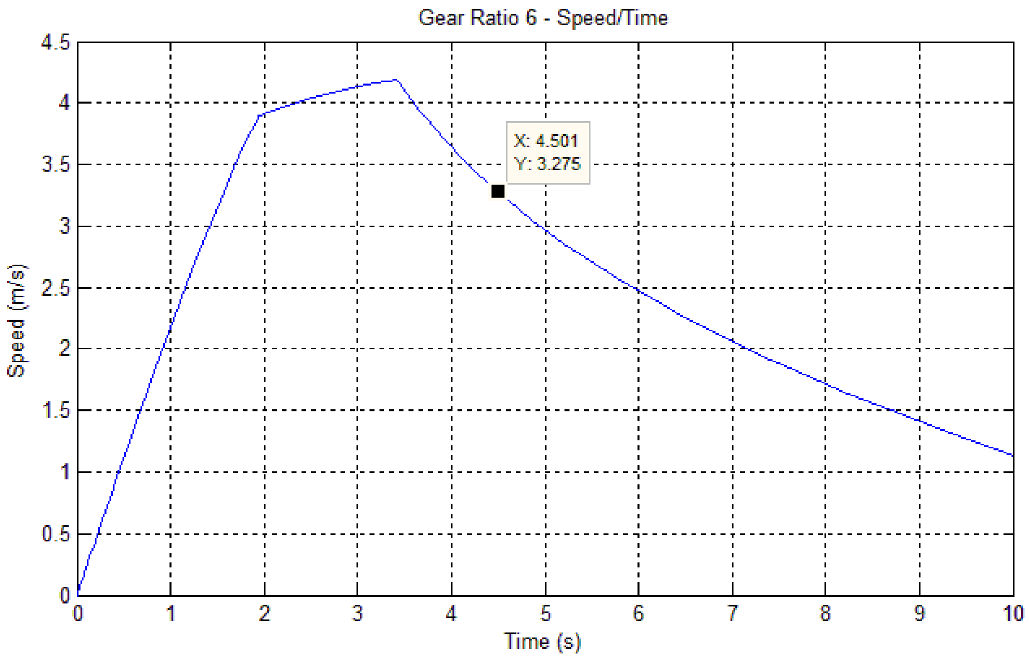




With a gear ratio of 5, the car arrives after 4.77 seconds, which is already faster than in the previous case. Also the arrival speed is much higher, namely 3 m/s, which is almost twice as much as was the case in the previous graph. We keep looking for better ratios, until these numbers are going down again.

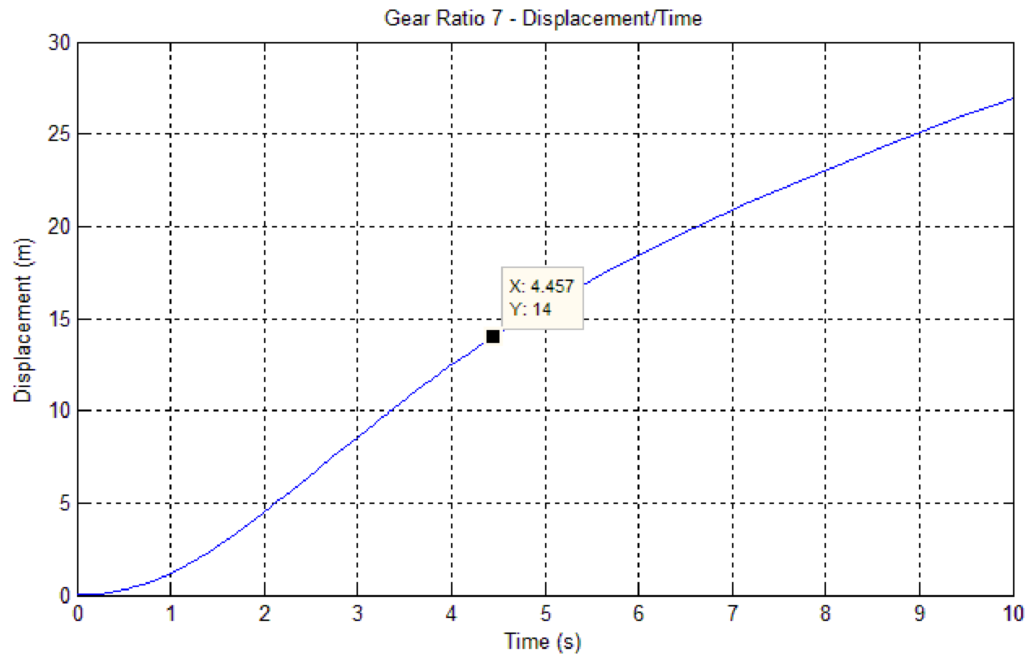
4) Gear Ratio 6

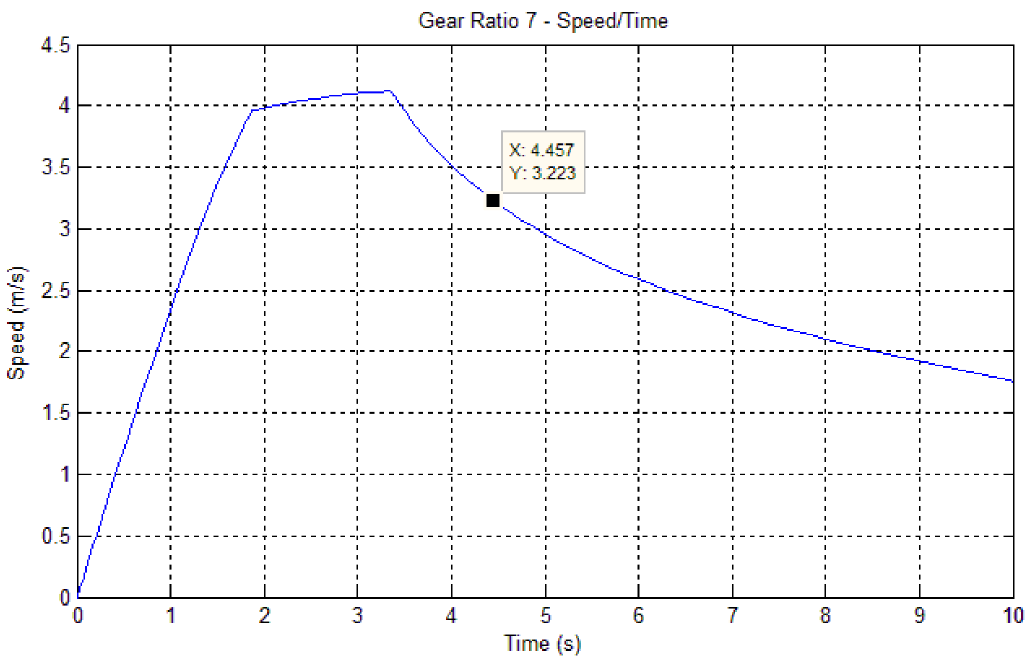




Again we can see that the numbers for gear ratio 6 have improved, with a finishing time of 4.501 seconds and an arrival speed of 3.275 m/s. So we keep increasing our gear ratio.

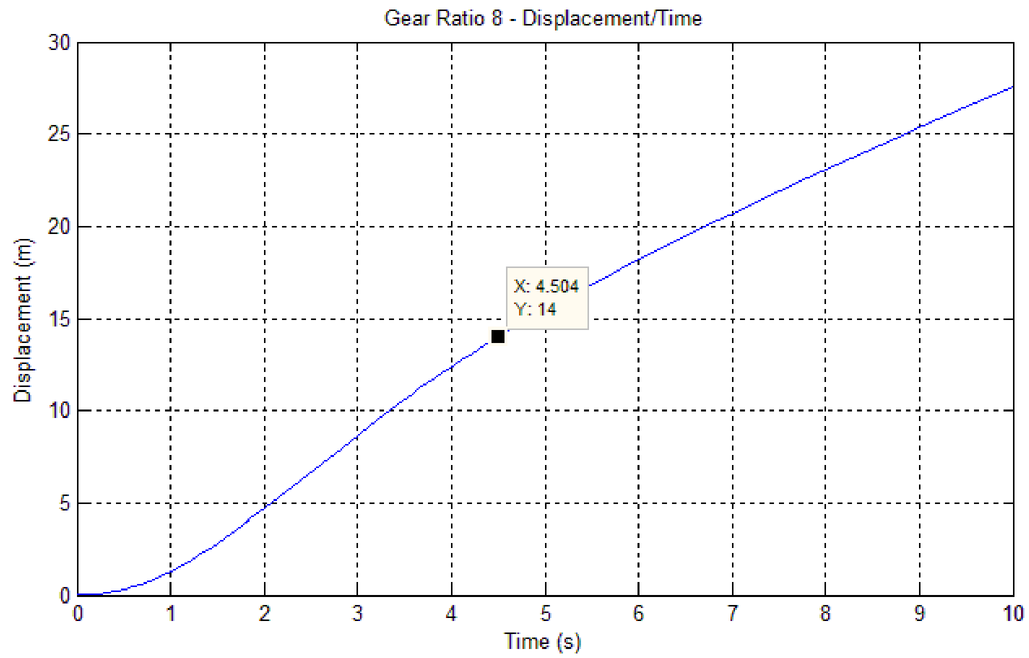
5) Gear Ratio 7

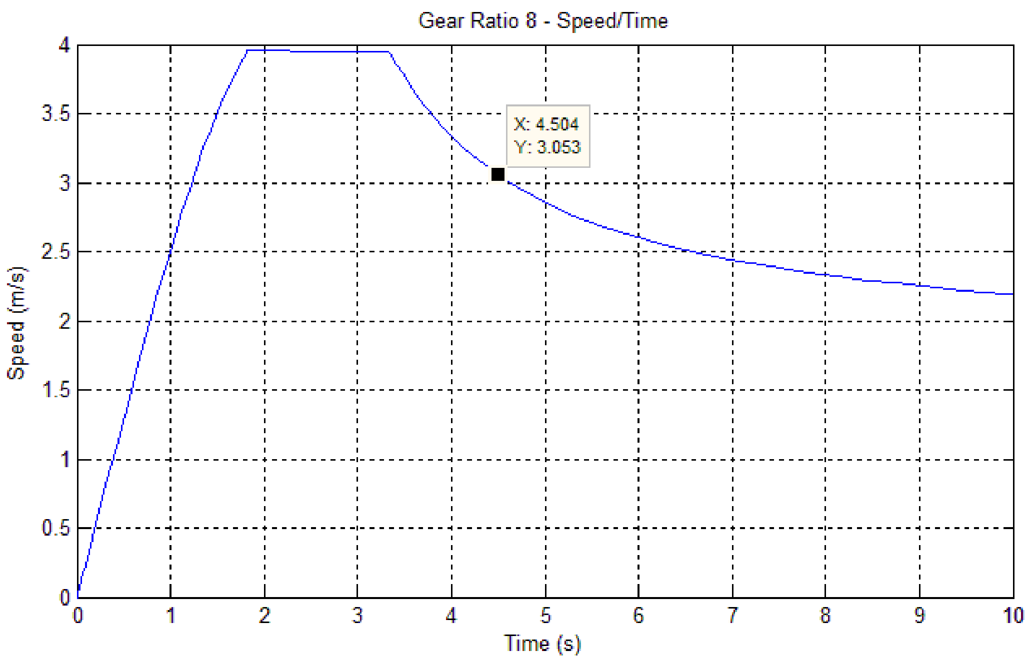




The time needed to finish is 4.457 seconds, the end speed 3.223 m/s. Remark that the time again is smaller than that of gear ratio 6. The arrival speed, on the other hand, has decreased a little bit compared to gear ratio 6. But the time is the most important factor to take into account, so the little decrease in arrival speed is negligible. When we already take a look at the next graph, we see that the time will increase again. So we can conclude that the best gear ratio for our car is 7. For this ratio our time needed to reach the finish is minimal. The results are also shown in a graph at the end of this part.

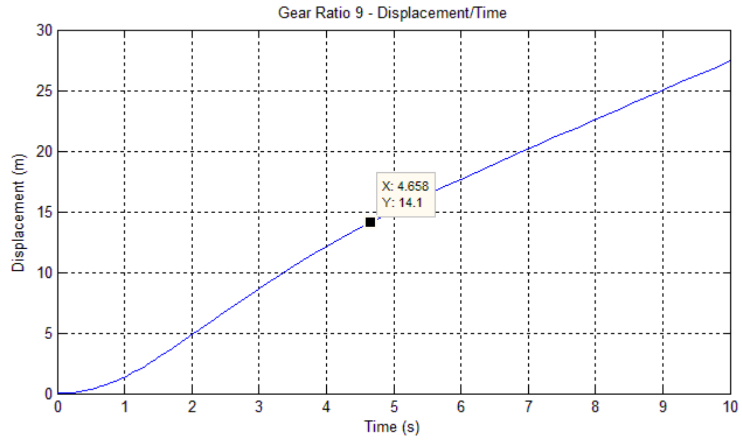
6) Gear Ratio 8

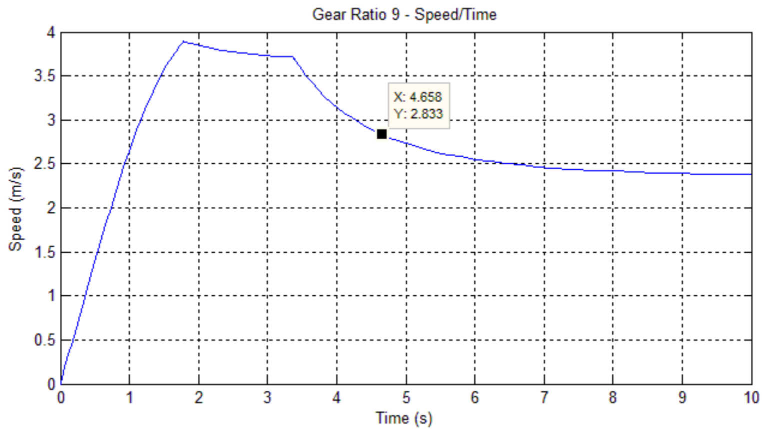




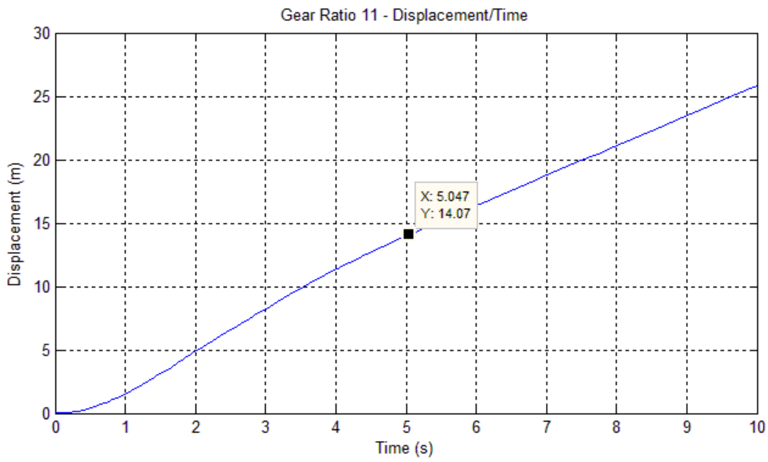
As we can see on this graph, the time needed to reach the finish starts to increase again. For gear ratio 8, this is 4.504 seconds, compared to the 4.457 seconds for gear ratio 7. From now on, the time values will keep increasing. The arrival time, on the other hand, keeps decreasing from now on. You can notice this on the following graphs.

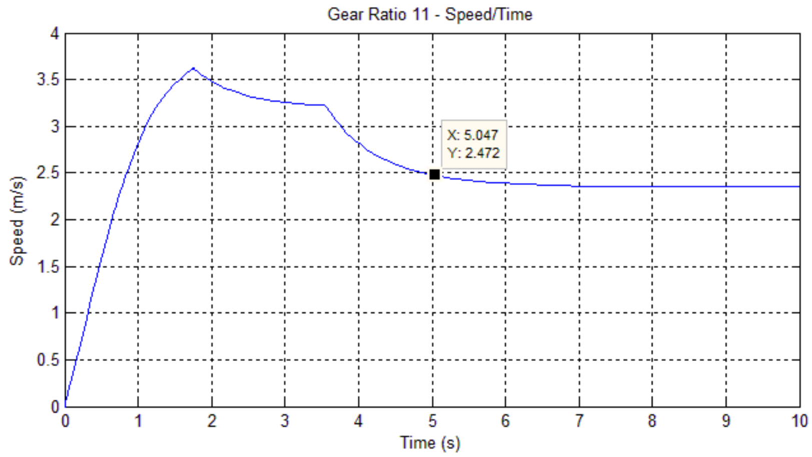
7) Gear Ratio 9



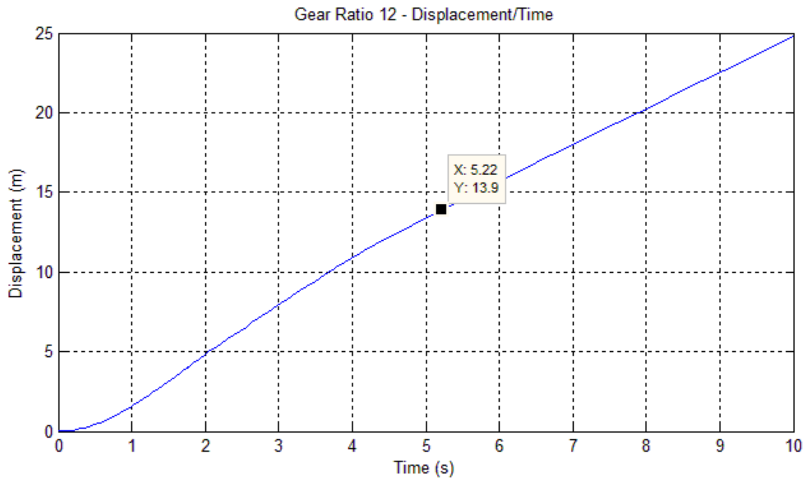


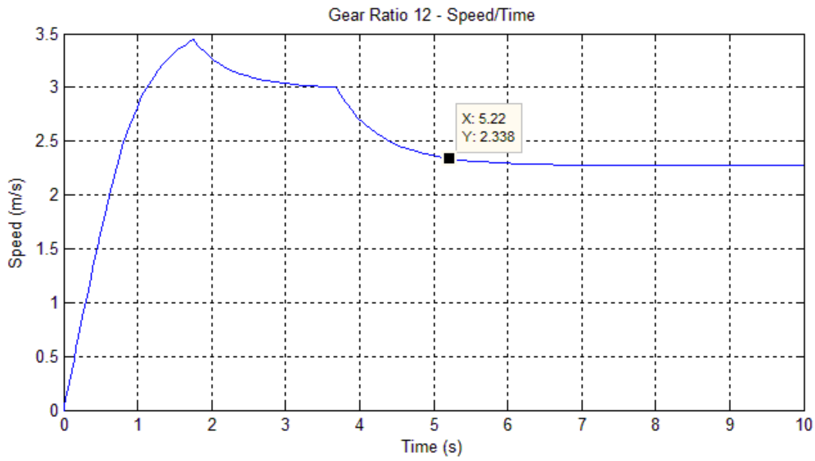
8) Gear Ratio 11



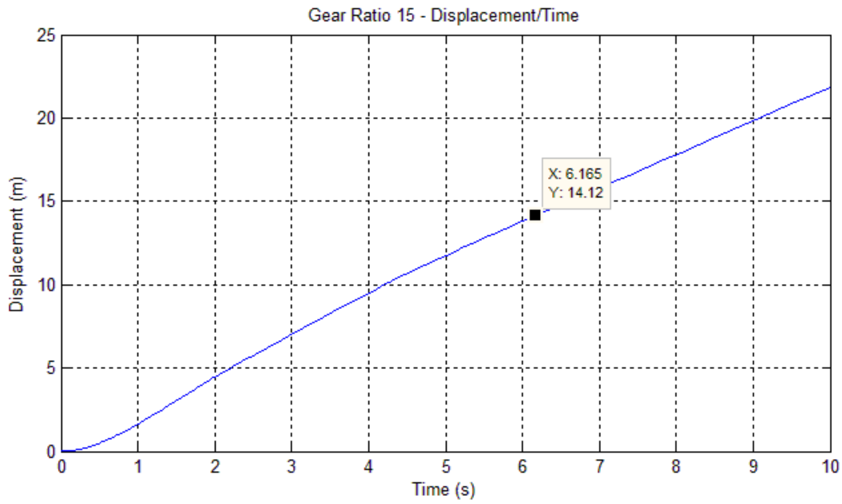


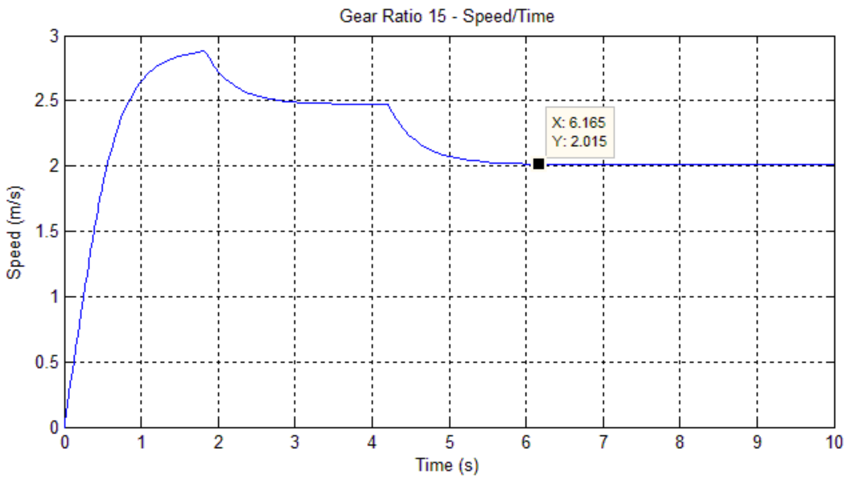
9) Gear Ratio 12





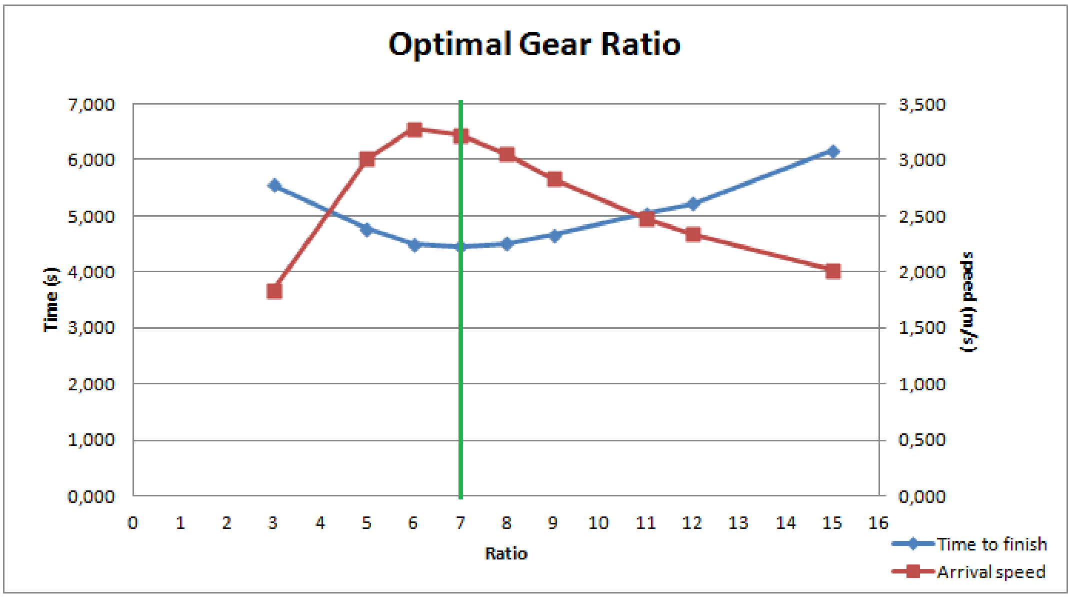
10) Gear Ratio 15





2.2 The time to reach finish line

Concluding graph



As you can see in the concluding graph, the time needed to finish is 4,46 seconds with a gear ratio of seven.

3. Practice with numerical method

We used the following data to do the calculations:

g = 9,81; angle = 0,1253278312; Crr = 0,012; Cephi = 0,00089285; r = 0,4; M = 1; Cw = 0,8; A = 0,025; *p* = 1,2041; Isc = 0,88; Is = $1*10^{-8}$; m = 1,18; N = 15; Ur = 0,0257; R = 3,32; gear = 7; T = 0,1

Here can you see a few calculations.

> POINT 1

PUNT 1

$$a0 := g*(\sin(angle)-\cos(angle)*Crr) + \frac{(0.88 \cdot Cephi*60*gear)}{2*3.14*r \cdot M};$$

$$v01 := a0*T;$$

$$s01 := 0 \cdot T + \frac{a0 \cdot T^2}{2};$$

$$E01 := Cephi*60*v01*gear/(2*3.14*r);$$

$$I01 := Isc - Is*(\exp(E01 + ((0.88*R)/(m*N*Ur)))-1);$$

$a0 := 2.423137066$ $v01 := 0.2423137066$ $s01 := 0.01211568533$ $E01 := 0.3617313415$ $I01 := 0.8799911707$

> POINT 2

PUNT 2

$$a01 := g*(\sin(angle)-\cos(angle)*Crr) + \frac{(I01 \cdot E01)}{M \cdot v01} - 3*Cw*A*p*\frac{v01^2}{2 \cdot M};$$

$$v02 := v01 + (a01 \cdot T);$$

$$s02 := s01 + v01 \cdot T + \frac{a01 \cdot T^2}{2};$$

$$E02 := Cephi*60*v02*gear/(2*3.14*r);$$

$$I02 := Isc - Is*(\exp(E02 + ((I01*R)/(m*N*Ur)))-1);$$

$a01 := 2.421002889$ $v02 := 0.4844139955$ $s02 := 0.04845207043$ $E02 := 0.7231440886$ $I02 := 0.8799873232$

> POINT 3

PUNT 3

$$a02 := g*(\sin(angle)-\cos(angle)*Crr) + \frac{(I02 \cdot E02)}{M \cdot v02} - 3*Cw*A*p*\frac{v02^2}{2 \cdot M};$$

$$v03 := v02 + (a02 \cdot T);$$

$$s03 := s02 + v02 \cdot T + \frac{a02 \cdot T^2}{2};$$

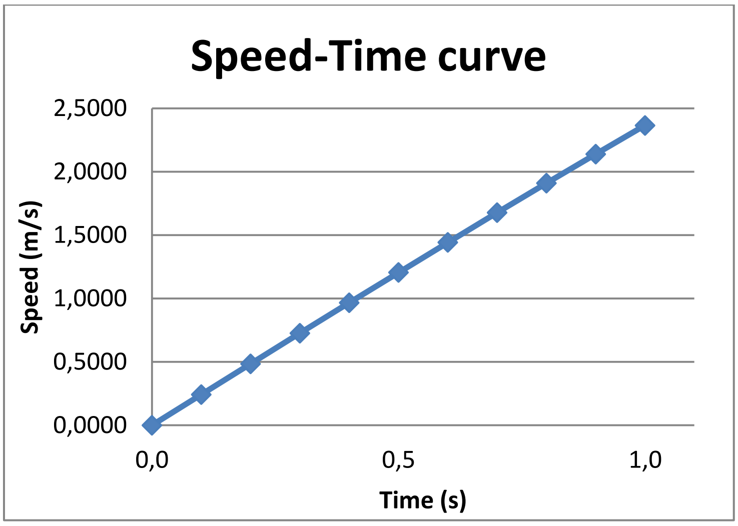
$$E03 := Cephi*60*v03*gear/(2*3.14*r);$$

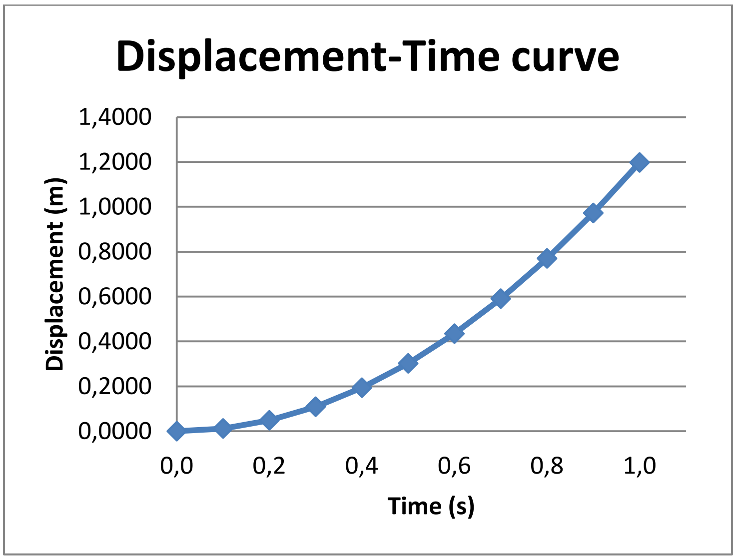
$$I03 := Isc - Is*(\exp(E03 + ((I02*R)/(m*N*Ur)))-1);$$

$a02 := 2.414641630$ $v03 := 0.7258781585$ $s03 := 0.1089666781$ $E03 := 1.083607212$ $I03 := 0.8799818177$

3.1 Situation one: time interval is 0,1 s

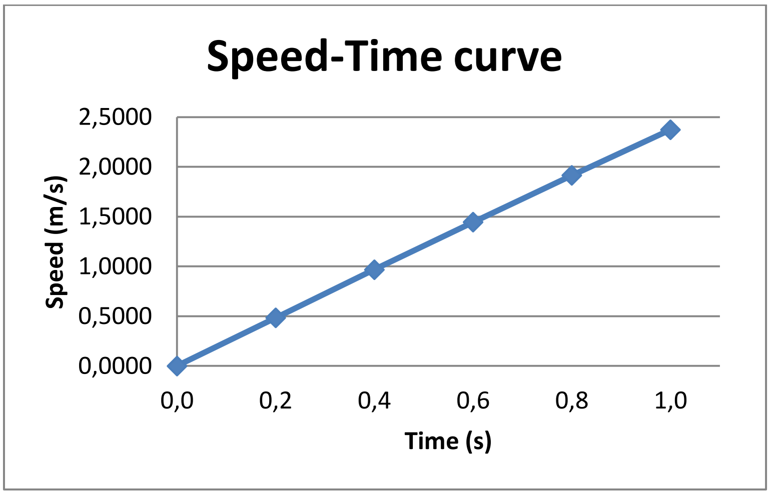
Time (s)	v (m/s)	s (m)
0,0	0,0000	0,0000
0,1	0,2423	0,0121
0,2	0,4844	0,0485
0,3	0,7259	0,1090
0,4	0,9663	0,1936
0,5	1,2052	0,3022
0,6	1,4423	0,4345
0,7	1,6771	0,5905
0,8	1,9092	0,7698
0,9	2,1383	0,9722
1,0	2,3641	1,1973

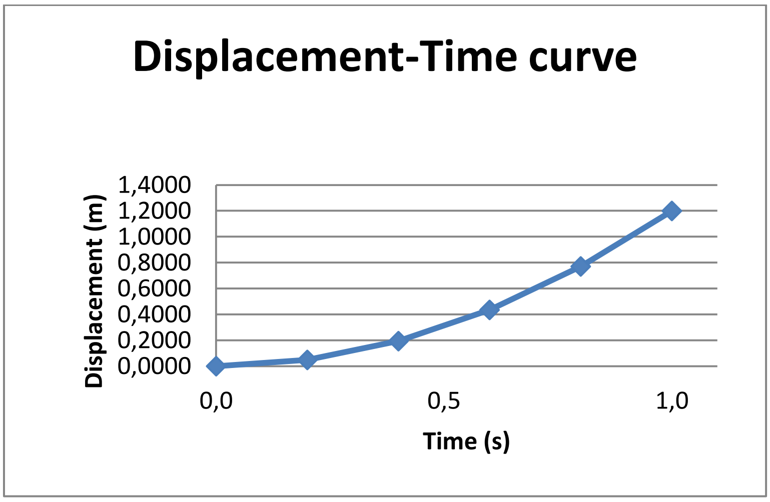




3.2 Situation two: time interval is 0,2 s

Time (s)	v (m/s)	s (m)
0,0	0,0000	0,0000
0,2	0,4846	0,0485
0,4	0,9676	0,1937
0,6	1,4454	0,4350
0,8	1,9149	0,7710
1,0	2,3730	1,1998





Conclusion:

When comparing the results (received by using a 0,1s and a 0,2s interval), a difference between them is noticeable.

The result at each moment would be exactly right if the time interval would be infinitely small. When the interval isn't infinitely small, the result will have an error. The bigger the interval if chosen, the bigger the error will be. This is also the reason why there is a difference between the results calculated with a 0,1s and a 0,2s interval.

4. Sankey diagrams

In order to create a Sankey diagram we must examine all the power gained and lost by the SSV. Firstly we assume that the race will take place at a clear sunny day. This means we can roughly assume that the solar radiation will be about 800 W/m^2.

To calculate the amount of energy gained by the Solar panel we assume that all the solar radiation that falls on the solar panel is absorbed as energy. Our solar panel has an area of $0.04m^2$. Thus:

$$P = 0.04 \times 800 = 32W$$

4.1 Condition one: SSV reaches 4m

To see how much of this energy is actually used to power the SSV and how much of it is lost, we can calculate this by Current and Voltage. We can calculate these starting from the velocity of the SSV. As requested by our professor we will do this for two cases. Firstly at the 4m mark(where the car reaches the flat part) and secondly at maximum velocity (just while starting on the hill). In the first case we have a velocity of $3.964ms^{-1}$.These values are gained from our Matlab simulation. This value can be used to gain the angular velocity.

$$\frac{3.964}{0.04} = 99.1\, rads^{-1}$$

From here we can find the angular velocity of the motor by using the gear ratio. Our gear ratio is 7.

$$99.1 * 7 = 693.7rads^{-1}$$

From here we can find our back EMF

$$E = 0.0085 \times 693.7 = 5.9V$$

With these values we only have one unknown in our characteristic equation being I. We solved this iteratively in maple for both cases gaining the following value:

$$I_{Case\ 1} = 0.715A$$

From here we can then gain the Voltage:

$$U = 3.32 \times 0.715 + 5.9 = 8.2738V$$

Thus the power for the solar panel for the first case:

$$P = 0.715 \times 8.27 = 5.92W$$

This means that the solar panel has the following efficiency:

$$\frac{5.92}{32} \times 100 = 18.5\%$$

This means we have 5.92W available to us. However there are other losses such as air resistance, road resistance loss in transmissions of gears and the motor. The motor has a maximum efficiency of 86% thus:

$$P_{MLoss} = 0.14 \times 5.92 = 0.82W$$

This means we only have 5.1W of energy still available to us and there is a loss of about 2.5% on total power. There is also a loss in gear transmission we estimate this to be about 20%.

$$P_{GLoss} = 0.20 \times 5.1 = 1.02W$$

This leaves us with a remaining power of 4.08W. In addition there is the road resistance as follows:

$$F = 0.008 \times 1 \times 9.81 = 0.078N$$

This leads to the counter torque on the axis:

$$T = 0.078 \times 0.04 = 0.0031Nm$$

Leading to P_{loss}:

$$P_{RLoss} 0.0031 \times 99.1 = 0.3W$$

Additionally there is air friction:

$$Flw = 0.025 \times 0.4 \times 3.964^2 \times \frac{1}{2} 1.204 = 0.095N$$

$$T = 0.095 \times 0.04 = 0.0038Nm$$

$$P = 0.0038 \times 99.1 = 0.37W$$

This is 2.9% of the total energy. This leaves us with a Net Power off:

$$P_{net} = 32 - 26.08 - 0.82 - 1.02 - 0.3 - 0.37 = 3.41W$$

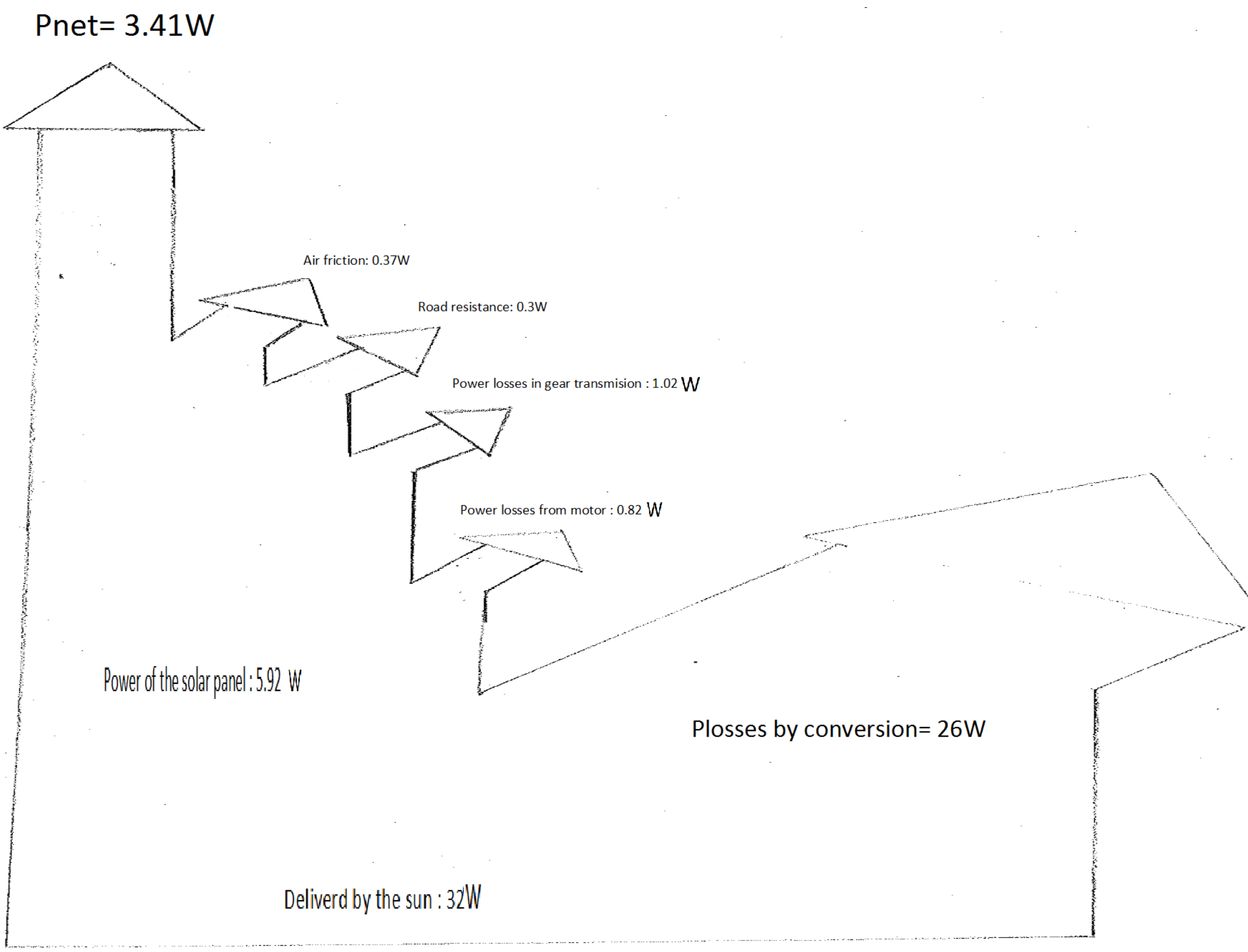


Figure 1: Sankey diagram: SSV reaches 4m

4.2 Condition two: SSV reaches its maximum speed

As our maximum speed we have $4.121ms^{-1}$. Using the same methods as in case 1 gave the following results for Case 2:

$$I_{Case\ 2} = 0.633A$$

$$\frac{4.121}{0.04} = 103.025\ rads^{-1}$$

Angular velocity of the motor:

$$103.025 * 7 = 721.175 rads^{-1}$$

From here we can find our back EMF :

$$E = 0.0085 \times 721.175 = 6.12V$$

From here we can then gain the Voltage:

$$U = 3.32 \times 0.633 + 6.12 = 8.22V$$

Thus the Power for the solar panel for the second case:

$$P = 0.633 \times 8.22 = 5.20W$$

This means that the solar panel has the following efficiency:

$$\frac{5.2}{32} \times 100 = 16.25\%$$

Power loss of the motor:

$$P_{MLoss} = 0.14 \times 5.2 = 0.728W$$

This is a loss of about a 2.2% on the total power. Loss in gear transmission:

$$P_{GLoss} = 0.20 \times 4.47 = 0.89W$$

This leaves us with a remaining power of 3.58W. Road resistance:

$$F = 0.008 \times 1 \times 9.81 = 0.078N$$

This leads to the counter torque on the axis:

$$T = 0.078 \times 0.04 = 0.0031Nm$$

Leading to P_{loss}:

$$P_{RLoss} 0.0031 \times 99.1 = 0.3W$$

Additionally there is air friction:

$$Flw = 0.025 \times 0.4 \times 4.121^2 \times \frac{1}{2} 1.204 = 0.102N$$

$$T = 0.102 \times 0.04 = 0.0041Nm$$

$$P = 0.0041 \times 99.1 = 0.41W$$

This leaves us with a Net Power off:

$$P_{net} = 32 - 26.8 - 0.728 - 0.89 - 0.3 - 0.41 = 2.87W$$

Normally this should be 0 to be at maximum speed but because we consider de SSV as a point not a body in these calculation the actual point of maximum speed will be somewhere in between before the hill and on the hill.

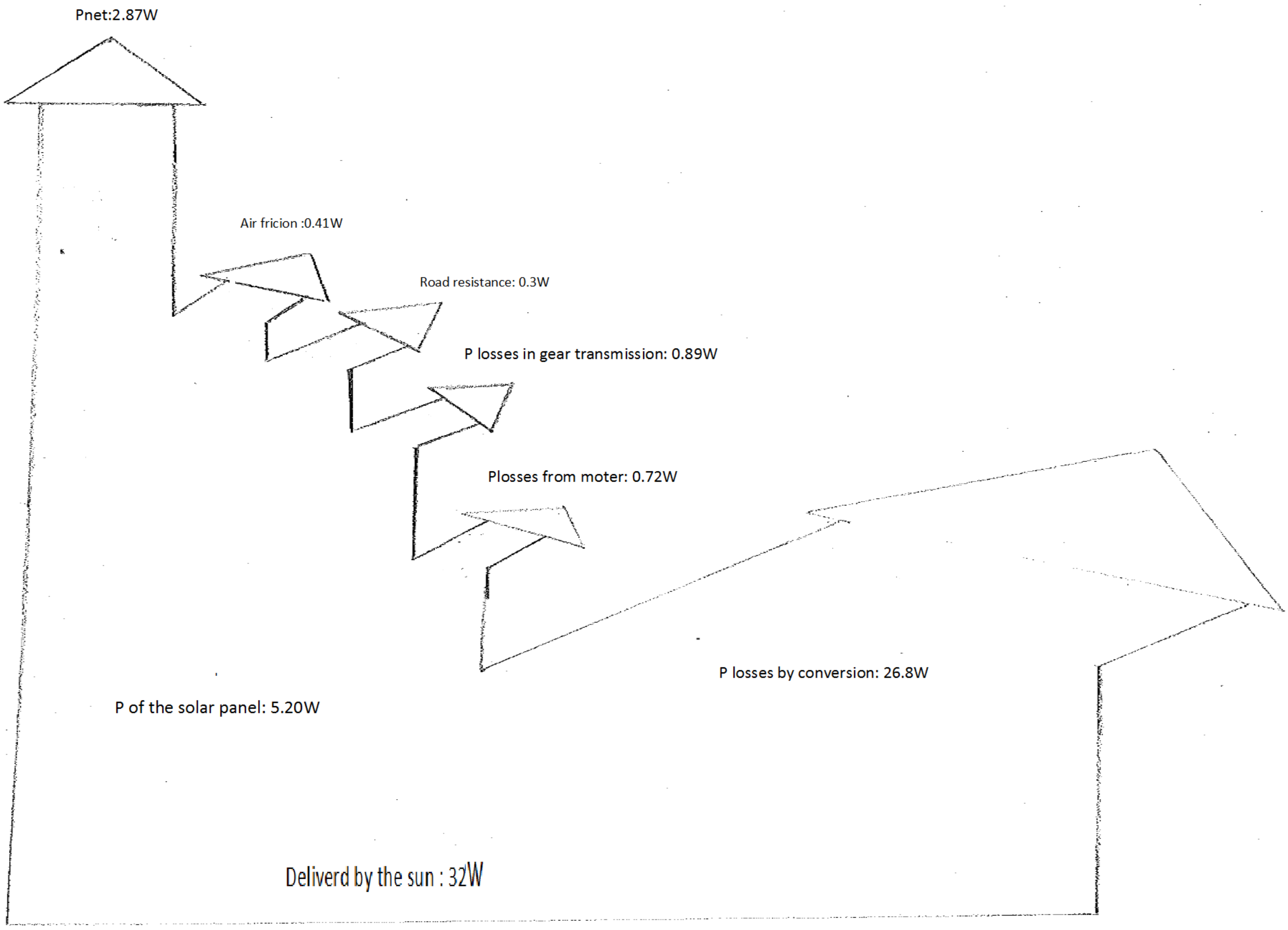


Figure 2: Sankey diagram: SSV maximum speed

Simulink

1. Optimal power transfer

These are the constants we have used to calculate the optimal power transfer

Ir = 800; % solar irradiance [W/m^2]

Is= 1e-8 ;% saturation current [A/m^2]

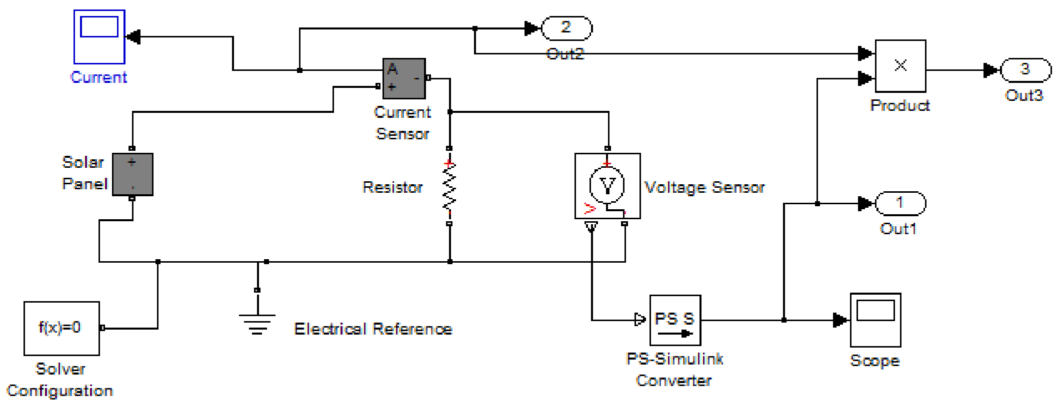
Isc= 0.88; %short circuit current [A]

Voc = 0.56; %Open circuit voltage [V]

Ir0=700; %irradiqance used for measurements [W/m^2]

N = 15; %diode quality factor

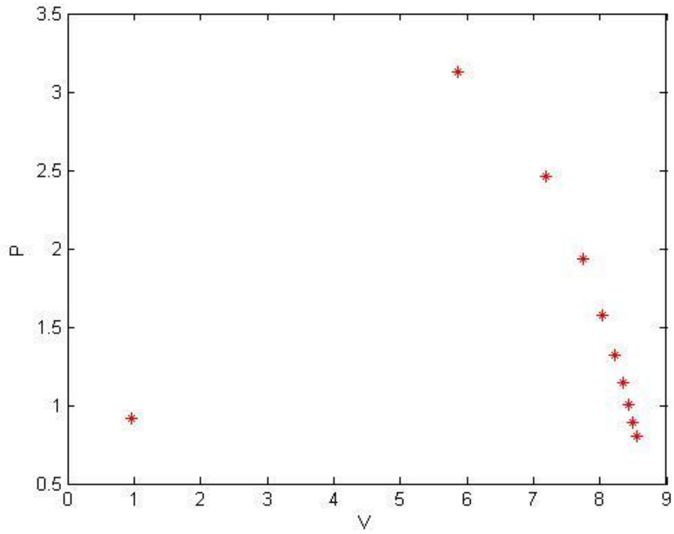
The Simulink design we used.



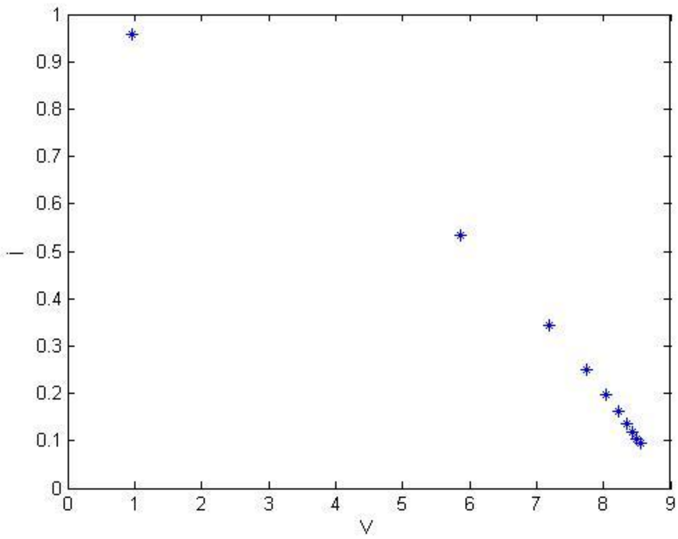
Results:

The script on Toledo that we used gave us these 2 charts.

Current in function of voltage level



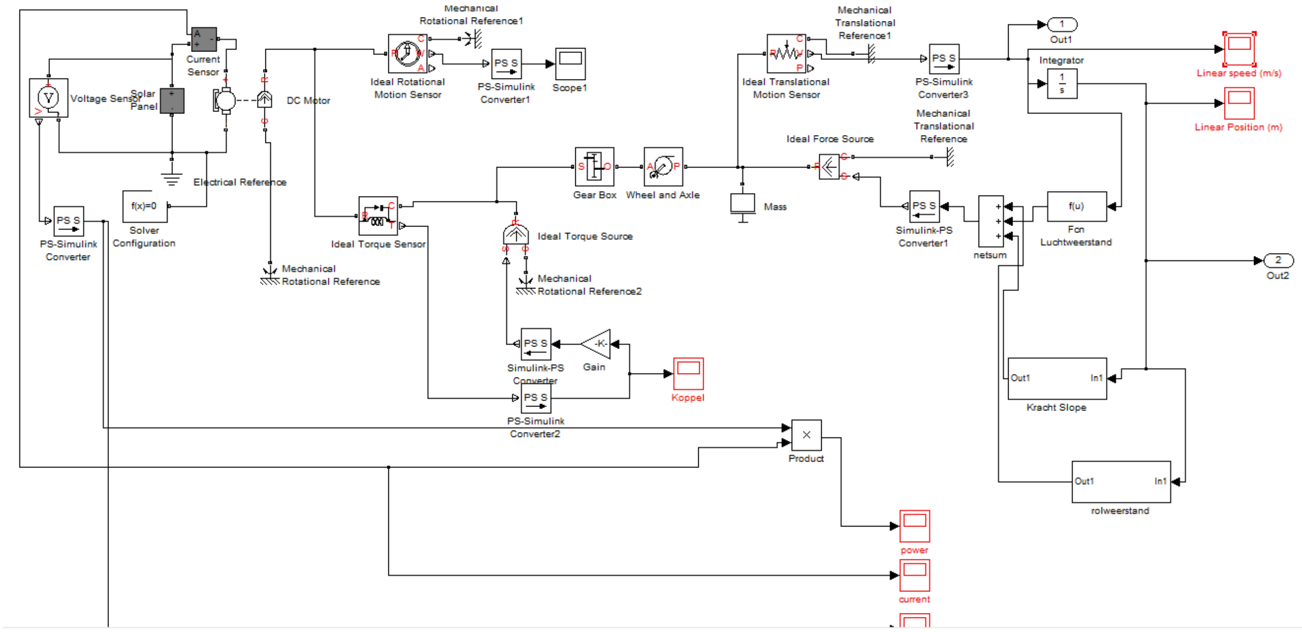
Current in function of voltage level



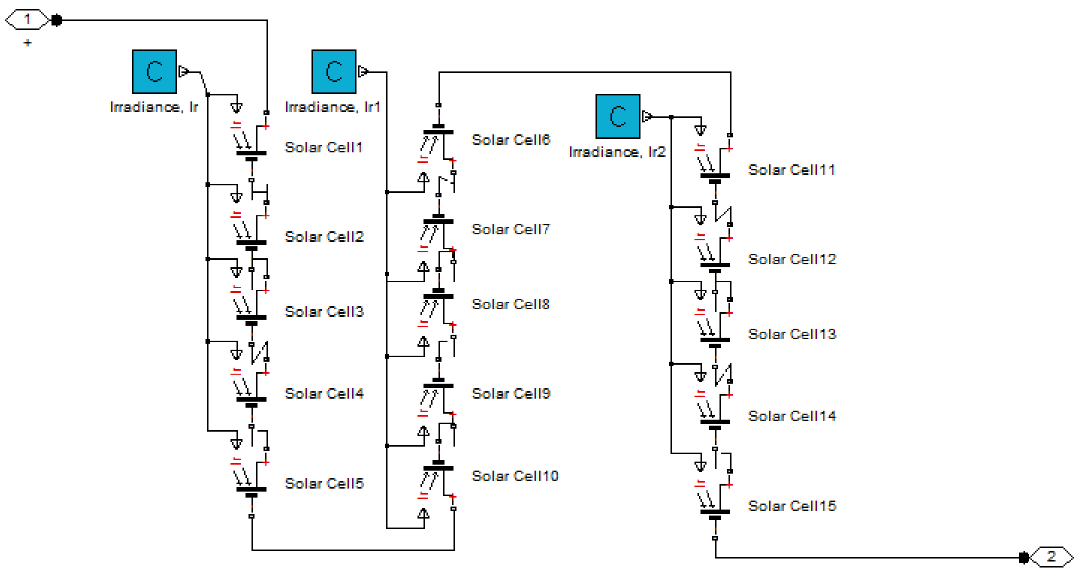
On the first chart we can see that the most power is dissipated on the second measurement. We used resistance values between 10 and 100 ohm with steps of 10 ohm. From this we can conclude that optimal power transfer to the resistance is achieved when a resistance of 20 ohm is used. The second chart confirms this. If you multiply the value of I and V from the second dot, the solution will indeed be the highest value of all measured resistances.

2. The total distance traveled by the SSV when the solar panel is disconnected

Our Simulink clutch looks as follow.



The grey colored box called 'Solar panel' is a subsystem. Inside this box are our various solar cells located. We used a constant irradiance rate of 800 w/m².

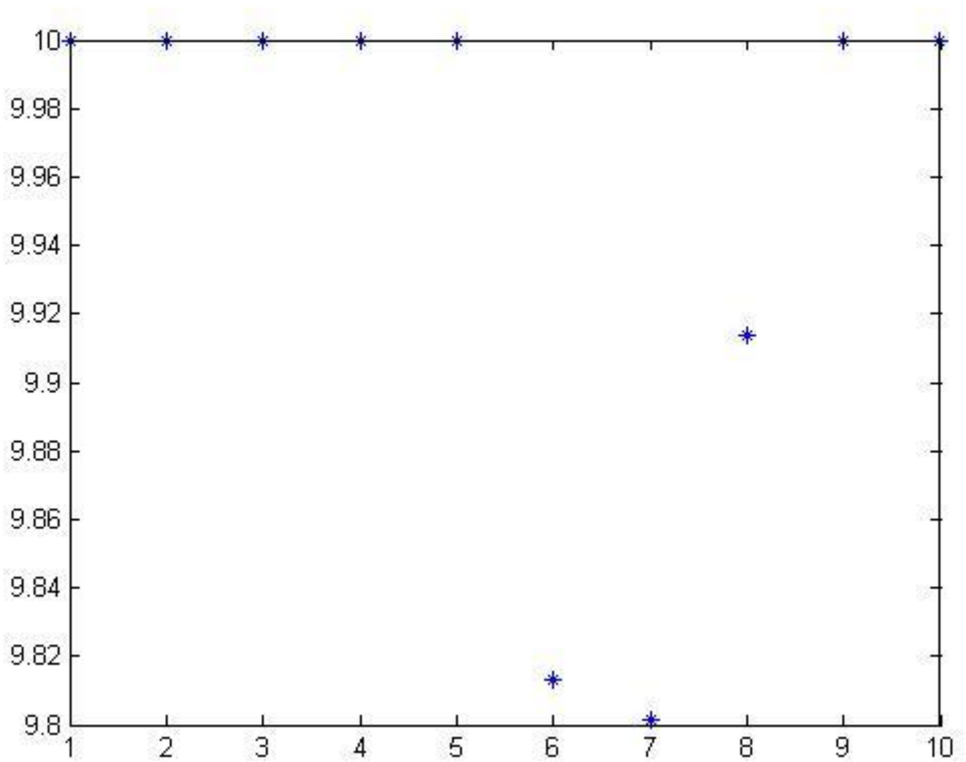


Here is a list of the parameters we used, the properties of the motor, the solar cells and the SSV, and the script.

```
%%% Solar Power
Ir = 800; % W/m^2
Isc= 0.88  ; %Ampere
Voc = 8.5; %Volt
Ir0 = 700
Is= 1e-8; %Ampere
N = 1.18;
%%% Motor parameters
Ra = 3.32  ; %ohm
Kt= 8550 ; %Nm/A
La= 0.00022 ; %H
Im = 0.41  ;% kg*m^2
Cm = 1e-6 ;% N*m/(rad/s)
%%% SSV parameter
m =1; % kg
r = 0.04; % wheel radius [m]
n =7 ; % gear ratio

tn=[]; %% initialize empty vector
result=[];

tn=[]; %% initialize empty vector
result=[];

for n=1:10
tn=[tn n];     %% Extend vector with gear ratio n

sim('step7',10); % Simulate Simulink model for 10 sec.

[i,j] = find(yout(:,2)>14); % find when position of 14 m is achieved
if isempty(i)
   result =[result 10]; %% if not achieved take time =10 sec
else
    result=[result tout(i(1))]; %% put travel time in vector
end
end

figure(1)
plot(tn,result,'*') %% plot gear ratio versus travel time
[opt,i]=min(result); %%% find minimal travel time

n=tn(i); %% take gear ratio corresponding with minimal travel time
sim('step7',10);
```

Also, the counterforces used in simulink are the same as calculated in the Sankey diagram.

This script resulted in the following graphic, racetime in function of gearratio.



Although this does not give us an answer on the total distance travelled by SSV question but it does show that our written calculations of the gear ratio is the same than the simulinks calculation. The racetime is least long when gear ratio 7 is used.

The total distance travelled is unknown as we could not reach an answer that made any sense.