SSV case 1

EE4

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Table of contents

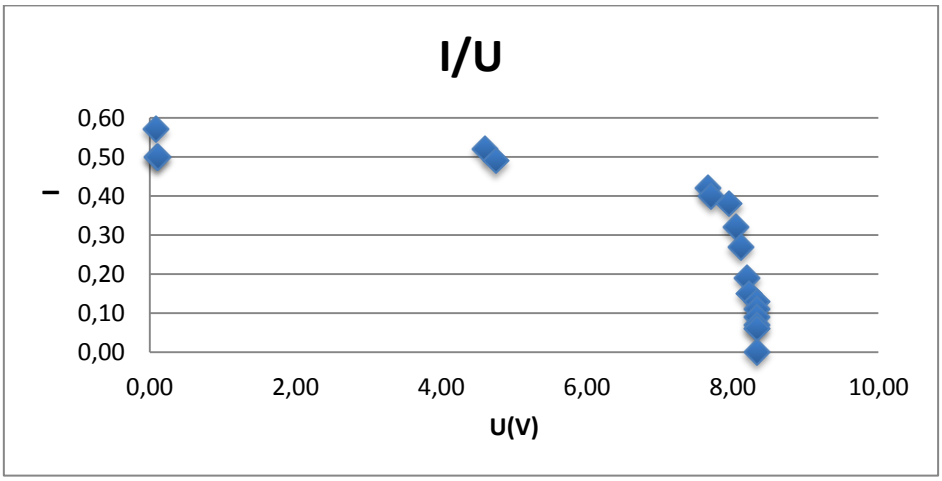
I. Solar characteristic

To determine the ideal gear ratio of our SSV, we need all the characteristics of the solar panel. One of them is the diode factor.

The diode factor is calculated by measuring the voltage and the current of a certain resistance. The resistance is changed a couple times which gave different values for the voltage and the current. The value of the resistance can be calculated by $R=\frac{U}{I}$ (Ohm's law). The values are:

Table 1 - Measured values ot the lab

R(Ohm)	U(V)	I(A)
0,14	0,08	0,57
0,20	0,10	0,50
0,22	0,11	0,50
8,85	4,60	0,52
9,69	4,75	0,49
18,24	7,66	0,42
19,25	7,70	0,40
20,92	7,95	0,38
25,13	8,04	0,32
30,04	8,11	0,27
43,16	8,20	0,19
54,87	8,23	0,15
64,15	8,34	0,13
75,73	8,33	0,11
92,56	8,33	0,09
119,00	8,33	0,07
138,83	8,33	0,06
8330,00	8,33	0,001



Graph 1 - Graph diode factor

With these values the diode factor can be calculated by the following formula: $I=Isc-Is(e^{\frac{U}{m.N.Ur}}-1)$
We calculated the diode factor for every value so that we get 18 diode factors.

The diode factors are:

Table 2 - Values diode factor

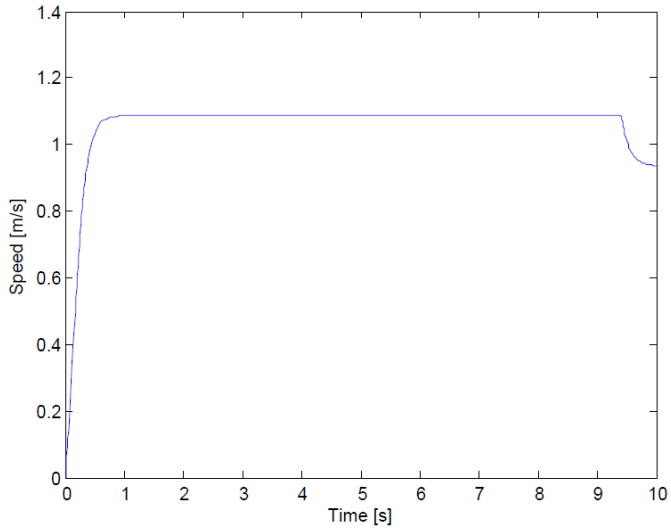
m
0,015
0,016
0,018
0,765
0,769
1,198
1,196
1,227
1,222
1,220
1,217
1,215
1,228
1,223
1,220
1,218
1,216
1,209

When we take the average of all the diode factors we found a diode factor of 1.022.

II. Gear ratio

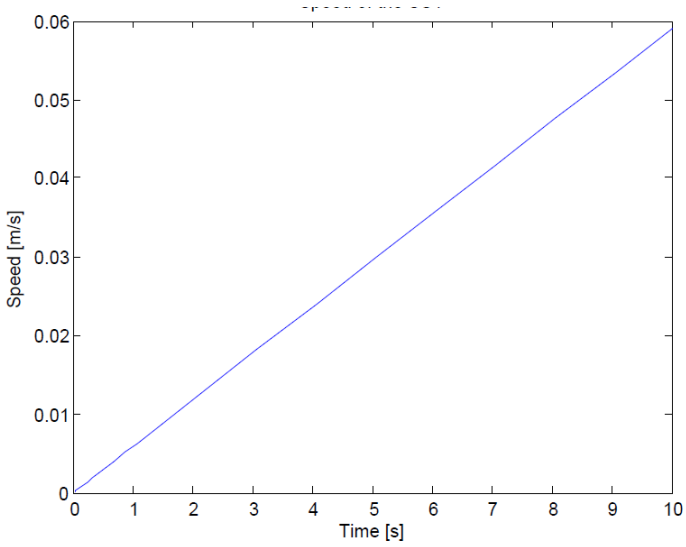
The gear ratio is one of the most important things in modeling our SSV. Because we're going to shift gears, we need 2 gear ratios. We will thus start with a gear ratio that has a high acceleration. When this gear ratio is at its top speed, we'll shift to the second gear ratio which has a lower acceleration but a higher top speed. When we reach the slope, we shift back to the first gear ratio. We'll switch back just when the SSV is fully on the slope, not right before. This was decided because we'd rather slow down because of the slope, than to slow the SSV down because the higher gear ratio can't handle the speed achieved with the other ratio.

We simulated two extreme values; a gear ratio of 1,2:1 and one of 30:1. As you can see in the graphs below, with a very high ratio (30:1), the acceleration is very high but the top speed is low.



Graph 2 - Speed of the SSV (30:1)

In the simulation with a low ratio of 1,2:1, we can see that the acceleration isn't so high, but the top speed is (probably) a lot highe than the top speed of the gear ratio of 30:1.



Graph 3 - Speed of the SSV (1,2:1)

We can conclude that we want a starting ratio that is higher than our second ratio. After a lot of simulations, we concluded that the best combination of ratios is 10:1 (as starting ratio) and 6:1 (as second ratio).

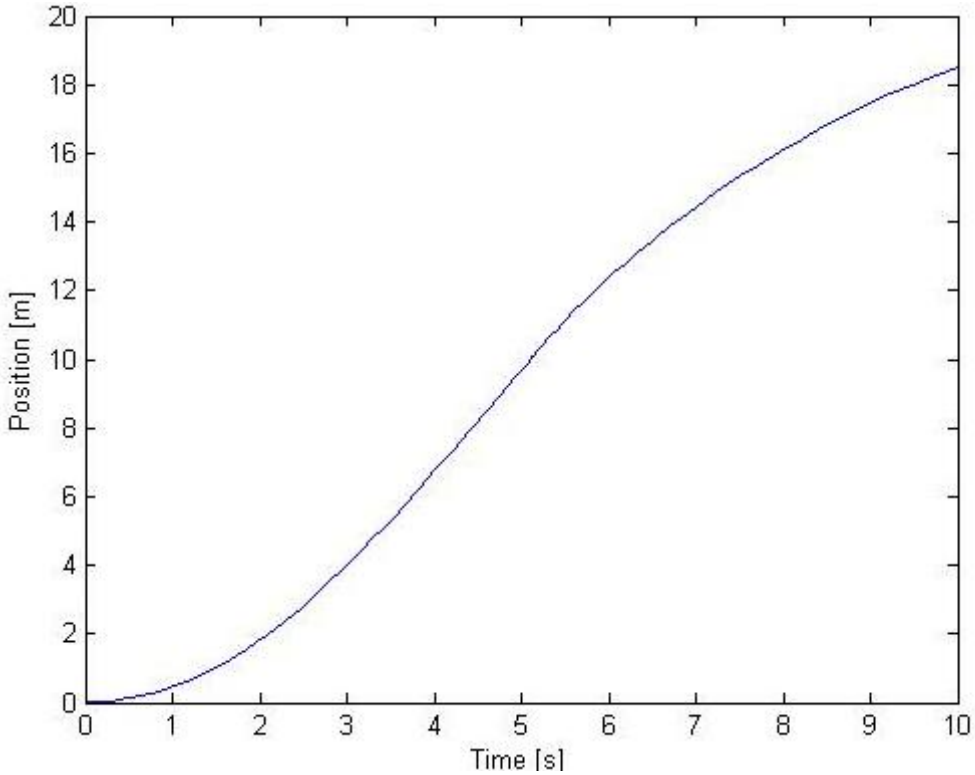
Notice the sharp downwards slope in the speed graph of gear ratio 6:1 and the flattening of the speed curve of gear ratio 10:1 around 3m/s. Here we notice that, using gear ratio 10:1, the highest achievable speed is not much higher than 3m/s. Assuming the switching of the gears works as intended, we could achieve a higher maximum velocity. But, as we were to switch the gear back before the SSV is on the slope, the motor itself would slow down the SSV, because the speed of the SSV is higher than the speed this gear ratio can handle.

With our simulations we noticed the top speed of the first ratio is achieved at about 3 meters. Considering we would like to switch the gears by remote control, it's better to look at what distance we will shift than at which speed because we can't really see the speed of the SSV with our own eyes. Thus we will switch to the heavier gear ratio when the SSV reaches the 3m mark.

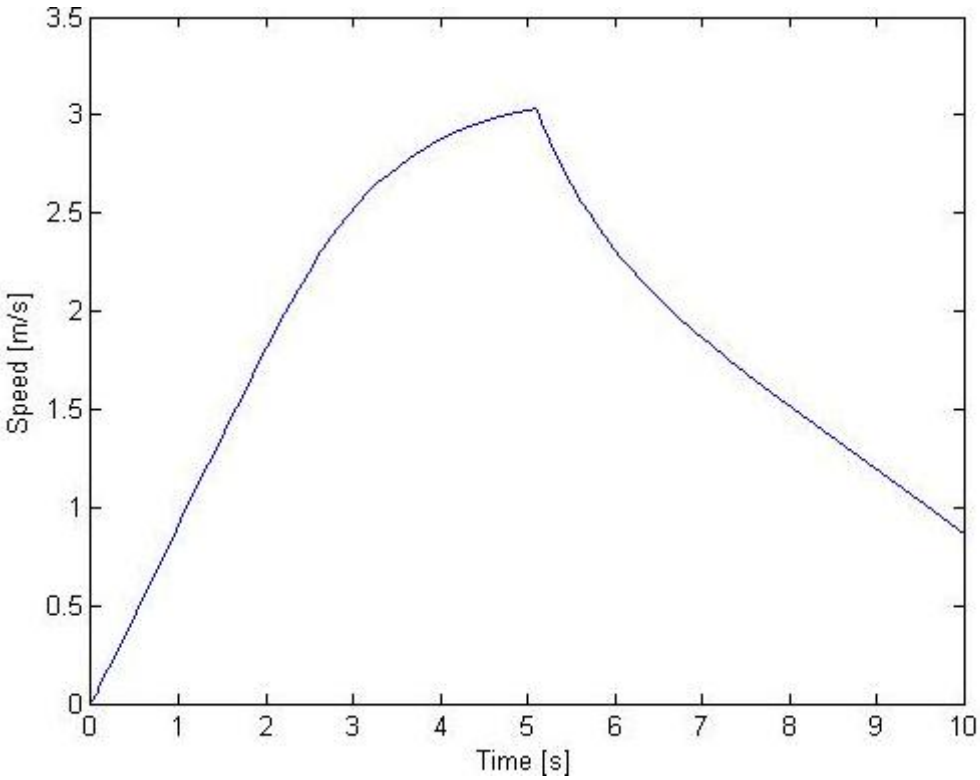
Our goal at first was to try and put in the switching of the gears into our simulation program, but because of some complications that couldn't be fixed even with the help of the coaches this wasn't possible. Thus we chose gear ratios that seemed to shift easily into each other, as you can see in the graphs below.

These graphs were simulated using MatLab. For the used values see the MatLab files in attachment.

Gear ratio = 10:1

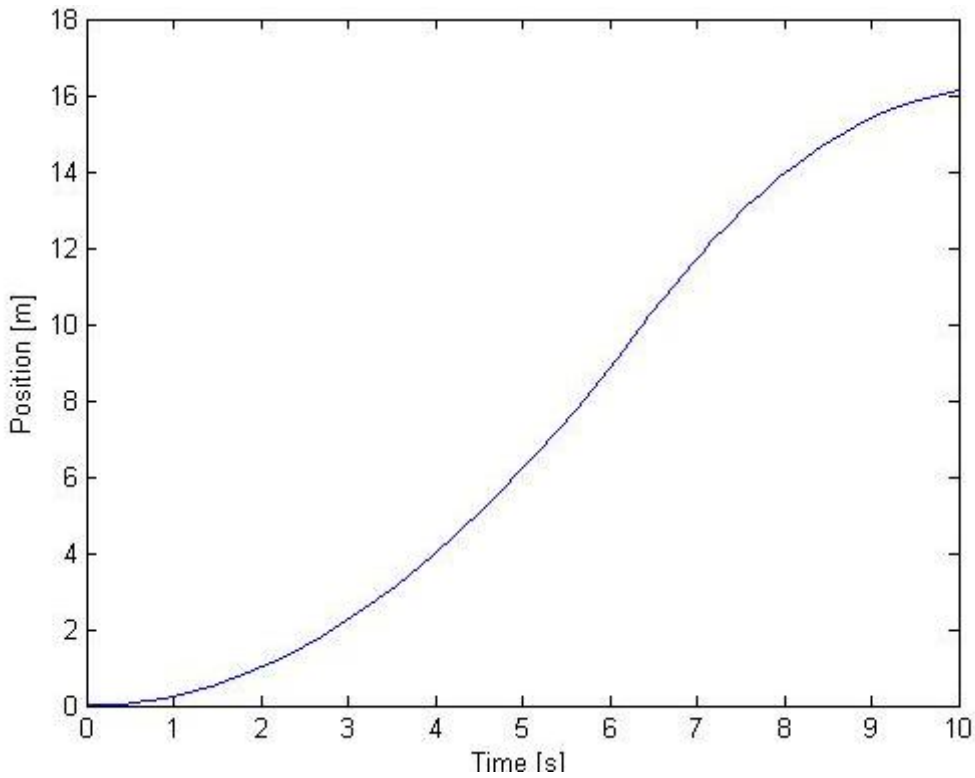


Graph 4 - Position of the SSV (10:1)

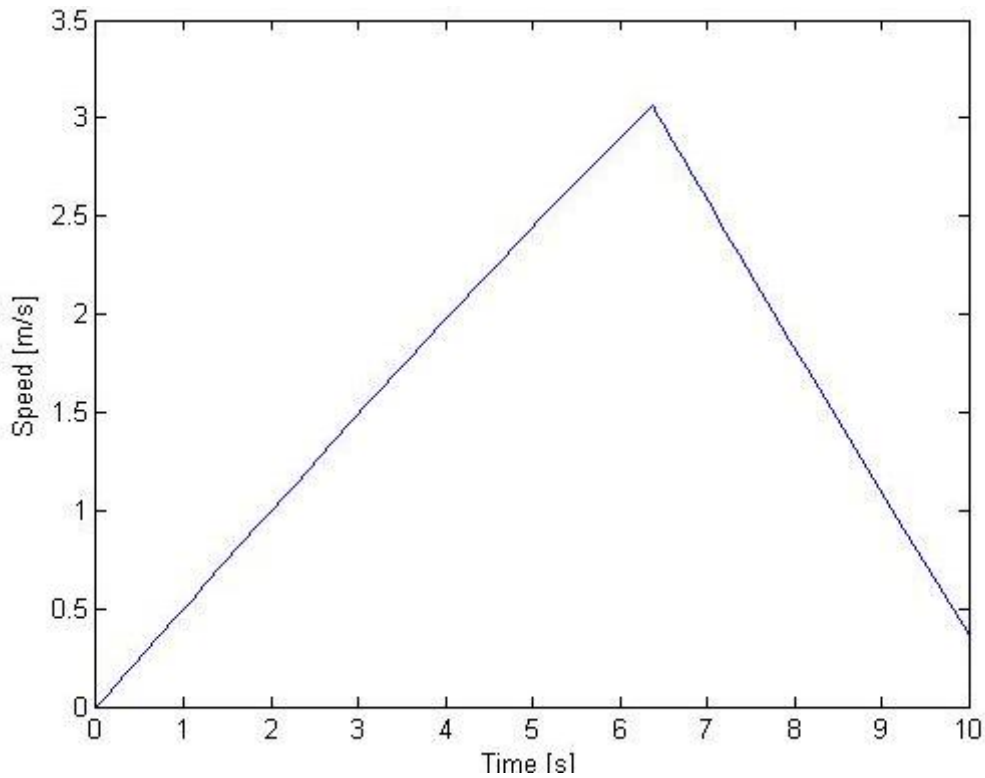


Graph 5 - Speed of the SSV (10:1)

Gear ratio = 6:1



Graph 6 - Position of the SSV (6:1)



Graph 7 - Speed of the SSV (6:1)

III. Bisection method

First of all, we found that our optimal gear ratio is 10, by using MathLab. With this, we started calculating the displacement and velocity for the first second. We will calculate it first with intervals of 0,1 seconds, and then with intervals of 0,2 seconds.

We assume that our acceleration is constant over a time period of 0,1 seconds. We can find our initial acceleration by Newton's Second law F=m.a.

The adapted formula for our case is:

$$a(t) = \frac{E(t)*I(t)}{m*V(t)} - g * Crr - \frac{1}{2}\frac{Cw*V(t)^2*\rho*A}{m}$$

With $E(t) = \frac{Ce*\Phi*60*V(t)*gear\ ratio}{2*\pi*r}$

and $I(t) = Isc - Is * (e^{\frac{E(t)+I(t)*Rr}{M*N*Ur}} - 1)$

Calculating a(0)

For our initial acceleration, the formula reduces to:

$$a(0) = \frac{E(0)*I(0)}{m*V(0)} - g * Crr - \cancel{\frac{1}{2}\frac{Cw*V(0)^2*\rho*A}{m}}$$

because there is no air resistance at t=0.

E(0) and V(0) are both zero, so this would give zero/zero, which is impossible. We can solve this by filling in E(0) and that way, V(0) can be eliminated.

$$a(0) = \frac{Ce*\Phi*60*\cancel{V(0)}*gear\ ratio*I(0)}{2*\pi*r*m*\cancel{V(0)}} - g * Crr$$

With:

I(0) = 0.88 A	g=9.81 N/m	Crr=0.012	Ce* Φ=8.9285*10^-4 V/rpm
r=0.04 m	m=1.2 kg	Cw=0.5	A=0.035 m²
P=1.293 kg/m³	Isc=0.88 A	Is=1*10^-8 A/m²	M=1.022
N=15	Ur=0.0257 V	Ra=3.32 ohm	Gear ratio = 10

We become an initial acceleration of 1,44540 m/s². We can use this in the calculations for intervals of both 0,1 and 0,2 seconds.

0,1 s time intervals

We divide our function in very small parts, so we can assume that the acceleration is constant over the time interval, we can use the formula for rectilinear motion:

$V(t) = V_0 + a(t)*(t-t_0)$

$X(t) = S_0 + V_0*(t-t_0) + \frac{1}{2}a(t)*(t-t_0)^2$

$E(t) = \frac{Ce*\Phi*60*V(t)*gear\ ratio}{2*\pi*r}$

With these values, we have to calculate I(t). As you can see, I(t) is a function of itself. To find the right I(t), we change the formula from I(t) to

$$0 = Isc - Is * (e^{\frac{E(t)+I(t)*Rr}{M*N*Ur}} - 1) - I(t)$$

We know every value, except the value of I(t). We can find this by using the bisection method.

The bisection method

For I(0,1), we first tried 0,9 A and we got -0.0200158.. This is too little, which means that we have to lower our $I_{test.}$

Then we tried 0.85, which gave us 0.019988… This is too low, so it has to be something in between.

We saw that it had be around I(0), which is 0.88 A, so we tried that. It gave us -0.000033358..

Now we chose our I a little smaller: 0.87999. This gave -0.000026.

This is close enough to zero so we took 0.87999 for I(0,1).

As we kept calculating further, we had to try lower values, until we reached the 0.848 A at 1 second. This is a decrease of 3.63%.

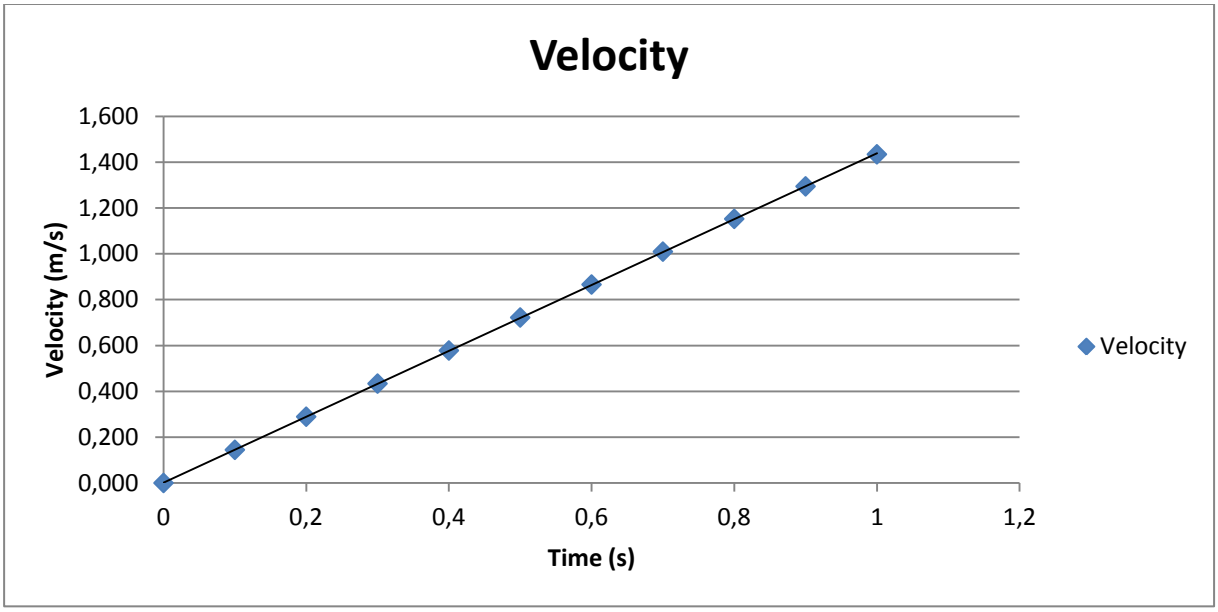
For I(0,2) , we did the same. We first tried 0,87999 which gave -0.0000694. This is too small so we tried a value of 0.87990, this gave a value of 0.0000206.

This is close enough to zero, so we took 0.8799 for I(0,2).

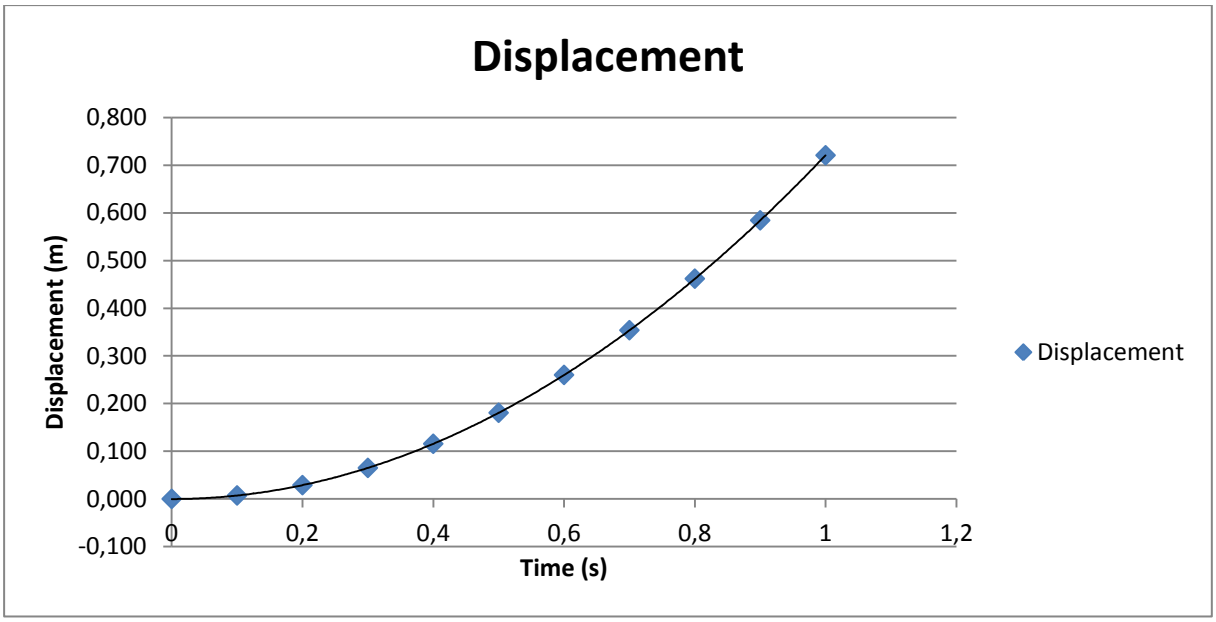
We repeat this until we reach 1 second. These are our results:

t (s)	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
a (m/s²)	1,445	1,445	1,444	1,443	1,442	1,439	1,435	1,429	1,418	1,400	1,370
V (m/s)	0	0,145	0,289	0,434	0,578	0,722	0,866	1,009	1,152	1,294	1,434
x (m)	0	0,007	0,029	0,065	0,116	0,181	0,260	0,354	0,462	0,584	0,721
E	0	0,308	0,616	0,924	1,232	1,539	1,846	2,152	2,456	2,758	3,057
I (Amp)	0,880	0,880	0,880	0,880	0,880	0,879	0,878	0,876	0,872	0,863	0,848

Here are the curves of velocity and displacement:



Graph 8 - Velocity of the SSV



Graph 9 - Displacement of the SSV

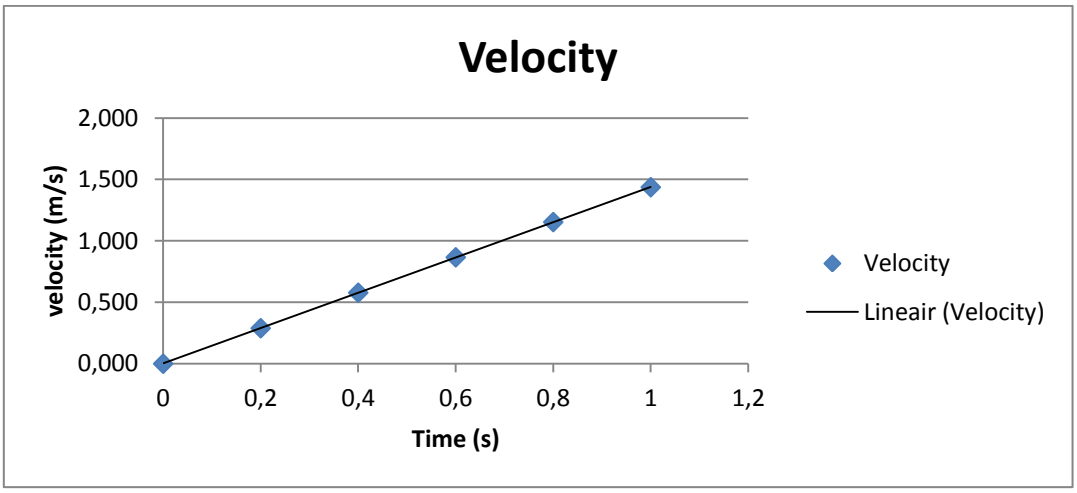
0,2 s time intervals

We use the same method as explained before, the only difference is ($t-t_0$).

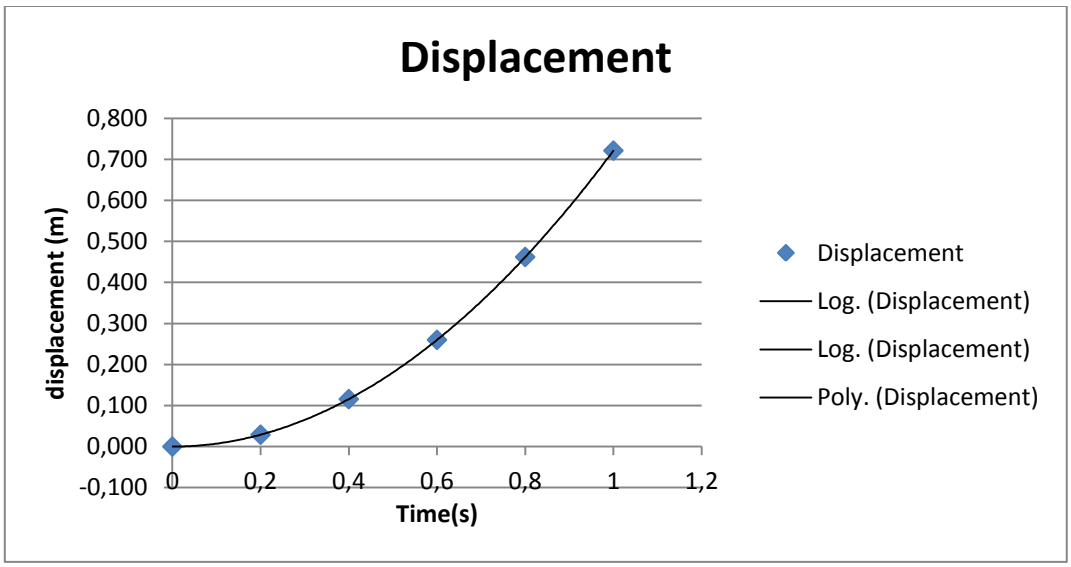
The results:

t (s)	0	0,2	0,4	0,6	0,8	1
a (m/s²)	1,445	1,444	1,442	1,435	1,419	1,372
V (m/s)	0	0,289	0,578	0,866	1,153	1,437
x (m)	0	0,029	0,116	0,260	0,462	0,721
E	0	0,616	1,232	1,847	2,458	3,063
I (Amp)	0,880	0,880	0,880	0,878	0,872	0,849

The curves:



Graph 10 - Velocity of the SSV



Graph 11 - Displacement of the SSV

Interpretation of the results

We'll compare the values of our two methods.

0.1 s intervals	***0.2 s intervals***
V(1 s) = 1.445 m/s	V(1 s) = 1.460 m/s
X(1 s) = 0.732 m	X(1 s) = 0.742 m

We have a slight, negligible difference, only 1%. The reason for this small difference is our bisection method for finding I(t). It is never totally exact, but we can conclude that our final results are accurate enough.

IV. Sankey Diagram

A Sankey diagram is a sort of flow diagram, in which the different arrows show you how the energy 'flows'. This gives you an image of where and how much energy gets lost at a certain moment.

For the case SSV part 1 we need to make two Sankey diagrams based on the theoretical power losses, one at the moment when the SSV reaches its maximum speed, under the assumption that the SSV is driving on an infinitely long and another one when the SSV drives half of the prior found maximum speed, but on the slope, in case of the race track as described in the competition rules.

The calculations of the different power losses can be found below.

Maximum velocity

Start

The amount of solar energy that reaches the earth, is $800\frac{W}{m^2}$ in Belgium. Multiplying this with the surface area of the solar panel, it's possible to determine the amount of energy that reaches the solar panel.

$$P = 800\frac{W}{m^2} \cdot (0{,}18 \cdot 0{,}22)m^2 = 31{,}68\ W$$

Losses solar panel

The solar panel can't convert all the solar energy to electrical energy. There are losses due to reflection and heat.

Our max velocity is 3,7 m/s

$$\omega_{wheel} = \frac{v}{r} = \frac{3{,}7}{0{,}04} = 92{,}5$$

$$\omega_{motor} = \omega_{wheel} \cdot 6 = 555$$

$$E = \omega_{motor} \cdot K_e = 555 \cdot 8{,}55 \cdot 10 - 3 = 4{,}745$$

$$U = I \cdot R + E$$

With bisection method we solved the equation below, and determined I.

$$I = I_{sc} - I_0\left(e^{(I*R+E)/(m*N*U_r)} - 1\right)$$

$$\mathrm{I} = 0{,}6039\mathrm{A}$$

$$U = I \cdot R + E = 0{,}6039 \cdot 3{,}32 + 4{,}745 = 6{,}750V$$

$$P = U \cdot I = 4{,}077W$$

Loss motor

In the datasheets of the motor we can find that the maximum efficiency is 84%.

$$P = 0{,}84 \cdot 4{,}077$$
$$P = 3{,}424W$$

Loss air resistance

$$F_{air} = \rho \cdot A \cdot C_w \cdot v^2/2$$
$$F_{air} = 1{,}293 \cdot 0{,}02 \cdot 0{,}5 \cdot 3{,}7^2/2 = 0{,}0885N$$

$$P_{air\ loss} = F \cdot v = 0{,}0885 \cdot 3{,}7 = 0{,}327W$$

$$P = 3{,}097W$$

Loss rolling resistance

$$F_{rolling} = m \cdot g \cdot Crr = 1{,}2 \cdot 9{,}81 \cdot 0{,}012 = 0{,}142$$

$$P_{loss\ rolling} = F \cdot v = 0{,}142 \cdot 3{,}7 = 0{,}525W$$

$$P = 2{,}572W$$

Loss transmission

We can estimate that the loss due to the transmission equals 6%.

$$P = 0.94 \cdot 2.572 = 2{,}418W$$

Conclusion

Normally the power left at maximum velocity should be zero. Because of some losses we didn't took into account we still have 2.42W left.

Half of maximum velocity (at slope)

Start

The amount of solar energy that reaches the earth, is $800\frac{W}{m^2}$ in Belgium. Multiplying this with the surface area of the solar panel, it's possible to determine the amount of energy that reaches the solar panel.

$$P = 800\frac{W}{m^2} \cdot (0{,}18 \cdot 0{,}22)m^2 = 31{,}68\,W$$

Loss solar panel

The solar panel can't convert all the solar energy to electrical energy. There are losses due to reflection and heat.

Our velocity at this point is 1.85 m/s

$$\omega_{wheel} = \frac{v}{r} = \frac{1{,}85}{0{,}04} = 46{,}25$$

$$\omega_{motor} = \omega_{wheel} \cdot 10 = 462{,}5$$

$$E = \omega_{motor} \cdot K_e = 462{,}5 \cdot 8{,}55 \cdot 10 - 3 = 3{,}954$$

$$U = I \cdot R + E$$

With bisection method we solved the equation below, and determined I.

$$I = I_{sc} - I_0\left(e^{(I*R+E)/(m*N*U_r)} - 1\right)$$

$$\mathrm{I} = 0{,}7514$$

$$U = I \cdot R + E = 0{,}7514 \cdot 3{,}32 + 3{,}954 = 7{,}240V$$

$$P = U \cdot I = 5{,}4405W$$

Loss motor

In the datasheets of the motor we can find that the maximum efficiency is 84%.

$$P = 0{,}84 \cdot 5{,}4405$$
$$P = 4{,}570W$$

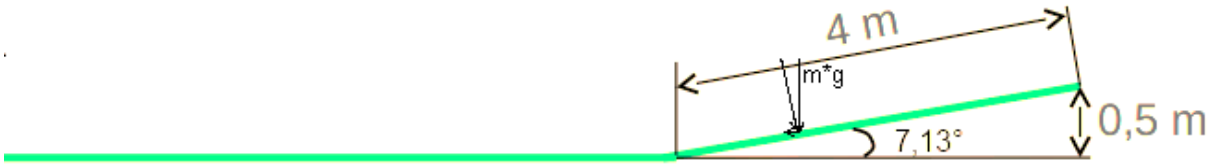
Loss air resistance

$$F_{air} = \rho \cdot A \cdot C_w \cdot v^2/2$$
$$F_{air} = 1{,}293 \cdot 0{,}02 \cdot 0{,}5 \cdot 1{,}85^2/2 = 0{,}0221N$$

$$P_{air\ loss} = F \cdot v = 0{,}0221 \cdot 1{,}85 = 0{,}0409W$$

$$P = 4{,}529W$$

Loss rolling resistance



$$F_{rolling} = m \cdot g \cdot \cos\left(\arctan\left(\frac{1}{8}\right)\right) \cdot Crr = 1{,}2 \cdot 9{,}73 \cdot 0{,}012 = 0{,}140$$

$$P_{loss\ rolling} = F \cdot v = 0{,}140 \cdot 1{,}85 = 0{,}259W$$

$$P = 4{,}269W$$

Loss transmission

We can estimate that the loss due to the transmission equals 6%.

$$P = 0.94 \cdot 2.559 = 4{,}014W$$

Loss slope

There is a force working against the velocity of the vehicle.

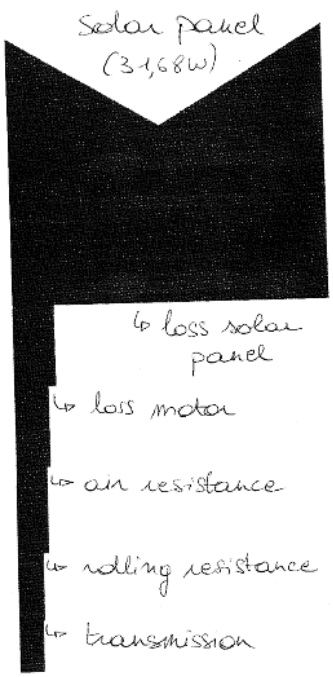
$$\mathrm{F} = \sin(\arctan(1/8)) \cdot 1{,}2 \cdot 9{,}81 \cdot 1{,}85 = 2{,}701$$
$$P = 1{,}312W$$

Conclusion

At maximum speed we saw there was 2.4W of losses which we didn't took into account. This means the power left at half of the maximum speed and at the slope is -1,1W. This explains the loss of velocity at the slope.

Diagrams

Top speed



Half top speed on slope