SSV CASE PART I

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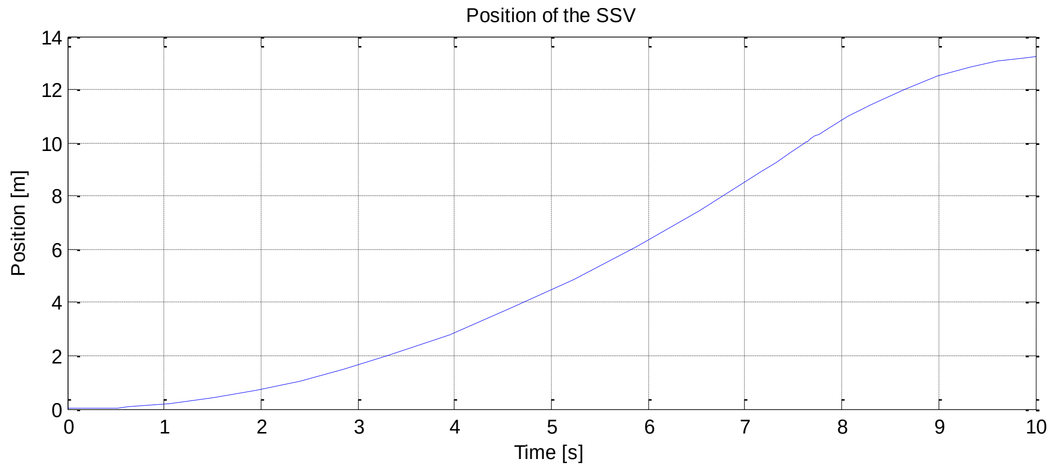
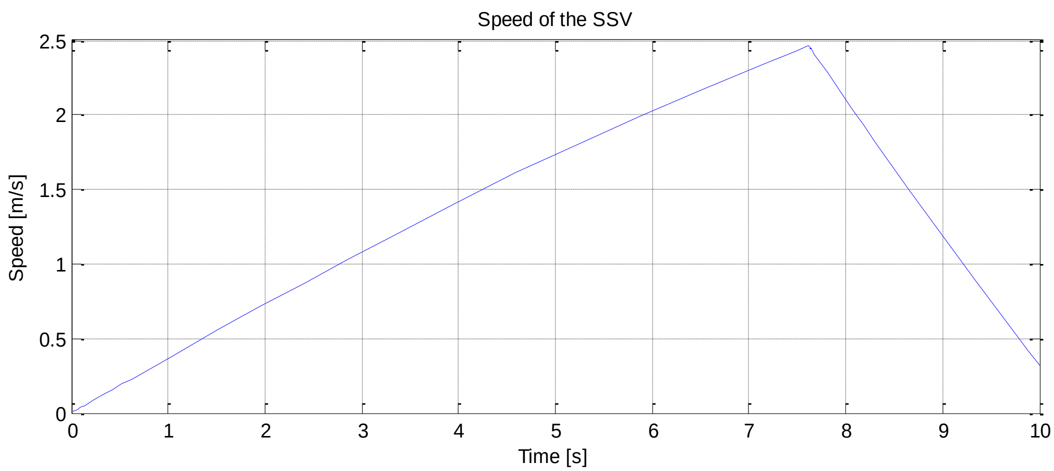
1. Gear Ratio's SSV Final mass 1Kg

Choosing the right gear ratio is the best thing to do in mechanical systems where there rotation has to be transformed into motion. So depending on the power that your motor will deliver is good to have a gear ratio that will favor the criteria that you are interested in.

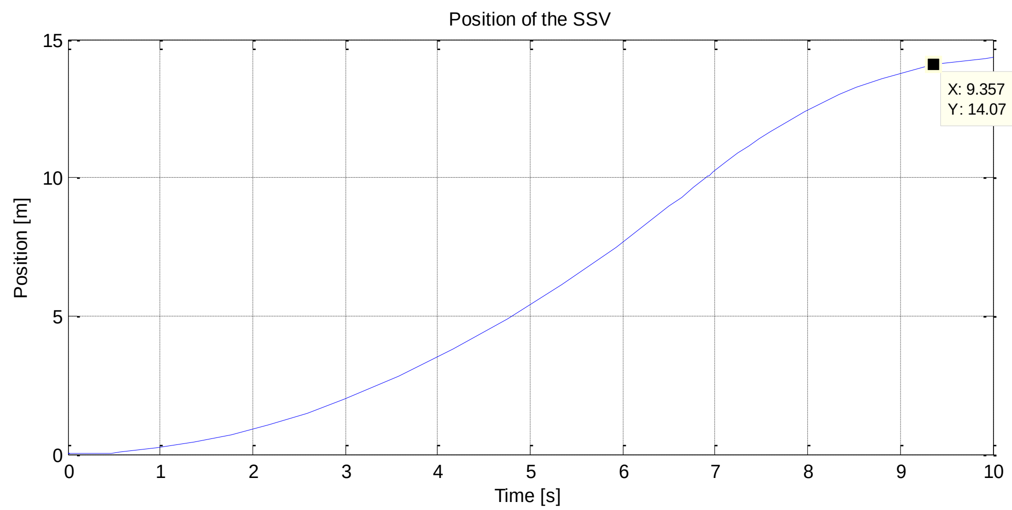
We are going to use a program written in Matlab to plot different charts of (time, position) and (time, speed) for every gear ratio we are going to look at the plot; and we are interested in a gear ratio that will cover the 14m in the shortest time possible.

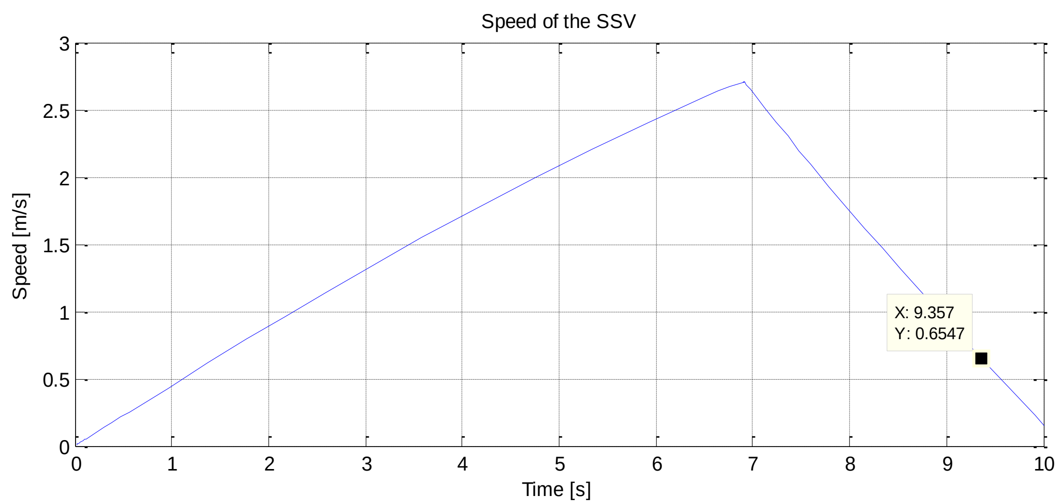
1.1 Gear Ratio 6





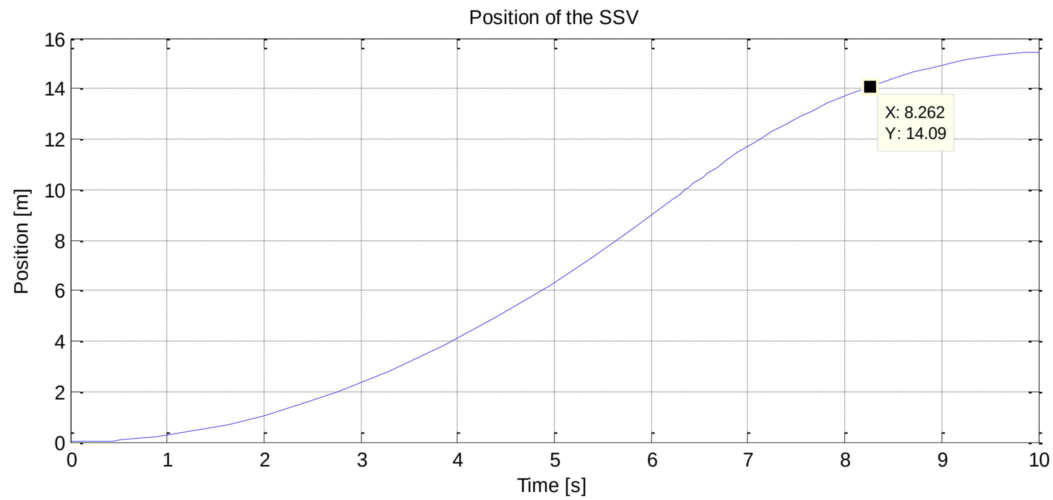
1.2 Gear Ratio 7

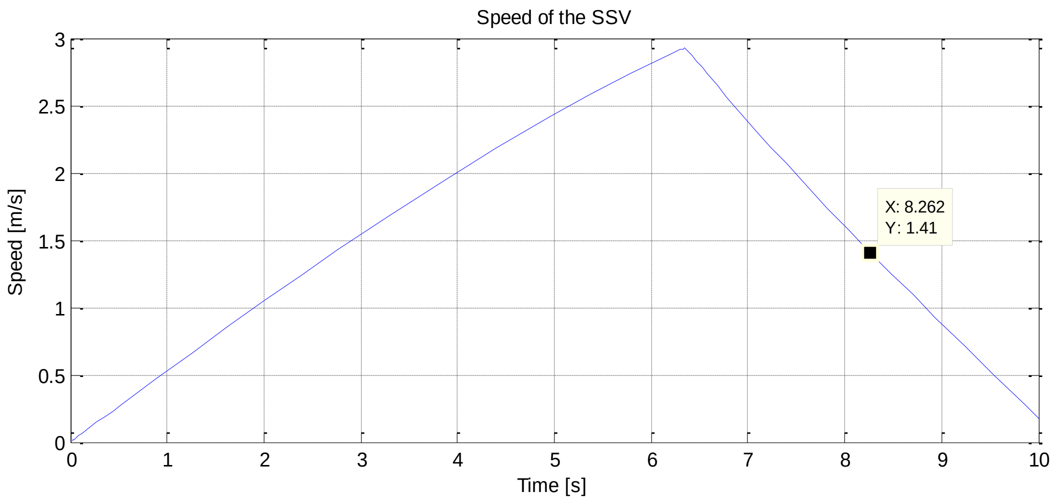




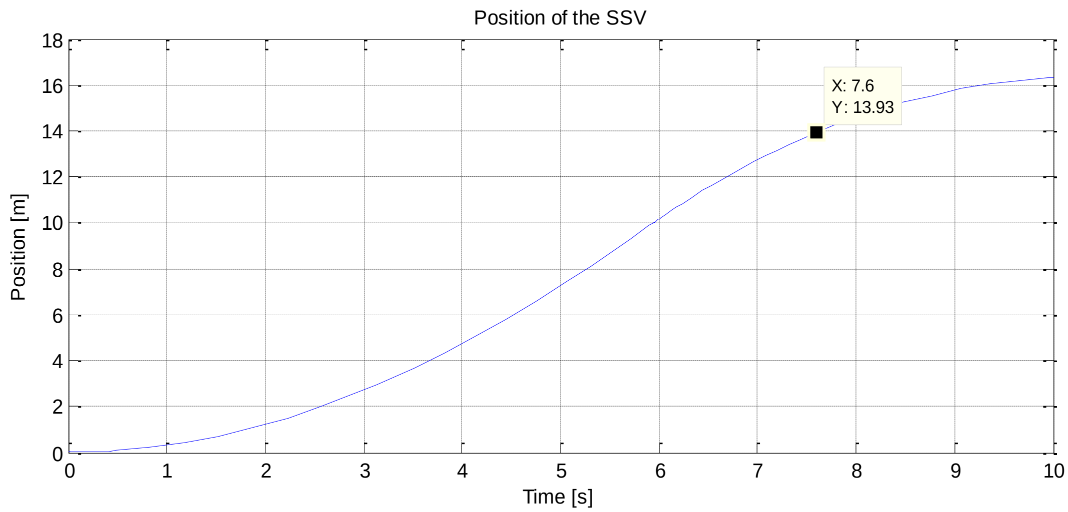
With gear ratio 7, we are able to reach to the position of 14m in 9.357, and since is the first time we are able to reach position 14 on our (time, position) plot. We assume intuitively that this is not our best gear ratio and we are going to plot other charts with different ratio's to see which one helps us to cover the 14m displacement in the shortest time.

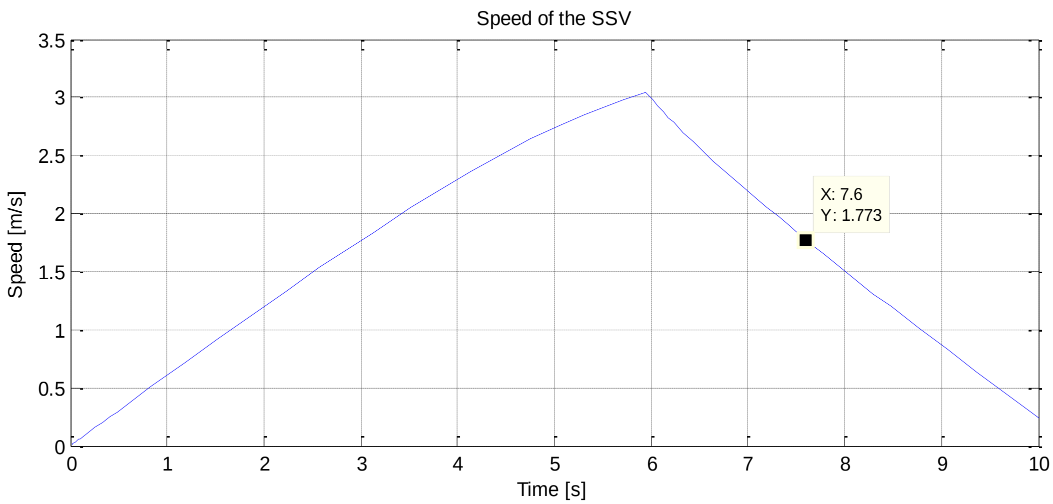
1.3 Gear Ratio 8



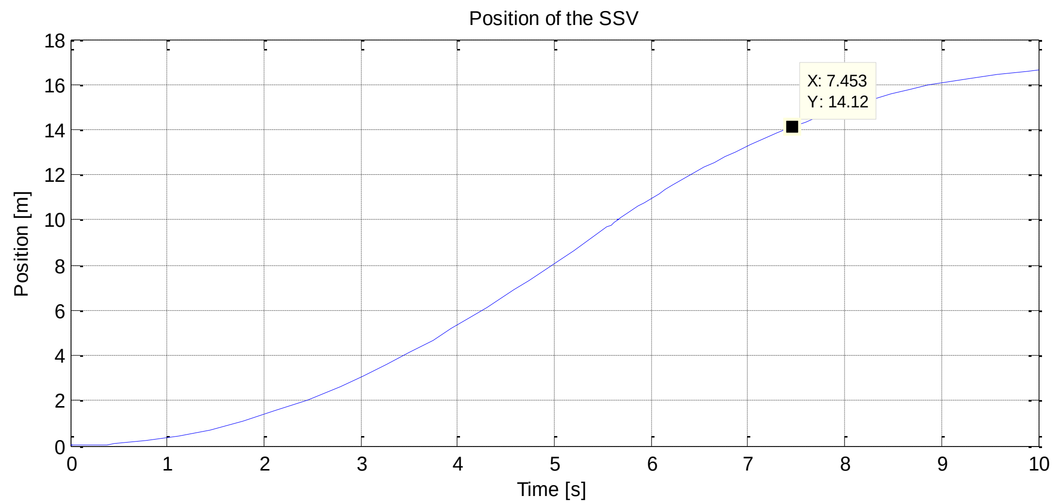


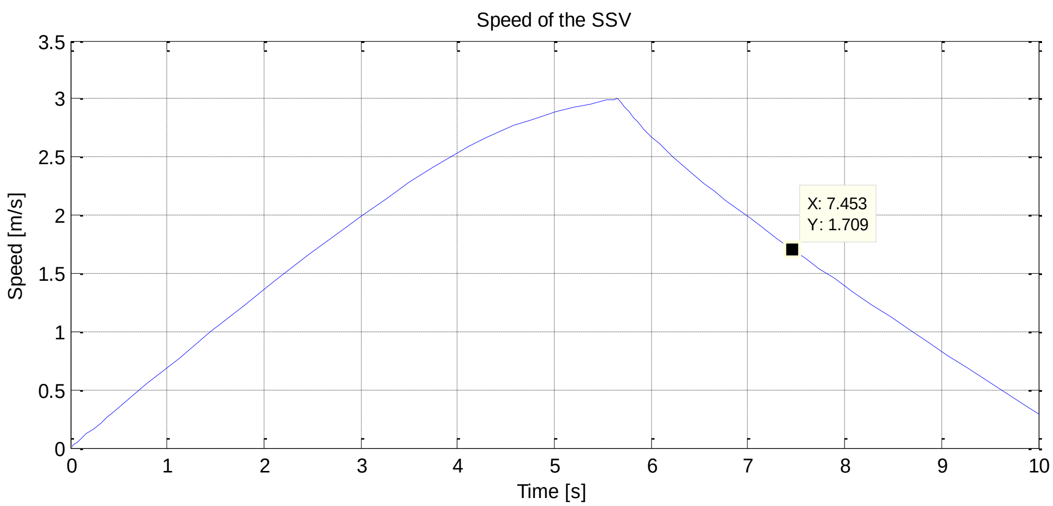
1.4 Gear Ratio 9



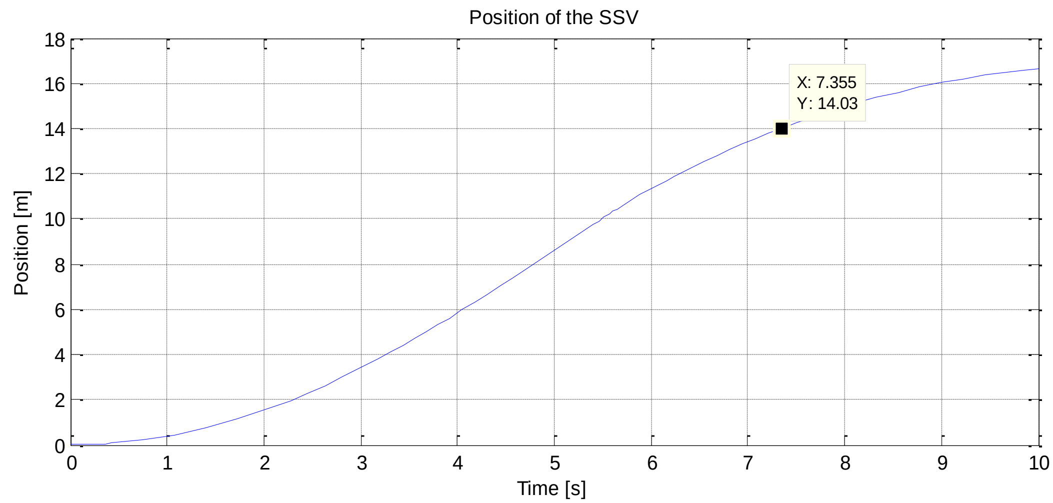


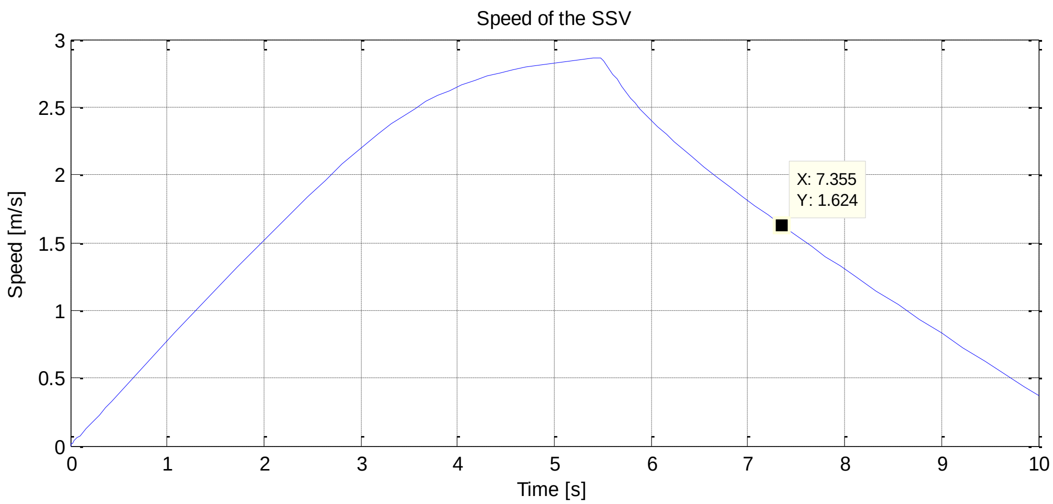
1.5 Gear Ratio 10





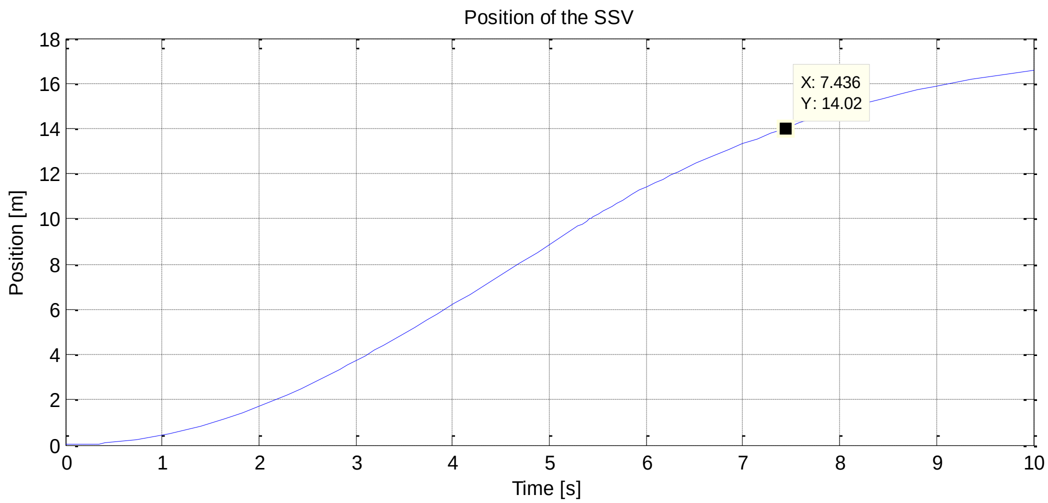
1.6 Gear Ratio 11

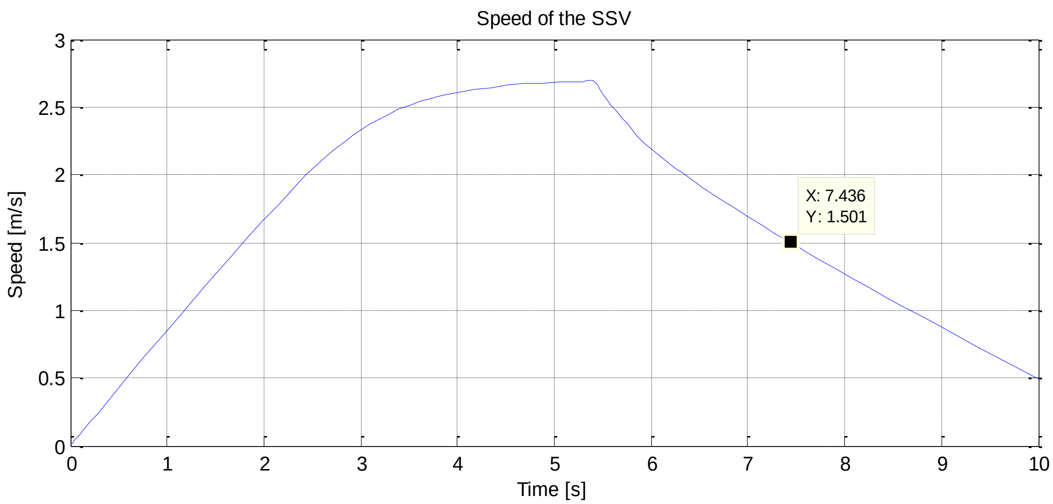




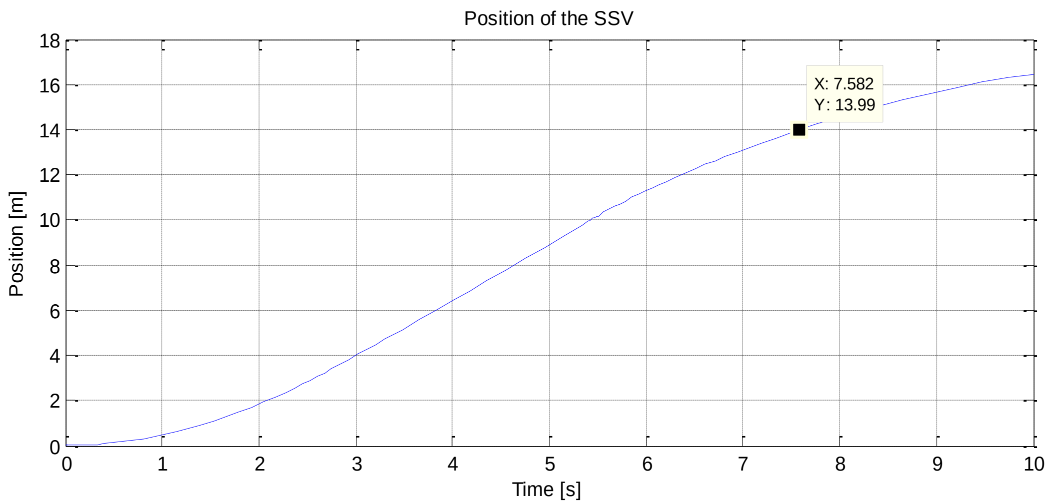
This plot seems to be our best plot, with a gear ratio of 11. With a such high gear ratio; it mean it's a gear ratio that favours the Mechanical advantage.

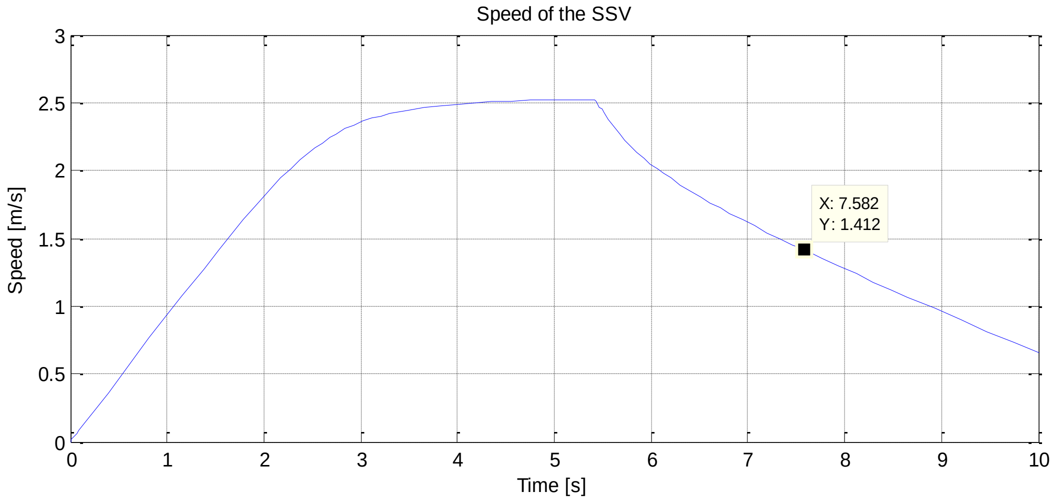
1.7 Gear Ratio 12



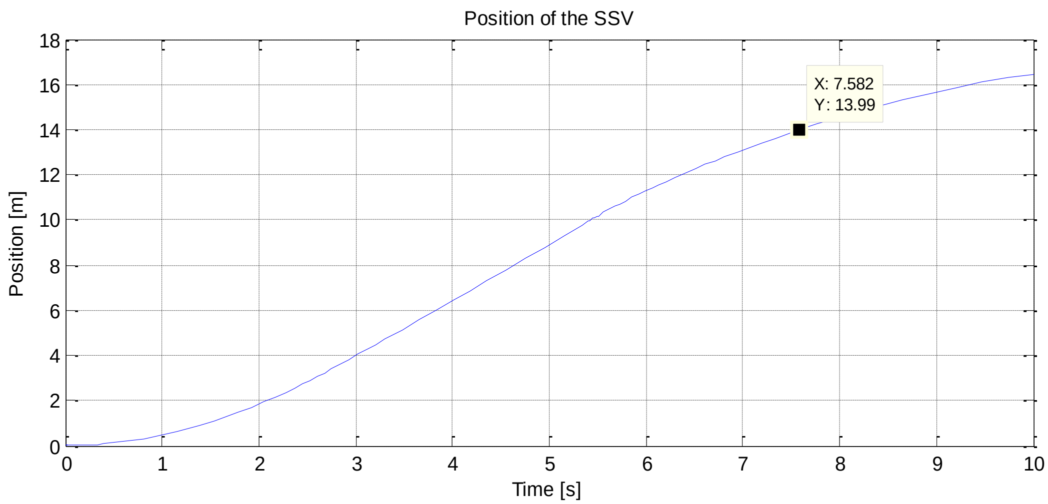


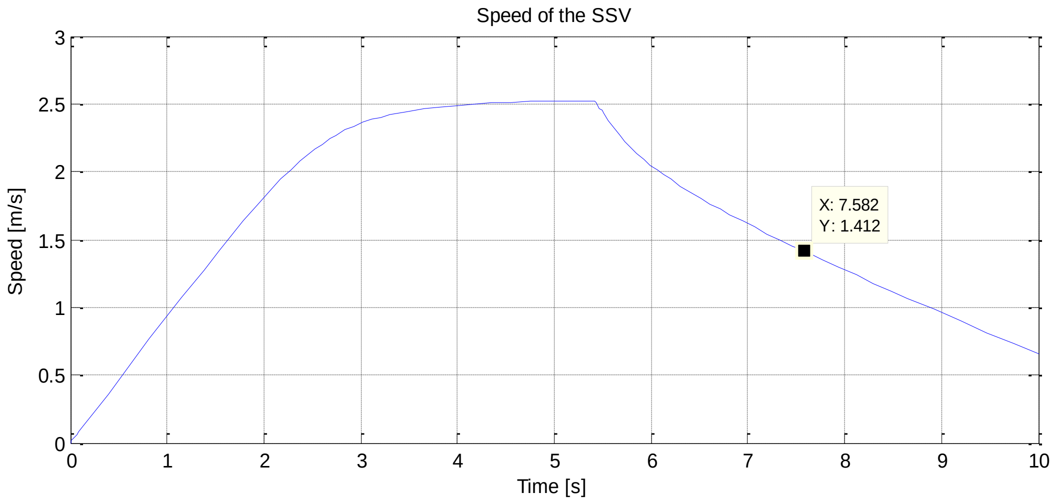
1.8 Gear Ratio 13





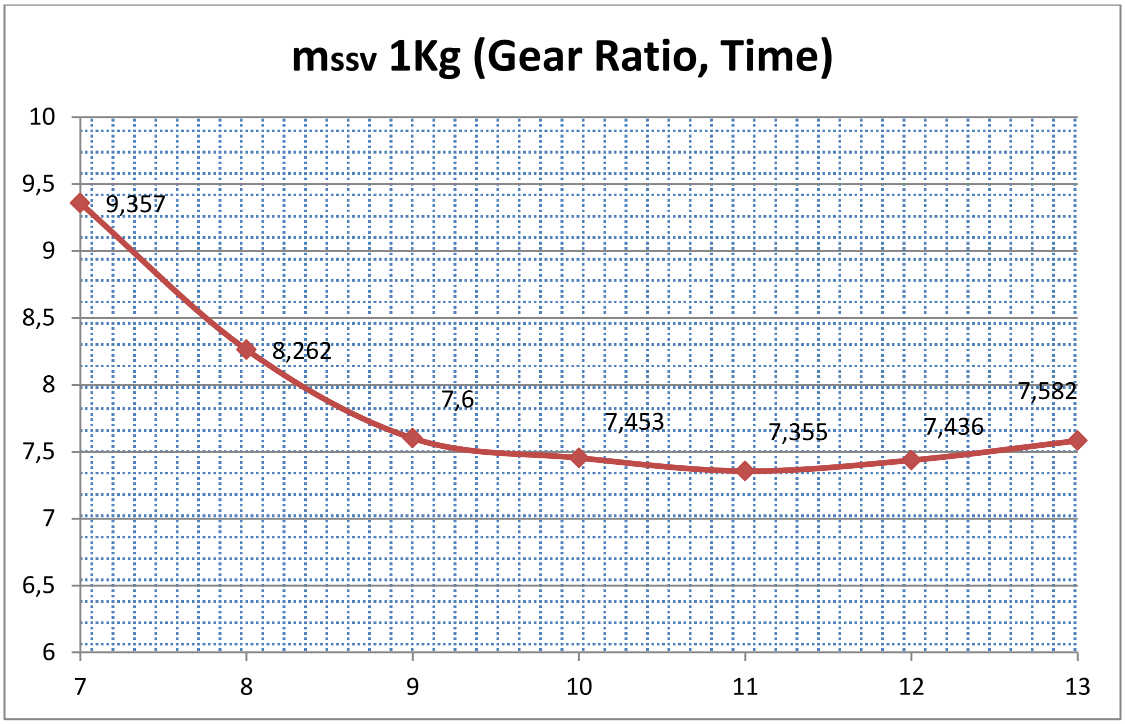
1.9 Gear Ratio 14

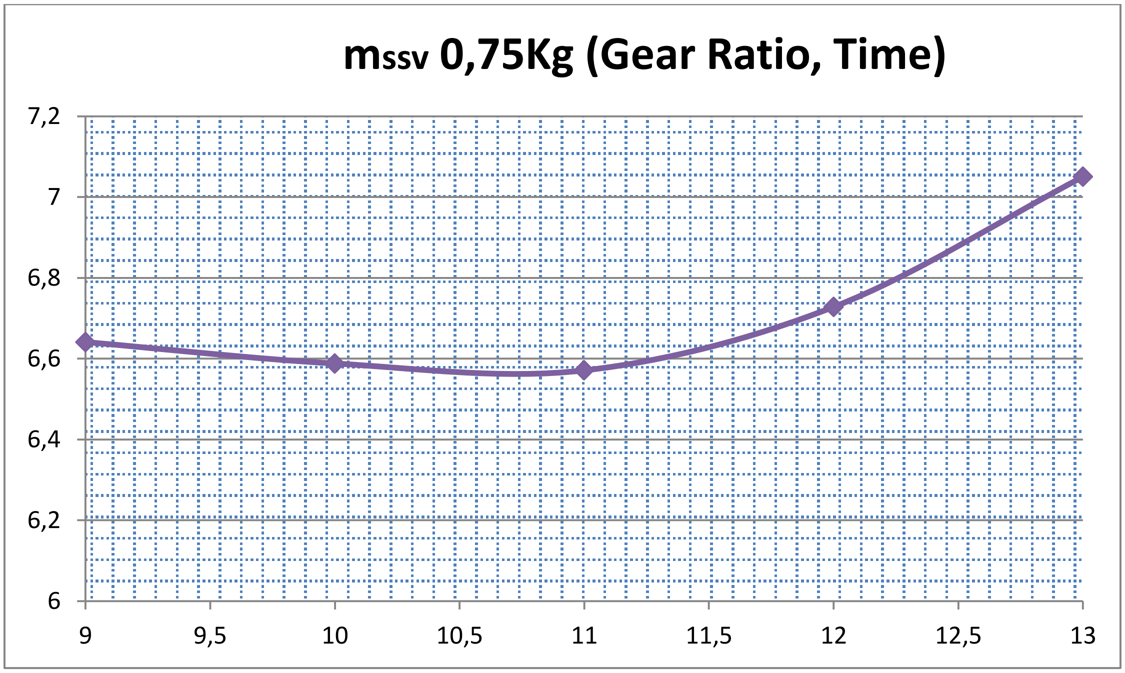




1.10 Conclusion

We assumed that our final total mass of our Solar vehicle would be 1Kg, since we have a small DC motor and the efficiency is not 100% of the whole system, we found that our gear ratio would have to be 11, and this would allow us to cover the 14 meter in 7,355 Seconds. Such a high gear ratio means that the motor is not powerful enough, but if we would want to take a much powerful motor we would have to increase the number of solar cell. These two are limited in choice and every one that will compete in the race has these constraints. So the only option we are left with is to minimize the weight of our final SSV mass to choose the material that are light and in the same time provide us with the enough strength.





The above charts clearly show that gear ratio 11 is our best choice. On one we used an expected final mass of SSV 1kg and on the other 0,75kg; these charts indeed show that indeed by reducing the mass we will cover the 14m displacement in lesser time.

2. Practice with numerical method

2.1 Solar car parameters:

α = 0,1253rad; g = 9,81N/kg; C_{rr} = 0,012; $C_E.\Phi$ = 8,9285*10^{-4} V/rpm; r = 0,04 m; mass = 1kg; C_w = 0,8; A = 0,039m^2; ρ (density of the air) = 1,293 kg/m^3

2.2 Solar panel parameters:

$I(t)=I_{sc} – I_s.(e^{E(t) + I(t).Ra/M.N.Ur} - 1)$

I_{sc} = 0,88A; I_s = 10^{-8}A/m^2; m = 1,1; the number of solar cells in series N = 15; thermal Voltage U_r = 0,0257 V; R_a = 3,32Ω

For the motor:

$E(t) = K_e \times \omega = C_E.\Phi \times 60 \times v(t) \times \text{gear ratio} /(2\pi r)$

2.3 TIME INTERVAL (t = 0,1s)

The initial conditions at t = 0s are s(0) = 0; v(0) = 0; I(0) = 0,88A

From here on, we can find:

$E(0)= C_E.\Phi \times 60 \times v(0) \times$ gear ratio $/(2\pi r)=0$

$a(0) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0) \times E(0)/(M \times v(0)) - 3C_wA\rho \times v^2(0)/2M = 1{,}758971083$

The units of acceleration, velocity, displacement, current and back bmf E, are m/s^2, m/s,m,A, and volt respectively.

We assume that during each interval, the acceleration is constant, and t=0,1s always.

(0-0,1)

$a(0{,}1) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0{,}1) \times E(0{,}1)/(M \times v(0{,}1)) - 3C_wA\rho \times v^2(0{,}1)/2M = 1{,}757066853$

$v(0{,}1) = v(0) + a(0) * t = 0{,}175897108$

$s(0{,}1) = s(0) + v(0) *t + a(0)* t^2/2 =0{,}008794855$

$E(0{,}1) = C_E.\Phi \times 60 \times v(0{,}1) \times$ gear ratio $/(2\pi r) =0{,}375118789$

$I(0{,}1) = I_{sc} - I_s.(e^{E(0,1) + I(0,1).Ra/M.N.Ur} - 1) =0.879976227$

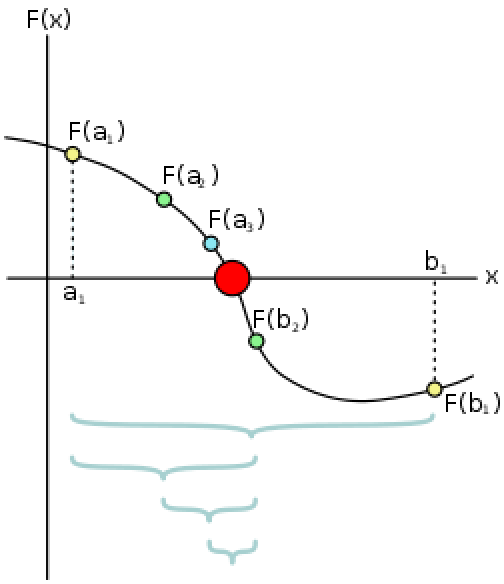
In the previous section (gear ratio calculation examples), the value of I(t) was calculated by doing a numeric approximation method, because I(t) is a function of itself. In this part, one calculation example will be given for finding the value of I(t) by using Excel. The values found for the rest intervals follow the same principle.

2.4 Table 1. I(t)

[t;t+0.1]	T sec	E(t) volt	I(t) A	F(I(t))
[0;0,1]	0.1	0.375118789	0	-0.87999999
		0.375118789	0.88	2.3778E-05
		0.375118789	0.44	-0.43999925
		0.375118789	0.66	-0.21999576
		0.375118789	0.77	-0.10998996
		0.375118789	0.825	-0.05498454
		0.375118789	0.8525	-0.02748083
		0.375118789	0.86625	-0.01372865
		0.375118789	0.873125	-0.00685247
		0.375118789	0.8765625	-0.00341435
		0.375118789	0.87828125	-0.00169529
		0.375118789	0.879140625	-0.00083576
		0.375118789	0.879570313	-0.00040599
		0.375118789	0.879785156	-0.00019111
		0.375118789	0.879892578	-8.3664E-05
		0.375118789	0.879946289	-2.9943E-05
		0.375118789	0.879973145	-3.0822E-06
		0.375118789	0.879986572	1.0348E-05
		0.375118789	0.879979858	3.6329E-06
		0.375118789	0.879976501	2.7537E-07
		0.375118789	0.879974823	-1.4034E-06
		0.375118789	0.879975662	-5.6402E-07
		0.375118789	0.879976082	-1.4432E-07
		0.375118789	0.879976292	6.5525E-08
		0.375118789	0.879976187	-3.9398E-08
		0.375118789	0.879976239	1.3063E-08
		0.375118789	0.879976213	-1.3167E-08
		0.375118789	0.879976226	-5.2016E-11
		0.375118789	0.879976233	6.5057E-09
		0.375118789	0.879976229	3.2268E-09
		0.375118789	0.879976228	1.5874E-09
		0.375118789	0.879976227	7.677E-10
		0.375118789	0.879976227	3.5784E-10

The formula used in Excel was the following one:

F(I(0,1)) = I(0,1)+(10^-8)*(EXP((E(0,1)+I(0,1) *3.32)/(1.1*15*0.0257))-1)-0.88 = 0



The expression has to be made equal to 0 in order to apply the bisection method. The value of I(t) will be between 0 and 0,88A (I_{sc}). The starting point being 0A and the maximum being 0,88A; we find the average between these two values and we observe if F(I(t)) is a positive or negative value. If F(I(t))is negative, we take the previous value of I(t) that gave a positive F(I(t)), we add it to this actual I(t) and we divide it by two to find the average between both. If the value of F(I(t)) obtained is still negative, we continue doing the same until we get a positive F(I(t)). When we get a positive F(I(t)), we apply the same procedure, but this time we use the previous value of I(t) that gave a negative F(I(t)).

Once the I(t) value does not get more precise and stays constant, we can say that we found the approximate value of I(t).

Same procedure was used for following intervals:

(0,1-0,2)

$a(0,2) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,2) \times E(0,2)/(M \times v(0,2)) - 3C_wA\rho \times v^2(0,2)/2M = 1,751383593$

$v(0,2) = v(0,1) + a(0,1) * t = 0,351603794$

$s(0,2) = s(0,1) + v(0,1) *t + a(0,1)* t^2/2 =0,035169901$

$E(0,2) = C_E.\Phi \times 60 \times v(0,2) \times \text{gear ratio} /(2\pi r) =0,749831482$

$I(0,2) = I_{sc} - I_s.(e^{E(0,2) + I(0,2).Ra/M.N.Ur} - 1) =0,87995$

(0,2-0,3)

$a(0,3) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,3) \times E(0,3)/(M \times v(0,3)) - 3C_wA\rho \times v^2(0,3)/2M = 1{,}741904237$

$v(0,3) = v(0,2) + a(0,2) * t = 0{,}526742153$

$s(0,3) = s(0,2) + v(0,2) *t + a(0,2)* t^2/2 = 0{,}079087198$

$E(0,3) = C_E.\Phi \times 60 \times v(0,3) \times \text{gear ratio} /(2\pi r) = 1{,}123332161$

$I(0,3) = I_{sc} - I_s.(e^{E(0,3) + I(0,3).Ra/M.N.Ur} - 1) = 0{,}87987$

(0,3-0,4)

$a(0,4) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0) \times E(0,4)/(M \times v(0,4)) - 3C_wA\rho \times v^2(0,4)/2M = 1{,}72853719$

$v(0,4) = v(0,3) + a(0,3) * t = 0{,}700932577$

$s(0,4) = s(0,3) + v(0,3) *t + a(0,3)* t^2/2 = 0{,}140470934$

$E(0,4) = C_E.\Phi \times 60 \times v(0,4) \times \text{gear ratio} /(2\pi r) = 1{,}494811268$

$I(0,4) = I_{sc} - I_s.(e^{E(0,4) + I(0,4).Ra/M.N.Ur} - 1) = 0{,}87967$

(0,4-0,5)

$a(0,5) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,5) \times E(0,5)/(M \times v(0,5)) - 3C_wA\rho \times v^2(0,5)/2M = 1{,}711087091$

$v(0,5) = v(0,4) + a(0,4) * t = 0{,}873786296$

$s(0,5) = s(0,4) + v(0,4) *t + a(0,4)* t^2/2 = 0{,}219206878$

$E(0,5) = C_E.\Phi \times 60 \times v(0,0,5) \times \text{gear ratio} /(2\pi r) = 1{,}863439715$

$I(0,5) = I_{sc} - I_s.(e^{E(0,5) + I(0,5).Ra/M.N.Ur} - 1) = 0{,}879211$

(0,5-0,6)

$a(0,6) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,6) \times E(0,6)/(M \times v(0,6)) - 3C_wA\rho \times v^2(0,6)/2M = 1{,}688957991$

$v(0,6) = v(0,5) + a(0,5) * t = 1{,}044895005$

$s(0,6) = s(0,5) + v(0,5) *t + a(0,5)* t^2/2 = 0{,}315140943$

$E(0,6) = C_E.\Phi \times 60 \times v(0,6) \times \text{gear ratio} /(2\pi r) = 2{,}228346747$

$I(0,6) = I_{sc} - I_s.(e^{E(0,6) + I(0,6).Ra/M.N.Ur} - 1) = 0{,}87815$

(0,6-0,7)

$a(0,7) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,7) \times E(0,7)/(M \times v(0,7)) - 3C_wA\rho \times v^2(0,7)/2M = 1{,}660755318$

$v(0,7) = v(0,6) + a(0,6) * t = 1{,}213790804$

$s(0,7) = s(0,6) + v(0,6) *t + a(0,6)* t^2/2 = 0{,}428075233$

$E(0,7) = C_E.\Phi \times 60 \times v(0,7) \times \text{gear ratio} /(2\pi r) = 2,58853452$

$I(0,7) = I_{sc} - I_S.(e^{E(0,7) + I(0,7).Ra/M.N.Ur} - 1) = 0,87575$

(0,7-0,8)

$a(0,8) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,8) \times E(0,8)/(M \times v(0,8)) - 3C_w A\rho \times v^2(0,8)/2M = 1,623670864$

$v(0,8) = v(0,7) + a(0,7) * t = 1,379866336$

$s(0,8) = s(0,7) + v(0,7) * t + a(0,7) * t^2/2 = 0,55775809$

$E(0,8) = C_E.\Phi \times 60 \times v(0,8) \times \text{gear ratio} /(2\pi r) = 2,942707781$

$I(0,8) = I_{sc} - I_S.(e^{E(0,8) + I(0,8).Ra/M.N.Ur} - 1) = 0,870583$

(0,8-0,9)

$a(0,9) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,9) \times E(0,9)/(M \times v(0,9)) - 3C_w A\rho \times v^2(0,9)/2M = 1,573103531$

$v(0,9) = v(0,8) + a(0,8) * t = 1,542233422$

$s(0,9) = s(0,8) + v(0,8) * t + a(0,8) * t^2/2 = 0,703863078$

$E(0,9) = C_E.\Phi \times 60 \times v(0,9) \times \text{gear ratio} /(2\pi r) = 3,288972398$

$I(0,9) = I_{sc} - I_S.(e^{E(0,9) + I(0,9).Ra/M.N.Ur} - 1) = 0,860334$

(0,9-1,0)

$a(1) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(1) \times E(1)/(M \times v(1)) - 3C_w A\rho \times v^2(1)/2M = 1,503836129$

$v(1) = v(0,9) + a(0,9) * t = 1,699543775$

$s(1) = s(0,9) + v(0,9) * t + a(0,9) * t^2/2 = 0,865951938$

$E(1) = C_E.\Phi \times 60 \times v(1) \times \text{gear ratio} /(2\pi r) = 3,624453009$

$I(1) = I_{sc} - I_S.(e^{E(1) + I(1).Ra/M.N.Ur} - 1) = 0,842324$

2.5 TIME INTERVAL (t = 0,2s)

(0-0,2)

$a(0,2) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,2) \times E(0,2)/(M \times v(0,2)) - 3C_w A\rho \times v^2(0,2)/2M = 1,751375488$

$v(0,2) = v(0) + a(0) * t = 0,35179422$

$s(0,2) = s(0) + v(0) * t + a(0) * t^2/2 = 0,035179422$

$E(0,2) = C_E.\Phi \times 60 \times v(0,2) \times \text{gear ratio} /(2\pi r) = 0,750237579$

$I(0,2) = I_{sc} - I_S.(e^{E(0,2) + I(0,2).Ra/M.N.Ur} - 1) = 0,87995$

(0,2-0,4)

$a(0,4) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,4) \times E(0,4)/(M \times v(0,4)) - 3C_wA\rho \times v^2(0,4)/2M = 1,728440682$

$v(0,4) = v(0,2) + a(0,2) * t = 0,702069314$

$s(0,4) = s(0,2) + v(0,2) * t + a(0,2) * t^2/2 = 0,140565775$

$E(0,4) = C_E.\Phi \times 60 \times v(0,4) \times \text{gear ratio} /(2\pi r) = 1,497235479$

$I(0,4) = I_{sc} - I_s.(e^{E(0,4) + I(0,4).Ra/M.N.Ur} - 1) = 0,87967$

(0,4-0,6)

$a(0,6) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,6) \times E(0,6)/(M \times v(0,6)) - 3C_wA\rho \times v^2(0,6)/2M = 1,688552863$

$v(0,6) = v(0,4) + a(0,4) * t = 1,047757451$

$s(0,6) = s(0,4) + v(0,4) * t + a(0,4) * t^2/2 = 0,315548451$

$E(0,6) = C_E.\Phi \times 60 \times v(0,6) \times \text{gear ratio} /(2\pi r) = 2,234451209$

$I(0,6) = I_{sc} - I_s.(e^{E(0,6) + I(0,6).Ra/M.N.Ur} - 1) = 0,87813$

(0,6-0,8)

$a(0,8) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(0,8) \times E(0,8)/(M \times v(0,8)) - 3C_wA\rho \times v^2(0,8)/2M = 1,622215271$

$v(0,8) = v(0,6) + a(0,6) * t = 1,385468023$

$s(0,8) = s(0,6) + v(0,6) * t + a(0,6) * t^2/2 = 0,558870999$

$E(0,8) = C_E.\Phi \times 60 \times v(0,8) \times \text{gear ratio} /(2\pi r) = 2,95465396$

$I(0,8) = I_{sc} - I_s.(e^{E(0,8) + I(0,8).Ra/M.N.Ur} - 1) = 0,87034$

(0,8-1,0)

$a(1) = g(\sin(\alpha) - \cos(\alpha) \times Crr) + I(1) \times E(1)/(M \times v(1)) - 3C_wA\rho \times v^2(1)/2M = 1,498408732$

$v(1) = v(0,8) + a(0,8) * t = 1,709911077$

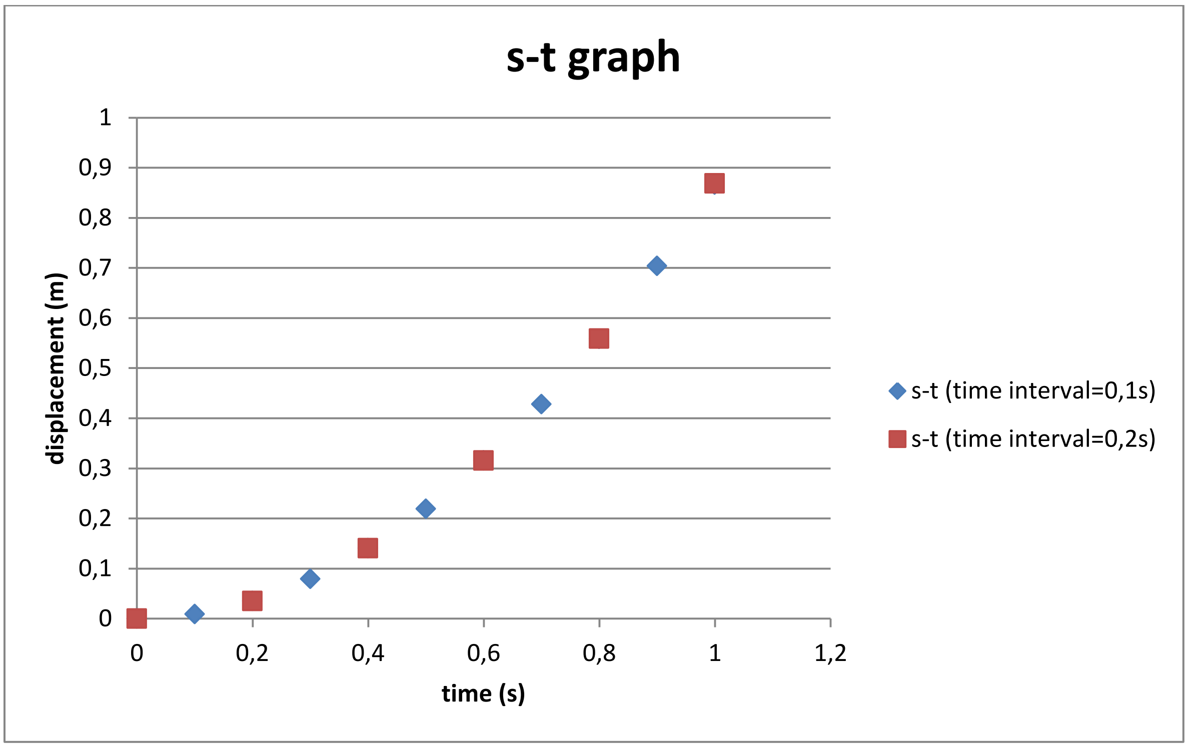
$s(1) = s(0,8) + v(0,8) * t + a(0,8) * t^2/2 = 0,868408909$

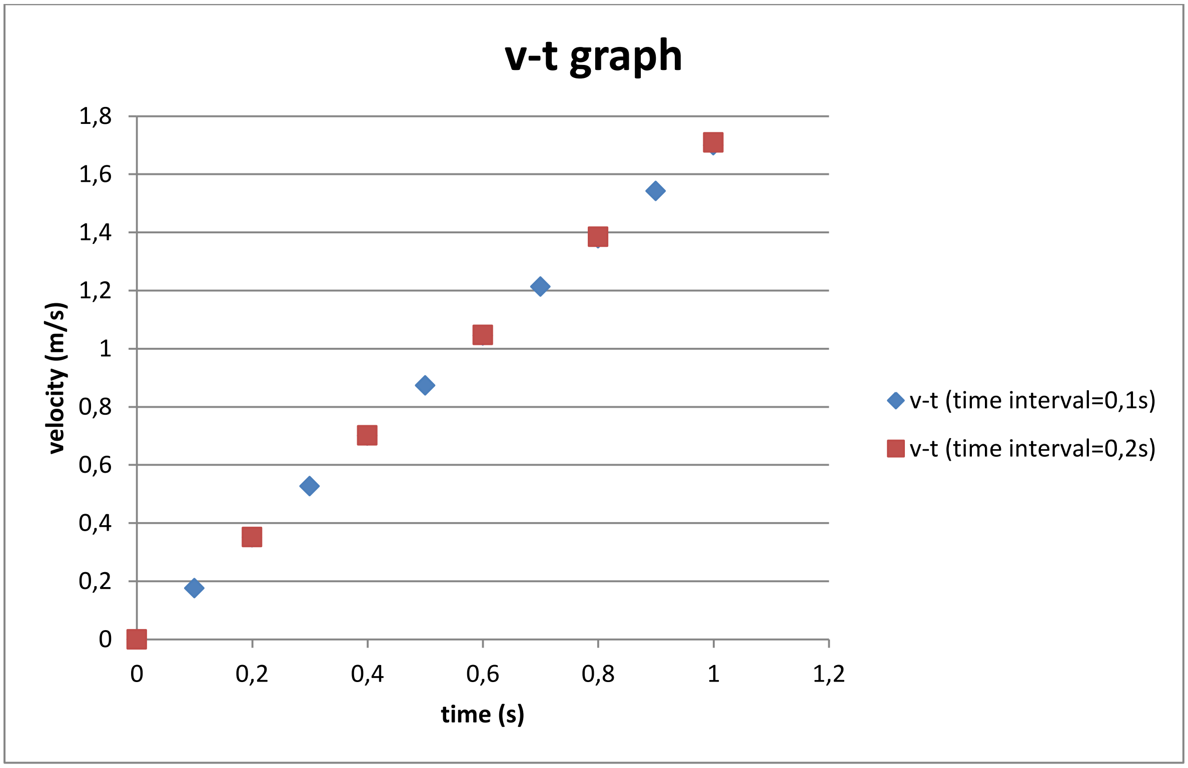
$E(1) = C_E.\Phi \times 60 \times v(1) \times \text{gear ratio} /(2\pi r) = 3,646562354$

$I(1) = I_{sc} - I_s.(e^{E(1) + I(1).Ra/M.N.Ur} - 1) = 0,840782$

2.6 Conclusion

t(s)	s(T=0,1s)	s(T=0,2s)	v(T=0,1)	v(T=0,2)
0	0	0	0	0
0,1	0,00879486		0,17589711	
0,2	0,0351699	0,03517942	0,35160379	0,35179422
0,3	0,0790872		0,52674215	
0,4	0,14047093	0,14056577	0,70093258	0,70206931
0,5	0,21920688		0,8737863	
0,6	0,31514094	0,31554845	1,044895	1,04775745
0,7	0,42807523		1,2137908	
0,8	0,55775809	0,558871	1,37986634	1,38546802
0,9	0,70386308		1,54223342	
1	0,86595194	0,86840891	1,69954378	1,70991108





If we compare these two situations, the table above shows that there is slightly difference. This happens because we assumed the acceleration to be constant in both case with different time interval which are small but not infinitesimal small enough to avoid the error. Thus, the smaller your interval is, the smaller is your error, and the bigger the interval is, the bigger is your error. All this is due to the effect of instantaneous characteristics.

3 The Sankey Diagram

The sankey diagram will give us an estimation of energy flow through our SSV. We put into consideration all the possible causes of loss and gain of power.

The maximum power the sunlight can give our solar panel can be found by light intensity of the sun. If we assume that our race takes place during a bright sunny day we can take sunlight intensity is around 800 W/m^2 according to Belgium's latitude.

Using the area of solar panel we find the maximum power we can gain from the sun.

$$800\, W/m2\ \times (0.078m \times 0.039m \times 16)$$

38.93 watt

3.1. For the motor

$U = E + Ia.Ra$

$\omega = \frac{V}{r}$ V = 1.64 and r =0.04m.

$\omega = \frac{1.64\ m/s}{0.04}$ = 41 rad/s

By using the angular speed we can find out how the gear ratio will multiply speed

41 rad/s × 11 = 451 rad /s

For the counter EMF , we already found the angular speed so we can just easily substitute the formula

E= Ke*ω

E=0.0085 × 451 = 3.83 V

Too find the maximum current we make use of the current formula, we need the amount of current that will be drawn when the solar panel gives maximum power. The current in this case is 0.83 A.

For the armature voltage, we have the current and terminal resistance so we can simply exchange the numbers in the formula.

Va =Ia. Ra

3.32×0.83=2.76 V

U= E+ Ia. Ra

2.76+3.83=**6.58**

Power drawn by the motor

6.58V × 0.83A = **5.47**watt

3.2. Efficiency of solar panel

The efficiency of the solar panel is determined by how much sunlight it will absorb and convert it to useful electricity which will be used for our motor. The maximum power we can collect from the sun is 38.93 watt and our motor use around 5.47 watts. The efficiency is

$$\eta = \frac{5.47}{38.93} \times 100\ \% = 14.05\ \%$$

There is a loss of 85.95 % , this is mainly due to reflection and heat that the small solar panel glasses cause. Only 14.05 % is converted into useful electricity.

3.3. Loss on the motor

Motor has an efficiency of 86%

5.47×0.14=0.77 *W*

This leaves us with 4.7 watt which will be transferred to the gears.

3.4. Gear loss

If we assume we design and make a good gear with little error we can say our gear efficiency to be around 90%

$4.7 \times 0.1 = 0.47W$

The power that left after the gear loss will be 4.23W.

3.5. Loss on rolling resistance

Fr= $M \times Crr \times g$

Where $M=0.756$ kg , $Crr=0.008$, $g=9.81m/s^2$

Fr=0.059 W

The power loss P= $0.059 \times 1.64 = 0.097W$

3.6. Aerodynamic Loss

$Fw= ½ \cdot Cw \cdot A \cdot \rho \cdot v^2$

P=1.23 kg , A= 0.39 m^2 , Cw=0.82 , V=1.624m/s

Fw=0.518 N

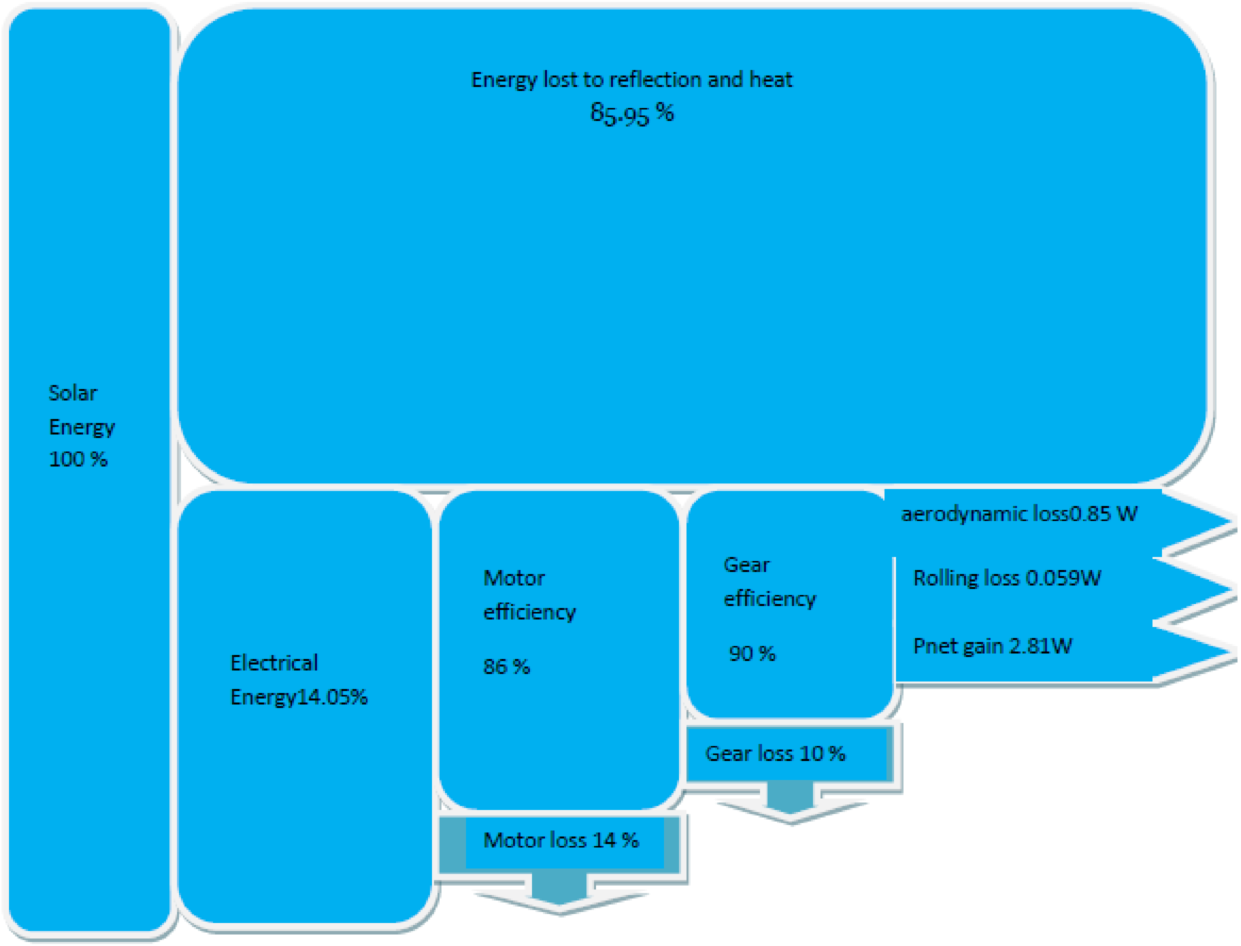
Power loss P=$0.518 \times 1.64 = 0.85W$

3.7. Net Power gain

Pnetg = 4.23-0.85-0.097-0.47

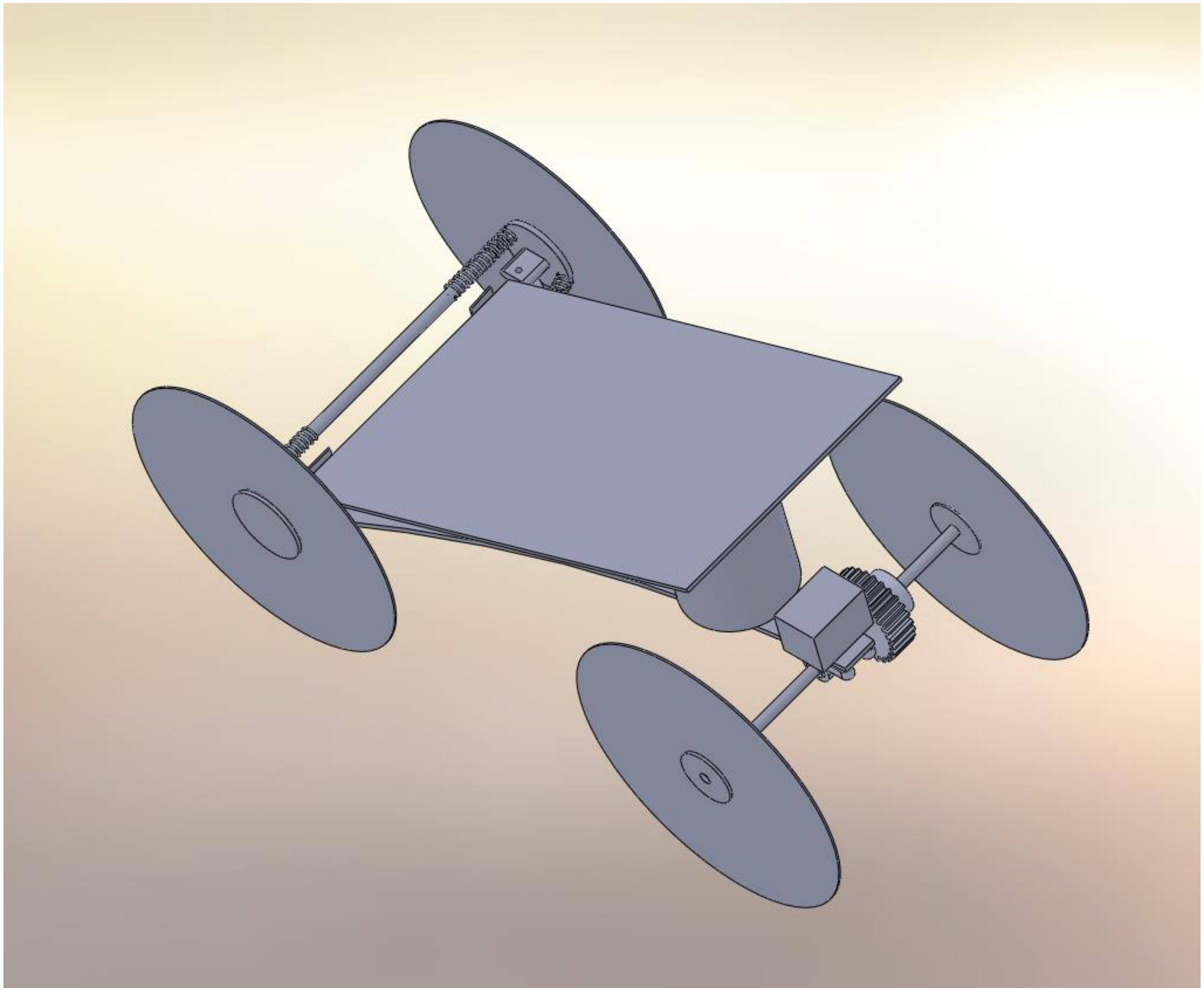
2.81Watt

3.8 Diagram



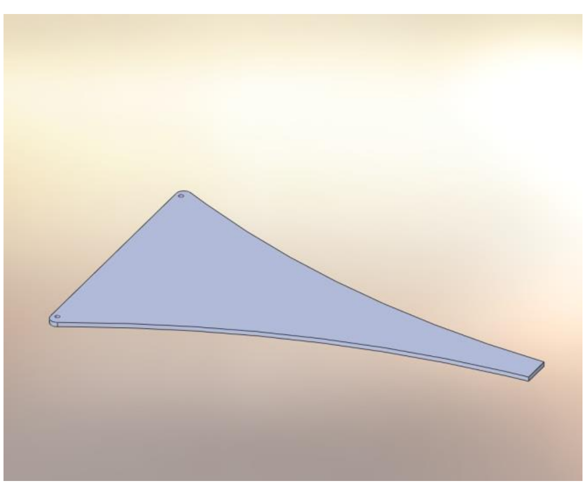
Energy lost to reflection and heat
85.95 %
Solar
Energy
100 %
aerodynamic loss0.85 W
Rolling loss 0.059W
Pnet gain 2.81W
Gear
efficiency
90 %
Motor
efficiency
86 %
Electrical
Energy14.05%
Gear loss 10 %
Motor loss 14 %

4. Designing SSV



4.1 The Elements of the SSV

4.1.1 The Frame



While designing the frame, we were looking for a material that combines light weight, strength and easy modelling. While first considering the material available from Fablab Leuven, we were considering both Plexiglas and MDF, however while Plexiglas has a rather low specific tensile strength compared to the weight, MDF troubled us, as it is not only a broad term, so we would not know the precise characteristics. Also, MDF is not very resistive to water, and as we are considering using glue, this might prove to be a problem.
So we broadened our search to other common material for model building and found Balsa wood. As shown in table below, it shows an outstanding strength-to-weight ratio. As it is also easily processed, this is our number one choice for the frame.

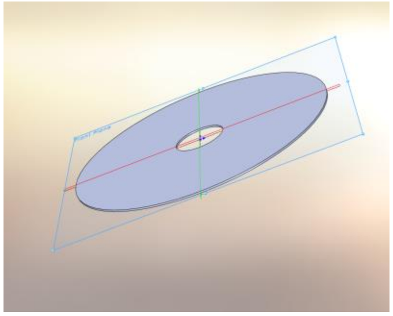
Material	Young's Modulus	Density	Yield Strength	Specific Tensile Strength
Plexiglas	3210 MPa	1190 kg/m³	80 Mpa	67.2 kNm/kg
Triplex (ply wood)	12400 MPa	615 kg/m³	/	/
Balsa	1130 – 6000 MPa	150 kg/m³	0-75 Mpa (avg. 37.5 Mpa)	250 kNm/kg
Aluminium	70000 Mpa	2702 kg/m³	600 MPa	222 kNm/kg

"Engineering Experience 4: Design a Small Solar Vehicle/Nl/Team PM7/Design rapport - Wikiversity". Bezocht 22 maart 2013. http://en.wikiversity.org/wiki/Engineering_Experience_4:_Design_a_Small_Solar_Vehicle/Nl/Team_PM7/Design_rapport#Het_zonnepanee

"Balsa Facts". Bezocht 22 maart 2013. http://www.mat.uc.pt/~pedro/ncientificos/artigos/techbal.html.

The specific form was chosen, to give enough strength, while limiting weight. We decided to give it the shape of a filled triangle, as we can make it then from one piece, while while a hollow frame would increase the risks of the wood breaking along the fibres.

4.1.2 The Wheels



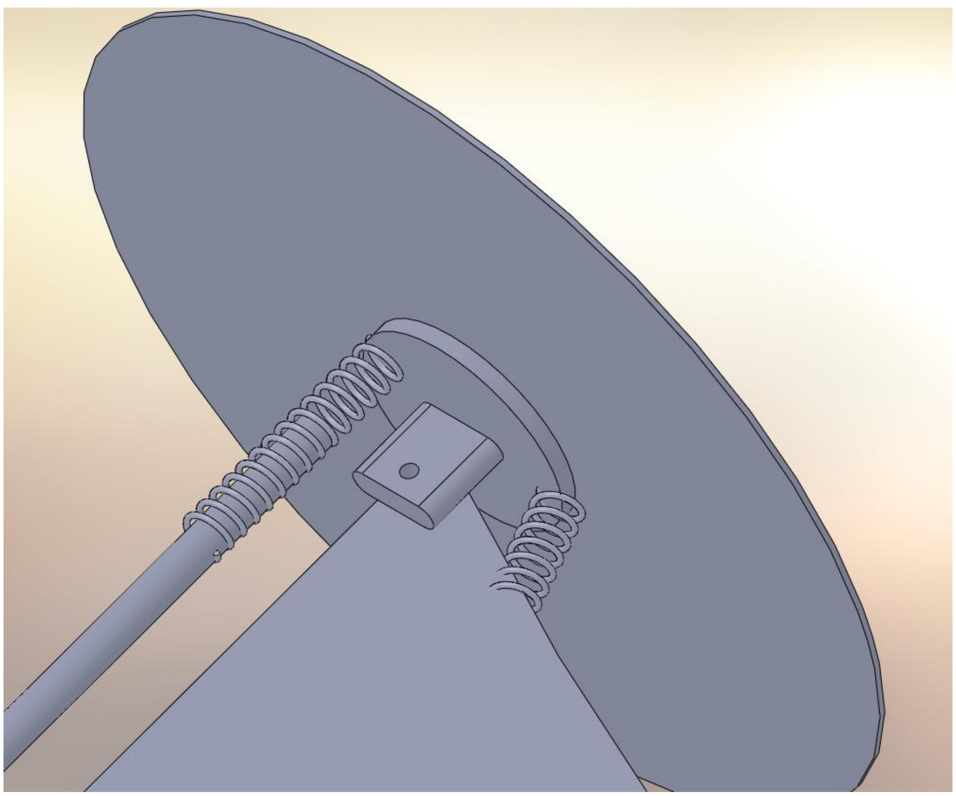
For the design of the wheels we looked for something simple, yet good. After considering several possibilities, we decided on settling for a 4 wheeled, rear driven car, as this complements the square shape of the solar panel and will survive a possible crash with the race track borders.

For wheels, we settled for simple Mini-CD's, as we saw several advantages in them:

- They are readily available and cheap.
- They are built to norm, their shape will be as close to perfect, as possible.
- They are lightweight, yet strong and have little rotational inertia.
- Their shape allows little air resistance.
- Friction will be limited, due to the small surface touching the ground. As the tracks are made from rubber, this is exactly what we want. In case the friction turns out to be too little, the CDs can easily be modified by applying sticky fluids (hair spray, coke,…) or by stretching a rubber balloon over the CDs.

To attach the back wheels to the axle, we will use rubber spacers, that are tightly fit, so that axle and wheel are firmly attached. A drop of glue can enhance the rigid connection.

4.1.3 The Front

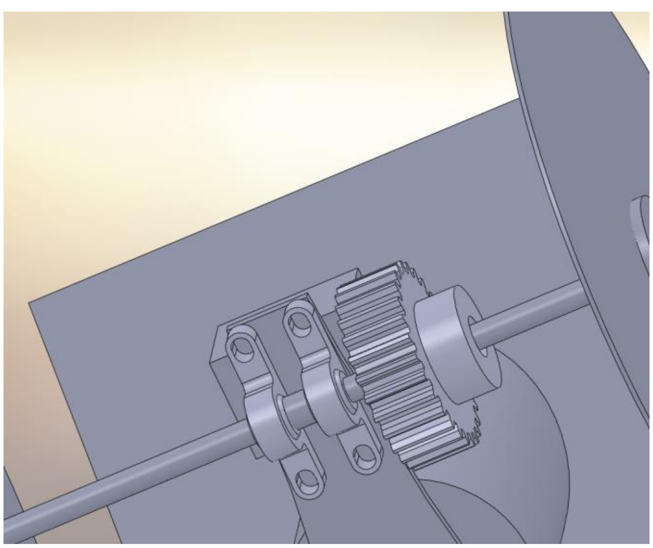


The front wheels are attached in a more complex way. Each wheel will be rotating a separate axis, that is attached via a pin connection to the main frame. The Pin will made by a double screw, as shown in the picture.

“Deutsch Duden online >> schrauben”. Bezocht 22 maart 2013. http://worterbuchmitbedeutung.com/schrauben.

One spring will connect each axle part to the mainframe, helping the wheel to stay in parallel to the moving direction. Another spring will make a connection to a light bamboo stick, that spans across the front of the SSV, connection both frontal axles.
The springs will be standard helical springs, as can be found in ball pens, for example. Due to the odd shape, the axle and connection part will probably be made using the 3D-printer from Fablab Leuven.
This construction will ensure, that if the SSV crashes against the railing, one of the front wheels will hit the wall. Because of the spring system, both wheels will then turn, due to the bamboo connection, stretching the back springs and forcing the vehicle to become parallel aligned again. The vehicle will then continue to drive along the railings, until it finishes.

4.1.4 The Back Axle

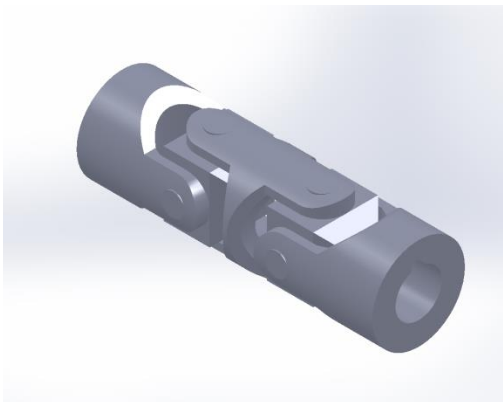


The rear axle will be firmly attached to the back wheels, and rotating in two Pillow Block Bearings, that are attached to the main frame. To keep the axle in place, a plastic spacer

will be placed between the two bearings and rigidly attached to the axle. On one side of the main frame, the driven gear will be attached to the axle, creating the rotation.
As material we are opting for an aluminium axle. Though brass is commonly used in model building due to lower costs, and stainless steel has a higher tensile strength, we chose aluminium, as it also incorporates a high specific strength, just allowing the axle to be light.

http://en.wikipedia.org/wiki/Specific_strength

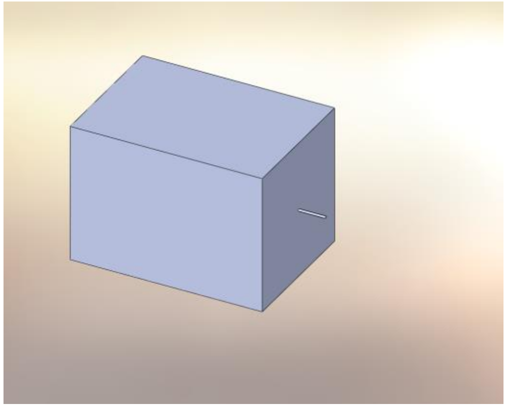
4.1.5 The Solar Panel



The solar panel will be supported by the main frame in the front, keeping it in place by two brackets, attached to the main frame. The Solar panel will then be propped up in an adjustable angle by a Double Cardan Joint. This will allow us, to adjust the angle of the panel depending on the position of the sun, while at the same time having a closed frontal area, reducing drag forces. Our expected angle will be at around 35° for a race in Belgium, facing southern direction.

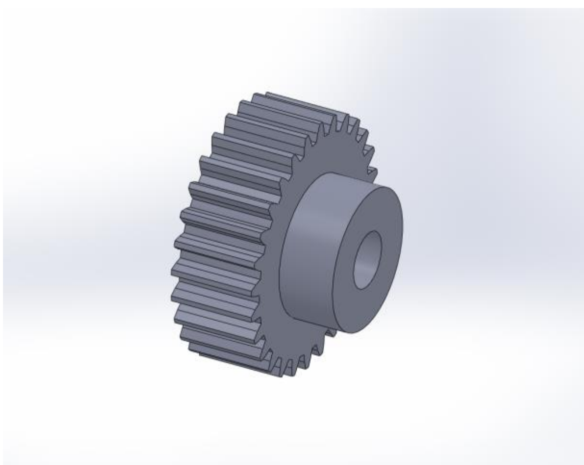
http://www.zonnecellen.be/faq/v3.htm

4.1.6 The Motor



The Motor will be attached at the rear, so that it can drive the back axle just connecting with two gears. For attaching we will make a small housing from balsa wood, keeping the motor in place.

4.1.7 The Gears



The gears will also be printed in the Fablab, as this allows us, to be independent of the prices and delivery times of other suppliers, while at the same time giving us the possibility, to have the gears be custom made, so that they will fit exactly on the motor shaft and on the axle, while having the optimum gear ratio.
The driven gear might be design with a longer inner cylinder, as shown on the picture. This will us to have a bigger fixation surface with the axle.

4.2 The Total Weight

In the following table are all the items listed, that we expect to use in the SSV. This will give us an approximation of the total weight. The weight for each element is either known for a specific type of the element (Solar Panel, Bearing,...) or approximated (frame, glue,...) using the characteristics of the material and the dimensions of the element.

ITEM	AMOUNT	WEIGHT (g)
Frame	1	15
Mini-CDs	4	6,913
Front Connector	1	3
Back Axle	1	9
Solar Panel	1	370
Motor	1	54
Driving Gear	1	5
Driven Gear	1	30
Springs	4	1
Pillow Block Bearing	2	2,88
Double Cardan Joint	1	1,68
Plugs	2	1
Front System	2	50
Front Pin	2	3,5
Bracket	2	2
Glue	1	3
	Total	639,092

As this is below the required minimum weight of 0,75 kg we leave us the option open to use a heaver material for the frame, to add extra material for style purposes or strategically placed weights.

"Engineering Experience 4: Design a Small Solar Vehicle/Nl/Team PM7/Design rapport - Wikiversity". Bezocht 22 maart 2013. http://en.wikiversity.org/wiki/Engineering_Experience_4:_Design_a_Small_Solar_Vehicle/Nl/Team_PM7/Design_rapport#Het_zonnepaneel.

"Mouse Trap Cars | Mousetrap Car Winning Secrets | CD Wheels". Bezocht 22 maart 2013. http://www.docfizzix.com/topics/construction-tips/Mouse-Trap-Cars/using-cds.shtml.

4.3 Forces

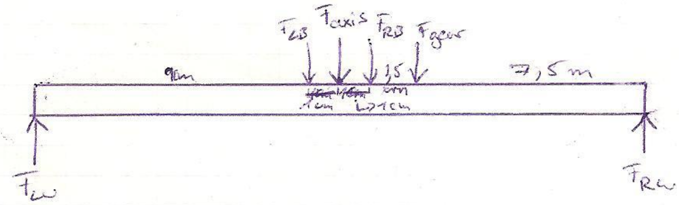
In designing models of products, the analysis of the force distribution is extremely important.

This can help for a lot of things, like estimation of power usage, behaviour alculation, like speed, and also choice of materials. As an example, we will show here, what shear forces and moments act on the back axle of the SSV. With those results we can compare shear stresses with the caracteristics of materials, and hence figure out what amount of what material needs to be used, to withstand those forces.

The forces acting on our axle are:

- Normal forces by the wheels
- Mass of axle * gravity
- Mass of gear * gravity
- Mass of (frame, solar panel,... devided over front and back axles) * gravity

Force Diagram of Back Axle



Assumptions: $g = 9{,}81\ m/s^2$

$$F_{axle} = 9{,}81\ m/s^2 \cdot 0{,}01\ kg = 0{,}0981\ N$$

$$F_{gear} = 9{,}81\ m/s^2 \cdot 0{,}03\ kg = 0{,}2943\ N$$

$$F_{LB} = F_{RB} = \frac{1}{2}\Big(\underbrace{\frac{1}{3}\cdot\frac{15}{1000} + \frac{100}{1000} + \frac{200}{1000}}_{\text{frame, solar panel, motors, ...}}\Big)\cdot 9{,}81\ m/s^2 = 1{,}5\ N$$

$$F_{LW} = F_{RW}$$

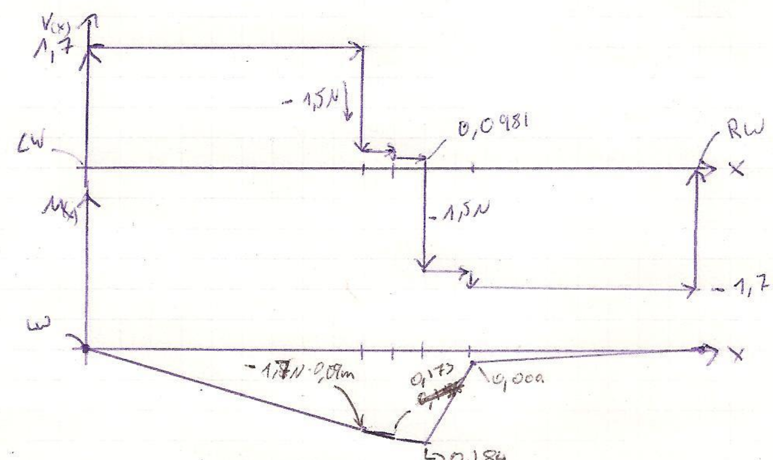
We can calculate F_{LW} and F_{RW} by $\Sigma F_y = 0$

$$F_{LW} + F_{RW} = F_{axle} + F_{gear} + F_{LB} + F_{RB}$$

$$F_{LW} = F_{RW} = \cancel{0{,}8} \cdot \cancel{1{,}496}\ \cancel{1{,}888\ N} = 0{,}5 \cdot 3{,}3924\ N$$

$$= \cancel{0{,}94\ N}\ 1{,}6962\ N$$

With these information, we can calculate the shear forces and moments in every part of the axle. The results give us the following diagrams:



→ Maximum shear force is 1,7 N

→ maximum moment is 0,184 Nm

Conventions