GROEP T
INTERNATIONALE HOGESCHOOL LEUVEN

SSV Case II

WEIGHT LIGHT

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Building a small solar vehicle
Lightweight

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Foreword

After a lot of hard work and having met several times a week, the first part of our small solar vehicle, or in short SSV, has been finished successfully. Not only the calculation of every small detail of the SSV was an extremely hard task but also a real experience to extend our knowledge as an engineer. It demanded knowledge of the theory, practice and a lot of persistence.

We don't want to take all the credit because our SSV wouldn't have come to this point without the help of the four coaches. Therefore we want to give a special thanks to Pauwel Goethals, Tan Ye, Yunhao Hu and Pieter Spaepen. These coaches gave a weekly seminar with the information on how to build a SSV. But we want to thank in particular Tan Ye because he was our personal coach who helped us greatly along the way.

Besides the four coaches we also want to thank Marc Lambaerts, FabLab manager, who gave an important and informative session about FabLab. FabLab is the Fabrication Lab where we will build a lot of parts for the SSV.

The project was not an easy project, it was a lot of blood sweat and tears but it was an enormous experience to complete as a student.

We hope you enjoy our report.

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Resume

In this rapport the impact test is discussed, we want to see how the SSV will react during a collision. Parameters are compared with measurements found in case I.

There is also a Sankey diagram created, where it is possible to see the losses. It is very interesting to see the different losses and see where improvements are possible.

A 2D drawing is added to the report. The drawing gives a view on how our SSV-frame developed, and which dimensions it has. The maximum forces in the frame and in weak places are calculated, to get an idea how great a force can be before the car brakes.

At the end there is an exercise we had to solve about the collision of three masses in total. This can be compared to with the car colliding with the ball.

Introduction

The small solar vehicle, SSV, is a small car entirely driven by solar energy which has to resist multiple impacts with a steel ball. This car was built in account of the EE4 project and has multiple goals. Like mentioned before it has to resist multiple impacts but that's not the only or main goal. The SSV has to be a pièce de resistance, a real masterpiece on different levels. These levels are: innovation, speed, strength and looks.

The EE4 project is a project with the motto 'Make stuff work'. As future engineers this is an important part of our set of skills which makes the project of greater value for the students. Not only the part of making stuff work is important but also having the background of different fields of science is crucial like: aerodynamics, dynamics, strength of material, technology of materials, algebra, and energy. These fields will stand out throughout the report.

The needs of all these fields are explained quit easily by explaining the project. The SSV will compete in a race in which it has to accelerate as fast as possible. After having accelerated for 10 meters the car has to face a metal ball of 735 grams which it will have to push as high as possible on a ramp. The car cannot break because it has to compete in multiple races. All the different fields are needed to create this SSV.

The race shows only one of the two important criteria of becoming the best SSV. Like mentioned before, the SSV has to be a pièce de resistance. Therefore it has to look good. This is the second criteria it will be quoted on. The entire design but also the appearance is a crucial part.

This report is written by the members of the team Light Weight who will try to fascinate you with their masterpiece.

This cases deals with the actual build of the SSV as well as the tests that needed to be performed to see if car will perform good on the day of the race.

1. Impact test

The car is tested with a Piëzo-electrometer to test its reaction upon impact.

1.1 The test

To get an idea about the forces that will impact on the car during the collision, there was a small impact test. This test consists of a weight of 750 grams, which is about the same as the ball that will hit the car. The weight is attached with a rope to a wooden construction. The mass was pulled up to a certain height and released in order to get a collision with the SSV. The same test could be done when we let the car ride against the mass, but we only did the first test.

Figure 1 Wooden construction

To get some information about this test, there was a Piëzo-electrometer attached to the mass. The Piëzo-electrometer can register vibrations, by the difference in voltage that varies with the collision. The Piëzo meter measures the voltage every 1e-5 of a second.

1.1.1 Specifications Piëzo-electrometer

Sensitivity: 56, mv/KN

This is the voltage output per kilo Newton (unit of force). The amplitude of the AC signal will correspond to the amplitude of the vibration measured. The proportion is the same.

Electric/spectral noise:
This parameter depends on the force supplied to the Piëzo-meter. Low forces will have a lot of noise, which means that there is a large error.

Maximum static force: 133.44 kN
This is not the maximum dynamic force. It's the static force that can be applied. Important to note is that the Piëzo-meter can't measure a static force. It generates an electrostatic field which will empty after a certain amount of time (discharge time > 2000sec). That means that the static force will decrease for the Piëzo-meter after 2000sec while it is still there.

Before the signal is sent to the DAQ (data acquisition) , the amplifier amplifies the signal by a factor of 100. After the amplification of the signal, the amplitude of the noise will be 10 times higher. It gives a better margin of error and is more precise. Now we can see the differences on the graph better. The DAQ will process the information to a program, where the voltages are registered and plotted.

Figure 2 On the left amplifier, on the right the DAQ

Thousands of signals were registered and plotted into a graph. The test was executed three times and each graph has got the same shape and the three same peaks. The three peaks mean that the mass will have 3 times contact during one collision. We can't see these contacts. The expectation was that the first peak would be the highest, during the first contact because the most energy is transferred. But on the graph there is a smaller peak first. There is a hypothesis for that: the accelerometer is attached to the mass and during the collision the mass will have some delay. The Piëzo hits the ball first and that is the first peak, after that, the mass joins the Piëzo-meter that is the second peak. So the first peak is the collision of the SSV with only the meter and the second peak is the collision of the SSV with the Piëzo-meter plus the mass (which had some delays during the first peak).

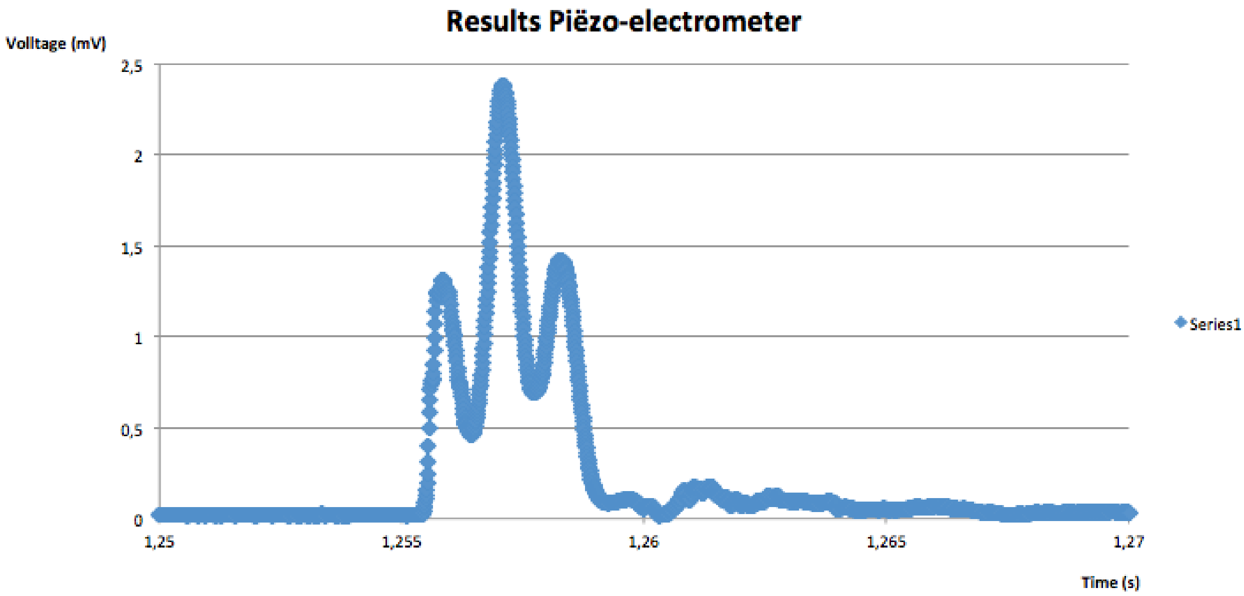


Figure 3 Results Piëzo-electrometer

Besides the measurements from the Piëzo-electrometer, the length of rope (L) and the distance (X) from the mass to the SVV were measured.

L = 1.2m
X1 = 0.25m
X2 = 0.54m
X3 = 0.97m

1.2 Coefficient of restitution

The coefficient of restitution can be determined out of the graph. The highest peak is at 2.3V and at this moment the largest energy is transferred. After the first peak there is an action-reaction moment, some of the energy will be lost. The last peak measures 1.4 V, this is the moment when the car leaves the mass. The ratio of these measurements will approach the Coefficient of restitution. We take measurements of the last because this is the most significant. Because the restitution coefficient is dependent on the forces you apply on the object. A low force isn't significant for the calculations because the error will be higher, the higher the force the more accurate the results will be (but it's important the Piëzo or SSV doesn't brake).

$$Cr = \frac{1.4}{2.3} = 0.60$$

If we compare this with the result we did in case SSV 1 where the Cr was 0.85, we can conclude that this is an ok result but there are still some error. For example: the Piëzo-meter didn't hit the ball in the exact centre of the ball which will cause a less accurate result. The golf ball is in fact a good object to hit the steel ball, it won't absorb all of the energy and also damps the collision a little.

1.3 Speed of the car

Based on the information it is possible to calculate the speed of the car after it has been hit by the mass. In the beginning the mass only has potential energy, the car will receive a kinetic energy from the weight. By the law of conservation of energy we can calculate the speed of the car.

$$\frac{m \cdot V^2}{2} = m \cdot g \cdot h$$

m = mass of weight = 0.750 kg
V = speed of the car
M = mass of SSV = 1.5 kg
g = gravity constant = 9.81 N/kg
h = height of the ball

The height of the ball can be calculated with Pythagoras, the length of the rope (longest side = 1.2m) and the distance between the mass en vehicle are known (0.25m; 0.54m; 0.97m).

The heights are:
h1 = 0.026m
h2 = 0.12m
h3 = 0.49m

The last height is filled in the equitation, this will come the closest to the effective speed of the car.

V = 2.13 m/s

The car has a speed of 2.13m/s, in comparison with 3.17 m/s (the speed calculated in Case SSV I) there is still a difference. The calculated speed hasn't taken the losses into account, if divided with the coefficient of restitution, a value of 3.55 m/s is the result. This measurement is the effective speed of the car.

1.4 Conversion of the data

The datasheet provides the sensitivity of the PCB200C20 (Piëzo model). The data can then be converted into Newton; this is useful to interpret the data properly. The general formula is:

$$\frac{y}{a} = x \cdot s$$

$$y = x \cdot 100 \cdot 56.2 \cdot \frac{mV}{kN}$$

With:

y = the measured voltage (V)
x = the measured force (N)
a = the amplifier factor (100 [dimensionless])
s = sensitivity is the voltage output per newton (56.2 [mV/kN])

The formula must be converted to get the force:

$$x = \frac{y}{56.2 \times 10^{-4} \frac{V}{N}}$$

Peak values

Height(m)	Voltage(V)	Force(N)
0.026	0,229792	40,88
0.12	1,17616	209,28
0.49	2,375262	422,64

Departure values

Voltage(V)	Force(N)
0,174354	31,02
0,832115	148,06
1,40089	249,26

The peak values are the values at the moment the Piëzo-meter plus mass hits the car. This will be used in the strength analysis. The departure value is the force that the ball is going to absorb. It can be used to calculate the restitution coefficient.

1.5 Conclusion

With this test it is possible to recalculate the parameters from our previous report and compare them. We can conclude that there is a little difference between them, which means that this a representative test. The test gave a better view of how the car will react on the collision, and the parameters are more specific for the car. The SSV survived the collision, it is strong enough to resist the impact (see calculation forces). The golf ball is a good object to hit with, because it has also the capacity to damp (this has as result the balls will take the hit and not the frame which is good). During the test there was only 1 golf ball attached to our SSV, and this surface is too small to hit. It is possible that we miss the steel ball, because of that some improvements were done to our SSV. A second golf ball and a steel plate was installed, which connects the two golf balls. Now is the surface bigger and now the SSV will surely hit the steel ball. The weight of the car was also a little too high that is why some mass was removed.

2 Sankey-diagram

The Sankey-diagram is used to show the energy flow in a certain process. To use that for an SSV, the losses have to be determined. This text was structured according to the energy flow.

2.1 The Sankey diagram at maximum velocity on an infinitely long track

2.1.1 The Solar Panel (89.2%)

To find the efficiency, input of the sun is needed. In Belgium the radiation is considered to be 800W/m^2 (the same is used in the simulation). The surface of the solar panel was taken from the data sheet.

$$P_{sun} = A_{solar\ panel} \cdot E_{sun}$$

$$P_{sun} = 16 \cdot (0.039m \cdot 0.078m) \cdot 800 \frac{W}{m^2}$$

$$P_{sun} = 38.9W(100\%)$$

$$P_{solar\ panel} = 4.2W(10.8\%)$$

The maximum power that the panel can deliver has already been found in case SSV I. The measured power is used and not the calculated one from the Mathlab simulation. The car is assumed to be in this status because it has reached its maximum speed.

$$P_{loss\ solar\ panel} = P_{sun} - P_{solar\ panel} = 38.9W - 4.2W = 34.7W$$

This means that only a small portion of the sun will be used by the solar panel. This is due to reflection and thermal losses.

2.1.2 The DC-motor (1.8%)

The electrical power of the solar panel (4.2W) is going to be transformed to mechanical power by the motor with an efficiency of 84%. The motor is going to lose 16% of the electrical power delivered by the solar panel but only 1.8% compared to the input of the sun.

$$P_{motor} = 4.2W \cdot 0.84 = 3.5W$$

$$P_{loss\ motor} = 4.2W - 3.5W = 0.7W$$

Only 9% (3.5W) of the sun input will be used to move the car and that includes some other losses too. Those are the air friction (no wind), rolling resistance and gears.

2.1.3 Air friction (2.99%)

The parameters used for this calculation can be found in SSV case 1. The maximum velocity was found with the Mathlab simulation.

$$F_w = ½ \cdot C_w \cdot A \cdot \rho \cdot v^2$$

$$F_w = 0.5 \cdot 0.5 \cdot 0.03m^2 \cdot 1.293 \frac{kg}{m^3} \cdot (4\frac{m}{s})^2 = 0.258N$$

$$P_{loss\ air\ friction} = F_w \cdot v = 0.258 \cdot 4.51 \frac{m}{s} = 1.16W$$

2.1.4 Rolling resistance (2.04%)

$$Fr = Crr \times N = 0.012 \times 1.5\ kg \times 9.81 \frac{N}{kg} = 0.176N$$

$$P_{loss\ rolling\ resistance} = Fr \times v = 0.176 \times 4.51 \frac{m}{s} = 0.795W$$

2.1.5 Gears and remaining losses (3.97%)

The remaining losses will be attributed to the gears, shaft and bearings friction.

$$P_{loss\ gear} = P_{motor} - P_{loss\ rolling\ resistance} - P_{loss\ air\ friction}$$

$$P_{loss\ gear} = 3.5W - 0.795W - 1.16W = 1.545W$$

In this status the velocity has reached its maximum and is constant. The SSV is in equilibrium because all the delivered power is compensated by the losses. There is no power left to accelerate. In this case it's possible to assume that the remaining power can be allocated to the gears, bearing and shaft. This will be useful for the calculation at half speed.

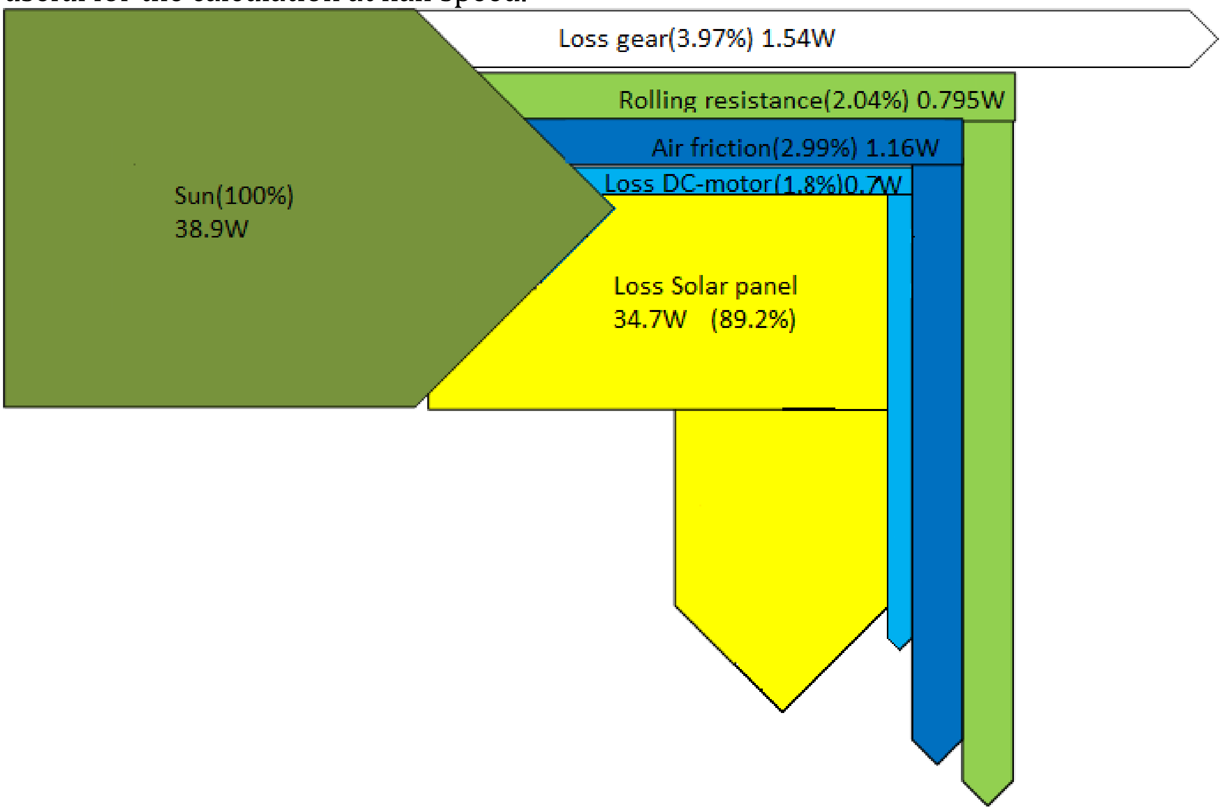


Figure 4 Sakey diagram

2.2 The Sankey diagram at half of the maximum velocity on an infinitely long track

The energy flow stays the same up to the motor (not speed related). The air friction and the rolling resistance are the two only parameters changing.

2.2.1 Air friction (1.49%)

The force doesn't change because the SSV is on a straight track (applicable to the rolling resistance too).

$$P_{loss\ air\ friction} = F_w \cdot v = 0.258 \cdot 2.25 \frac{m}{s} = 0.580W$$

2.2.2 Rolling resistance (1.01%)

$$P_{loss\ rolling\ resistance} = Fr \cdot v = 0.176 \cdot 2.25 \frac{m}{s} = 0.396W$$

All the losses have to be added to determine the total loss of the SSV.

$$P_{loss} = P_{loss\ solar\ panel} + P_{loss\ motor} + P_{loss\ gear} + P_{loss\ air\ friction} + P_{loss\ rolling\ resistance}$$

$$P_{loss} = 34.7W + 0.7W + 1.545W + 0.580W + 0.396W = 37.92W$$

The following is to find the remaining power for the acceleration of the car.

$$P_{surplus} = P_{sun} - P_{loss}$$

$$P_{surplus} = 38.9W - 37.92 = 0.98W(2.52\%)$$

At half speed the SSV has 0.98W left. The SSV will use this to accelerate to its maximum speed.

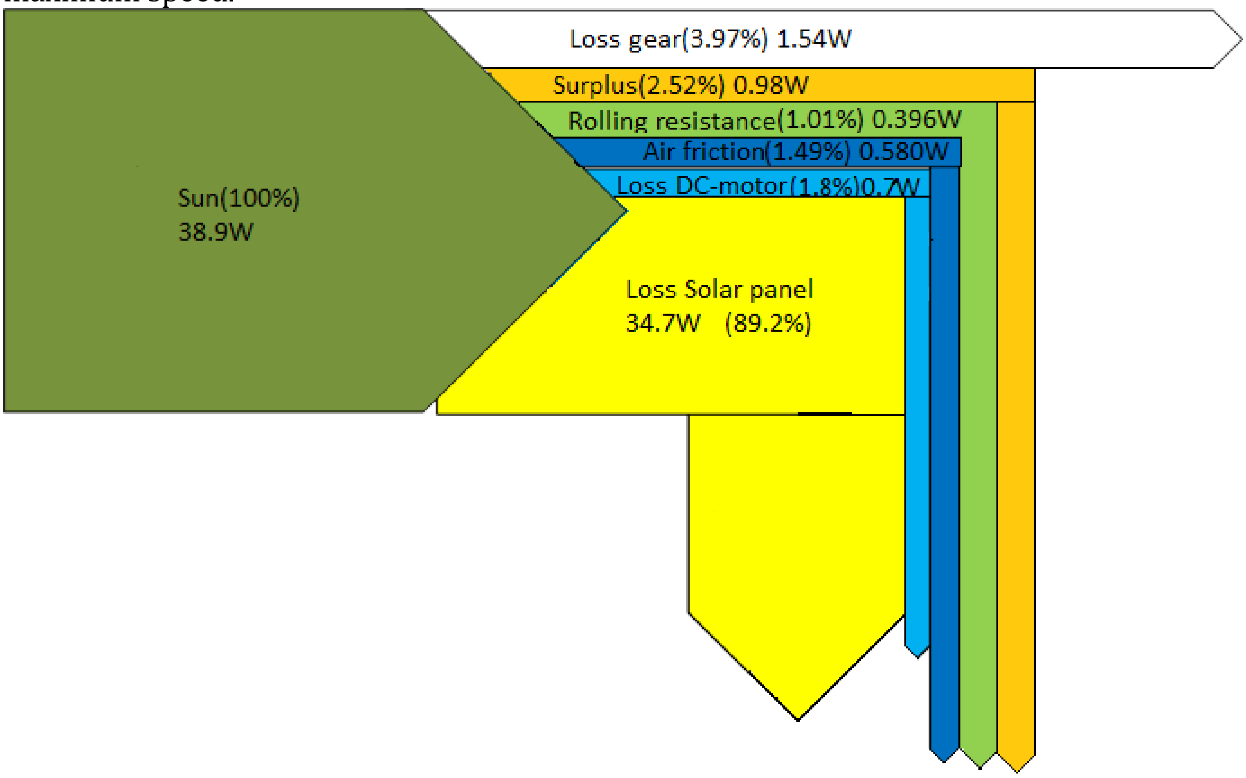


Figure 5 Sankey diagram II

3 2D technical drawing

In figure6 the technical drawing in 2 dimensions of the frame of the car can be found. Based on the information of the seminars of dimensioning, the measurements are correct attached to the drawing.

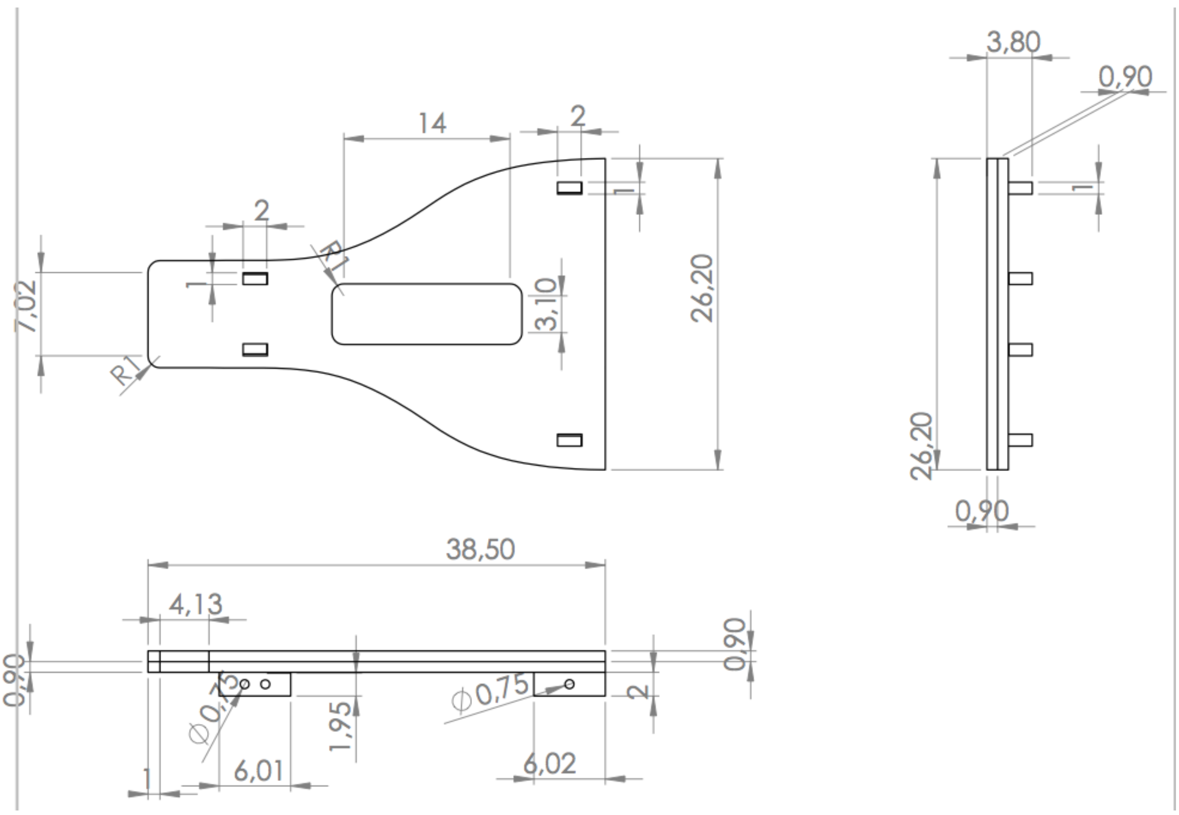


Figure 6 2D technical drawing

4 Strength calculations

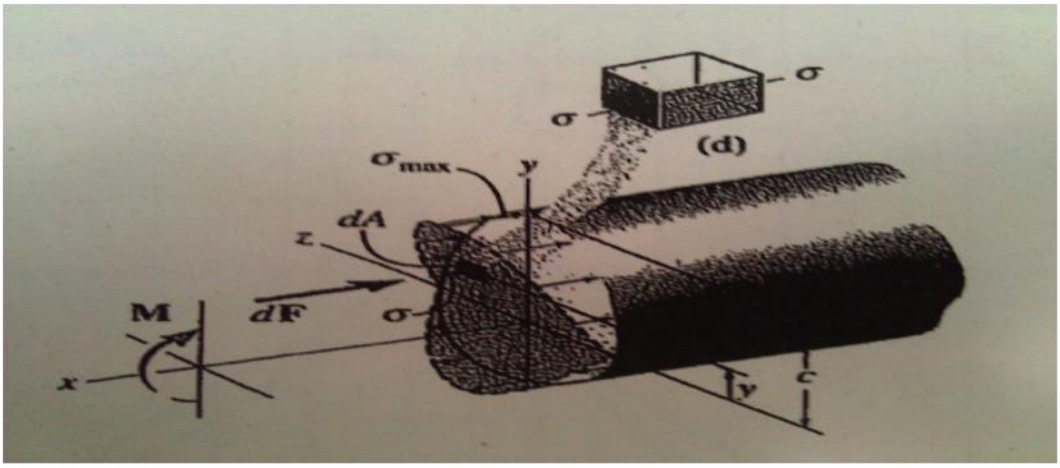


Figure 7 Forces and momentum

Because the solar panel has a lot of different levels, the possibly crucial forces will be due to momentum. Shearing is not possible, because the steal L shape will bend first before it will break the screws also there are 4 thick screws used.

4.1 Point 1

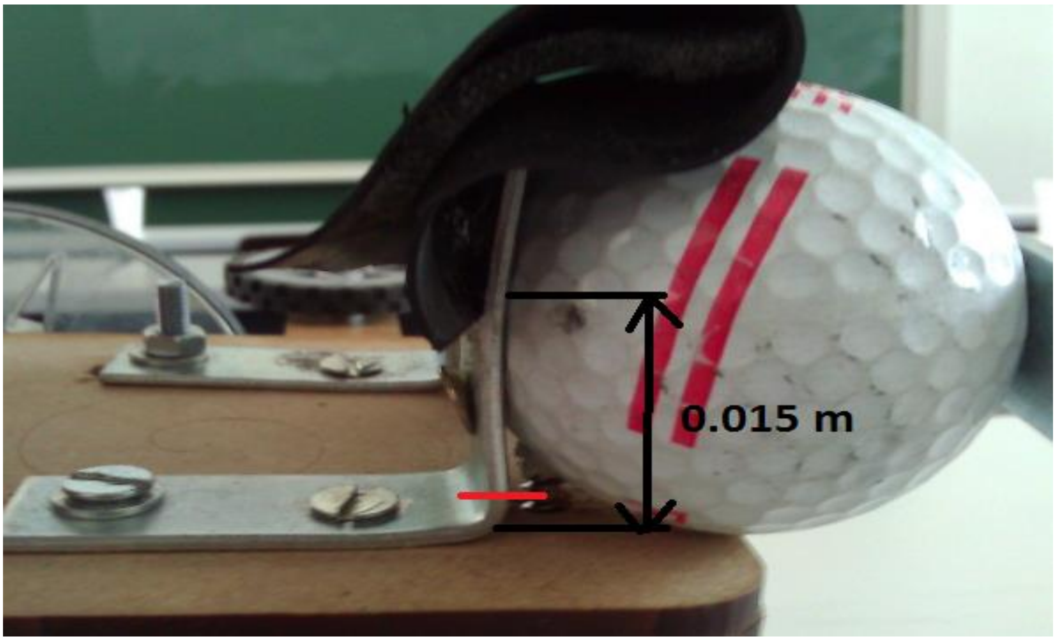
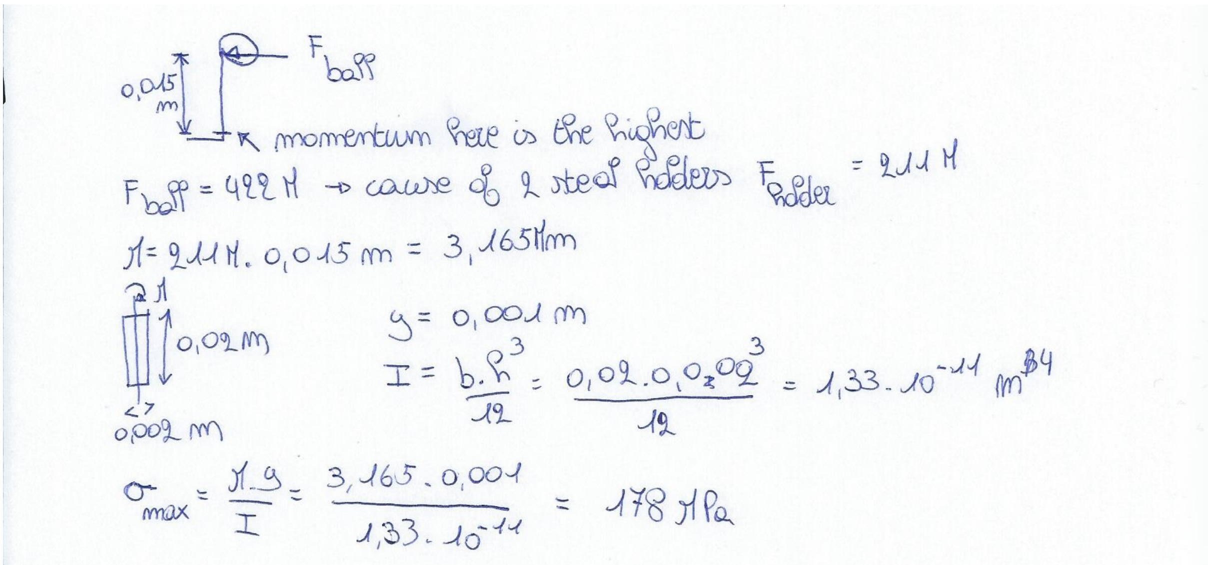


Figure 8 Golf ball with L-frame

The steel L-frame that holds the ball is the first point which might break, the moment is here the highest at the lowest point before the bend:



The value of 178MPa is safe; it will not bend. The maximum bending stress for this type of steel is about 250MPa (construction steel).

4.2 Point 2

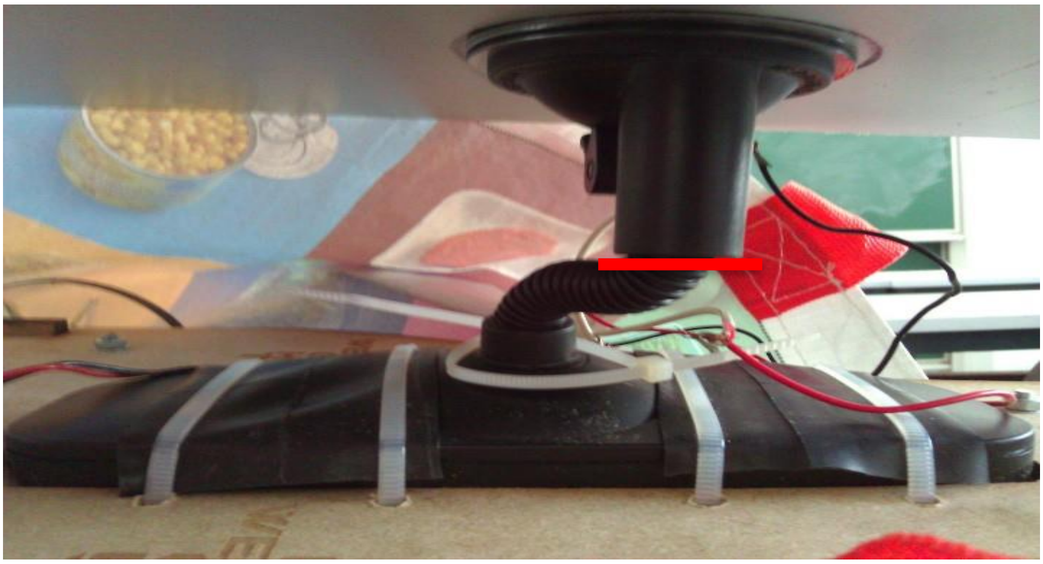
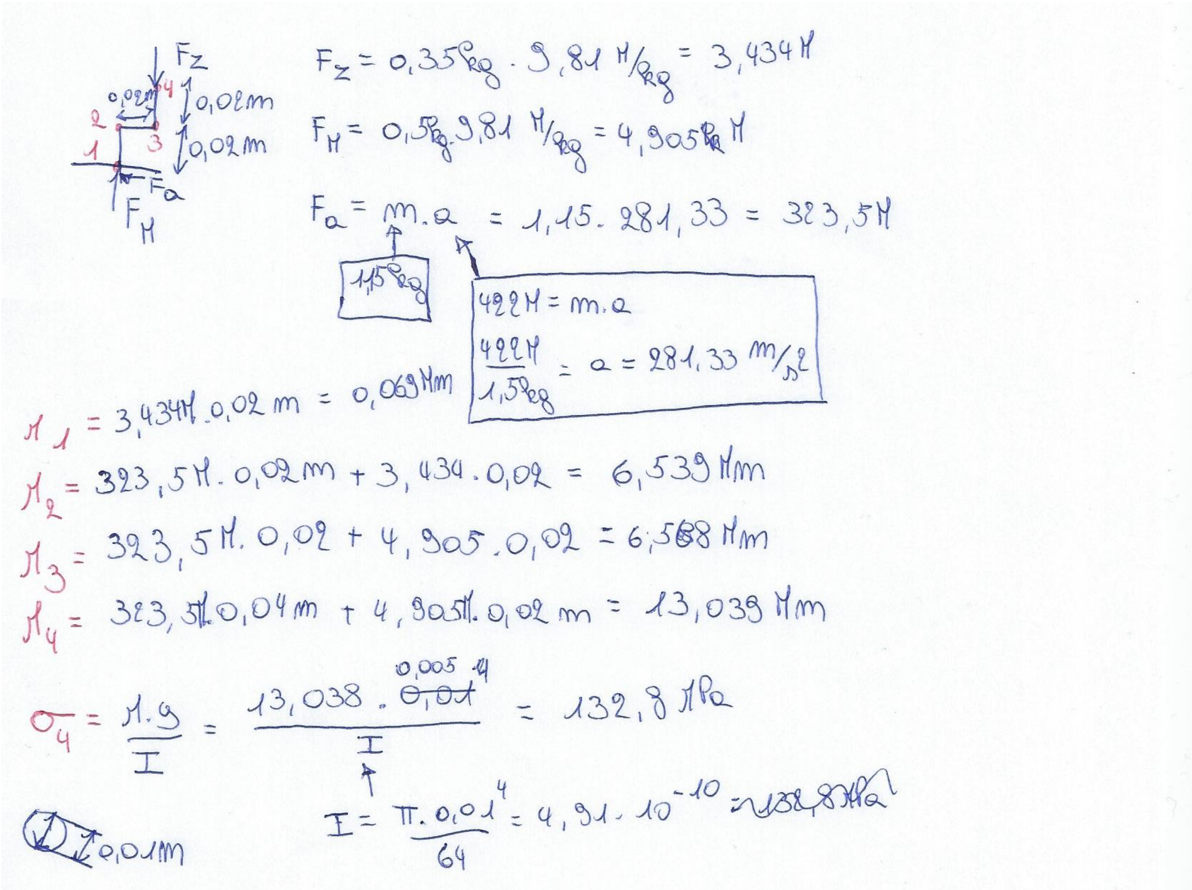


Figure 9 Holder Solar panel

Another possible critical point is the solar panel holder; it sticks out above the car which creates a large momentum at the time of collision. The car will decelerate to a standstill but the solar panel will keep moving forward for an instant. At this point the moment forces are the biggest. To prevent the holder from breaking it has a thick 1 cm diameter and is made out of steal (not pure steel because that's not that easy to bend but here will be assumed it's just steel for simplicity). The point of maximum momentum is not clear from the beginning, therefore the momentum for four different places are calculated.



After calculations the maximum momentum is found to be immediately beneath the solar panel. The bending stress of 132.8 MPa is also safely lower than the maximum bending force of 250 MPa.

5 The collision process

This is a small exercise to fully understand the collision process. There are three masses, mass A,B and C which are moving frictionless on a surface. A and B both have a mass of 2 kilograms and a speed of 6 meters per second. C has a mass of 4 kilograms and stands still. The spring between A en B is long enough for the masses not to hit. The collision of B and C is completely inelastic.

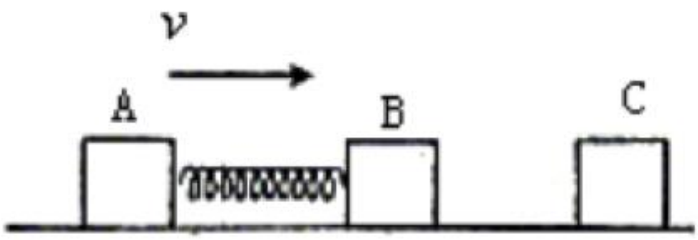


Figure 10 initial situation of the two object before collision

5.1 Question a

What is the movement speed of object b and c immediately after the impact?

The collision between B and C is perfectly inelastic. This means that the two objects will move as one object after the collision.
To calculate the final speed of this object (B&C) we will use the following equations:

Vc $=\frac{Crmb(ub-uc)+mbub+mcuc}{ma+mb} = 2\,\frac{m}{s}$

Vb $= \frac{Crmc(uc-ub)+mbub+mcuc}{ma+mb} = 2\,\frac{m}{s}$

va is the final velocity of the first object after impact
vb is the final velocity of the second object after impact
ua is the initial velocity of the first object before impact
ub is the initial velocity of the second object before impact
ma is the mass of the first object
mb is the mass of the second object
CR is the coefficient of restitution;

<u>To solve this equation the following parameters are used:</u>
Cr=0 (Because this is an inelastic collision, the coefficient of restitution is zero)
Mb= 2 kg
Mc= 2 kg
Ua= 6 $\frac{m}{s}$
Ub = 0 $\frac{m}{s}$

5.1.1 Conclusion

This result is convenient because the object b and c will move as on object so the speed will and needs to be the same.

5.2 Question c

How much is the maximum spring potential energy?

Like calculated in question a, the speed of object B&C will be 2 m/s immediately after the collision. Because object A has a velocity of 6 m/s, the velocity of A will decrease until the speed of the system is the same. The kinetic energy will go to potential energy in the spring, the spring will push on the system BC so their speed will increase a bit.
This potential energy will have a maximum value when the speed of the whole system is the same. The maximum energy that object A could transport to potential energy in the spring is easy to determine. Immediately after collision, the speed of object A is 4 m/s higher than the speed of object BC. So the difference in (kinetic) energy is:

$Ekin = \frac{mv^2}{2} = 16j$

<u>Following parameters are used in the equation:</u>
Ma: (the mass of object a): 2kg
Va: (The speed of object a after collision) = 6m/s

So the maximum potential energy that the spring could absorb is 16j, this is when speed of the whole system is the same.

5.3 Question b

First question C is calculated because now it easier to calculate the speed of the whole system when the potential energy of the spring is the highest.
Immediately after the collision the total energy of the system can be calculated by using the equations for the kinetic energy.

Esystem=Ekin1 + E kin2

- The kinetic energy of object A is represented by Ekin1.

Ekin1= $\frac{mv^2}{2}$= 36 j
Parameters:
Ma = 2 kg
Va= 6m/s

- The kinetic energy of object B&C is represented by Ekin2:

Ekin2= $\frac{mv^2}{2}$= 12 j
Parameters:
Mb&c= 6kg
Vb&c= 2 m/s

So now the total energy of the system can be calculated.
Esystem=48 j
After some time the speed of the whole system will be the same, for a short time. This will be when the potential energy in the spring will reach a maximum. The total energy of the system will maintain the same, this is the principle of conservation of energy. But now there are two aspects of energy, there is one part kinetic energy but also some potential energy in the spring.
Esys= Ekin + Epot

- Ekin=$\frac{mv^2}{2}$=?

Parameters:
Msyst= 8kg
Vsyst= unknown

- Epot=16 j (see question c)

The only unknown parameter in this equation is the velocity of the total system, so the equation can be solved and a velocity of 2.83 m/s was found.

5.4 Question d

Obtained by the momentum conservation

$$ma \cdot v + mb \cdot v = ma \cdot va + (mb + mc) \cdot vb$$

Let A left velocity direction, va>0 then vb > 4m/s.

After the role of A, B, C, and kinetic energy

$$Ek = \frac{1}{2} \cdot ma \cdot va^2 + \frac{1}{2} \cdot (mb + mc) \cdot vb^2 > 48J$$

In fact the system mechanical energy

$$E' = Ep + \frac{1}{2}(ma + mb + mc) \cdot va^2 = 48J$$

According to the law of conservation of energy, Ek > E' is impossible. Therefore, A cannot move to the left.

6 The final version of the SSV

In this part the final model of the SSV will be discussed together with all its components and the important decisions that were made.

6.1 Top of the SSV

Picture is a picture of the SSV at this moment. Some final adjustments may be made to improve its look, it might be painted. But in this section only the choice of materials and the construction will be discussed.

In the beginning there were some important choices that had to be made, the material of the frame, wheels,… all these decisions can be found in the report case SSV I. But they will be discussed here shortly. As frame material, mdf was used, this is because it is light, strong, easy to adjust and not very expensive. This has been bought and made at FabLab.

As collision material, a golf ball seemed a good solution. This is because golf ball are hard and have a high restitution coefficient, this will result in a good punch to the ball. In the first case, it was intended to use only one golf ball, this is in fact better for the punch but this makes it harder to hit the steel ball. That's why two golf balls were implemented. Also the two steel L-shaped forms are not chosen randomly. When colliding with the ball they will act as a spring and a spring doesn't lose energy. Also the plate in the front makes it easier to hit the ball but contributes to an effective collision with the ball.

The solar panel is kept in place with a mirror from a car. This mirror has a suction cup at one end en the mirror at the other end connected to each other with a flexible arm. This flexible arm will make sure the solar panel can be directed to sun.

The wheels are made of Plexiglas but this hasn't a specific goal. They are 8 mm thick which is pretty thick but this way they won't break. They also look better than wooden wheels.

The SSV has been provided with some support wheels which will make sure the SSV keeps driving on a straight line. The wheels are from Knexx and are provided with a bearing inside to reduce friction losses.

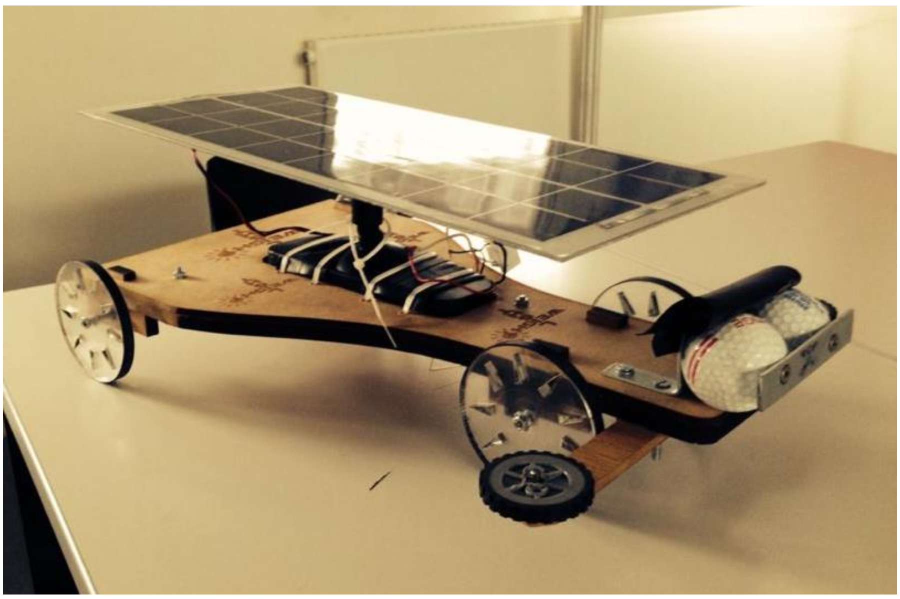


Figure 11 Final version of the ssv (top)

6.2 Bottom of the SSV

On figure 12 it's easy to see the how the different gears and axles are implemented .

Figure 12 Final version of the ssv (bottom)

Every axle (3) visible on the picture is provided with 2 bearing located in the wooden parts. This was actually a tricky part to produce because the bearings can't fall out and they had to stand straight. In the picture below the different parts provided with a bearing can be seen.

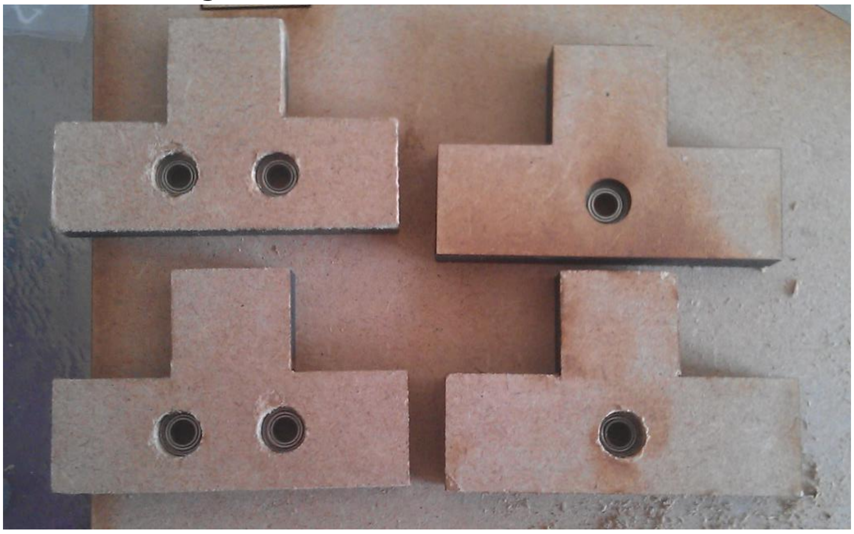


Figure 13 parts provided with bearings

That hardest part was to align the gears perfectly, this is a crucial part for the SSV because this might cause a lot of losses. The motor is kept in place with a metal strip covered with some kind of rubber so the motor can't vibrate or slide out of its place.

On the final picture (figure 14) one of the ends of an axle can be seen. To keep the wheel in its place and to prevent them from spinning round the axle they had to be bolted to the axle (if the wheels spin round the axle this will cause more friction than when they spin together with the axle in the bearing). That's why screw-thread was provided to the axles to bolt the wheels with the axles.

Figure 14 axle provided with screw-thread

7 Conclusion

This report has dealt with the different factors the SSV has to handle with. These are the different stresses during the impact, the impact itself and the power dissipation. The main result that can be derived from all of these tests is that the SSV will definitely survive the race according to the stress calculations in the weak points. But it will also have a good collision with the ball according to the test with the Piëzo-electrometer. This showed that the golf ball has a good coefficient of restitution which means the kinetic energy from the car will be passed on good. And as last the power dissipated by the engine was calculated and illustrated with a Sankey-diagram. This diagram thought us that only a fraction of the total power generated is efficiently used to move the car, the rest is lost due to friction or other losses.

But as conclusion it's possible to state that the car will survive the test and perform very well during the race.

8 Resources

Sterkteleer, Russel C.Hibbeler (2013) achtste editie

MEGGITT. (sd). Practical understanding of key accelerometer specifications.

PCB piezotronics. (2014). *Introduction to Piezoelectric Force Sensors*. Opgeroepen op April 26, 2014, van pcb: http://www.pcb.com/TechSupport/Tech_Force

Storr, W. (2014). *Introduction to the Amplifier*. Opgeroepen op April 26, 2014, van Basic Electronics Tutorials: http://www.electronics-tutorials.ws/amplifier/amp_1.html