SSV part II

1. New Sankey diagram

Like explained in the manual, we had to let our car roll of the ramp and measure how far it can get before it stopped. The distance that we measured, 1,95 m, was a lot smaller than in our ,simulation so the only conclusion we could make was that our rolling resistance coefficient is bigger than we expected. This is normal because in the simulation, we had only calculated the friction between the tires and the track while in real life there are more places on the car where there is friction. So based on the distance that we have measured, we have made some new calculations to make a better Sankey Diagram.

We have only made new calculations about the aerodynamic and rolling resistance losses. For the other parts we had already thought about extra losses so they should be rather fine.

1.1 Aerodynamic losses

In our first Sankey diagram, we have made some assumptions. Although the most of these assumptions were rather correct, there were also some things that have changed like the thickness of the wheels and the gear ratio.

Drag force: $F_D = 0{,}5 * \rho * C_D * A * v^2$.

Density of the fluid (air): $\rho = 1{,}204\ kg/m^3$

Drag coefficient: $C_D = 0{,}09$ (Streamlined Half-body)

Reference area (frontal area):

Size of solar panel: 22 cm * 28 cm, $\theta = 30°$

$A = 14\ cm * 22\ cm + 4\ cm * 4\ cm * 2 = 0{,}034\ m^2$

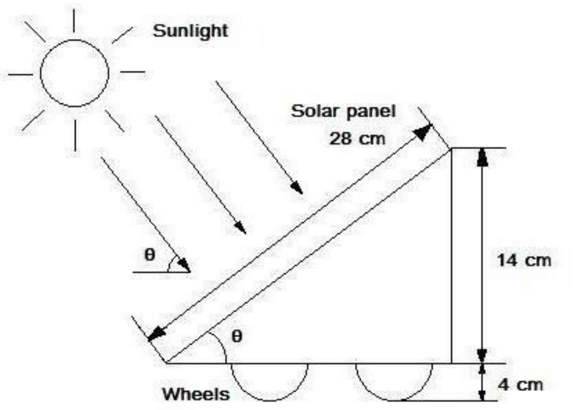
Maximum velocity at the maximum power: $V = P_{real} / F_{wheel} = 4{,}31 / 1{,}19 = 3{,}43\ m/s$

According to the formula, drag force: $F_D = 0{,}5 * 1{,}204 * 0{,}09 * 0{,}034 * 3{,}43^2$

$$F_D = 0{,}022\ N$$

Power of drag force at the maximum velocity: $P_A = F_D * v = 0{,}022\ N * 3{,}43\ m/s = 0{,}08\ W$

$\eta = (P_A / 4{,}0964) * 100\% = 1{,}95\%$



Conclusion: the frontal area was in real life a little bit bigger than we expected but the velocity of the car was also a little bit lower than we had calculated so the actual percentage is still the same.

1.2 Rolling resistance.

The rolling resistance of the car was bigger than we expected so we have calculated a new rolling resistance coefficient.

Mass (m) = 0,962 kg

Fr = Crr * N

N * cos 3° = - m * g

N = (- m * g) / cos 3°

N = (- 0,962 * 9,81)/cos 3°

N = 9,43 N

Potential Energy = m * g * h

m * g * h = F * s

$m * g * h = g * \cos 3° * C_{rr} * d_{slope} + g * C_{rr} * d_{flat}$

$0,962 * 9,81 * 1 * \sin 3° = C_{rr} * (g * \cos 3° * d_{slope} + g * d_{flat})$

$C_{rr} = (0,962 * \sin 3° * 9,81) / (9,81 * \cos 3° + 9,81 * 0,95)$

$C_{rr} = 0,026$

$F_r = 0,026 * 9,43$

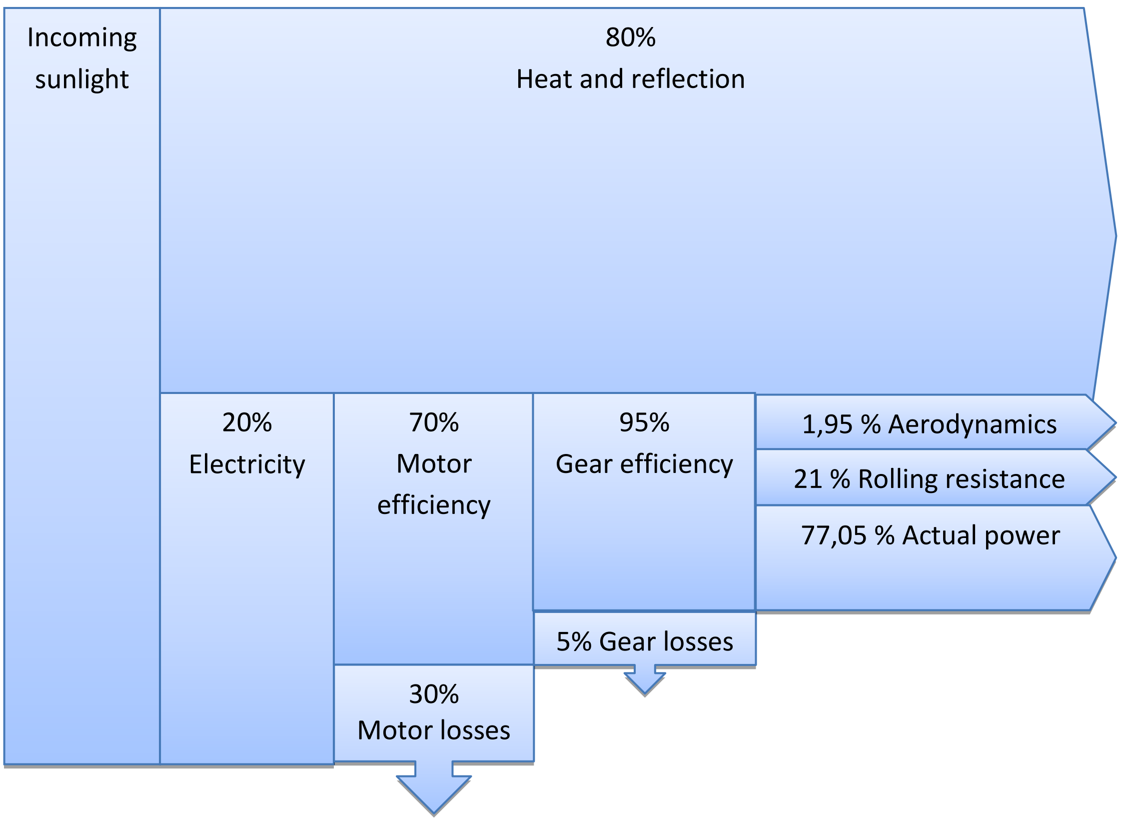
$F_r = 0,25$ N

Power of rolling resistance at the maximum velocity: $P_r = F_{rolling} * V = 0,25 * 3,43 = 0,86$ W

η= (P_r / 4,0964) * 100% = 21%

Conclusion: In the previous Sankey diagram we had a rolling resistance of 0,1 Newton while now we have one of 0,25 Newton. This means that there really is more friction on the car than only between the tires and the track.

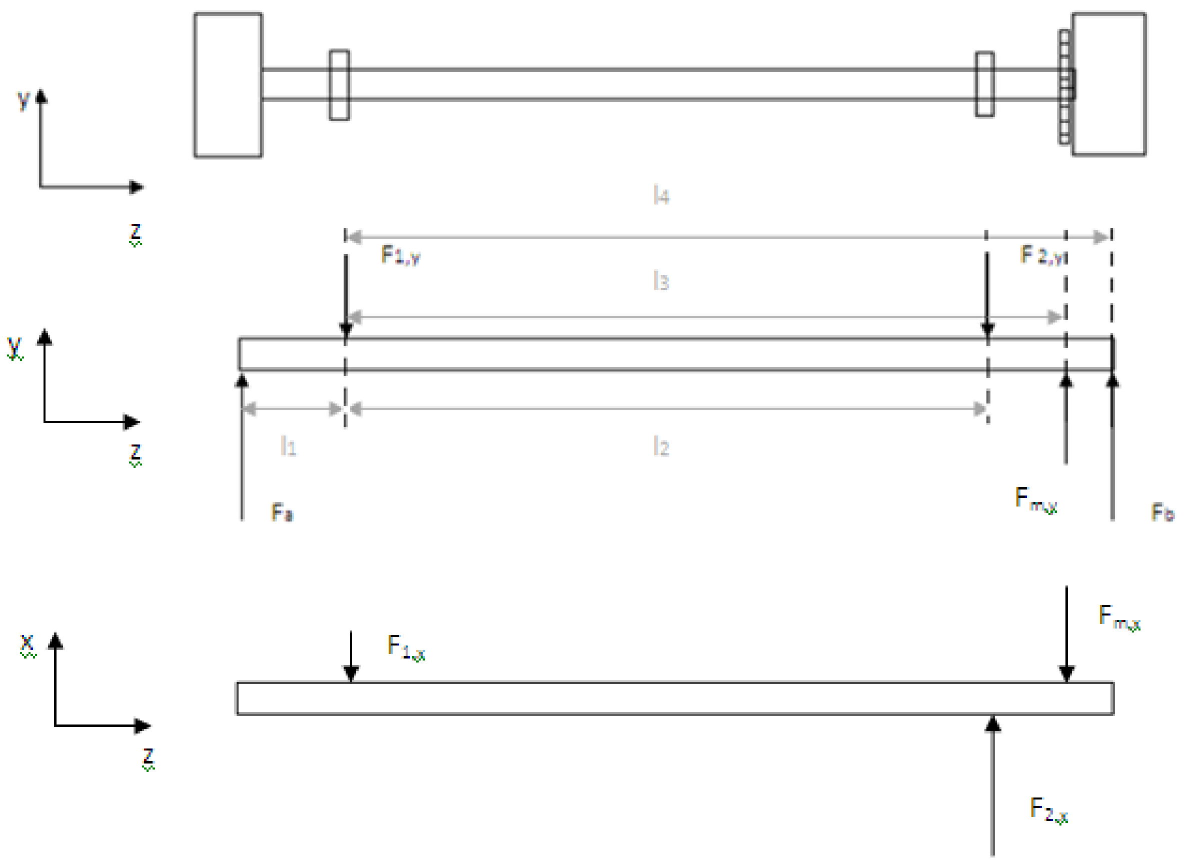
1.3 Sankey Diagram



Actual power is again the energy that is used to accelerate the car. This is no wasted energy.

2. Calculations concerning the shaft

2.1 Sketch of shaft



2.2 List of parameters

The elements that have influence on the mechanical load of the shaft are:
The two wheels (F_a, F_b), the two bearings attached to the body (F_1, F_2) and the gear because of motor forces (F_m).

2.3 Calculations

Determining forces

$F_a = F_b = ½ \, m * g = ½ * 0.962 * 9.81 = 4.72$ N

$F_m = T_m / R_1 = (5.09 * 10^{-3}) / (3 * 10^{-3}) = 1.70$ N

- ⇨ $F_{m,x} = F_m * \cos(20°) = 1.59$ N
- ⇨ $F_{m,y} = F_m * \sin(20°) = 0.58$ N

m = 0,962 (mass)
$T_m = 5{,}09*10^3$
(T_{max} motor)
$R_1 = 3*10^{-3}$
(radius small gear)

$\underline{y:}$

$$\begin{cases} \mathbf{\sum F_y = 0} \\ F_{1,y} + F_{2,y} = F_a + F_{\mathbf{b}} + F_{m,y} \\ \mathbf{\sum M_1 = 0} \\ -F_a * l_1 - F_{2,y} * l_2 + F_{m,y} * l_3 + F_b * l_4 = 0 \end{cases}$$

$\Rightarrow F_{2,y} = F_{m,y} * l_3 - F_a * l_1 + F_b * l_4 = 5.55$ N

$\Rightarrow F_{1,y} = F_a + F_a + F_{m,y} - F_2 = 4.47$ N

l_1 = 28.5 mm l_2 = 208 mm l_3 = 230 mm l_4 = 245 mm

$\underline{x:}$

$$\begin{cases} \mathbf{\sum F_x = 0} \\ F_{2,x} = F_{m,x} + F_{1,x} \\ \mathbf{\sum M_1 = 0} \\ F_{2,x} * l_2 - F_{m,x} * l_3 = 0 \end{cases}$$

$\Rightarrow F_{2,x} = (F_{m,x} * l_3) / l_2 = 1.76$ N

$\Rightarrow F_{1,x} = F_{2,x} - F_{m,x} = 0.16$ N

<u>Calculating $M_{b,max}$ and T_{max}:</u>

$M_{b,y}$ = 186,5 mNm $M_{b,y}$ = 33,3 mNm

(see attachment 1 for diagrams of D, M and T)

$M_{b,max} = (M_{b,y}^2 + M_{b,x}^2)^{(1/2)} = (186.5^2 + 33.3^2)^{(1/2)} * 10^{-3} = 189.4 * 10^{-3}$ Nm

$T_{max} = T_g / 2 = (T_m / i) / 2 = (5.09 * 10^{-3} / 7.38) / 0.345 = 345 * 10^{-3}$ Nm

(T_g = Torque caused by gear)

Determining stresses

<u>Bending stress:</u>

$\sigma_b = M_b / w_b$

$\sigma_b = (M_b * 32 * D) / [\pi * (D^4 - d^4)] = 25.9 \approx$ **26 MPa**

D = 6 mm d = 5.4 mm $M_b = 189 * 10^{-3}$ Nm $T_{max} = 945 * 10^{-3}$ Nm

Torsion stress:

$\tau_T = T / w_T$

$\tau_T = (T * y_{max}) / I_p = [T * (D/2) * 16] / [\pi * (D^4 - d^4)] = 11.8 \approx$ **12 kPa**

Shear stress:

$\tau = (M_b * S_y) / (I * b_m)$

With:
- $S_y = y_z * A$
- $y_z = (4\pi/3) * [(D / 2) + (d / 2)]$
  $= (4\pi/6) * (D + d)$
- $A = ½ * \pi * [(D / 2)^2 + (d / 2)^2]$
  $= (\pi/8)(D^2 + d^2)$
- $I = w_b * y_{max} = [\pi * (D^4 - d^4)] / 64$

$\tau = [M_b * (4 / 6\pi) * (D + d) * (1 / 8) * (D^2 - d^2)] / [\pi (D^4 - d^4) * (D - d) / 64]$

$= 29.8 \approx$ **30 kPa**

2.4 Dynamic forces

In motion the shaft experiences some different forces.
The resistance in the bearings is a reason for little differences.
When the surface is not flat, the forces caused by the weight can peak to higher amplitudes.

3. Sankey diagram Umicar

3.1 Total energy losses

Electricity generation losses

As everyone knows, the sunlight is diffuse on its way to the earth. As a result, solar panels at different position get different intensity of light. Besides, the energy is also related to the area of the solar panel.

Intensity of light in Belgium: 800 W/m² (25 °C)

Umicar has two kinds of solar cells. They are 280 RWE solar cells whose average efficiency is 30% and 2578 Emcore solar cells with a 24.5% average efficiency.

Total area of the solar cells: A = 7.94 m^2

RWE solar cells A_1 = 280 cells * 30.18 cm^2/cell = 0.845 m^2

Emcore solar cells A_2 = 7.94 m^2 – 0.845 m^2 = 7.095 m^2

Total energy of the sun to the solar panel: 800 W/m² * 7.94 m² = 6352 W

Total energy given by the solar panel:

P = 800 W/m² * 0.845 m^2 * 30% + 800 W/m² * 7.095 m^2 * 24.5% = 1593.42 W

Electricity generation: η = 1593,42 W / 6352 W *100 % = **25%**

Reflection and heat: 75%

From all the energy of the sunlight, we can only use 25 percent for the electricity part. The rest of energy is lost due reflection and heat.

Motor and controller losses

Umicar uses the motor *New Generation Motors - smc 150* with 95% efficiency and the controller *Tritium Gold* with 99% efficiency.

Motor final energy: 1593.42 W * 95% = 1513.75 W

Controller final energy: 1513.75 W * 99% = 1498.61 W

Other losses

When a vehicle is running on the road, there are some frictions which lead to losses in energy. Here we just consider the two most important ones: aerodynamic losses and rolling resistance.

Total maximum power: $P = P_r + P_D = F_r * v + F_D * v$

Aerodynamic resistance

Drag force: $F_D = 0.5 * \rho * C_D * A * v^2$

Density of the fluid (air): $\rho = 1.204\ kg/m^3$

Drag coefficient: $C_D = 0.2$

Frontal area: $A = 0.81\ m^2$

Rolling resistance

Rolling resistance force: $F_r = C_{rr} * N$

Rolling resistance coefficient: $C_{rr} = 0.0056$

Normal force: $N = \mu*m*g = 0.8 * 225\ kg * 9.81\ m/s^2 = 1765.8\ N$

3.2 Determining maximum speed

Total maximum power: $P = F_r * v + F_D * v = C_{rr} *N * v + 0.5 * \rho * C_D * A * v^2 * v$

$1498.61 = 0.0056 * 1765.8 * v + 0.5 * 1.204 * 0.2 * 0.81 * v^3$

Maximum speed: $v = 23.5\ m/s$

3.3 At the maximum speed

The Umicar is riding at the maximum speed $v = 23.5\ m/s$

Aerodynamic losses: $P_D = F_D * v = 0.5 * \rho * C_D * A * v^3 = 1265.65\ W$

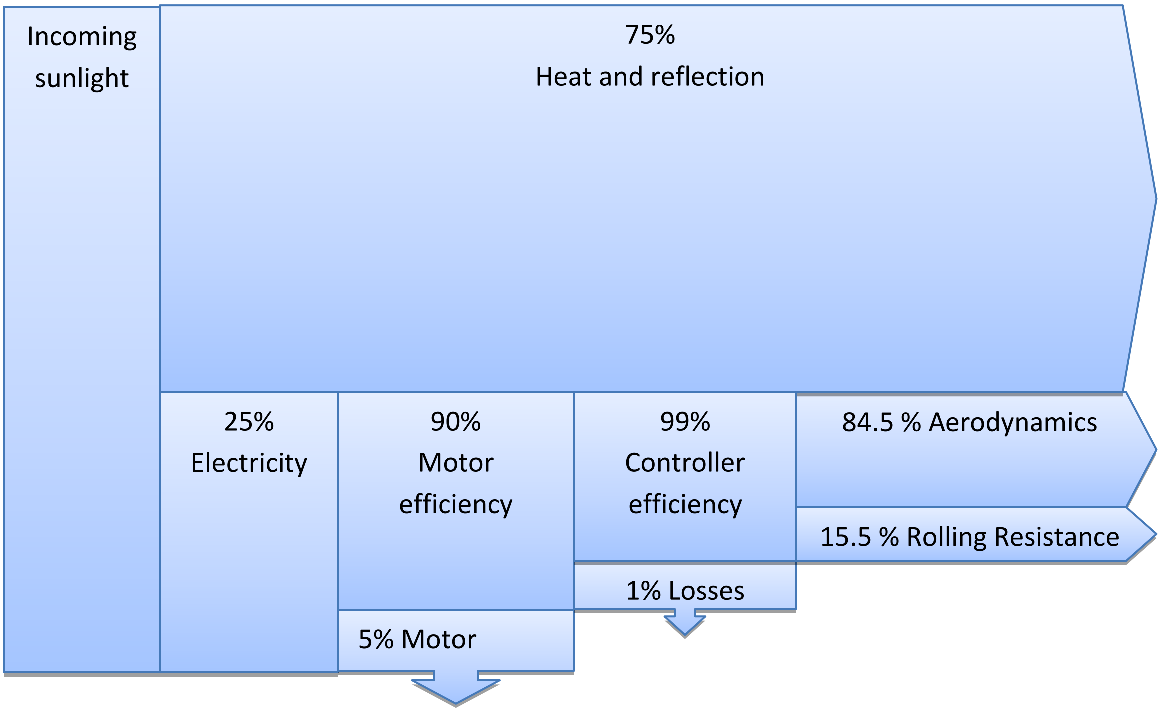
$\eta = (1265.65 / 1498.61) * 100\% = 84.46\%$

Rolling resistance: $P_r = F_{rolling} * v = 9.89\ N * 23.5\ m/s = 232.38\ W$

$\eta = (232.38 / 1498.61) * 100\% = 15.51\%$

Sankey diagram

When the vehicle is running at the maximum speed, all the effective power is used for aerodynamics and rolling resistance. In this condition there is no power left to accelerate the vehicle, so that it runs at the top velocity.



3.4 At the half of maximum speed

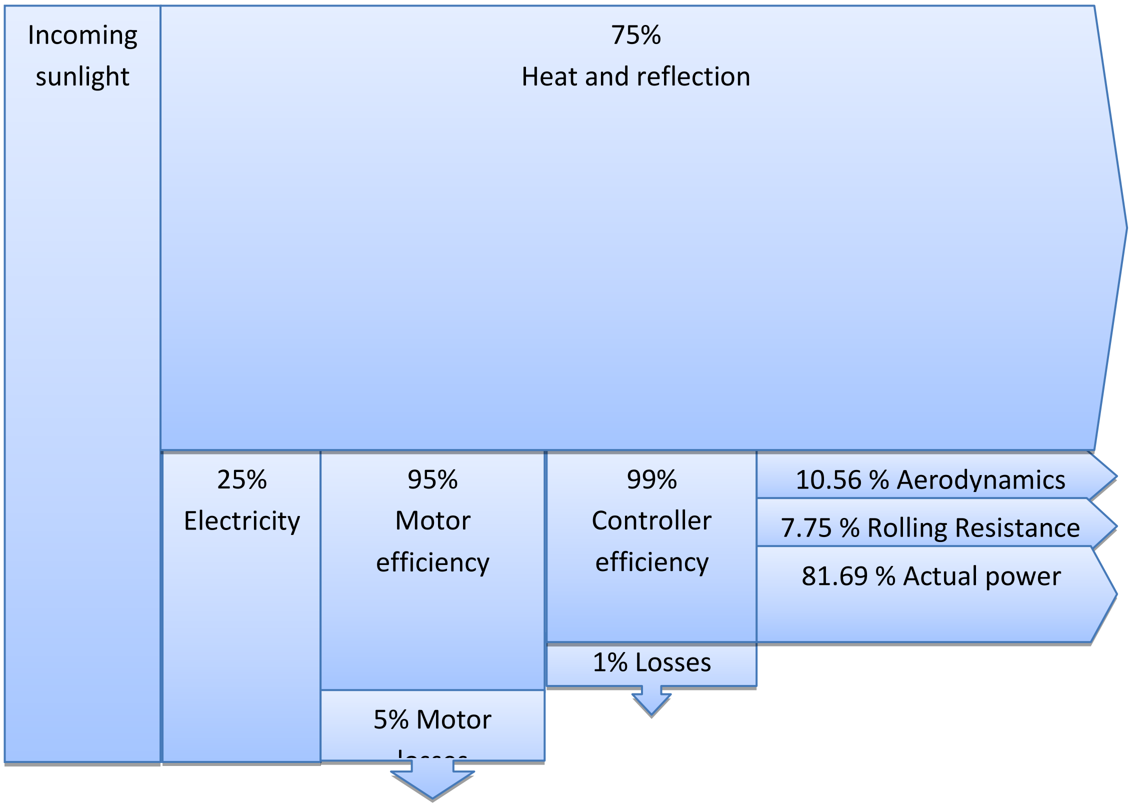
The Umicar is riding at the half of maximum speed v = 11.75 m/s

Aerodynamic losses: $P_D = F_D * v = 0.5 * \rho * C_D * A * v^3 = 158.21$ W

$\eta = (158.21 / 1498.61) * 100\% = 10.56\%$
Rolling resistance: $P_r = F_{rolling} * v = 9.89$ N * 11.75 m/s = 116.21 W
$\eta = (116.21 / 1498.61) * 100\% = 7.75\%$

Sankey diagram

When Umicar is running at the half of the maximum speed, the loss of the frictions is a quite small part of the total energy. It means that Umicar has a good performance. The rest of the energy, so-called “Actual power”, is large enough to move the car forward.


Incoming sunlight
75%
Heat and reflection
25%
Electricity
95%
Motor efficiency
99%
Controller efficiency
10.56 % Aerodynamics
7.75 % Rolling Resistance
81.69 % Actual power
1% Losses
5% Motor

4. Drawings

In attachment 2 the drawings of the car can be found. For a better view on the car also some 3D sketches are added.