Assignment 1: Powertrain

Jan-Hendrik Dürkop Fikri Farhan Witjaksono
durkop@student.chalmers.se fikrif@student.chalmers.se

Group number : 5

VEHICLE PARAMETERS

Table 1. Mercedes Benz 300 SL-24

Value in Matlab	Description
g = 9.81	Gravitation Force [m/s2]
V = 2.960e-3	Engine displacement volume [m^3]
maxT = 272	Maximum engine torque [Nm]
MaxRPM = 6300	Maximum engine speed [RPM]
gearRatios=[4.15 2.52 1.69 1.24 1.00]	Gear ratios [first gear, second gear, third gear]
finalDriveRatio = 3.92	Final drive gear ratio
m=1690	Mass of vehicle [kg]
A=2.26	Frontal area for drag calculation [m^2]
rho=1.2	Air density [kg/m^3]
fr=0.013	Coefficient of rolling friction
Cd=0.3	Coefficient of drag
width = 225	Width of tyre [mm]
profile = 50	Tyre profile [%]
diameter = 16	Rim diameter [inches]
Q_lhv = 43.5	Lower heating value of gasoline [MJ/kg]
rho_fuel = 0.7197	Density of gasoline [kg/litre]
R0 = 0.3382	Tyre Radius [m]
etad=0.9	Driveline Efficiency

In this assignment, we chose our vehicle to be Mercedes-Benz 300 SL-24. It has an Engine with maximum engine horse power of 170 kW(231 HP) as well as maximum Torque of 255 Nm at engine speed of 4400 rpm. This vehicle is really fast. It could reach 100 km/h from 0 km/h in 8.1 s. It also have a maximum speed of 240 km/h. The tyre radius (R0) was calculated using the matlab code below. This tyre radius value will be used in several of the tasks that we did.

```
R0 = (25.4*diameter+2*0.6*width)*0.5*10^-3;
```

The values shown in Table 1 are basic parameters that are used in the assignment. However, values like power, torque and maximum speed are not written in the basic parameters, nevertheless been used in some of the calculation that we have done. Moreover, since the engine is a four-stroke engine, we assumed that the value for n_R=2 for all calculations.

TASK I

In this task, firstly we try to rescale the original BMEP diagram to fit with the new vehicle parameters (new maximum power value), thus giving us a new BMEP diagram. This is done by rescale the engine speed to the new vehicle specification.

However, after we done the rescaling to fit the engine speed at the power maximum diagram, the maximum power increases to 172.29 kW which is not our maximum engine power in the vehicle specification (170 kW). Therefore, we try to introduce a scale factor whose purpose is to fit the new engine speed with the new maximum power. The scale factor is calculated by ***(new car's maximum bmep)/(old car's maximum bmep)*(p_me_max).*** Here p_me_max and p_me_col is a vector with the bmep and the maximum bmep.

We denote the new max bmep as new_p_me and new_p_me_col for the new bmep. On the other hand, the old max bmep as p_me_max and old bmep as p_me_col.
The terms and the scaling factor calculation are shown below in Fig. 1 and Fig. 2.

```
%w_CE_row: engine speed (rad/s)
%w_CE_max: max engine speed (same as _row)
%p_me_col: bmep (Pa)
%p_me_max: max bmep
%gkWh_CE_map: brake specific fuel consumption (g/kWh) (isolines)
```

Fig. 1. Original terms definition

```
bmep_max = (2*nr*pi*maxT)/V;
eng_speed_max_torque = (4600/60)*2*pi;

new_p_me = p_me_max.*(9.76/10.5);
new_p_me_col = p_me_col.*(9.76/10.5);
new_w_ce = w_CE_max.*(293.215/366.5);
```

Fig. 2. Scaling factor, bmep and engine speed calculation

The result of this scaled bmep is shown below in Fig. 3.

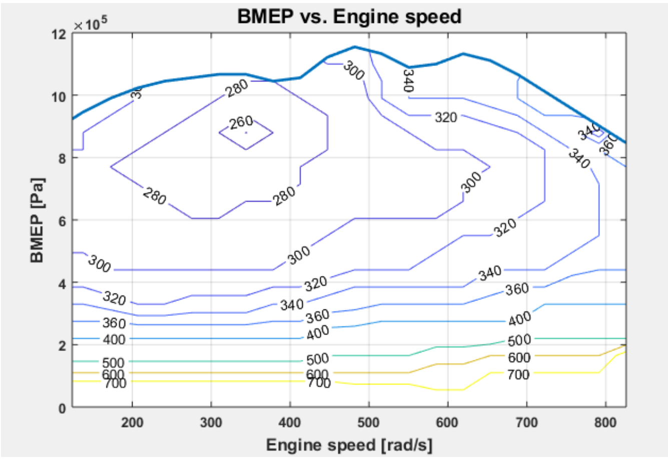


Fig. 3. Scaled BMEP diagram

The first step after the scaling is to create the torque vector. In order to create a torque vector, we could use the scaled 'new_p_me_col'. This new_p_me_col then will be calculated using the formula below and represented in MATLAB script by fig. 4.

$$Te = \frac{Pme*V}{2*\pi*nR} \quad \text{[eq.1]}$$

Pme = Engine Power [kW]

V = Engine Displacement Volume [m^3]

nR = 1 (for 2-stroke) or 2 (for 4-stroke)

Te = Engine Torque [Nm]

```
Torque = (new_p_me_col.*V)/(2*pi*nr);
```

Fig. 4. Torque calculation

The next step is to create the coordinate grid. This could be done by using the MATLAB script below in Fig. 5. Here, the 'meshgrid' function is to create 2-D grid coordinates with *x*-coordinates defined by the vector x and *y*-coordinates defined by the vector y where the vector x is scaled new engine speed (new_w_ce) and the vector y is the Torque [1].

```
[wwMatrix, ppMatrix] = meshgrid(new_w_ce, Torque)
```

Fig. 5. Coordinate grid making

The next step would be to calculate the Engine Power Mesh using the formula below and the MATLAB script is shown in Fig. 6. Power Mesh will be used to draw the fuel efficiency lines in the plot.

```
power_mesh = ppMatrix.*wwMatrix;
```

Fig. 6. Engine Power Mesh

However, in order to calculate the engine power line, we use the eq.2 below.

$$p = Te*\omega e \quad \text{[eq.2]}$$

P = Engine Power [kW]

Te = Engine Torque [Nm]

ωe = Engine Speed [rpm]

In the MATLAB program, the engine power calculation is represented by the script below.

```
power_eng = (((new_p_me_max.*V)/(2*pi*nr)).*new_w_ce);
```

Moreover, in order to calculate the fuel efficiency line, we change the unit of the original bsfc [g/kWh] into the new bsfc [kg/MJ] by multiplying it by 3600. The fuel efficiency calculation is characterized by the formula below.

$$\eta_T = \frac{1}{bsfc} * \frac{1}{QLHV} * 3600 \quad \text{[eq.4]}$$

bsfc = Brake Specific Fuel Consumption [g/kWh]

Q_{LHV} = Lower heating value of gasoline [MJ/kg]

η_f = Fuel efficiency [dimensionless]

In the MATLAB, the fuel efficiency calculation is represented by the script below.

```
fuel_eff = (3.6*1./(gkWh_CE_map.*10^-3)).*(1./Q_lhv);
```

To plot the fuel efficieny isolines and the power-engine speed diagram, we use the script below.

```
sB=subplot('position',[0.5,0.5,0.4,0.4]);
fuel_eff_lines = [0.3 0.28 0.26 0.24 0.22 0.2 0.18 0.16 0.14 0.12];
[CC,hh] = contour(wwMatrix, ppMatrix, fuel_eff, fuel_eff_lines);
patch([w_CE_row, w_CE_row(end:-1:1)],
[power_eng, ones(1,length(power_eng))*1000000],'w','EdgeColor','w');
hold on;
plot(w_CE_max,power_eng);
clabel(CC,hh);
```

Here in the first line is written in order to position the subplot on the upper right side in the combined plot perspective.

The second line corresponds to the chosen value of the fuel efficiency that we want to plot.

The third line corresponds to the '[CC,hh] = contour(___)' syntax whose function is to return the contour matrix and the contour object 'hh'. 'hh' was used to set properties after displaying the contour plot. The fourth and fifth line corresponds to the patch function. The syntax patch (X,Y,C) creates one or more filled polygons using the elements of X and Y as the coordinates for each vertex. Patch connects the vertices in the order that you specify them. To create one polygon, specify X and Y as vectors. To create multiple polygons, specify X and Y as matrices where each column corresponds to a polygon. C determines the polygon colors [2]. Here, Patch is basically used to color different fuel efficiency lines in the contour function so that it is distinguishable in the isolines plot.

The result of the calculation is plotted as shown in Fig. 7.

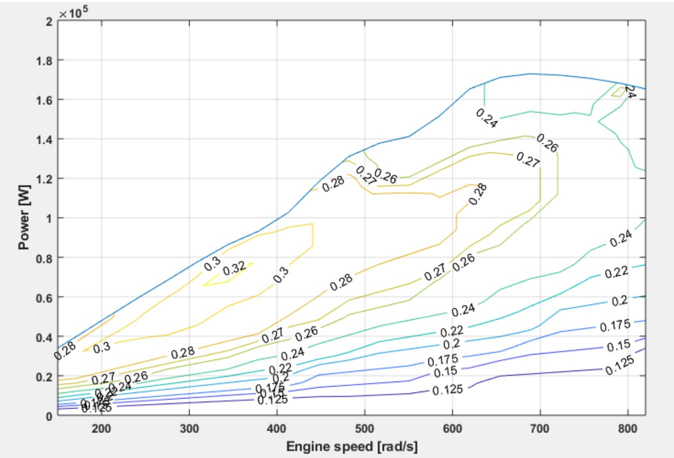


Fig. 7. Power-Engine Speed diagram

Finally, we set the x-axis and y-axis label and setting the grid to be visible in the plot and set the input for the x-axis by the engine speed limit and the y-axis by the power limit. The MATLAB script is shown below.

```
set(gca,'fontweight','bold') %Make the axis text bold
xlabel('Engine speed [rad/s]')
ylabel('Power [W]')
grid on;
axis([engSpeedLim, powerLim]);
```

The power diagram can not be fitting with the vehicle specifications given by the manufacturer, because we use the rescaled engine speed for calculating the engine power. The engine speed was scaled to fit the point of maximum bmep with the given vehicle specification.

TASK II

In this task, we firstly create a vehicle speed vector denoted by 'veh_speed' in the MATLAB script. This veh_speed vector is shown below.

```
veh_speed = [0:0.01:70];
```

The next step is to calculate the power on the wheel based on the three different road grades. In order to calculate the power on the wheel, we need to use Fx as a base. Fx could be derived from the equation in Fig. 8.

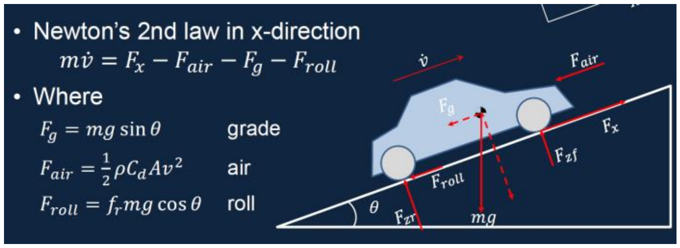


Fig. 8. Newton 2nd law in Traction Force Calculation [3]

$$F_{traction} = F_{air} + F_g + F_{roll} + F_{acceleration} \quad \text{[eq.5]}$$

The term *Facceleration* is zero, because we imply that we drive at a constant speed. By multiplying the F*traction* with vehicle speed, we could get the power on the wheel equation as shown below

$$P_{wheel} = F_{traction} * \text{Vehicle Speed} = \text{Vehicle Speed} * (F_{air} + F_g + F_{roll}) * \frac{1}{\eta T} \quad \text{[eq.6]}$$

$\frac{1}{\eta T}$ is added to represent the power on engine. Moreover, to calculate the θ which represents *road grade percentage*, we use the following equation.

$$\theta_{roadgrade} = \arctan(\%\text{-roadgrade}) \quad \text{[eq.7]}$$

In the MATLAB script, the equation above is shown below in Fig.8.

```
pow_grad_0 = (veh_speed.*(0.5*A*Cd*rho.*veh_speed.*veh_speed+m*g*sin(0)
+m*g*fr*cos(0)))*(1/etad);
pow_grad_4 = (veh_speed.*(0.5*A*Cd*rho.*veh_speed.*veh_speed+m*g*sind(2.29)
+m*g*fr*cosd(2.29)))*(1/etad);
pow_grad_8 = (veh_speed.*(0.5*A*Cd*rho.*veh_speed.*veh_speed+m*g*sind(4.57)
+m*g*fr*cosd(4.57)))*(1/etad);
```

Fig. 9. Power on the wheel with $\theta_{roadgrade}$ input

Here, it could be observed that we separated the Power on the wheel based on 3 different road grade (0%, 4%, 8%). These road grades then be convert into 3 different $\theta_{roadgrade}$. Except for the 0% grade where we insert the $\theta_{roadgrade}$ directly, we convert the value into cosθ and sinθ and insert it into the power on the wheel equation. Moreover, in the MATLAB script, we used sind and cosd because the input is in degree.

Next, we plot the result of the equation by the following script in the next page.

```
sA=subplot('Position',[0.1,0.5,0.4,0.4]); hold on;
plot(veh_speed,pow_grad_0);
plot(veh_speed,pow_grad_4);
plot(veh_speed,pow_grad_8);
set(gca,'XDir','reverse')
axis([vehSpeedLim, powerLim]);
grid on;

set(gca,'XDir','reverse','YTickLabel',[],'fontweight','bold')
xlabel('Vehicle velocity [m/s]');
```

Then, the result is shown by the Fig. 10 below.

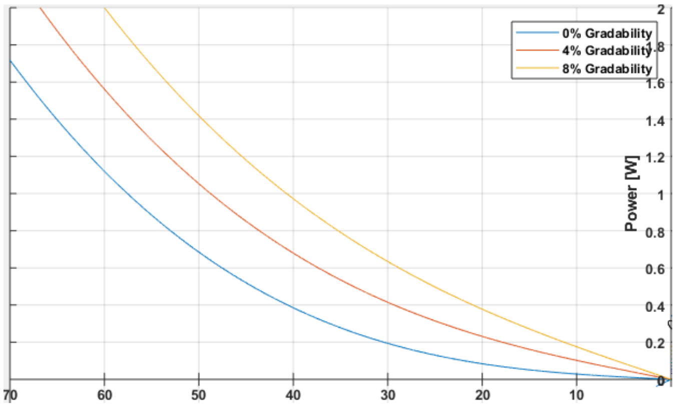


Fig. 10. Power on the wheel based on different road grade

Here, it is shown that the blue line represented the case for 0% road grade, the red line for 4% and the orange line for 8%. It is shown that the 8% has the highest line slope whereas the 0% case has the lowest line slope.

This is normal due to the equation which has cosθ and sinθ component where $\theta_{gradeability}$ relies on the arctan of the percentage of the road grade. Thus, by travelling in an increased road grade means that more power is needed to travel in a certain constant velocity as shown in the figure 6 above.

Thus, we could conclude that

$$\theta_{roadgrade} \propto P_{wheel}$$

TASK III

In order to calculate and plot the transmission gear ratio, we need to know the Wheel Speed corresponds to the Engine Speed Value. In this case, to find out the wheel speeds values, we could use the formula stated below.

$$\omega w = \omega e * \frac{1}{ri} * \frac{1}{rFD} \text{ [eq.8]}$$

ωw = Wheel Speed [rad/s]

ri = i-th Gear Ratio

rFD = Final Gear Ratio

ωe = Engine Speed [rad/s]

In the MATLAB script, we denote *the wheel speed* as shown below.

```
w_speed_g1 = new_w_ce.*(1/finalDriveRatio)*(1/gearRatios(1));
w_speed_g2 = new_w_ce.*(1/finalDriveRatio)*(1/gearRatios(2));
w_speed_g3 = new_w_ce.*(1/finalDriveRatio)*(1/gearRatios(3));
w_speed_g4 = new_w_ce.*(1/finalDriveRatio)*(1/gearRatios(4));
w_speed_g5 = new_w_ce.*(1/finalDriveRatio)*(1/gearRatios(5));
```

We separated the wheel speed value into 5 different equation as we have 5 different gears. Moreover, to plot the diagram we use the following script.

```
sD=subplot('position',[0.5,0.1,0.4,0.4]);
plot(new_w_ce,w_speed_g1,'--');
hold on;
plot(new_w_ce,w_speed_g2,'--');
plot(new_w_ce,w_speed_g3,'--');
plot(new_w_ce,w_speed_g4,'--');
plot(new_w_ce,w_speed_g5,'--');
set(gca,'YDir','reverse','XTickLabel',[],'fontweight','bold')
grid on;
ylim(whSpeedLim)
xlim(engSpeedLim)
ylabel('Wheel speed [rad/s]')
legend('1st Gear','2nd Gear','3rd Gear','4th Gear','5th Gear');
```

In the script, the first line corresponds to positioning of the subplot in the combined diagram plot. In the second line, we use w_CE_max as the x-plot value and w_speed_g1 (wheel speed at 1st gear) as the y-plot value. Moreover, to create the dotted line plot, we use '--'. We repeat this plot syntax for all gear values.

Then, we wrote the x-axis limit with the wheel speed limit and the y-axis limit with engine speed limit. Finally, we put the ylabel as 'wheel speed' since we share the xlabel (engine speed) with the power-engine speed plot.

The result of the plot is shown in Fig. 11 below,

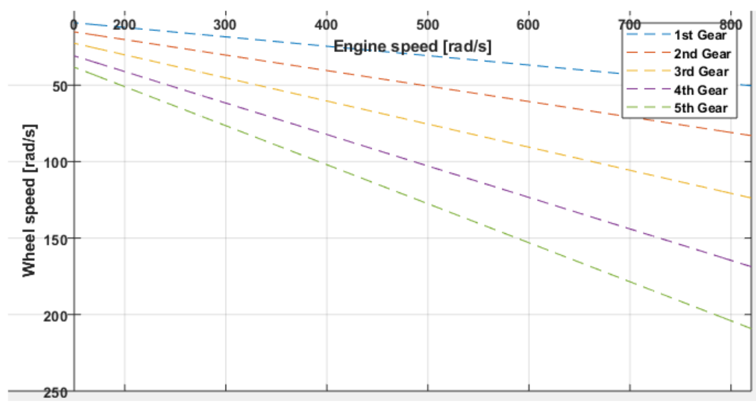


Fig. 11. Gear Ratio Diagram Plot

In the plot, the blue plot is for 1st gear ratio plot, the red plot is for 2nd gear ratio, the orange plot is 3rd the gear ratio plot, the purple is for 4th gear and the green is for 5th gear ratio plot.

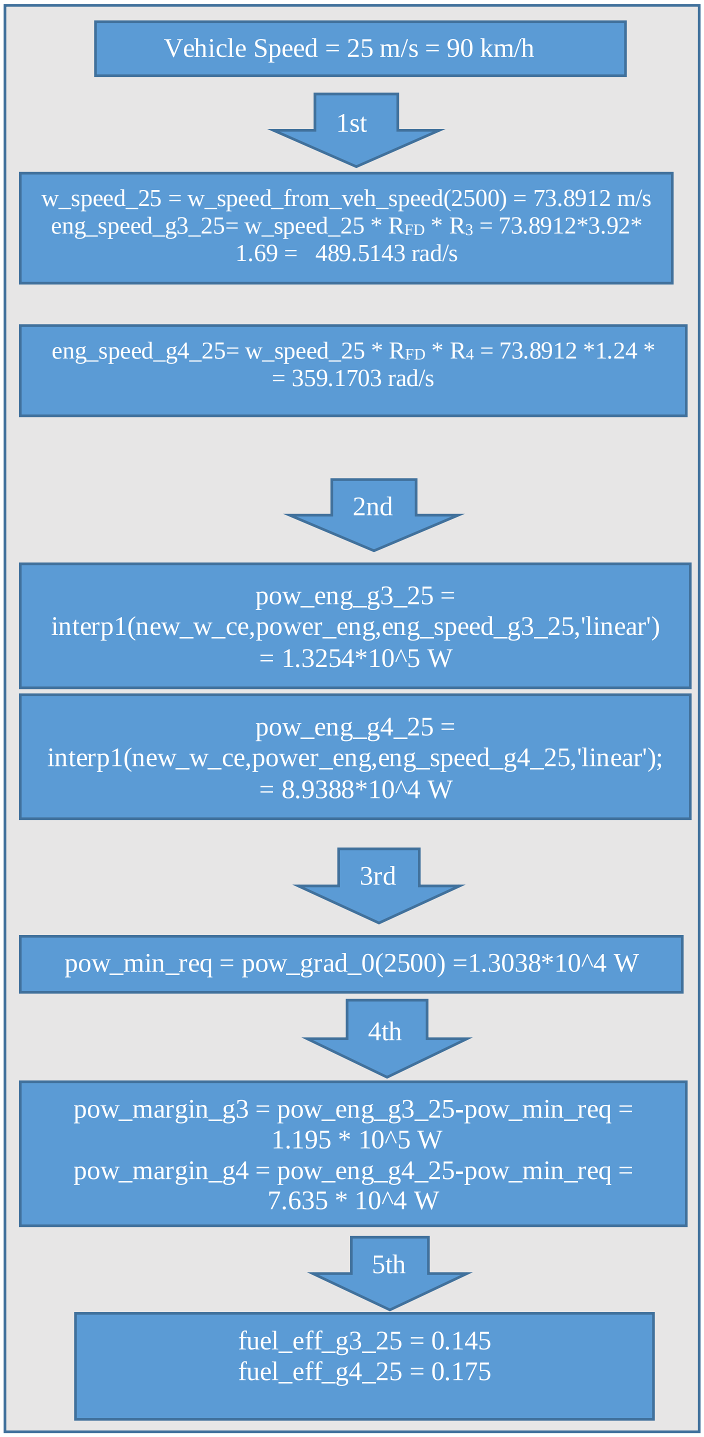
Thus, we could conclude that

$$\frac{1}{ri} \propto \omega w$$

TASK IV

a). In task IV part a), we need to assume that the velocity is constant thus acceleration = 0 m/s^2 and choose arbitrarily which vehicle speed we were going to work on. We chose 25 m/s as our vehicle speed. Moreover, the road is assumed to be flat which means that the $\theta_{gradeability} = 0°$.

The Power margins is the difference between maximum power and minimum required power, at a certain constant speed and it is denoted by ΔP.[3]
In MATLAB, to calculate the Power margins and fuel efficiencies, we follow the steps as shown by the flowchart below.



1 : Calculate the Wheel Speed from 25 m/s of Vehicle Speed by calculating wheel speed value from the equation

(Vehicle Speed) * 1/(R0) = **73.8912 m/s.**

After that, by approximation to find the value in the w_speed_from_**veh_speed(n) array**, we approximate n to be 2500. Next, by using eq.8, we calculate the engine speed at the 3rd gear and 4th gear as we choose arbitrarily the 3rd gear and 4th gear and found the value to be ***489.3143 rad/s*** and ***359.1703 rad/s.***

2 : Calculate the power of engine at 3rd gear and 4th gear by using the *interp1(x,v,xq,'linear')* syntax which function is to return interpolated values of a 1-D function at specific query points using linear interpolation. Here, Vector x contains the sample points, and v contains the corresponding values, *v*(*x*). Vector xq contains the coordinates of the query points. The default method is 'linear'. [4]

Here, the x is represented by **'new_w_ce'** which is the scaled engine speed, y is 'power_eng' which is the engine power and xq is '**eng_speed_g3_25**' which we calculated in step 1. At the end, we get the interpolated engine power as ***1.3254*10^5 W***.The same method follow for '**eng_speed_g4_25**' which resulted in interpolated engine power of ***8.9388*10^4 W.***

3 : Calculate the minimum power required from the plot in Fig. 6 by taking n value in '**pow_grad_0_(n)**' array as 2500 as it correspond to the vehicle speed that wheel speed that we chose in Step 1.
Here, we choose the road gradability as 0 % as we deliberately chose the road to be flat. The result is ***1.3038*10^4 W.***

4 : The power margin could be calculated by substracting the value from Step 2 (pow_eng_g3_25 and pow_eng_g4_25) with the result from Step 3 (pow_min_req).

5 : The fuel efficiency could be observed directly from Power-Engine Speed plot shown in fig. 7 by comparing the y-axis value as the results of Step 2 (pow_eng_g3_25 and pow_eng_g4_25) as well as x-axis value as the results of Step 1 (eng_speed_g3_25 and eng_speed_g4_25). By mere eye observation, this will give us the fuel efficiency at 90 km/h at 3rd gear and 4th gear as 0.14 and 0.175 respectively.

Discussion : Here we could observe that driving in 3rd gear gives us higher power margin than 4th gear. This means that driving in the 3rd gear in a flat road gives us higher power compare to driving 4th gear. On the other hand, it gives us lower fuel efficiency compare to the 4th gear ***(0.145 vs 0.175)*** b). For TASK IV part b), we calculate the acceleration capability manually, assuming that the

Mass = 1690 kg, Vehicle Speed = 25 m/s and the driveline efficiency ηT *equals to 0.9.*

The acceleration capability **(a_c)** is:
*The acceleration capability **(a_c)** describes the acceleration the car is capable of, while driving at a constant velocity in a certain gear and going "full-throttle".[3]*

<u>Gear 3</u> : From Step 2,the value of Power margin is **119.5 kW**

By the equation below:

$$\eta T * P_e = F * v$$

$$\Downarrow$$

$$F = \frac{Pe}{v} * \eta T = 4302 \text{ N}$$

$$\Downarrow$$

$$a_c = \frac{F}{m} = 2.546 \text{ m/s^2}$$

<u>Gear 4</u>:From Step 2, the value of Power margin is **76.35 kW**.

By the equation below:

$$\eta T * P_e = F * v$$

$$\Downarrow$$

$$F = \frac{Pe}{v} * \eta T = 2748.6 \text{ N}$$

$$\Downarrow$$

$$a_c = \frac{F}{m} = 1.626 \text{ m/s^2}$$

c). In TASK IV c), we calculated the gradability of the car by using the MATLAB script in Fig. 12.

Gradeability could be defined as the maximum grade that a vehicle is capable of climbing, at a certain constant speed (at a certain road friction level and with a certain load) [3]

In Fig. 12, it is shown that by using the loop **for θ=0-45°**, if the difference of *(Maximum Power at Gear 3/4 [Step 2] – Power on the Wheel [eq.6]) is less than 1000 W*, then the gradeability is calculated as in [eq.7]. Moreover, the loop of the function will keep looping as the angle increase incrementally by 0.05 degrees until the the Power on the Wheel matches the maximum engine Power corresponding to 3rd gear and 4th gear.

The process of this loop is shown by the MATLAB script below. *The resulting $\theta_{gradeability}$ from the loop for the 3rd gear and 4th gear are* ***26,7949°*** *and* ***17,6327°*** *respectively.*

```
for angle= 0:45
    if (max(pow_eng_g3_25)-((v/etad)*(0.5*A*Cd*rho*v^2
        +m*g*fr*cosd(angle)+m*g*sind(angle)))) < 1000
        gradability_g3_25 = tand(angle)*100;
        break

    else
         angle = angle+0.05;
    end
end

for angle= 0:45
    if (max(pow_eng_g4_25)-((v/etad)*(0.5*A*Cd*rho*v^2
        +m*g*fr*cosd(angle)+m*g*sind(angle)))) < 1000
        gradability_g4_25 = tand(angle)*100;
        break

    else
         angle = angle+0.05;
    end
end
```

Fig. 12. MATLAB Loop for gradeability calculation

TASK V

In Task 5, We start by calculating the maximum Torque on the Car Engine by the [eq.1], with MATLAB script shown below,

```
T_max = (new_p_me_max.*V)/(2*pi*nr);
```

Secondly, we calculate the Traction Force (**Fx**) through the equation which is shown in [eq.11] and [eq. 14] below. Here, we inserted [eq.9] to [eq.10] which resulted in [eq.11] as well as we used [eq. 12] to be inserted into [eq.13] to be resulted in [eq.14].

$$T_w' = \eta_T * ri * rFD * Te \quad \text{[eq.9]}$$

$$\frac{Tw'}{R0} = Fx \quad \text{[eq. 10]}$$

$$\frac{\eta T * ri * rFD * Te}{R0} = F_x \quad \text{[eq. 11]}$$

Fig. 13. Formula Process for Traction Force

$$\omega_w' = \omega e' * \frac{1}{ri} * \frac{1}{rFD} \quad \text{[eq. 12]}$$

$$v = R0 * \omega_w' \quad \text{[eq. 13]}$$

$$v = R0 * \omega e' * \frac{1}{ri} * \frac{1}{rFD} \quad \text{[eq. 14]}$$

Fig. 14. Formula Process for Vehicle Speed

```
for n=1:22
    Force_g1(n) = (etad.*T_max(n)*gearRatios(1)*finalDriveRatio)/R0;
    vel_g1(n) = (new_w_ce(n).*R0)/(gearRatios(1)*finalDriveRatio);
    Force_g2(n) = (etad.*T_max(n)*gearRatios(2)*finalDriveRatio)/R0;
    vel_g2(n) = (new_w_ce(n).*R0)/(gearRatios(2)*finalDriveRatio);
    Force_g3(n) = (etad.*T_max(n)*gearRatios(3)*finalDriveRatio)/R0;
    vel_g3(n) = (new_w_ce(n).*R0)/(gearRatios(3)*finalDriveRatio);
    Force_g4(n) = (etad.*T_max(n)*gearRatios(4)*finalDriveRatio)/R0;
    vel_g4(n) = (new_w_ce(n).*R0)/(gearRatios(4)*finalDriveRatio);
    Force_g5(n) = (etad.*T_max(n)*gearRatios(5)*finalDriveRatio)/R0;
    vel_g5(n) = (new_w_ce(n).*R0)/(gearRatios(5)*finalDriveRatio);
end
```

Fig. 15. MATLAB syntax for Traction Force and Speed

The MATLAB script is shown in Fig. 15. Here, we first assume *Force and Torque is an equation containing vector n with value ranging from 1 to 22 in order to plot the Traction Force vs vehicle speed diagram.* After that, we used [eq.11] and [eq.14] to construct a script as shown above.

Next, we chose a speed vector ‘v’ which ranged from **1 to 80 m/s** and inserted it into the traction force equation as shown in [eq.5] by assuming that the car travel in flat road (0% road grade). The MATLAB script is shown below.

```
V_speed_t5 = 1:80;

for v = 1:80
    F(v) = (0.5*A*Cd*rho*v*v+m*g*sin(0)+m*g*fr*cos(0));
end
```

The next step of this task is to calculate the power at the maximum speed, where maximum speed could be obtained from the observing the intersection between the fifth gear traction diagram and the vehicle speed vector which is found to be 69.3 m/s. Whereas the power at maximum speed is found to be 147 kW. **[By Observation]**

Then, we calculate the vehicle speed using the **[eq. 14]** and using the $\omega e'$ at net engine horsepower of **170 kW** at the engine speed of **6300 rpm.**

$$v = R0 * \frac{1}{60} * \omega e' * \frac{1}{ri} * \frac{1}{rFD} = 64.45 \text{ m/s}$$

[By Vehicle Specification]

By the MATLAB script below, we create a new equation of power_at_max_speed, which is essentially found to be 147 kW and we try to look in the pow_grad_0(n) to find the vehicle speed which matched the engine power at its highest rpm. Next, we created a loop to check if the intersection value (69.3 m/s) is right.

Fortunately, it matched with the value found through eye observation (69.3 m/s). Furthermore, the *max_veh_speed_5_mps = 69 m/s* and the converted SI value is *max_veh_speed_5_kmh = 248.4 km/h.* **[By Loop]**

```
power_at_max_speed = pow_grad_0(6630);

for max_speed_5= 0:0.5:80
    if (max(power_eng(end))-((max_speed_5/etad)
        *(0.5*A*Cd*rho*(max_speed_5)^2+m*g*fr*cosd(0)
        +m*g*sind(0)))) < 1000
        max_veh_speed_5_mps = max_speed_5;
        max_veh_speed_5_kmh = max_speed_5*3.6;
        break
    end
end
```

Fig. 16. Check the max vehicle speed by Loop

Results plot for TASK V are shown by Fig. 17 below.

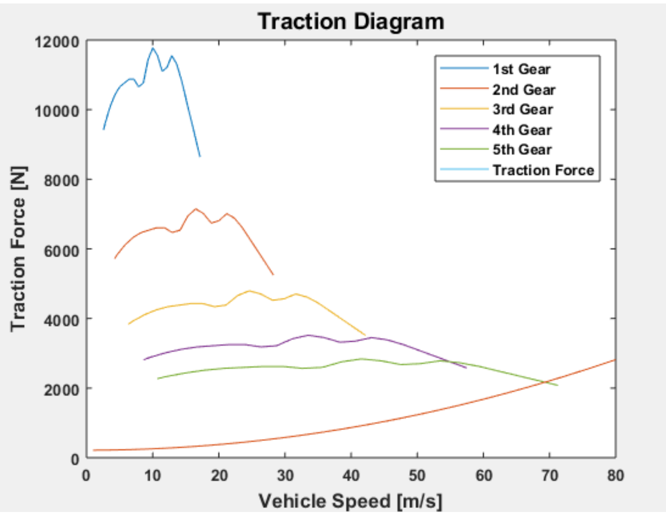


Fig. 17. Traction Diagram

Discussion : In the calculated value through both the loop and observation method, it is found that maximum speed at maximum power point is 69 m/s. However, if we use the data from vehicle specification, the maximum speed is found to be 64.45 m/s at 170 kW.

This could be caused by 3 sources of errors :

1) Road grade used in the real experimental condition is not exactly 0%
2) Different types of Tyres and Road might imply less friction.
3) Accuracy during this assignment's calculation.

The point of maximum speed does not coincide with the point of maximum power. This is caused by the gear ratio. The motor has enough power to give the vehicle a higher velocity, but the tyres can not rotate faster. The engine speed at that point in combination with the gear and final drive ratio limit the maximum velocity.

The calculated maximum vehicle speed is not the same like the maximum vehicle speed given by the manufacturer. This could be caused by a different road grade, which could maybe be not exactly 0%, the use of different tyres on another road, which leads to a different road friction, and the accuracy during the calculations.

TASK VI

For calculating the fuel consumption we use the fifth gear. In the end we will see, if the chosen gear matched with the fuel consumption given by manufacturer.

Firstly, we have to calculate the wheel speed at the given speed. This could be found by using equation below.

Wheel Speed$_{90km/h}$ [m/s] =(Vehicle Speed/3.6) * 1/(R0) = **25 m/s**

Wheel Speed$_{120km/h}$ [m/s] =(Vehicle Speed/3.6) * 1/(R0) = **33,33 m/s**

Wheel Speed$_{240km/h}$ [m/s] =(Vehicle Speed/3.6) * 1/(R0) = **66,66 m/s**

The MATLAB script to do this is described below.

```
% get m/s
mps_90 = 90/3.6;
mps_120 = 120/3.6;
mps_240 = 240/3.6;

% set index
i_90 = mps_90*100;
i_120 = mps_120*100;
i_240 = mps_240*100;

% get wheel speed
w_speed_90 = w_speed_from_veh_speed(mps_90*100);
w_speed_120 = w_speed_from_veh_speed(round(mps_120*100));
w_speed_240 = w_speed_from_veh_speed(round(mps_240*100));
```

Secondly, we calculate the corresponding engine speed. This could be done by using **[eq. 8]** with the results as follow.

$$\omega w_{90\text{km/h}} = 289.65 \text{ rad/s}$$

$$\omega w_{120\text{km/h}} = 386,2 \text{ rad/s}$$

$$\omega w_{240\text{km/h}} = 772.64 \text{ rad/s}$$

Moreover, the MATLAB script is shown below

```
eng_speed_90 = w_speed_90*finalDriveRatio*gearRatios(5);
eng_speed_120 = w_speed_120*finalDriveRatio*gearRatios(5);
eng_speed_240 = w_speed_240*finalDriveRatio*gearRatios(5);
```

Next, to get the lowest fuel consumption, we need to drive with the lowest power possible to drive with a constant velocity. We get this power by looking at the upper-left subplot, which gives us the minimum power required to drive on a flat road. Look at the MATLAB script below.

```
% get minimum power required
p_eng_90 = pow_grad_0(i_90);
p_eng_120 = pow_grad_0(round(i_120));
p_eng_240 = pow_grad_0(round(i_240));
```

To get a value for fuel consumption per 100km, we have to calculate the time you need for driving a distance of a 100km with a certain speed. (Time = Distance/Speed)

$Time_{90km/h}$ = 100/90 = 1,11 hour
$Time_{120km/h}$ = 100/120 = 0.833 hour
$Time_{240km/h}$ = 100/240 = 0.4167 hour

With the point of lowest power required and the corresponding engine speed, we can get the fuel efficiency at this point from the upper-right subplot by reading it off. Moreover, the MATLAB script is shown below.

```
% read off fuel efficiency
fuel_eff_90 = 0.195;
fuel_eff_120 = 0.225;
fuel_eff_240 = 0.235;
```

Finally we can calculate the fuel consumption by using the following formula.

$$\eta_{fuel} = \frac{Pe}{c*mif} = \frac{Pe}{c*\rho*Vf}; \qquad [eq. 15]$$

$$\frac{\Delta Vf}{100\text{ km}} = \frac{Pe}{c*\rho*\eta fuel} * \frac{Time[h]}{100\ km} * 3600\ \frac{s}{h}$$

The MATLAB script is shown below.

```
fc_90 = (time_h_90*p_eng_90*3600)/(c*10^6*rho_fuel*fuel_eff_90);
fc_120 = (time_h_120*p_eng_120*3600)/(c*10^6*rho_fuel*fuel_eff_120);
fc_240 = (time_h_240*p_eng_240*3600)/(c*10^6*rho_fuel*fuel_eff_240);
```

The results from the MATLAB scripts are

$$\frac{\Delta Vf}{100\text{ km}}[90km/h] = 8.543 \text{ litre/km}$$

$$\frac{\Delta Vf}{100\text{ km}}[120km/h] = 10.5195 \text{ litre/km}$$

$$\frac{\Delta Vf}{100\text{ km}}[240km/h] = 30.5518 \text{ litre/km}$$

We see that the calculated values for 90 km/h and 120 km/h are very close to the given consumption by the manufacturer. This proves that the gear that we chose in the beginning was the right one. The small differences come from reading off the fuel consumption, accuracy during the calculations and the possibility that the road grade and friction are slightly different in our data.

TASK VII

To fulfil this task we have to rescale the given data for the electrical machines. We take the data for the “Max-Power”-mode and match the point of maximum power and the corresponding engine speed to the data that is given in the vehicle specifications. For this we take the current point and divide by those values. After that we multiply the value with the values that we want for the new maximum point to be at.

$$\omega e = r_{FD} * \omega tyre = r_{FD} * (\text{Vehicle Speed}) * 1/(R0)$$

$$r_{FD} = \frac{\omega e * R0}{Vehicle\ Speed} \qquad [eq. 16]$$

We also rescale the data for the “Continuous”-mode with the same factor. The script and the result is shown in Fig. 18 and Fig. 19.

```
% Rescale the engine speed with the factor to fit point of max power of
% engine
w_EM_max_col_new = w_EM_max_row.*(659.73/628.3);
w_EM_cont_col_new = w_EM_cont_row.*(659.73/628.3);

% Rescale the engine power with factor to fit max power of engine
P_EM_max_col_new = P_EM_max_col*(170/145.1);
P_EM_cont_col_new = P_EM_cont_col*(170/145.1);
```

Fig. 18. MATLAB script for plot rescaling

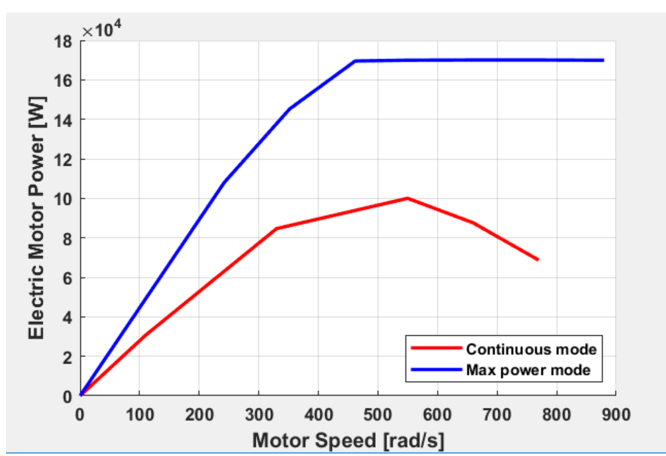


Fig. 19. Rescaled EM Continuous mode

To find the maximum vehicle speed, we create a traction force diagram for the vehicle with the electrical engine in continuous mode. For this we need to calculate the torque of the engine. After that, we can calculate the traction force. The velocity has to be calculated as well. Compared to Task 5, we do not have a gear ratio, because we do not have a gear box.

We do the calculation in a for-loop to be able to plot the resulting traction diagram.

```
for index=1:6
    Torque_em(index) = P_EM_cont_col_new(index)/w_EM_cont_col_new(ind
    Velo_em(index) = (w_EM_cont_col_new(index).*R0)/(finalDriveRatio_
    Force_em(index) = (etad.*Torque_em(index)*finalDriveRatio_em)/R0;
end
```

Furthermore, we have to add the power curve for a flat road with no wind. For this we have to set a final drive ratio before we do the calculation. We start with a ratio of 3.1.

The point, where the two curves are cutting each other, we can read off the maximum speed of the vehicle. For this ratio this would be around 57.54 m/s. Now we lower the ratio to 3.05 and read the maximum vehicle speed again. This time the value is around 57.52 m/s. If we higher the ratio to 3.2 the resulting maximum vehicle speed is around 57.56 m/s. Going higher with the final gear ratio is lowering the maximum vehicle speed.

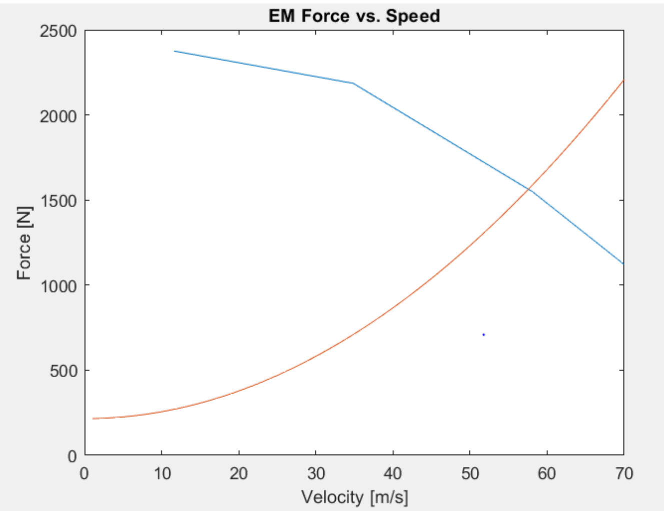


Fig. 21. EM Force vs Speed Plot (Gear ratio =3.2)

To check if the maximum vehicle speed is reasonable, we can calculate the maximum speed due to the maximum power of the electrical engine in the continuous mode.

```
for max_speed_7= 0:0.5:80
   if (max(P_EM_cont_col_new)-((max_speed_7/etad)
       *(0.5*A*Cd*rho*(max_speed_7)^2+m*g*fr*cosd(0)+m*g*sind(0)))) < 1000
       max_veh_speed_7_mps = max_speed_7;
       max_veh_speed_7_kmh = max_speed_7*3.6;
       break

   else
        max_speed_7 = max_speed_7+0.05;
   end
end
```

We get the maximum possible vehicle speed due to the driving resistances, which is around 57.5 m/s. This proves that the final drive ratio we chose is a good choice.

b). One of the differences is the noise level. Due to the electrical engine, this vehicle will be a lot quiter compared to the vehicle with the ICE. There will be almost just tyre and wind noise at this speed. The ICE will be at a high engine speed, which causes a high noise level.

References

[1]. Mathworks Support Documentation. Available at the site:https://www.mathworks.com/help/matlab/ref/meshgrid.html?s_tid=srchtitle

[2]. Mathworks Support Documentation. Available at the site:https://www.mathworks.com/help/matlab/ref/contour.html?s_tid=doc_ta

[3]. Assignment 2018_intro_PPT.pdf page 17 and 22. Available at the course page at Ping-Pong Chalmers.

[4]. Mathworks Support Documentation. Available at the site:https://www.mathworks.com/help/matlab/ref/interp1.html?s_tid=doc_ta

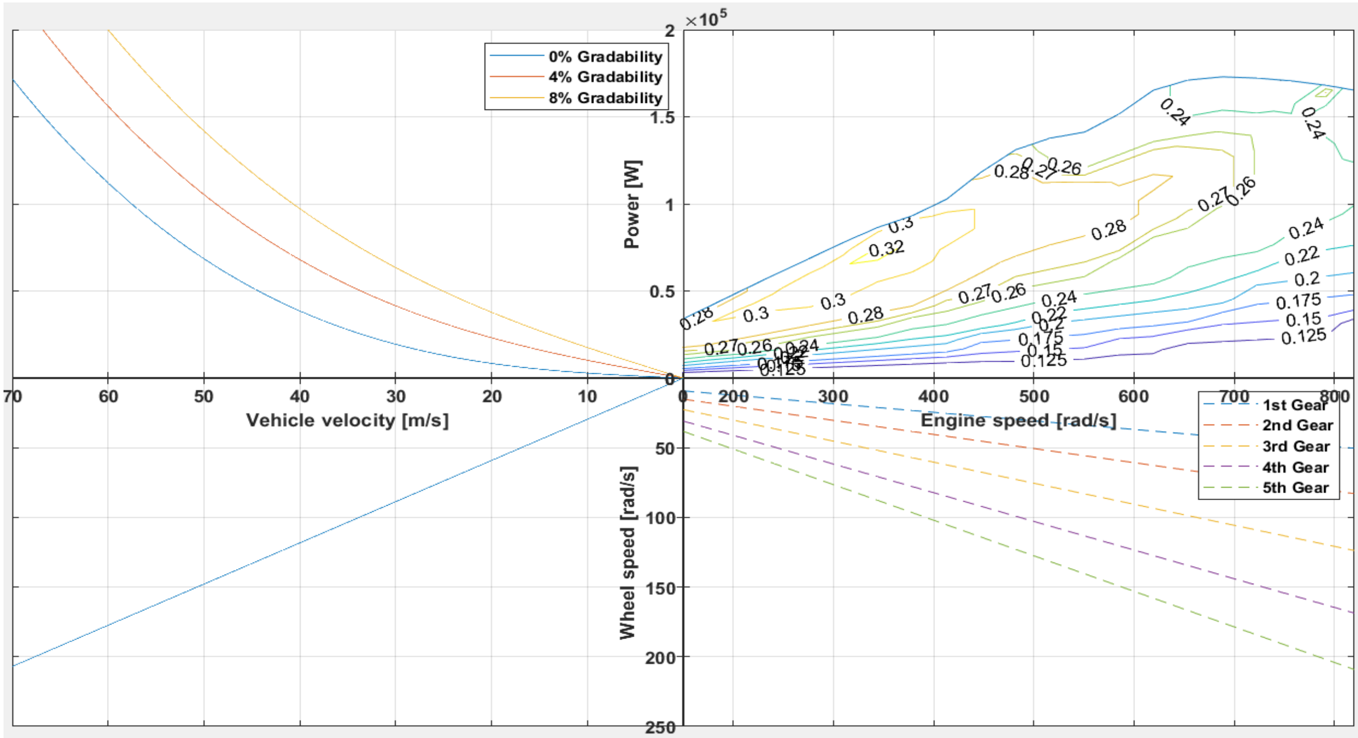
Contribution statement

Student A: MATLAB SCRIPT TASK IV-VII, REPORT WRITING TASK VI-VII

Student B: MATLAB SCRIPT TASK I-III, REPORT WRITING TASK I-V

APPENDICES

A. COMBINED POWERTRAIN DIAGRAM



B. VEHICLE PARAMETERS

Value in Matlab	Description
g = 9.81	Gravitation Force [m/s2]
V = 2.960e-3	Engine displacement volume [m^3]
maxT = 272	Maximum engine torque [Nm]
MaxRPM = 6300	Maximum engine speed [RPM]
gearRatios=[4.15 2.52 1.69 1.24 1.00]	Gear ratios [first gear, second gear, third gear]
finalDriveRatio = 3.92	Final drive gear ratio
m=1690	Mass of vehicle [kg]
A=2.26	Frontal area for drag calculation [m^2]
rho=1.2	Air density [kg/m^3]
fr=0.013	Coefficient of rolling friction
Cd=0.3	Coefficient of drag
width = 225	Width of tyre [mm]
profile = 50	Tyre profile [%]
diameter = 16	Rim diameter [inches]
Q_lhv = 43.5	Lower heating value of gasoline [MJ/kg]
rho_fuel = 0.7197	Density of gasoline [kg/litre]
R0 = 0.3382	Tyre Radius [m]
etad=0.9	Driveline Efficiency