MMF062 Vehicle Dynamics
Design Task 2 - Simulation of Longitudinal Dynamics using an electrified SAAB 9-3

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Figure 1: SAAB 9-3 (2014) [1].

Second group assignment in the course MMF062 - Vehicle Motion Engineering

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Abstract

This design task in vehicle motion engineering focuses on simulating a 100-meter drag race up an 8-degree hill using a Saab 93. We evaluate the performance of front-wheel drive (FWD) and rear-wheel drive (RWD) configurations in dry and wet conditions, considering the influence of traction control on power consumption. Our simulations use the "magic tire" formula and a mathematical model based on the free body diagram.

Task 1

Task 1 a)

Figure 2 illustrates normalized traction force as a function of slip, s_x. for the three different road conditions. One can draw the conclusion that dry conditions results in the highest traction force, which is reasonable.

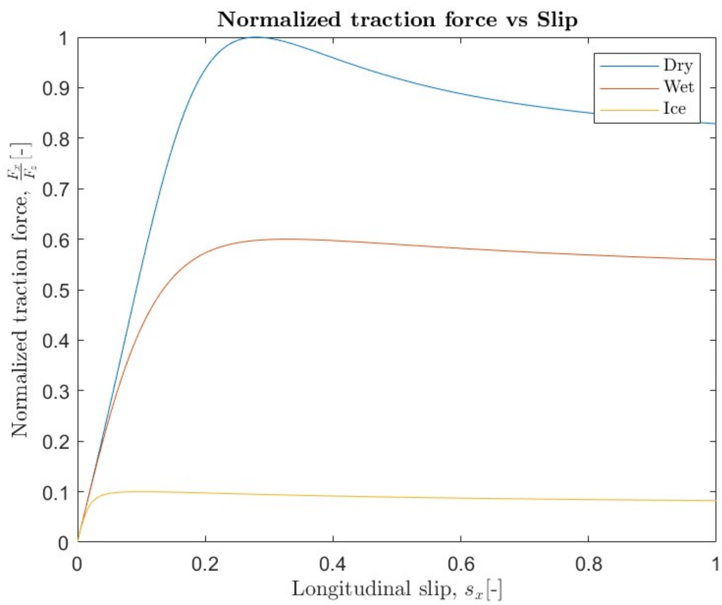


Figure 2: Normalized longitudinal froces as a function of slip s_x for three different road conditions: dry, wet and ice.

Task 1 b)

Normalized traction force was calculated given $0 \leq s_x \leq 1$ using the magic formula tyre model. Calculated values was then fitted against experimental data for slip, s_x, and Normalized longitudinal tyre force, $\frac{F_x}{F_y}$ by manually iterating C, D and E until a satisfiable result was achieved. It was determined that $C = 1.5, D = 0.95$ and $E = -4$ achieved similar results to the experimental data, see Figure 3.

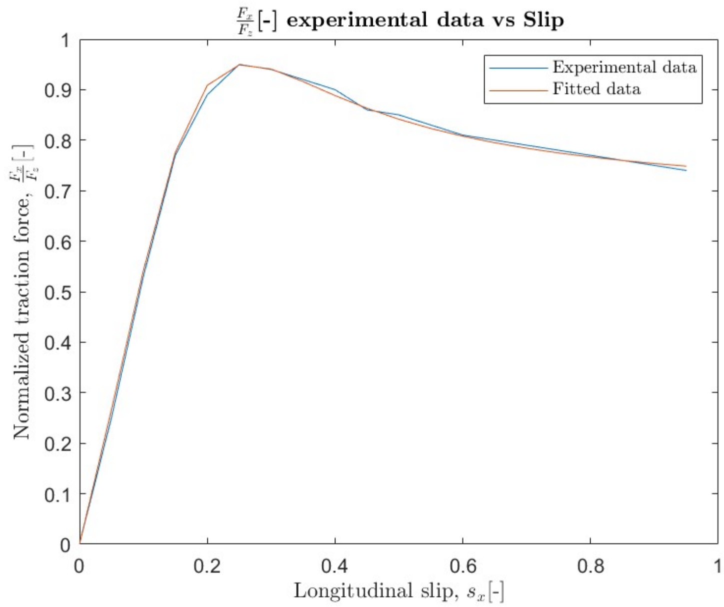


Figure 3: Normalized traction force for $C = 1.5, D = 0.95$ and $E = -4$ using magic formula tyre model fitted against given data.

Figure 4 illustrates the Experimental data and the fitted data with $E = 0$. E determines the curvature and position of the peak. In this case, increasing E leads to worse results, as illustrated in Figure 4.

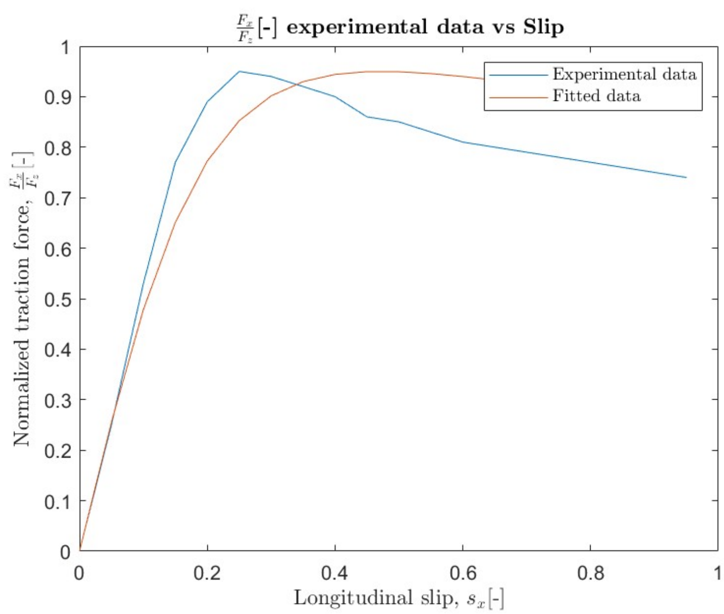


Figure 4: Normalized traction force for $C = 1.5, D = 0.95$ and $E = 0$ using magic formula tyre model fitted against given data.

Task 2

Task 2 a)

Figure 5, Figure 6 and Figure 7 illustrates the free body diagram of the car, wheels and ground respectively.

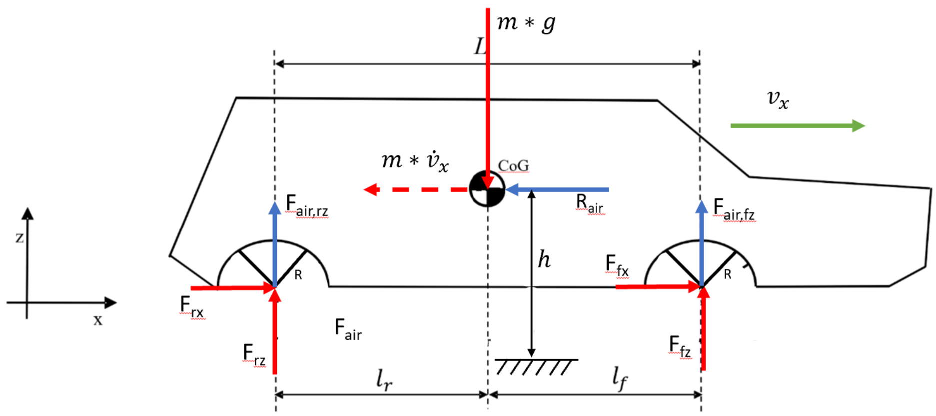


Figure 5: Free body diagram of the car.

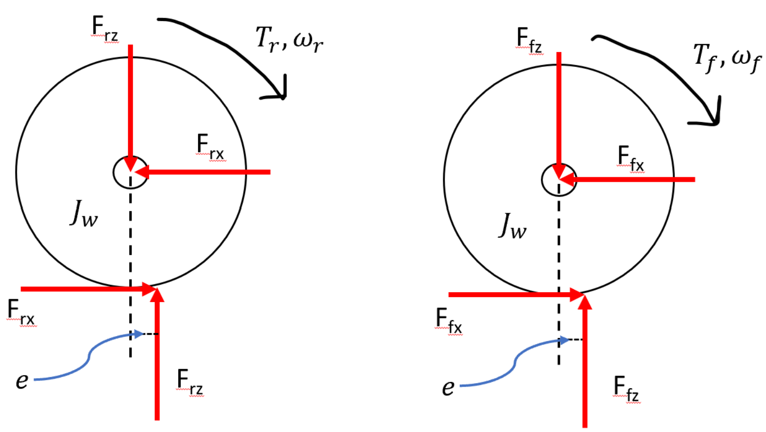


Figure 6: Free body diagram of wheels.

Figure 7: Forces acting on the ground.

Task 2 b)

The following equations can be derived from the free body diagrams to form a mathematical model:

$$\uparrow: F_{rz} + F_{air,r} + F_{fz} + F_{air,f} = mg \tag{1}$$
$$\rightarrow: m\dot{v} + R_{air} = F_{rx} + F_{fx} \tag{2}$$
$$\curvearrowright: (F_{rz} + F_{air,r})l_r - (F_{fz} + F_{air,f})l_f - (F_{rx} + F_{fx})h = 0 \tag{3}$$
$$\curvearrowright: T_f - J_w\dot{\omega}_f - F_{fx}R - F_{fz}f_rR = 0 \tag{4}$$
$$\curvearrowright: T_r - J_w\dot{\omega}_r - F_{rx}R - F_{rz}f_rR = 0 \tag{5}$$
$$F_{fx} = F_{fz}\mu_f \tag{6}$$
$$F_{rx} = F_{rz}\mu_r \tag{7}$$

Table 1 shows the different variables for the model. There are 7 equations and 7 unknowns which means that the system is solvable.

Table 1: Variables.

Parameters:	g, J_w, l_r, l_f, R, m, R_{air}, $F_{air,rz}$, $F_{air,fz}$, μ_f, μ_r, θ, T_r, T_f and f_r
Dependent variables:	F_{fx}, F_{fz}, F_{rx}, F_{rz}, $\dot{w}_f$, $\dot{w}_r$ and $\dot{v}_x$
Independent variable:	t

Task 2 c)

The car is now driving up a hill with road inclanation, θ. Figure 8 illustrates the updated free body diagram for the car.

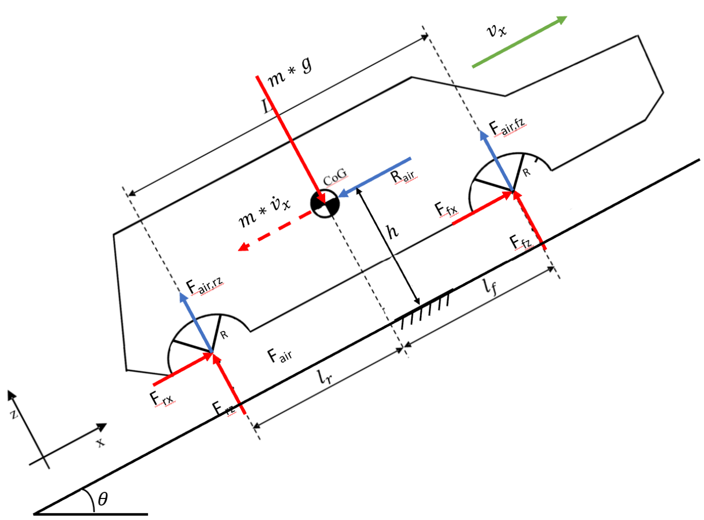
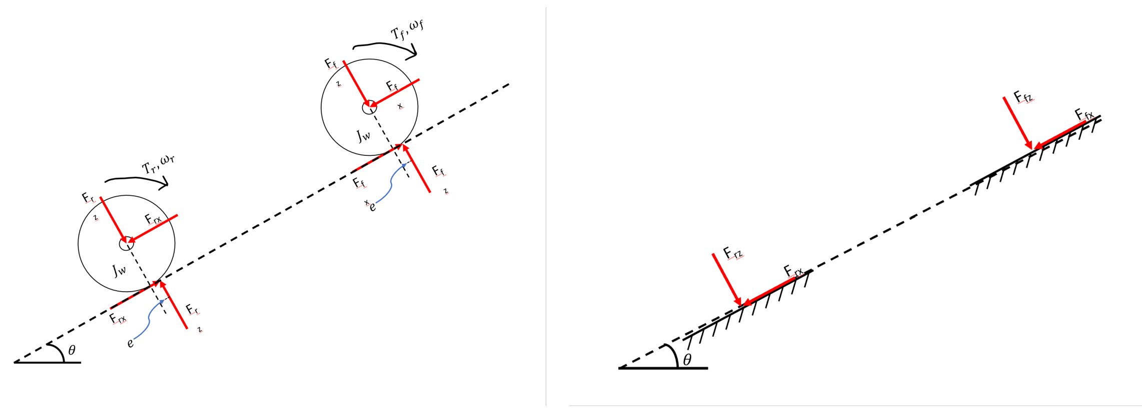


Figure 8: Free body diagram of the car driving up a hill with gradient θ.

Figure 9a and Figure 9b illustrates the updated free body diagrams for wheels and ground respectively.



(a) Wheels

(b) Force acting on the ground

Figure 9: Free body diagram of the wheels and ground when diving up the hill.

The mathematical model is updated to accommodate for the inclination, θ:

$$\uparrow: F_{rz} + F_{air,r} + F_{fz} + F_{air,f} = \cos(\theta) mg \tag{8}$$
$$\rightarrow: m\dot{v} + R_{air} + \sin(\theta) mg = F_{rx} + F_{fx} \tag{9}$$
$$\curvearrowright: (F_{rz} + F_{air,r})l_r - (F_{fz} + F_{air,f})l_f - (F_{rx} + F_{fx})h = 0 \tag{10}$$
$$\curvearrowright: T_f - J_w\dot{\omega}_f - F_{fx}R - F_{fz}f_r R = 0 \tag{11}$$
$$\curvearrowright: T_r - J_w\dot{\omega}_r - F_{rx}R - F_{rz}f_r R = 0 \tag{12}$$
$$F_{fx} = F_{fz}\mu_f \tag{13}$$
$$F_{rx} = F_{rz}\mu_r \tag{14}$$

Task 3

Task 3 a)

Code added to function `Sub_wheel_slip.m` that calculates the dimensionless relative speed, s_x, given input values vehicle speed, v, tyre angular speed, ω, and tyre radius, `CONST.R`:

```
slip = (CONST.R*w - v)/abs(CONST.R*w);
```

Task 3 b)

The following code was used in order to find expressions for the dependent variables, see Table 1.

```
sol = solve( ...
    Fzr + F_air_rz + Fzf + F_air_fz == M*g*cos(slope), ...
    M*derv_x + Rair + M*g*sin(slope) == Fxr + Fxf, ...
    (Fzr + F_air_rz)*L_r - (Fzf + F_air_fz)*L_f - (Fxr + Fxf)*h == 0,
        ...
    Tdrivf - J_w*derw_f - Fxf*R - Fzf*R*f_r == 0, ...
    Tdrivr - J_w*derw_r - Fxr*R - Fzr*R*f_r == 0, ...
    Fxf == Fzf*ff, ...
    Fxr == Fzr*fr, ...
    Fzf, derv_x, Fzr, derw_f, derw_r, Fxf, Fxr);
```

The solution can be observed in "`Sub_vehicle_dynamics.m`"

The output from the simulation is reasonable when observing the graphs. We can observe in Figure 10 that the Rear Motor speed is greater than the Front Motor speed, which is as expected since the vehicle is RWD (Rear wheel drive) for this simulation. This is due to slip of the driven wheels which can be confirmed in Figure 11, where the slip of the front wheels are zero, and the slip of the rear wheels are non-zero. The reason the front wheels have zero slip is due to that they are not driven and are therefore coasting at the same speed as the is vehicle travelling. Slip for the front wheel is therefore zero since $Rw - v_x = 0$. Changing the simulation from RWD to FWD would show that the slip is zero for the Rear wheels and non-zero for the Front (driven) wheels, as expected.

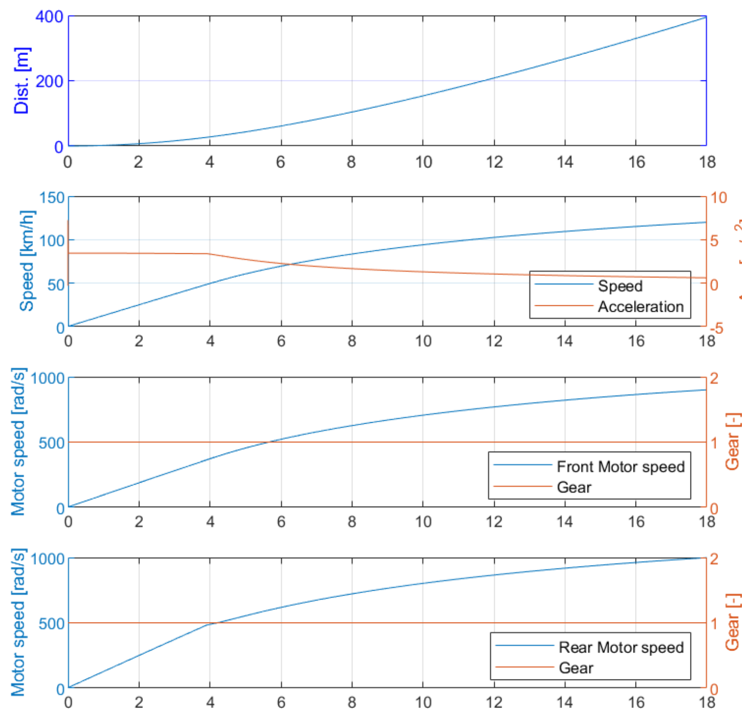


Figure 10: Distance [m], Acceleration [m/s^2], Speed[m/s], Motor speed [rad/s] (for front and rear motor) and gear as a function of time, t.

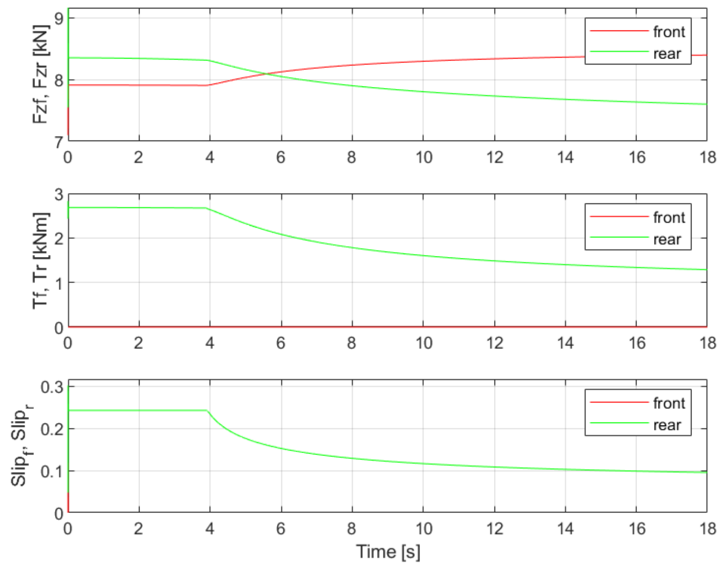


Figure 11: Vertical forces [N], Torque [Nm] and Slip as a function of time for front and rear wheel.

Task 3 c)

Table 2: 100m Drive times [s] for different road conditions and RW- and FW-drive

	RW	**FW**
Dry	7.8230s	8.0256s
Wet	12.1794s	11.5325s

Table 2 illustrates the time it takes for the vehicle to reach 100m during different road conditions and when switched between RWD and FWD. It can be concluded that using RWD yields the shortest acceleration time in dry conditions. The opposite is true in the wet condition.

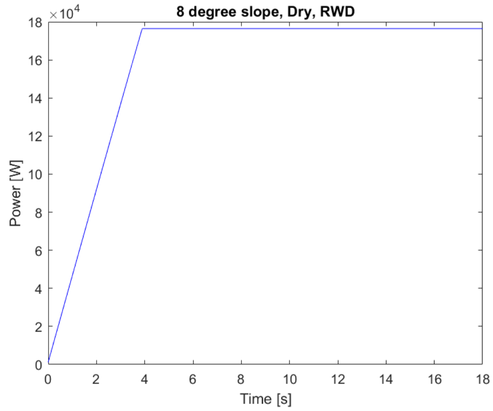
Task 4

Task 4 a)

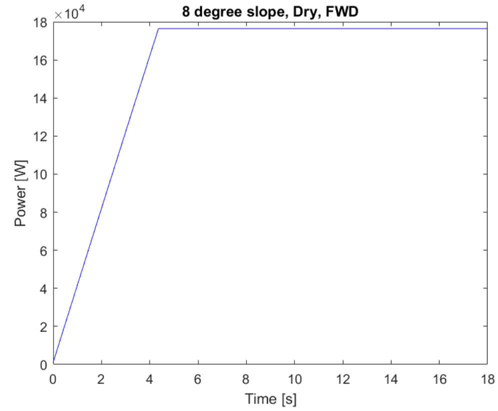
Efficiency of 85% was used. It can be observed that the RWD vehicle on dry road consumes most amount of power between the four cases. FWD in dry consumes second most followed by FWD and RWD on wet road. This can be interpreted as the TC (Traction Control) is limiting the power especially for wet conditions. Which results in slower acceleration times, as concluded in Task 3c.This is due to the Anti-slip controller detecting a greater slip than accepted which limits the power to the motor.

It can be inferred that there is a greater occurrence of slip for RWD on wet roads compared to FWD on wet roads. In Figure 12d, the power curve reaches its maximum, while in Figure 12c, the power curve struggles to reach max power because traction control TC restricts the power output throughout the race.

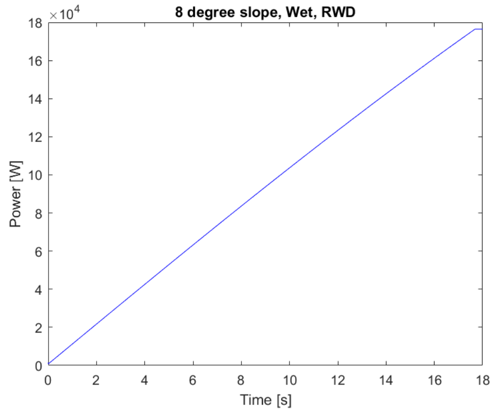
If you compare the slip between RWD and FWD in dry conditions, the RWD will have a greater slip versus the FWD. This means that the normalised traction force, see Figure 2, on the RWD car is greater than the FWD car. We can therefore conclude that the load transfer in the RWD car leads to a greater normalized traction force. This implies that the RWD car is more effective in transferring power to the ground, as illustrated in Figure 12a. In other words, the TC (sloped line) will be ”on” for the shortest time due to traction limitations.



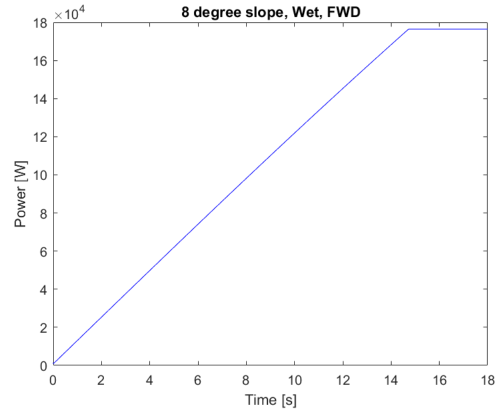
(a) RWD Dry road condition



(b) FWD Dry road condition.



(c) RWD Wet road condition.



(d) FWD Wet road condition.

Figure 12: Power consumption [W] as a function of time for FWD and RWD in different road conditions.

Task 4 b)

The vehicle without TC uses significantly more power at the start without taking into account the slip experienced by the wheels. This accounts for the steep slope at $0 \leq t \leq 0.075$ in Figure 13 below. The graphs in Task 4 a) utilises TC which measure the difference in velocity between wheel and vehicle. If the difference is larger than a certain value the TC limits the power supplied to the motor, thus the slope in these graphs are not as steep as the one in Figure 13.

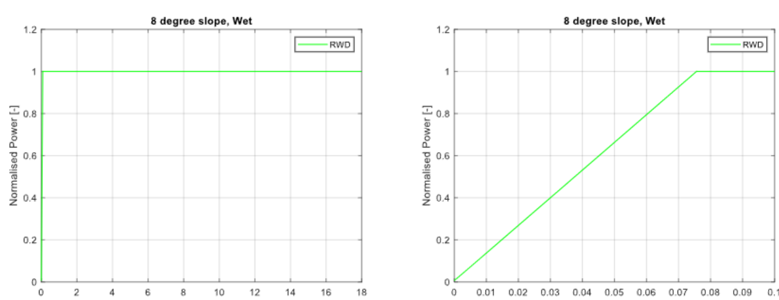


Figure 13: Power consumption for vehicle without TC. These plots were given in the task instructions.

References

[1] Wallpaperuse (2020) - SAAB 9-3. Published online at wallpaperuse.com Retrieved from: https://www.wallpaperuse.com/vien/hwxhxm/ [Online Resource]