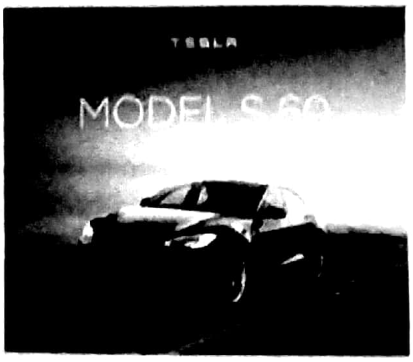
Electric Vehicle Design Exercise Question

I received the following advertisement from Tesla Motors on 9th of June 2016. Answer the following questions according to the information given in this advertisement.

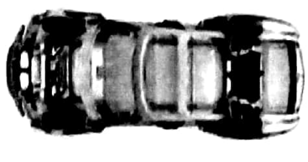


Today we're excited to reintroduce the Model S 60. Starting at $58,500 (after incentives) or $667 a month (details here), the Model S 60 delivers 210 miles (EPA est.) of range, a top speed of 130 mph and zero-to-60 acceleration in 5.5 seconds.

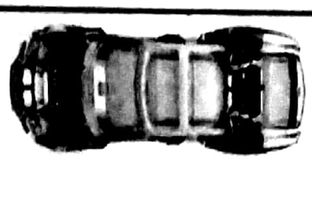
With all-wheel drive, the Model S 60D provides more range (218 miles EPA est.) and faster acceleration (zero-to-60 in 5.2 seconds).

Like all Tesla vehicles, the 60 and 60D come standard with active safety features and Autopilot hardware. And both versions can later be upgraded through a software update to 75 kWh for about 20% extra range.

Drive



Rear Wheel Drive



All-Wheel Drive
+ $5,000

Anyone who buys a 60 or any other new Model S or Model X between now and July 15 through the Tesla Referral Program gets a $1,000 credit towards the purchase. Just get the special personal code of any Tesla owner and enter it at the time of purchase.

60	75	90D	P90D
60 kWh Battery **Rear Wheel Drive**	75 kWh Battery **Rear Wheel Drive**	90 kWh Battery **All-Wheel Drive**	90 kWh Performance **All-Wheel Drive**
210 miles range (EPA est	**249** miles range (EPA)	**294** miles range (EPA)	**270** miles range (EPA)
130 mph top speed	**140** mph top speed	**155** mph top speed	**155** mph top speed
5.5 sec 0-60 mph	**5.5** sec 0-60 mph	**4.2** sec 0-60 mph	**3.1** sec 0-60 mph **2.8** sec with Ludicrous Speed Upgrade
	more power		

1. It was necessary to give an explanation in parentheses after range information 210 miles and 218 miles. What does this information mean? Are there other similar definitions? Give one more example.

It represents drive cycle on which range information is achieved. There are other drive cycles in the field. WLTP, FTP 72/75, NEDC and/or JC08 are other examples.

2. Are the given range values realistic for our daily trips? Explain your reasoning considering daily driving cycles and extra loads.

It depends.

No, Not really, In our daily trips, we climb hills. In drive cycles hills are not considered. Also wind and other environmental conditions can change fuel consumption, which is not considered in drive cycles.

3. Assume that the same electric machine and inverter as well as same battery cells are implemented in all Tesla Model S versions. However, the maximum speed of the car increases with the battery energy capacity, such as 130mph with 60 kWh and 140 mph with 75 kWh. Which battery characteristic influences the maximum speed? Write the power equation at the maximum speed limit on a flat road.

As battery capacity increases, more cells are connected in parallel, which decreases equivalent resistance of the battery. Thus, battery losses are decreased for the same output current. Therefore, as capacity increases, battery power increases, resulting in more speed.

$F_{traction} = F_{rolling} + F_w \Rightarrow F_t = f_r \times M \times g + 0{,}5 \rho A_f C_d (V_{max})^2$

4. Why can all-wheel drive have a faster acceleration? Explain in one sentence. Calculate the average acceleration from 0 to 60 mph (96.56 km/h) for add-wheel drive version that is Model S 60D.

Traction force is applied from all-four wheels rather than 2 wheels. Adhesive limit is higher (twice, almost)

$$a = \frac{dV}{dt} = \frac{96{,}56}{3{,}6 \times 5{,}2} = 5.2 \ m/s^2$$

5. State the most important reason of getting a longer range with all-wheel drive for a given battery energy capacity.

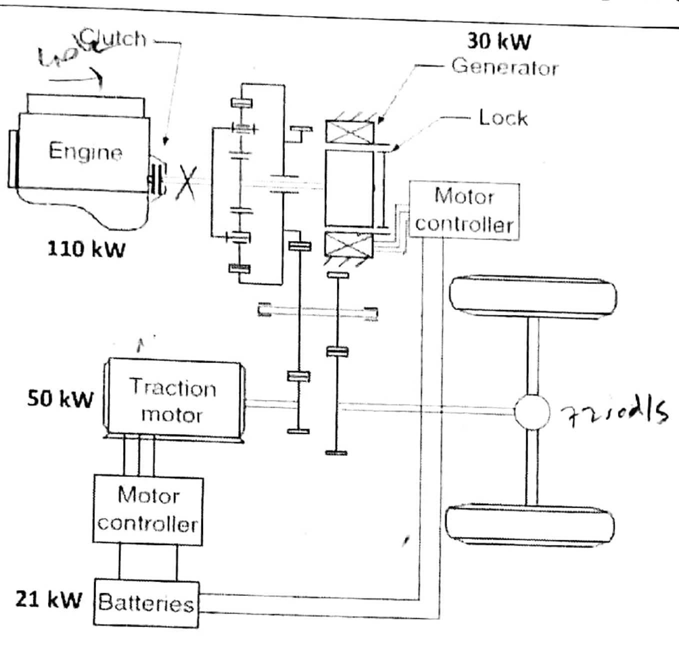
More regenerative energy is achieved rather than 2 wheels.

6. The email indicates that 75 kWh of battery result in about 20% more range than 60 kWh battery. The battery energy capacity is increased by 25 %, but range increases only be 20 %. Why does range not increase with the same ratio with the battery energy capacity? Explain in one sentence

Battery mass.

EE 7566 - Power Split Hybrid Exercise Calculations

Answer following questions according the following configuration and given information in Table 1.



a)

Fig. 2. Configuration of the 1st generation Toyota Prius.

series-parallel hybrid ev.

GM1 → generator

GM2 → em

✱ Gear ratios are torque multipliers!

Table 1 – Prius information

Radius of wheels	0.3 m
Gear ratio (electric motor to wheels)	4
Gear ratio (Ring gear to wheels) G_{r-w}	2
Gear ratio (Electric motor to ring gear) G_{GM2-r}	2
Number of ring gear teeth N_r	80
Number of sun gear teeth N_s	32

Torque coupler

$$\omega_{GM2} = \omega_w \overset{(2)}{G_{GM2-r}} \overset{(2)}{G_{r-w}} \longrightarrow \omega_{GM2} = 4 \times \omega_w \quad , \quad \omega_r = 2 \cdot \omega_m$$

$$T_{GM2} G_{GM2-r} + T_r = \frac{T_w}{G_{r-w}} \longrightarrow T_w = 4 \cdot T_{GM2} + 2 \cdot T_r$$

Speed coupler

$$\frac{\omega_{GM2}}{G_{GM2-r}} = \left(1 + \frac{N_s}{N_r}\right)\omega_{engine} - \frac{N_s}{N_r}\omega_{GM1} \longrightarrow \omega_{GM2} = 2.8 \times \omega_{engine} - 0.8 \times \omega_{GM1}$$

$$T_{ring} = \left(\frac{N_r}{N_r + N_s}\right) T_{engine} = \frac{N_r}{N_s} T_{GM1} \longrightarrow 14\, T_{ring} = 10\, T_{engine} = 35\, T_{GM1}$$

= pure ev mode =

1. Calculate the torque and rotational speed of the wheels, electric machine, ring gear, internal combustion engine, and generator when the electric machine produces 15 kW power and the internal combustion engine is **idle** (zero torque and speed), at 21.6 km/h. All losses in the system are ignored and required configuration information is given above. 6m/s

	Front wheels total (ω)	Electric machine (ω_{GM2})	Ring gear	ICE	Generator (GM1)
Rot. speed in rad/sec	20	80	40	0	-100
Torque in Nm	750	187.5	0	0	0
Power in kW	15	15kw	0	0	0

→ 12m/s

2. When the battery is critically low, the energy management system runs the internal combustion engine both to drive the wheels and charge the battery. The vehicle speed is 43.2 km/h, total power required on driven wheels is 30 kW, battery charging power is set to be 10 kW and the electric motor is **freewheeling** (zero output torque). All losses in the system can be ignored. Fill the following table for this operating point.

	Front wheels total	Electric machine	Ring gear	ICE	Generator
Rot. speed in rad/sec	40	160	80	76.19	66.66
Torque in Nm	750	0	375	525	150
Power in kW	30k	0	30k	40k	10k

$\frac{-80}{0.8}$

$V = \omega r$

$\omega_w = V/r$

$T_w = k_1 \cdot T_{GM2} + k_2 \cdot T_r$

$k_1 \to 4$, $k_2 \to 2$

$\omega_w = \frac{1}{4}\omega_{GM2} = \frac{1}{2}\omega_r$

$0.8\,\omega_{GM1} = 2.8\,\cancel{\omega_{eng}}^{0} - \omega_{GM2}$

=

3. Calculate an alternative power distribution among components for the operation when the total power required on driven wheels is 30 kW and the battery charging power is set to be 10 kW at 43.2 km/h such that the ICE operates at its maximum efficiency. Fill the following table for this optimal operation.

Hint: Efficiency of the ICE is an important criteria in power management. In Prius, the ICE is the main power source but its shaft is not directly coupled to the wheels. Therefore, the speed of the ICE can be chosen independent of the driving speed. Once the power and speed of ICE are known, power distribution between generator and ring gear can be calculated. This configuration is also called power-split hybrid because the power of ICE splits between ring and sun gears. The power versus speed characteristic at maximum efficiency of the internal combustion engine is shown in Fig. 3. Select the optimal operating point for the ICE according to the characteristic line, then calculate the other torque and rotational speed values.

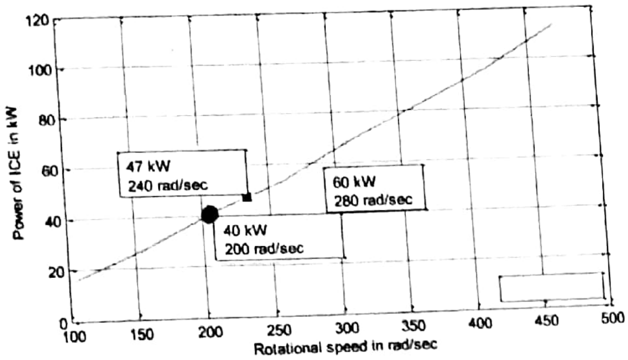


Fig. 3. Maximum efficiency line of the ICE.

	Front wheels total	GM2 Electric machine	Ring gear	ICE	GM1 Generator
Rot. speed in rad/sec	40	160	80	200	500
Torque in Nm	750	116.07	142.86	200	57.14
Power in kW	30k	18.57k	11.43k	40k	28.57k

4. Repat part 3 for P_{wheels}: 35 kW, P_{charge}: 5 kW

	Front wheels total	GM2 Electric machine	Ring gear	ICE	GM1 Generator
Rot. speed in rad/sec	40	160	80	200	500
Torque in Nm	875	147.32	142.86	200	57.14
Power in kW	35k	23.57	11.43	40	28.57

$\boxed{P_{ICE} = P_{ring} + P_{generator}}$

$\boxed{P_{wheel} = P_{ring} + P_{elect.\,motor}}$