Lecture 05 . (Part II) EngGen140

Topics : case study of energy balances (for car trip) } section 5.6

What you should be able to do :
- carry out simple energy accounting
- understand & calc. simple possible efficiency improvements (eg air resistance & speed etc)

Exam Q :

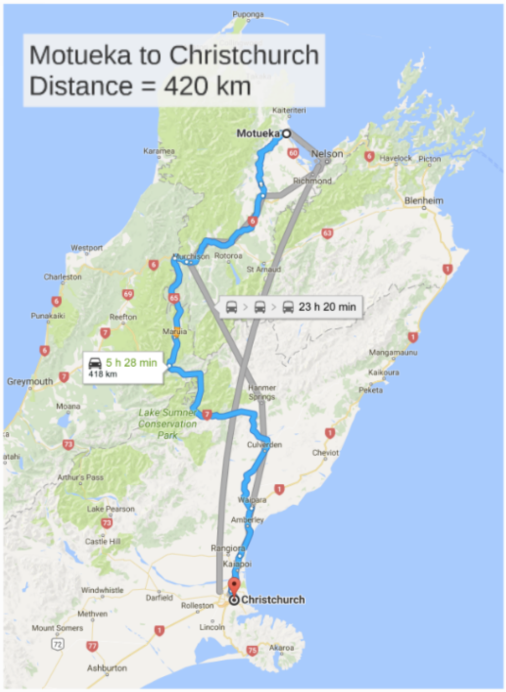
28) Simple physics provides us with ideas for reducing our transport energy cost. The work required to overcome air resistance (W_{air}) plays the biggest role in the total energy budget of a vehicle. The NZ Government are thinking about increasing the speed limit from 100 km/h to 110 km/h. What effect would this have on the percentage increase in fuel consumption?

(2 marks)

Answer:

The case study

The trip



The car

The crew

4 University students
mass = 75 kg each

Average speed

100 km/hr

Transportation takes up a significant fraction of NZ energy consumption (~ 37% of consumer energy demand)

How could we reduce energy consumption?

→ let's do a case study!

Kinetic energy : $\frac{1}{2}mv^2$

Total mass $= 1400\ kg + 4 \times 75\ kg$

$= 1700\ kg$

Speed $= \frac{100\ km}{hr}$

$= \frac{100\ km}{\cancel{hr}} \times \frac{1\ \cancel{hr}}{3600\ s}$

$= \frac{100 \times 10^3\ m}{3600\ s}$

$= 27.8\ m/s.$

$\Rightarrow E_K = \frac{1}{2}mv^2 = \frac{1}{2} \times 1700 \times 27.8^2$

$\approx 657\ kJ$

Consumption

Petrol consumption : 17 L/100km.

Petrol energy density : 34.2 MJ/L

① - Energy 'used up' via combustion?

② - Energy 'available' for useful work?

① Total petrol consumption

$= \frac{17\ L}{100 km} \times \frac{420 km}{Journey}$

$= 71.4\ L$

& Total energy consumed : L petrol used $\times$ $\frac{\text{energy}}{\text{L petrol}}$

$= 71.4\ \cancel{L} \times \frac{34.2\ MJ}{\cancel{L}}$

$\approx 2442\ MJ$

② Assume efficiency 25%

available $= 0.25 \times 2442\ MJ = 610\ MJ$

Note:

used 2442 MJ

useful 610 MJ ie 610×10^6 J

But only have

$E_k \approx 657$ kJ ie 657×10^3 J

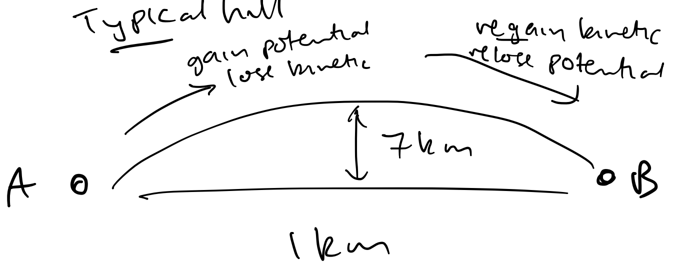
Where's the balance ??!

⇒ Energy 'lost' to heat energy

Petrol → Heat
Petrol → Motion

Possible: Assume climb hills
& use brakes
way down
→ lose, say, 50%
when braking
down hill.

Typical hill



+ lose some to heat while braking – key.

Lcf zero then no diff. bet. A & B.

Climb hill: $E_g = mgh = 1700\,kg \times 9.81\,m/s^2 \times 7\,m$
~ 117 kJ.

Lose 50% to heat on way down
lose $\sim 0.5 \times 117$ kJ over
1km hill.

Worst case: hill every 1km

$\Rightarrow$ lose $0.5 \times 117\,kJ \times 420\,\cancel{km} / 1\,\cancel{km}$

≈ 24.57 MJ

So :

0.657 MJ to get started

(KE : once going, don't need more)

24.57 MJ to brakes

↳ friction → heat

Still << 610 MJ !

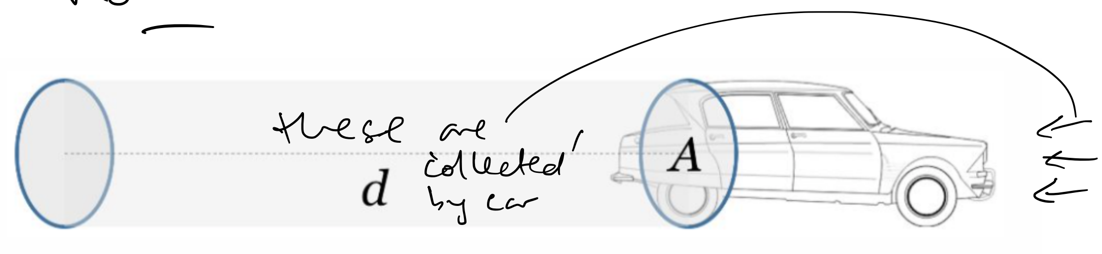
Other losses ?

- air resistance
- tire friction

→

Air Resistance

Motivation:



- car collides with molecules in tube of area A & length d

- car accelerates these molecules to velocity $\sim v$

$$W_{\text{air resis.}} = \Delta E_{K\,\text{air}} \approx \frac{1}{2} m v^2$$

mass in 'tube'

$$= \rho \cdot A \cdot d$$

density, volume.

empirically, use constitutive assumption

$$\boxed{W_{\text{air resis}} = \frac{1}{2} C_d \cdot (\rho A d) v^2}$$

drag coefficient (empirical, since approx.).

eg 'shape correction'

Air resistance cont'd

assume $C_d = 0.33$

$A = 3.2\,m^2$

$\rho = 1.2\ kg/m^3$

$$W_{air} = \frac{1}{2} C_d (A d \rho) v^2$$

$$= \frac{1}{2} \times 0.33 \times (3.2\,\cancel{m^2} \times \underbrace{420\times10^3\,\cancel{m}}_{\substack{d = \\ \text{total} \\ \text{distance} \\ \text{travelled}}} \times 1.2\,\frac{kg}{\cancel{m^3}} \times (27.8\,\tfrac{m}{s})^2)$$

$$= 206\times10^6\ \frac{kg\cdot m^2}{s^2}$$

$$= 206\ \underline{MJ}$$

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what happens if increase speed from 100 km/hr → 120 km/hr ?

(remember exam Q!)

$$\frac{W_2}{W_1} = \frac{\cancel{C}}{\cancel{C}} \times \frac{v_2^2}{v_1^2} = \boxed{\frac{v_2^2}{v_1^2}}$$ ← key

cancel

$$= \frac{120^2}{100^2} = 1.44.$$

⇒ $\boxed{\text{energy lost to air resistance} \uparrow 44\%}$

$$W_2 = 1.44 \times W_1 = 1.44 \times 206\,MJ$$

$$= \underline{297\ MJ}$$

Rolling resistance?

Car tyres on road

constitutive equation:

$$F_r = c \cdot \text{Weight}$$

in Newtons.

coeff. of rolling resistance (dimensionless factor)

c ↑ with speed

c ↓ with tyre pressure ↑ — keep tyre pressure ↑!

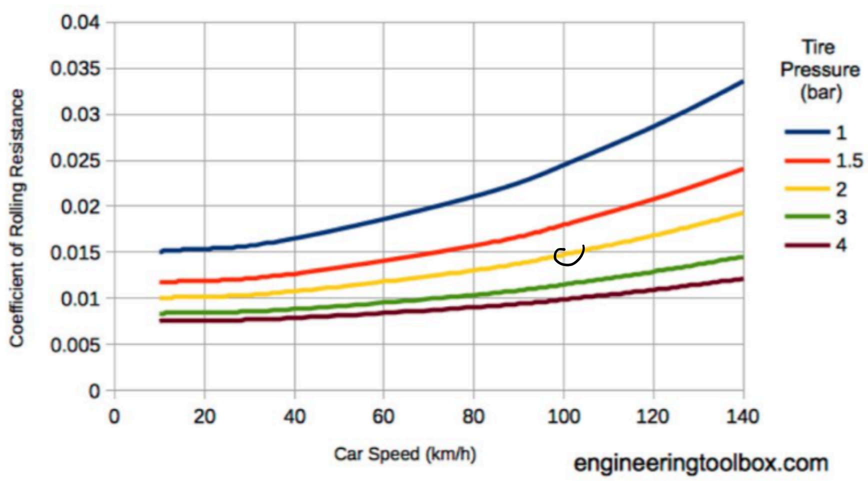

Figure 8: Coefficient of rolling resistance for car tyres. 1 bar = 10^5 Pa [engineering toolbox.com]

$$F_r = c \cdot \text{Weight}$$

$$= c \times 1700\,\text{kg} \times 9.81\,\text{m/s}^2$$

assume $c = 0.015$

$$\Rightarrow F_r = 250\,\text{N}.$$

$$W = F \times d = \underset{\text{N}}{250} \times \underset{\text{m}}{420 \times 10^3} = \underline{105\,\text{MJ}}$$

Final balance

0.6 MJ Kinetic energy
24.6 MJ Braking down hills
206 MJ Air resistance
105 MJ Rolling resistance

336.2 MJ Total accounted for.
(mechanical forms)

=> Much closer to 610 MJ
based on 25% eff.

what is 'true' efficiency if we
have accounted for everything?

=> Total chemical energy from
fuel (raw):

2442 MJ

used to drive

=> Efficiency of engine : $\frac{336.2}{2442} \times 100 = 14\%$

available from fuel