Registration Quiz 2025 Solutions

Formula Student Portugal

Formula Student Switzerland

01/02/2025

EV-Specific Questions

#1 Battery Module Cooling Design

Expected Time: 1 min

Question:
A battery module generates heat at a rate of 2 kW during operation. Consider a cooling system using liquid coolant with a specific heat capacity of 4.2 kJ/kg·K and a flow rate of 0.5 kg/s. Assume that the battery module only exchanges heat with the liquid coolant.

Calculate the temperature rise of the coolant, assuming the cooling system has reached its steady state condition.

Answer format: Do not round any intermediate results. Answer in degrees Kelvin and use the following format: 12.30 or 1.23 (no ',' comma, no letters), round final result to 2 decimal places.

Answer: 0.95

Resolution:

Heat absorbed, q, relation to mass, m, specific heat capacity, c_s, and temperature difference ΔT:

$$q = mc_s \Delta T$$

In steady state we can consider only the power, P and the mass flow m_f:

$$P = m_f c_s \Delta T \rightarrow \Delta T = \frac{P}{m_f c_s} = 0.952K$$

#2 Regenerative Braking System Analysis

Expected Time: 2 min

Question:
A regenerative braking system stores energy in a supercapacitor with a capacitance of 3 F. A vehicle with a mass of 300 kg slows down from 80 km/h to 30 km/h, storing energy during braking. Assume all the kinetic energy is converted into electrical energy stored in the supercapacitor, with no losses due to friction or resistance.

Calculate the total energy stored in the supercapacitor.

Answer format: Do not round any intermediate results. Provide your answer in kJ and use the following format: 12.300 or 1.234 (no ',' comma, no letters), round final result to 3 decimal places.

Answer: 63.657

Resolution:

$$KE = \frac{1}{2}mv^2$$

$$StoredEnergy = KE_{80km/h} - KE_{30km/h} = \frac{1}{2}300(80/3.6)^2 - \frac{1}{2}300(30/3.6)^2 = 63657\,J = 63.657\,kJ$$

#3 Charging Infrastructure Design

Expected Time: 3 min:

Question:
A charging station can deliver a maximum power of 50 kW to an EV battery with 75kWh. The battery begins charging at a state of charge (SOC) of 20%. The battery management system requests the following charging power based on the SOC range:

- 10 kW when 10%<SOC≤30%
- 60 kW when 30%<SOC≤60%
- 30 kW when 60%<SOC≤90%

Assume the battery charging efficiency remains constant at 97% and that the charging curve is flat within the presented ranges. What will be the state of charge of the battery after one hour of charging?

Answer format: Do not round any intermediate results. Provide your answer in % of total charge and use the following format: 12 or 1 (no ',' comma, no letters), round final result to 0 decimal places.

Answer: 45

Resolution:

From 20% to 30%
Required energy from charger with $\eta = 0.97$:

$$E_1 = (E_{@SOC=30\%} - E_{@SOC=20\%})/\eta = 7.732\,kWh$$

Time at $10kW$ charging:

$$t_{@10kW} = E_1/10 = 0.7732\,h$$

SOC after 0.7732h is 30%

From 30% to 60%
Consider charging at $50kW$ (maximum available power from the charger) during the remaining time. Energy charged:

$$E_2 = (1 - t_{@10kW}) \times 50kW \times \eta = 10.9998\,kWh$$

SOC after 1h

$$SOC_{@1h} = (0.3 + E_2/75) = 0.4466 \rightarrow 45\%$$

Note that 45%<60% so no extra calculations are needed.

CV-Specific Questions

#1 Hybrid Storage Container

Expected Time: 2 min

Question:
How large may the holes for cooling in the hybrid storage container be?

a) The holes must be smaller than 25 mm.

b) The total cutout area must be smaller than 500 mm².

c) Each cutout must be smaller than 200 mm².

d) The total cutout area must be below 25% of the surface of all single walls.

e) The total cutout area must be below 25% of the area of the respective single wall.

f) The holes can be made as big as necessary for wiring harness, ventilation, cooling, or fasteners.

Answer format: Multiple choice

Answer: e)

Resolution:

Formula Student Rules 2025 v1.1 CV 5.2.4: "*Holes, both internal and external, in the HSC, are only allowed for the wiring harness, ventilation, cooling, or fasteners. The total cutout area must be below 25% of the area of the respective single wall.*"

#2 Maximum Sound Level

Expected Time: 2 min

Question:
Which statement about the Noise Test is right?

a) The noise of the engine is measured 0.5m from the end of the exhaust outlet, at an angle of 45◦ with the outlet in the vertical plane.

b) The noise of the engine is measured 1 m from the end of the exhaust outlet, at an angle of 45◦ with the outlet in the horizontal plane.

c) The noise of the engine is measured with a free-field microphone and must be less than 103 dB(C) in any case.

d) The noise of the engine is measured with a free-field microphone and must be less than 110 dB(A) in any case.

e) The noise of the engine is measured with a free-field microphone and must be less than 110 dB(C) at an average piston speed of 15.25 m/s.

Answer format: Multiple choice

Answer: e)

Resolution:

Formula Student Rules 2025 v1.1 CV 3.2.1: "*The maximum sound level test speed for a given engine will be the engine speed that corresponds to an average piston speed of 15.25m/s. The calculated speed will be rounded to the nearest 500rpm. The maximum allowed sound level up to this calculated speed is 110dB(C), fast weighting.*"

Formula Student Rules 2025 v1.1 CV 3.2.2: "*The idle test speed for a given engine will be up to the team and determined by their calibrated idle speed. If the idle speed varies then the vehicle will be tested across the range of idle speeds determined by the team. At idle the maximum allowed sound level is 103dB(C), fast weighting.*"

Formula Student Rules 2025 v1.1 IN 10.1.4: "*Measurements will be made with a free-field microphone placed free from obstructions at the exhaust outlet level, 0.5m from the end of the exhaust outlet, at an angle of 45◦ with the outlet in the horizontal plane.*"

#3 Fuel Injection System

Expected Time: 2 min

Question:
Which statement is right?

a) DI is the shortcut for Dual Injection where the injection occurs to the combustion chamber.

b) DI is the shortcut for Direct Injection in which the ignition takes place in the injection system.

c) DI is the shortcut for Direct Injection where the injection occurs to the combustion chamber.

d) LPI is the shortcut for Laser Point Injection where a laser beam is responsible for the Ignition in the combustion chamber.

e) LPI is the shortcut for Low Pressure Injection where the fuel system is working with a pressure up to 20 bar.

Answer format: Multiple choice

Answer: c)

Resolution:

Formula Student Rules 2025 v1.1 CV 2.5: "*Low Pressure Injection (LPI) fuel systems are those functioning at a pressure below 10bar and High Pressure Injection (HPI) fuel systems are those functioning at 10bar pressure or above. Direct Injection (DI) fuel systems are those where the injection occurs directly into the combustion chamber.*"

Common Questions

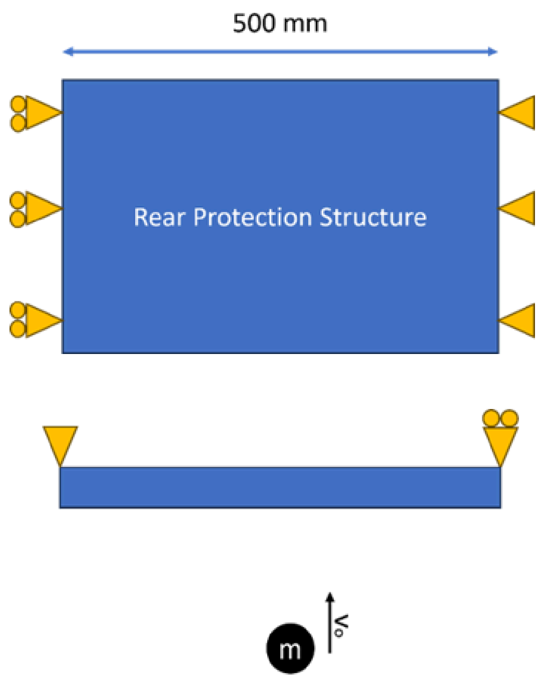
#4 Who threw a rock at my car??

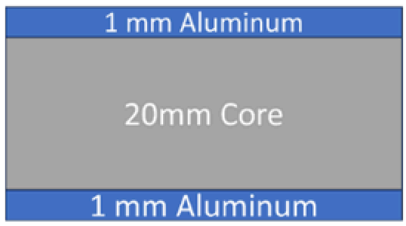
Expected Time: 10 min

Question:
Your team uses an aluminum monocoque. With the following laminate in the Rear Protection Structure: 1mm aluminum/ 20mm core/ 1mm aluminum. (Consider E=70 GPa).

While you are in the dynamic queue, a rock (mass=200 g) comes flying (v_o=30 m/s) and hits your Rear Protection Structure in the center, perpendicularly. What is the resulting peak impact force withstood by the Rear Protection Structure?

Ignore local effects, assume a perfectly elastic collision, assume elastic deformation, assume the car doesn't move, use the same assumptions as the SES regarding panel stiffness.





Answer format: Do not round any intermediate results. Provide your answer in kN. Use the following format: 12.3 or 1.2 (no ',' comma, no letters), round final result to 1 decimal place.

Answer: 23.1

Resolution:

Assuming the impact is a perfectly elastic collision, all the kinetic energy of the rock, KE_{rock}, will be transferred to the strain energy of the panel, SE_{panel}, thus:

$$KE_{rock} = SE_{panel} \Leftrightarrow \frac{1}{2}mv^2 = \frac{1}{2}P\delta$$

where v is the rock velocity, m is the rock mass, P is the load and δ is the peak deformation of the panel.

For a beam simply supported at the edges and subject to a central load the maximum deformation is given by:

$$\delta = \frac{PL^3}{48EI}$$

where E is the material Young's modulus, L is the length of the beam and I is the cross-sectional area moment of inertia.

Which can be combined with the previous equation to obtain:

$$\frac{1}{2}mv^2 = \frac{1}{2}P(\frac{PL^3}{48EI}) \Leftrightarrow P = \sqrt{\frac{mv^2 48EI}{L^3}}$$

The only unknown is the area moment of inertia. Using the same assumptions as SES, and since the skins have the same thickness, it can be computed through:

$$I_{skin} = I_{skin1} + I_{skin2} = (\frac{Lh^3}{12} + Ad_1^2) + (\frac{Lh^3}{12} + Ad_2^2)$$

Where A is the cross-section area, h is the skin thickness and d is the distance between the centroid of each skin and the centroid of the laminate, in this case:

$$d_1 = - d_2 = \frac{h}{2} + \frac{Core_{thickness}}{2}$$

Alternatively you can also use the SES to compute I_{skin}:

Thickness of panel, mm	22
Thickness of core, mm	20
Thickness of inner skin, mm	1
Thickness of outer skin, mm	1
Panel height,mm	500

	Outer	Inner		
b (m)	0.5	0.5		
h (m)	0.001	0.001		
A_1 (m^2)	5.00E-04		I_1 (m^4)	4.17E-11
A_2 (m^2)	5.00E-04		I_2 (m^4)	4.17E-11
y_1 (m)	0.0005		Ic_1 (m^4)	5.52E-08
y_2 (m)	0.0215		Ic_2 (m^4)	5.52E-08
Centroid (m)	0.0110		Ic_{12} (m^4)	1.10E-07

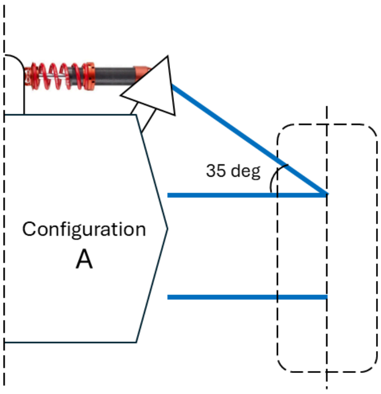
Putting it all results in:

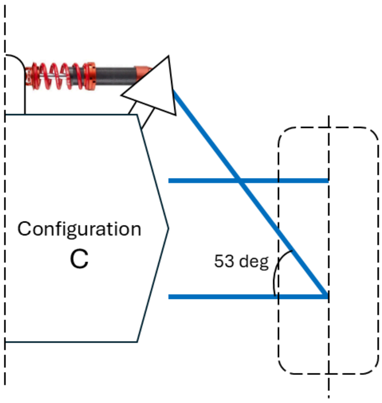
$$P = \sqrt{\frac{mv^2 48E*2(\frac{Lh^3}{12} + A\frac{(h + Core_{thickness})^2}{4})}{L^3}} = 23105\ N = 23.1\ kN$$

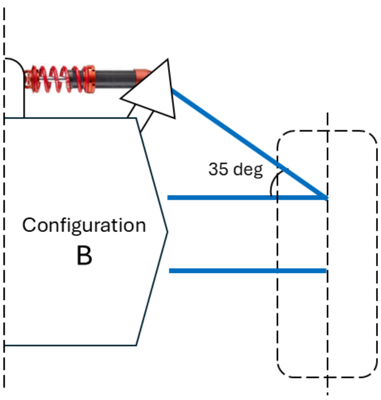
#5 Suspension Configurations

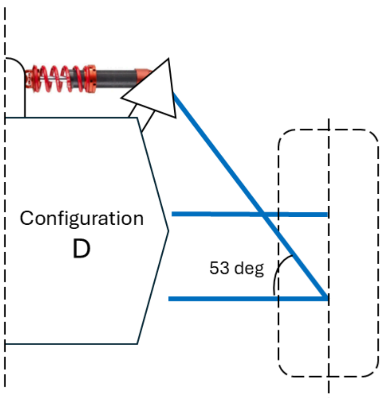
Expected Time: 6 min

Question:
The image below represents different configurations of a vehicle's rear suspension (left and right suspensions are independent and symmetric). In all cases, the push-rod configuration is used. The blue lines in the images represent the push-rod, upper A-arm and lower A-arm of the suspension system. All of the pick-up points of these three elements in the wheel are aligned vertically with the location of the contact patch. The pick-up points of the push-rod and upper A-arm on the wheel are coincident for configurations A and B; the pick-up points of the push-rod and lower A-arm on the wheel are coincident for configurations options C and D. Both A-arms are horizontal for all configurations. The height of the lower A-arm is the same for configurations A, C, and D, and this same height is higher for configuration B. The height of the upper A-arm is the same for configurations A, B and C, and this same height is lower for configuration D. Assume a load scenario consistent with the wheel represented in the image being the outer wheel in a corner, for which the lateral load applied in the contact patch is higher than the vertical load applied on the contact patch. Considering the front-view 2D model of the suspension, which configurations minimize in this load scenario: (1) the load applied on the upper A-arm; (2) the load applied on the lower A-arm? Only the magnitude of the load is relevant (whether the element is under compression or tension is not relevant).









a) (1) – D ; (2) – C

b) (1) – D ; (2) – D

c) (1) – C ; (2) – D

d) (1) – C ; (2) – C

e) (1) – A ; (2) – B

f) (1) – B ; (2) – B

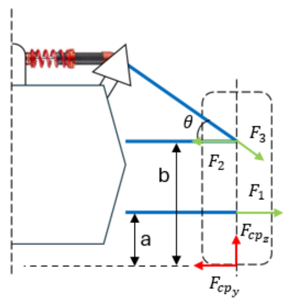
g) (1) – B ; (2) – A

h) (1) – A ; (2) – A

Answer format: Multiple choice

Answer: d)

Resolution:



$$\sum F_z = 0 \iff F_{cp_z} = F_3 \sin\theta \iff F_3 = \frac{F_{cp_z}}{\sin\theta}$$

$$\sum F_y = 0 \iff F_{cp_y} + F_2 = F_1 + F_3 \cos\theta = F_1 + \frac{F_{cp_z}}{\tan\theta}$$

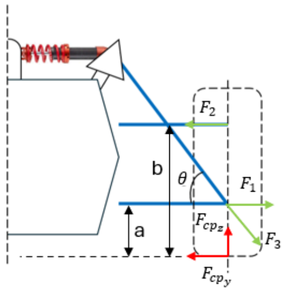
$$\iff F_2 = F_1 + \frac{F_{cp_z}}{\tan\theta} - F_{cp_y}$$

$$\sum M_{cp_x} = 0 \iff aF_1 - b(F_2 - F_3 \cos\theta) = 0$$

$$\iff aF_1 - b\left(F_1 - F_{cp_y}\right) = 0$$

$$\iff F_1 = \frac{bF_{cp_y}}{b-a}$$

$a \uparrow \Rightarrow F_1 \uparrow \Rightarrow F_2 \uparrow$ ⟶ F_1 and F_2 are lower for Configuration A than Configuration B



$$\sum F_z = 0 \iff F_{cp_z} = F_3 \sin\theta \iff F_3 = \frac{F_{cp_z}}{\sin\theta}$$

$$\sum F_y = 0 \iff F_{cp_y} + F_2 = F_1 + F_3 \cos\theta = F_1 + \frac{F_{cp_z}}{\tan\theta}$$

$$\iff F_1 = F_2 - \frac{F_{cp_z}}{\tan\theta} + F_{cp_y}$$

$$\sum M_{cp_x} = 0 \iff a(F_1 + F_3 \cos\theta) - bF_2 = 0$$

$$\iff a(F_2 + F_{cp_y}) - bF_2 = 0$$

$$\iff F_1 = \frac{aF_{cp_y}}{b-a}$$

$b \uparrow \Rightarrow F_1 \downarrow \Rightarrow F_2 \downarrow$ ⟶ F_1 and F_2 are lower for Configuration C than Configuration D

$$\frac{aF_{cp_y}}{b-a} < \frac{bF_{cp_y}}{b-a} \Rightarrow F_{1_C} < F_{1_A}$$

$$F_{1_C} < F_{1_A} \;\&\; \frac{F_{cp_z}}{\tan 53º} < \frac{F_{cp_z}}{\tan 35º} \Rightarrow F_{2_C} < F_{2_A}$$

⟶ Configuration C minimizes F1 and F2

#6 Wheel-brake distance

Expected Time: 2 min

Question:
Which statement is right?

a) The distance between brake assembly and the inner rim base must be at least 5mm in static condition.

b) The distance between the lowest point of the chassis and the ground must be at least 25mm in static condition.

c) The distance between outer diameter of the front and rear tires and other parts of the vehicle must be in the top view 75mm in static condition.

d) The distance between brake assembly and the inner rim base must be at least 5mm in static condition without the driver.

e) The distance between the lowest point of the chassis and the ground must be at least 30mm in static condition without the driver.

Answer format: Multiple choice

Answer: a)

Resolution:

Formula Student Rules 2025 v1.1 T 2.6.4: "*The radial clearance between any non-rotating part and the inside of the rim must be at least 5mm in static condition at any steering angle and any ride height.*"

Formula Student Rules 2025 v1.1 T 2.2.1: "*The minimum static ground clearance of any portion of the vehicle, other than the tires, including a driver, must be 30mm. If an active suspension system is installed, the static ground clearance is measured in the lowest adjustable position.*"

Formula Student Rules 2025 v1.1 T 2.1.3: "*Open wheel vehicles must satisfy the following, see also figure 4:*

• *The wheel/tire assembly must be unobstructed when viewed from the side.*

• *No part of the vehicle may enter a keep-out-zone defined by two lines extending vertically from positions 75mm in front of and 75mm behind the outer diameter of the front and rear tires in the side view of the vehicle, with steering straight ahead. This keep-out zone extends laterally from the outside plane of the wheel/tire to the inboard plane of the wheel/tire assembly.*"

#7 Material Costs

Expected Time: 3 min

Question:
What is the material cost of one anti intrusion plate (AIP) made of solid steel, which has the maximum allowed dimensions that you can use for your formula student car without using a diagonal or X-bracing in your front bulkhead or doing a crash test? The AIP should have the minimum allowed thickness. A DC01 sheet in medium format is placed on the laser machine as raw material. The basic price of the sheet per kilogramme is 3.57 euros. Assume a Steel density of $7.85\ gcm^{-3}$.

Answer format: Do not round any intermediate results. Provide your answer in € and use the following format: 12.30 or 1.23 (no ',' comma, no letters), round final result to 2 decimal places.

Answer: 5.89

Resolution:

T3.16.7 *A team may use one of the “standard” FSAE IAs, in order to avoid testing, provided that: if the front bulkhead width is larger than 400mm and/or its height is larger than 350mm a diagonal or X-bracing that is a front bulkhead support tube or an approved equivalent per T3.2, must be included in the front bulkhead.*

T3.16.3 *The baseline design for the AIP is a 1.5mm solid steel*

Steel density = $7.85gcm^{-3}$

Area=350mm*400mm= 140000mm^2

Volume=140000mm*1,5mm=210000mm^3=0,21dm^3

Mass=0,21dm^3*7,85dkg/dm^3= 1,6485kg

Cost=1,6485kg*3,57€/kg=5,89€ (rounded to 2 decimal places)

#8 Gas cylinder in the Portuguese sun

Expected Time: 2 min

Question:
A gas cylinder containing 10 litres of argon heats up from 20°C to 50°C in the Portuguese sun. The filling pressure of the gas cylinder is 100 bar. How great is the increase in pressure in the gas cylinder? (Assume that for the pressures ranges considered Argon behaves as an ideal gas)

Answer format: Do not round any intermediate results. Provide your answer in bar and use the following format: 12 or 1 (no ',' comma, no letters), round final result to 0 decimal places.

Answer: 10

Resolution:

Temperatures:

$T_1 = 293.15K$

$T_2 = 323.15K$

$p_{abs1} = 101\ bar$

$p_{abs2} = p_{abs1}\frac{T_2}{T_1} = 111,34\ bar$

$\Delta p = p_{abs2} - p_{abs1} = 10,34\ bar$

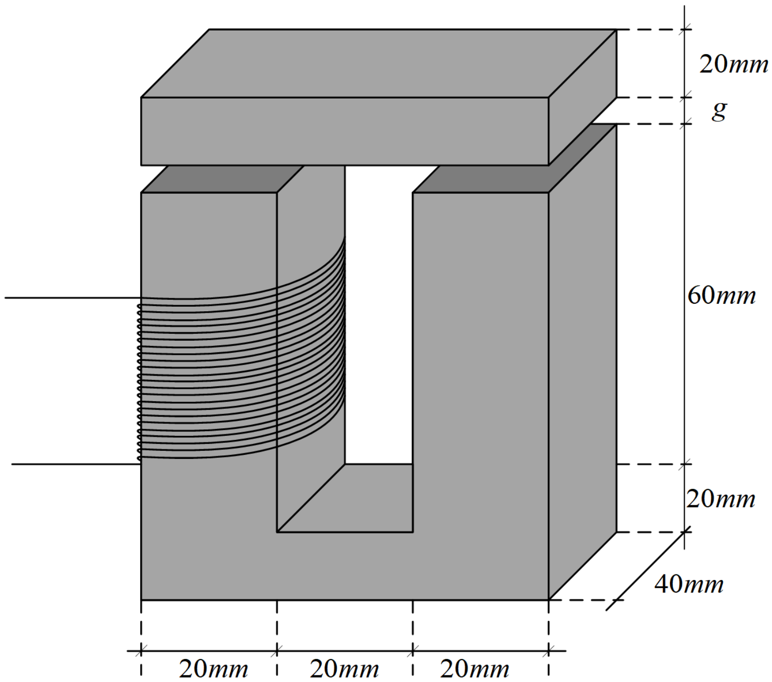
#9 A peculiar throttle position sensor

Expected Time: 6 min

Question:
Consider this very peculiar throttle pedal position sensor. It works by measuring the inductance of the variable inductor depicted. When the throttle request is 90% the air gap, g is equal to 3mm and when the throttle request is 10% then $g = 0.1mm$. It is reasonable to assume that the relation between the air gap and the throttle position is linear.

The core material relative permeability is 1000 and the air permeability is assumed to be that of vacuum $\mu_0 = 4\pi \times 10^{-7}$, the number of turns is 400. The core and armature material always have a thickness of 20mm and a depth of 40mm. Consider that the magnetic circuit mean length path of the core (not counting the air gap) is 240 mm.

Compute the throttle request in percentage when the measured inductance is 80 *mH*.



Answer format: Do not round any intermediate results. Provide your answer in percentage points and use the following format: 12 or 1 (no ',' comma, no letters, no symbols), round final result to 0 decimal places.

Answer: 32

Resolution:

Reluctance, R_m at 80mH

$$L = n_t/R_m \rightarrow R_m = 400^2/0.08 = 2\,000\,000\, H^{-1}$$

Core cross section, $S = 0.02 \times 0.04 = 0,0008\, m^2$

Magnetic reluctance contribution from the air gap

$$R_{mg} = 2g/(\mu_0 S) = g\frac{1}{16\pi} \times 10^{11}$$

Remaining path mean length:

$$R_{mc} = 0.24/(\mu_{rs}\mu_0 S) = \frac{0.24}{1000\times4\pi\times10^{-7}\times8\times10^{-4}} = \frac{0.24}{32\pi} \times 10^{8}$$

$$R_{mg} = R_m - R_{mc} = 2000000 - 238732$$

$$1761268 = g\frac{1}{16\pi} \times 10^{11} \rightarrow g = 0.8853mm$$

$$m = (0.9 - 0.1)/(3\,mm - 0.1\,mm) = 8/29\,mm^{-1}$$

$$b = 0.1 - m * 0.1\,mm = 0.0724$$

$$y(g = 0.8853\,mm) = 8/29 \times 0.8854\,mm + 0.0724 = 0.244 = 31.6\%$$

#10 Accurate car speed measurement

Expected Time: 6 min

Question:
An electric team is using a camera pointing straight down at the ground running an optical flow algorithm so they can accurately measure the car speed.
The camera the team is using is running at a constant 60 frames per second and has a projected field of view on the ground of 30cm by 30cm. For the optical flow algorithm to work properly it requires a feature to be present on at least 3 sequential frames.
The output shaft of the only motor is rigidly attached to a 20 teeth sprocket which engages in a chain that is also attached to a 120 teeth sprocket on the rear axle of the car. The car is equipped with tires that have an outside diameter of 18 inches.

To fine-tune the control algorithms the team is wondering: what is the maximum motor speed up to which the optical flow algorithm still gives accurate speed results?

Assume the car is driving straight on a flat plane at a constant speed with no wheel slippage or tire vertical deformation and with zero slip ratio. The projected field of view dimensions are constant. Assume the car velocity vector is perpendicular to one of the sides of the projected field of view and that the exposure time for each frame is small enough to be ignored. Assume the algorithm is capable of detecting features anywhere on the frame, including the edges.

Answer format: Do not round any intermediate results. Provide your answer in rpm. Use the following format: 12.3 or 1.2 (no ',' comma, no letters, no symbols), round final result to 1 decimal place.

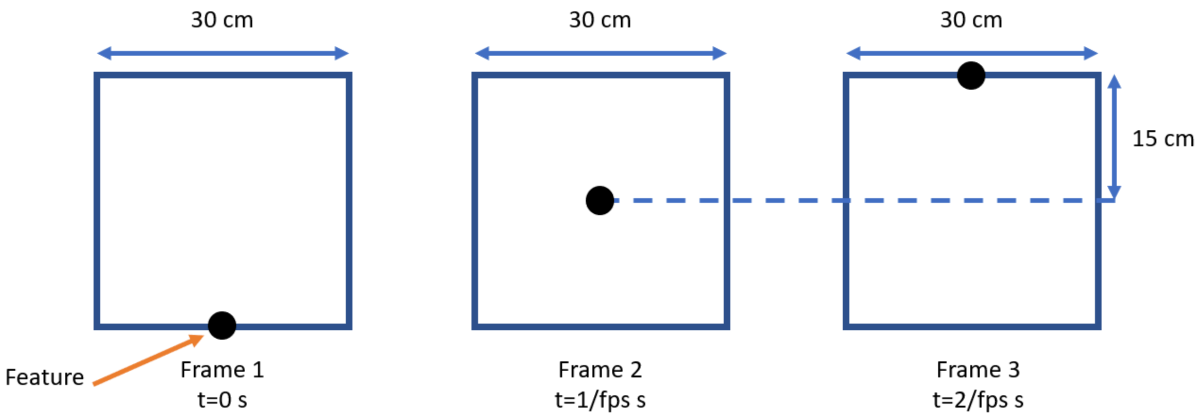
Answer: 2255.7

Resolution:

The car speed can be obtained from the motor speed through:

$v_{car} = 2\pi R_{Tire} \frac{\omega_{rpm}}{GR*60}$, where $GR = 120/20 = 6$ and $R_{tire} = 18 * 25.4/2 = 228.6\, mm$

The time between each frame of the camera is the inverse of the frame rate:
$t_{frame} = 1/fps = \frac{1}{60}$ s
Since a feature must be present in 3 sequential frames for accurate measurements and the projected field of view is 30cm by 30cm then the maximum distance the feature must travel within the time between each frame is $d = \frac{FOV_{size}}{3-1} = 15\, cm$



Hence, the maximum motor speed is:

$$\omega_{rpm} = \frac{d*fps*60*GR}{2*\pi*R_{tire}} = 2255.7\ rpm$$