Mass Calculation

One of the fundamental requirements of project FLAMEOUT is to minimise the mass (max is 6kgs), therefore the total mass of our robot is:

$$Total\ Mass = Mass\ of\ Top + Mass\ of\ Bottom\ (including\ wheels) + Mass\ of\ Scissor + Mass\ of\ Motors\ and\ Batteries + Mass\ of\ battery\ holder$$

$We've\ estimated\ the\ weight\ of\ a\ small\ DC\ motor\ to\ be \sim 150g\ and\ the\ weight\ of\ our\ batteries\ to\ be\ 30g. Therefore:$

$$Total\ Mass = 1kg + 2kg + 1.4kg + 3(0.15kg) + 2(0.03kg) + 0.1kg = 5.01kg$$

$The\ mass\ of\ the\ Top, Bottom\ and\ Scissor\ are\ given\ by\ our\ CAD\ design$

Concludes that our design is indeed less than 6kgs.

Motor Calculations

The following calculations allowed us to find a motor which could power and satisfy our design.

First we estimated the distance and time spent travelling the course (not stopped). Since the total length of the route seemed very close to twice the whole length of the track, we decided the distance travelled would be approximately:

$$Distance\ Travelled = 2.4m \times 2 = 4.8m$$

We also estimated that the time to travel this distance and avoid losing payloads or undergoing slip would be 20s. Therefore, the average velocity is:

$$v = \frac{d}{t} = \frac{4.8m}{20s} = \frac{0.24m}{s}$$

The mass of the robot without any load is 5kgs, therefore, if we simplify the model and assume the weight of 5 x 9.81 = 49.05N is symmetrical, then the normal force is equal to the weight 49.05N but in the opposite direction.

The wheels are made from rubber so the Static Coefficient of Friction between the rubber wheels and wooden ground is 0.95. Therefore, friction can be calculated as:

$$f_f = U_s N = (0.95)(49.05N) = 46.60N$$

Since we know the speed and force we can calculate an estimated power to get the robot moving:

$$P_{output} = Fv = (46.60N)\left(\frac{0.24m}{s}\right) = 11.18W$$

We then estimated the transmission efficiency as 0.7, 1 meshed pair, in order to calculate the power at the motor:

$$P_{source} = \frac{P_{output}}{n_{trans}} = \frac{11.18W}{0.7} = 15.98W$$

The capacity of the motor needs to be much greater than this power in order to compensate for extra friction in other places and changes in gradient of the surfaces, therefore:

$$P_{motor} = 2 \times 15.98W = 31.95W$$

Motor Selected: https://www.jaycar.co.nz/standard-high-power-d-c-motors-11000-rpm/p/YM2770

According to the above motor's datasheet, the rpm value at 31.95W is 10100RPM. We can convert this to more conventional units:

$$\omega = 10100RPM \times \frac{2\pi}{60s} = \frac{1058rad}{s}$$

From this, we can calculate the velocity the motor will produce and compare this to the desired velocity:

$$v = \omega r_{shaft} = \left(\frac{1058rad}{s}\right)(1.5mm) = 1.68m/s$$

For the velocity to be at 0.24m/s, we weed an 8:1 reduction ratio. The transmission efficiency was also assumed correct as one meshed gear is needed. Therefore, the motor selected should be more then satisfactory for the task required in project FLAMEOUT.

Battery

The following calculations determine the battery requirements and verify a capable battery.

We estimated that the robot will take 5 seconds at A, 8 seconds at B, 10 seconds at C and 15 seconds at D to deposit the payloads. Plus 30 seconds travelling time. Thus, the estimated complete time is about 70 seconds.

As the motor is operating at a power of 31.95 w, we can conclude that the energy consumed by the motor is:

$$E = P_{motor} \times t = 31.95W \times 70s = 2236.5J$$

Energy should be enough to complete two runs of the course, therefore:

$$E_{total} = 2236.5J \times 2 = 4473J$$

We can calculate the total charge required for a 12V battery as:

$$Q = \frac{4473J}{12V} = 372.75C$$

As a result, the capacity of the batteries needs to be:

$$372.75 \times \frac{1000}{3600} = 103.5mAh$$

Therefore, the following battery we chose satisfies this capacity:

https://www.mitre10.co.nz/shop/energizer-alkaline-battery-a23/p/108112?gclid=CjwKCAjwpqv0BRABEiwA-TySwbh49wF-codPZrDC6ocov0Qf4W5WjV8AzJyKZk7cu4famZ0zBl7WQRoCJVYQAvD_BwE&gclsrc=aw.ds

Geometry Calculations

The following calculations verify that the robot will not fall over at the top extremes (when the robot is holding all 10 balls and when it is extended to its maximum height).

Calculate the weight of each individual main components in the robot:

$$Wtop = 1kg \times \frac{9.81m}{s^2} = 9.81N, Xtop = 143.5mm$$

$$Wbottom = 2.6kg \times \frac{9.81m}{s^2} = 25.51N, Xbottom = 156mm$$

$$Wscissor = 1.39kg \times \frac{9.81m}{s^2} = 13.64N, Xscissor = 161.5mm$$

Sum these weights in order to find the total weight:

$$Total\ Weight = 9.81N + 25.51N + 13.64N = 48.99N$$

Use centroid theorem to determine the new distance from the origin O:

$$X_T = \frac{(9.81N)(143.5mm) + (25.51N)(156mm) + (13.67N)(161.5mm)}{48.99N} = 155.03mm$$

<u>Case 1: When the robot is extended to its max height (300mm)</u>

At maximum height the ball carries 4 payloads in slot D of the top section, therefore, the mass due to the balls is:

$$Mballs = 58g \times 4 = 232g, Wballs = 0.232kg \times 9.81 = 2.28N$$

$$Xballs = 114mm\ from\ CAD\ model\ (centre\ of\ slot\ D\ to\ outer\ edge)$$

We calculate the sum of the moments around wheel 1 (point 1) to determine N2:

$$\sum M_1 = (N2)(207.2mm) - (48.99N)(155.03mm - 3.5mm) - (2.28N)(144mm - 3.5mm) = 0$$

$$N2 = 37.04N$$

Then use the sum of the forces in the y direction to calculate N1:

$$\sum F_y = 0 = 37.04N + N1 - 48.99N - 2.28N$$

$$N1 = 14.23N$$

We then sum the moments about this origin point to determine whether the device is stable:

$$\sum M_O = (37.04N)(207mm + 3.5mm) + (14.23N)(3.5mm) - (48.99N)(155.03mm) - (2.28N)(114mm) = -8.115Nmm = -0.00812Nm$$

The moment calculated is very small, therefore, the device at maximum height will not fall over.

<u>Case 2: When the robot is carrying max load</u>

At max payload, the robot is carrying 10 payloads, therefore:

$$Mballs = 58g \times 10 = 580g, Wballs = 0.580kg \times 9.81 = 5.69N$$

$$Xballs = 147.5mm\ from\ CAD\ model$$

We take the sum of the moments at wheel 1 in order to find N2:

$$\sum M_1 = (N2)(207.2mm) - (48.99N)(155.03mm - 3.5mm) - (5.69N)(147.5mm - 3.5mm)$$

$$N2 = 39.80N$$

By taking the sum of the forces in the y direction we can calculate N1:

$$\sum F_y = 0 = 39.80N + N1 - 48.99N - 5.69N$$

$$N1 = 14.88N$$

By taking the sum of the moments at the origin we can verify if the device will tip over or not at point O:

$$\sum M_O = (39.8N)(207mm + 3.5mm) + (14.88N)(3.5mm) - (48.99N)(155.03mm) - (5.69N)(147.5mm) = -4.21Nmm = -0.00421Nm$$

The moment is very small; therefore, the device will not tip over when loaded with all 10 payloads.

<u>Case 3: Doesn't tip at max height while moving</u>

Assumption: Friction only occurs between the wheels and ground.

At this scenario, N2 = 0 (wheel 2 has started to lift off the ground). This will allow us to determine what the acceleration is at this point and whether our robot will reach this max acceleration.

$$\sum F_y = 0 = 48.99N + 2.28N + N1$$

$$N1 = 51.27N$$

By taking the sum of the moments at point O, we can determine the friction at wheel 1:

$$\sum M_O = (f_f)(104mm) - (48.99N)(155mm) - (2.28N)(114mm) + (51.27N)(3.5mm)$$

$$f_f = 73.8N$$

Therefore, the max acceleration at max height to cause the device to fall lift up would be:

$$\sum F_x = ma_x = f_f$$

$$a_x = \frac{73.8}{5kg} = \frac{14.76m}{s^2}$$

This max acceleration is much greater than any speed we will be putting our robot at, therefore, it's safe to assume that it is very unlikely our robot will lift and fall over while travelling.

Score

Assuming all payloads are deposited correctly into each of the vessels, the deposit score is:

$$(1 + 2 + 3 + 4)(10) = 100$$

We estimate the robot will take 5 seconds to deposit at A, 8 seconds at B, 10 seconds at C and 15 seconds at D, as well as 30 seconds travelling time (driving and rotating). Therefore:

$$Total\ Time = 5 + 8 + 10 + 15 + 30 = 68s$$

$$Run - time\ Score = (120 - 68)(0.5) = 26$$

We also assume that the robot manages to flawlessly go over the obstacle both times and return to the start zone, therefore:

$$Return\ Score = 20$$

$$Total\ Score = 20 + 26 + 100 = 146$$

The overall score for the 2020 Warman Project for our design is expected to be 146.

Cost*

The cost of the robot includes motor, battery and a gearbox. The rest is neglected as it can be 3D printed by the university.

The A23 batteries that supply 12V each have a capacity of 55mAh; thus, we need two batteries to store enough energy to complete the run. The cost of both batteries is $3.98 x 2 = $7.96

The cost of the driving motor is $18

Therefore, the total cost is: $25.96