11 - Design Justification Day 2

March 20, 2021 11:24 AM

$START_1$: 11:00 AM $START_2$: 2:15 PM

END_1: 1:15 PM END_2: 4:00 PM

Item #	Part #	Source	Description	Unit Price (CAD)*	Quantity	Total Price	Unit Weight (g)	Total Weight (g)
Intermediate Stage								
1	FILAMENT		3D Printed Components		1	$0.00	2074.403969	2074.403969
2	1528-1062-ND	DigiKey	Stepper Motor	$19.02	1	$19.02	200.03	200.03
3	TRM4000_0	Phidgets	8mm Rotary Shaft***	$6.50	0.95	$6.18	363.575	345.39625
4	1611-0514-0008	gobilda	8mm ID Ball Bearing, 2 pack	$4.36	4	$17.45	6	24
5	217-5887 or 217-5	VEX Robotics	GT3 Timing Belt	$8.49	1	$8.49		Negligible
6	2130	openbuilds	GT3 Timing Pulley, 20T, 9mm be	$12.49	2	$24.98		Negligible
7	90592A095	McMaster-Carr	M5x0.8mm Hex Nut	$0.02	16	$0.35	1.21	19.36
8	91290A231	McMaster-Carr	M5x0.8mm, 15mm long socket h	$0.26	16	$4.14	3.68	58.88
9	91290A572	McMaster-Carr	M3x0.5mm, 15mm long socket h	$0.25	12	$3.00	1.12	13.44
10	95947A502	McMaster-Carr	M3x0.5mm standoff, 50mm lon	$2.23	4	$8.90	2.17	8.68
11	95947A018	McMaster-Carr	M3x0.5mm standoff, 25mm lon	$1.35	2	$2.70	0.8	1.6
12	92605A652	McMaster-Carr	M3x0.5mm set screw	$0.33	5	$1.66	0.244	1.22
Output Stage								
1	FILAMENT		3D Printed Components		1	$0.00	1809.513459	1809.513459
2	1528-1062-ND	DigiKey	Stepper Motor	$19.02	1	$19.02	200.03	200.03
3	91290A231	McMaster-Carr	M5x0.8mm, 15mm long socket h	$0.26	10	$2.59	3.68	36.8
4	90592A095	McMaster-Carr	M5x0.8mm Hex Nut	$0.02	10	$0.22	1.21	12.1
5	90751A111	McMaster-Carr	M3x0.35mm, 8mm long socket h	$0.12	4	$0.46	0.84	3.36
					Total	$119.15		4809
							Mass in kg:	4.809

Constraint 2: Must be made from >= 30% recycled material

- Moving components are majorly made of new material
  - Motors have to be purchased, parts are 3D printed (such as the flap for the trap-door mechanism)
    - BUT 3D printed components were designed with PLA in mind as the material
      - Not necessarily recycled, but is biodegradable: https://www.creativemechanisms.com/blog/learn-about-polylactic-acid-pla-prototypes
- Outer housing (not designed due to time constraint) can definitely be made partially of recycled material
  - Outermost housing is essentially a stationary box
    - Can be made of any flat surface that can be combined together via fasteners/glue/etc.
      - Wood, recycled plastic, metal even, etc.
      - These materials can be sourced from recycled/repurposed materials

Constraint 3: Must identify/sort >= 6 items in a minute (1 every 10 seconds)

- Max speed for stepper motor can be calculated using the following eqs: https://www.allaboutcircuits.com/tools/stepper-motor-calculator/

$$\text{Max Speed} = \frac{V}{2LI_{max} \cdot spr}$$

$$\text{Minimum Time per Step} = \frac{2LI_{max}}{V}$$

V: Voltage (V)
L: Inductance (H)
I_{max}: current (A)
spr: steps per revolution

Using the motor's rated specs (https://cdn-shop.adafruit.com/product-files/324/C140-A+datasheet.jpG):
V = 12 V
I_{max} = 0.35 A
L = 33×10^{-3} H

Max Speed = $\frac{V}{2LI_{max}\times spr} = \frac{12}{2\times 33\times 10^{-3}\times 0.35\times 200}$ =2.597 rev/sec

Minimum Time per Step = $\frac{2LI_{max}}{V} = \frac{2\times 33\times 10^{-3}\times 0.35}{12}$ =1.925 msec

Intermediate stage:
Using the minimum time per step for 1/4 of a revolution (200 steps/4 = 50 steps for a quarter-revolution):
It would take 1.925 x 50 = 96.25 msec for the trap doors to make a quarter rotation (their assumed max movement to release an object completely).

Output stage:
Using the minimum time per step for a 3/5 rotation (the farthest the output would have to rotate from any point to get to any other output slot, assuming 5 sorting categories):
It would take $1.925 \times 200 \times \frac{3}{5} = 231$ msec max to get the output rotated into the correct position

After the motors move to position, the system relies on gravity to move the object itself.
- Assuming a drop height of ~______ from the trap doors to the bottom of the output
- Assuming friction of output diverter is negligible and that the object follows a fairly smooth path (doesn't get stuck)

Kinematic equation describing free fall motion is:

$$d = v_0 \times t + \frac{1}{2} \times a \times t^2$$

Where:
v_0 = initial velocity
t = falling time
a = acceleration
d = fall distance

Taking the initial velocity to be ~0, a to be 9.81 m/s^2 (acceleration due to gravity), and d to be ______:

$$d = \frac{1}{2} \times (9.81) \times t^2$$

$$t = \sqrt{\frac{d \times 2}{9.81}}$$

$$t =$$

The falling time would be approximately _____.

Constraint 4: Must cost <= $250
- Mechanical costs come to ~$119.15 (see Excel sheet screenshot above)

Constraint 5: Must accept items of up to size 7.5 x 7.5 x 22.5 cm rectangle
- Get screenshots of box fitting in all components (CAD)

Constraint 6: Must weigh <= 25 kg
- Mass of all components, excluding any outer housing, comes to ~4.8 kg (see Excel sheet screenshot above)
  - Very realistic to assume that with housing and electrical components we'll double the weight at worst
  - Either way, still have ~20 kg of wiggle room

Constraint 8: Must meet all applicable Canadian Safety Standards
- Kept safety in mind while designing: limiting pinch points, designing enclosures for moving parts, etc.
- Further safety standards would have to be verified in the prototyping/testing stage, which is out of scope for our project
  - For example, motor testing: https://www.machinedesign.com/markets/article/21828181/how-to-meet-canadian-standards

Constraint 9: Must be compatible with standard recycling/garbage bin sizes
- Modular design allows for customizability
- Outer casing not designed (out of scope for this project) but it is not vital to the success of the sorting system itself
  - Can be designed however user sees fit to fit the user's exact needs and output bin sizes/geometry
    - Compatible with all bin sizes by default due to open source/modular nature

Objective 11: Should have a long lifespan >= 15 years
- Under regular conditions in a room, PLA can survive for up to 15 years: https://3dprintergeeks.com/pla-3d-printed-object-durability/
  - We will likely not reach our 15 year objective without needing some upgrades/replacements, but we could get close
    - This also likely depends on frequency of use
  - However, luckily, PLA will begin to fail because it will begin to biodegrade
    - Supports our environmental ethos for this project
    - Replacement parts could simply be reprinted and the cycle could continue

Objective 12: Should fit in average Canadian appliance footprint for residential design
- Basing this off of:
  - So the objective noted in early research was based off of an average 50 litre garbage bin = 0.05m^3
  - also, residential garbage bins can be up to 0.06m^3

Objective 13: Should be open source
- 3D printed components are modelled in SolidWorks
  - Can easily upload them to a platform such as GrabCAD or thingiverse for use by others

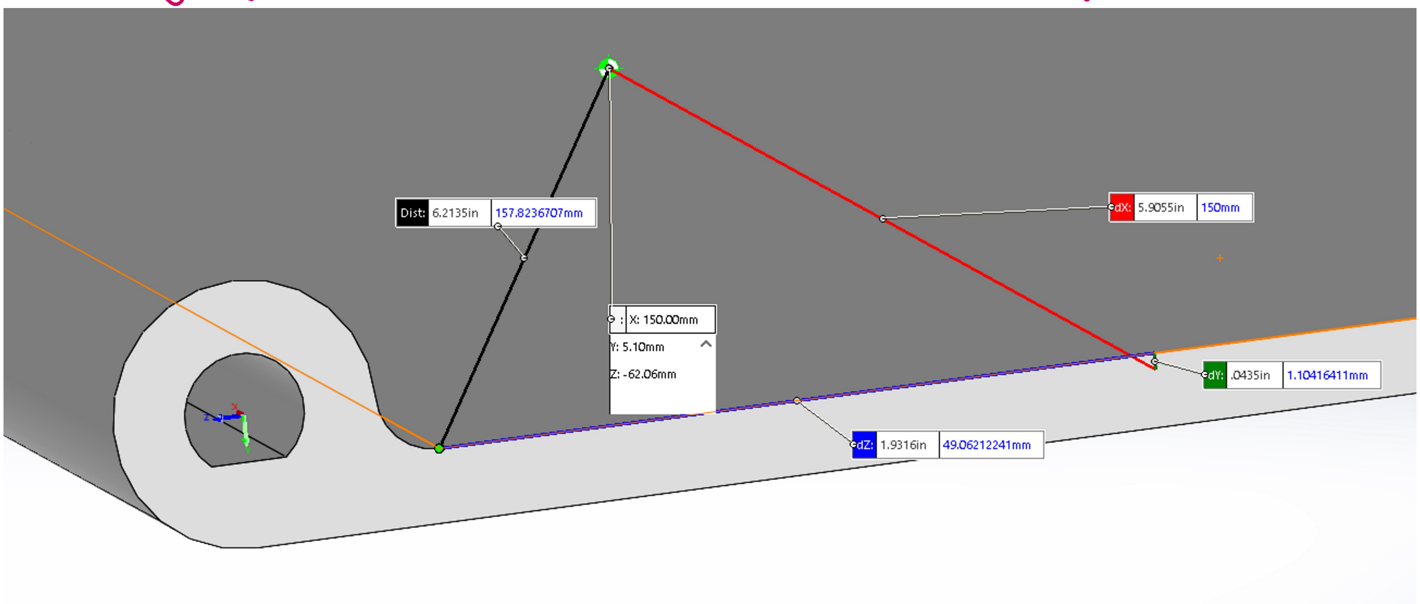
Objective 14: Should be modular
- Because many major components are 3D printed, adjusting the design to fit exact user needs is fairly simple

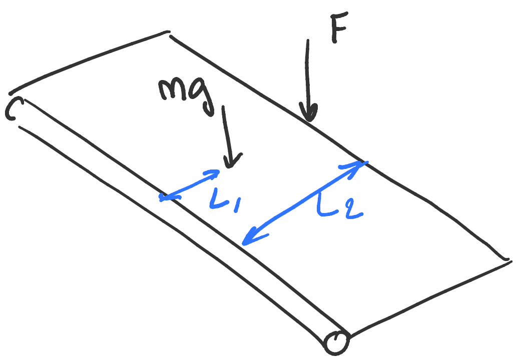
Objective 15: Should be scalable
- Similar note as with modularity. Only concern would be the strength of the materials - i.e. You would probably have to start looking into stronger materials for 3D printing to handle increasingly large torques
  - May lose biodegradable perk of using PLA
  - Could use metal for very large scales though, which would be recyclable

Objective 16: All parts should be available locally/within Canada
- Much of the mechanical design consisted of 3D printed components
  - PLA printing filament can be found locally
- Other parts are hobby level (items such as the bearings and timing pulleys)
  - Could potentially be found at local hobby shops
    - Slightly different sizes are acceptable too (because of the modularity/scalability of the design)
- Items such as rotary shafts can be found at any metal supplier - wouldn't be difficult to find local source

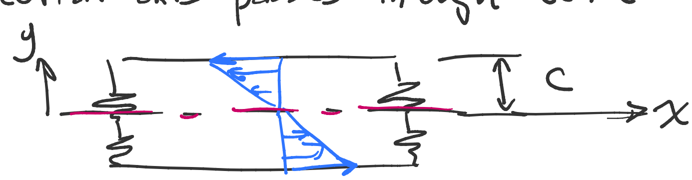
- US sources were just used as a base sometimes for this design because they provided unit prices without having to request quotes
    - Quick way to estimate the cost

Checking against bending failure where door meets hinge, right below fillet





- Distance to $(mg) = L_1 = 49.062$ mm
- Distance to $F = L_2 = 140.917$ mm
- Neutral axis passes through center

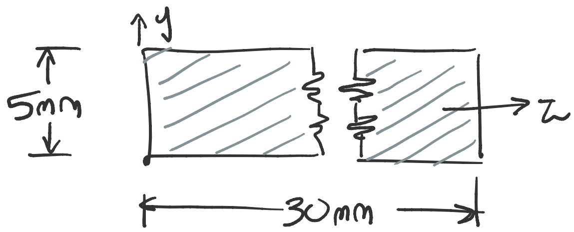


neutral axis

$$c = \frac{w}{2} = \frac{5mm}{2} = 2.5 \text{ mm}$$

cross-section of beam (door):

$$I = \frac{bh^3}{12} = \frac{(30 \times 10^{-3}) \times (5 \times 10^{-3})}{12} = 1.25 \times 10^{-5} \text{ m}^4$$



$$I_z = \frac{bh^3}{12} = \frac{(30\times10^{-3})\times(5\times10^{-3})}{12} = 1.25\times10^{-5}\ m^4$$

$$\sigma_{max} = \frac{Mc}{I}$$

$$= \frac{\left[\cancel{F}^{\,2.7N\ (\text{glass bottle})} \times (140.917\times10^{-3}) + \cancel{(mg)}^{\,(356.05\times10^{-3})(9.81)}(49.062\times10^{-3})\right]\times(2.5\times10^{-3})}{1.25\times10^{-5}\ m^4}$$

$$= 110.37\ Pa \ll \text{tensile strength} = 35.9\ MPa$$

$\therefore$ won't fall under bending