1. **Appendix G: Mass calculations**

Notation:

p :	density
m :	mass
V :	volume

The mass of each part will be calculated using the below equation:

Mass = density x volume

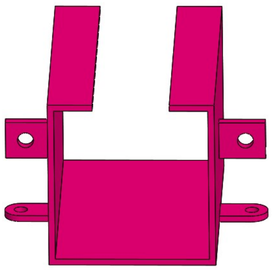
Density will be a value specific to the material used. The volume will be a value from solidworks, because solidworks is able to calculate the volume of complex parts accurately.

3D printed parts

The material that will be used for 3D printed parts is PLA plastic.

$$\rho_{PLA} := 1240 \cdot \frac{kg}{m^3}$$

<u>Battery holder</u>

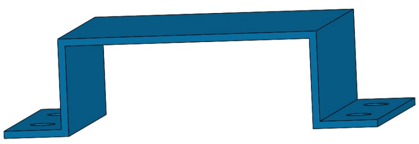


$$V_{bh} := 30227.85 \cdot mm^3$$

$$m_{bh} := \rho_{PLA} \cdot V_{bh}$$

$$m_{bh} = 0.037 \ kg$$

<u>Motor lifter</u>

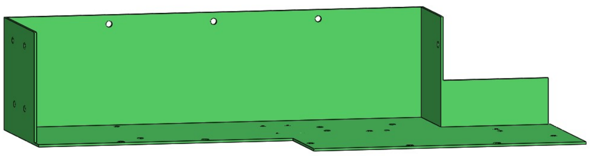


$$V_{ml} := 2810.52 \cdot mm^3$$

$$m_{ml} := \rho_{PLA} \cdot V_{ml}$$

$$m_{ml} = 0.003 \ kg$$

Lower housing

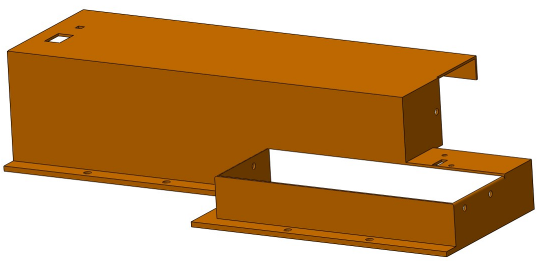


$$V_{lh} := 128903.53 \cdot mm^3$$

$$m_{lh} := \rho_{PLA} \cdot V_{lh}$$

$$m_{lh} = 0.16\ kg$$

Upper housing

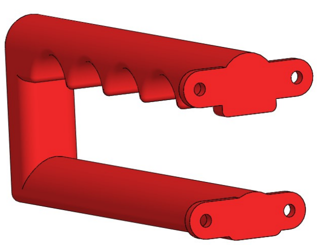


$$V_{uh} := 120305.23 \cdot mm^3$$

$$m_{uh} := \rho_{PLA} \cdot V_{uh}$$

$$m_{uh} = 0.149\ kg$$

Handle

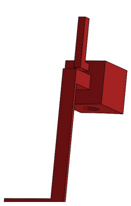


$$V_h := 77838.31 \cdot mm^3$$

$$m_h := \rho_{PLA} \cdot V_h$$

$$m_h = 0.097\ kg$$

Angle lock

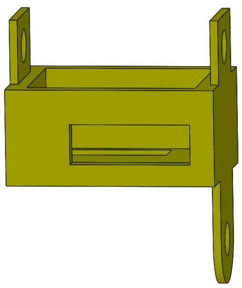


$$V_{al} := 409.63 \cdot mm^3$$

$$m_{al} := \rho_{PLA} \cdot V_{al}$$

$$m_{al} = \left(5.079 \cdot 10^{-4}\right)\ kg$$

Microswitch holder

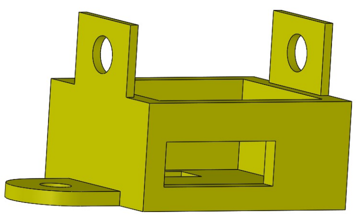


$$V_{mch} := 3068.22 \cdot mm^3$$

$$m_{mch} := \rho_{PLA} \cdot V_{mch}$$

$$m_{mch} = 0.004 \ kg$$

Microswitch holder two

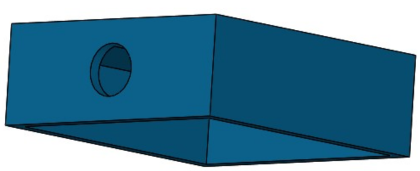


$$V_{mcht} := 3223.97 \cdot mm^3$$

$$m_{mcht} := \rho_{PLA} \cdot V_{mcht}$$

$$m_{mcht} = 0.004 \ kg$$

Two microswitch upper holders

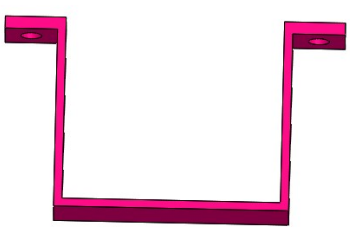


$$V_{muh} := 1494.40 \cdot mm^3$$

$$m_{muh} := 2 \cdot \rho_{PLA} \cdot V_{muh}$$

$$m_{muh} = 0.004 \ kg$$

Two battery clamps



$$V_{b\_clamp} := 4286.19 \cdot mm^3$$

$$m_{b\_c} := 2 \cdot \rho_{PLA} \cdot V_{b\_clamp}$$

$$m_{b\_c} = 0.011 \ kg$$

$$M_{3D\_p} := m_{bh} + m_{ml} + m_{lh} + m_{uh} + m_h + m_{al} + m_{mch} + m_{mcht} + m_{muh} + m_{b\_c}$$

$$M_{3D\_p} = 0.469\ kg$$

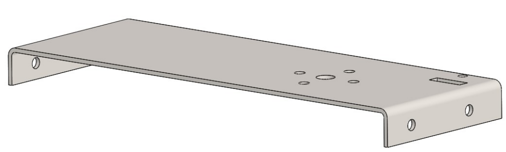
Sheet metal parts

Sheet metal will be made using hot rolled mild steel. The density varies based on the alloying constituents but usually ranges between **7750** and **8050 kg/m3.**

To design for maximum conditions, I'll assume that the density of hot rolled mild steel is 8050 kg/m3.

$$\rho_{mild\_steel} := 8050 \cdot \frac{kg}{m^3}$$

Base

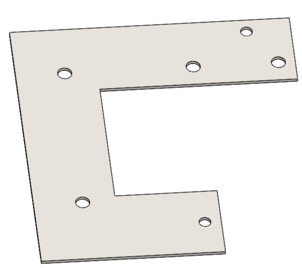


$$V_{base} := 20288.17 \cdot mm^3$$

$$m_{base} := \rho_{mild\_steel} \cdot V_{base}$$

$$m_{base} = 0.163\ kg$$

Lower shaft support

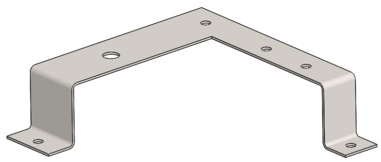


$$V_{lss} := 4197.34 \cdot mm^3$$

$$m_{lss} := \rho_{mild\_steel} \cdot V_{lss}$$

$$m_{lss} = 0.034\ kg$$

Upper shaft support

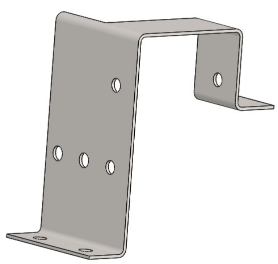


$$V_{uss} := 5116.73 \cdot mm^3$$

$$m_{uss} := \rho_{mild\_steel} \cdot V_{uss}$$

$$m_{uss} = 0.041\ kg$$

Motor support

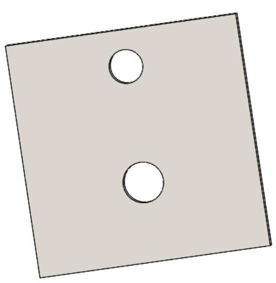


$$V_{motor\_s} := 4596.91 \cdot mm^3$$

$$m_{motor\_s} := \rho_{mild\_steel} \cdot V_{motor\_s}$$

$$m_{motor\_s} = 0.037\ kg$$

Two sheet support

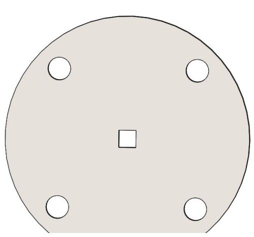


$$V_{sheet\_s} := 552.52 \cdot mm^3$$

$$m_{sheet\_s} := 2 \cdot \rho_{mild\_steel} \cdot V_{sheet\_s}$$

$$m_{sheet\_s} = 0.009\ kg$$

Two double plate for 48T gear

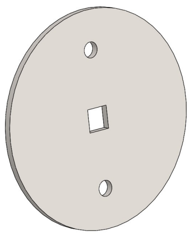


$$V_{D\_48T} := 3049.80 \cdot mm^3$$

$$m_{D\_48T} := 2 \cdot \rho_{mild\_steel} \cdot V_{D\_48T}$$

$$m_{D\_48T} = 0.049\ kg$$

Double plate for 36T gear

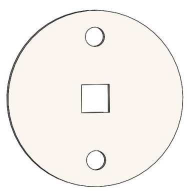


$$V_{D\_36T} := 689.14 \cdot mm^3$$

$$m_{D\_36T} := \rho_{mild\_steel} \cdot V_{D\_36T}$$

$$m_{D\_36T} = 0.006\ kg$$

Double plate for 24T gear



$$V_{D\_24T} := 296.44 \cdot mm^3$$

$$m_{D\_24T} := \rho_{mild\_steel} \cdot V_{D\_24T}$$

$$m_{D\_24T} = 0.002\ kg$$

Total mass of the machined parts:

$$M_s := m_{base} + m_{lss} + m_{uss} + m_{motor\_s} + m_{sheet\_s} + m_{D\_48T} + m_{D\_36T} + m_{D\_24T}$$

$$M_s = 0.341\ kg$$

Machined parts

Machined components will be made up of low carbon steel. Low carbon steel has a density of
7850 kg/m3.

$$\rho_{carbon\_steel} := 7850 \cdot \frac{kg}{m^3}$$

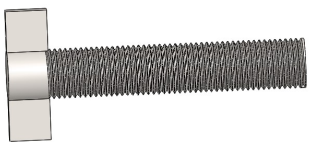
Die positioner

$$V_{Die\_p} := 113.22 \cdot mm^3$$

$$m_{Die\_p} := \rho_{carbon\_steel} \cdot V_{Die\_p}$$

$$m_{Die\_p} = \left(8.888 \cdot 10^{-4}\right)\ kg$$

Die lock

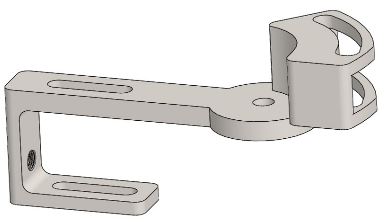


$$V_{Die\_l} := 122.48 \cdot mm^3$$

$$m_{Die\_l} := \rho_{carbon\_steel} \cdot V_{Die\_l}$$

$$m_{Die\_l} = \left(9.615 \cdot 10^{-4}\right)\ kg$$

Clamp platform

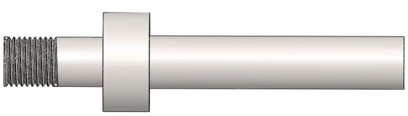


$$V_{Clamp\_p} := 3055.02 \cdot mm^3$$

$$m_{Clamp\_p} := \rho_{carbon\_steel} \cdot V_{Clamp\_p}$$

$$m_{Clamp\_p} = 0.024\ kg$$

Circular custom shaft



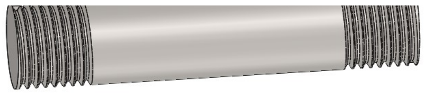
$$V_{Custom\_s} := 242.83 \cdot mm^3$$

$$m_{Custom\_s} := \rho_{carbon\_steel} \cdot V_{Custom\_s}$$

$$m_{Custom\_s} = 0.002\ kg$$

Angle positioner

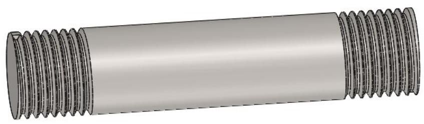
$$V_{Angle\_p} := 94.76 \cdot mm^3$$



$m_{Angle\_p} := \rho_{carbon\_steel} \cdot V_{Angle\_p}$

$m_{Angle\_p} = \left(7.439 \cdot 10^{-4}\right)\ kg$

Bending die



$V_{Die\_b} := 229.77 \cdot mm^3$

$m_{Die\_b} := \rho_{carbon\_steel} \cdot V_{Die\_b}$

$m_{Die\_b} = 0.002\ kg$

Total mass of the machined parts: $M_{machine} := m_{Die\_p} + m_{Die\_l} + m_{Clamp\_p} + m_{Custom\_s} + m_{Angle\_p} + m_{Die\_b}$

$M_{machine} = 0.03\ kg$

Bought parts

Some parts will be bought. Their mass is given.

100rpm Motor: $m_{motor} := 0.09 \cdot kg$

Two 12T spur gears: $m_{12T\_s} := 2 \cdot \frac{1.2}{1000} \cdot kg = 0.002\ kg$

Two 24T bevel gears: $m_{24T\_b} := 2 \cdot \frac{1.2}{1000} \cdot kg = 0.002\ kg$

Two 36T spur gears: $m_{36T\_s} := 2 \cdot \frac{5.2}{1000} \cdot kg = 0.01\ kg$

Two 48T spur gears: $m_{48T\_s} := 2 \cdot \frac{7.5}{1000} \cdot kg = 0.015\ kg$

Square shaft 30 long: $m_{30\_sq} := \frac{77}{1000} \cdot \frac{30}{1000} \cdot kg = 0.002\ kg$

Square shaft 70 long: $m_{70\_sq} := \frac{77}{1000} \cdot \frac{70}{1000} \cdot kg = 0.005\ kg$

Square shaft 45 long: $m_{45\_sq} := \frac{77}{1000} \cdot \frac{45}{1000} \cdot kg = 0.003\ kg$

Three high strength square shaft 30 long: $m_{30\_hsq} := 3 \cdot \frac{77}{1000} \cdot \frac{30}{1000} \cdot kg = 0.007\ kg$

Shaft coupler: $m_{shaft\_c} := \frac{2.3}{1000} \cdot kg = 0.002\ kg$

Four cells with caps: $m_{cell\_w\_caps} := 4 \cdot \frac{54}{1000} \cdot kg = 0.216\ kg$

Two cell links: $m_{cell\_link} := 2 \cdot \frac{1}{1000} \cdot kg = 0.002\ kg$

Fused link: $m_{fused\_link} := \frac{1.5}{1000} \cdot kg = 0.002\ kg$

Two microswitches: $m_{microswitch} := 2 \cdot \frac{2.2}{1000} \cdot kg = 0.004\ kg$

Ten spacers 3.2 long: $m_{3.2\_spacer} := 10 \cdot \frac{0.25}{1000} \cdot kg = 0.003\ kg$

Spacer 6.4 long: $m_{6.4\_spacer} := \frac{0.5}{1000} \cdot kg = \left(5 \cdot 10^{-4}\right)\ kg$

Three spacers 9.5 long: $m_{9.5\_spacer} := 3 \cdot \frac{0.75}{1000} \cdot kg = 0.002\ kg$

Two spacers 12.7 long: $m_{12.7\_spacer} := 2 \cdot \frac{1}{1000} \cdot kg = 0.002\ kg$

Two button head screws: $m_{b\_screws} := 2 \cdot \frac{1.3}{1000} \cdot kg = 0.003\ kg$

Six (2.9x6.5) self $m_{2.9x6.5\_screws} := 6 \cdot \frac{1.3}{} \cdot kg = 0.008\ kg$

tapping screws: $\qquad \frac{}{1000}$

Twelve (3.5x9.5) self tapping screws: $m_{3.5x9.5\_screws} := 12 \cdot \frac{1.5}{1000} \cdot kg = 0.018\ kg$

Four (4.2x16) self tapping screws: $m_{4.2x16\_screws} := 12 \cdot \frac{1.6}{1000} \cdot kg = 0.019\ kg$

Twenty one (4.2x9.5) self tapping screws: $m_{4.2x9.5\_screws} := 21 \cdot \frac{1.6}{1000} \cdot kg = 0.034\ kg$

Seven hex M5 (16x10) bolts: $m_{16x10\_bolt} := 7 \cdot \frac{2.72}{1000} \cdot kg = 0.019\ kg$

Seven hex M5 nut: $m_{M5\_nut} := 7 \cdot \frac{0.85}{1000} \cdot kg = 0.006\ kg$

Five hex M3 nut: $m_{M3\_nut} := 5 \cdot \frac{0.85}{1000} \cdot kg = 0.004\ kg$

Six M5 washers: $m_{M5\_washer} := 6 \cdot \frac{0.44}{1000} \cdot kg = 0.003\ kg$

Big roller: $m_{Big\_roller} := \frac{65}{1000} \cdot kg = 0.065\ kg$

Push button: $m_{push\_b} := \frac{27}{1000} \cdot kg = 0.027\ kg$

Control switch: $m_{control\_s} := \frac{30}{1000} \cdot kg = 0.03\ kg$

$$M_1 := m_{control\_s} + m_{push\_b} + m_{Big\_roller} + m_{M5\_washer} + m_{M5\_nut} + m_{M3\_nut} + m_{16x10\_bolt} + m_{4.2x9.5\_screws}$$

$$M_2 := m_{4.2x16\_screws} + m_{3.5x9.5\_screws} + m_{2.9x6.5\_screws} + m_{b\_screws} + m_{12.7\_spacer} + m_{9.5\_spacer} + m_{6.4\_spacer}$$

$$M_3 := m_{3.2\_spacer} + m_{microswitch} + m_{fused\_link} + m_{cell\_link} + m_{cell\_w\_caps} + m_{shaft\_c} + m_{30\_hsq} + m_{45\_sq}$$

$$M_4 := m_{70\_sq} + m_{30\_sq} + m_{48T\_s} + m_{36T\_s} + m_{24T\_b} + m_{12T\_s} + m_{motor}$$

Total mass of the bought parts:

$$M_{bought} := M_1 + M_2 + M_3 + M_4$$

$$M_{bought} = 0.607\ \boldsymbol{kg}$$

Total CAD mass:

$$M_{tot} := M_{bought} + M_{machine} + M_s + M_{3D\_p}$$

$$M_{tot} = 1.447\ \boldsymbol{kg}$$