Team 18

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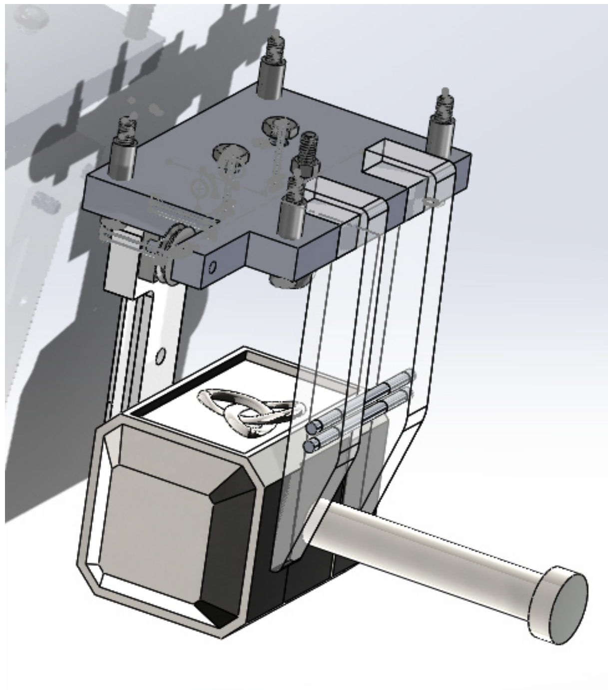
Project 2

Final Report

11/30/2015



Rationale of Design:

The design consists of a stationary wall and a movable wall that clamp the hammer. These walls are attached to a mounting plate connected half an inch directly below the robot wrist. The mounting plate is a thin acrylic sheet designed to simplify assembly to the robot wrist and also minimize the length of the walls.

A 3D printed ABS spool is connected to the driveshaft. The spool has two shafts of different diameters to connect to two 65lb strength fishing lines. The first string attached to the smaller diameter shaft is used to clamp the hammer. The second string is attached to the larger diameter and brings the movable wall to its initial position when the motor is in reverse.

Our stationary wall is two acrylic prongs that have two thin aluminum rods running through them. The clamping string runs around each rod to generate normal force. With two walls, they share the tension force through the rods and therefore can be thinner.

Our movable wall has an I-beam cross section. This allows us to maximize the area moment of inertia, which minimizes bending stress in the wall and allows us to minimize mass. The movable wall has an eye bolt in the center to connect to the clamping string. The eye bolt is placed on the lowest point on the wall that does not interfere with the hammer. The low eye bolt placement allows for the highest normal force from contact with the hammer. We also used football “Cutter” gloves on all of the walls because it generated the highest coefficient of friction between the walls and the hammer.

Peak Force: 9.91 lbs for each wall (Page 3)

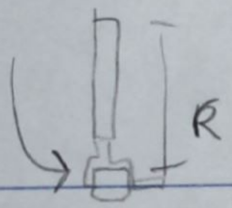
Factor of Safety for Grip: 1.634 (Page 5)

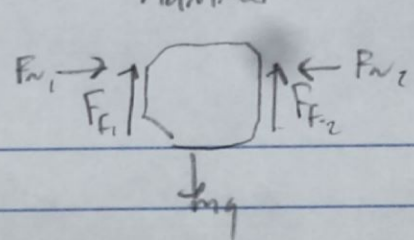
Factor of Safety Strength: 1.096 (Page 9)

Weakest Component:

We believe our weakest component will be our movable wall. Due to the complexity of the design we had to 3D print it out of ABS Plastic, which has a lower yield strength compared to acrylic and aluminum, which are used for other materials in our design. We therefore believe failure would occur due to bending at the center point where the eye-hook is.

Peak force calculation





by symmetry: $F_{N_1} = F_{N_2}$
& $F_{f_1} = F_{f_2}$ (same μ)

$\Sigma F_y = 0 = 2F_f - mg = \frac{mv^2}{R}$

$v_{max}^2 = \sqrt{2gR}$

so need F_f max

$\therefore\ 2F_f - mg = \frac{m(\sqrt{2gR})^2}{R}$

$= \frac{2mgR}{R}$

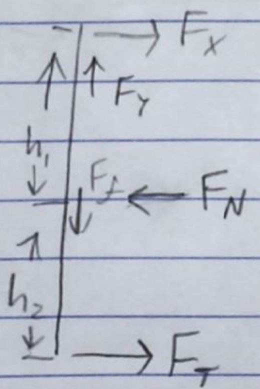
$2F_f = 3mg \Rightarrow$ total friction force needed

each wall needs F_f of $1.5mg$

total upward force needed for hammer: $\boxed{44.10\,N = 9.91\,lbs = F_p}$

each wall has $\mu = 0.5$ and equal F_N

$\boxed{F_N \text{ each wall} = 44.10\,N}$



$\Sigma M_h = 0 = F_N \cdot h_1 + F_T \cdot (h_1 + h_2)$

$F_T = \frac{F_N \cdot h_1}{h_1 + h_2}$

$h_1 = 2.25\,in$

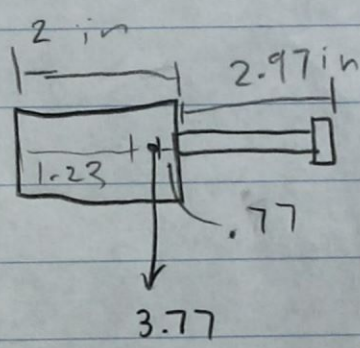
$h_2 = .25\,in$

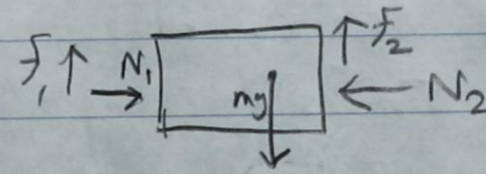
$F_N = 44.1\,N = 9.91\,lbs$

$\boxed{F_T = 8.919\ lbs}$

Tension force required

I





$\Sigma M_1 : -mg(.031) + f_2(.0769)$

$f_2 = \frac{mg(.038)}{(.0769)}$

$f_2 = 5.9258\,N$

$\Sigma F_y : f_1 + f_2 - mg = m\frac{v^2}{r}$

$f_1 = 38.118\,N$

$v =$

$\Delta V_e = 0$

$\Delta V_g : V_{g1} = -mg(28)$

$V_{g2} = 0$

$\Delta T : T_1 = 0$

$T_2 = \frac{1}{2}mv^2 \quad (m_H + m_{grip})$

$\frac{1}{2}mv^2 = mg(28)$

$(m_H + m_{gr})$ .119

28 in = .7112 m

$v^2 = 2g(28)$

$v = \sqrt{2g(.7112)}$

$v = 3.73\ m/s$

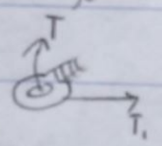
Tension Generated

μ for nylon-aluminum = 0.22

$T_f = Te^{-\mu\beta}$ β = angle of string

$T = 49.17$ lb

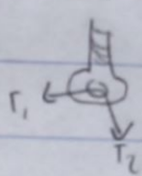
First eye-hook



$\beta = 90°$ $T_1 = Te^{-\mu\beta} = 49.17e^{-0.22(\pi/2)}$

$T_1 = 34.80$ lb

Mounting Plate eye-hook



$\beta \approx 90°$ $T_2 = T_1 e^{-\mu\beta} = 34.80e^{-0.22(\pi/2)}$

$T_2 = 24.6$ lb

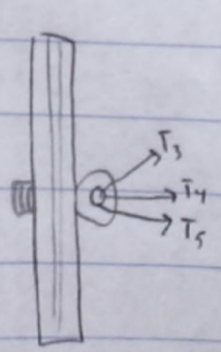
Then goes through 3 180° loops on aluminum bars / eye hooks

$T_3 = T_2 e^{-\mu\beta} = 24.6e^{-0.22(\pi)} = 10.2$ lb

$T_4 = T_3 e^{-\mu\beta} = 10.2e^{-0.22(\pi)} = 4.2$ lb

$T_5 = T_4 e^{-\mu\beta} = 4.2e^{-0.22(\pi)} = 1.8$ lb

Movable wall

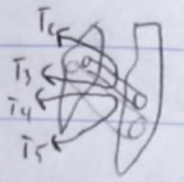


$F_T = T_3 + T_4 + T_5$

$= 16.2$ lb

F.O.S. = 1.634

stationary wall



F_T per wall $= \frac{T_2 + T_3 + T_4 + T_5}{2}$

$= 20.4$ lb

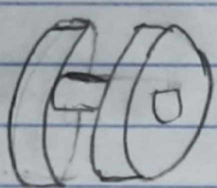
F.O.S. = 2.05

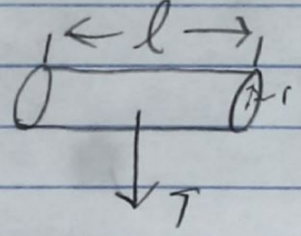
(2)

Finding Tension force of fishing line from spool

First must find minimum possible diameter of spool so the maximum tension is obtained from torque of motor but not small enough that ABS fails.

Max force experience in inside of spool is bending at the edges





l is Known

$T = \frac{\tau}{r}$ ← Torque from motor

$\tau = 1.1\,N \cdot m = 9.736\,lb \cdot in$

$$\Sigma M_{edge} = \frac{Tl}{2}$$

$$\sigma = \frac{My}{I} = \frac{\frac{Tl}{2} \cdot r}{\frac{\pi}{4} r^{4\,3}} = \frac{2\tau l}{\pi r^4} \qquad I \text{ of circle C.S} = \frac{\pi}{4} r^4$$

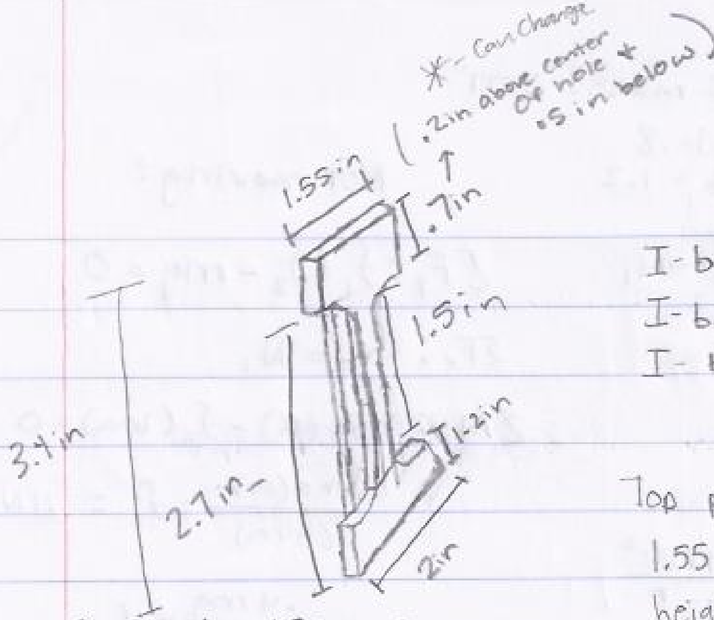
For ABS $\sigma_Y = 7000\ lb/in^2$

$$\sigma = \frac{\sigma_Y}{F.O.S}$$ say for now that F.O.S = 10

$$r = \left(\frac{2\tau l}{\pi} \cdot \frac{F.O.S}{\sigma_Y}\right)^{1/4}$$

$r = .1981\,in$

$\therefore\ T = \frac{\tau}{r} =$ **49.17 lbs**



I-beam-depth (overall h) = .4 in into page

I-beam-width (b) = .7in

I- beam Length ≈ 2.7 in * - figure out somethin for screws

Top part Hinge attaches to:

1.55 in = width

height = .7in ← * - may change

eye bolt = 1.55 in from bottom

holes for screws: 3.2in from bottom

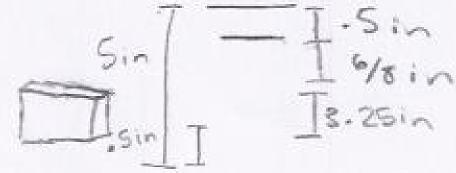
bottom plate:

1.2in high

2in wide

Arm length = 3.2 in

X = .5" in   Face = 1.2 in

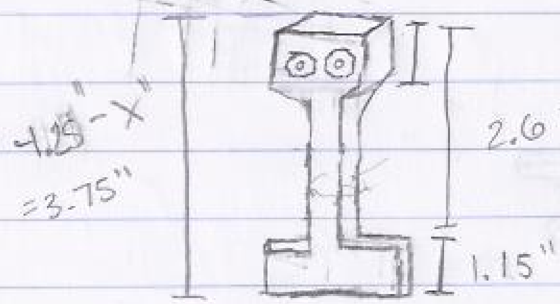


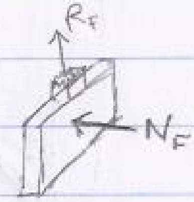
X" = height plate dropped down

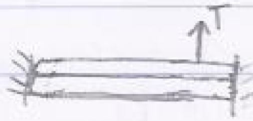
$A = Wh$

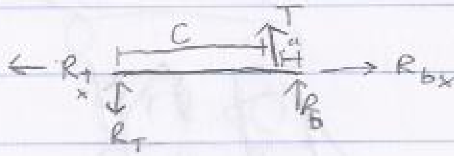
T = String tension

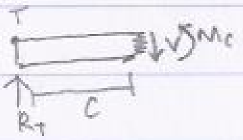
$I_{rec} = \frac{1}{12} bh^3$











$\Sigma F_y: T + R_B = R_T$

$\Sigma F_x: R_{Tx} = R_{bx}$

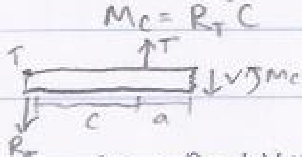
$\Sigma M_B: T(a) = R_T(C + a)$

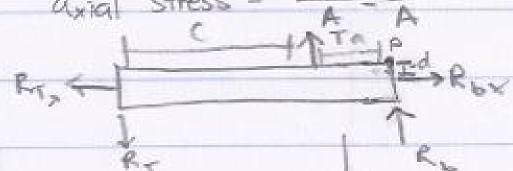
$\Sigma F_y: V = R_T$

$\Sigma M: -R_T C + M_c = 0$

$M_c = R_T C$

axial Stress $= \frac{R_{Tx}}{A} = \frac{R_{bx}}{A}$





$\Sigma F_y: R_T + V = T$

$\Sigma M: R_T(C) - T(a) + M_c = 0$

bending Stress: $\sigma_{max} = \frac{M_{max} \, h/2}{1/12 \, bh^3} = \frac{6 M_{max}}{bh^2}$

Max shear stress: $\frac{V_{max}}{A} = \tau_{max}$

$\sigma_{max} = \frac{\sigma_y}{FS}$

$\Sigma M_P: R_T(C+a) + R_{Tx}(d) - T(a) + R_{bx}(d) = 0$

$R_{Tx} = \frac{R_T(C+a) - T(a) + R_{bx}(d)}{(d)}$

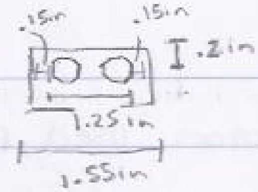
$T = \frac{N_H (\text{distance from hinge to } N_H)}{(\text{distance from hinge to Tension})}$

bending stress max

$$\sigma_{max} = \frac{M h/2}{\frac{bh^3}{12}} = \frac{6 M_{max}}{bh^2}$$

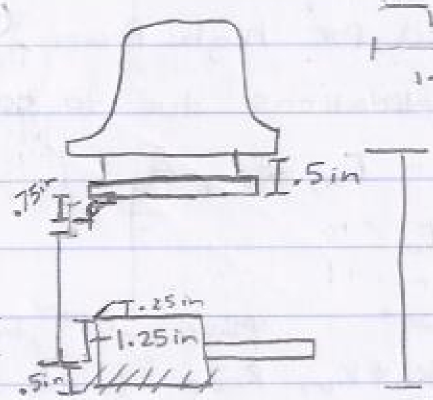
$$(20531.731) = \frac{6(35)}{bh^2}$$

$bh^2 = .1022$



If b = .7in
h = .3821in

$\sigma_m = 14.16$ MPa
$= 2053.73$ PSI



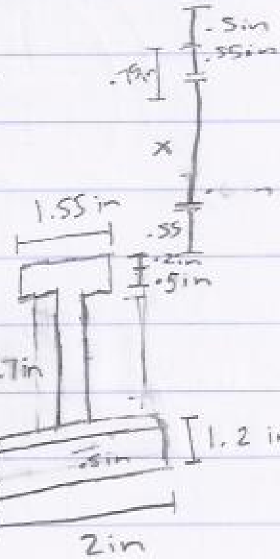
FS = 3

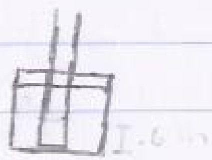
$\frac{\sigma_y}{\sigma_m} = FS$

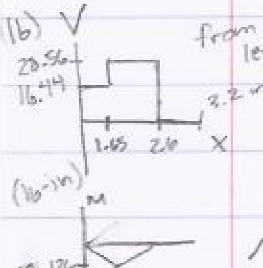
ABS plastic

$\sigma_y = 42.5$ MPa

x = 3.4 in

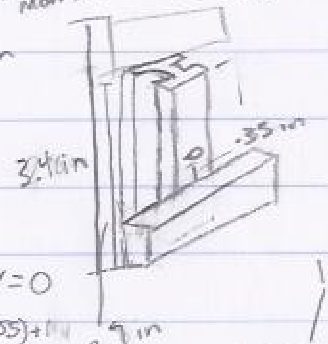






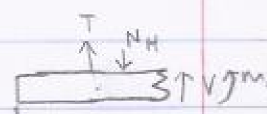
assume max moment is 35 lb-in = 4 N·m

Max Moment = 27.126 lb-in



T

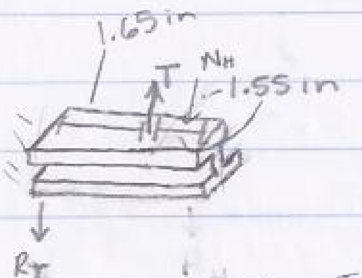
T = 45 lb = 200.16 N



$\Sigma F_y: T - N_H - R_T = V = 0$

$\Sigma M_c: R_T(3.2) - T(1.55) + N_H(.6) = M_c = 0$

N_H is .6 in from end of bar



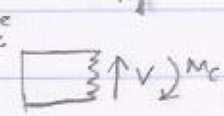
$\Sigma F_y: T = R_T + N_H$

$\Sigma M_H: T(.95in) = R_T(2.6in)$

$R_T = 16.44$ lb $= 73.12$ N

$N_H = 28.56$ lb
$= 127.04$ N

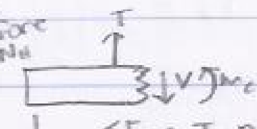
Before T:



$\Sigma F_y: V = R_T$

$\Sigma M: M_c = R_T(1.65)$

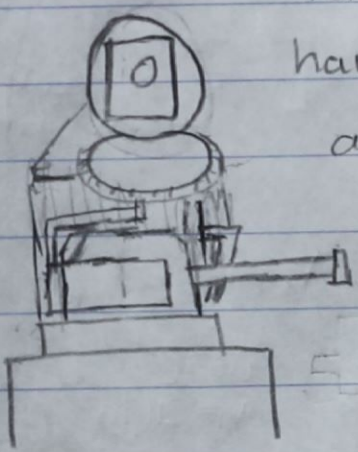
Before N_H

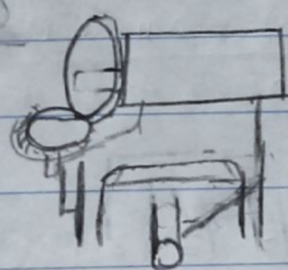


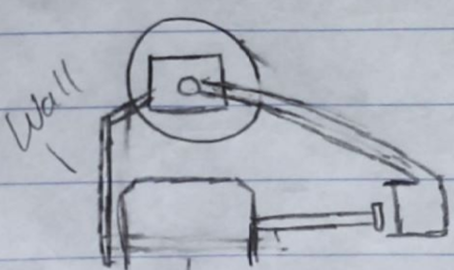
$\Sigma F_y: T - R_T = V$

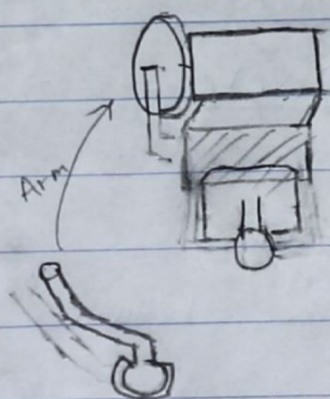
$\Sigma M: M_c = -R_T(2.6) + T(.95)$

Front like arm that moves hammer towards back wall and Squeezes hammer

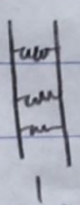








maybe wall



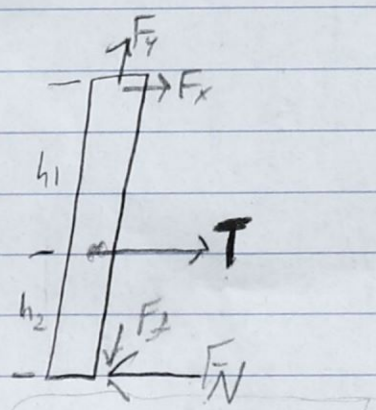
Springs that when compressed want to return to rest

Optimizing the fixed wall

1st. optimize structure for type of loading to be experienced

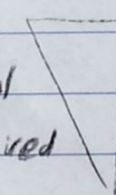
Center of pressure on same line as COM
Equidistant on both sides of the handle
Minimum surface area while making sure contact force
isn't too high
Select ideal material
- Options:
  - ABS ($\sigma_s = 6160$-6500 psi) ($\rho = .0376$ lb/in^3
  - Acrylic ($\sigma_s = 10000$ psi) ($\rho = .04$ lb/in^3)

.25in



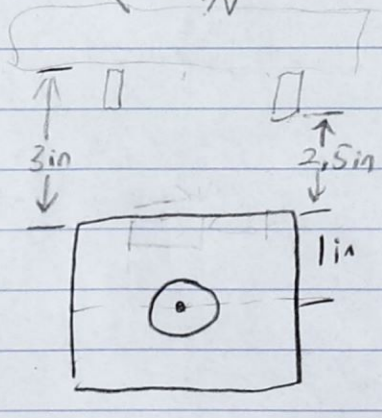
$$\Sigma M_{1h} = h_1 T - F_N \cdot h_2 = 0$$

$$F_N = \frac{3mg}{\mu}$$ Calculated based on Normal force required



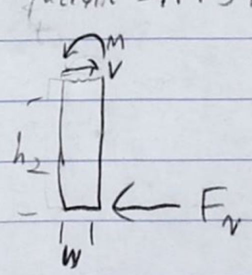
$$T = \frac{F_N(h_2 + h_1)}{h_1}$$

$$T = \frac{3mg\,h_2}{\mu h_1}$$



$h_1 \approx 2.4$in $h_2 \approx 1$in

$t_{acrylic} = .173$ in $t_{ABS} = ?$



$$M = F_N \cdot h_2$$

$$\sigma = \frac{My}{I}$$

$$\sigma = \frac{F_N h_2 \cdot w/2}{t w^3 /12} = \frac{F_N h_2 6}{t w^2}$$

mg = 3.308 lbs
F.O.S = 5

$$w = \sqrt{\frac{F.O.S \cdot 3mg \cdot h_2 \cdot 6}{t\,\sigma_y 2\mu}}$$

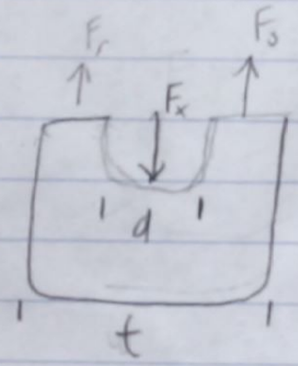
1.77in

w = .435in for acrylic

Analysis if chose to screw fixed wall to mounting plate.

$F_x = \frac{F_N(h_2 + th)}{h_1} F_{fd} - 4.5485$ lbs

Thickest acrylic = .375 in
$w = .2955$ in



$F_2 = 1/2 F_x$

$\sigma = \frac{F}{A}$

Assume $k_t \approx 2.2$

Must account for k_T and cylical loading

$\sigma = \frac{\sigma_Y}{F.O.S \cdot k_t}$ F.O.S = 5 $k_t = 2.2$
$\sigma_Y = 10000$

$\sigma = 909.1$ psi

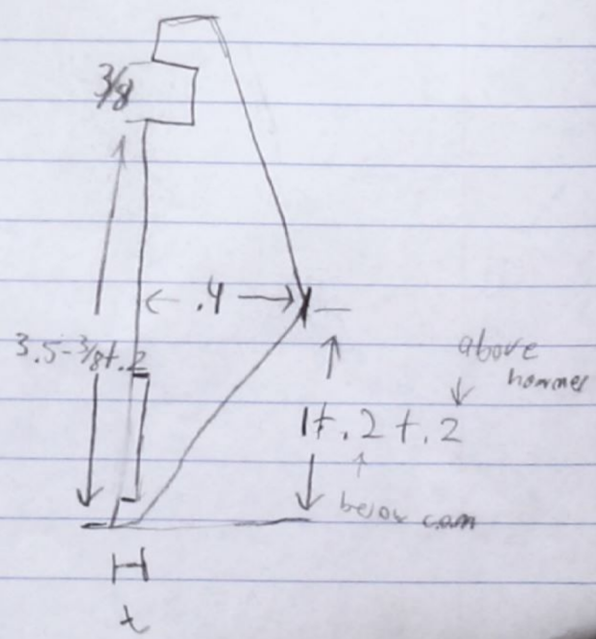
$A = (w - d) \cdot t$ $F = \frac{1}{2} F_x$

Assume d to be 1/16 set screw

$909.1 = \frac{1/2 F_x}{(t - d) \cdot w}$

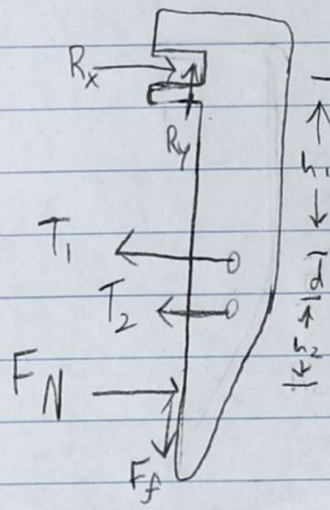
$w = .008$ in

Think about tension and no normal force situation.



Analyzing Normal force based on tension from strings

Fixed wall slip fit and acrylic glued to mounting plate



$$\Sigma M_R = 0 = F_N \cdot (h_2 + d + h_1) - T_1(h_1) - T_2(d + h_1)$$

From analysis done on another page for tension loss

$T_2 = 14.4$ lbs

$T_1 = 9.8$ lbs

$h_1 = 2.2$ in

$d = .2$ in

$h_2 = .9$ in

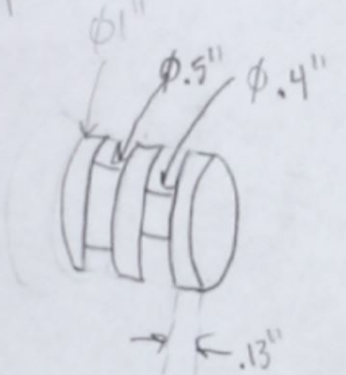
$F_N = 17.01$ lbs

$F_f = \mu F_N$

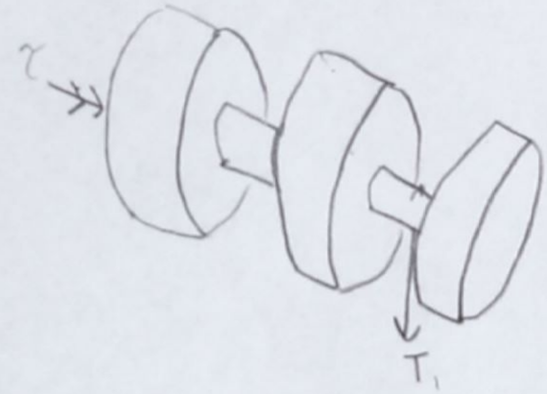
$\mu = .5$

$F_f = 17.01 \cdot .5 = 8.5$ lbs

Spool calculations



When motor turned on:



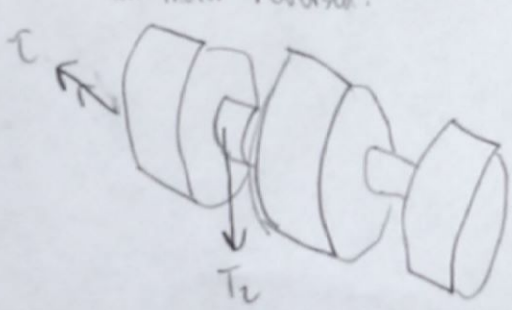
$\Sigma M_{center} = 0$

$\tau - T_1(.2") = 0$

$T_1 = \frac{\tau}{.2"} = \frac{1.3\ N\cdot m}{.2"}$

$T_1 = \frac{1.3}{.00508\ m} = 256\ N$

When motor reversed:



$\Sigma M_{center} = 0$

$-\tau + T_2(.25") = 0$

$T_2 = \frac{\tau}{.25"} = \frac{1.3\ N\cdot m}{.00635}$

$T_2 = 204.7\ N$

$\sigma_{y,\ ABS\ 3D\ printed} \approx 36\ MPa$

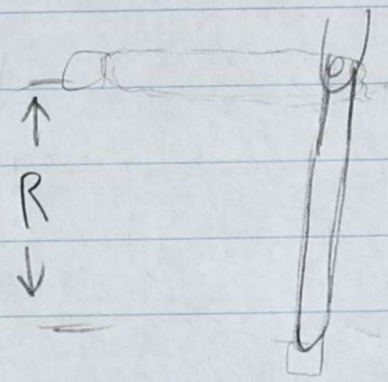
Miscellaneous

Biggining calculations on force required from the gripper due to the swing of the robotic arm and the weight of the hammer.

Driving Torque = $1.3 \pm .2 \, N \cdot m$

max speed $13 \frac{rad}{s}$

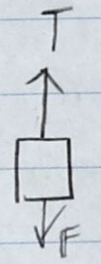
W



$PE_1 = KE_2$

$mgh = \frac{1}{2} m v^2$

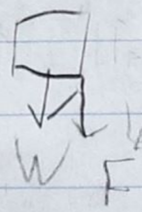
$\sqrt{2gh} = V$



$T = \frac{mv^2}{R}$ highest at the bottom

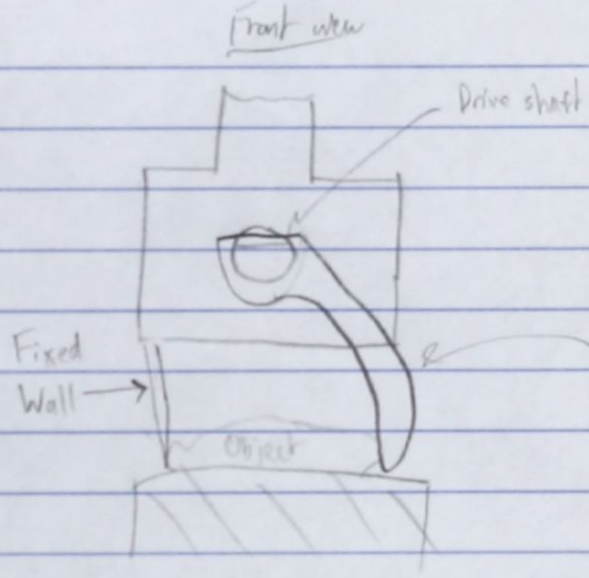
$F = \frac{2gRm}{R}$

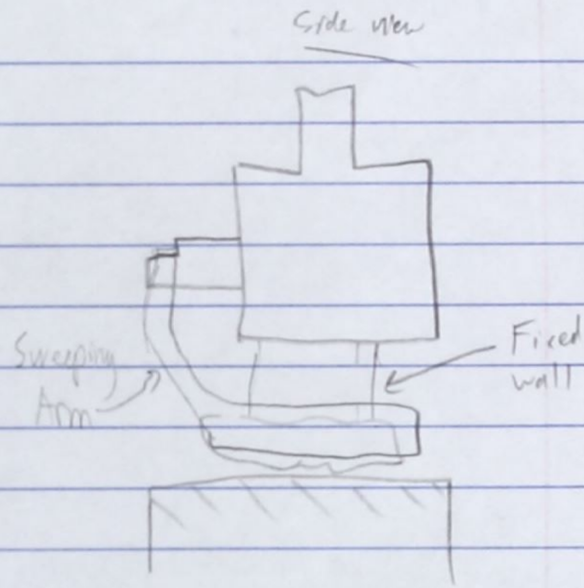
$F = 2gm$



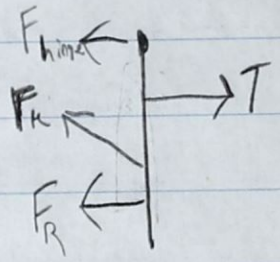
$F = 3gm$ Total force going down that we must counteract

Miscellaneous





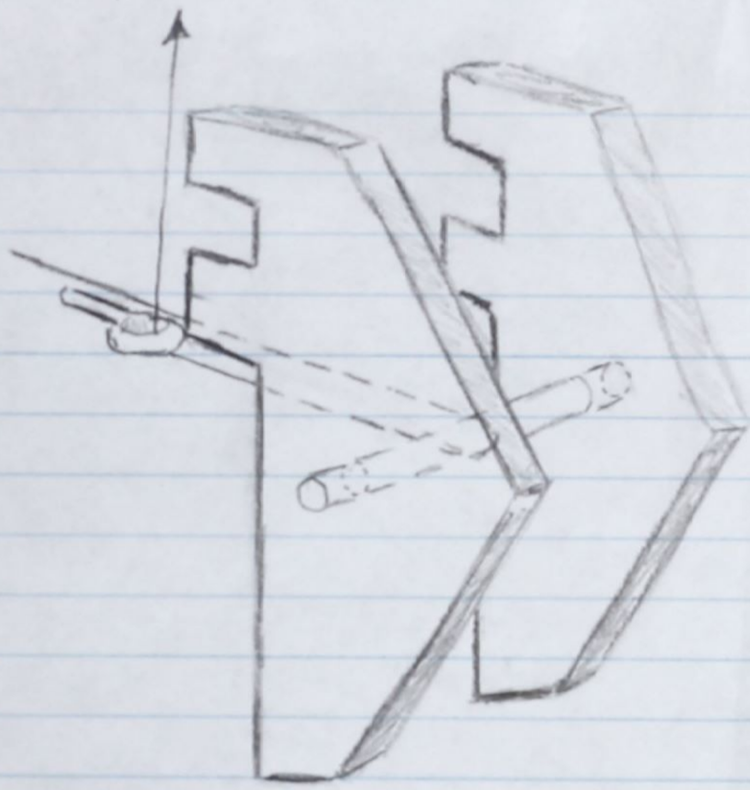
highest possible Force from rotating wall to fixed wall



$$T_2 = T_1 e^{\mu_s \beta}$$ ← angle

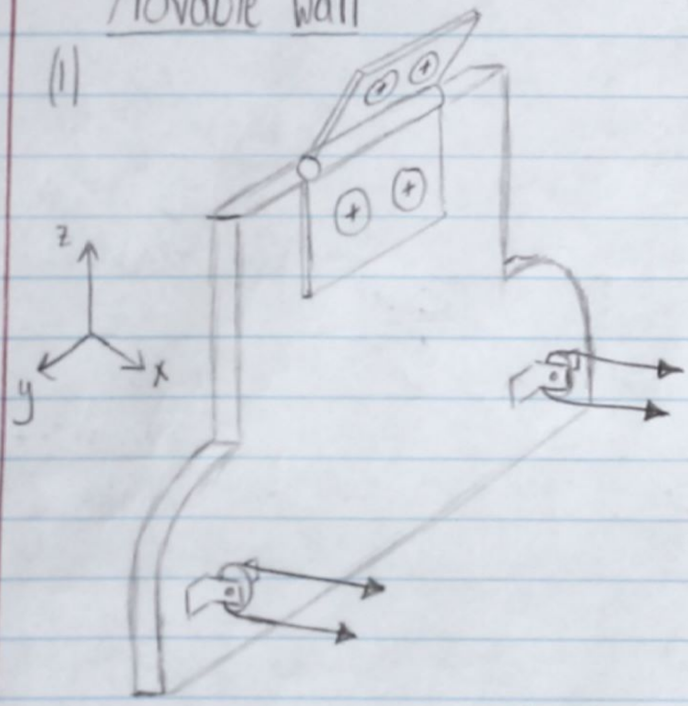
μ and N
↑ material selection
\ string location

Miscellaneous



Movable Wall

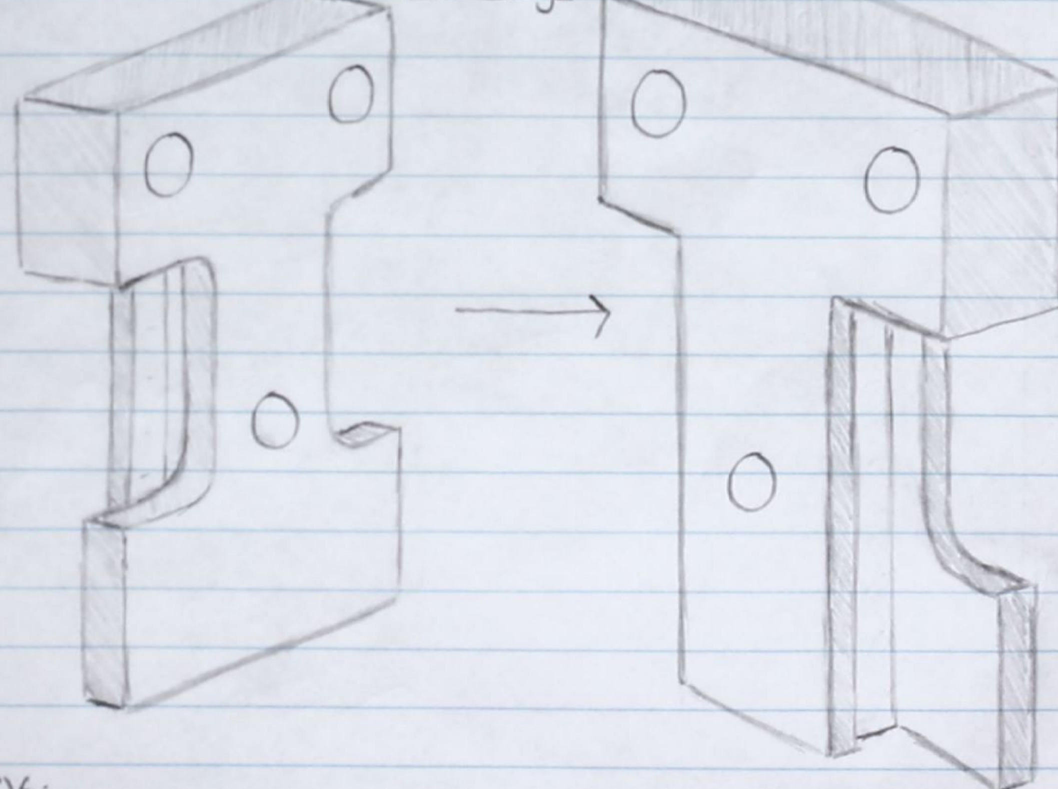
(1)



PROS:
- Large mass
- Tension differences cause moment about z-axis
  - ↳ created unequal pressure
- Unoptimized geometry for bending stress

* Final Design *

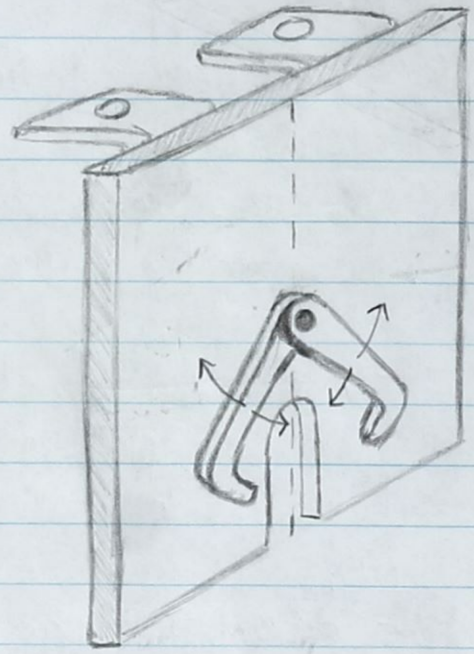
(2)



PROS:
- Minimal mass; lightweight material
- Optimized geometry
  - ↳ I-beam is optimal for bending stress experienced

Stationary Wall

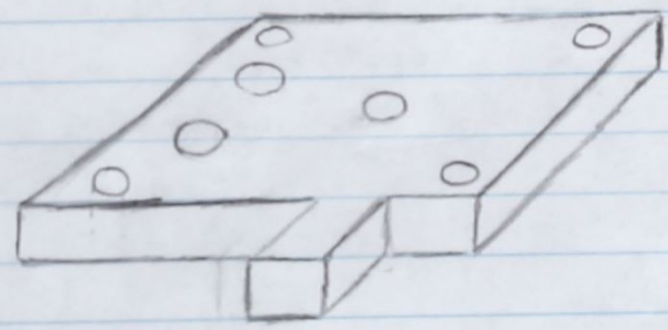
(1)



CONS:
- Large mass
- Unoptimized geometry
- Too complex
  ↳ Mechanism to move arms too complicated, scrapped that idea

PROS:
- Provided leverage under actual object (hammer)
- Reduced required vertical friction force to reach equilibrium.

Mounting Plate



PROS

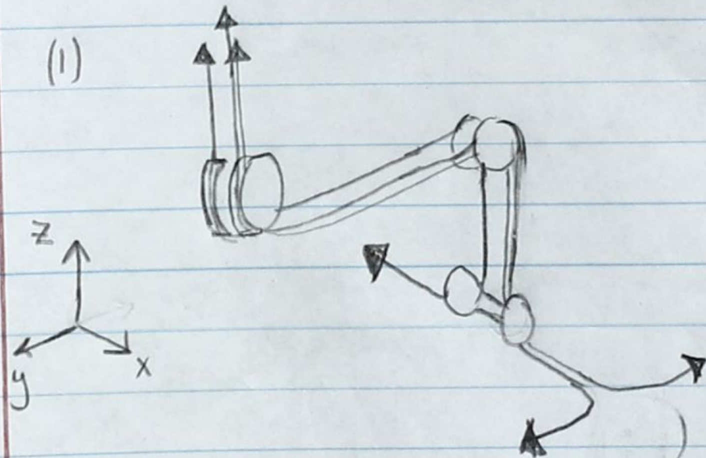
- lower fixed attachment surface for ports
  - ↳ movable + fixed walls

Optimization

- Worked w/ FEA and fundamental understanding of materials to optimize:
  - thickness
  - material

Pulley System

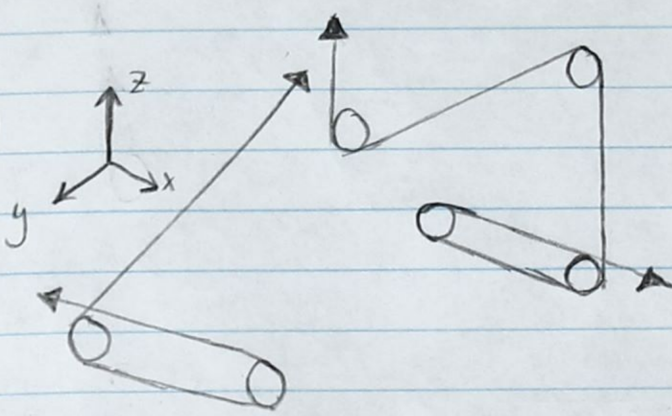
(1)



PROS
- avoids heavy gear machinery

CONS
- Difficult to redirect strings
- Short-circuit failure
  - ↳ one string pulls taught before the others and ceases mechanism

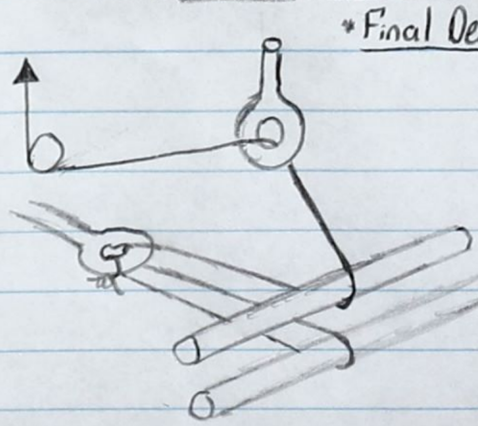
(2)



PROS:
- Lightweight
- Takes advantage of force-length relationship in pulley system

CONS
- Alignment/tensioning difficulty
- Slightly unequal force on each side, results in unequal contact
  - ↳ Moment about z-axis

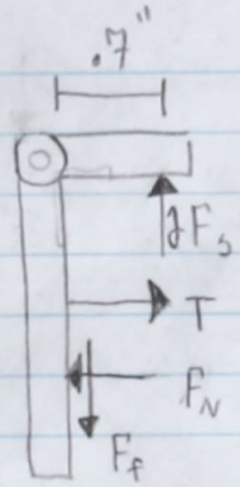
(3) *Final Design*



PROS
- Single string design (WAY EASIER)
- Still uses mechanical advantage of pulley system
- Avoids moment caused in multi-string design in (2)

Movable Wall + Hinge

T=45 lb



$\Sigma F_y = 0$; $F_f = 9.92$

$2F_s - F_f = 0$

$[F_s = 4.96 \text{ lbs}]$

← Force exerted by each screw

$\Sigma F_x = 0$

$F_N = T$

$[F_N = 45 \text{ lb}]$

Section 5: Material Selection

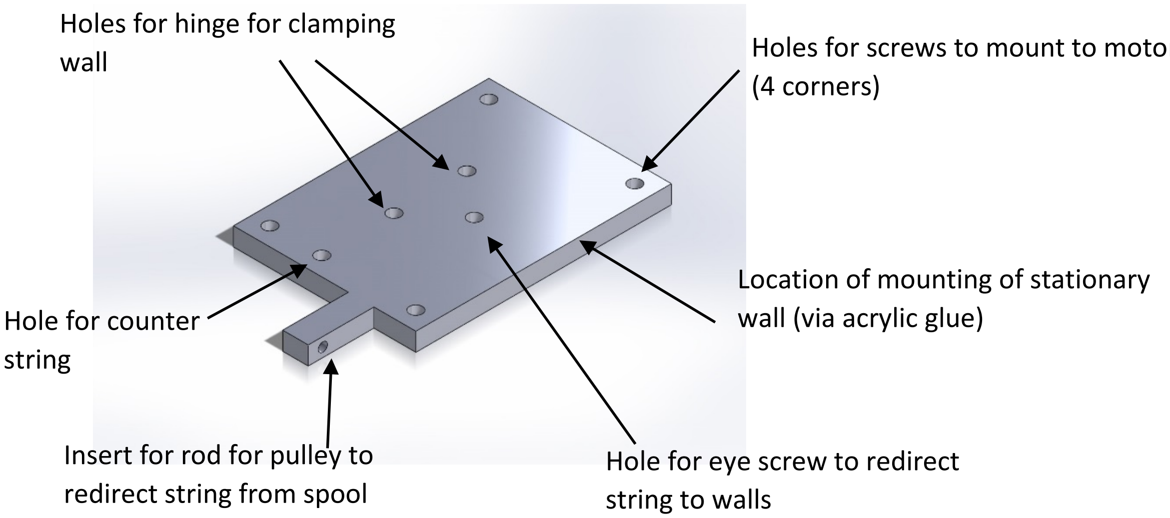
Mounting Plate – 3/8" Acrylic: Based on the loads experienced throughout the system (mostly just vertical forces), 3/8" acrylic supported our desired factor of safety with any loads (found on page 26). We also kept changing placement of certain things on the mounting plate so it was cheaper and easier to iterate with laser cutting acrylic.

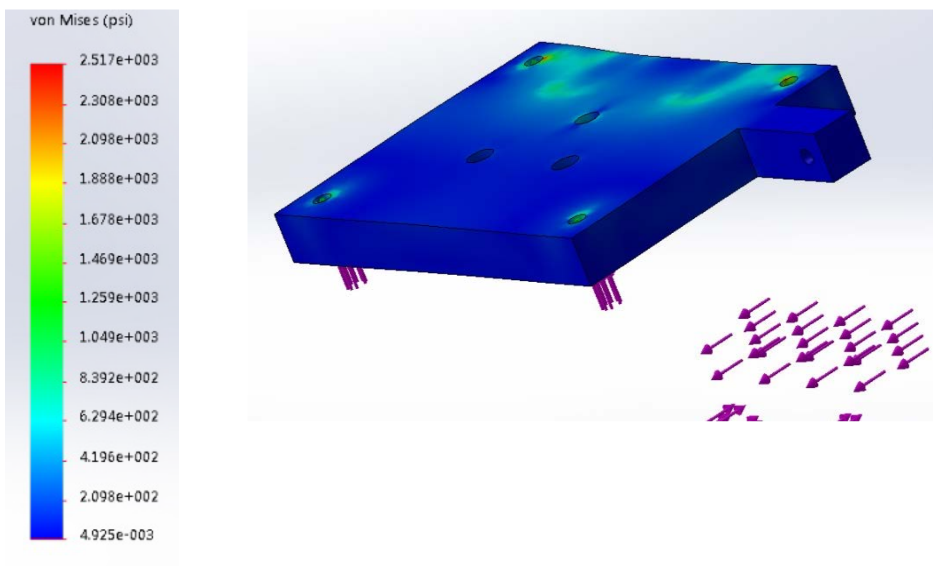
Stationary Wall Arms (2) – 3/8" Acrylic: Iteration of these arms were key based on different test designs we went through so laser cutting acrylic was perfect because it still had a high enough yield strength for the forces it experienced (found on page 12) and we could cut out many different parts. Since they got attached to the mounting plate we could also use acrylic glue, which reduced weight due to geometry changes and loss of screws.

Spool – ABS Plastic: geometry was very complex so even though we had to make the outer spool a little wider to withstand the loads (found on page 6), 3D printing a part like this is much easier, and the part is so small that cost was minimal and the additional safety length added was negligible for the weight of the entire system.

Movable Wall – ABS Plastic: Slightly complex geometry after optimizing to reduce weight where 3D printing was the most logical solution for manufacturing. 3D printing can also increase the strength because we can control how the layering works in our favor based on the loads applied to the part (found on page 9), making a lightweight ABS plastic a perfect choice.

Mounting Plate Model and Analysis





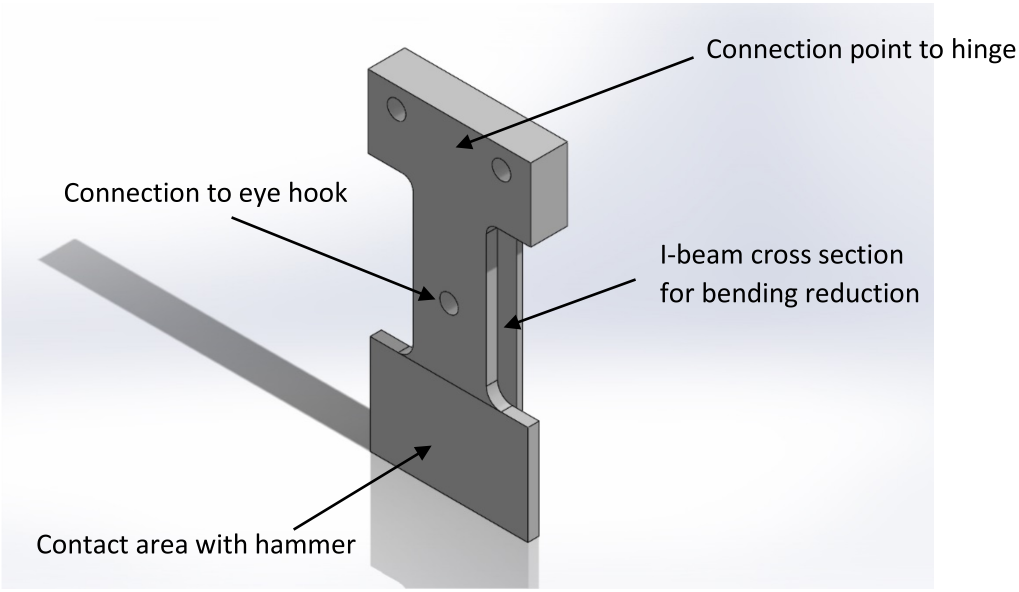
Material: Acrylic

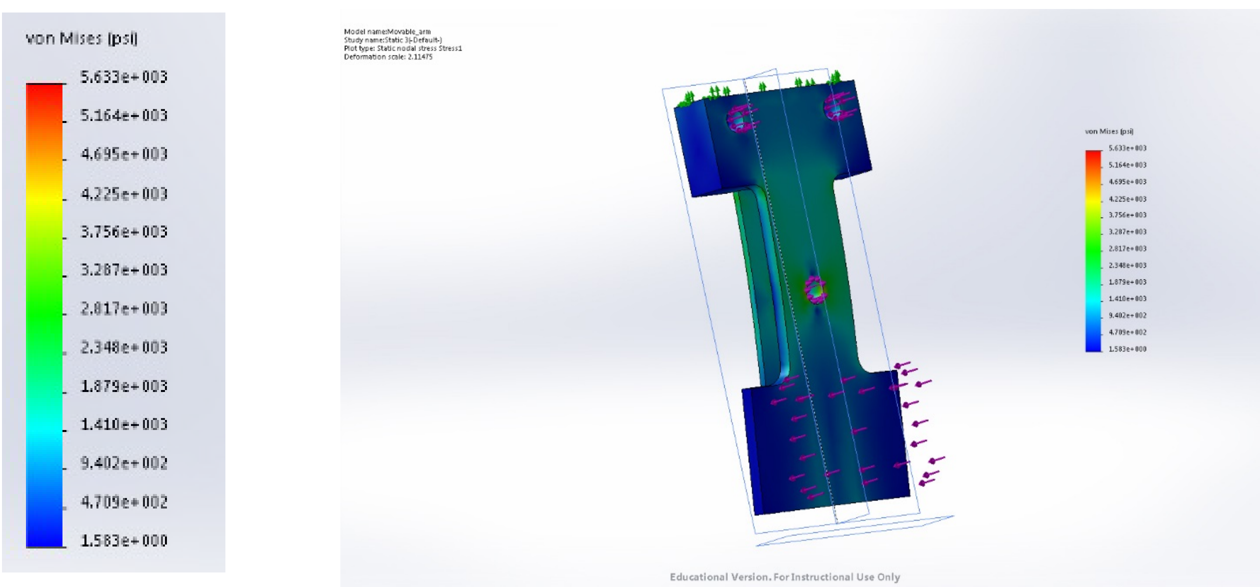
Yield Strength of Material: 10,000 psi

Part Mass: 43.76 grams

F.O.S.: 3.92

Movable Arm Model and Analysis





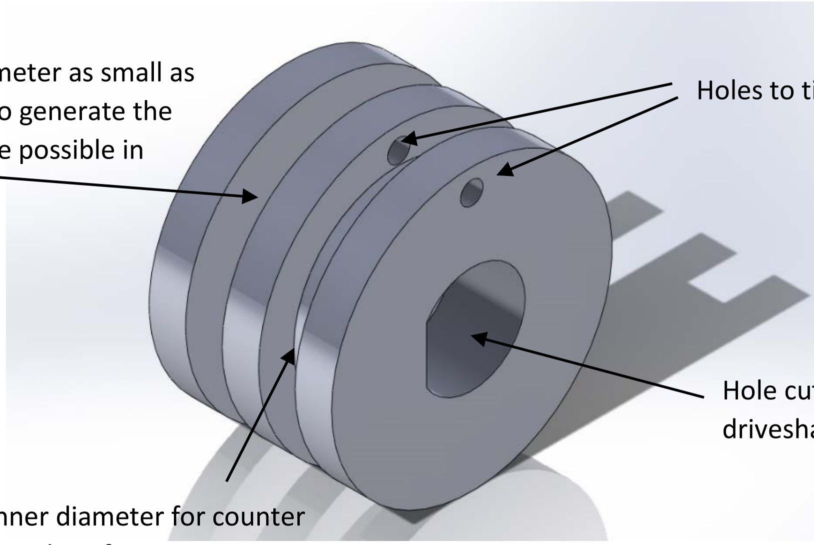
Material: ABS Plastic

Yield Strength of Material: 6160 psi

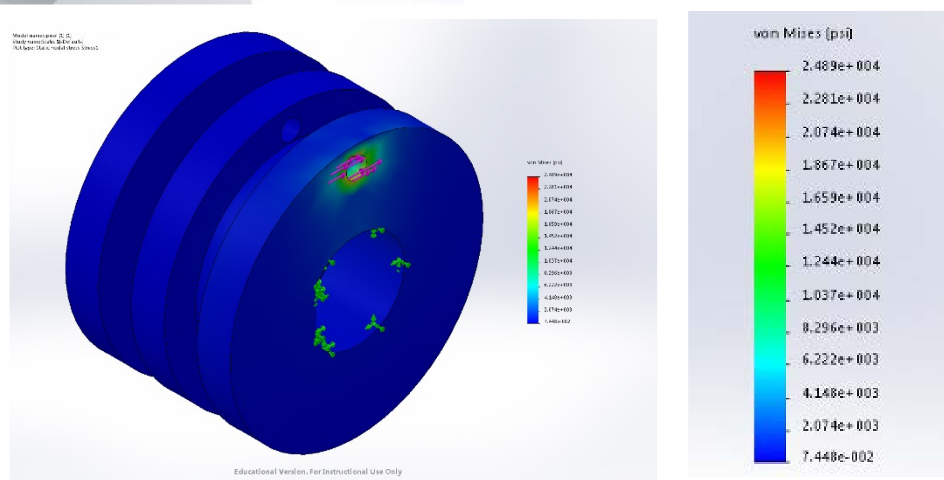
Part Mass: 13.81 grams

F.O.S.: 1.096

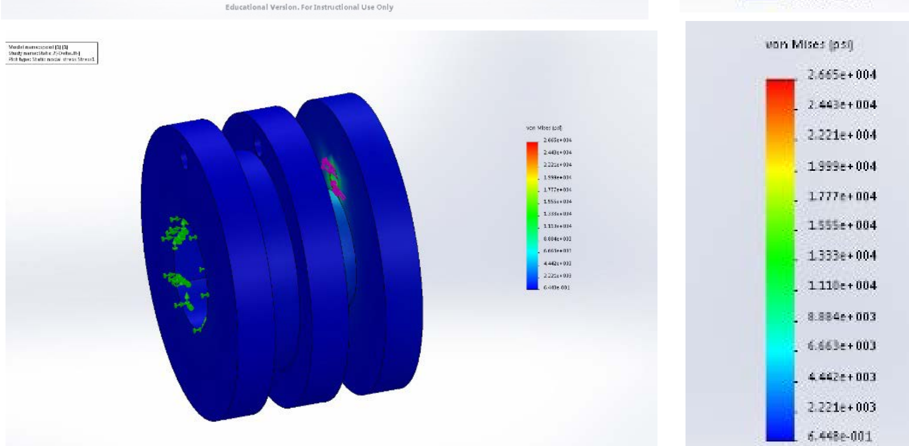
Spool Detailed Model and Analysis of Final Design



Counter string analysis



Clamping string analysis



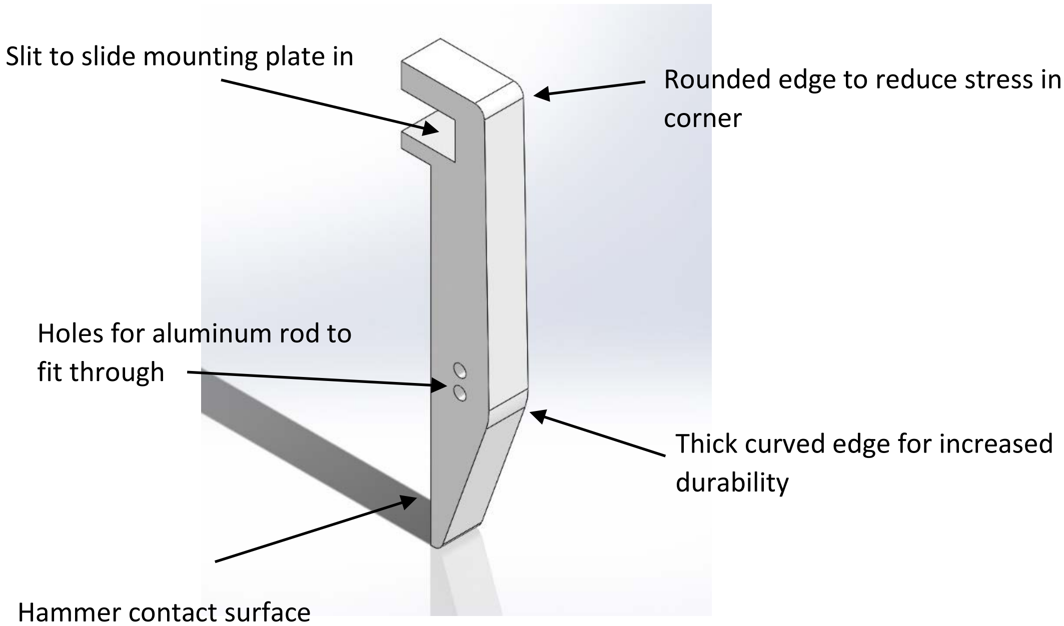
Material: ABS Plastic

Yield Stress of Material: 6160 psi

Part Mass: 5.84 grams

F.O.S.: 2.31

Stationary Wall Model and Analysis

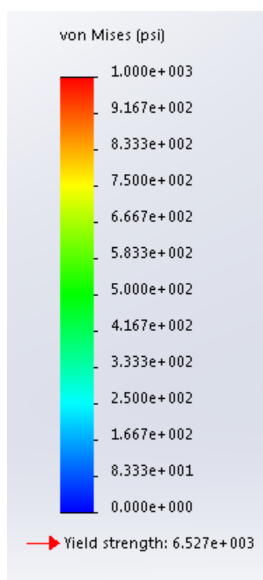


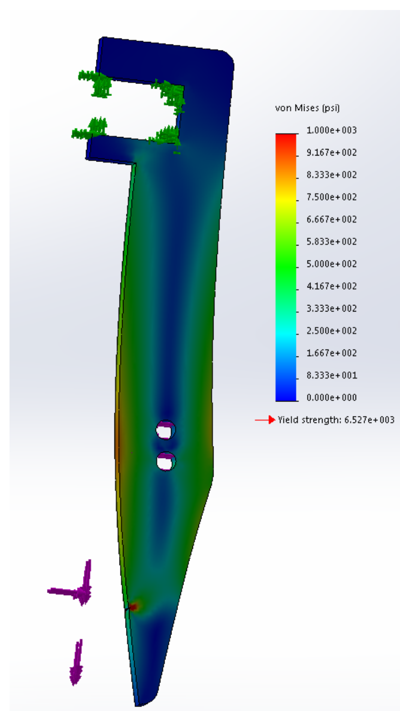
Material: Acrylic

Yield Strength of Material: 10,000 psi

Part Mass: 15.62 grams

F.O.S.: 10





Section 7: Catalog Component Selection

8-32 Screws: The screws were the correct size to fit into the motor mounting plate, and were the proper length to give us our desired gap length between our mounting plate and motor. Also made it easy to remove walls from mounting plate for quick changes.

1/8" Aluminum Bar: gave us desired strength for being such a thin bar to hold the tensions from the strings as well as the pulley. Aluminum also had the lowest coefficient of friction with the nylon rope out of possible options so less tension was lost throughout the system.

8-32 Nuts and Washers: Fit the screws we were using within the system.

1" Hinge: Was the smallest hinge we could find for our movable wall which reduced overall weight.

Plastic Pulley: Smallest pulley we could find that reduced weight. Went with a little more expensive pulley because it has a built in bearing so that the pulley will spin easier, providing a smaller tension lost in the spring.

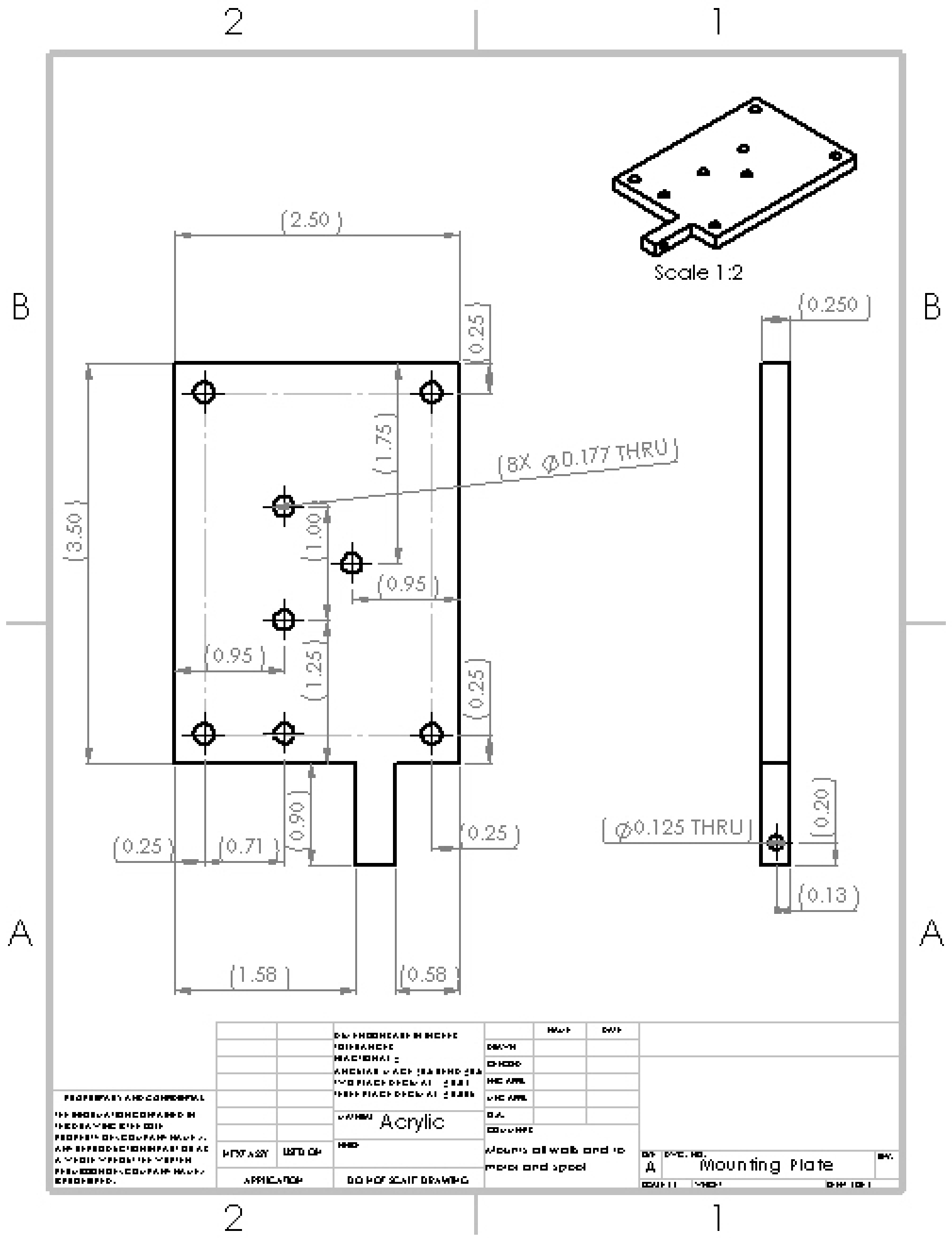
"Cutter Gloves": Proved to provide the greatest coefficient of friction between the wall and the hammer to increase our friction force to keep the hammer up. Were also readily available from group members on the football team.

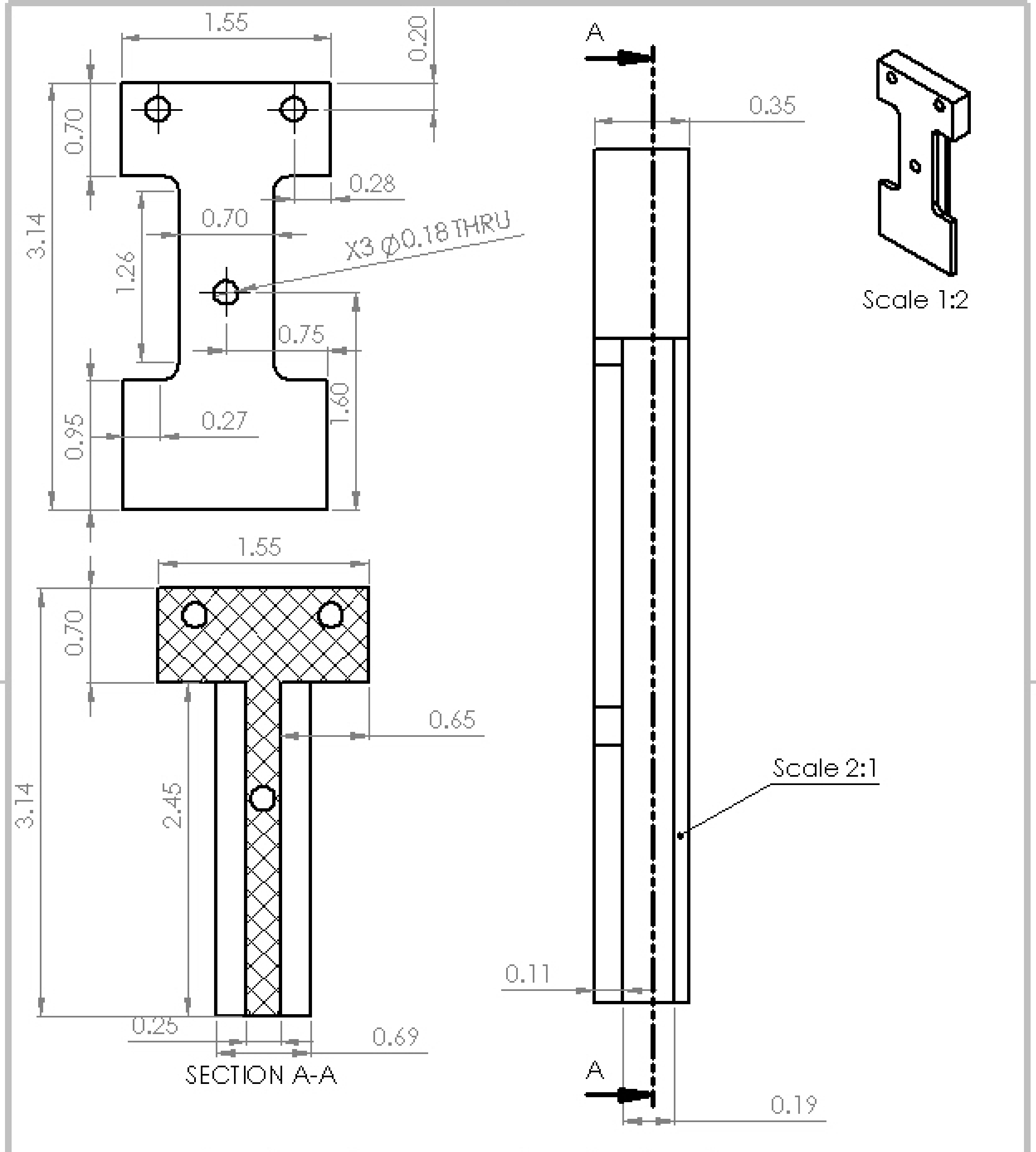
Spring: provided a high enough spring constant to be able to retract our movable wall back when the tension in the string was lost, but also was short enough to fit nicely within our smaller system.

High Strength Fishing Line: Provided more then enough strength based on our factor of safety and was already owned by one of the group members.

Eye Hook: Easier to use then small pulleys. Redirected string from spool to walls and still had low enough coefficient of friction with fishing line to reduce tension lost throughout system.

0.5" Spacers: Kept the mounting plate at exactly the same height from the motor to ensure the walls contacted the same location of the hammer every time.


Scale 1:2
(2.50)
(0.25)
(3.50)
(1.75)
(8X ⌀0.177 THRU)
(1.00)
(0.95)
(0.95)
(1.25)
(0.25)
(0.90)
(0.25)
(0.71)
(0.25)
(1.58)
(0.58)
(0.250)
(⌀0.125 THRU)
(0.20)
(0.13)
Acrylic
Mounting Plate
A
2
1
B
A



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NEXT ASSY | USED ON

APPLICATION

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ±DS BEND ±DS
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

MATERIAL ABS Plastic

FINISH

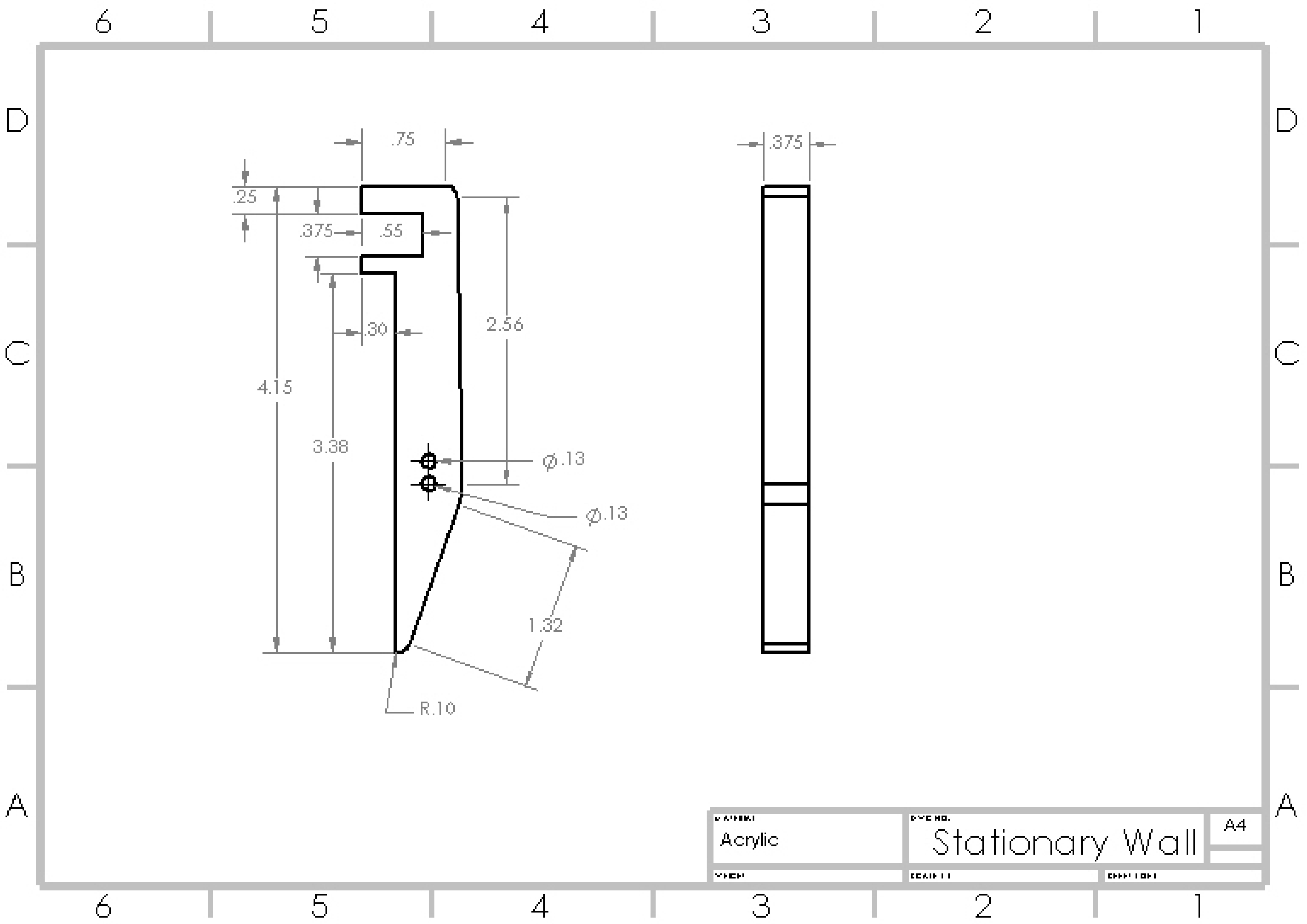
DO NOT SCALE DRAWING

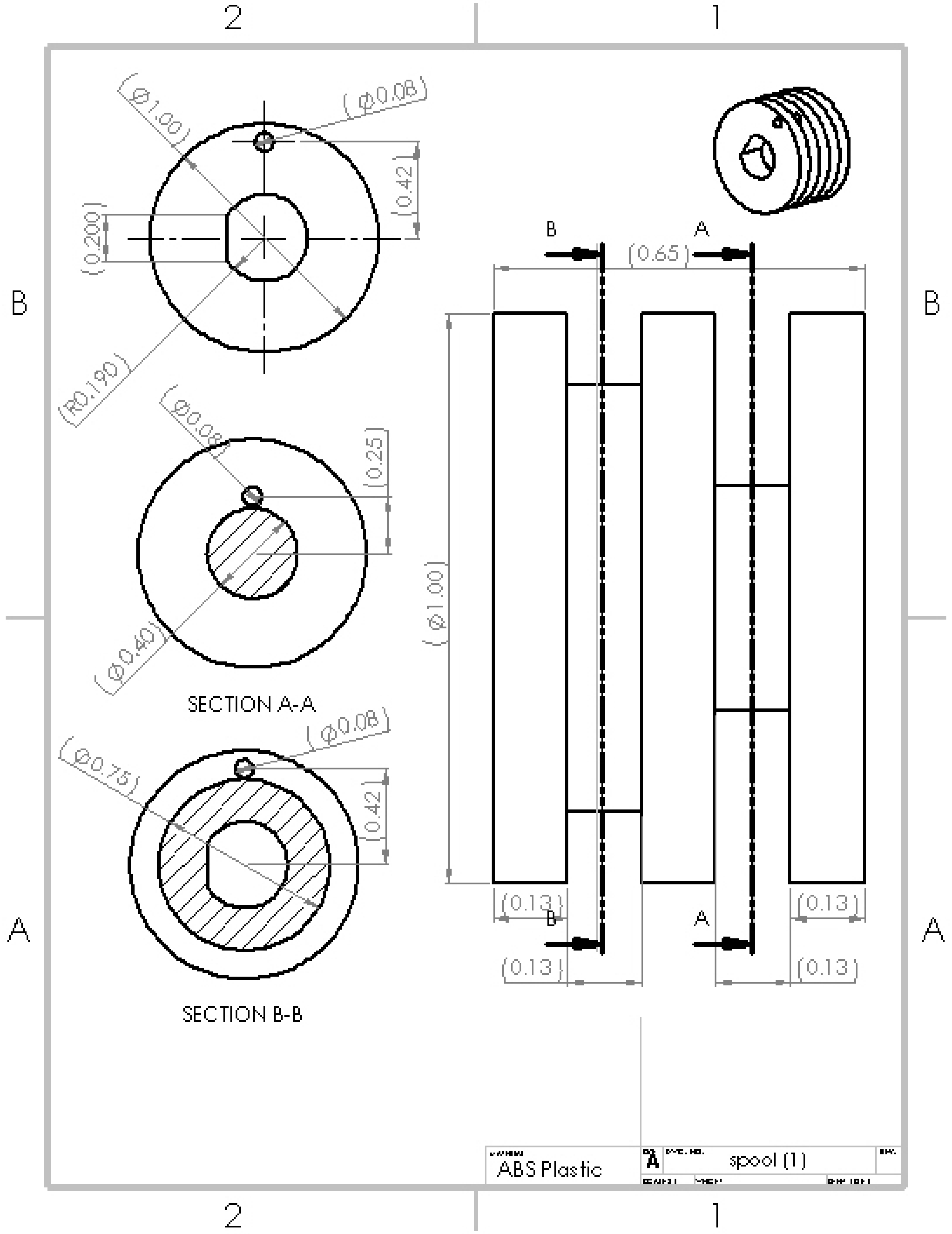
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR		
MFG APPR		
Q.A.		

COMMENTS:
Wall that clmps
to hammer

SIZE A | DWG. NO. Clamping Arm | REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1


.75
.25
.375
.55
.30
4.15
3.38
2.56
⌀.13
⌀.13
1.32
R.10
.375
Acrylic
Stationary Wall
A4



2
1
B
A
(Ø1.00)
(Ø0.08)
(0.42)
(0.200)
(R0.190)
(Ø0.08)
(0.25)
(Ø0.40)
SECTION A-A
(Ø0.75)
(Ø0.08)
(0.42)
SECTION B-B
(0.65)
(Ø1.00)
(0.13)
(0.13)
(0.13)
(0.13)
ABS Plastic
A
spool (1)