Team 1

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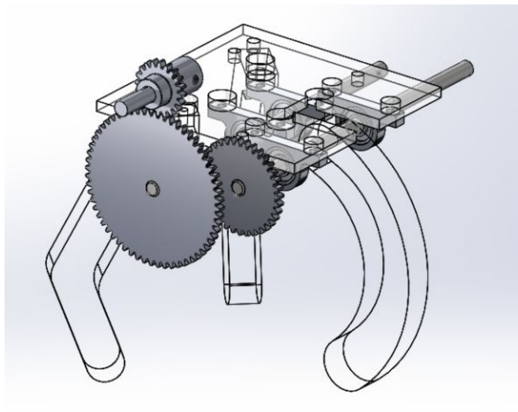
Project 2: Final Report

November 21, 2016

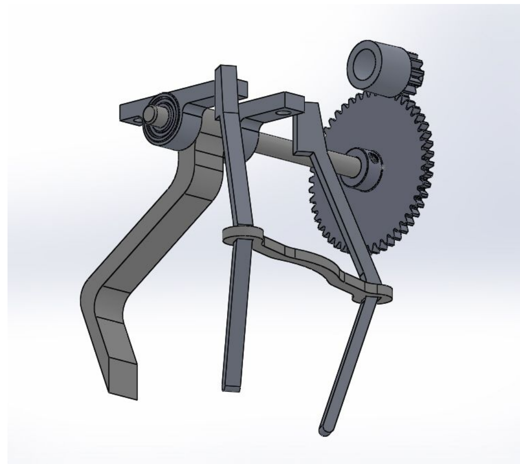
2. Summary Page:

Isometric View of Assembly

Prototype 1



Prototype 2



Description:

Our second gripper design consists of a stationary aluminum bifork with two tines connected by an acrylic strut and a rotating acrylic unifork pinned to a shaft that is turned by our gear system. We changed from acrylic to aluminum bifork which allowed us to thread the holes for the screws and eliminated the potential to crack when tightening the screw. The strut connects the two tines, preventing them from spreading apart and unscrewing from the mounting screws. The end of the unifork is designed to have one small, flat contact point with the pokeball at the equator unlike the first prototype which extends below the equator. This prevents upward push against the pokeball. A small strip of non-slip material is attached to the ends of the bifork tines and the unifork, at the contact points with the pokeball, in order to increase friction. This replaced the sponge from our first prototype for higher friction and neater appearance. The steel shaft is supported by two metal bearings encased in acrylic housings that also screw into the pegboard. At the end of the shaft is a two inch, aluminum gear that is turned by a half inch gear which sits on an aluminum shaft reducer. The shaft reducer is in turn attached to the drive shaft of the wrist assembly. We eliminated one of two sets of gears from the first prototype because we had initially overestimated the required torque. Components that undergo high stresses and/or require high precision such as the gears and biforks are made of aluminum, which is strong, but relatively light. Other components like the unifork, strut, and bearing housings were laser cut from acrylic for lower mass. We also got rid of the base plate to reduce mass.

Peak Force in Vertical Direction:

F = 9 lb (see page 23)

Factor of Safety With Respect to Dropping the Object:

FOS = 1.667 (see page 29)

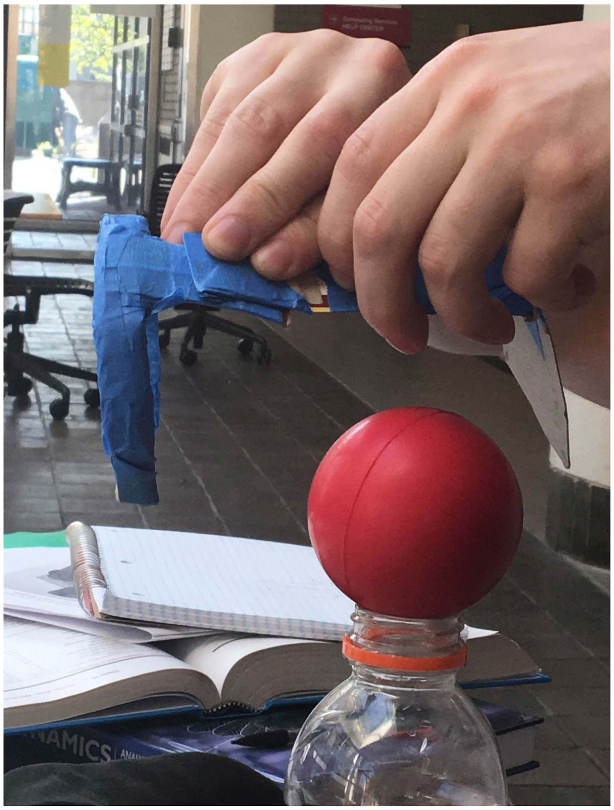
Factor of Safety With Respect to Component Failure

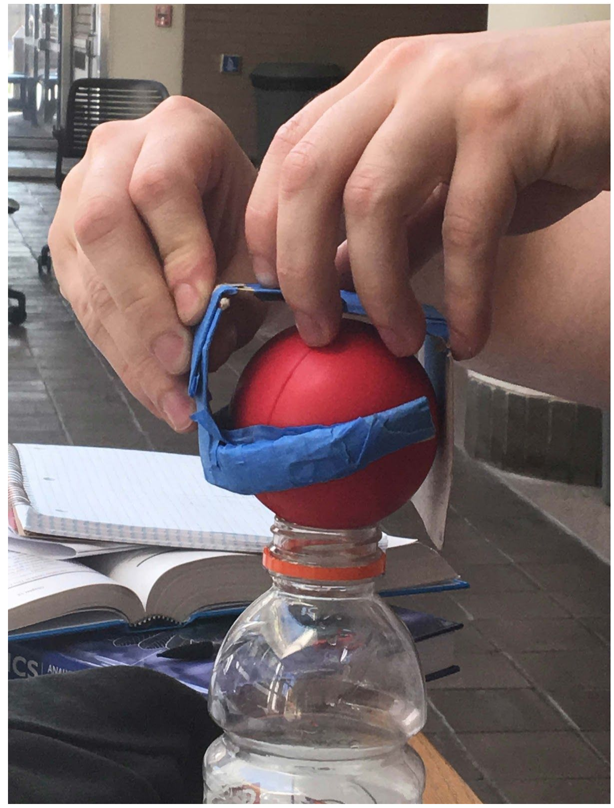
FOS = 2.7 (see page 27)

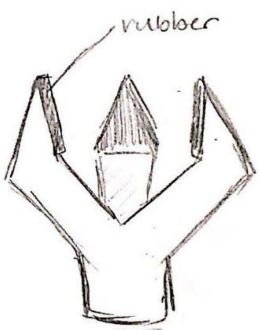
Weakest Link Guess:

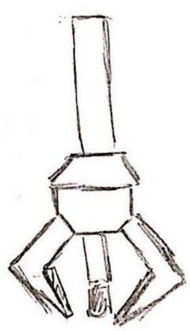
The weakest link is our unifork as the acrylic is brittle and subject to stress concentrations at the pin hole and contact with the robotic wrist, where it will likely break if the motor is left in reverse long enough.

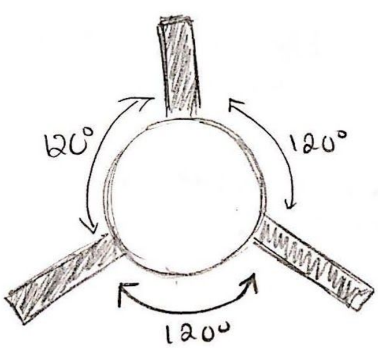
3. Conceptual Design Sketches



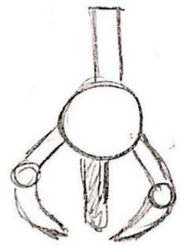




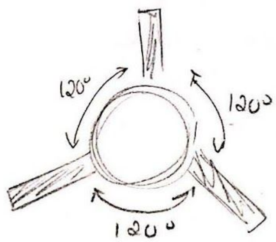




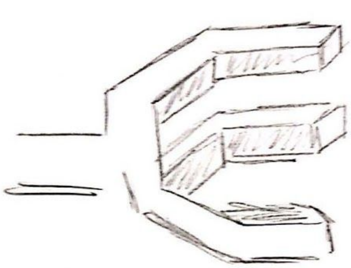
- 3 arms
  - ↳ more stable than 2
  - ↳ less mass than 4
- rubber tips
  - ↳ better "grip"
- symmetry
  - ↳ easier to analyze
  - ↳ easier to produce
- all arms movable
  - ↳ movable joints are weaker
- straight arms easier to produce than rounded



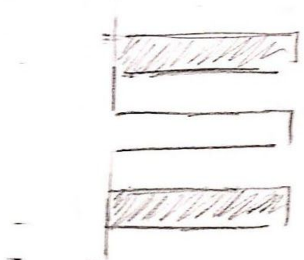
- rounded arms
  - ↳ better matches shape of ball
    - → less movement during "swing"
  - ↳ harder to produce
  - ↳ less room for error
- symmetry
  - ↳ easier to analyze



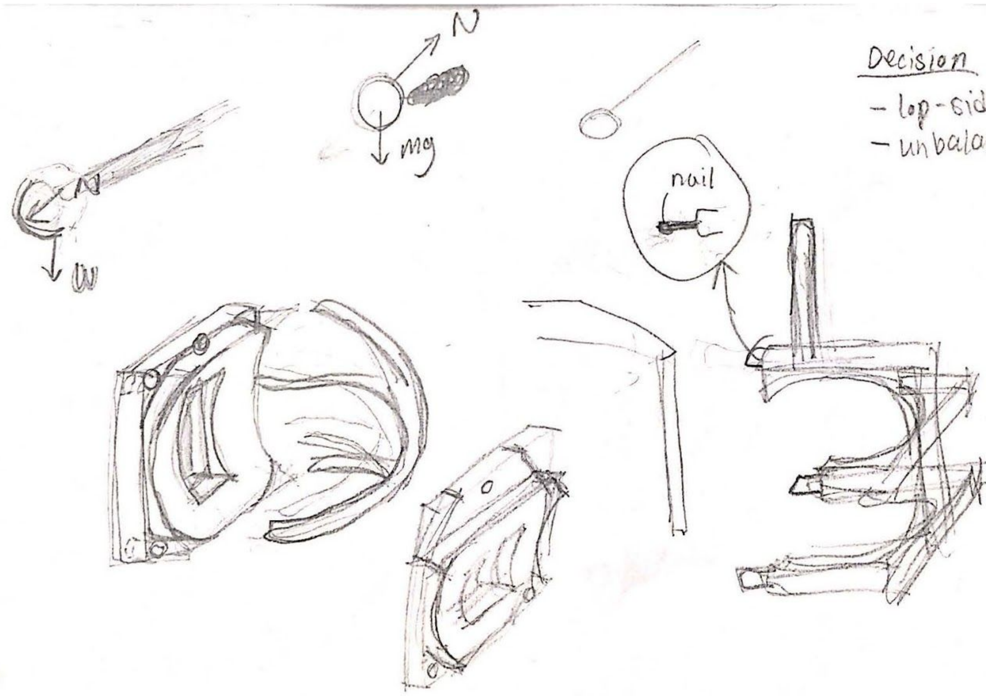
- rounded base
  - ↳ allows for more degrees of freedom
    - ↳ more options in terms of movement
    - ↳ more things that could go wrong
      - ↳ stresses act in weird directions



- straight arms
  - ↳ easier to produce
- sideways grip
  - ↳ completely avoids problem of touching sides
  - ↳ more room for error in "swing"

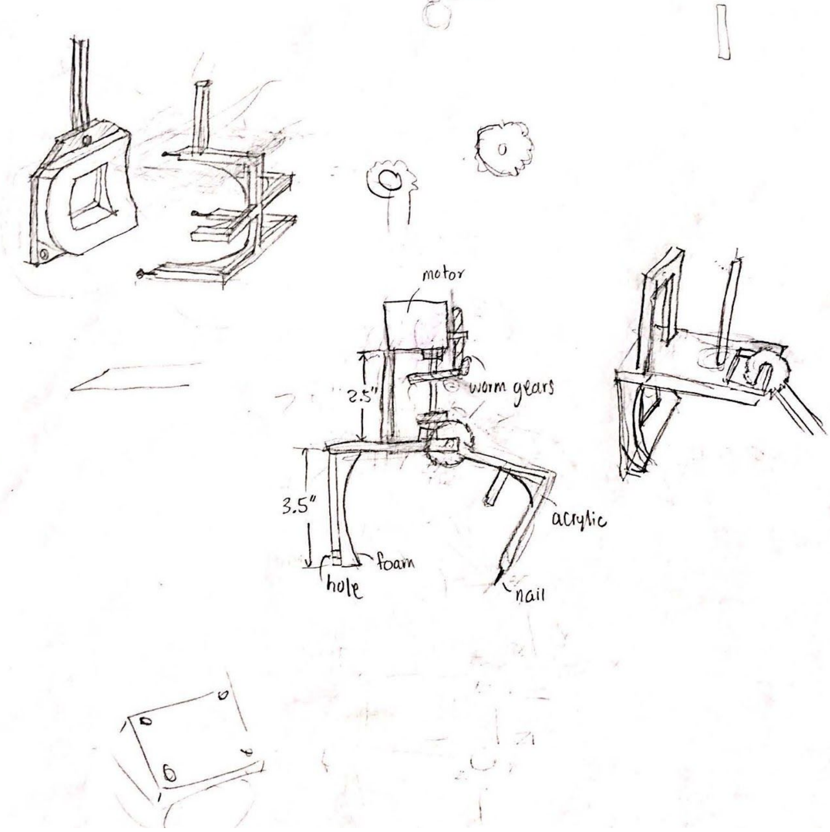


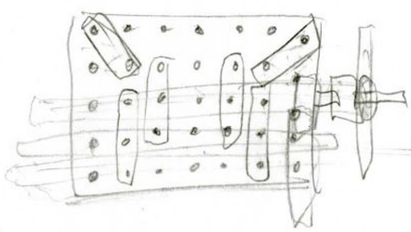
Decision
- lop-sided? or
- unbalanced weight

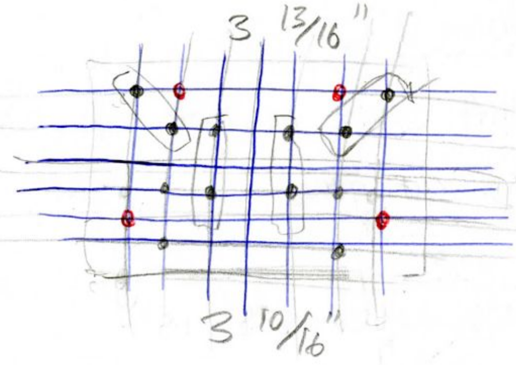


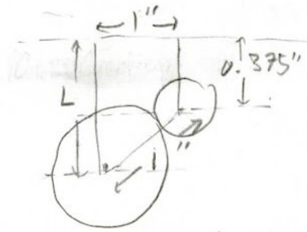
Notes

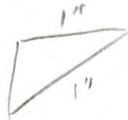
- perpendicular to axis of motion
-









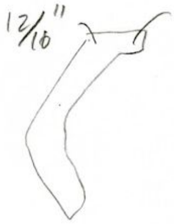


L = 0

both shafts are level!

Acrylic

D = 7/16" (washer OD)
0.4375

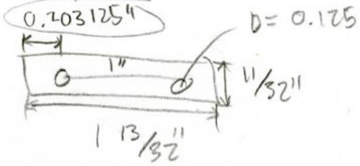


cut out 3/16" of 12/16"

cut out 7/16" of

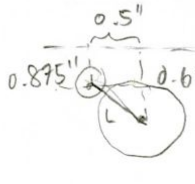
Hole sizes = 6/32" = d — metal
0.1875

Bearing Houses

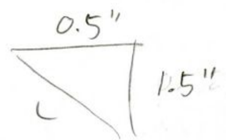


Revision 2

- shift shaft to right by 0.5"
- laser cut gears



0.625 + 0.875 = 1.5"

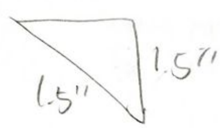


$L = \sqrt{0.5^2 + 1.5^2} = 1.5811"$

D_{large} = 2.53"	48 teeth	inner diameter = 0.24"
D_{small} = 0.6325"	12 teeth	or

0.5" – 2.5"
0.5" – 3"

Alternatively

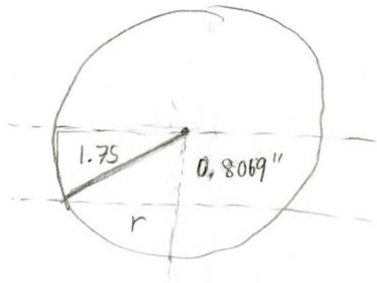


0.875" 21 teeth (S1066Z-024A021)

2.5" 60 teeth (S1066Z-024S60)

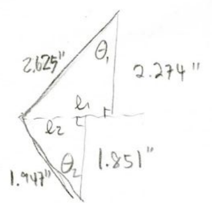
0.625"
2.5"

0.75 + 1 = 1.75



$$r = \sqrt{1.75^2 - 0.8069^2} = 1.553''$$

$$D = 2r = 3.106''$$

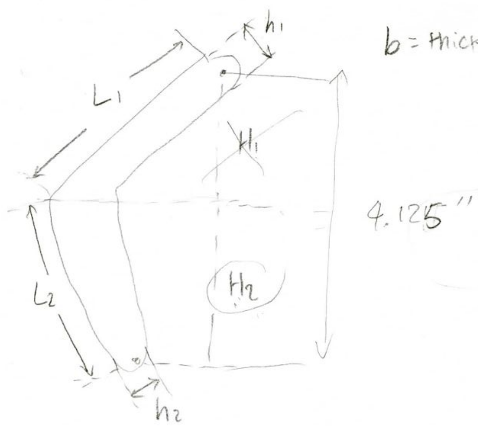


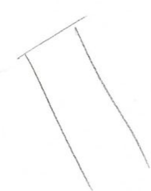
$$\theta_1 = \cos^{-1}\left(\frac{2.274}{2.625}\right) = 30^\circ \qquad l_1 = 2.625 \sin\theta_1 = 1.31''$$

$$\theta_2 = \cos^{-1}\left(\frac{1.851}{1.947}\right) = 18^\circ \qquad l_2 = 1.947 \sin\theta_2 = 0.6''$$

L1, L2, H2, b, h1, h2

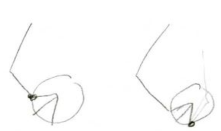
b = thickness

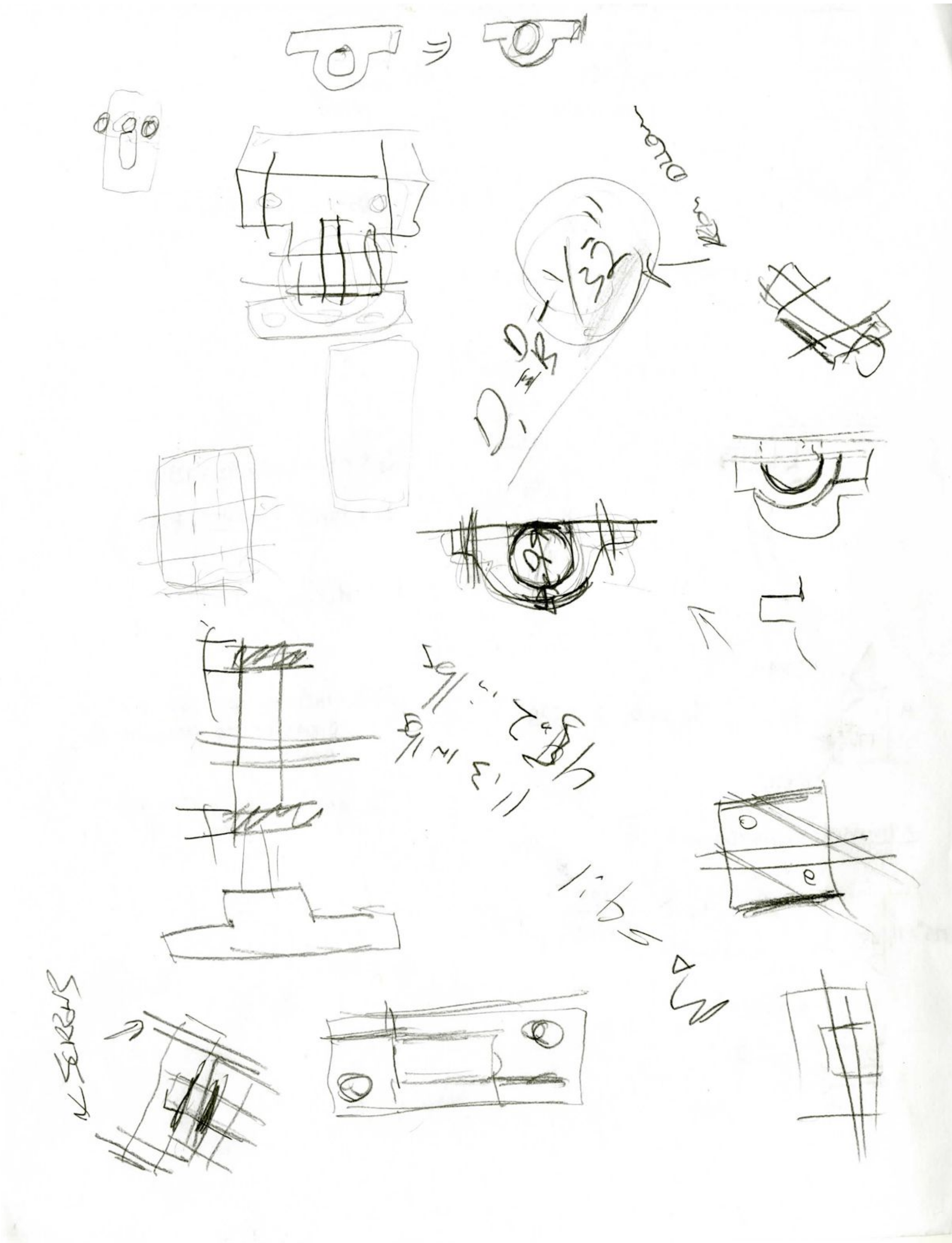


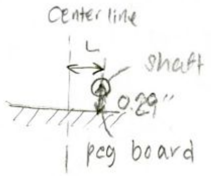


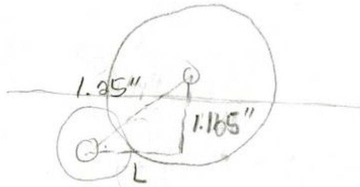
L1 L2, H2, b, h1, h2

P = 2 * peg diag

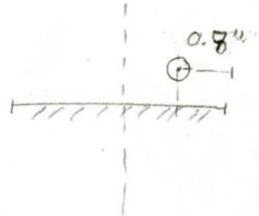


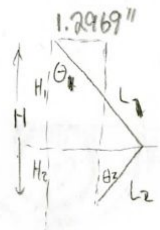






$L = \sqrt{1.25^2 - 1.165^2} = \boxed{0.4531''}$

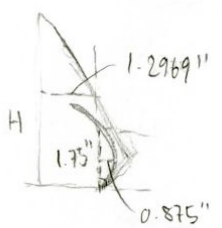




$L_1 \sin\theta_1 - L_2 \sin\theta_2 = 1.2969''$

$\theta_1 = \tan^{-1}\left(\frac{L_2 \sin\theta_2 + 1.2969}{H_1}\right)$

$L_1 = H_1 / \cos(\theta_1)$

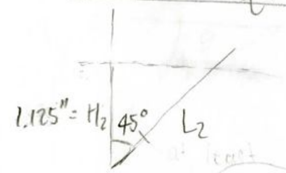


$L_2 \sin\theta_2 > 0.875''$

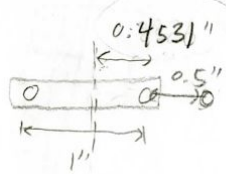
Note: inflate ball by +1" in diameter to account for arm thickness

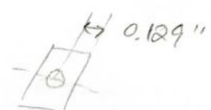
So assume ball D = 4.5"

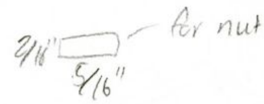
minimal requirement



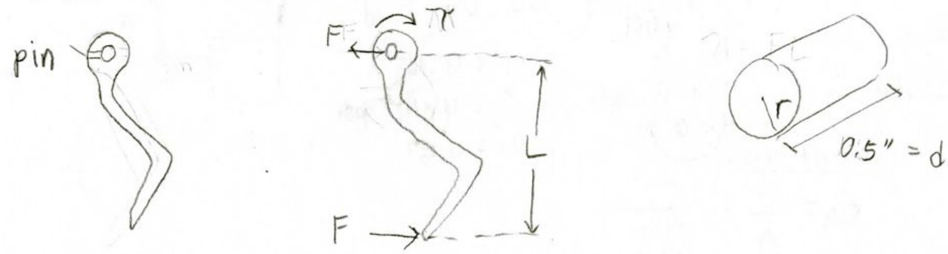
$L_2 > \frac{1.125}{\cos 45^\circ} = 1.6''$

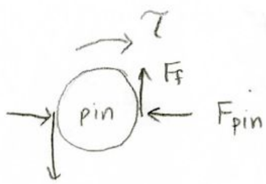






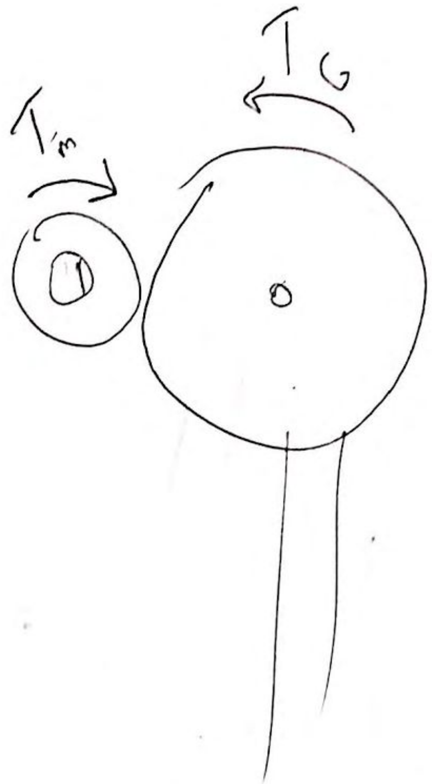
Unifork Pin

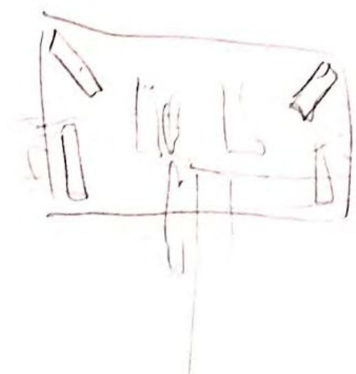


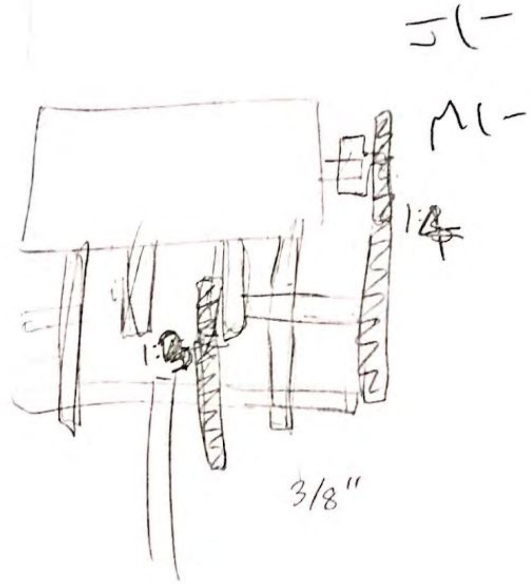


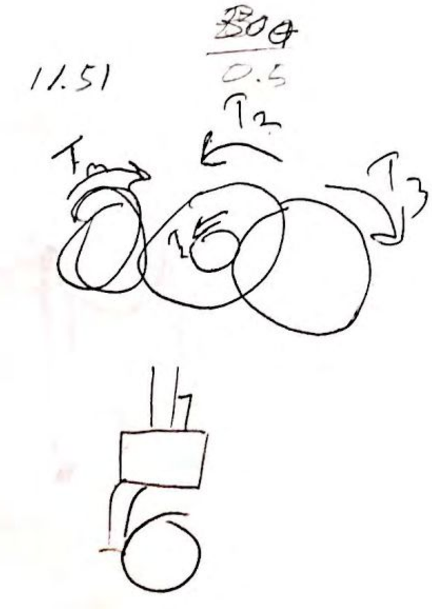
$$\tau = FL = 2F_f r = 2\mu F_{pin} r$$

$$F_{pin} = \frac{FL}{2\mu r}, \quad F_f = \frac{FL}{2r}$$

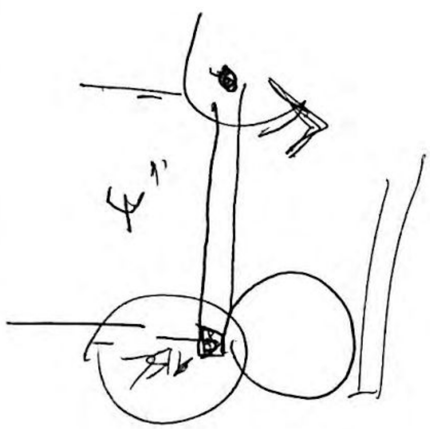

Tm
TG




3/8"

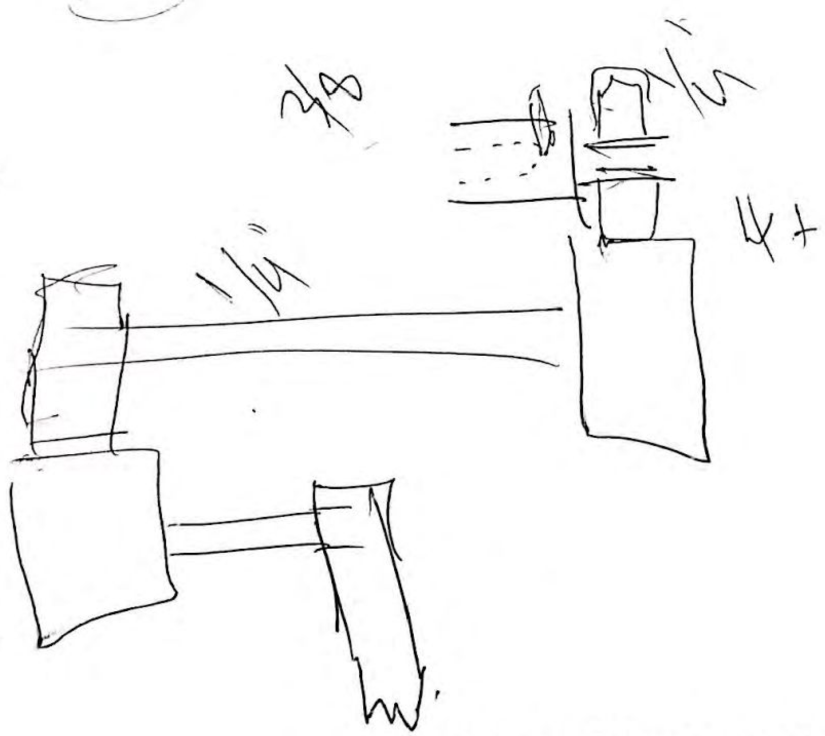

11.51
0.5
T2
Tm
T3

$2^n \quad \frac{4}{1} \quad \frac{3}{1}$



$\frac{4" \times 75\,lbs}{3}$

125 in

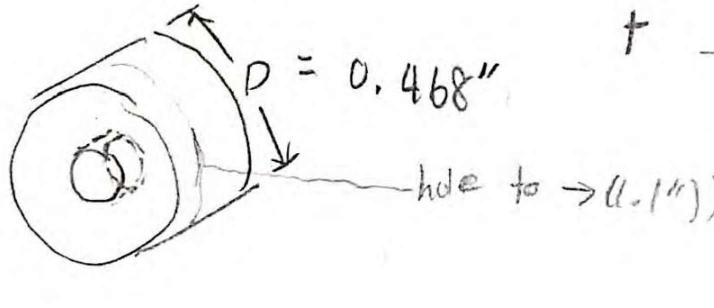


Rubber Hinge

Parameters:

D_i → ((.2"))

t → ((.3"))

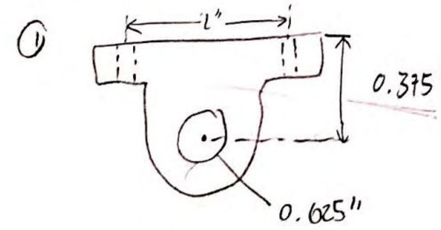


Shaft

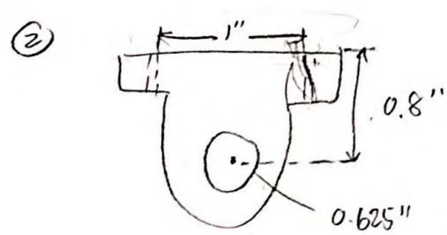
material: steel (1215)

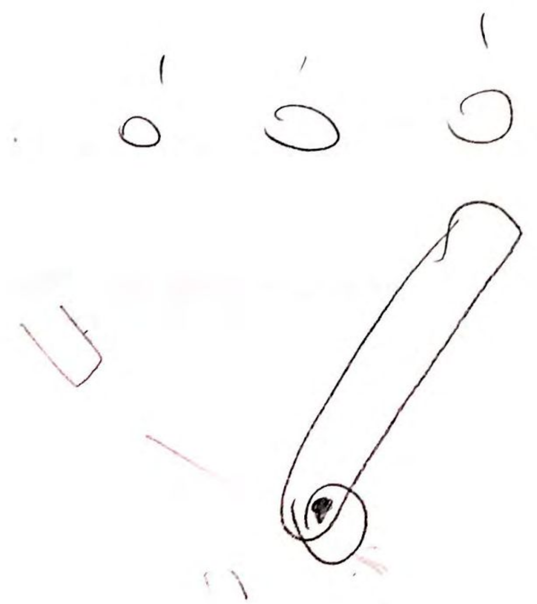
D = 1/4"

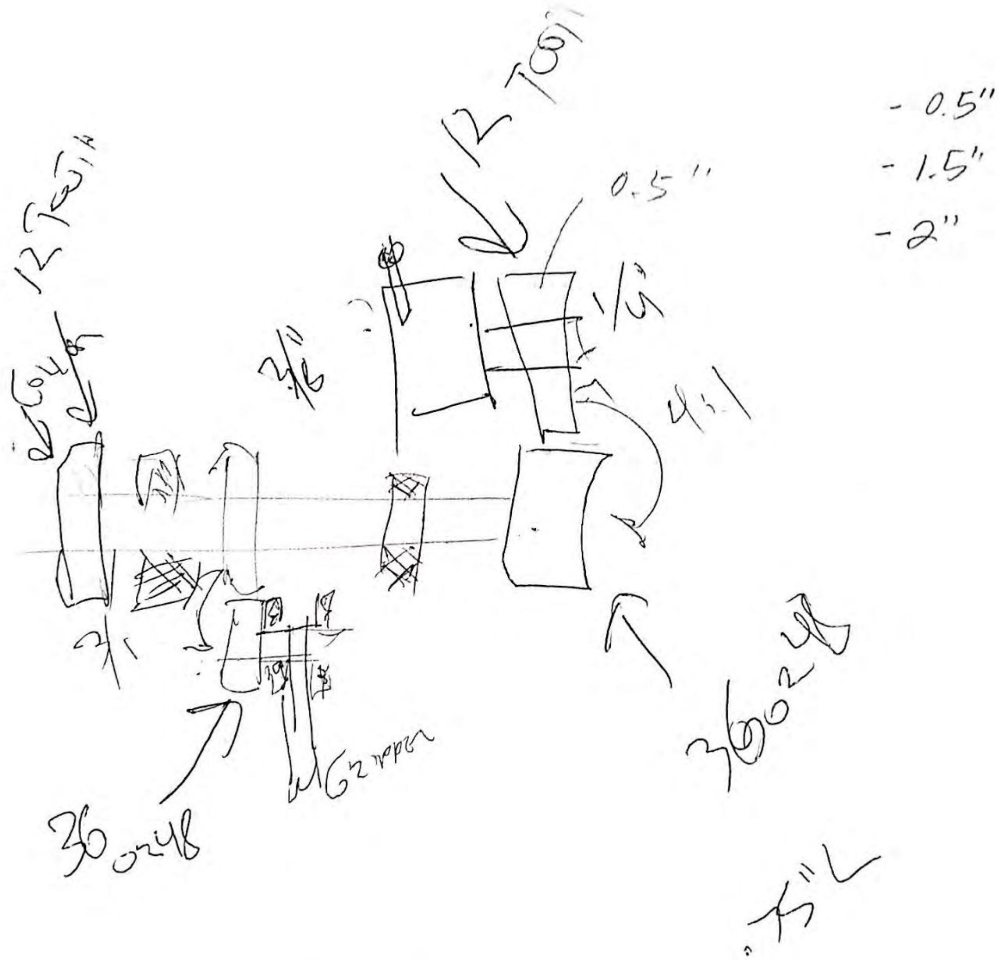
Bearing Housing



t = 0.196''





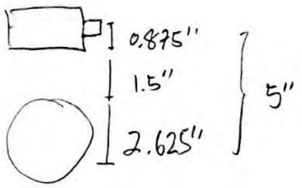


- 0.5"
- 1.5"
- 2"
12 Tooth
12 Tooth
0.5"
4:1
Gripper

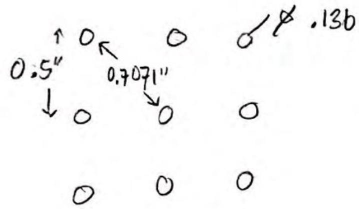
1.3 Nm = 11.51 in lbf = T_i

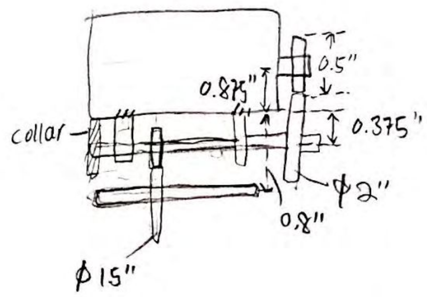
Gear Ratio

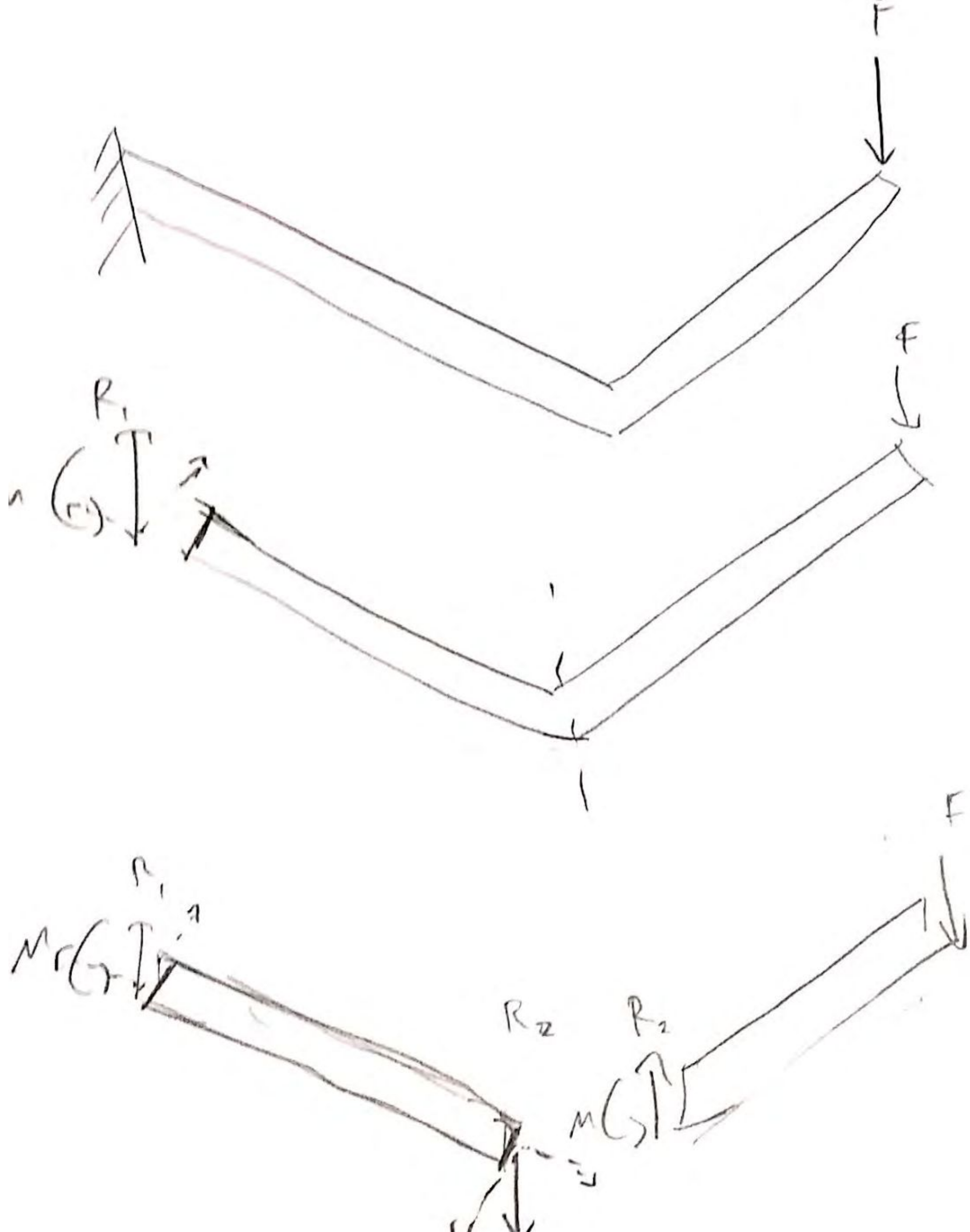
$$\frac{R_o}{R_i} = \frac{T_o}{T_i} = \frac{75(4)/3}{11.5} = \frac{8.7}{1} \Rightarrow$$ approx. about 10:1

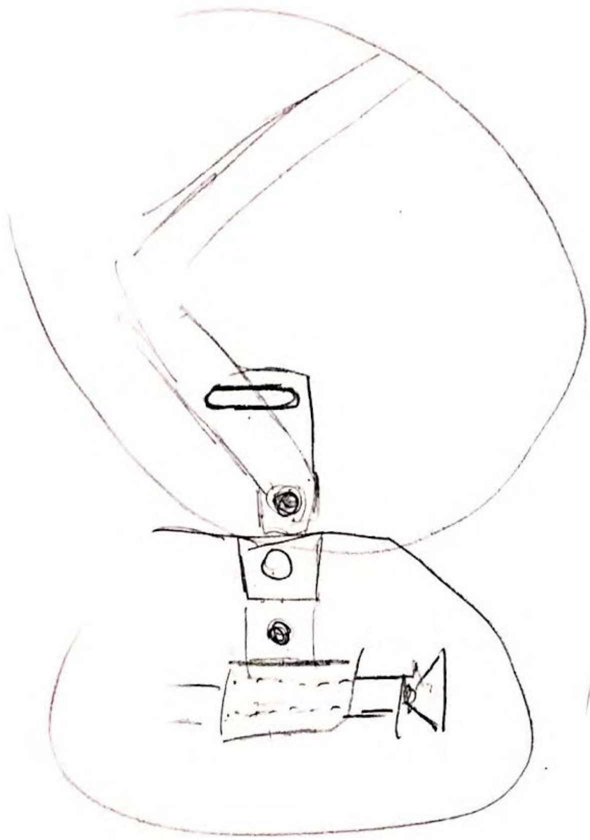


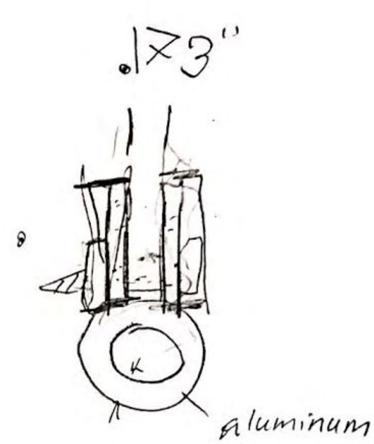
peg distances





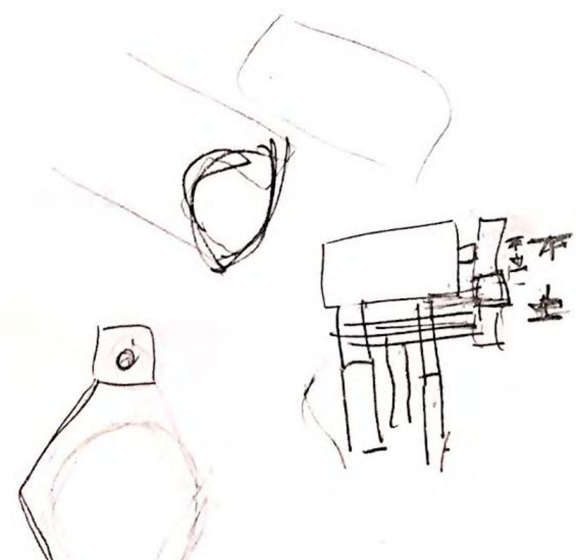

F
F
R_1
F
R_1
R_2
R_2

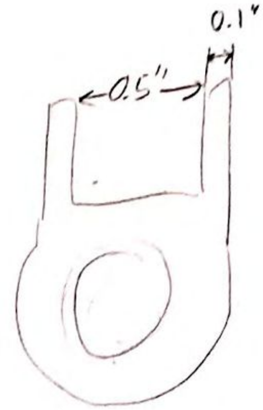


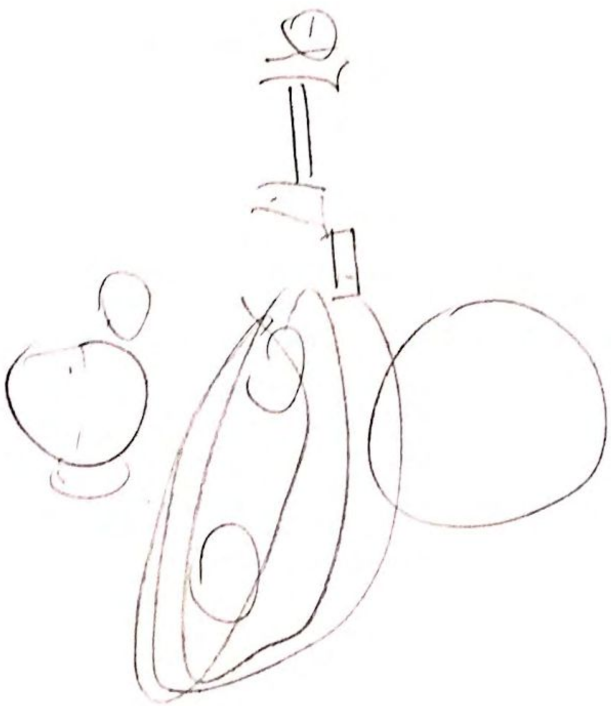


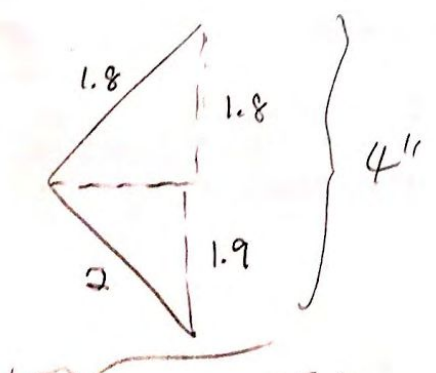
Materials

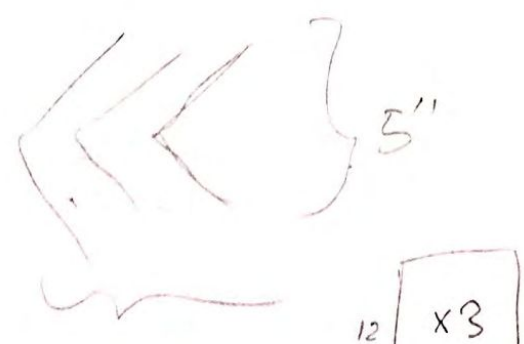
- Acrylic
* rubber
- bolts/nuts
* aluminum
* gears

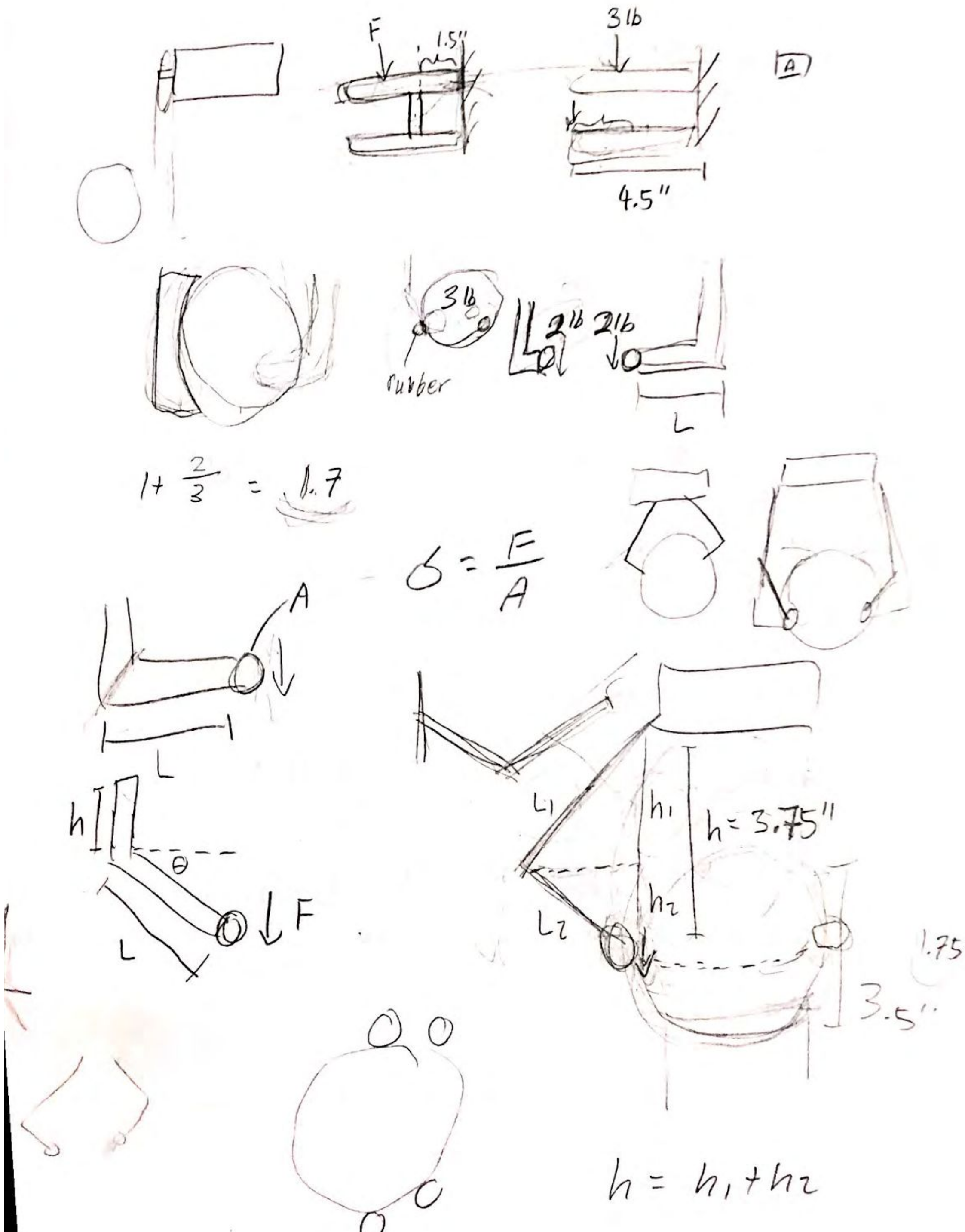


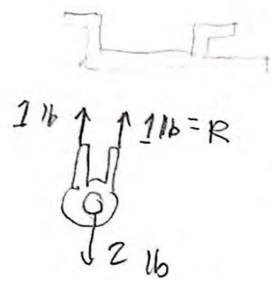

0.1"
0.5"

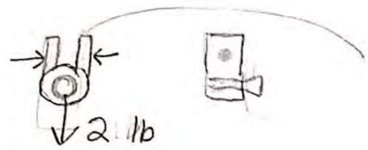



1.8
1.8
4"
2
1.9
0.063 in
2"

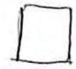

5"
6"
12
x3
12


F
1.5"
3 lb
A
4.5"
3 lb
rubber
2 lb
2 lb
L
1 + 2/3 = 1.7
σ = F/A
A
L
h
θ
F
L
L1
h1
h = 3.75"
L2
h2
1.75
3.5"
h = h1 + h2





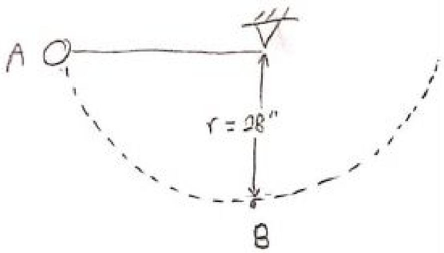
Cross-section



$A = h_2 t$

$$\sigma = \frac{R}{A} = \frac{R}{h_2 t} = FOS \cdot \sigma_y \Rightarrow t = \frac{R}{FOS \cdot \sigma_y h_2}$$

Peak Verical Force



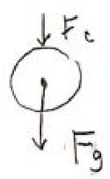
Velocity at bottom of arc, B

$$U_{A\text{-}B} = \Delta V_g + \Delta T = \cancel{mgh_B}^{\,0} - \cancel{m}gh_A + \tfrac{1}{2}\cancel{m}(V_B^2 - \cancel{V_A^2}^{\,0}) = 0$$

$$\Rightarrow V_B = \sqrt{2gr} = \sqrt{2(32.2)(28)(12\ \text{in/ft})}$$

$$= \boxed{147\ \text{in/s}}$$

Force on gripper at B

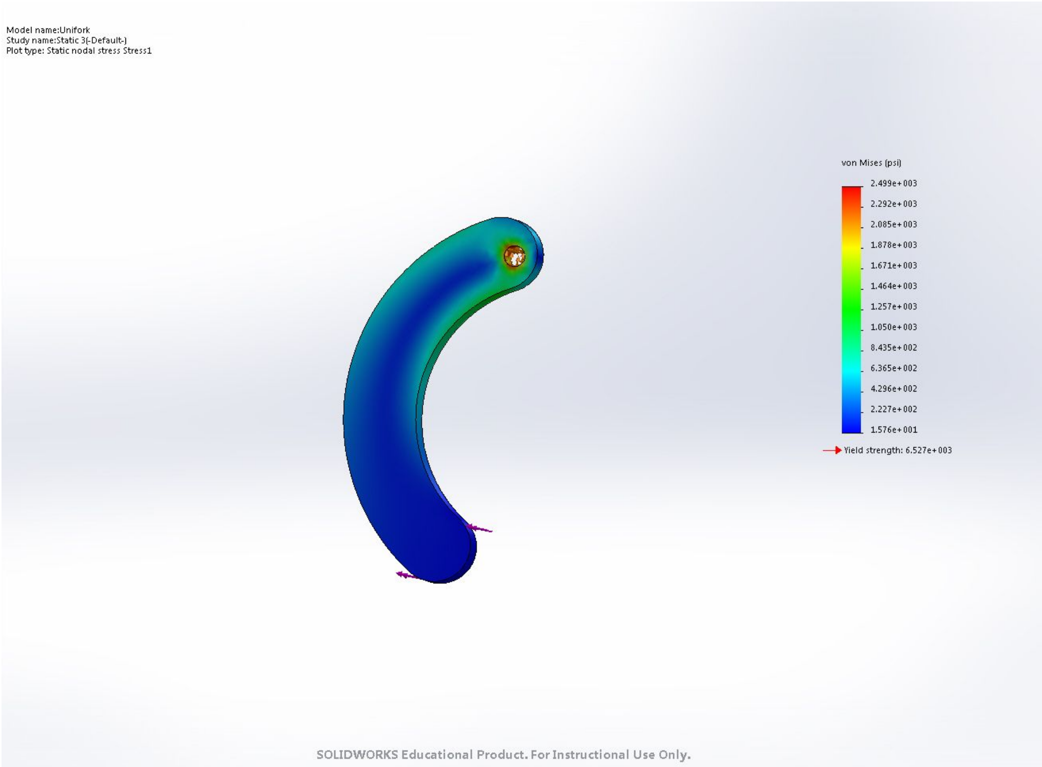


$$F_c = \frac{mV_B^2}{r}, \quad m = F_g/g = \frac{3}{32.2(12)} = 0.00776\ \text{slugs}$$

$$\Sigma F_y = F_c + F_g = \frac{mV_B^2}{r} + F_g$$

$$= \frac{0.00776(147)^2}{28} + 3$$

$$= 8.99\ \text{lb} \approx \boxed{9\ \text{lb}}$$



Model name:Unifork
Study name:Static 3(-Default-)
Plot type: Static nodal stress Stress1
von Mises (psi)
2.499e+003
2.292e+003
2.085e+003
1.878e+003
1.671e+003
1.464e+003
1.257e+003
1.050e+003
8.435e+002
6.365e+002
4.296e+002
2.227e+002
1.576e+001
Yield strength: 6.527e+003
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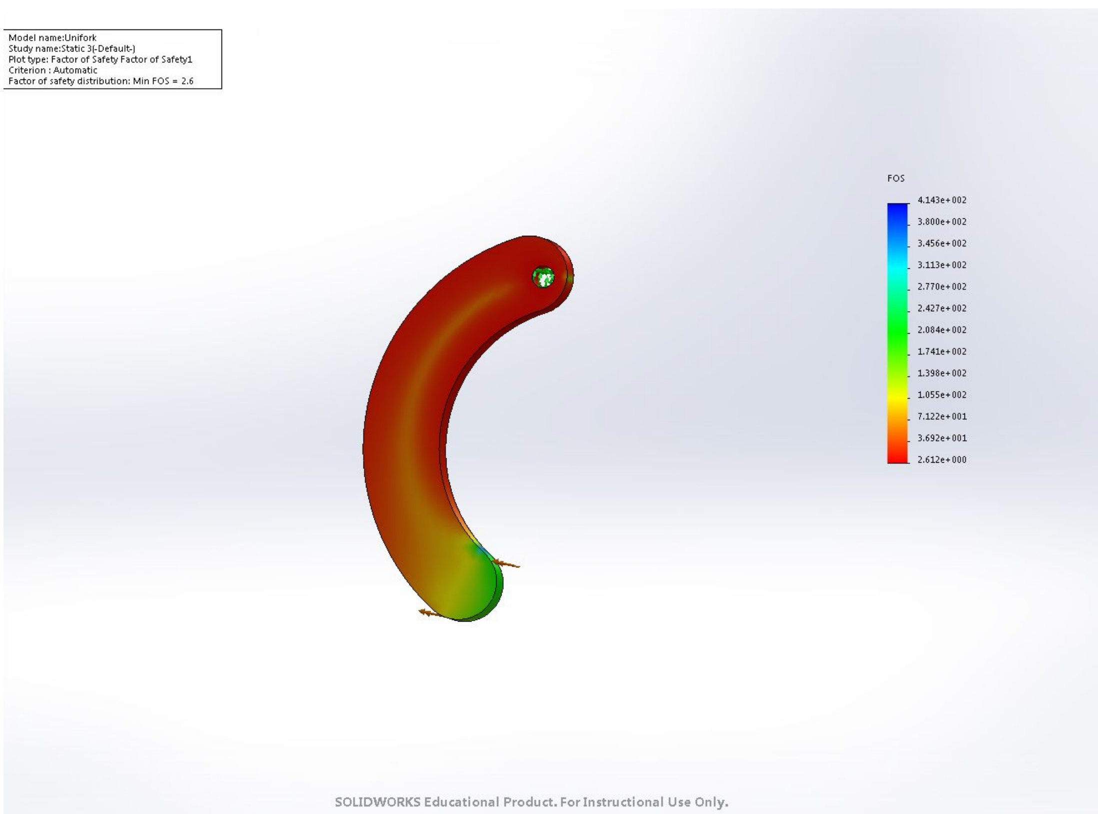

Model name:Unifork
Study name:Static 3(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Automatic
Factor of safety distribution: Min FOS = 2.6
FOS
4.143e+002
3.800e+002
3.456e+002
3.113e+002
2.770e+002
2.427e+002
2.084e+002
1.741e+002
1.398e+002
1.055e+002
7.122e+001
3.692e+001
2.612e+000
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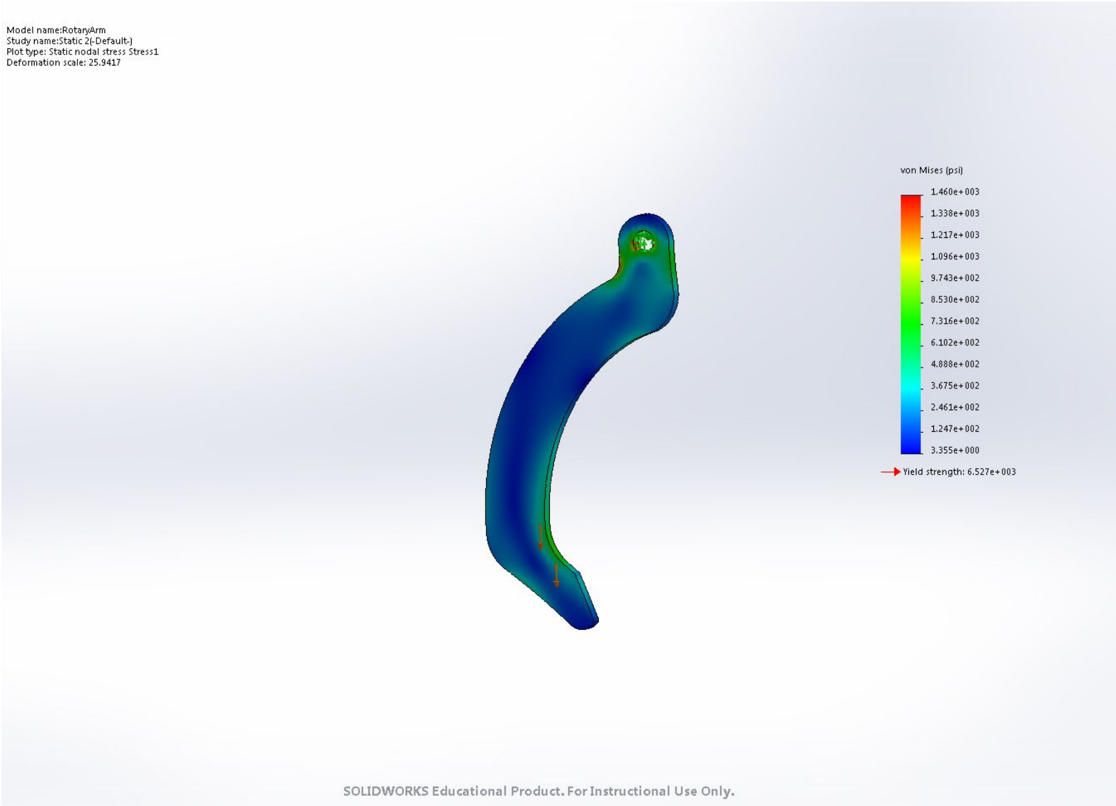
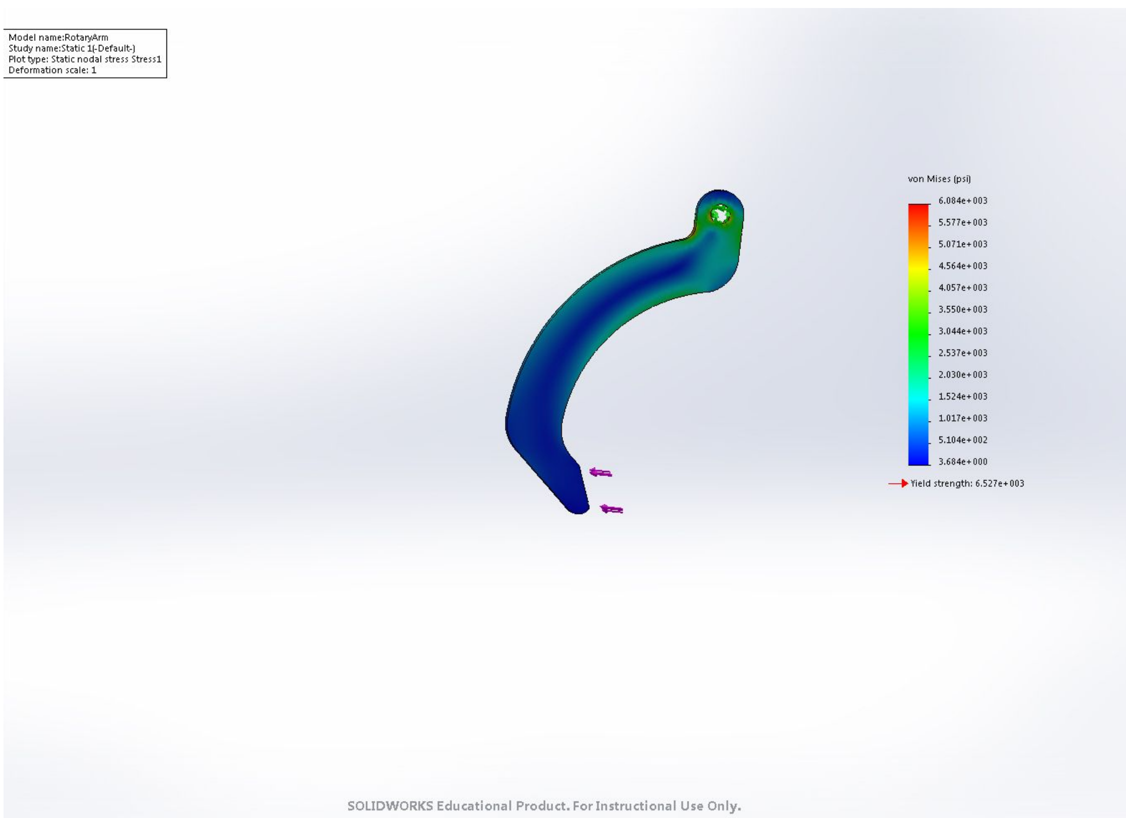
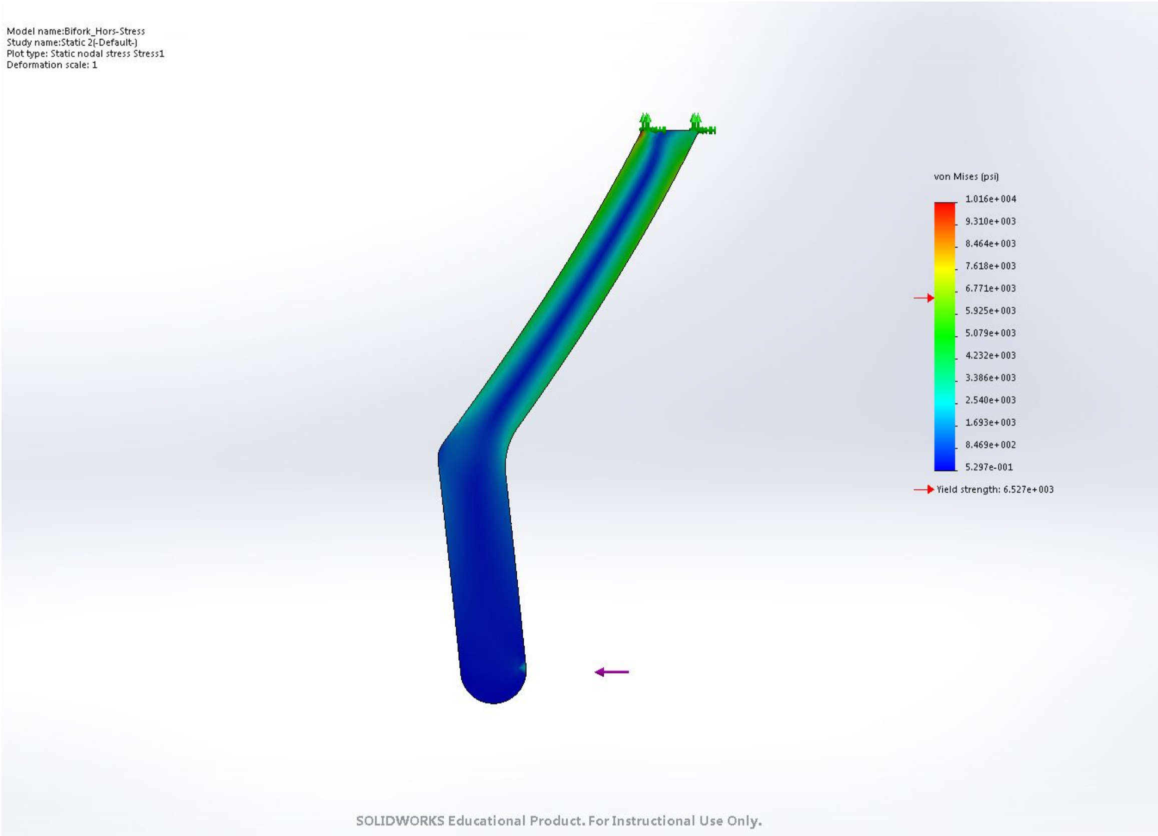
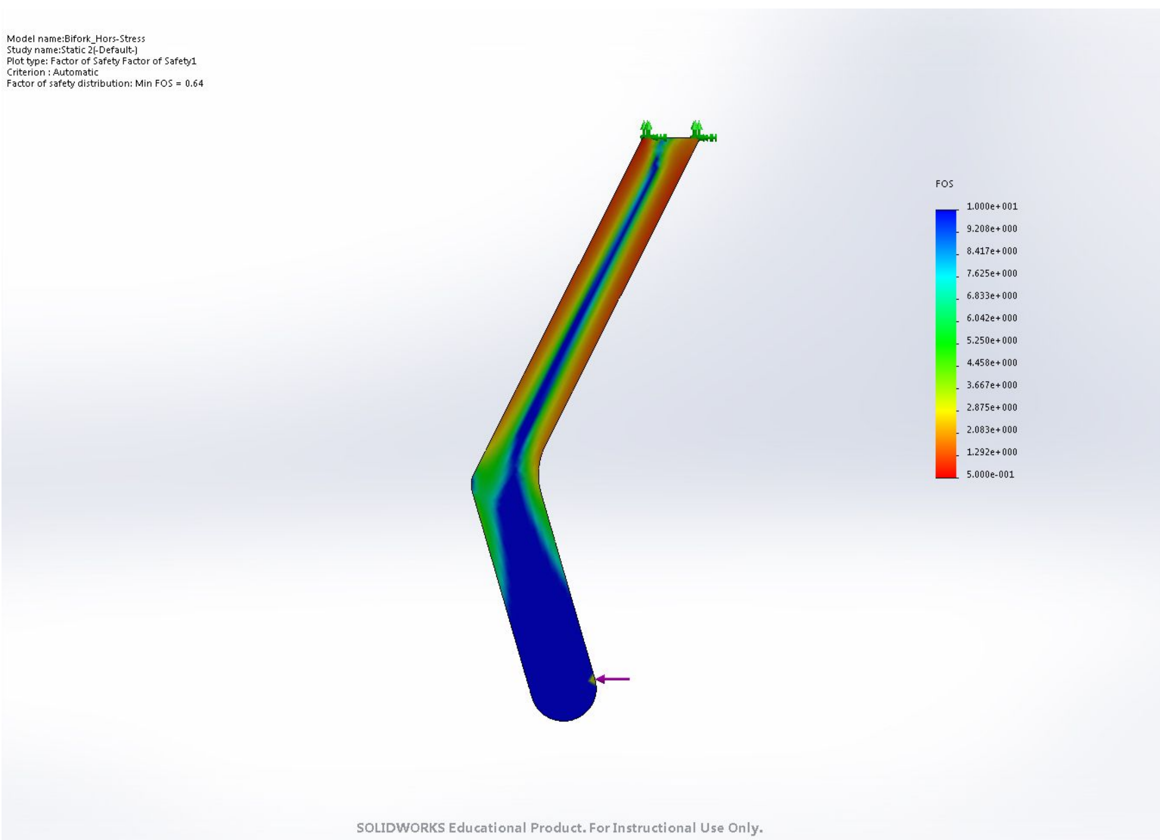

Model name:RotaryArm
Study name:Static 2(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 25.9417
von Mises (psi)
1.460e+003
1.338e+003
1.217e+003
1.096e+003
9.743e+002
8.530e+002
7.316e+002
6.102e+002
4.888e+002
3.675e+002
2.461e+002
1.247e+002
3.355e+000
Yield strength: 6.527e+003
SOLIDWORKS Educational Product. For Instructional Use Only.


Model name:RotaryArm
Study name:Static 1(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 1
von Mises (psi)
6.084e+003
5.577e+003
5.071e+003
4.564e+003
4.057e+003
3.550e+003
3.044e+003
2.537e+003
2.030e+003
1.524e+003
1.017e+003
5.104e+002
3.684e+000
Yield strength: 6.527e+003
SOLIDWORKS Educational Product. For Instructional Use Only.


Model name:Bifork_Hors-Stress
Study name:Static 2(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 1
von Mises (psi)
1.016e+004
9.310e+003
8.464e+003
7.618e+003
6.771e+003
5.925e+003
5.079e+003
4.232e+003
3.386e+003
2.540e+003
1.693e+003
8.469e+002
5.297e-001
Yield strength: 6.527e+003
SOLIDWORKS Educational Product. For Instructional Use Only.


Model name:Bifork_Hors-Stress
Study name:Static 2(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Automatic
Factor of safety distribution: Min FOS = 0.64
FOS
1.000e+001
9.208e+000
8.417e+000
7.625e+000
6.833e+000
6.042e+000
5.250e+000
4.458e+000
3.667e+000
2.875e+000
2.083e+000
1.292e+000
5.000e-001
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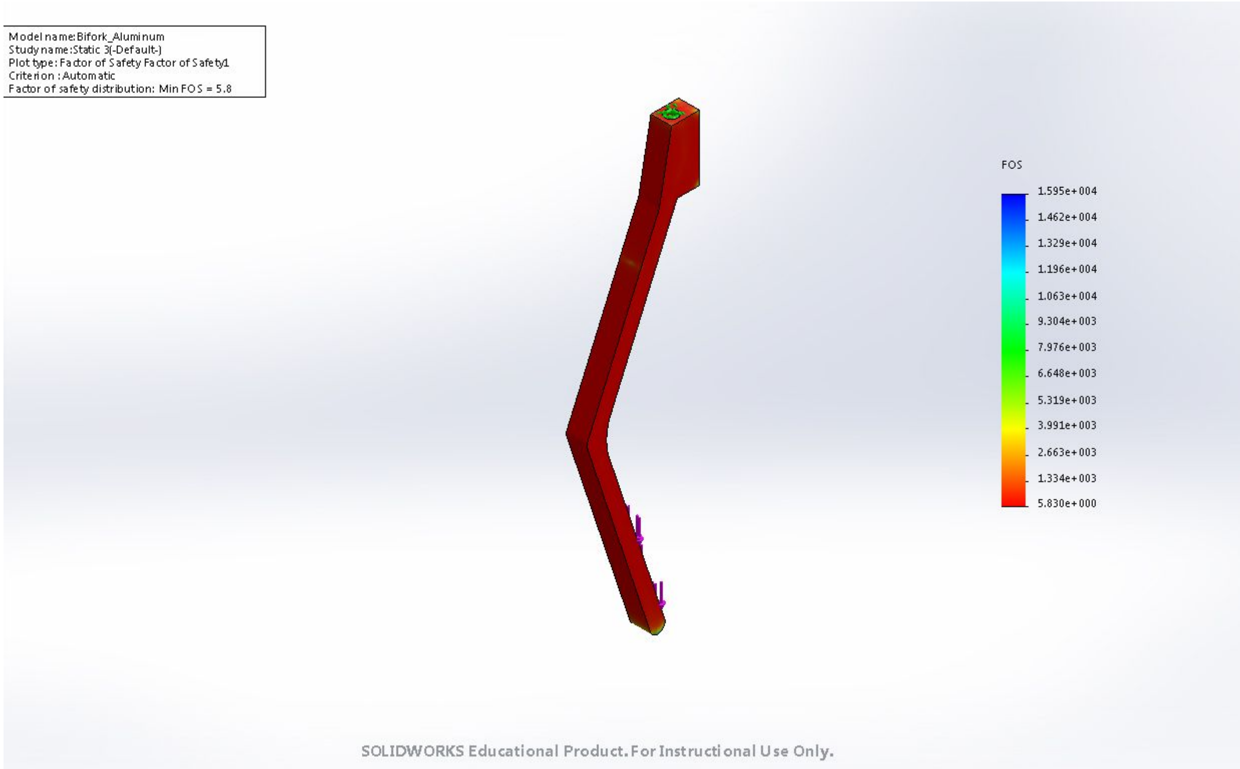
Model name:Bifork_Aluminum
Study name:Static 3(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Automatic
Factor of safety distribution: Min FOS = 5.8
FOS
1.595e+004
1.462e+004
1.329e+004
1.196e+004
1.063e+004
9.304e+003
7.976e+003
6.648e+003
5.319e+003
3.991e+003
2.663e+003
1.334e+003
5.830e+000
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Model name:RotaryArm_Final
Study name:Static 4(-Default-)
Plot type: Factor of Safety Factor of Safety1
Criterion : Automatic
Factor of safety distribution: Min FOS = 2.7
FOS
1.190e+003
1.091e+003
9.925e+002
8.935e+002
7.945e+002
6.956e+002
5.966e+002
4.976e+002
3.986e+002
2.997e+002
2.007e+002
1.017e+002
2.739e+000
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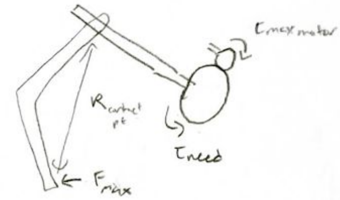
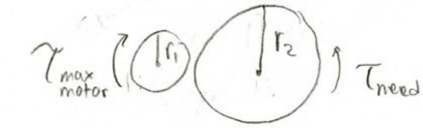
4. Simple Modeling of Candidate Designs



Gear Ratio Calculations

$\tau_{max\ motor} = 1.3 \pm 0.2\ N \cdot m \rightarrow 11.5$ lb-in



need $F_{max} = 9$ lb , $R_{contact\ pt} = 3.065$ in

so need τ applied to shaft to $= F_{max} \cdot R_{contact\ pt}$

$\tau_{need} = F_{max} \cdot R_{contact\ pt} = (9)(3.065) = 27.6$ lb-in

gear ratio $= \frac{\omega_{need}}{\omega_{max\ motor}}$ OR $\frac{\tau_{need}}{\tau_{max\ motor}} \Rightarrow \frac{27.6}{11.5} = 2.4 \Rightarrow 3 = \frac{r_2}{r_1} = \frac{N_2}{N_2}$

ROUND UP

WHICHEVER IS GREATER THAN 1

$N \equiv$ # OF TEETH

FOS With Respect To Dropping Ball

$$\frac{\tau_{actual}}{\tau_{need}} = FOS$$

$$\tau_{actual} = \frac{48}{12} \cdot \tau_{max\ motor}$$

$$\Rightarrow 46 \text{ in-lbs}$$

$$FOS = \frac{46 \text{ in-lbs}}{27.6 \text{ in-lbs}}$$

$$\omega_2 = 48$$

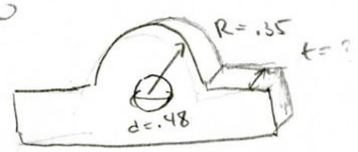
$$\omega_1 = 12$$

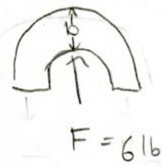
$$= 1.667$$

Bearing Housing - contact stress

$\sigma_y = 10000$

$fos = 5$





$$\sigma_c = \frac{F}{A_c} = \frac{F}{dt}$$

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

① $$fos = \frac{\sigma_y}{\sigma_c} = \frac{\sigma_y d t}{F}$$

$$t > \frac{fos \cdot F}{\sigma_y d} = \frac{5(6)}{10^4(0.48)} = 0.00625''$$

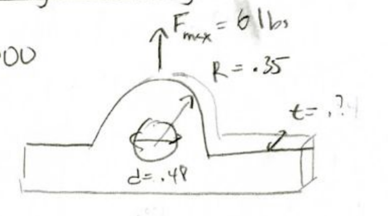
Let $t = 0.25''$

② $$fos = \frac{\sigma_y}{\sigma} = \frac{\sigma_y t b}{F} \Rightarrow b > \frac{fos \cdot F}{\sigma_y t} = \frac{5(6)}{10^4(0.25)} = 0.012''$$

Bearing Housing - stress concentrations

$\sigma_y = 10000$

fos = 5



$\frac{d/2}{2R} = 0.34$, $K = 2.25$

$$\sigma_{max} = K \sigma_{nom}$$

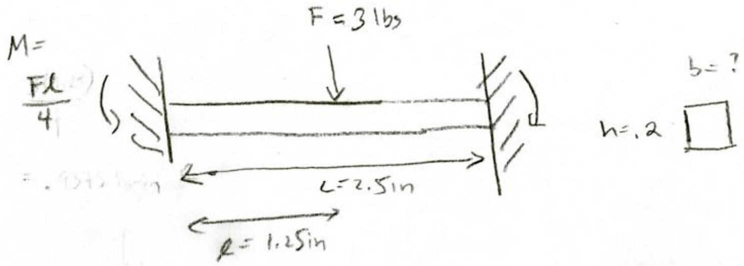
$$\sigma_{max} = K \frac{F}{(2R-d)t}$$

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

$$fos = \frac{\sigma_y}{\frac{KF}{(2R-d)t}} = \frac{\sigma_y (2R-d)t}{KF}$$

$$\Rightarrow t > \frac{K F fos}{\sigma_y (2R-d)} = \frac{2.25(6)(5)}{10^4(2(0.35)-0.48)} = 0.03''$$

Strut- Stress Calculations



$\sigma_y = 10000$

$fos = 9$

$$\sigma_b = \frac{Fl}{4\left(\frac{I}{(h/2)}\right)} = \frac{Fl}{\frac{8I}{h}} = \frac{Flh}{8I} = \frac{Flh}{8\left(\frac{bh^3}{12}\right)} = \frac{Flh}{\frac{2bh^3}{3}}$$

$$= \frac{3Flh}{2bh^3} = \frac{3Fl}{2bh^2}$$

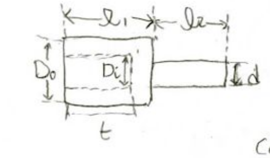
$$fos = \frac{\sigma_y}{\sigma_b} = \frac{\sigma_y}{\left(\frac{3Fl}{2bh^2}\right)} = \frac{\sigma_y 2bh^2}{3Fl}$$

$$\Rightarrow \quad b = \frac{fos\, 3Fl}{\sigma_y 2h^2}$$

$$= \frac{(9)(3)(3)(1.25)}{(10000)(2)(.2)^2}$$

$$= \boxed{0.125\text{ in}}$$

Shaft Reducer



Constrained: fos, D_i, F, d

fos = 5

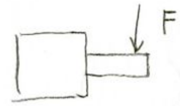
$D_i = 0.385''$

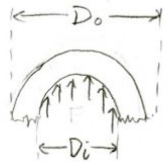
$d = 0.25''$

F = 9 lb

$\sigma_y = 4 \times 10^4$ psi

$l_1 = 0.5''$





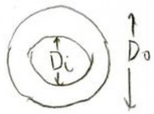
Contact stress

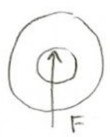
$$\sigma_c = \frac{F}{A} = \frac{F}{D_i t}$$

$$fos = \frac{\sigma_y}{\sigma_c} = \frac{\sigma_y D_i t}{F} \Rightarrow t = \frac{fos \cdot F}{\sigma_y D_i}$$

$$t > \frac{(5)(9)}{4 \cdot 10^4 (0.385)} = 0.003''$$

Determine D_o





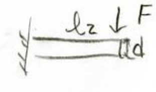
$$\sigma = \frac{F}{A} = \frac{F}{(D_o - D_i) l_1}$$

$$fos = \frac{\sigma_y}{\sigma} = \frac{\sigma_y (D_o - D_i) l_1}{F} \Rightarrow D_o = \frac{fos\, F}{\sigma_y l_1} + D_i$$

$$D_o \geq \frac{5(9)}{4 \cdot 10^4 (0.5)} + 0.385 = 0.38725''$$

Determine l_2

model as cantilever

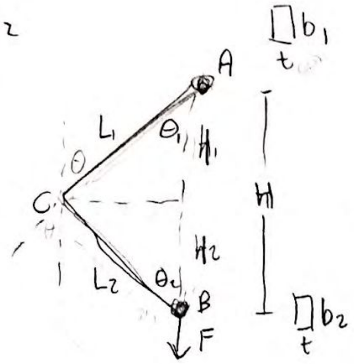


$M = F l_2$, $I = \frac{\pi d^4}{64}$

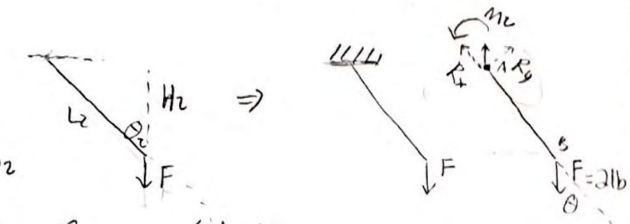
$$\sigma = \frac{My}{I} = \frac{F l_2 d/2 (64)}{\pi d^4} = \frac{F l_2 32}{\pi d^3} \Rightarrow fos = \frac{\sigma_y}{\sigma} = \frac{\sigma_y \pi d^3}{F l_2 32}$$

$$l_2 < \frac{\sigma_y \pi d^3}{F\, fos\, 32} = \frac{4 \cdot 10^4 \pi (0.25)^3}{9(5)32} = 1.36''$$

$h = h_1 + h_2$



Assumptions: - points A & B are Vertical?
- neglect weight



$\sum F_y = R_y - F\sin\theta = 0$

$\Rightarrow$ $R_{y_2} = F\sin\theta_2$

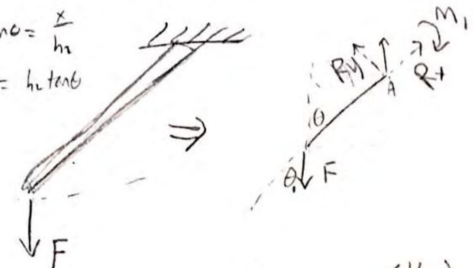
$\sum F_x = R_x - F\cos\theta = 0$

$\Rightarrow$ $R_{x_2} = F\cos\theta_2$

$\theta_2 = \cos^{-1}\left(\frac{H_2}{L_2}\right)$

$\tan\theta = \frac{x}{h_1}$

$x = h_1\tan\theta$



$\theta_1 = \cos^{-1}\left(\frac{H_1}{L_1}\right)$

$\sum F_y = R_y - F\sin\theta = 0$

$\Rightarrow$ $R_{y_1} = F\sin\theta_1$

$\sum F_x = R_x - F\cos\theta = 0$

$\Rightarrow$ $R_{x_1} = F\cos\theta_1$

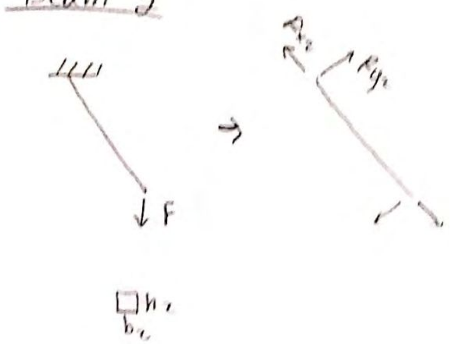
$\sum M_A = 0 = -F\sin\theta(L_1) + M_1$

$\Rightarrow$ $M_1 = FL_1\sin\theta_1$

$\sum M_C = FL_2\sin\theta_2 - M_2 = 0$

$\Rightarrow$ $M_2 = FL_2\sin\theta_2$

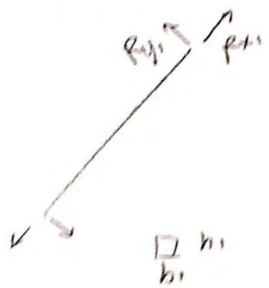
Beam 2



$$\sigma_{b_2} = \frac{M_2 y_2}{I_2} = \frac{12 M_2 \frac{h_2}{2}}{b_2 h_2^3} = \frac{6 F L_2 \sin\theta_2}{b_2 h_2^2}$$

$$\sigma_{T_2} = \frac{F_2}{A_2} = \frac{R_{x_2}}{b_2 h_2} = \frac{F \cos\theta_2}{b_2 h_2}$$

Beam 1



$$\sigma_{b_1} = \frac{M_1 y_1}{I_1} = \frac{12 M_1 \frac{h_1}{2}}{b_1 h_1^3} = \frac{6 F L_1 \sin\theta_1}{b_1 h_1^2}$$

$$\sigma_{T_1} = \frac{F_1}{A_1} = \frac{R_{x_1}}{b_1 h_1} = \frac{F \cos\theta_1}{b_1 h_1}$$

$$fos = \frac{\sigma_y}{\sigma_b} = \frac{\sigma_y b h^2}{6 F L \sin\theta} \Rightarrow \boxed{h = \sqrt{\frac{fos \cdot 6 F L \sin\theta}{\sigma_y b}}}$$

based on bending stress

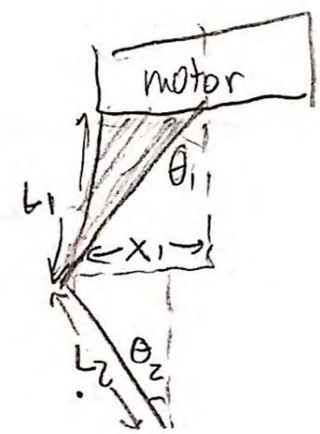
Buckling Analysis

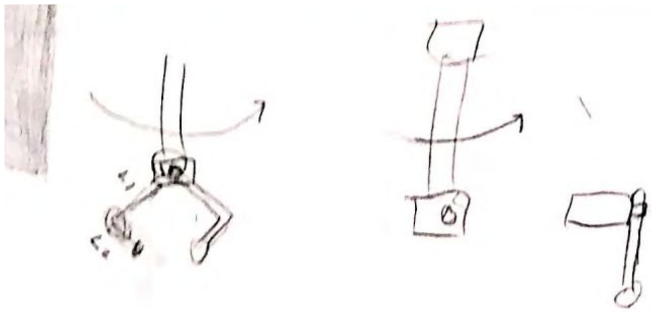
$$I = \frac{bh^3}{12}$$

$$F_{crit} = \frac{C\pi^2 E I}{L^2} = \frac{C\pi^2 E b h^3}{12 L^2} = FOS \times R$$

$$\Rightarrow \quad h = \left(\frac{FOS \times R \times 12 L^2}{C\pi^2 E b} \right)^{1/3}$$

Given θ_2, L_2, solve for L_1



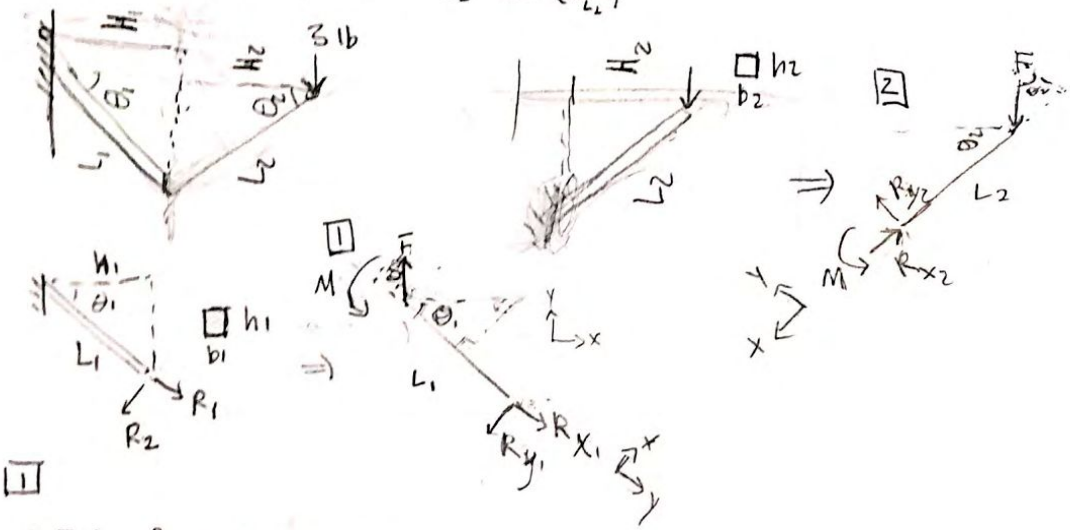


① $\Sigma F_x,\ \Sigma F_y,\ \Sigma M$

② Horizontal position ←

$$\theta_1 = \cos^{-1}\left(\frac{H_1}{L_1}\right)$$

$$\theta_2 = \cos^{-1}\left(\frac{H_2}{L_2}\right)$$



1

$\Sigma F_y: \quad R_y - F\cos\theta_1 = 0$

$\Sigma F_x: \quad F\sin\theta_1 - R_x = 0$

$\Sigma M: \quad M - R_y L_1 = 0$

$\Rightarrow R_{y_1} = F\cos\theta_1$

$\Rightarrow R_{x_1} = F\sin\theta_1$

$\Rightarrow M_1 = R_y L_1$

$= F\cos\theta_1 L_1$

2

$\Sigma F_y: \quad R_y - F\cos\theta_2 = 0$

$\Sigma F_x: \quad F\sin\theta_2 - R_x = 0$

$\Sigma M: \quad M - R_y L_2 = 0$

$\Rightarrow R_{y_2} = F\cos\theta_2$

$\Rightarrow R_{x_2} = F\sin\theta_2$

$\Rightarrow M_2 = R_{y_2} L_2$

$= F\cos\theta_2 L_2$

1

$$\sigma_b = \frac{M_1 y}{I} = \frac{L_1 F \cos\theta_1 \left(\frac{h_1}{2}\right)}{\frac{b_1 (h_1)^3}{12}} = \frac{6 F \cos\theta_1 L_1}{b_1 h_1^2}$$

$$\sigma_T = \frac{R_{y_1}}{A} = \frac{F \sin\theta_1}{b_1 h_1}$$

$$fos = \frac{S_Y}{\sigma_b} = \frac{S_y b_1 h_1^2}{6 F \cos\theta_1 L_1}$$

$$\Rightarrow \boxed{h_1 = \sqrt{\frac{fos\, 6 F \cos\theta_1 L_1}{S_Y b_1}}}$$

$$fos = \frac{S_Y}{\sigma_T} = \frac{S_Y b_1 h_1}{F \sin\theta_1}$$

$$\Rightarrow h_1 = \frac{fos\, F \sin\theta_1}{S_Y b_1}$$

$$m = \rho V = \rho h_1 b_1 L_1$$

2

$$\sigma_b = \frac{M_2 y}{I} = \frac{F \cos\theta_2 L_2 \left(\frac{h_2}{2}\right)}{\frac{b_2 (h_2)^3}{12}} = \frac{6 F \cos\theta_2 L_2}{b_2 h_2^2}$$

$$\sigma_T = \frac{R_{x_2}}{A} = \frac{F \sin\theta_2}{b_2 h_2}$$

$$Fos = \frac{S_Y}{\sigma_b} = \frac{S_Y b_2 h_2^2}{6 F \cos\theta_2}$$

$$\Rightarrow \boxed{h_2 = \sqrt{\frac{fos\, 6 F \cos\theta_2 L_2}{S_Y b_2}}}$$

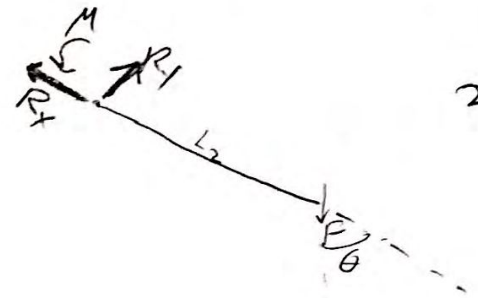
$$Fos = \frac{S_Y}{\sigma_T} = \frac{S_Y b_2 h_2}{F \sin\theta_2}$$

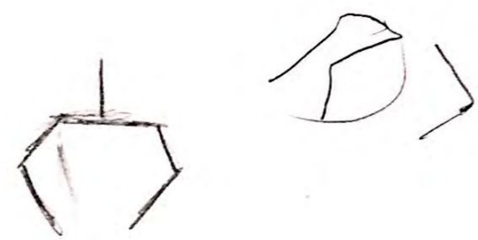
$$\Rightarrow h_2 = \frac{fos\, F \sin\theta_2}{S_Y b_2}$$

$$m = \rho V = \rho h_2 b_2 L_2$$

2b

DA1112





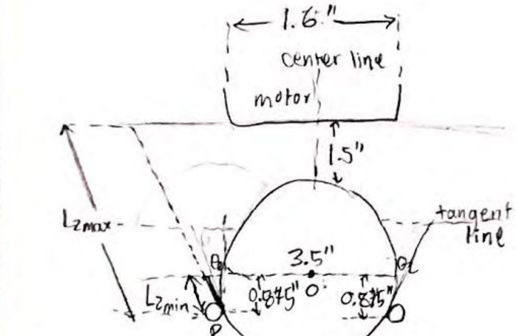
Determine required rubber contact area

Assume circular cross-section

$$\sigma_s = \frac{F}{A} = \frac{F}{\pi r^2}$$

$$FOS = \frac{\sigma_{y\,rubber}}{\sigma_s} = \frac{\sigma_{y\,rubber}\,\pi r^2}{F} \Rightarrow \boxed{r = \sqrt{\frac{F \cdot FOS}{\sigma_{y\,rubber}\,\pi}}}$$

$$m = \rho b h L$$



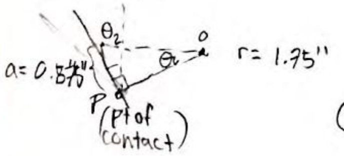
Constraints

① attachment pts of forks should not cross (the center line) & must stay w/ in peggable region of motor

② Angle of lower part (link 2) of fork should be greater than that of tangent from contact pt (to prevent interference w/ ball)

③ Link 2 of fork should extend at least to center level of ball

a = arclength

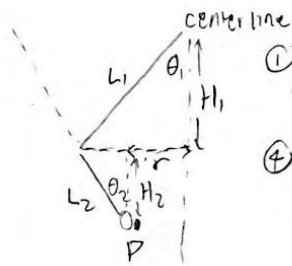


② $\frac{a}{2\pi r} = \frac{\theta_2}{360°} \Rightarrow \theta_2 = \frac{a}{2\pi r}360° = \frac{0.875}{2\pi(1.75)}360° = \boxed{28.6° > \theta_2}$ must be greater than

※ to be safe use 30°

$d = r\sin\theta_2 = 1.75 \sin 30° \approx 0.875"$

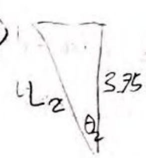
③ $L_{2min} = \frac{d}{\cos\theta_2} = \frac{0.875"}{\cos\theta_2} \Rightarrow \boxed{L_2 > \frac{0.875"}{\cos\theta_2}}$



$r - \frac{1.6}{2} < L_1\sin\theta_1 - L_2\sin\theta_2$

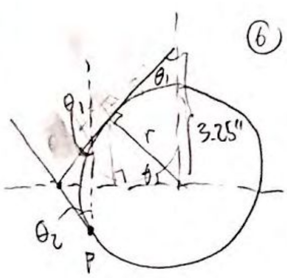
① $\boxed{r > L_1\sin\theta_1 - L_2\sin\theta_2}$

④



$\boxed{L_2 < \frac{3.75"}{\cos\theta_2}}$

⑥ $3.25 < \frac{r}{\sin\theta_1}$



$\theta_1 < \sin^{-1}\left(\frac{r}{3.25}\right) = \sin^{-1}\left(\frac{1.75}{3.25}\right)$

$\boxed{\theta_1 < 32.6°}$ ※ to be safe use 30°

Constraints continued

④ link 2 of fork should not extend beyond motor

⑤ $\boxed{\theta_2 < 90°,\ \theta_1 > 0°}$

⑥ Link 1 (top half) of fork should not interfere w/ ball

⑦ Links 1 & 2 of fork should be limited to less than 4" (for the purpose of Matlab calculation and efficiency)

$\boxed{L_1 < 4",\ L_2 < 4"}$

Summary

$0 < \theta_1 < 30°$

$18° < \theta_2 < 90°$

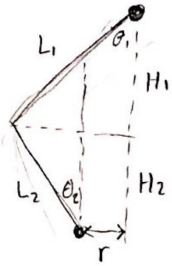
$\frac{0.875"}{\cos\theta_2} < L_2 < \frac{3.75"}{\cos\theta_2}$

$L_1 < 4",\ L_2 < 4"$

$L_1 > \frac{r - 1.6 + L_2\sin\theta_2}{\sin\theta_1}$

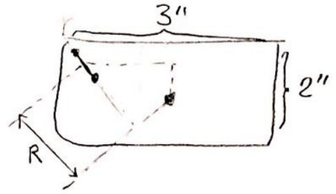
$r > L_1\sin\theta_1 - L_2\sin\theta_2 \Rightarrow L_1 < \frac{r + L_2\sin\theta_2}{\sin\theta_1}$

Redimensionalize Based on Set Up Constraints



Constraints

h_1 = (thickness of top link) = 0.5" ?



R = 1"

$$\Rightarrow r = \left(\frac{0.35}{2}\right)\frac{3}{4} - R = 0.3125"$$

$$L = \frac{S_y b h^2}{6 F \text{ fos} \sin\theta}$$

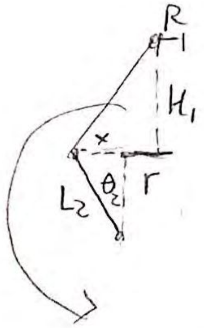
$$L_1 \sin\theta_1 - L_2 \sin\theta_2 = r$$

$$\Rightarrow \frac{S_y b h_1^2}{6 F \text{ fos}} - \frac{S_y b h_2^2}{6 F \text{ fos}} = r$$

$$\Rightarrow \boxed{h_2 = \sqrt{\left(\frac{S_y b h_1^2}{6 F \text{fos}} - r\right)\frac{6 F \text{ fos}}{S_y b}}}$$

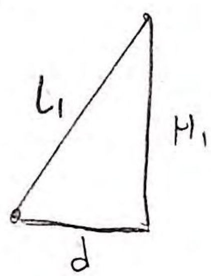
$$H_1 + H_2 = L_1 \cos\theta_1 + L_2 \cos\theta_2 = 3.25"$$

Upper Link



$r = 0.875''$

$R = 0.5''$



$$d = x + r - R = L_2 \sin\theta_2 + r - R$$

$$L_1 = \sqrt{d^2 + H_1^2}$$

$K_t = 1 + 2\left(\frac{a}{c}\right)$ FOR CIRCLE accor STRESS CONCENTRATIONS

$\therefore K_t = 3$

FOR BIFORK

FOR GRIPPER ARM

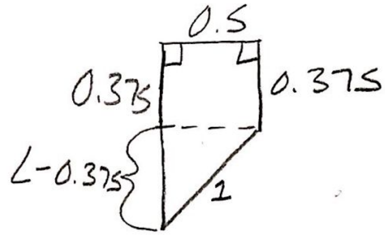
TABLE LOOK UP IN MACHINE DESIGN, NORTON 5TH ED.

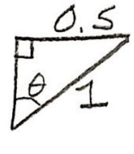
$d = 1/16''$ $W = 1/2''$ $\Rightarrow d/w = 1/8''$

$h = 1/8''$ $\Rightarrow \frac{d}{h} = .5$ $\Rightarrow A = 2.46620$, $b = .77215$

$K_t = Ae^{-b\frac{d}{w}}$

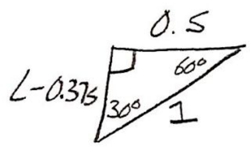
$\Rightarrow K_t = 2.24$





$$\frac{\sin 90^\circ}{1} = \frac{\sin\theta}{0.5}$$

$$\theta = 30^\circ$$

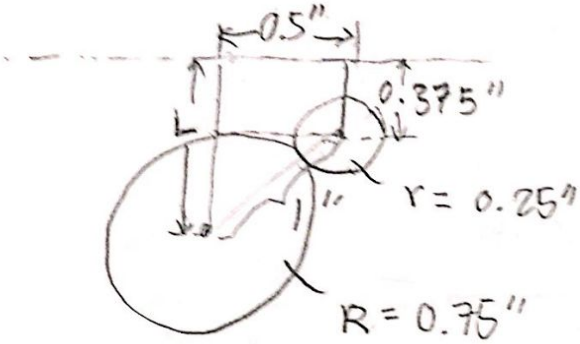


$$\frac{\sin 60^\circ}{L-0.375} = \frac{\sin 90^\circ}{1}$$

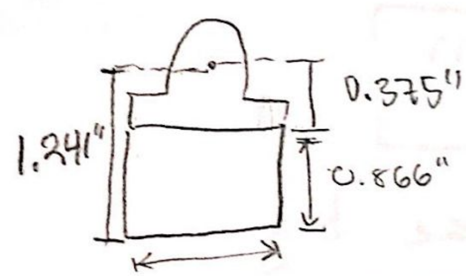
$$L-0.375 = \frac{\sqrt{3}}{2} \rightarrow \boxed{L = 1.24''}$$

Already at height of 0.8'' so must raise by $(1.24-0.8)'' = \underline{0.44''}$

Gear Placement

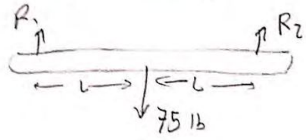


Bearing Housing



↳ CAD estimation → 1.20 in
↳ ruler → 1 7/16" → 1.4375 in

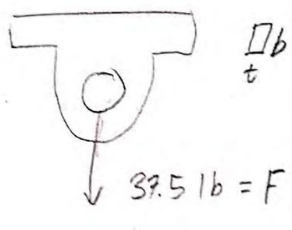
Bearing Housing



$$\Sigma F_y = R_1 + R_2 - 75 = 0 \Rightarrow R_1 + R_2 = 75 \text{ lb}$$

$$\Sigma M = R_2(2L) - 75L = 0 \Rightarrow R_2 = 37.5 \text{ lb}$$

$$R_1 = 75 - R_2 = 37.5 \text{ lb}$$



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

$$fos = \frac{S_y}{\sigma} = \frac{S_y bt}{F} \Rightarrow b = \frac{fos \cdot F}{S_y t} = \frac{5(37.5)}{4 \cdot 10^4(.196)} = 0.02''$$

5. Material Selection

We decided to manufacture our components out of either aluminum or acrylic since they are some of the most common materials available. From the material indices calculated on page 65, aluminum has the highest index of 326,410 and acrylic has the lowest index of 44,958. We used aluminum for components that require high performances and acrylic for components that don't require high performance to reduce mass.

Acrylic Strut:

Since the acrylic strut was a last minute part and does not undergo high stresses, we chose to laser cut the part out of acrylic that was left over from other parts. The part is designed to simply prevent slight twisting/unscrewing of the bifork.

Bifork:

The stationary supports were machined from aluminum after joining difficulties with laser cut acrylic parts. These were machined by a friend of a group member, with CNC machining ability, from scrap aluminum. Aluminum was selected as it has the highest material index and is a low mass metal but capable of being threaded to receive a screw to allow for easy attachment.

Unifork:

Acrylic for the gripper was selected due to its ease of laser cutting for the organic curve and do to a lack of CNC machining ability for the team. The material is low cost allowing for several prototypes.

Shaft Reducer:

The shaft reducer was based off a steel purchased design but was later machined in aluminum. This saved weight due to aluminum's density of 2.7 g/cm^3 versus steel's density of 8.05 g/cm^3. Part geometry is overengineered due to limitations in interfacing with other purchased parts.

Bearing Housing:

Acrylic was also used for the bearing housings, due to a lack of easily sourced properly sized COtS parts, and low mass for a low stress part. Originally we used the aluminum bearing housings that were part of the COtS, to fit our geometry requirements.

6. Detailed Model and Analysis of Final Design

Acrylic Strut:

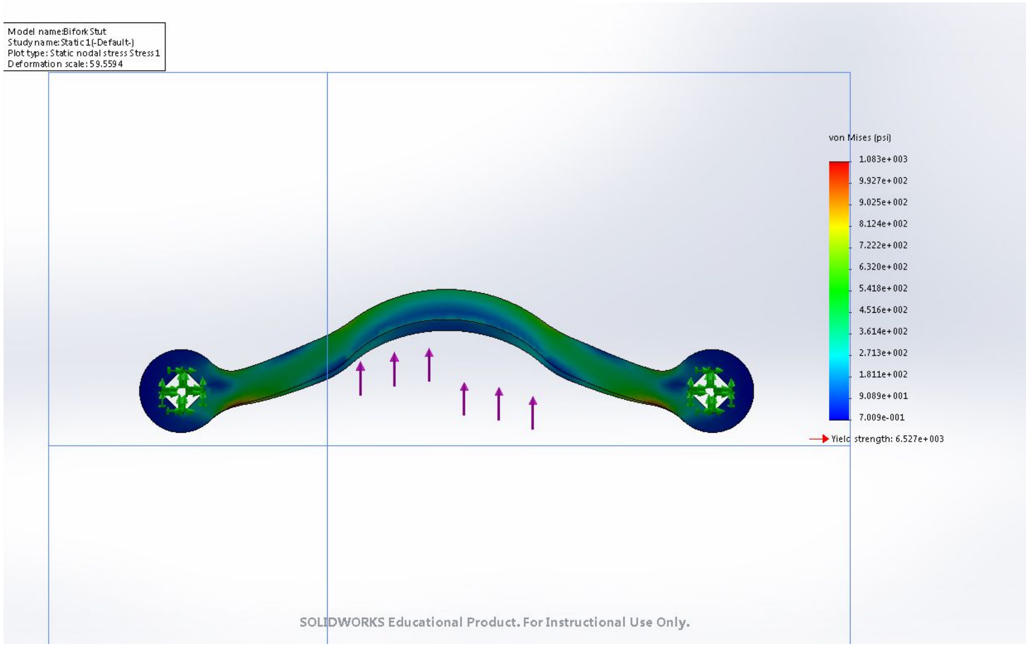
An ⅛ inch thick acrylic strut connects the bifork tines. This strut connection prevents the tines from spreading apart and twisting/unscrewing from the mounting screws. It also increases the factor of safety of the bifork and help keep our pokeball in place by providing an extra contact point.

The general shape of our strut was chosen to contour the spherical shape of the pokeball that it needs to grip. The thickness of our strut was chosen based on hand calculations shown on page 32.

The FEA done on this component involves fixing the regions where it connects with the bifork with "fixed geometry" and applying a force perpendicular to its center region (where it contacts the pokeball), thus simulating peak stress. We approximated the force to be 3 lbf assuming that there are three contact points spreading the 9 lbf peak vertical force between the bifork tines and the strut.

<u>Isometric View</u>

Stress Analysis



Material and Yield Strength: Acrylic, 6526.698195 psi
Component Mass: 2.07 grams

Aluminum Bifork

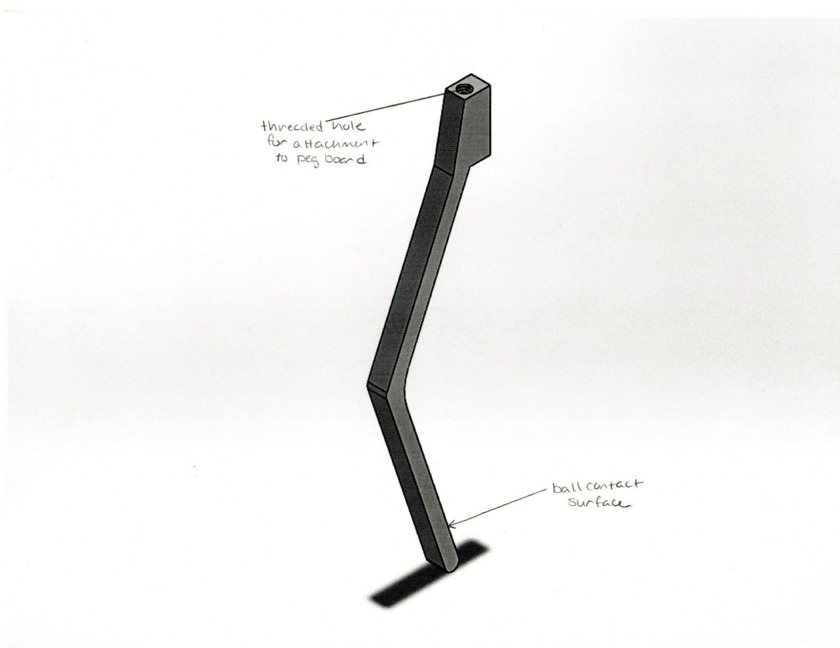
The bifork is made of two individual tines. Its function is to provide a stationary contact to fix the position of the pokeball with respect to the robotic wrist. Initially, we used acrylic to manufacture the bifork, but it required the thickness to be at least ½ inch thick in order to drill #18 size through-hole for the 8/32 screw, which unnecessarily increased the mass. Additionally, the brittle acrylic cracked when it was screwed in too tight. Hence, we changed the material to aluminum. Using aluminum allowed the bifork to be threaded for the screw, which in turn allowed us to use the thinner 4/40 screw. Using 4/40 screw allowed us to design a thinner bifork, which reduced the mass overall.

A strip of non-slip material is attached to the ends of the bifork to increase friction, which prevents slippage on the pokeball.

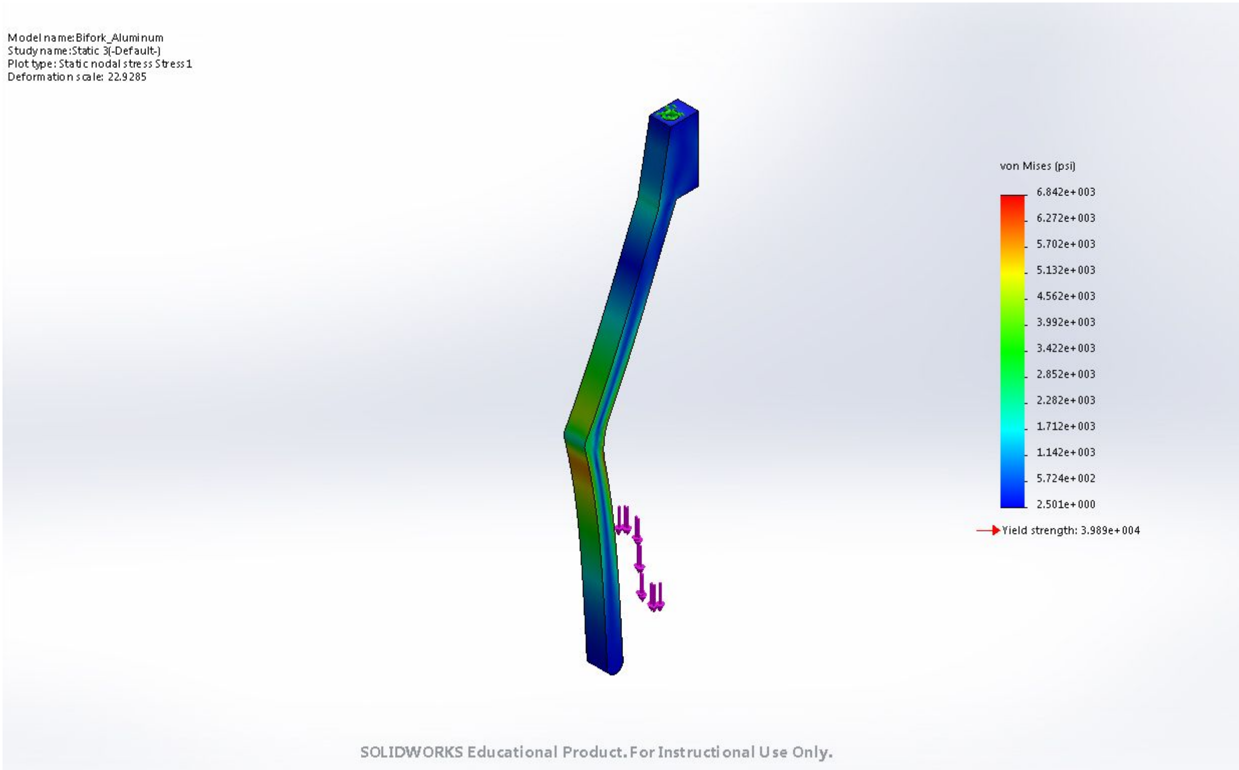
The optimal dimensions of our bifork were calculated on pages 34-42 and using MATLAB for optimization. (Note: This component is 0.05 inch thinner than the calculation due to a manufacturing error during CNC routing) - please reference MATLAB section in "Suporting Notes".

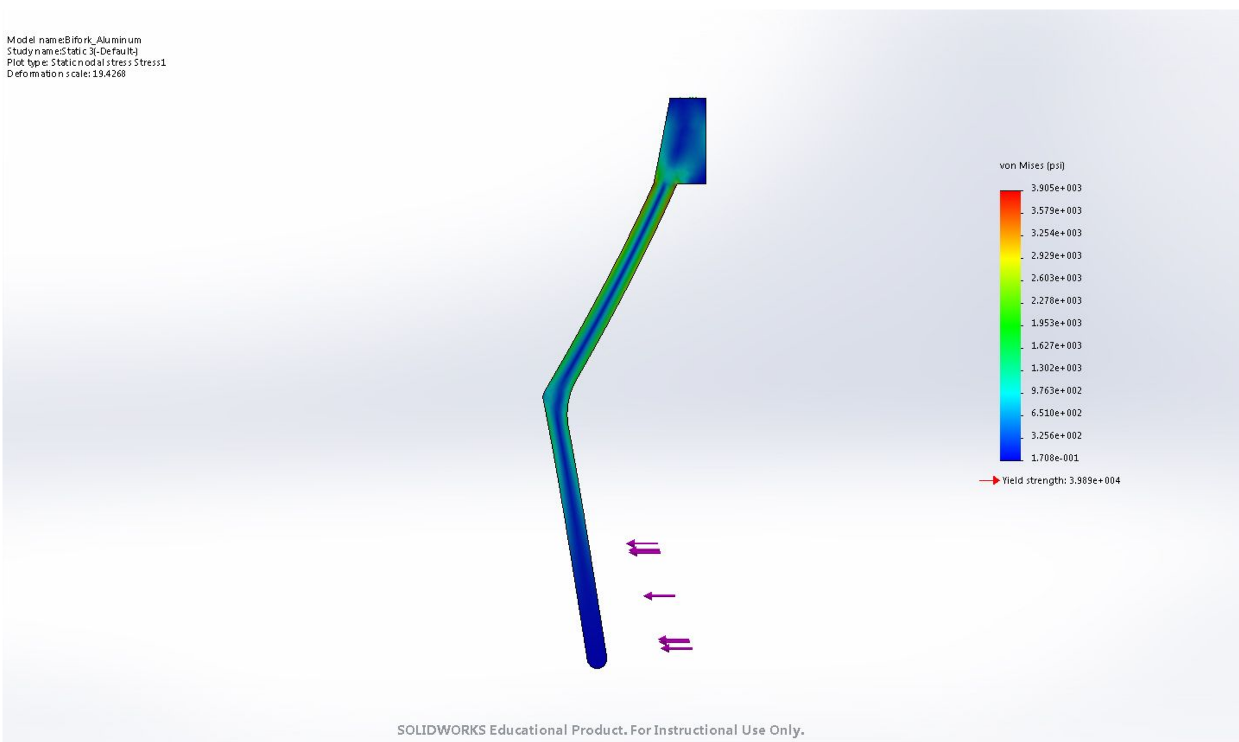
The bifork tine was analyzed in CAD by fixing the threaded hole with "fixed geometry." We ran two simulations for each of the horizontal and vertical arm positions. We used downward force at the contact point of the bifork for vertical arm position and normal force to the surface of the contact plane for horizontal arm position, respectively. We approximated the force to be 9 lbf to account for the fact that one of the tines may not contact with the pokeball due to the offset center of mass while keeping high factor of safety.

<u>Isometric View</u>



Stress Analysis





Material and Yield Strength: 6061 Aluminum, Yield Strength: 275000000.9 psi

Component Mass: 6.8641 grams

Acrylic Unifork:

The function of the unifork in our design is to move and grip the ball when the motor is activated and to keep it pressed against the bifork as the robotic arm experiences dynamic motion.

The acrylic unifork was modified multiple times using CAD and FEA analysis. Further along the design process, the unifork was modified to achieve many goals including: smaller contact area, less weight, better contact angle, and better resistance to fracture. The final design contacts the pokeball at its equator to avoid upward or downward push against the ball.

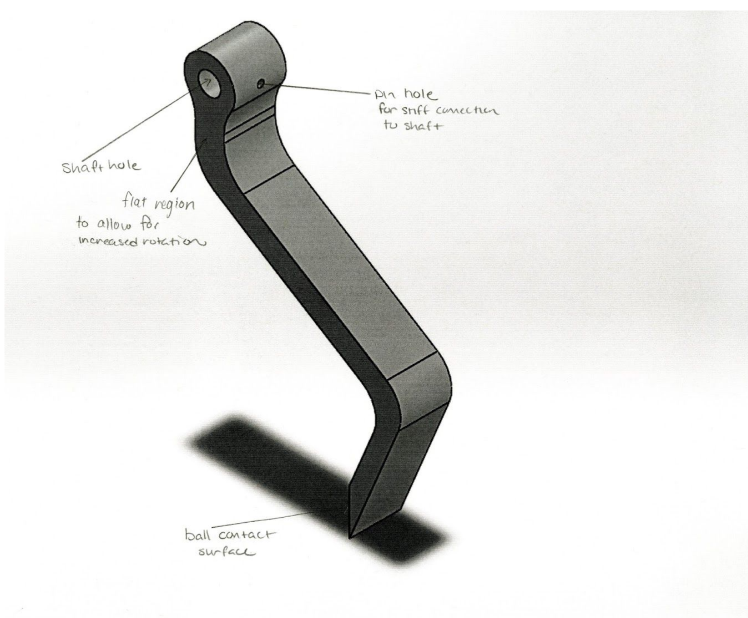
After the first design review, we modified our unifork to a shape that no longer contoured that of the pokeball. We flattened the contact point of the unifork to reduce the contact area, which increases the normal force due to the pokeball, thus maximizing friction.

One issue we had to cope with was that the unifork broke when the motor ran continuously in reverse (ungripping/opening) due to bending stress from contacting the edge of the robotic arm's peg board. This was fixed by adding a radial offset from the axis of rotation which reduced the bending stress by decreasing the length of the lever arm.

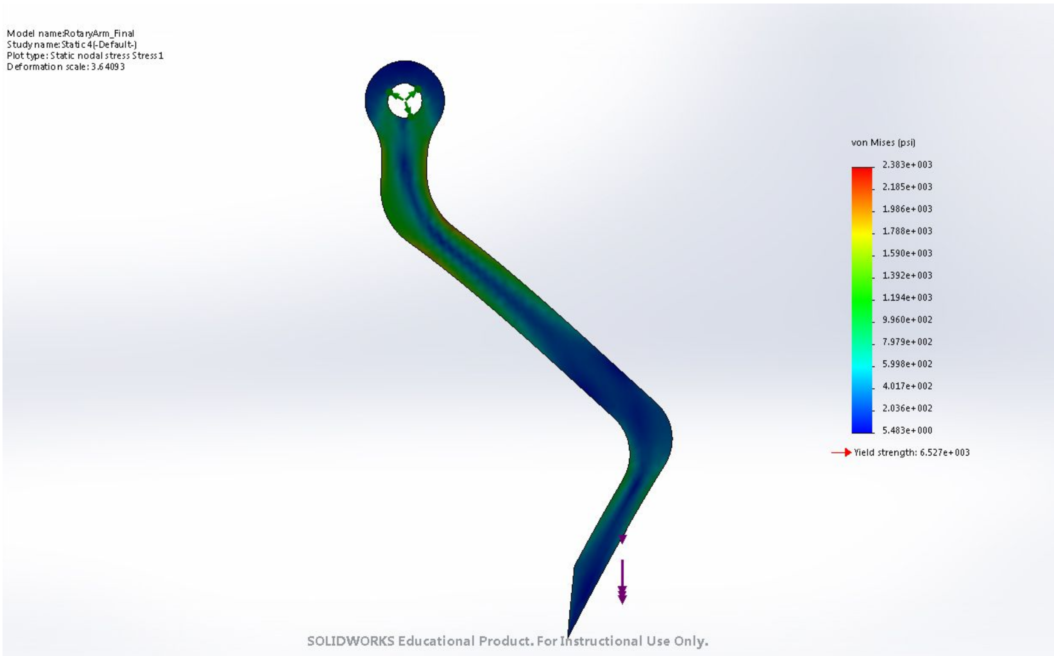
On our second iteration, we used 0.173" acrylic to manufacture the unifork. It was subject to an unexpected bending that caused the part to fail. So we increased the thickness to 0.5" because that was the acrylic we had available.

The FEA simulation analysis and hand calculations are shown below (see below). We fixed the hole of the unifork using "fixed geometry." Similar to bifork, we approximated the force to be 9 lbf to account for the fact that one of the tines may not contact with the pokeball due to the offset center of mass while keeping high factor of safety.

<u>Isometric View</u>



Stress Analysis



Material and Yield Strength: Acrylic, 6526.698195 psi

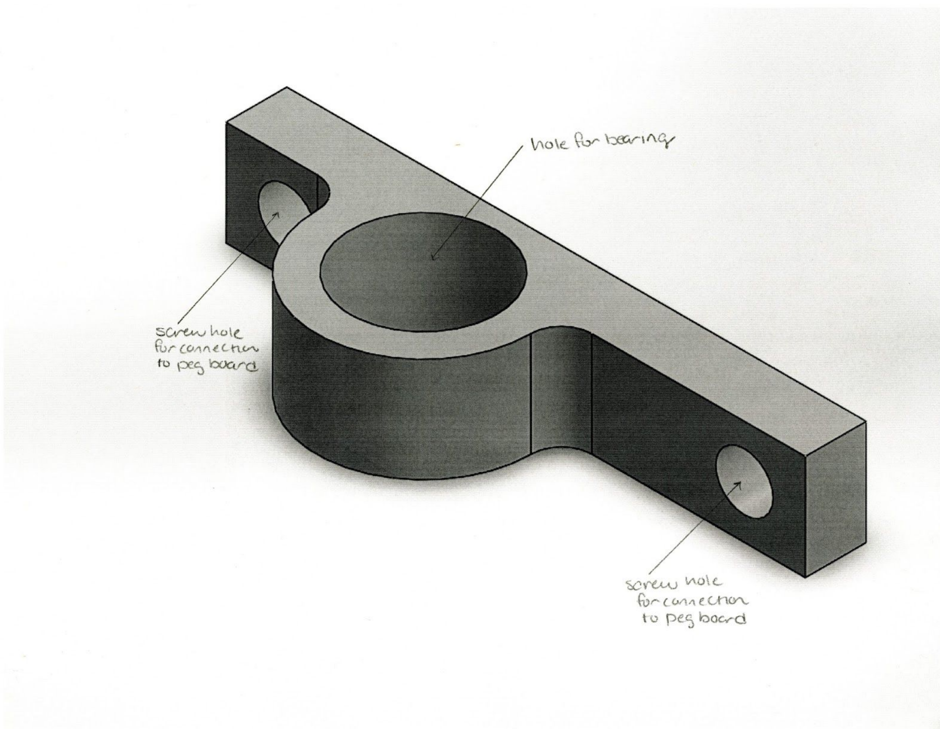
Component Mass: 10.10 grams

Acrylic Bearing Housings:

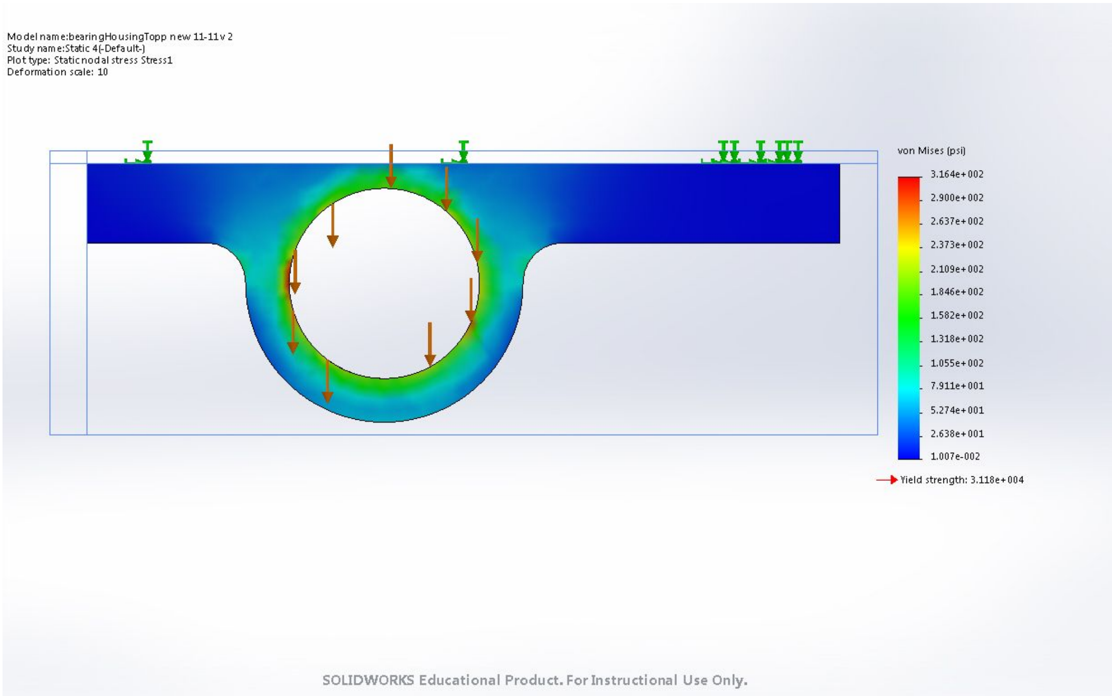
Our design has two individual bearing housings with the same dimensional parameters. The bearing housings are used to hold the ball bearings in place. Through hand calculation, we estimated the required thickness of the housings. In the Solidworks FEA, we fixed the screw holes with "fixed geometry" and then applied a force vertically downward on the bearing housing. We approximated the force to be 3 lbf due to each contact point supporting ⅓ the load.

The designs of the acrylic bearing housings were modified and laser-cut multiple times to meet the parameters of our redesigns and withstand the loadings and potential damage from reconfiguration. The holes were laser-cut under-sized and reamed to press-fit diameters. Please see the CAD profiles and parameters of the bearing housings shown below (see below).

<u>Isometric View</u>



Stress Analysis



Material and Yield Strength: Acrylic, 6526.698195 psi

Component Mass: 6.62 grams

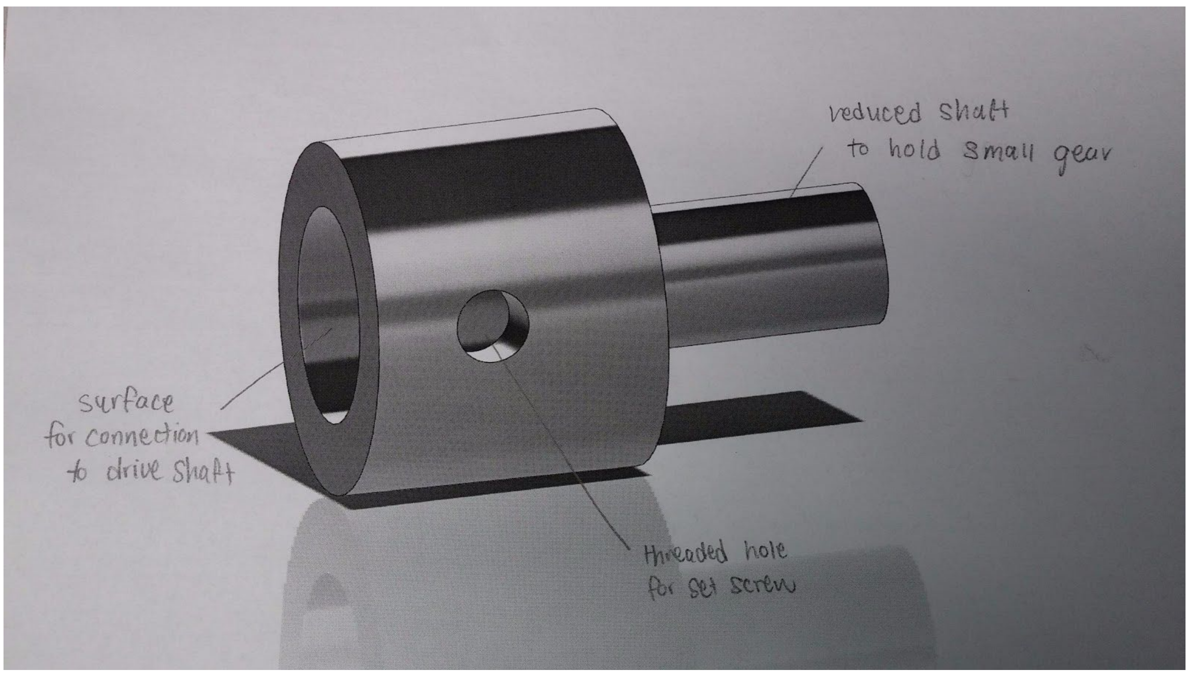
Aluminum shaft reducer:

The purpose of our shaft reducer is to attach a gear with a ¼ inch hole to the motor shaft. The diameter of the motor shaft is too large for the gear.

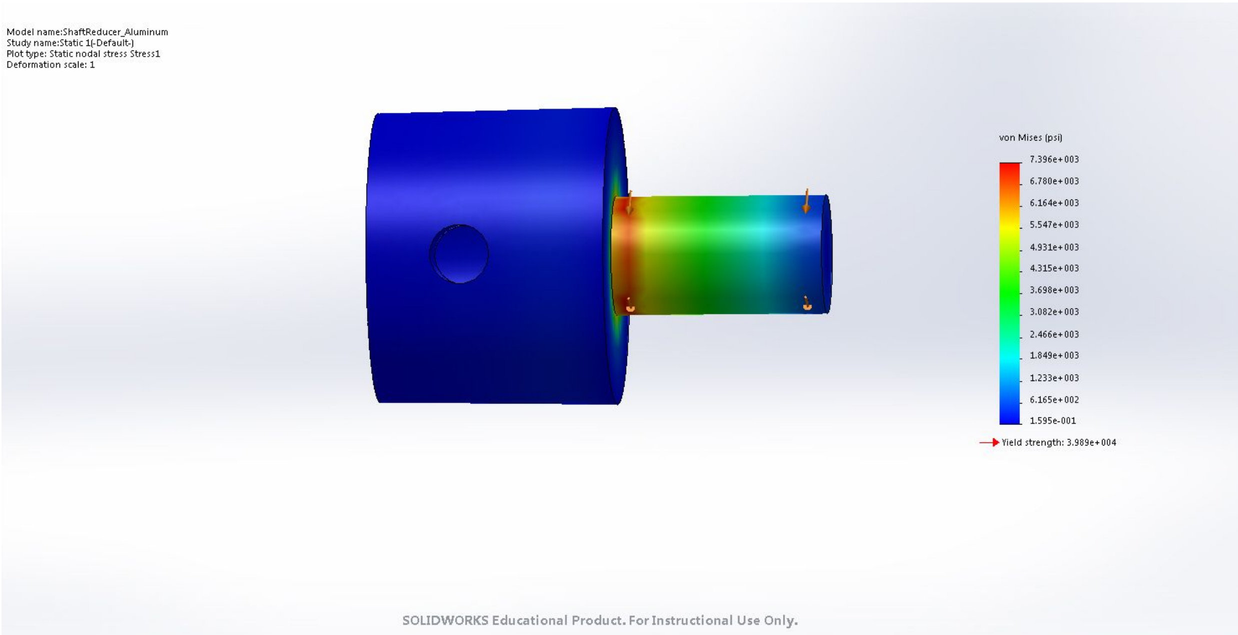
In our first prototype, we used catolog steel shaft reducer. However, for the final design, we manufactured the shaft reducer out of aluminum with the same radial dimensions, but a shorter shaft length. This saved us approximately 5.5 grams in our overall gripper design.

A FEA analysis was done for torsion on this part. The hole where it connects to the motor shaft was fixed with “fixed geometry” and a torsional force (equal to that of the motor) of 1.3 N-m was applied on the shaft reducer in the region where it contacts the attached gear.

<u>Isometric View</u>



Stress Analysis



Material and Yield Strength: 6061 Aluminum, 275000000.9 psi

Component Mass: 5.59 grams

7. Catalog Component Selection

We decided to make our components from either aluminum, steel or acrylic which are some of the most common materials found. From the material indices calculated on page 65, aluminum has the highest index of 326,410 and then steel whose index is 56,381 and then acrylic with an index of 44,958. For most of our small catalog components, such as screws, bearings, and pins, we chose steel since these components required sufficient performance and, although steel is dense, the components' small sizes didn't significantly affect the overall mass.

We purchased steel screws because screws are time consuming to manufacture and we needed large quantity. We chose steel which has the second highest material index because our bifork is aluminum and using aluminum screw could have caused galling, leading to friction welded parts. Aluminum screws are also more expensive.

We purchased washers because they are time consuming to manufacture and we needed large quantity. The washers were useful in increasing the space between the bifork and the peg board and are of a softer material, which allows for greater tolerance in the tension in screw.

We purchased "non slip" Dycem because it would not have been possible for us to manufacture it with the manufacturing tools available. We also picked it because it was an easy way to increase the friction on the gripper.

We purchased the steel pin that attaches the unifork to the shaft because COtS pins are extremely cheap.

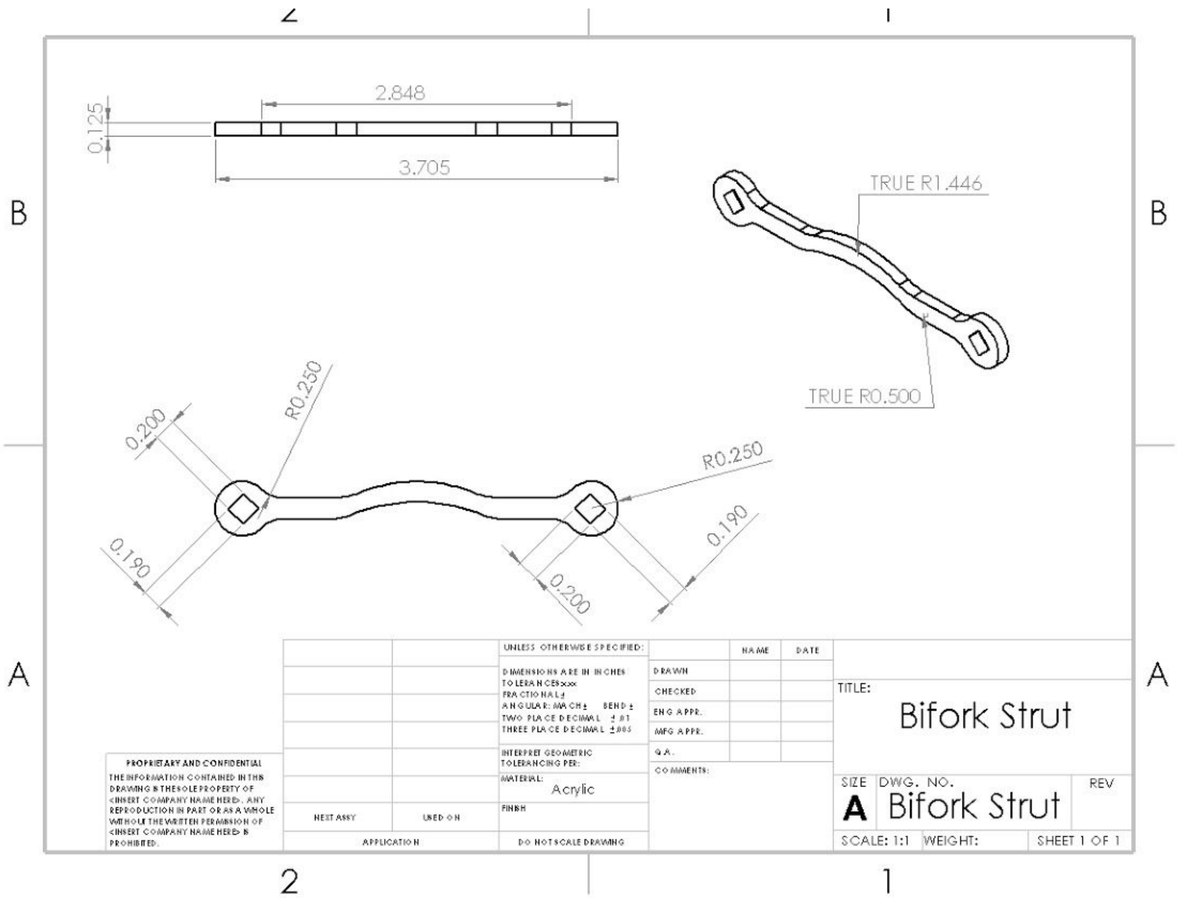
We purchased the steel shaft of ¼" diameter because it was the size that provided the most optimal combination of precision and price. This size shaft was also easy to source appropriately sized gears and bearings for without requiring additional machining. .

We purchased 2 steel ball bearings because they would be impossible to manufacture.

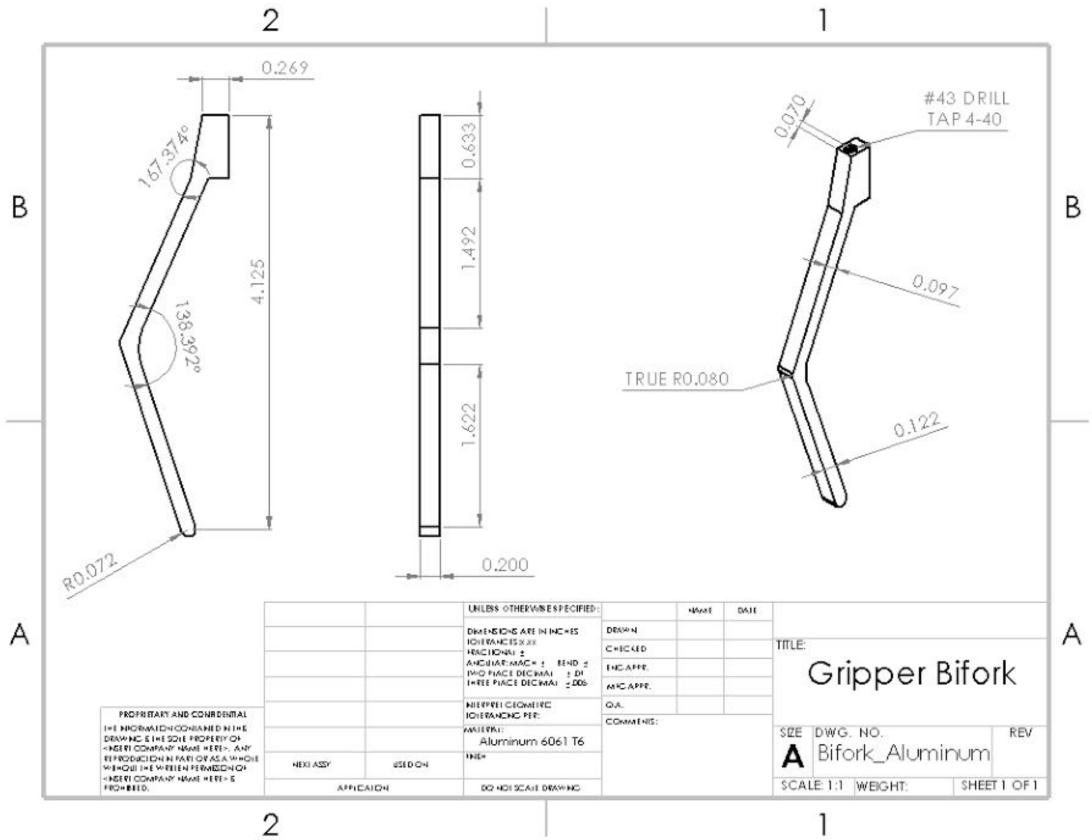
We purchased aluminum gears instead of laser-cutting acrylic gears because acrylic gears have a tendency to have backlash - providing less efficiency. The gears include a small hub. This hub increases the strength of the gear attachments by allowing for the use of a set screw, and potentially a dowel pin/key. It also increases the contact area with the shaft and thus decreasing the stress on the gear. Aluminum was selected for its high density to yield strength ratio, which is required for high performance gears. Aluminums easy machinability also leads to low cost, precision gears, compared to a stronger metal like steel.

8. Engineering Drawings

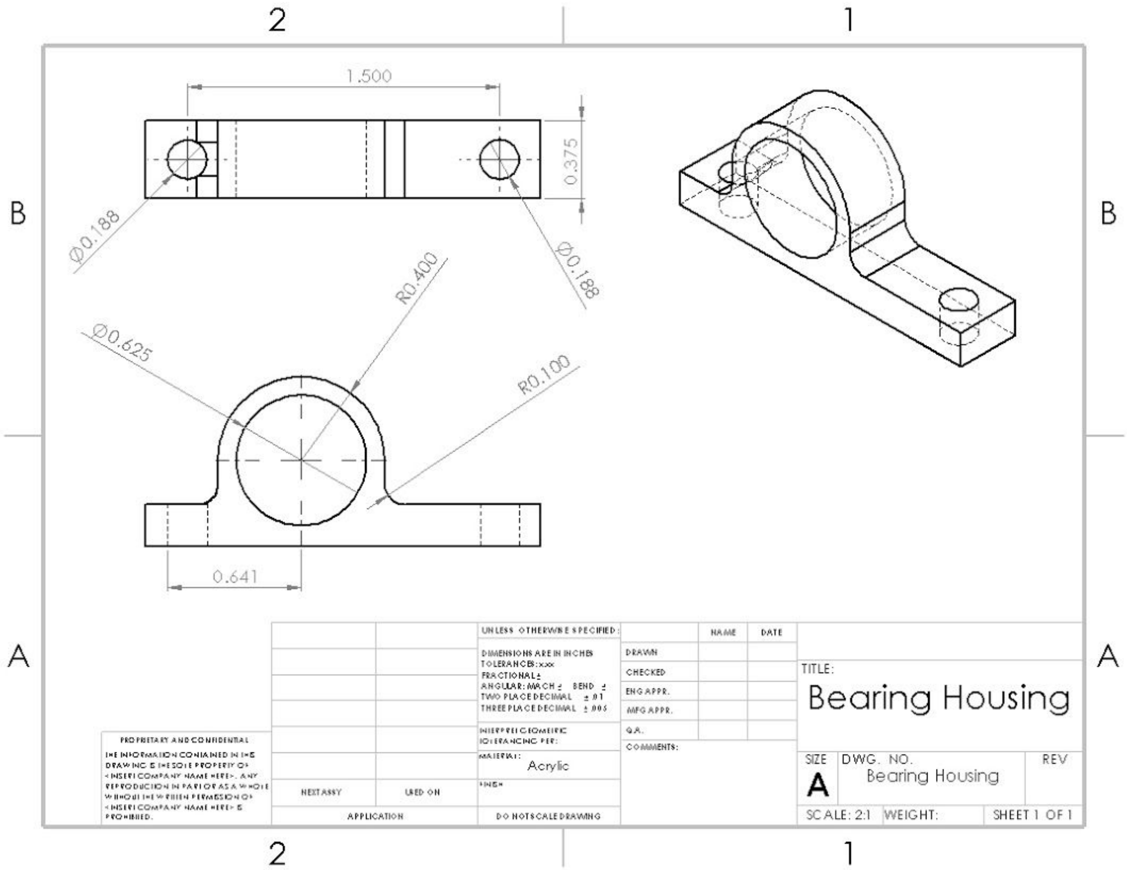
- <u>Acrylic Strut</u>



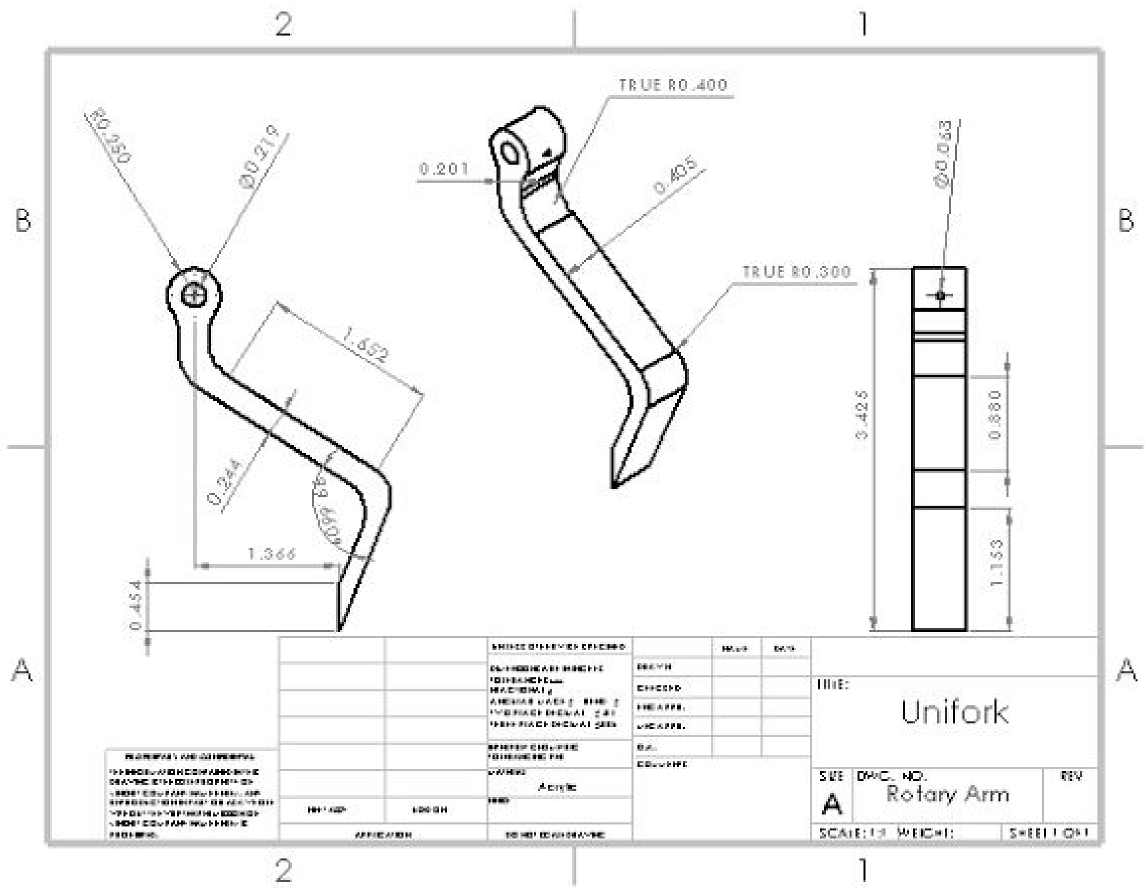
- Aluminum Bifork



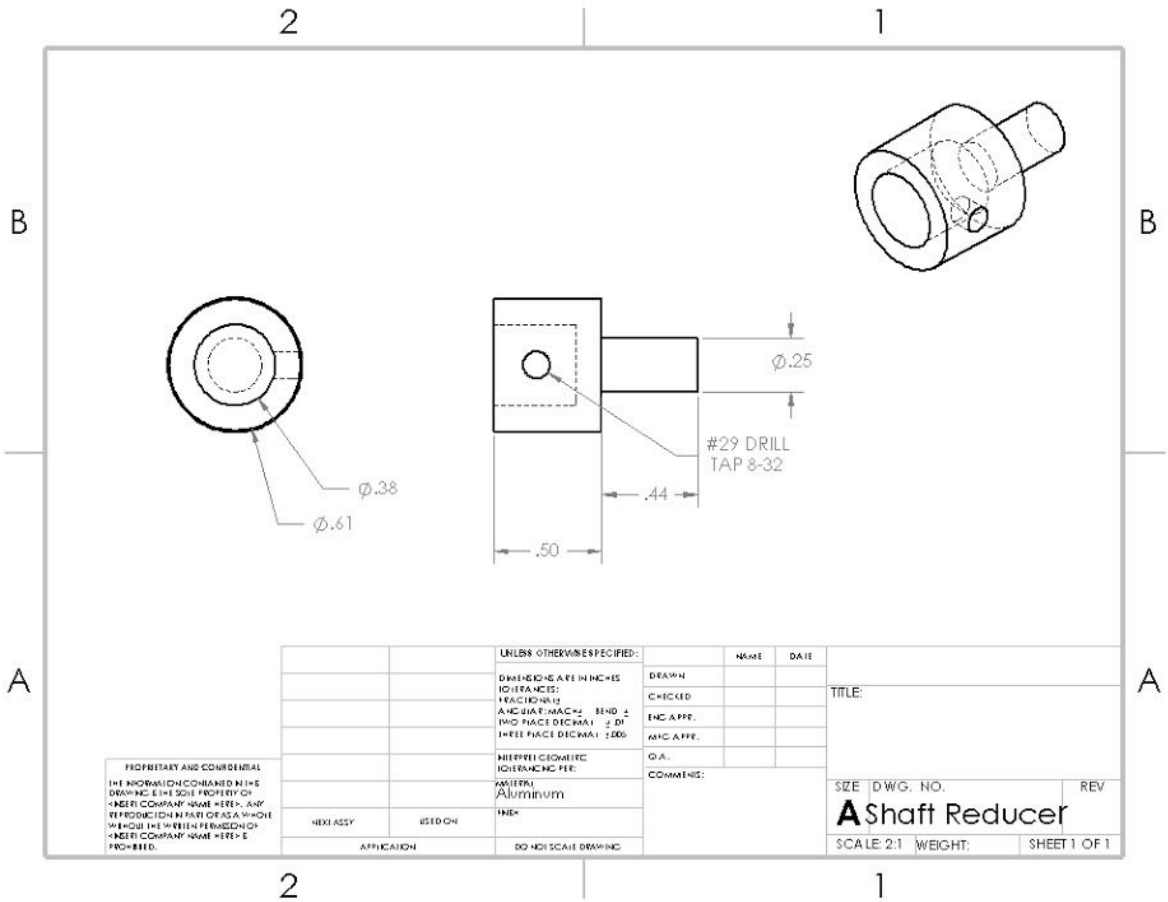
- <u>Acrylic Bearing Housing</u>



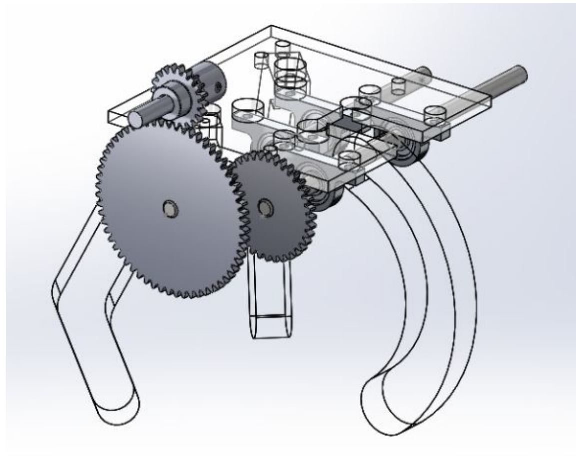
- <u>Acrylic Unifork</u>

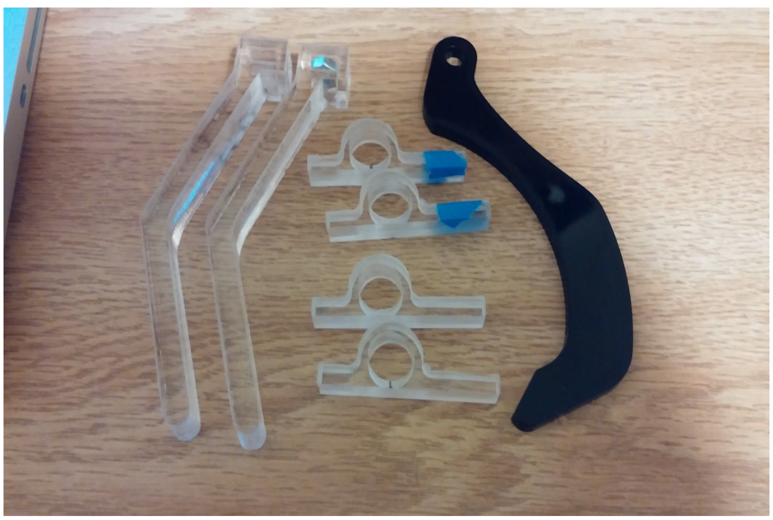


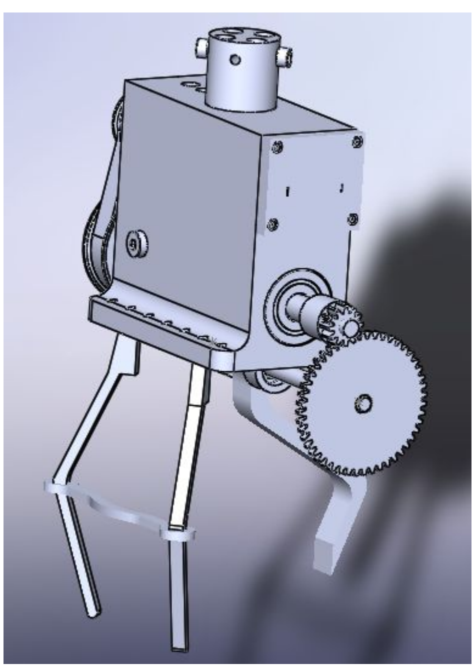
- <u>Aluminum Shaft Reducer</u>



Supporting Notes:
Iterative designs







Material Indice

$$M = \frac{E^{.5}}{\rho}$$

$E_{STEEL} = 206E9$ Pa

$E_{AL} = 76.7E9$ Pa

$E_{ACRYLIC} = 2.8E9$ Pa

$\rho_{STEEL} = 8.05\ gr/cm^3$

$\rho_{AL} = 2.70\ gr/cm^3$

$\rho_{ACRYLIC} = 1.17\ gr/cm^3$

SUBSTITUTE & CALCULATE

$M_{STEEL} = 56381.6$

$M_{AL} = 326409.57$

$M_{ACRYLIC} = 44957.54$

MATLAB

```
%%%%%%% Optimization for Initial State %%%%%%
% Written by Christine Amin & Esther Lim
%
% Goal: Find the optimal set of L,H,b,h that would give lowest mass
% Note: Link 1 indicates top half of gripper fork;
%       Link 2 indicates bottom half of gripper fork;
%       Material: acrylic
% Initial State = arm is vertical

%%% Dimensions
peg_dist = 0.5; % inches (distance between peg holes)
peg_diag = 0.7071; % inches (diagonal distance between peg holes)

%%% Constraints
% Unifork Side
F1 = 9; % lb (vertical position)
F2 = 9/2 + 3; % lb (horizontal position)
p = 0.3826; % inches
G = 1.185; % inches (gear region)
H = 3.25 - G; % inches (assuming contact point is center of pokeball)

% Acrylic Properties
rho = 0.04; % lb/in^3 (density)
sigY = 10000; % psi
E = 400000; % psi (elastic modulus)

r = 1.75; % inches (radius of Pokeball)
C = 1;
fos = 3;

%%% Find the lowest mass combination!
L1_values = []; % Initialize arrays of L1
L2_values = []; % Initialize arrays of L2
H1_values = []; % Initialize arrays of H1
H2_values = []; % Initialize arrays of H2
b_values = []; % Initialize arrays of b
h1_values = []; % Initialize arrays of h1
h2_values = []; % Initialize arrays of h2
m_values = []; % Initialize arrays of m

n = 10;
```

```
b = 0.5;

%%% Lower Link
th2 = pi/8; % radians
H2 = 1.125; % inches
L2 = H2/cos(th2); % inches

%%% Upper Link
H1 = H - H2;
d = L2*sin(th2) + .875 - .5;
th1 = atan2(L2*sin(th2)+1.3674,H1); % 1.3674 is the horizontal distance between the arm's
pivot point and the other end that pinches the ball
L1 = H1/cos(th1);

% When arm is in vertical position
% Find axial force on Links 1 and 2
Rx1v = F1*cos(th1);
Rx2v = F1*cos(th2);
% Find bending force on Links 1 and 2
Ry1v = F1*sin(th1);
Ry2v = F1*sin(th2);

% Solve for h1,h2
% a) Based on axial stress
h1av = ((12*fos*Rx1v*L1^2)/(C*pi^2*E*b))^(1/3);
h2av = ((12*fos*Rx2v*L2^2)/(C*pi^2*E*b))^(1/3);
% b) Based on bending stress
h1bv = sqrt(fos*6*Ry1v*L1/(sigY*b));
h2bv = sqrt(fos*6*Ry2v*L2/(sigY*b));

% When arm is in horizontal position
% Find axial force on Links 1 and 2
Rx1h = F2*sin(th1);
Rx2h = F2*sin(th2);
% Find bending force on Links 1 and 2
Ry1h = F2*cos(th1);
Ry2h = F2*cos(th2);

% Solve for h1,h2
% a) Based on axial stress
h1ah = (fos*Rx1h)/(sigY*b);
h2ah = (fos*Rx2h)/(sigY*b);
% b) Based on bending stress
```

```
h1bh = sqrt((fos*6*Ry1h*L1)/(sigY*b));
h2bh = sqrt((fos*6*Ry2h*L2)/(sigY*b));

h11 = max(h1av,h1bv);
h12 = max(h1ah,h1bh);
h1 = max(h11,h12);
h21 = max(h2av,h2bv);
h22 = max(h2ah,h2bh);
h2 = max(h21,h22);

% Calculate mass
m1 = rho*b*h1*L1;
m2 = rho*b*h2*L2;
m = m1+m2;

% Record the values
L1_values(end+1) = L1;
L2_values(end+1) = L2;
H1_values(end+1) = H1;
H2_values(end+1) = H2;
h1_values(end+1) = h1;
h2_values(end+1) = h2;
b_values(end+1) = b;
m_values(end+1) = m;

% Get indices of lowest mass
[m,i] = min(m_values);
L1 = L1_values(i);
L2 = L2_values(i);
H1 = H1_values(i);
H2 = H2_values(i);
b = b_values(i);
h1 = h1_values(i);
h2 = h2_values(i);
m = m*453.592; % convert lb to grams

fprintf(['\n\tL1 = %6.3f inches\n\tL2 = %6.3f inches\n\tH1 = %6.3f inches' ...
    '\n\tH2 = %6.3f inches\n\tb = %6.3f inches\n\th1 = %6.3f inches' ...
    '\n\th2 = %6.3f inches\n\tm = %6.3f grams\n'],L1,L2,H1,H2,b,h1,h2,m);
```

```
%%%%%%% Optimization for Initial State %%%%%%
% Written by Christine Amin & Esther Lim
%
% Goal: Find the optimal set of L,H,b,h that would give lowest mass
% Note: Link 1 indicates top half of gripper fork;
%       Link 2 indicates bottom half of gripper fork;
%       Material: acrylic
% Initial State = arm is vertical

%%% Dimensions
peg_dist = 0.5; % inches (distance between peg holes)
peg_diag = 0.7071; % inches (diagonal distance between peg holes)

%%% Constraints
% Bifork Side
F1 = 9/2; % lb (vertical position)
F2 = (9/2 + 3)/2; % lb (horizontal position)
p = 2*peg_diag;
H = 4.125; % inches (assuming contact point is halfway down the lower hemisphere)

% Aluminum Properties
rho = 0.0975; % lb/in^3 (density)
sigY = 40000; % psi
E = 10000000; % psi (elastic modulus)

r = 1.75; % inches (radius of Pokeball)
C = 1;
fos = 5;

%%% Find the lowest mass combination!
L1_values = []; % Initialize arrays of L1
L2_values = []; % Initialize arrays of L2
H1_values = []; % Initialize arrays of H1
H2_values = []; % Initialize arrays of H2
b_values = []; % Initialize arrays of b
h1_values = []; % Initialize arrays of h1
h2_values = []; % Initialize arrays of h2
m_values = []; % Initialize arrays of m

n = 10;
b = 0.2;
for b = b
    th2_min = deg2rad(18);
```

```
    th2_max = deg2rad(90);
    for th2 = linspace(th2_min,th2_max,n)
        L2_min = 0.875/cos(th2);
        L2_max = min(H/cos(th2),4);
        for L2 = linspace(L2_min,L2_max,n)
            th1_min = 0;
            th1_max = deg2rad(30);
            H2 = L2*cos(th2);
            H1 = H - H2;
            for th1 = linspace(th1_min,th1_max,n)
                L1 = H1/cos(th1);
                if (r-p+L2*sin(th2))/sin(th1) < L1 && L1 < (r+L2*sin(th2))/sin(th1) % within motor peg
board
                    % When arm is in vertical position
                    % Find axial force on Links 1 and 2
                    Rx1v = F1*cos(th1);
                    Rx2v = F1*cos(th2);
                    % Find bending force on Links 1 and 2
                    Ry1v = F1*sin(th1);
                    Ry2v = F1*sin(th2);

                    % Solve for h1,h2
                    % a) Based on axial stress
                    h1av = ((12*fos*Rx1v*L1^2)/(C*pi^2*E*b))^(1/3);
                    h2av = ((12*fos*Rx2v*L2^2)/(C*pi^2*E*b))^(1/3);
                    % b) Based on bending stress
                    h1bv = sqrt(fos*6*Ry1v*L1/(sigY*b));
                    h2bv = sqrt(fos*6*Ry2v*L2/(sigY*b));

                    % When arm is in horizontal position
                    % Find axial force on Links 1 and 2
                    Rx1h = F2*sin(th1);
                    Rx2h = F2*sin(th2);
                    % Find bending force on Links 1 and 2
                    Ry1h = F2*cos(th1);
                    Ry2h = F2*cos(th2);

                    % Solve for h1,h2
                    % a) Based on axial stress
                    h1ah = (fos*Rx1h)/(sigY*b);
                    h2ah = (fos*Rx2h)/(sigY*b);
                    % b) Based on bending stress
                    h1bh = sqrt((fos*6*Ry1h*L1)/(sigY*b));
```

```
            h2bh = sqrt((fos*6*Ry2h*L2)/(sigY*b));

            h11 = max(h1av,h1bv);
            h12 = max(h1ah,h1bh);
            h1 = max(h11,h12);
            h21 = max(h2av,h2bv);
            h22 = max(h2ah,h2bh);
            h2 = max(h21,h22);

            % Calculate mass
            m1 = rho*b*h1*L1;
            m2 = rho*b*h2*L2;
            m = m1+m2;

            % Record the values
            L1_values(end+1) = L1;
            L2_values(end+1) = L2;
            H1_values(end+1) = H1;
            H2_values(end+1) = H2;
            h1_values(end+1) = h1;
            h2_values(end+1) = h2;
            b_values(end+1) = b;
            m_values(end+1) = m;
          end
        end
      end
   end
end

% Get indices of lowest mass
[m,i] = min(m_values);
L1 = L1_values(i);
L2 = L2_values(i);
H1 = H1_values(i);
H2 = H2_values(i);
b = b_values(i);
h1 = h1_values(i);
h2 = h2_values(i);
m = m*453.592; % convert lb to grams

fprintf(['\n\tL1 = %6.3f inches\n\tL2 = %6.3f inches\n\tH1 = %6.3f inches' ...
   '\n\tH2 = %6.3f inches\n\tb = %6.3f inches\n\th1 = %6.3f inches' ...
   '\n\th2 = %6.3f inches\n\tm = %6.3f grams\n'],L1,L2,H1,H2,b,h1,h2,m);
```

```
%{
Gear Train for Gripper
Written: Ben Reibman
Created: 28OCT2016
Last Edited: 30OCT2016
%}

clear all; close all; clc

%%
%Var Declaration
tau_motor = 11.50597; %[lb*in] +- .2 Motor torque
v_motor = 13; %[Rads/s] Unloaded Motor Speed
D_driveshaft = .375; %[in] motor drive shaft
eta  = .95; %[%] efficiency

%Parameters
FoS = 1.5;%Factor of Safety for drive torque
tau_req = 75*(2.925+1.2)/3; %[lb*in] Required Torque based off required force and lever arm
length.
r_motor = .4; %[in] motor pulley diameter

%%
%Calculations
tau_req_mod = tau_req*FoS; %[N*m] Torque required with FoS
%m_A = r_out/r_in;
%m_A = N_out/N_in;
r_drive = eta*tau_req_mod*r_motor/tau_motor;

%https://sdp-si.com/eStore/CenterDistanceDesigner
```