ENME 304 Machine Design
Design Update 3

Submitted to Professor Janelle Clark
11/24/25

Group 10 Members-
Adam Beall
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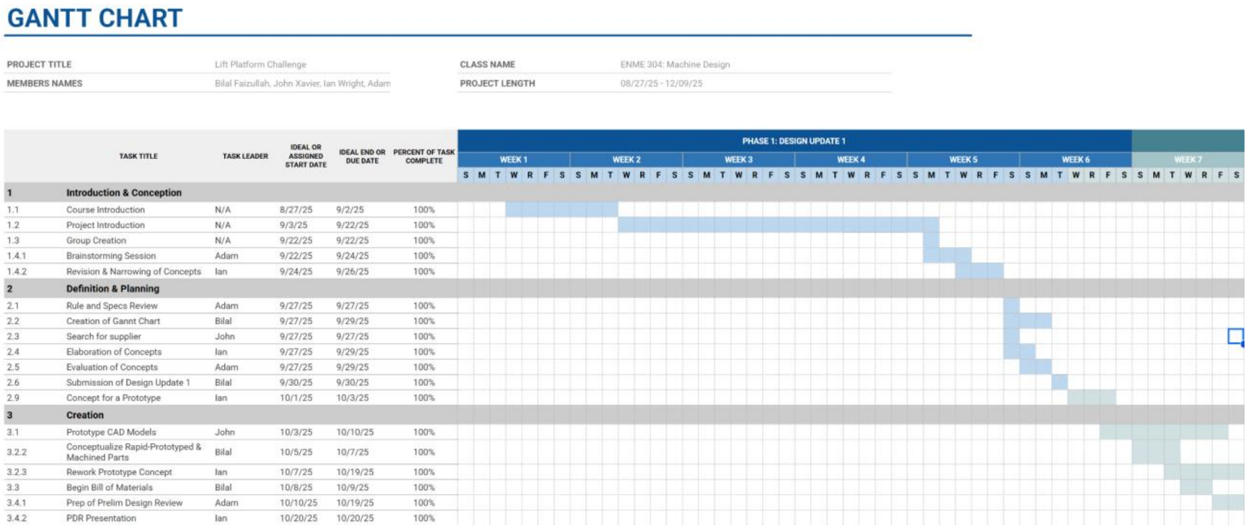
Gantt Chart

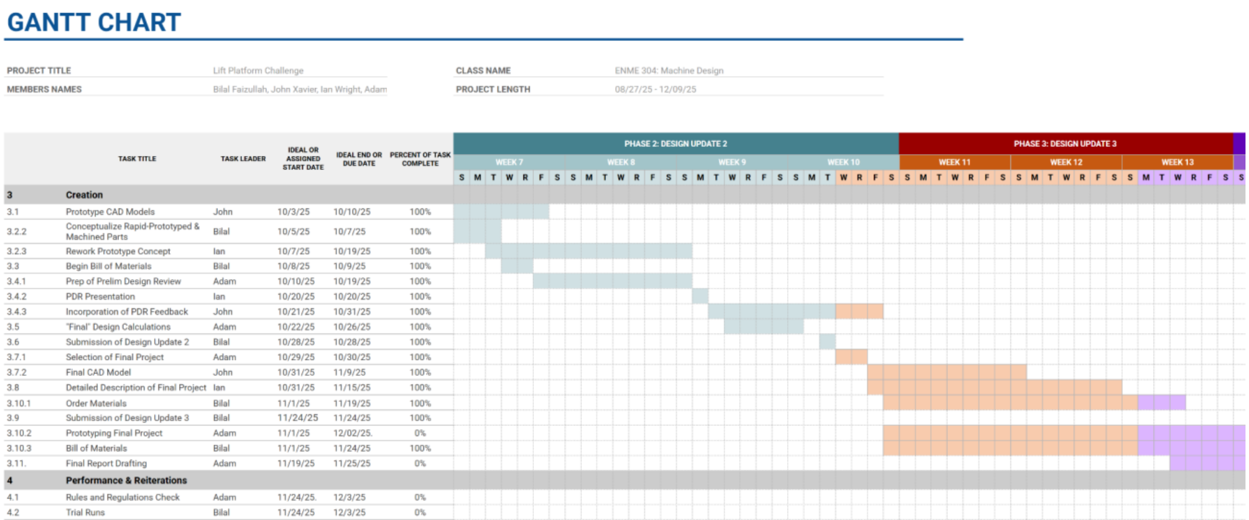


GANTT CHART

PROJECT TITLE	Lift Platform Challenge	CLASS NAME	ENME 304: Machine Design
MEMBERS NAMES	Bilal Faizullah, John Xavier, Ian Wright, Adam	PROJECT LENGTH	08/27/25 - 12/09/25

	TASK TITLE	TASK LEADER	IDEAL OR ASSIGNED START DATE	IDEAL END OR DUE DATE	PERCENT OF TASK COMPLETE
1	**Introduction & Conception**				
1.1	Course Introduction	N/A	8/27/25	9/2/25	100%
1.2	Project Introduction	N/A	9/3/25	9/22/25	100%
1.3	Group Creation	N/A	9/22/25	9/22/25	100%
1.4.1	Brainstorming Session	Adam	9/22/25	9/24/25	100%
1.4.2	Revision & Narrowing of Concepts	Ian	9/24/25	9/26/25	100%
2	**Definition & Planning**				
2.1	Rule and Specs Review	Adam	9/27/25	9/27/25	100%
2.2	Creation of Gannt Chart	Bilal	9/27/25	9/29/25	100%
2.3	Search for supplier	John	9/27/25	9/27/25	100%
2.4	Elaboration of Concepts	Ian	9/27/25	9/29/25	100%
2.5	Evaluation of Concepts	Adam	9/27/25	9/29/25	100%
2.6	Submission of Design Update 1	Bilal	9/30/25	9/30/25	100%
2.9	Concept for a Prototype	Ian	10/1/25	10/3/25	100%
3	**Creation**				
3.1	Prototype CAD Models	John	10/3/25	10/10/25	100%
3.2.2	Conceptualize Rapid-Prototyped & Machined Parts	Bilal	10/5/25	10/7/25	100%
3.2.3	Rework Prototype Concept	Ian	10/7/25	10/19/25	100%
3.3	Begin Bill of Materials	Bilal	10/8/25	10/9/25	100%
3.4.1	Prep of Prelim Design Review	Adam	10/10/25	10/19/25	100%
3.4.2	PDR Presentation	Ian	10/20/25	10/20/25	100%

Figure 1: First of three Parts of the Gantt Chart



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3	**Creation**				
3.1	Prototype CAD Models	John	10/3/25	10/10/25	100%
3.2.2	Conceptualize Rapid-Prototyped & Machined Parts	Bilal	10/5/25	10/7/25	100%
3.2.3	Rework Prototype Concept	Ian	10/7/25	10/19/25	100%
3.3	Begin Bill of Materials	Bilal	10/8/25	10/9/25	100%
3.4.1	Prep of Prelim Design Review	Adam	10/10/25	10/19/25	100%
3.4.2	PDR Presentation	Ian	10/20/25	10/20/25	100%
3.4.3	Incorporation of PDR Feedback	John	10/21/25	10/31/25	100%
3.5	"Final" Design Calculations	Adam	10/22/25	10/26/25	100%
3.6	Submission of Design Update 2	Bilal	10/28/25	10/28/25	100%
3.7.1	Selection of Final Project	Adam	10/29/25	10/30/25	100%
3.7.2	Final CAD Model	John	10/31/25	11/9/25	100%
3.8	Detailed Description of Final Project	Ian	10/31/25	11/15/25	100%
3.10.1	Order Materials	Bilal	11/1/25	11/19/25	100%
3.9	Submission of Design Update 3	Bilal	11/24/25	11/24/25	100%
3.10.2	Prototyping Final Project	Adam	11/1/25	12/02/25.	0%
3.10.3	Bill of Materials	Bilal	11/1/25	11/24/25	100%
3.11.	Final Report Drafting	Adam	11/19/25	11/25/25	0%
4	**Performance & Reiterations**				
4.1	Rules and Regulations Check	Adam	11/24/25.	12/3/25	0%
4.2	Trial Runs	Bilal	11/24/25	12/3/25	0%

Figure 2: Second of three Parts of the Gantt Chart

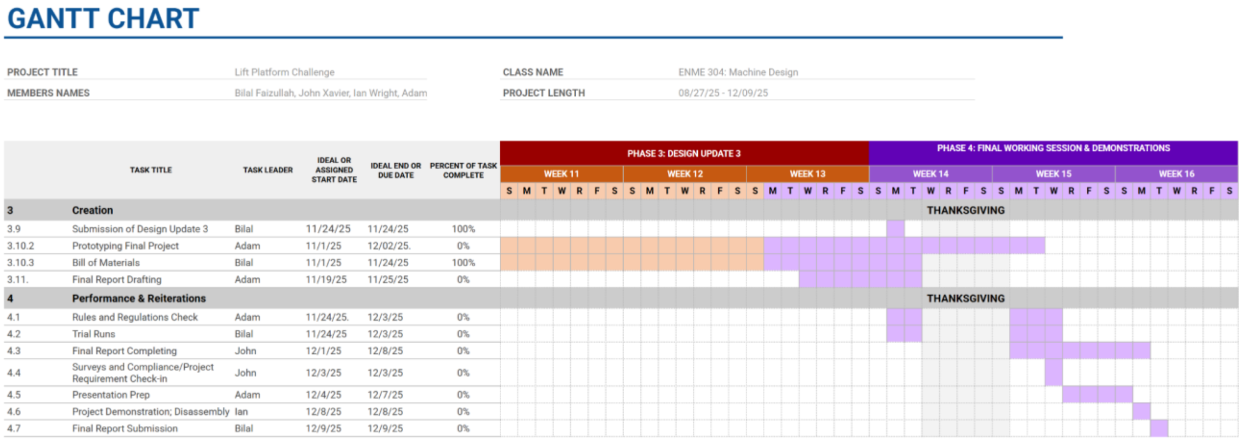


Figure 3: Second of three Parts of the Gantt Chart

Bill of Materials (BOM)

	Item Name	Item Description	3D Print Volume	Individual Cost	Quantity Needed	Total Cost	Ordered	Arrived
1	Multipurpose 6061 Aluminum 90 Degree Angle	1" ht, 1" wd 1/8" thick 90 deg. 8ft long	N/A	$19.50	1	$19.50	☑	☑
2	18-8 Stainless Steel Washer	Spacer for Pivots under motion	N/A	$7.81 pack of 100	1 pack	$7.81	☑	☑
3	Zinc-Plated Low-Strength Steel Hex Nuts	8-36 threaded nut	N/A	$3.17 pack of 100	1 pack	$3.17	☑	☑
4	Passivated 18-8 Stainless Steel Pan Head Phillips Screw	Machine Screw For Holding our Device together	N/A	$8.25 Pack of 25	1 pack	$8.25	☑	☑
5	12 Tooth Plastic Gear	12 tooth Plastic Spur Gear	N/A	$4.30	3	$12.90	☑	☐
6	24 Tooth Plastic Gear	24 tooth Plastic Spur Gear	N/A	$4.33	1	$4.33	☑	☐
7	36 Tooth Plastic Gear	36 tooth Plastic Spur Gear	N/A	$5.60	1	$5.60	☑	☐
8	60 Tooth Plastic Gear	60 tooth Plastic Spur Gear	N/A	$8.81	1	$8.81	☑	☐
9	Moisture- and Wear-Resistant Nylon Rod	Gear Shaft Machined down to Proper size, 1ft	N/A	$6.72	1	$6.72	☑	☑
10	Aluminum Metal Bar	4 ft Aluminum Bar for Scissor Lift Arms 1-1/4in wide 1/8th in thick	N/A	$12.50	1	$12.50	☑	☑
11	Barrel Extension 7/8 in	7/8inch 8-32 thread Entention for Barrel of Axle	N/A	$3.85	3	$11.55	☑	☑
12	Machine Screw 12-24 1/2 inch long	Machine Screw For Holding our Device together	N/A	$6.93 pack of 25	1	$6.93	☑	☑
13	Low Profile Barrel and Screw	5 inch long 8-32 thread Barrel and screw for Pully/Spool Axle	N/A	$6.87	4	$27.48	☑	☑
14	Barrel Extension 3/4 in	3/4inch 8-32 thread Entention for Barrel of Axle	N/A	$3.76	1	$3.76	☑	☑
15	Fishing line	Pulls spool	N/A	$4.59	1	$4.59	☑	☑
16	Chemical Resistant PVC Sheet	12x12", 1/8" thick For top plate		$8.76	1	$8.76	☑	☑
17	Sloblo Fuse	2A fuse pack of 20		6.99	1	6.99	☑	☑
18	DPDT Switch	6 pins	N/A	$2.47	1	$2.47	☑	☐
19	Fuse Holder	Fit Slo blo Fuse pack of 5	N/A	$5.19	1	$5.19	☑	☑
20	PLA Plastic	Creality 2kg Black & White PLA 1.75mm Filament Bundle for 3D F	N/A	$25.49	1	$25.49	☑	☐
					Summed Prices	$192.80		

Figure 4: First of two Parts of the Bill of Materials

	Item Name	Ordered	Arrived	Material	Part #	URL
1	Multipurpose 6061 Aluminum 90 Degree Angle	☑	☑	6061 Aluminum	8982K4	https://www.mcmaster.com/8982K4-8982K21/
2	18-8 Stainless Steel Washer	☑	☑	Carbon Steel	92141A223	https://www.mcmaster.com/92141A223/
3	Zinc-Plated Low-Strength Steel Hex Nuts	☑	☑	Zinc Plated Steel	90480A185	https://www.mcmaster.com/90480A185/
4	Passivated 18-8 Stainless Steel Pan Head Phillips Screw	☑	☑	Stainless Steel	91772A925	https://www.mcmaster.com/91772A925/
5	12 Tooth Plastic Gear	☑	☐	Durcan Acetal M90-44 Plastic	DS1-12	https://www.khkgears.us/catalog/product/DS1-12/
6	24 Tooth Plastic Gear	☑	☐	Durcan Acetal M90-44 Plastic	DS1-24	https://www.khkgears.us/catalog/product/DS1-24/
7	36 Tooth Plastic Gear	☑	☐	Durcan Acetal M90-44 Plastic	DS1-36	https://www.khkgears.us/catalog/product/DS1-36/
8	60 Tooth Plastic Gear	☑	☐	Durcan Acetal M90-44 Plastic	DS1-60	https://www.khkgears.us/catalog/product/DS1-60/
9	Moisture- and Wear-Resistant Nylon Rod	☑	☑	Nylon	8641T52	https://www.mcmaster.com/8682K83/
10	Aluminum Metal Bar	☑	☑	6063 Aluminum	89755K31	https://www.mcmaster.com/89755K31-89755K311/
11	Barrel Extension 7/8 in	☑	☑	18-8 Stainless Steel	93122A117	https://www.mcmaster.com/93122A117/
12	Machine Screw 12-24 1/2 inch long	☑	☑	Steel	91772A923	https://www.mcmaster.com/91772A923/
13	Low Profile Barrel and Screw	☑	☑	18-8 Stainless Seel	94887A251	https://www.mcmaster.com/94887A251/
14	Barrel Extension 3/4 in	☑	☑	18-8 Stainless Seel	93122A116	https://www.mcmaster.com/93122A116/
15	Fishing line	☑	☑		B09N72VZGW	https://a.co/d/9v8UW7j
16	Chemical Resistant PVC Sheet	☑	☑	PVC Type 1	8747K112	https://www.mcmaster.com/8747K112/
17	Sloblo Fuse	☑	☑		B07X3GFV8K	https://a.co/d/8z74kEH
18	DPDT Switch	☑	☐		EG5646-ND	https://www.digikey.com/short/nmt8hfjv
19	Fuse Holder	☑	☑		B00H3CVSXQ	https://a.co/d/3ZTMF1t
20	PLA Plastic	☑	☐	PLA Plastic	B0C4TNQZYY	https://a.co/d/4kG0Vdi

Figure 5: Second of two Parts of the Bill of Materials

Stress Concentrations Affecting our Gear Train Shafts

1 - Stress concentration factor for our Gear Train Shafts

All stress concentrations came from (A-15-1) and (A-15-8)

12-24T shaft: (r/d) = (0.0394/0.1575) = 0.25, (d/D) = 1.25, K = 1.19

12-36T shaft: (r/d) = (0.0787/0.1575) = 0.5, (D/d) = 1.5, K = 1.19, 12-60T Shaft: K = 1.19

Shafts: fluctuating load in torsion from 0 (static) and maximum torque (dynamic/rotating) because gear exerts force as friction.

2 - Notch sensitivity required for our transmission shafts

Stress concentration: $d = 0.24in, w = 0.75in, \frac{d}{w} = 0.32, K_t = 2.36$

Notch Sensitivity: $\sqrt{a} = 0.246 - (3.8E-3)(27) + (1.51E-5)(27)^2 - (2.67E-8)(27)^3 = 0.14$

$$q = \frac{1}{1 + \sqrt{a}/\sqrt{r}} = 0.707, K_f = 1 + (0.707)(2.36 - 1) = 1.96$$

Arms: repeated between compression (platform up) and tension (platform down) at F = 3.9705 lb. However, this is very small, considering the arms have a much higher ultimate tensile strength, which means that it would have a larger design factor compared to the nylon shafts.

Fatigue Failure of Our Gear Train Shafts

1 - Each transmission shafts Maximum and Minimum points of highest stress.

Shaft 1 - (Pinion Gear Shaft) τ = .330 lb-in $r_0 = 0\ in$ r_1= .12 in r_2=.08 in

Inertia Calculations - I = $\frac{\pi R^4}{2}$

$$J = I_{tot} = I_1 + I_2 = \frac{\pi(r_1)^4}{2} + \frac{\pi(r_2)^4}{2} = \frac{\pi(.12)^4}{2} + \frac{\pi(.08)^4}{2} = 3.9x10^{-4} \text{ lbf-in-s^2}$$

$$\tau_{max} = \frac{\tau r}{J} = \frac{.330(.12)}{3.9x10^{-4}} = 92.31\ Psi \qquad \tau_{min} = \frac{\tau r}{J} = \frac{.330(0)}{3.9x10^{-4}} = 0\ Psi$$

Shaft 2 - τ = .660 lb-in $r_0 = 0\ in$ r_1= .1 in r_2=.08 in

Inertia Calculations - I = $\frac{\pi R^4}{2}$

$$J = I_{tot} = I_1 + I_2 = \frac{\pi(r_1)^4}{2} + \frac{\pi(r_2)^4}{2} = \frac{\pi(.1)^4}{2} + \frac{\pi(.08)^4}{2} = 2.21x10^{-4} \text{ lbf-in-s^2}$$

$$\tau_{max} = \frac{\tau r}{J} = \frac{.660(.1)}{2.21x10^{-4}} = 298.08\ Psi \qquad \tau_{min} = \frac{\tau r}{J} = \frac{.660(0)}{2.21x10^{-4}} = 0\ Psi$$

Shaft 3 - τ = 1.981 lb-in $r_0 = 0\ in$ r_1= .155 in r_2=.08 in

Inertia Calculations - I = $\frac{\pi R^4}{2}$

$$J = I_{tot} = I_1 + I_2 = \frac{\pi(r_1)^4}{2} + \frac{\pi(r_2)^4}{2} = \frac{\pi(.155)^4}{2} + \frac{\pi(.08)^4}{2} = 9.71x10^{-4} \text{ lbf-in-s^2}$$

$$\tau_{max} = \frac{\tau r}{J} = \frac{.660(.1)}{2.21x10^{-4}} = 316.23\ Psi \qquad \tau_{min} = \frac{\tau r}{J} = \frac{.660(0)}{2.21x10^{-4}} = 0\ Psi$$

Shaft 4 - τ = 9.903 lb-in $r_0 = 0\ in$ r_1= .155 in

Inertia Calculations - I = $\frac{\pi R^4}{2}$

$J = I_{tot} \quad = \frac{\pi (r_1)^4}{2} = \frac{\pi (.155)^4}{2} = 1.81x10^{-3}$ lbf-in-s^2

$\tau_{max} = \frac{\tau r}{J} = \frac{9.903(.155)}{1.81x10^{-3}} = 848.05\ Psi$ $\quad\quad \tau_{min} = \frac{\tau r}{J} = \frac{9.903(0)}{1.81x10^{-3}} = 0\ Psi$

2 - The mean and alternating stress at point of highest stress for each transmission shaft

Shaft 1 - $\tau_{max} = 92.31\ Psi \quad \tau_{min} = 0\ Psi$

$\tau_a = \left|\frac{\tau_{max} - \tau_{min}}{2}\right| = \left|\frac{92.31 - 0}{2}\right| = 46.155\ Psi \quad \tau_m = \frac{\tau_{max} - \tau_{min}}{2} = \frac{92.31 - 0}{2} = 46.155\ Psi$

Shaft 2 - $\tau_{max} = 298.08\ Psi\ \tau_{min} = 0\ Psi$

$\tau_a = \left|\frac{\tau_{max} - \tau_{min}}{2}\right| = \left|\frac{298.08 - 0}{2}\right| = 149.04\ Psi \quad \tau_m = \frac{\tau_{max} - \tau_{min}}{2} = \frac{298.08 - 0}{2} = 149.04\ Psi$

Shaft 3 - $\tau_{max} = 316.23\ Psi\ \tau_{min} = 0\ Psi$

$\tau_a = \left|\frac{\tau_{max} - \tau_{min}}{2}\right| = \left|\frac{316.23 - 0}{2}\right| = 158.115\ Psi \quad \tau_m = \frac{\tau_{max} - \tau_{min}}{2} = \frac{316.23 - 0}{2} = 158.115\ Psi$

Shaft 4 - $\tau_{max} = 848.05\ Psi\ \tau_{min} = 0\ Psi$

$\tau_a = \left|\frac{\tau_{max} - \tau_{min}}{2}\right| = \left|\frac{848.05 - 0}{2}\right| = 424.02\ Psi \quad \tau_m = \frac{\tau_{max} - \tau_{min}}{2} = \frac{848.05 - 0}{2} = 424.02\ Psi$

3 - Estimated number of Life Cycles for each Transmission shaft

No data is available for Pa612. However, Pa612 is similar to Pa12, so use data [1] (3.4, IM):

To get: $a = 54.4, b = -0.05, s_f = 28\ MPa, N = (\frac{28}{54.4})^{-20} = 5.87E5\ cycles$

4 - Endurance limit for the Gear train Shafts with the proper Marin Factor

Properties for Nylon, such as UTS, were obtained from [2]

Nylon UTS = 10 kpsi

Shafts: $k_a = 2(10000)^{-0.217} = 0.271, K_b = 1\ (d < 0.3\ in), k_c = 0.59, at\ T = 70^oF: k_d = 1.0014,$

$$S_e' = 0.5(10) = 5000psi, S_e = 800.68\ psi$$

5 - First Yield Check for our Transmission Shaft

Only available data sheet for pa612 is from [3] as (pure pa612), $S_y \approx 6800\ psi$

6 - The 2 Best Evaluation methods to determine Fatigue Failure Criteria

The 2 Fatigue Life Criteria we will use will be Goodman and SWT (Smith-Watson-Topper)

The Goodman fatigue criteria provides the most basic and universal finite cycle evaluations. Along with this there isn't any specific class of material this fatigue method was created for like other fatigue testing methods so it will be the best fit for the nylon shafts we are using.

The SWT Fatigue criteria works for us because our system matches many of the Pros it has to offer. These are that we have a low level of fatigue with our high total life cycles and that we experience a very small level of plastic deformation due to our shaft being fixed on each end severely limiting any form of plastic deformation that could occur.

7 - Factor of Safety for gear train shafts based on our chosen Fatigue Failure Criteria

Shaft 1 - $\tau_m = 46.155\ Psi$ $\tau_a = 46.155\ Psi$

Goodman - $n_f = (\frac{\tau_a}{S_e} + \frac{\tau_m}{S_{ut}})^{-1} = (\frac{46.155}{800.68} + \frac{46.155}{10000})^{-1} = 16.06$

SWT (Smith-Watson-Topper) - $n_f = \frac{S_e}{\sqrt{(\tau_m+\tau_a)\tau_a}} = \frac{800.68}{\sqrt{(46.155+46.155)46.155}} = 12.27$

Shaft 2 - $\tau_m = 149.04\ Psi \quad \tau_a = 149.04\ Psi$

Goodman - $n_f = (\frac{\tau_a}{S_e} + \frac{\tau_m}{S_{ut}})^{-1} = (\frac{149.04}{800.68} + \frac{149.04}{10000})^{-1} = 4.97$

SWT (Smith-Watson-Topper) - $n_f = \frac{S_e}{\sqrt{(\tau_m+\tau_a)\tau_a}} = \frac{800.68}{\sqrt{(149.04+149.04)149.04}} = 3.80$

Shaft 3 - $\tau_m = 158.115\ Psi \quad \tau_a = 158.115\ Psi$

Goodman - $n_f = (\frac{\tau_a}{S_e} + \frac{\tau_m}{S_{ut}})^{-1} = (\frac{158.115}{800.68} + \frac{158.115}{10000})^{-1} = 4.69$

SWT (Smith-Watson-Topper) - $n_f = \frac{S_e}{\sqrt{(\tau_m+\tau_a)\tau_a}} = \frac{800.68}{\sqrt{(158.115+158.115)158.115}} = 3.58$

Shaft 4 - $\tau_m = 424.02\ Psi \quad \tau_a = 424.02\ Psi$

Goodman - $n_f = (\frac{\tau_a}{S_e} + \frac{\tau_m}{S_{ut}})^{-1} = (\frac{424.02}{800.68} + \frac{424.02}{10000})^{-1} = 1.75$

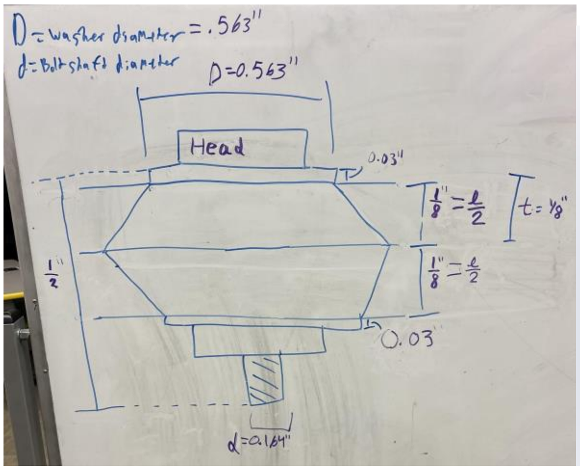
SWT (Smith-Watson-Topper) - $n_f = \frac{S_e}{\sqrt{(\tau_m+\tau_a)\tau_a}} = \frac{800.68}{\sqrt{(424.02+424.02)424.02}} = 1.34$

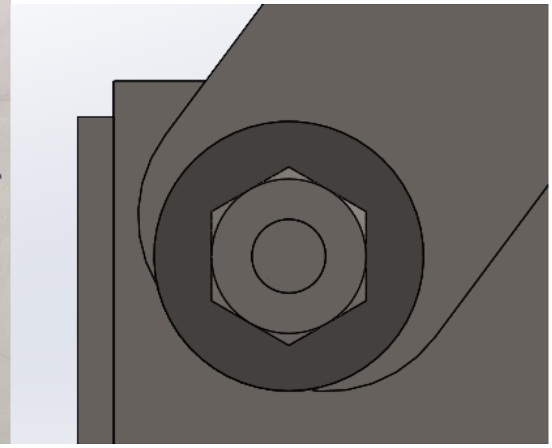
8 - Calculate the endurance limit with the proper Marin factors

The endurance limit Se is going to be the same as what we calculated above. This is because even though the diameter of the shafts change the material properties or things like temperature do not change which is what would have a tangible effect of our Martin Factors but since that is not the case Se does not change.

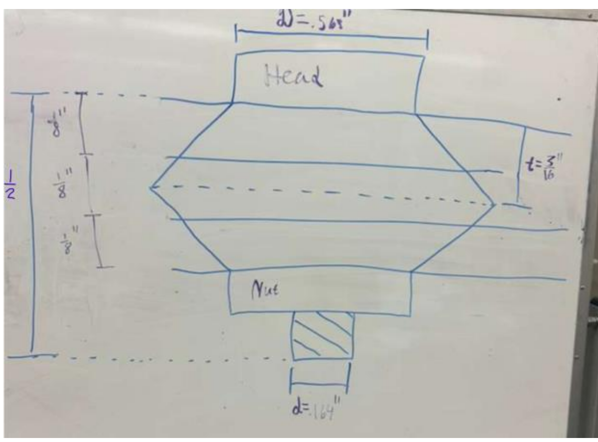
Bolt Analyses of Stiffness and Safety

1 - The free body along with the cad model for the bolts in our design.





Figures 6 & 7: FBD of Rigid Scissor Lift Pivot



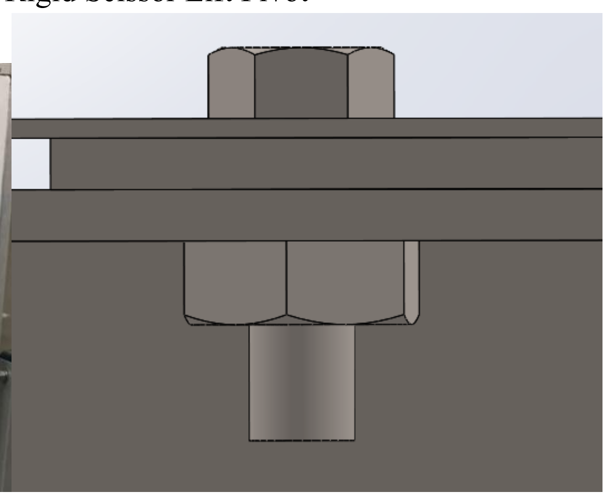


Figure 8 & 9: FBD of Bolt Fastening the Top Plate and Top Brackets

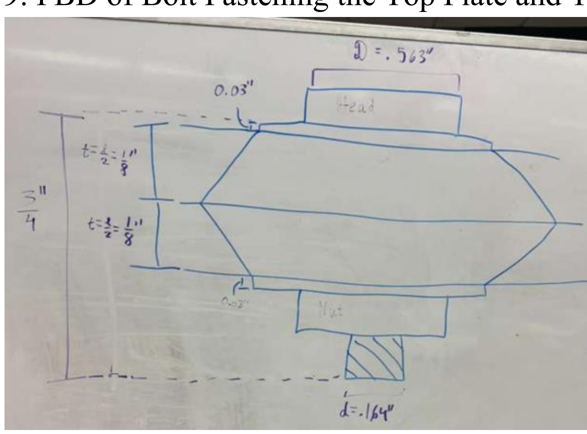


Figure 10: FBD of Bolt The Scissor Lift Body to the Legs.

2 - The stiffnesses for each member in the joint for each selected bolts

$E_{Al} = 10.3 * 10^6$ psi

$E_{Steel} = 30 * 10^6$ psi

Stiffness for Figure 6 and 7

$$K_{plate} = \frac{.5774 * E_{Aluminum} * \pi * .164}{ln\left(\frac{(1.155t + D - d)(D + d)}{(1.155t + D - d)(D + d)}\right)} = \frac{.5774 * 10.3 * 10^6 * \pi * .164}{ln\left(\frac{((1.155 * \frac{1}{8}) + .540 - .164)(.563 + .164)}{((1.155 * \frac{1}{8}) + .540 + .164)(.563 - .164)}\right)}$$

$$= 2528125.239 \frac{lbf}{in}$$

$$K_{washer} = \frac{.5774\pi E}{2 * ln\left(5 * \frac{(.5774 * l) + (.5d)}{(.5774 * l) + (2.5d)}\right)} = \frac{.5774 * \pi * 30 * 10^6}{2 * ln\left(5 * \frac{(.5774 * .03) + (.5 * .164)}{(.5774 * .03) + (2.5 * .164)}\right)}$$

$$= 181073029.6 \frac{lbf}{in}$$

$$K_m = \left(\frac{2}{K_{plate}} + \frac{2}{K_{washer}}\right)^{-1} = \left(\frac{2}{2528125.239} + \frac{2}{181073029.6}\right)^{-1} = 10594150.69 \frac{lbf}{in}$$

$$l_t = \frac{1}{2} in$$

$A_t = .01474 in^2$ from table 8-2

$K_b = \frac{A_t A_d E_{Steel}}{A_d l_t + A_t l_d}$ since $l_d = 0$, $K_b = \frac{A_t E_{Steel}}{l_t} = \frac{.01474 * 30 * 10^6}{.5} = 884400$

Stiffness for Figure 8 and 9

$E_{pvc} = 3275\ MPa \rightarrow 474998.6\ Psi$ [4]

$$K_{plate} = \frac{.5774 * E_{Aluminum} * \pi * .164}{ln\left(\frac{(1.155t + D - d)(D + d)}{(1.155t + D - d)(D + d)}\right)} = \frac{.5774 * 10.3 * 10^6 * \pi * .164}{ln\left(\frac{((1.155 * \frac{1}{8}) + .540 - .164)(.563 + .164)}{((1.155 * \frac{1}{8}) + .540 + .164)(.563 - .164)}\right)}$$
$$= 2528125.239 \frac{lbf}{in}$$

$$K_{washer} = \frac{.5774\pi E}{2 * ln\left(5 * \frac{(.5774 * l) + (.5d)}{(.5774 * l) + (2.5d)}\right)} = \frac{.5774 * \pi * 30 * 10^6}{2 * ln\left(5 * \frac{(.5774 * .03) + (.5 * .164)}{(.5774 * .03) + (2.5 * .164)}\right)}$$
$$= 181073029.6 \frac{lbf}{in}$$

$$K_{pvc} = \frac{.5774 * E_{PVC} * \pi * .164}{ln\left(\frac{(1.155t + D - d)(D + d)}{(1.155t + D - d)(D + d)}\right)} = \frac{.5774 * 474998.6 * \pi * .164}{ln\left(\frac{((1.155 * .125) + .540 - .164)(.563 + .164)}{((1.155 * .125) + .540 + .164)(.563 - .164)}\right)}$$
$$= 1106618.768 \frac{lbf}{in}$$

$$K_m = \left(\frac{2}{K_{plate}} + \frac{2}{K_{washer}} + \frac{1}{K_{pvc}}\right)^{-1} = \left(\frac{2}{2528125.239} + \frac{2}{181073029.6} + \frac{1}{110618.768}\right)^{-1}$$
$$= 1001958.548 \frac{lbf}{in}$$

$$l_t = \frac{1}{2} in$$

$K_b = \frac{A_t A_d E_{Steel}}{A_d l_t + A_t l_d}$ since $l_d = 0$, $K_b = \frac{A_t E_{steel}}{l_t} = \frac{.01474 * 30 * 10^6}{.5} = 884400$

For Figure 10

$$K_{plate} = \frac{.5774 * E_{Aluminum} * \pi * .164}{ln\left(\frac{(1.155t + D - d)(D + d)}{(1.155t + D - d)(D + d)}\right)} = \frac{.5774 * 10.3 * 10^6 * \pi * .164}{ln\left(\frac{((1.155 * \frac{1}{8}) + .540 - .164)(.563 + .164)}{((1.155 * \frac{1}{8}) + .540 + .164)(.563 - .164)}\right)}$$
$$= 2528125.239 \frac{lbf}{in}$$

$$K_{washer} = \frac{.5774\pi E}{2 * ln\left(5 * \frac{(.5774 * l) + (.5d)}{(.5774 * l) + (2.5d)}\right)} = \frac{.5774 * \pi * 30 * 10^6}{2 * ln\left(5 * \frac{(.5774 * .03) + (.5 * .164)}{(.5774 * .03) + (2.5 * .164)}\right)} = 181073029.6 \frac{lbf}{in}$$

$$K_m = \left(\frac{2}{K_{plate}} + \frac{2}{K_{washer}}\right)^{-1} = \left(\frac{2}{2528125.239} + \frac{2}{181073029.6}\right)^{-1} = 10594150.69 \frac{lbf}{in}$$

$$l_t = \frac{3}{4} in$$

$K_b = \frac{A_t A_d E_{Steel}}{A_d l_t + A_t l_d}$ since $l_d = 0$, $K_b = \frac{A_t E_{Steel}}{l_t} = \frac{.01474 * 30 * 10^6}{.75} = 589600$

3 - Calculate the stiffness constant and load taken on by each of the selected bolts

For Figure 6 and 7

$$C = \frac{k_b}{k_b + k_m} = \frac{884400}{884400 + 10594150.69} = .077$$

For Figure 8 and 9

$$C = \frac{k_b}{k_b + k_m} = \frac{884400}{884400 + 1001958.548} = .4688$$

For Figure 10

$$C = \frac{k_b}{k_b + k_m} = \frac{589600}{589600 + 10594150.69} = .37$$

4 - Torque load on each selected bolt

S_y from [5]

$$S_P = 0.85S_y = 0.85(205 * 10^6) = 174.25\ MPa = 25.273\ kpsi$$

Nonpermanent Fasteners, thus 75% Proof Load: $F_i = 0.75A_tS_p$

$$F_i = 0.75A_tS_p = 0.75(.01474)(25.273 * 10^3) = 279.39lb$$

Machine screw: K = 0.3 (nonplated)

$$\tau = KF_id = 13.75bl - in$$

All 3 iterations of the bolt would be under the same estimated torque.

5 - Tensile Stress and the Factor of Safety For Static Stress on each selected bolt

Only one bolt selected doesn't have members in tension

$$R_{y2} = 3.016\ lbf = P, \sigma_{b1} = \frac{0.077(3.016)+279.39}{0.01474} = 18.97\ kpsi, n_{p1} = \frac{25.273}{18.97} = 1.33$$

$$W = 0.0914lb, \sigma_{b3} = \frac{0.37(0.0914) + 279.39}{0.01474} = 18.96\ kpsi, n_{p3} = \frac{25.273}{18.96} = 1.33$$

6 - Factor of Safety the situations of overloading and load separation on the selected bolt

Factor of Safety for Figure 6 & 7 -

$$n_L = \frac{S_pA_t - F_i}{CP} = \frac{(25.273 * 10^3)(.0174) - (279.39)}{(0.077)(3.016)} = 401.04$$

$$n_0 = \frac{F_i}{P(1-C)} = \frac{P_0}{P} = \frac{(279.39)}{(3.016)(1-0.077)} = 100.36$$

Factor of Safety for Figure 8 & 9 - Cant be obtained because the Bolt is not under Tension so Stress is Zero so our Factor of Safety is Zero.

Factor of Safety for Figure 10 -

$$n_L = \frac{S_p A_t - F_i}{CP} = \frac{(25.273 * 10^3)(0.01475) - (279.39)}{(0.37)(3.016)} = 83.46$$

$$n_0 = \frac{F_i}{P(1-C)} = \frac{P_0}{P} = \frac{(279.39)}{(3.016)(1-0.37)} = 147.04$$

7 - Calculate the Minimum and Maximum load on the selected bolts

For Figure 6 and 7

$$F_{bmin} = CP_{min} + F_i = .077 * 0 + 279.39 = 279.3lb$$

$$F_{max} = CP_{max} + F_i = .077 * 3.016 + 279.39 = 279.622lb$$

For Figure 8 and 9

$$F_{bmin} = CP_{min} + F_i = .4688 * 0 + 279.39 = 279.3lb$$

$$F_{max} = CP_{max} + F_i = .4688 * 3.016 + 279.39 = 280.803lb$$

For Figure 10

$$F_{bmin} = CP_{min} + F_i = .37 * 0 + 279.39 = 279.3lb$$

$$F_{max} = CP_{max} + F_i = .37 * 3.016 + 279.39 = 280.505lb$$

8 - Factor of Safety Based on our rationale from the Fatigue Criteria we selected

Morrow Factor of Safety For Figures 6 & 7 -

$$\sigma_a = \frac{CP}{2A_t} = \frac{0.077(3.016)}{0.01474} = 7.877 \quad \sigma_m = \frac{CP}{2A_t} + \frac{F_i}{A_t} = \frac{0.077(3.016)}{0.01474} + \frac{279.39}{.01474} = 18962.42$$

$$n_f = \left(\frac{\sigma_a}{S_e} + \frac{\sigma_m}{\sigma_f{}'}\right)^{-1} = \left(\frac{7.877}{800.68} + \frac{18962.42}{120000}\right)^{-1} = 5.96$$

There is no Morrow Factor of Safety for Figures 8 & 9 due to the bolt not being under tension. Stress is zero and thus the factor of safety is zero.

Morrow Factor of Safety for Figure 5 -

$$\sigma_a = \frac{CP}{2A_t} = \frac{0.37(3.016)}{0.01474} = 37.85 \quad \sigma_m = \frac{CP}{2A_t} + \frac{F_i}{A_t} = \frac{0.37(3.016)}{0.01474} + \frac{279.39}{.01474} = 18992.40$$

$n_f = \left(\frac{\sigma_a}{S_e} + \frac{\sigma_m}{\sigma_f{}'}\right)^{-1} = \left(\frac{37.85}{800.68} + \frac{18992.40}{120000}\right)^{-1} = 4.87$

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