RBE 2001 Project Presentation: Team 8

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Overview of Strategy and Systems

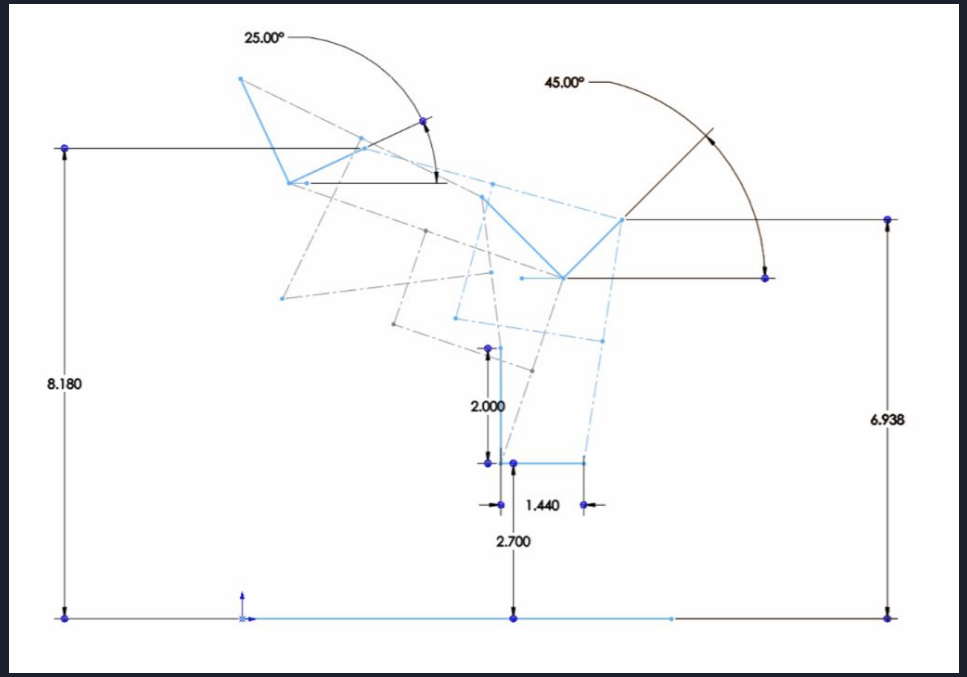
Strategy:

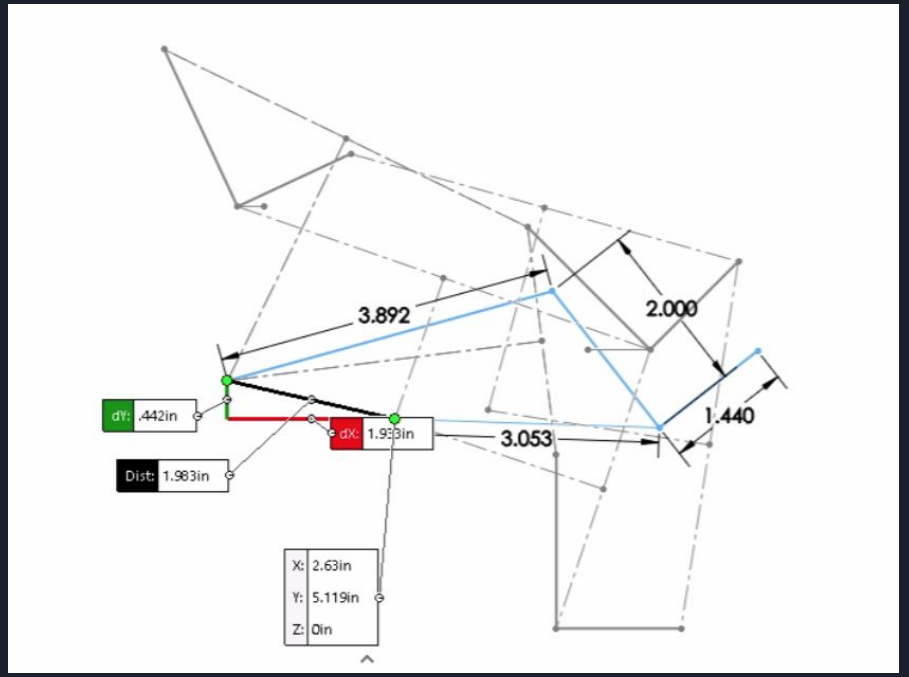
- Our goal is to autonomously complete the entire challenge in one run
- Aim to earn the most amount of bonus points possible
- Fine tune PID for increased accuracy and precision
- Robot completely assembled 3 days prior to demo

Systems:

- Maintain less than 25% stall torque
- Designed gripper to be in toggle point when in locked position
- Designed 18:1 compound transmission
- Designed lifting mechanism base to maximize space for electronics and sensors

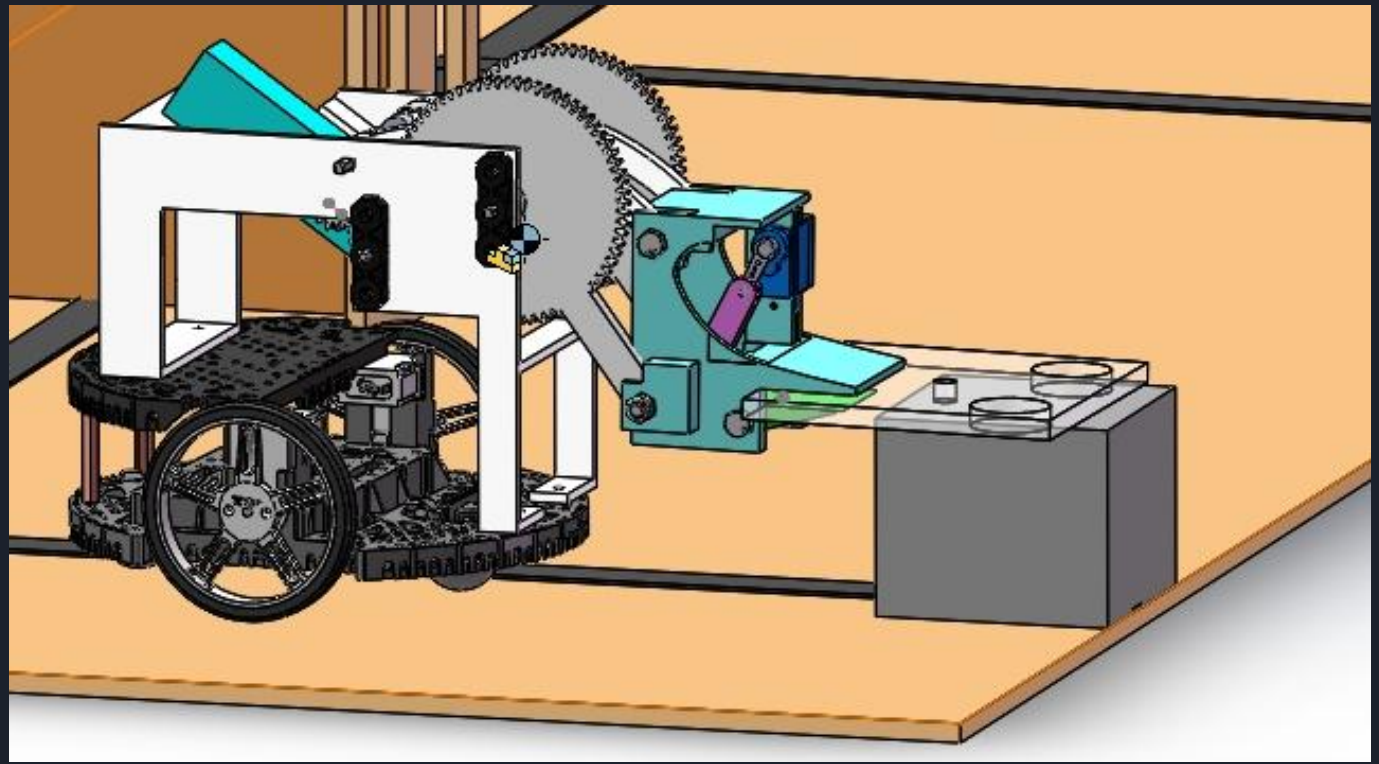
Linkage Synthesis Design Process





Video Demonstration of SolidWorks Model

Screenshots of Complete Robot with Aluminum Plate in Max. Reach Positions



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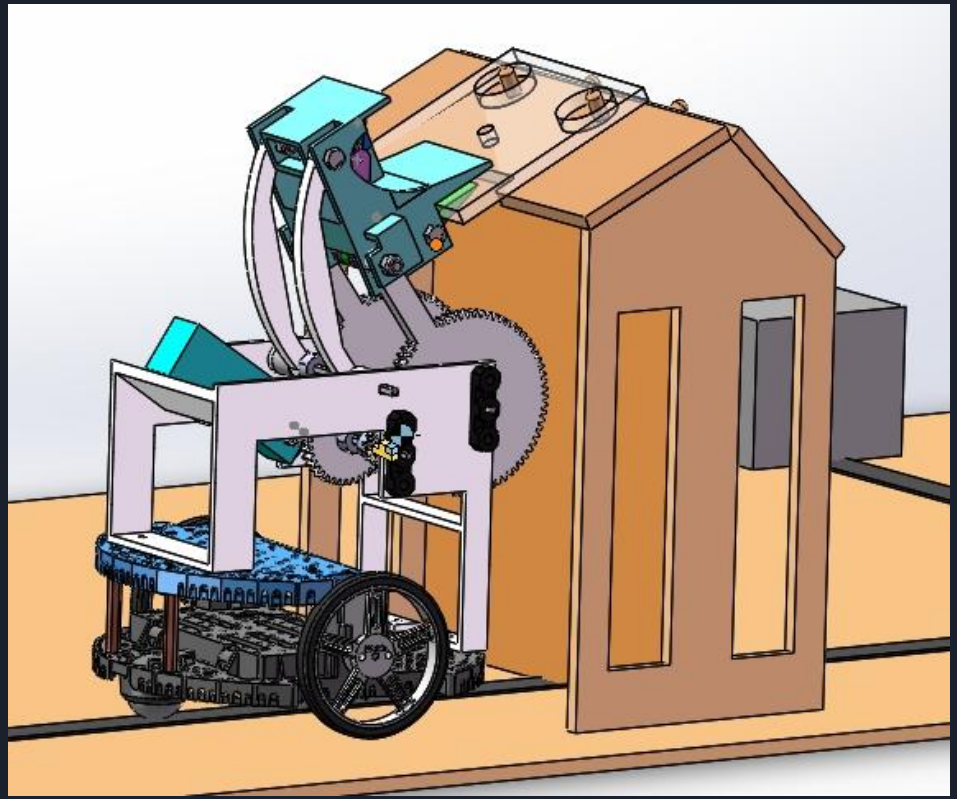
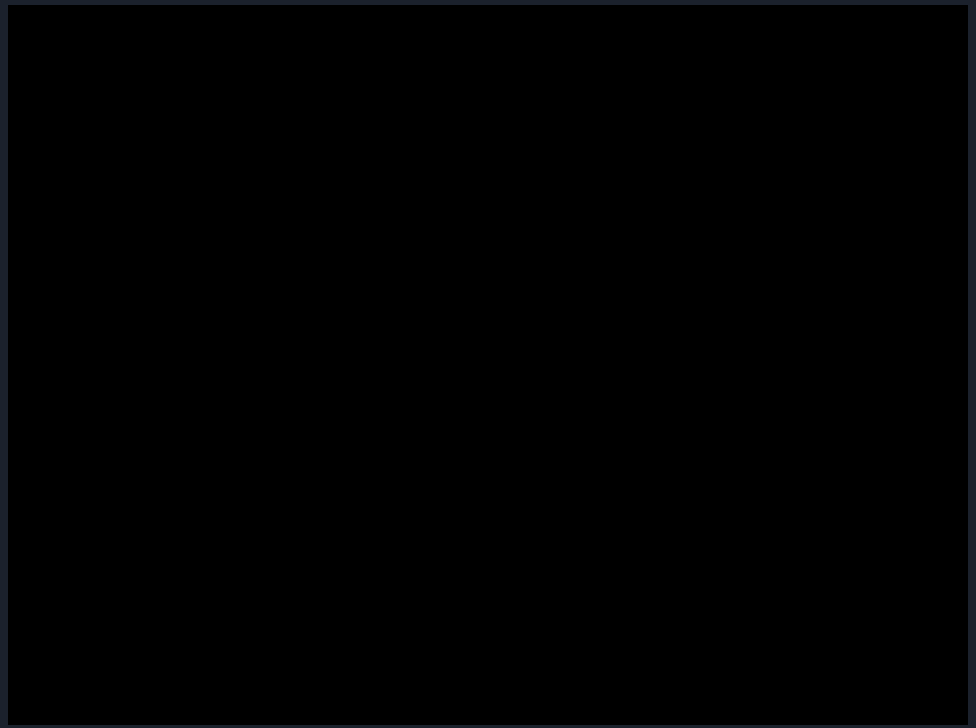
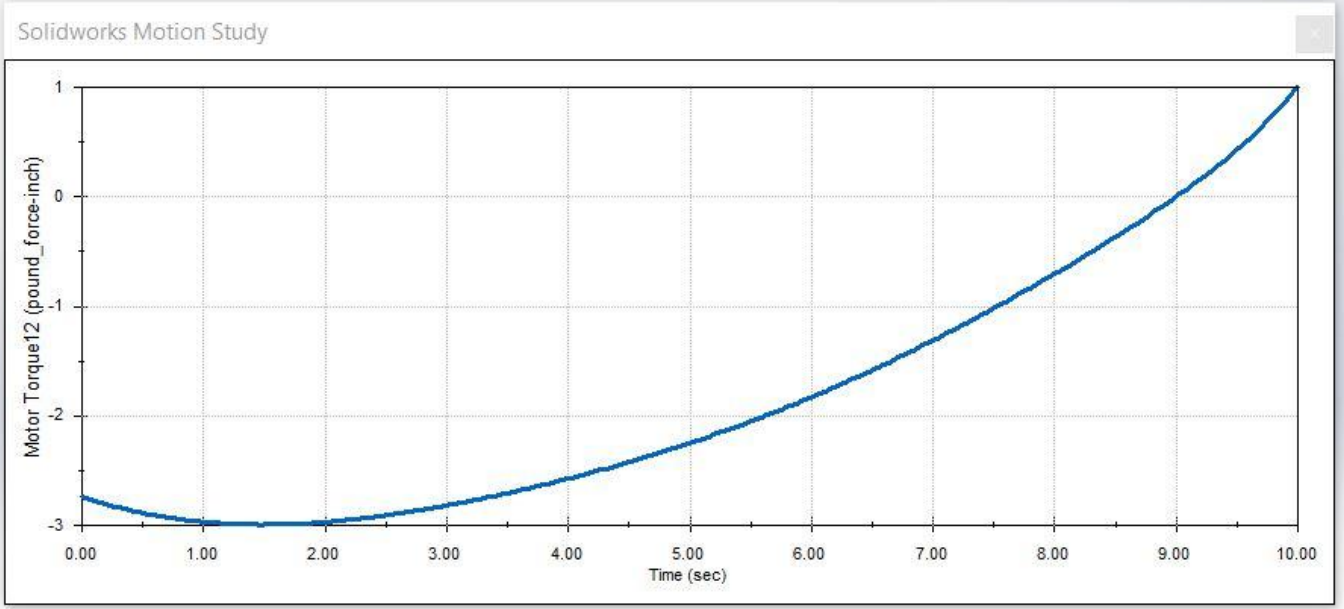
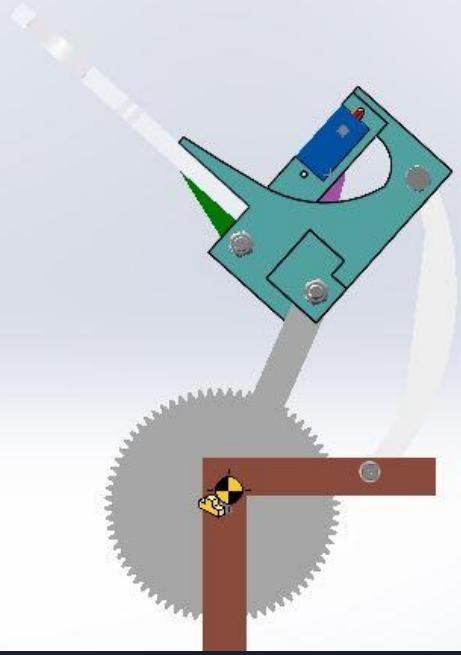


Video Demo of SolidWorks Motion Study: Crank Torque through Range of Motion



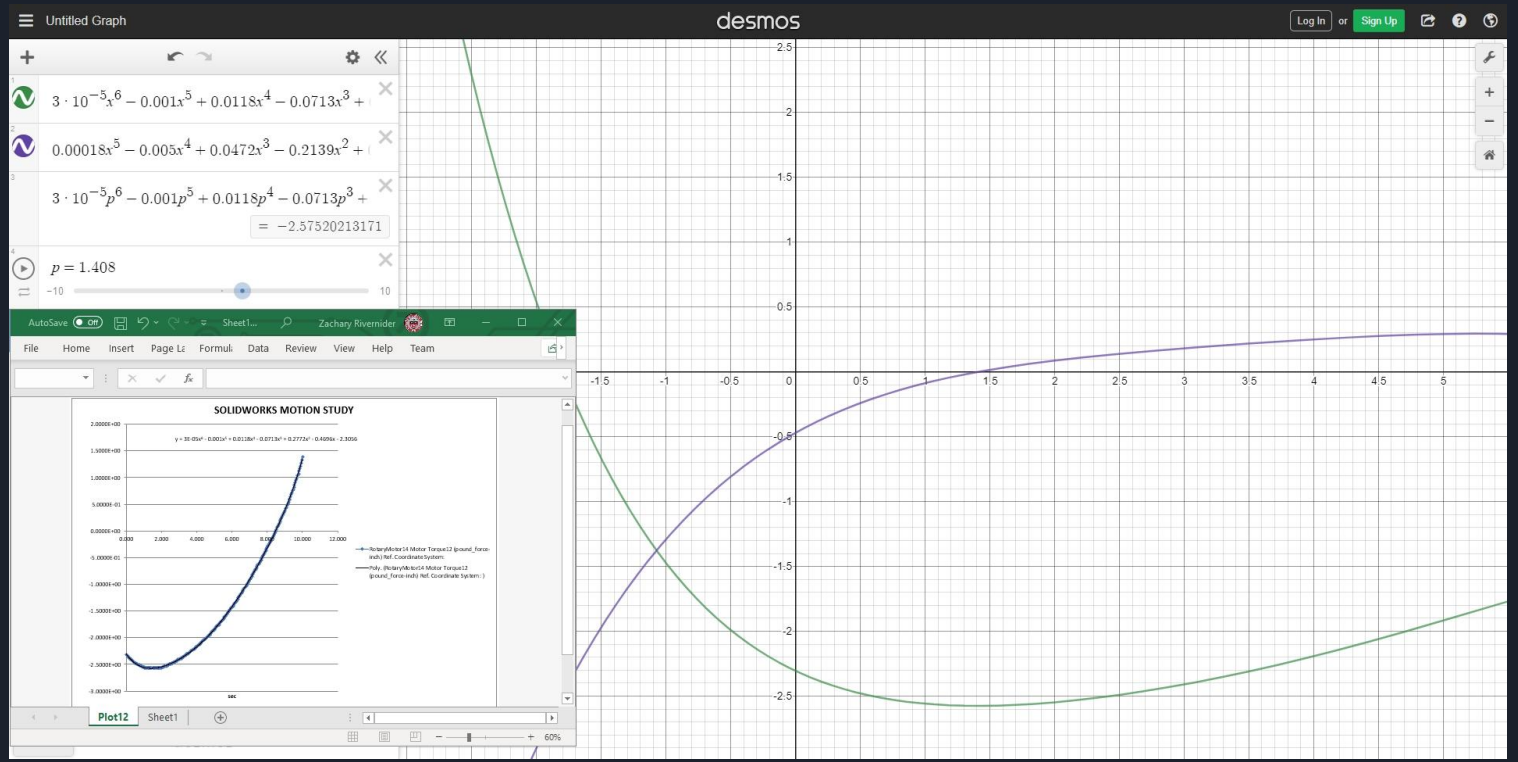
Solidworks Motion Study



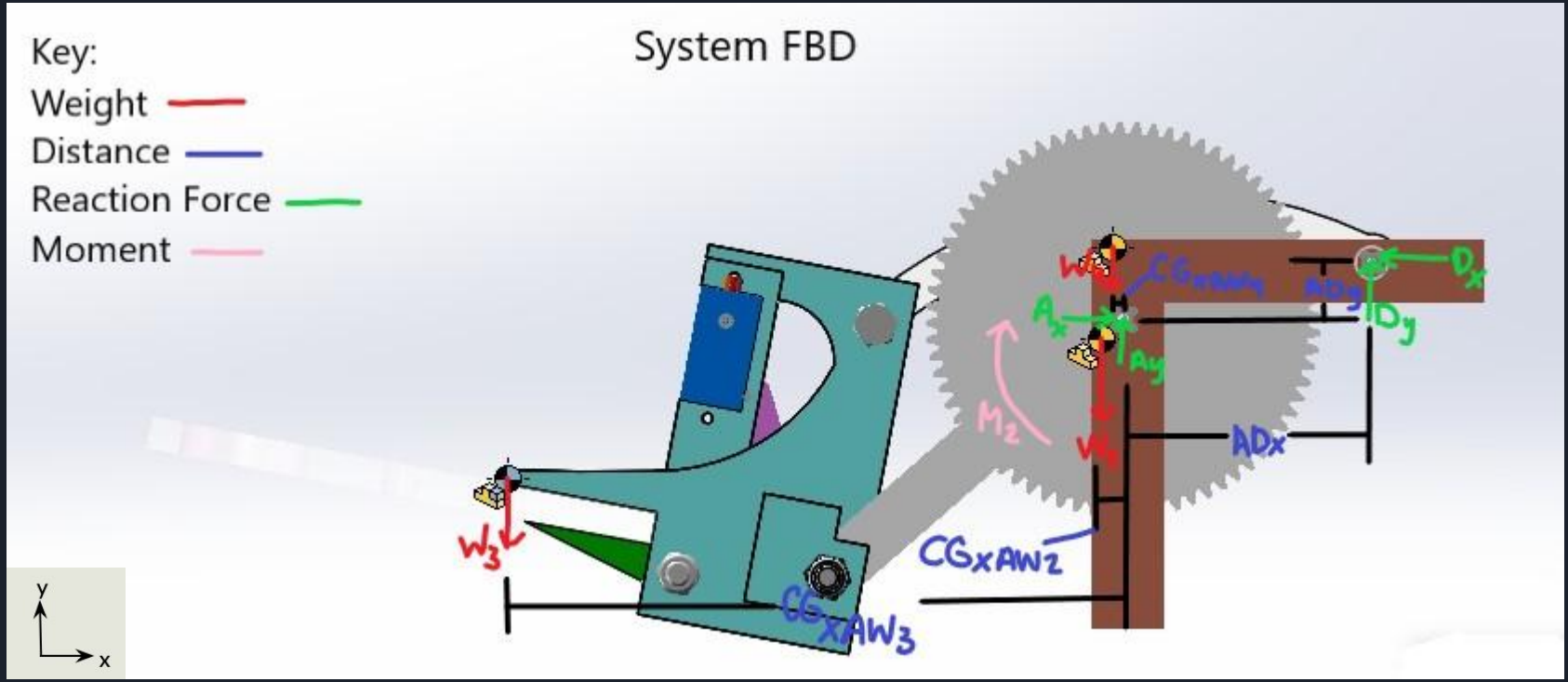


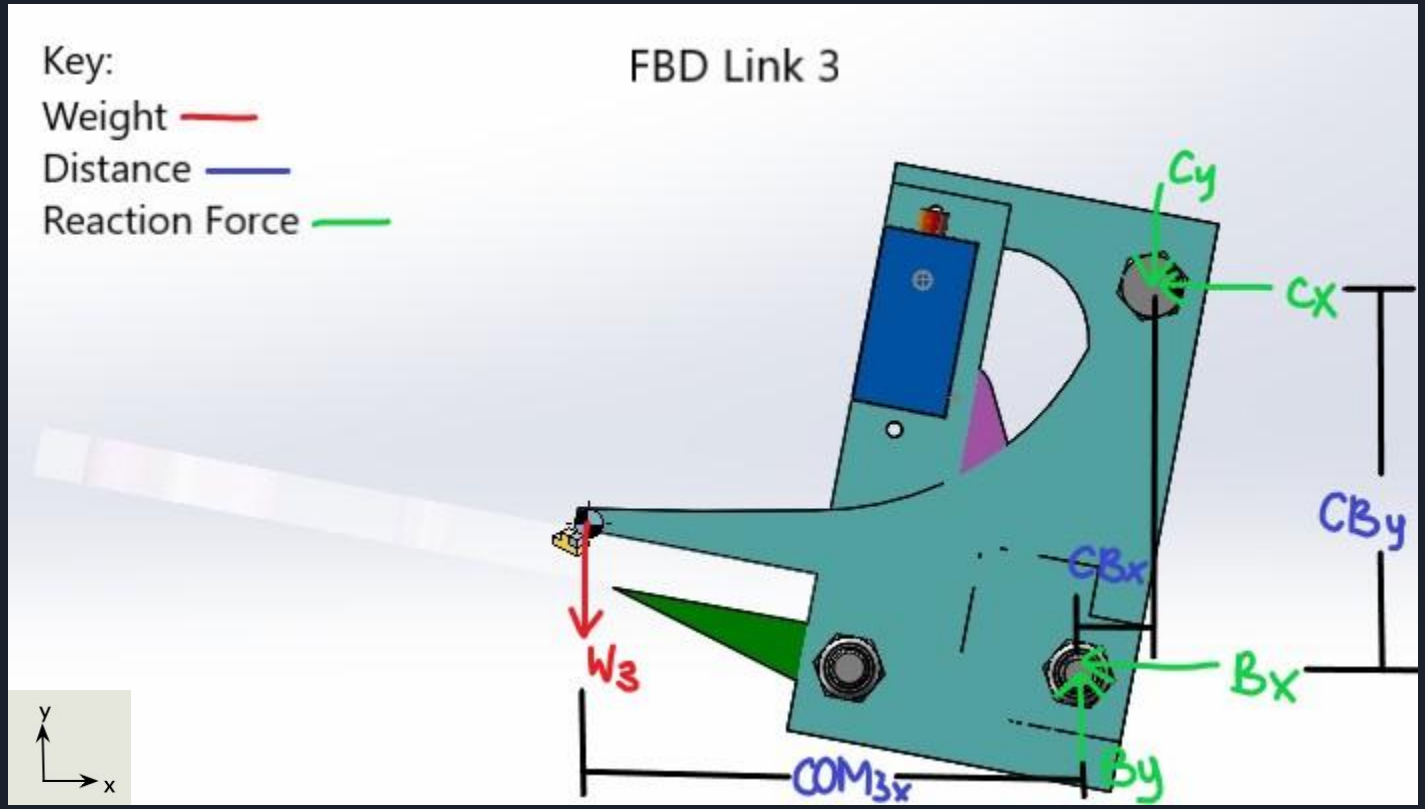
Evaluating Solidworks Motion Study

T_{MAX}= 2.575 in-lbf



Lifting Mechanism Force Analysis: Crank Torque and Forces on Joints

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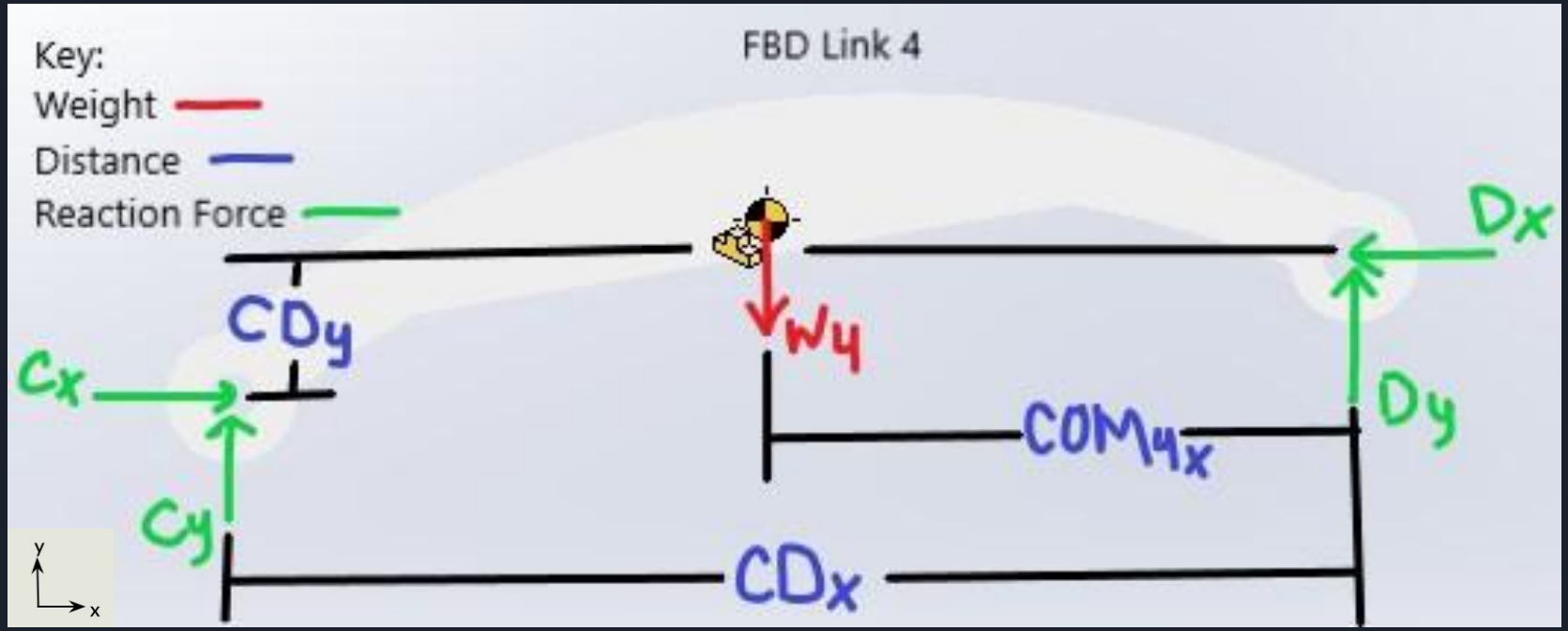
Weight
Distance
Reaction Force
FBD Link 3
Cy
Cx
CBy
CBx
W3
Bx
By
COM3x
y
x


FBD Link 4
Key:
Weight
Distance
Reaction Force
CDy
Cx
Cy
W4
COM4x
CDx
Dx
Dy
y
x

Known Parameters:

$a := 3.053in$ $b := 2in$ $cc := 3.892in$ $d := 1.983in$ $W_4 := .021lbf$ $CG_{xAW2} := .169in$ $CG_{xAW3} := 4.785in$ $CG_{xAW4} := 0.062in$ $CB_x := .373in$ $CB_y := 1.965in$

$W_2 := .07157lbf$ $W_3 := 0.56lbf$ $Theta_2 := 47.20deg$ $Theta_4 := 79.67deg$ $COM_{3x} := 2.581in$ $COM_{4x} := 1.969in$ $AD_x := 1.933in$ $AD_y := .442in$ $CD_x := 3.862in$ $CD_y := .482in$

Supply initial guesses for unknowns:

$A_x := 2lbf$ $A_y := 2lbf$ $B_x := 2lbf$ $B_y := 2lbf$

$C_x := 2lbf$ $C_y := 2lbf$ $D_x := 2lbf$ $D_y := 2lbf$

$M_2 := 4in \cdot lbf$ $M_4 := 4in \cdot lbf$

From equations of equilibrium we have nine equations with nine unknowns:

Given

From FBE of L_2, L_3, and L_4 as a system:

$0 = -M_2 + W_2 \cdot CG_{xAW2} + W_3 \cdot CG_{xAW3} + W_4 \cdot CG_{xAW4} + D_x \cdot AD_y + D_y \cdot AD_x$ $\Sigma M_A := 0$

$0 = A_x - D_x$ $\Sigma F_x := 0$

$0 = A_y + D_y - W_2 - W_3 - W_4$ $\Sigma F_y := 0$

From FBE of L_3:

$0 = W_3 \cdot COM_{3x} + C_x \cdot CB_y - C_y \cdot CB_x$ $\Sigma M_B := 0$

$0 = -C_x - B_x$ $\Sigma F_x := 0$

$0 = B_y - C_y - W_3$ $\Sigma F_y := 0$

From FBE of L_4:

$0 = W_4 \cdot COM_{4x} + C_x \cdot CD_y - C_y \cdot CD_x$ $\quad \Sigma M_D := 0$

$0 = C_x - D_x$ $\quad \Sigma F_x := 0$

$0 = C_y + D_y - W_4$ $\quad \Sigma F_y := 0$

$$\begin{pmatrix} SA_x \\ SA_y \\ SB_x \\ SB_y \\ SC_x \\ SC_y \\ SD_x \\ SD_y \\ SM_2 \end{pmatrix} := \text{Find}(A_x, A_y, B_x, B_y, C_x, C_y, D_x, D_y, M_2)$$

$SA_x = -0.75\,\text{lbf}$

$SA_y = 0.55\,\text{lbf}$

$SB_x = 0.75\,\text{lbf}$

$SB_y = 0.48\,\text{lbf}$

$SC_x = -0.75\,\text{lbf}$

$SC_y = -0.08\,\text{lbf}$

$SD_x = -0.75\,\text{lbf}$

$SD_y = 0.1\,\text{lbf}$

$SM_2 = 2.56\,\text{in}\cdot\text{lbf}$

Gear Teeth Force Analysis

Given

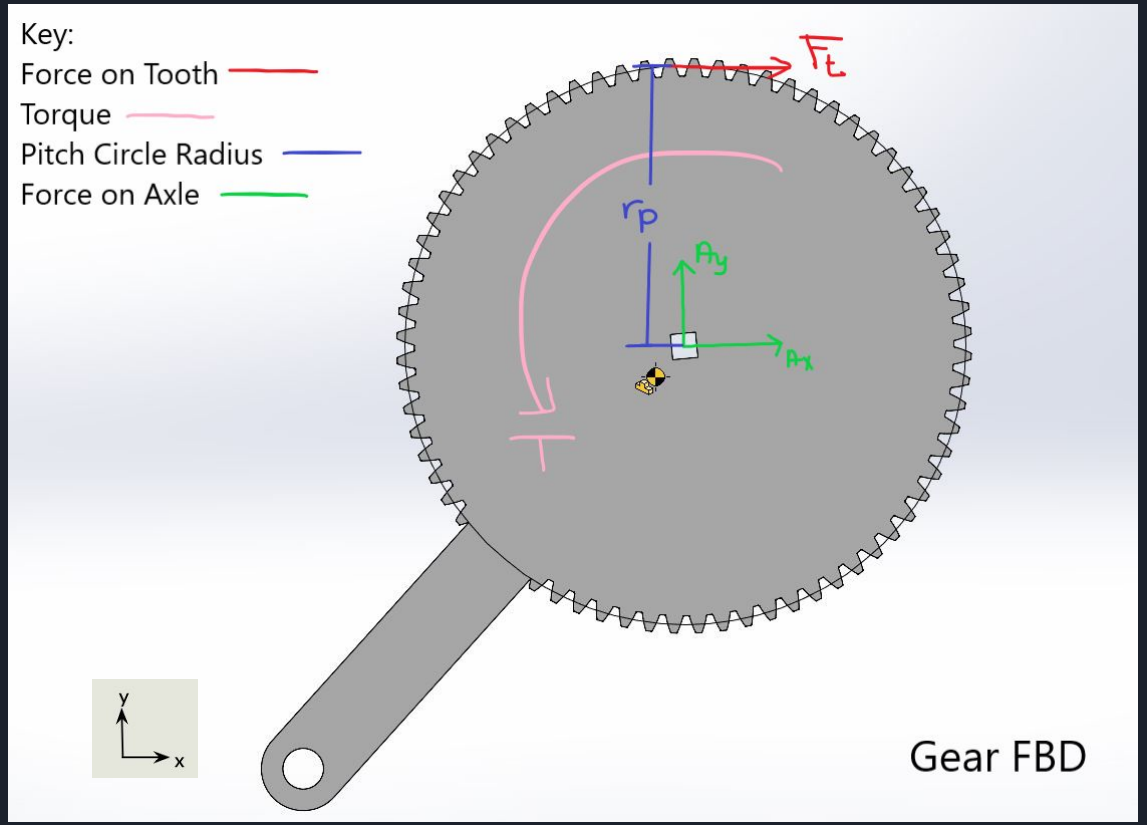
$T := 2.57 in\,lbf \qquad r := 1.5 in$

Guess

$F_t := 2 lbf$

$0 = T - F_t \cdot r \qquad \Sigma M_A := 0$

$Find(F_t) = 1.713\,lbf$



Stresses and Factor of Safety of Gear Teeth

Stress Analysis

Given

$b := .25in \qquad P := 24\frac{1}{in} \qquad T := 2.57in\,lbf \qquad r := 1.5in$

Equations

$t := \frac{\pi}{2P} \qquad d := 2r \qquad F := \frac{(2T)}{d} \qquad A := b \cdot t \qquad \tau := \frac{F}{A}$

$\tau = 104.711\,psi$

Factor of Safety

Given

$\tau := 104.711psi \qquad \tau_y := 2500psi$

$FOS := \frac{\tau_y}{\tau} = 23.875$

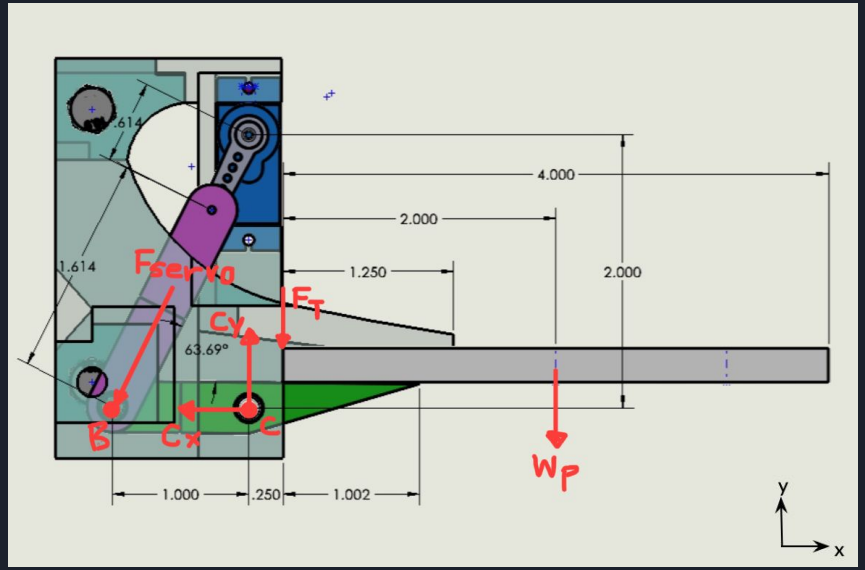
Gripping Mechanism in Locked Position Force Analysis

F_{servo} = 1.116 lbf

C_y = 1.916 lbf

C_x = -0.494 lbf

Torque of servo is **zero** because the line of action of F_{servo} passes through the pivot point.



$$\text{Find}(F_{servo}, C_y, C_x) = \begin{pmatrix} 2.12 \\ 3.32 \\ -0.939 \end{pmatrix} \cdot \text{lbf}$$

Finding F_T

Knowns

$W_P := 0.4 \cdot \text{lbf}$ $d_{wp1} := 2 \cdot \text{in}$ $d_{Fb} := 1.00 \cdot \text{in}$

Guesses for F_T and F_B

$F_T := 1 \cdot \text{lbf}$ $F_B := 1 \cdot \text{lbf}$

Given

$0 = F_B \cdot d_{Fb} - W_P \cdot d_{wp1}$ $\Sigma M_{pivot} = 0$

$0 = F_B - F_T - W_P$ $\Sigma F_y = 0$

$\text{Find}(F_B, F_T) = \begin{pmatrix} 0.8 \\ 0.4 \end{pmatrix} \text{lbf}$

Finding Forces on Joints

Knowns

$W_P := 0.4 \cdot \text{lbf}$ $d_{CW} := 2.25 \cdot \text{in}$ $d_{CFt} := 0.25 \cdot \text{in}$ $d_{CB} := 1 \cdot \text{in}$

$\text{theta} := 63.69 \cdot \text{deg}$ $F_T := 0.4 \cdot \text{lbf}$

Guesses for F_{Σ} and F_B

$F_{servo} := 1 \cdot \text{lbf}$ $C_y := 1 \cdot \text{lbf}$ $C_x := 1 \cdot \text{lbf}$

Given

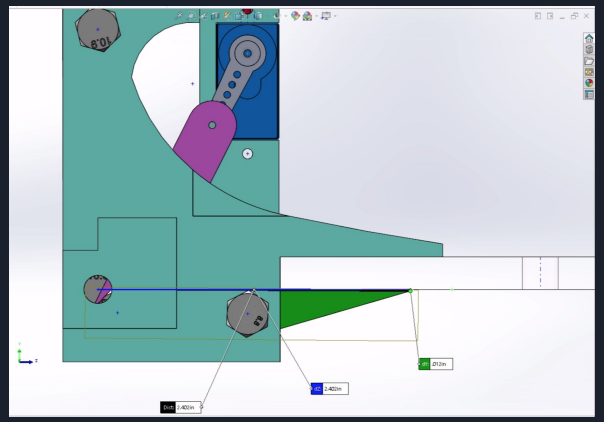
$0 = F_{servo} \cdot \sin(\text{theta}) \cdot d_{CB} - F_T \cdot d_{CFt} - W_P \cdot d_{CW}$ $\Sigma M_C = 0$

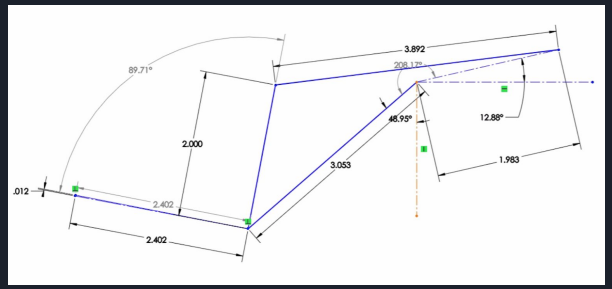
$0 = -F_{servo} + C_y - F_T - W_P$ $\Sigma F_y = 0$

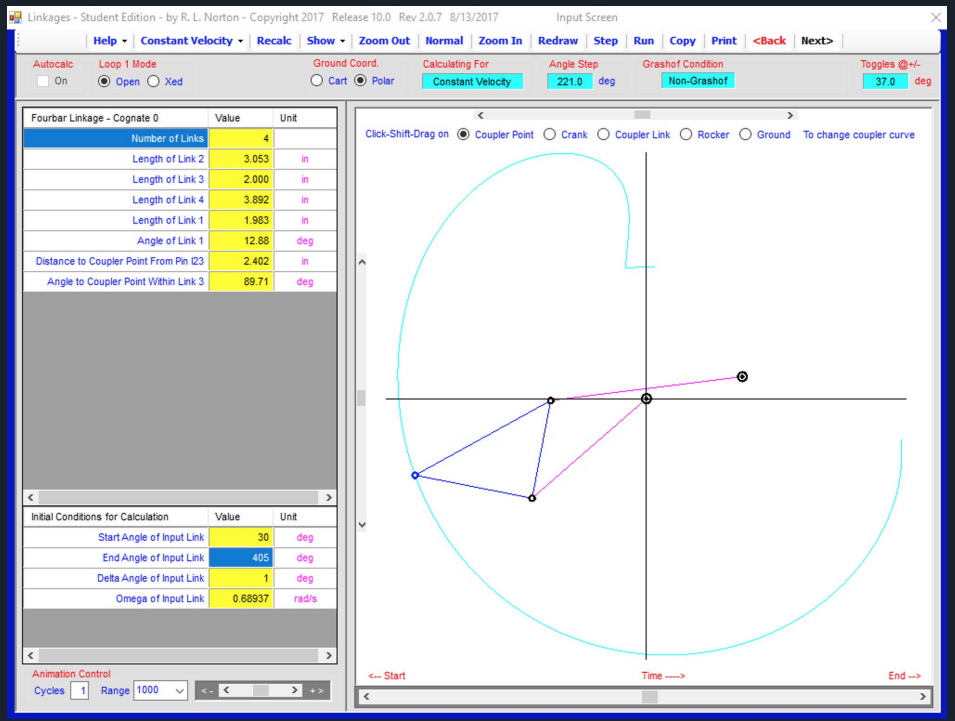
$0 = -F_{servo} \cdot \cos(\text{theta}) - C_x$ $\Sigma F_x = 0$

$\text{Find}(F_{servo}, C_y, C_x) = \begin{pmatrix} 1.116 \\ 1.916 \\ -0.494 \end{pmatrix} \text{lbf}$

Four-Bar Component Speeds at Max. Torque Position

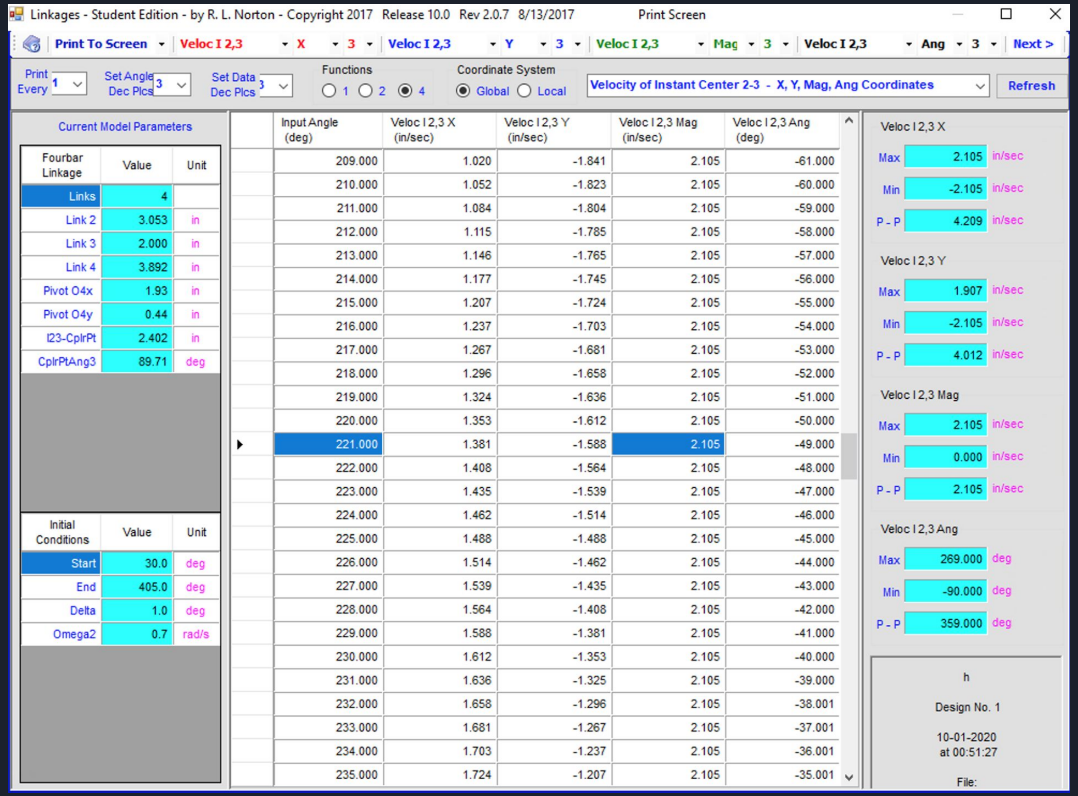






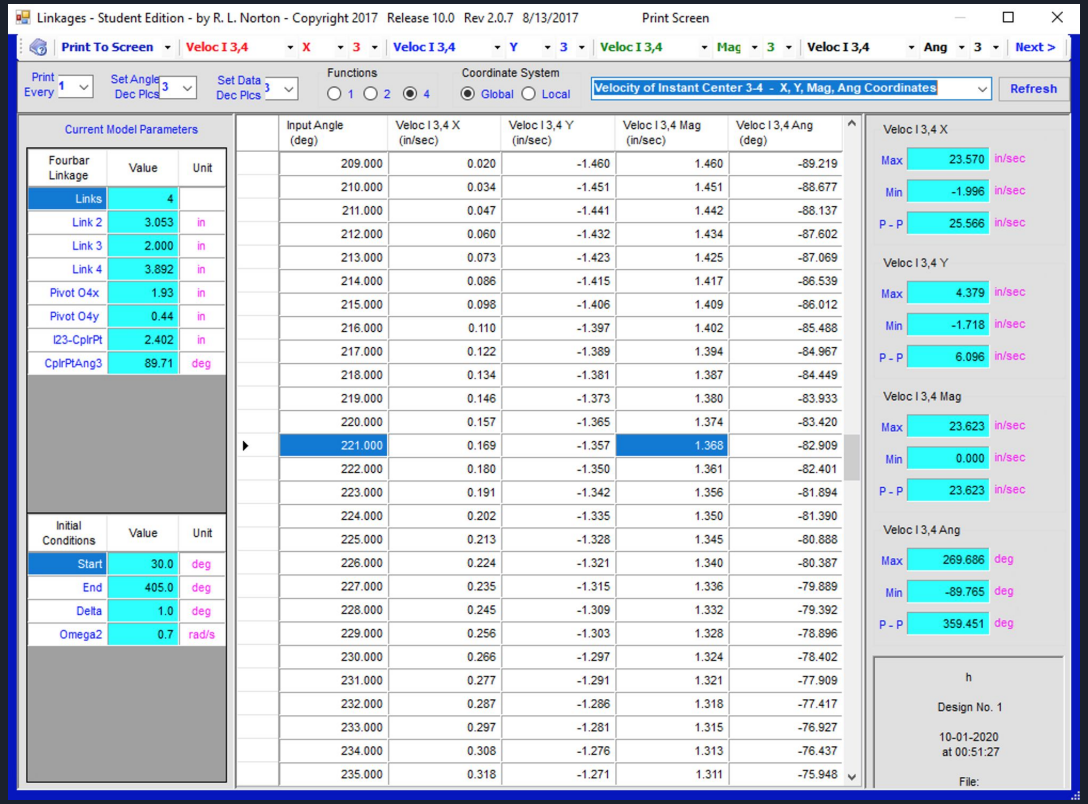
Four-Bar Component Speeds at Max. Torque Position: Linkages Software Results

V_A = 2.105 in/s



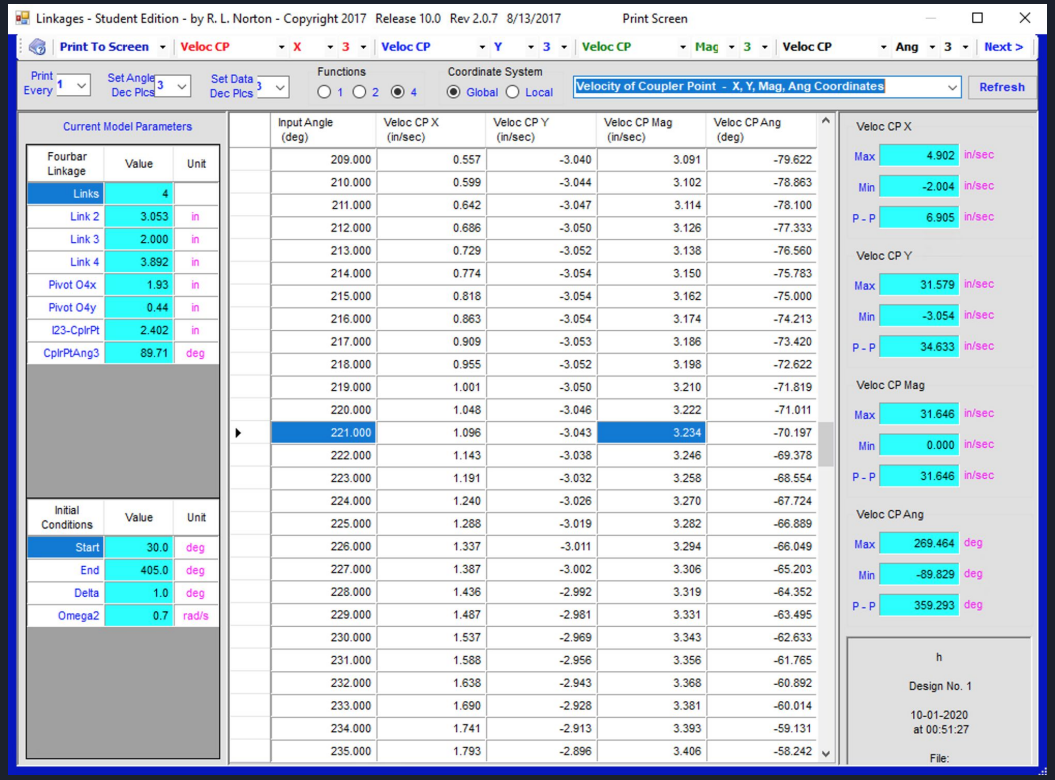
Four-Bar Component Speeds at Max. Torque Position: Linkages Software Results

V_B = 1.368 in/s



Four-Bar Component Speeds at Max. Torque Position: Linkages Software Results

$V_{coupler} = 3.234$ in/s



Four-Bar Component Speeds at Max. Torque Position: Mathcad Results

Speed of **A** at maximum torque position was found to be 2.105 in/s.

Speed of **B** at maximum torque position was found to be 1.367 in/s.

Speed of **coupler** at maximum torque position was found to be 3.234 in/s.

Answers obtained using Linkages software and Mathcad are the same.

$a := 3.053 \cdot in \quad b := 2 \cdot in \quad c := 3.892 \cdot in \quad d := 1.983 \cdot in \quad theta2 := 208.17 deg$

$p := 2.402 \cdot in \quad angToC := 89.71 deg$

$K_1 := \frac{d}{a} = 0.65 \quad K_2 := \frac{d}{c} = 0.51 \quad K_3 := \frac{\left(a^2 - b^2 + c^2 + d^2\right)}{2 \cdot a \cdot c} = 1.027$

$A := \cos(theta2) - K_1 - K_2 \cdot \cos(theta2) + K_3 = -0.055$

$B := -2 \cdot \sin(theta2) = 0.944$

$C := K_1 - (K_2 + 1) \cdot \cos(theta2) + K_3 = 3.007$

$theta4_2 := 2 \cdot atan\left(\frac{-B + \sqrt{B^2 - 4 \cdot A \cdot C}}{2 \cdot A}\right) = -139.963 \cdot deg$

$alternate\_theta4_2 := theta4_2 + 2 \cdot \pi = 220.037 \cdot deg$

$theta4_1 := 2 \cdot atan\left(\frac{-B - \sqrt{B^2 - 4 \cdot A \cdot C}}{2 \cdot A}\right) = 174.236 \cdot deg$

$K_4 := \frac{d}{b} = 0.992 \quad K_5 := \frac{c^2 - d^2 - a^2 - b^2}{2 \cdot a \cdot b} = -0.172$

$D := \cos(theta2) - K_1 + K_4 \cdot \cos(theta2) + K_5 = -2.578 \quad E := -2 \cdot \sin(theta2) = 0.944$

$F := K_1 + (K_4 - 1) \cdot \cos(theta2) + K_5 = 0.485$

$theta3_2 := 2 \cdot atan\left(\frac{-E + \sqrt{E^2 - 4 \cdot D \cdot F}}{2 \cdot D}\right) = -32.085 \cdot deg$

$alternate\_theta3_2 := theta3_2 + 2 \cdot \pi = 327.915 \cdot deg$

$theta3_1 := 2 \cdot atan\left(\frac{-E - \sqrt{E^2 - 4 \cdot D \cdot F}}{2 \cdot D}\right) = 66.358 \cdot deg$

$alternate\_theta3_1 := theta3_1 + 2 \cdot \pi = 426.358 \cdot deg$

$\omega_2 := 0.68937 \cdot \frac{rad}{s}$

$V_A := a \cdot \omega_2 = 2.105 \cdot \frac{in}{s}$

$\omega_3 := \frac{a \cdot \omega_2 \cdot \sin(theta4_1 - theta2)}{b \cdot \sin(theta3_1 - theta4_1)} = 0.617 \cdot \frac{rad}{s}$

$\omega_4 := \frac{a \cdot \omega_2 \cdot \sin(theta2 - theta3_1)}{c \cdot \sin(theta4_1 - theta3_1)} = 0.351 \cdot \frac{rad}{s}$

$V_{Ax} := a \cdot \omega_2 \cdot (-\sin(theta2)) = 0.994 \cdot \frac{in}{s}$

$V_{Ay} := a \cdot \omega_2 \cdot (\cos(theta2)) = -1.855 \cdot \frac{in}{s}$

$V_{Amag} := \sqrt{V_{Ax}^2 + V_{Ay}^2} = 2.105 \cdot \frac{in}{s}$ **Confirms V_A calculated previously**

$V_{Bx} := c \cdot \omega_4 \cdot \left(-\sin(theta4_1)\right) = -0.137 \cdot \frac{in}{s}$

$V_{By} := c \cdot \omega_4 \cdot \left(\cos(theta4_1)\right) = -1.36 \cdot \frac{in}{s}$

$V_{Bmag} := \sqrt{V_{Bx}^2 + V_{By}^2} = 1.367 \cdot \frac{in}{s}$ **V_B calculated result**

$V_{CAx} := p \cdot \omega_3 \cdot -\sin(theta3_1 + angToC) = -0.601 \cdot \frac{in}{s}$

$V_{CAy} := p \cdot \omega_3 \cdot \cos(theta3_1 + angToC) = -1.355 \cdot \frac{in}{s}$

$V_{Cx} := V_{Ax} + V_{CAx} = 0.392 \cdot \frac{in}{s}$

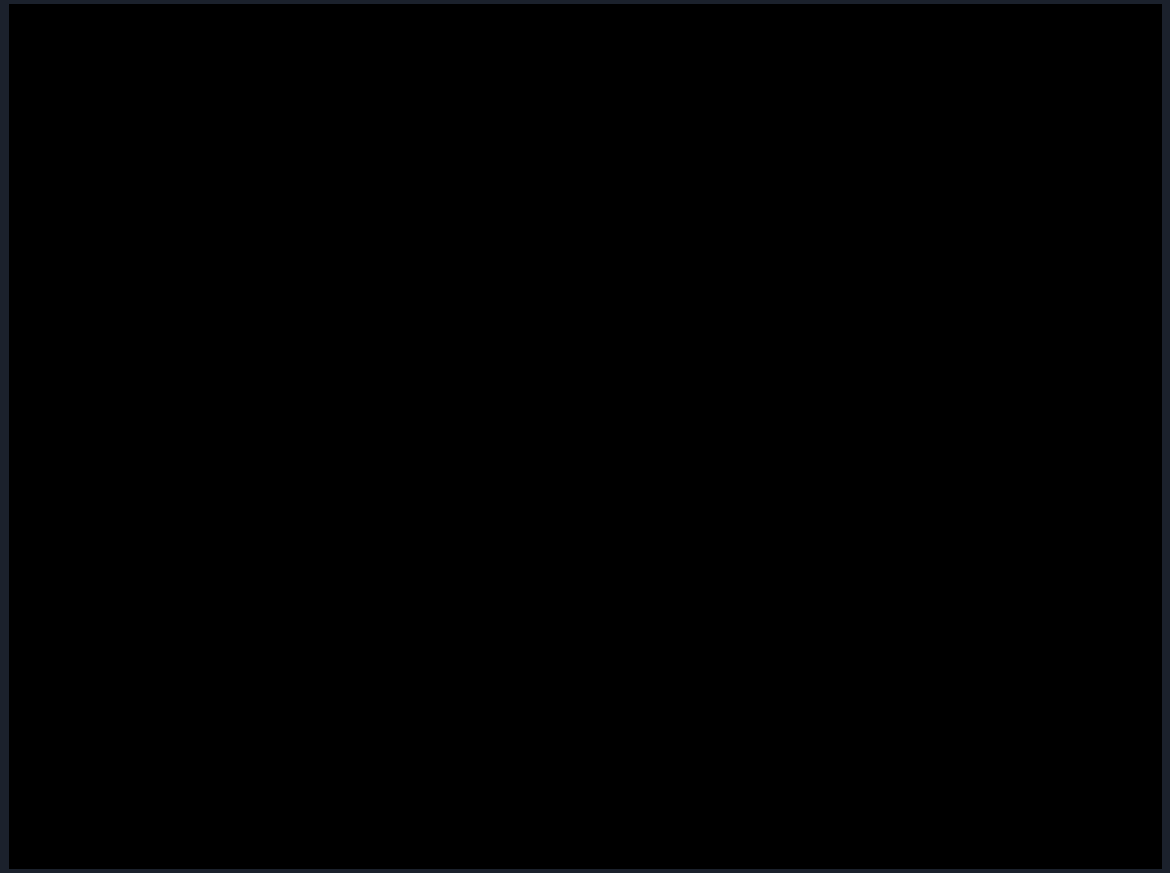
$V_{Cy} := V_{Ay} + V_{CAy} = -3.211 \cdot \frac{in}{s}$

$V_{Cmag} := \sqrt{V_{Cx}^2 + V_{Cy}^2} = 3.234 \cdot \frac{in}{s}$ **V_C calculated result**

Summary of Sensors

- Ultrasonic sensor (range/distance finder)
  - Used to navigate the field, to find distance between robot and house/loading platform
- IR receiver
  - Used to receive commands from the remote; turns on robot; confirms before moving on to next state.
- QTR Reflector sensor array (line tracking)
  - Used to navigate the field, to trace the line on the field from house to box
- BlueMotor encoder
  - Used to drive the lifting mechanism; indicates position of Blue Motor (through encoder count)
- Chassis motors encoders
  - Used to drive robot chassis; allows for drive() and turnAngle() by keeping track of encoder counts.
- Servo analog input
  - Used to get servos current position to determine whether gripper is completely open or closed

Assembly Video of Gripper



Blue Motor Current Requirement at Max. Torque Position

Blue Motor	
Tstall (in-lbf)	0.7047
wnoload (RPM)	158
Inoload (A)	0.033
Istall (A)	0.3
Ref Voltage	9
R_A	30
$V_T = R_A I_A + E_A$	

Speed (RPM)	Torque (N	Torque (in-lbf	Current (A)	Pout (W)	Efficiency	Pin (W)	Heat (W)	back-EMF (V)
0	0.0796	0.705	0.300	0.000	0.000	2.700	2.700	0.000
5	0.0771	0.682	0.292	0.040	1.538	2.624	2.584	0.253
7	0.0761	0.673	0.288	0.056	2.150	2.594	2.538	0.355
11	0.0741	0.656	0.281	0.085	3.369	2.533	2.447	0.558
13	0.0731	0.647	0.278	0.099	3.975	2.502	2.403	0.659
20	0.0695	0.615	0.266	0.146	6.079	2.396	2.250	1.014
27	0.0660	0.584	0.254	0.187	8.152	2.289	2.103	1.369
33	0.0630	0.558	0.244	0.218	9.902	2.198	1.980	1.673
40	0.0595	0.526	0.232	0.249	11.907	2.092	1.843	2.028
47	0.0559	0.495	0.221	0.275	13.867	1.985	1.710	2.383
53	0.0529	0.468	0.210	0.294	15.504	1.894	1.600	2.687
60	0.0494	0.437	0.199	0.310	17.358	1.787	1.477	3.042
67	0.0459	0.406	0.187	0.322	19.138	1.681	1.359	3.397
73	0.0428	0.379	0.177	0.327	20.595	1.590	1.262	3.701
79	0.0398	0.352	0.167	0.329	21.976	1.499	1.169	4.005
80	0.0393	0.348	0.165	0.329	22.198	1.483	1.154	4.056
87	0.0358	0.317	0.153	0.326	23.673	1.377	1.051	4.411
93	0.0328	0.290	0.143	0.319	24.811	1.286	0.967	4.715
100	0.0292	0.259	0.131	0.306	25.955	1.179	0.873	5.070
107	0.0257	0.227	0.119	0.288	26.844	1.073	0.785	5.424
118.5	0.0199	0.176	0.100	0.247	27.511	0.898	0.651	6.008
119	0.0197	0.174	0.099	0.245	27.511	0.890	0.645	6.033
121	0.0186	0.165	0.096	0.236	27.478	0.860	0.623	6.134
125	0.0166	0.147	0.089	0.218	27.245	0.799	0.581	6.337
135	0.0116	0.103	0.072	0.164	25.330	0.647	0.483	6.844
142	0.0081	0.071	0.060	0.120	22.187	0.540	0.420	7.199
149	0.0045	0.040	0.048	0.071	16.308	0.434	0.363	7.554
156	0.00	0.009	0.036	0.016	5.028	0.327	0.311	7.909

Program Pseudocode

Start robot

Line follow until ultrasonic sensor measures desired distance from house

Raise arm into position for picking up from roof

Open gripper and move forward a bit to have grabber around plate

Close gripper and pause until given signal from IR sensor to continue

Take off plate and drive to block (line following again)

Place plate and pause until given signal from IR sensor to continue

Fully let go and pause until given signal from IR sensor to continue

Grab new plate, fift new plate up and drive to house

Place plate on pins and wait to continue

Release plate, raise lifting mechanism and drive to other side of house (using driveDistance and line tracking)

Pick up plate and pause until given signal from IR sensor to continue

Drive to block and place plate and pause until given signal from IR sensor to continue

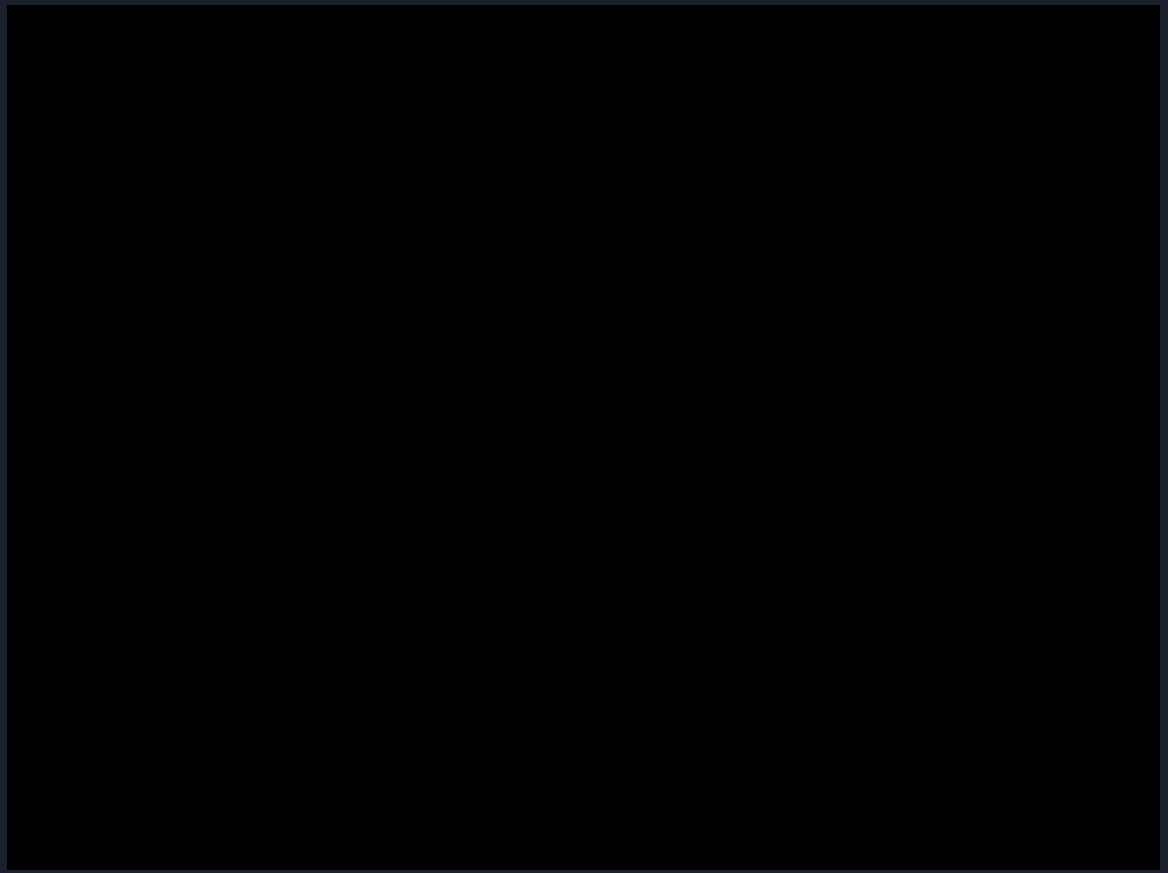
Release plate and pause until given signal from IR sensor to continue

Pick up new plate and pause until given signal from IR sensor to continue

Drive back to house and place on pins and pause until given signal from IR sensor to continue

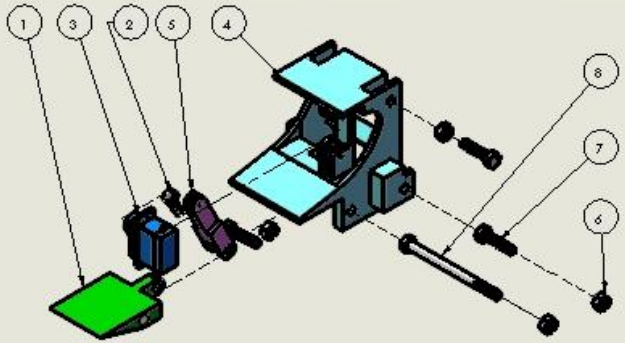
Release

Assembly Video of Lifting Mechanism



Exploded View of Gripper and Bill of Materials (BOM)

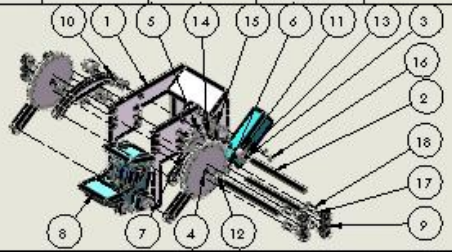
ITEM NO.	PART NUMBER	QTY.	UNIT COST	EXT. COST	MATERIAL	WEIGHT (LBS)	EXT. WEIGHT (LBS)
1	GRIPPER BOTTOM JAW	1	$.24	$0.24	PLA	0.0229	0.0229
2	SERVO HORN	1	$0.00	$0.00	NYLON	0.0004	0.0004
3	SERVO	1	$7.95	$7.95	SERVO	0.0156	0.0156
4	TOP JAW AND MOUNT	1	$1.31	$1.31	PLA	0.0993	0.0993
5	GRIPPER LINK 3	1	$0.10	$0.10	PLA	0.0076	0.0076
6	M5 NYLON INSERT LOCKNUT	6	$.04	$0.24	STEEL	0	0
7	M5 X 20 MM BOLT	5	$0.09	$0.45	STEEL	0	0
8	M5 X 45 MM BOLT	1	$0.13	$0.13	STEEL	0	0
				ASSEMBLY COST $10.42			EXT. WEIGHT (LBS) 0.1458



TEAM 8	SCALE: 1:2	GRIPPER ASSEMBLY	OCTOBER 6, 2020

Exploded View of Four Bar Mechanism and Bill of Materials (BOM)

ITEM NO.	PART NUMBER	QTY.	UNIT COST	EXT COST	MATERIAL	UNIT WEIGHT (LBS)	EXT. WEIGHT (LBS)
1	BASE FIXTURE	1	$3.41	$3.41	PLA	0.1637	0.1637
2	.4 INCH AXLE VEX	3	$0.83	$2.49	STEEL	0.0023	0.0069
3	BLUE MOTOR	1	$5.95	$5.95	MOTOR	0.696	0.696
4	72 TOOTH GEAR LINK	2	$1.08	$2.16	PLA	0.0716	0.1432
5	MOTOR 12 TOOTH GEAR	1	$0.03	$0.03	PLA	0.0015	0.0015
6	12 TOOTH GEAR	2	$0.03	$0.06	PLA	0.0016	0.0032
7	36 TOOTH GEAR	1	$0.25	$0.25	PLA	0.016	0.016
8	GRIPPER SUBASSEMBLY	1	$10.42	$10.42	GRIPPER SUBASSEMBLY	0.1568	0.1568
9	FLAT BEARING VEX	4	$0.54	$2.16	DELRIN	0.0034	0.0136
10	3.892 INCH CURVED LINK	2	$0.26	$0.52	PLA	0.0165	0.033
11	.5 INCH SPACER	2	$0.03	$0.06	NYLON	0.0031	0.0062
12	.25 INCH SPACER	2	$0.01	$0.02	PLA	0.0015	0.003
13	.125 INCH SPACER	2	$0.01	$0.02	PLA	0.0008	0.0016
14	SHAFT COLLAR VEX	8	$0.56	$4.48	STEEL	0.0012	0.0096
15	M3 x 40 MM BOLT	2	$0.16	$0.32	STEEL	0.0006	0.0012
16	M3 X 0.5 NUT	2	$0.01	$0.02	STEEL	0.0001	0.0002
17	#8-32 LOCK NUTS VEX	8	$0.04	$0.32	STEEL	0.0005	0.004
18	8-32 HEX 5/8 INCH VEX	8	$0.06	$0.48	STEEL	0.0006	0.0048
				ASSEMBLY COST $33.17			ASSEMBLY WEIGHT (LBS) 1.2645



TEAM 8	SCALE: 1:5	4-BAR WITH GRIPPER	OCTOBER 6, 2020