



RBE 2001 Project Presentation: Team 8

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Overview of Strategy and Systems

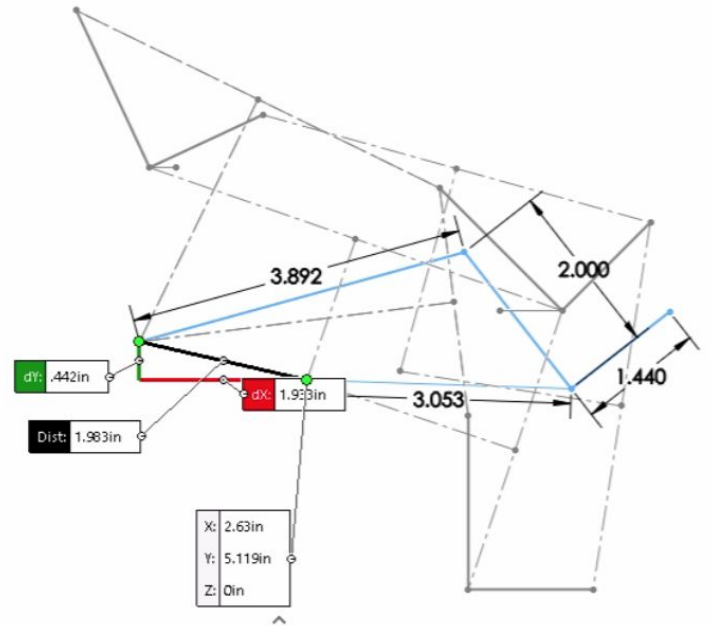
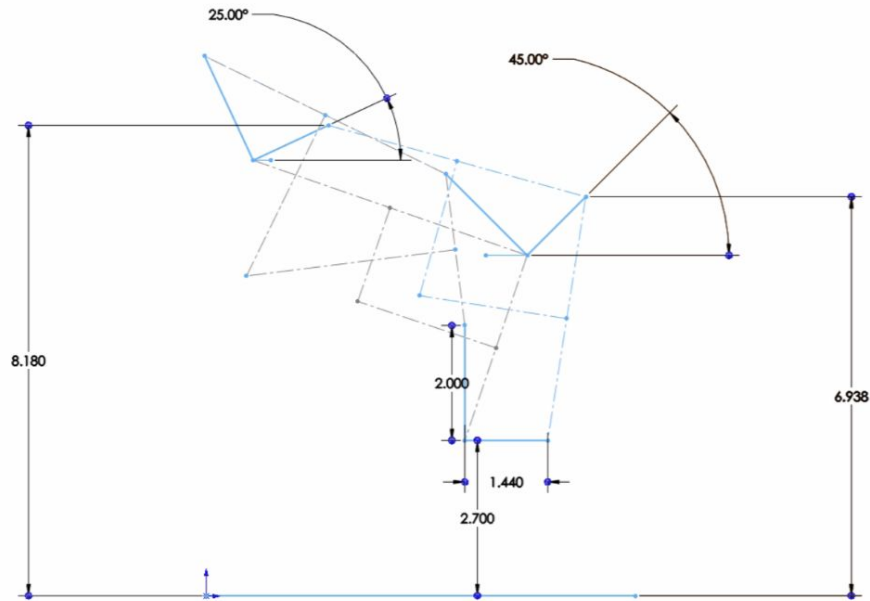
Strategy:

- 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

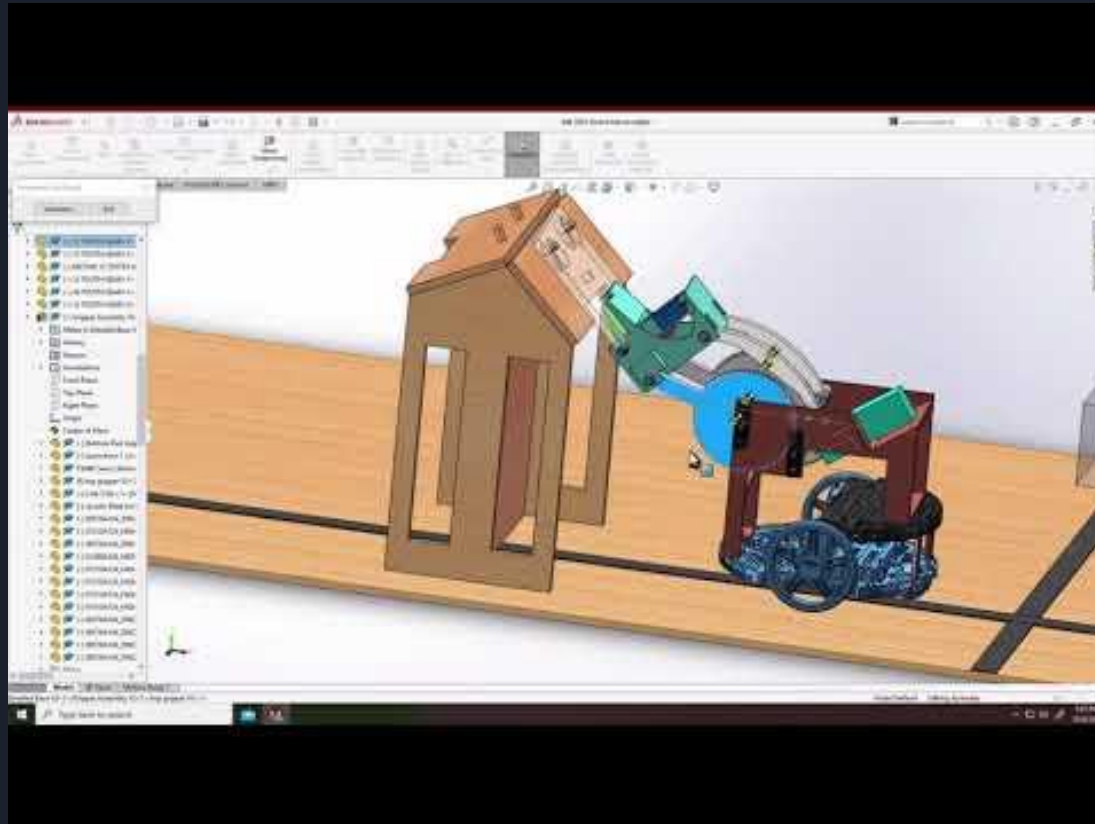
Systems:

- 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

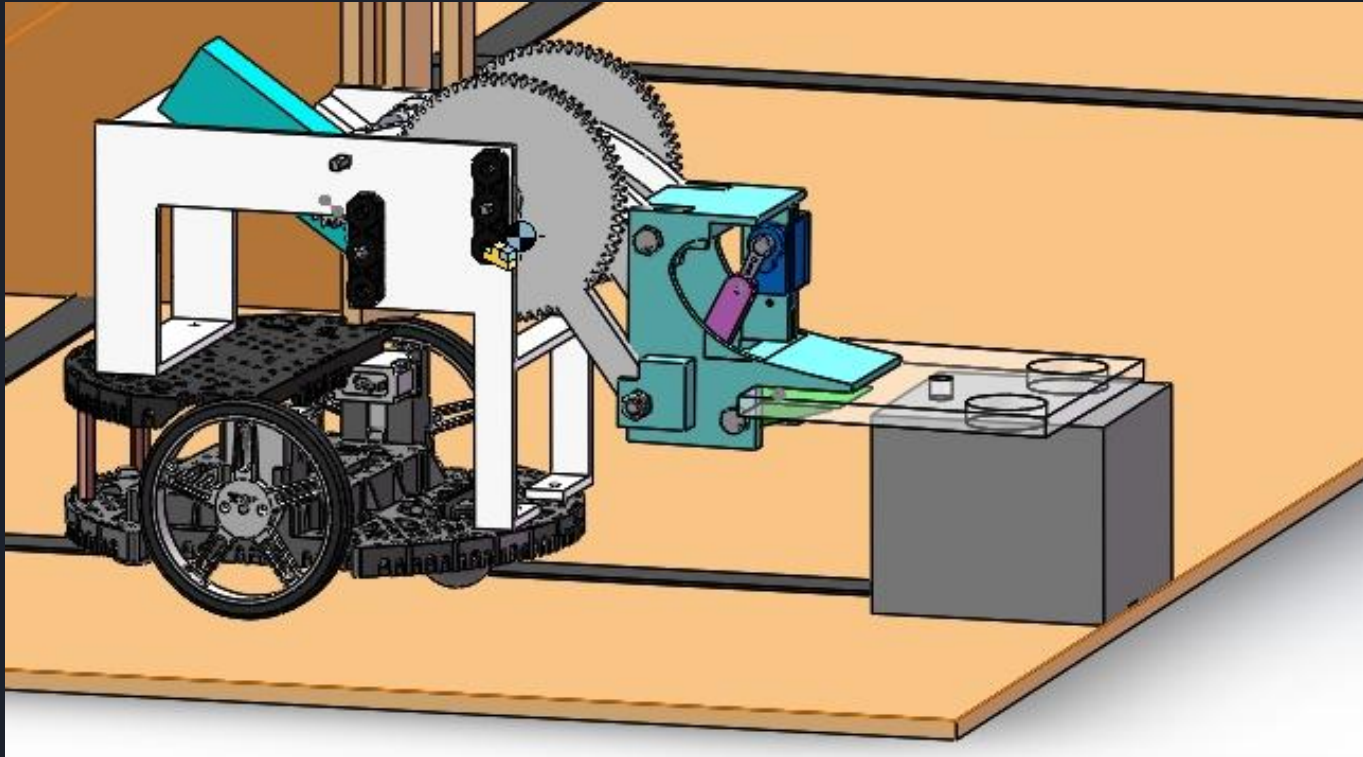
Linkage Synthesis Design Process



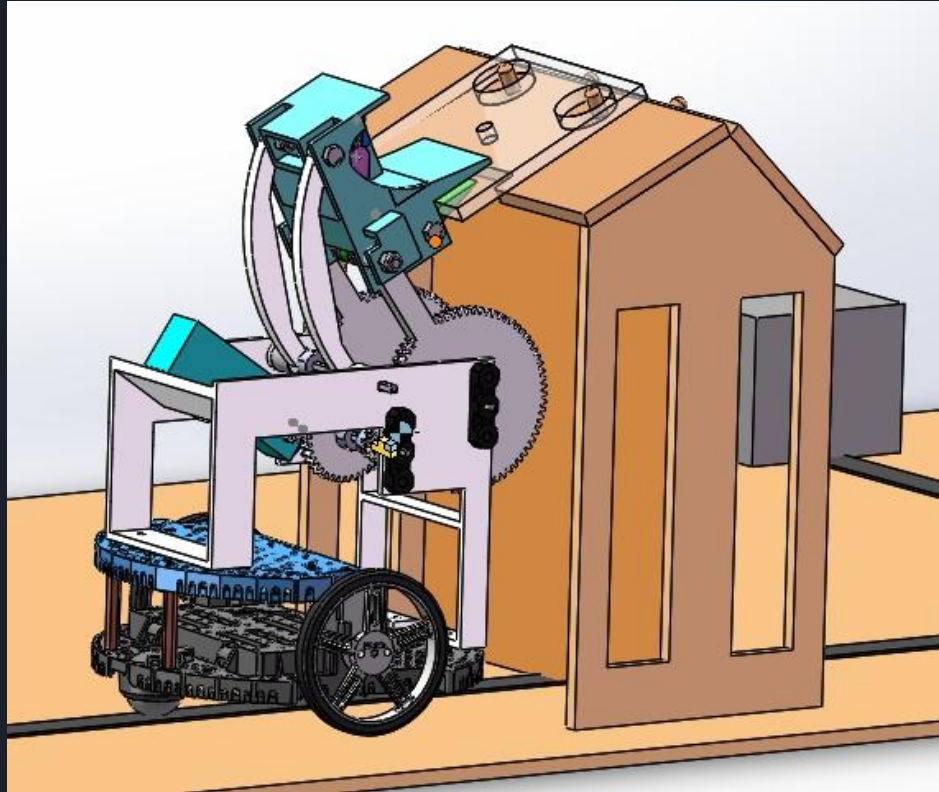
Video Demonstration of SolidWorks Model




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

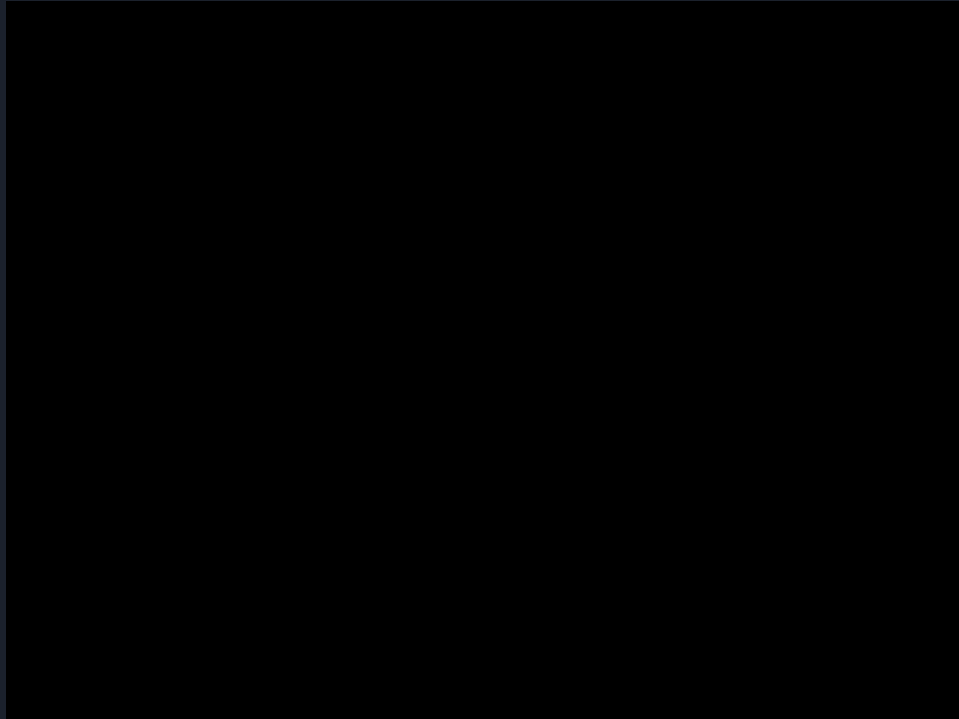


Screenshots of Complete Robot with Aluminum Plate in Max. Reach Positions

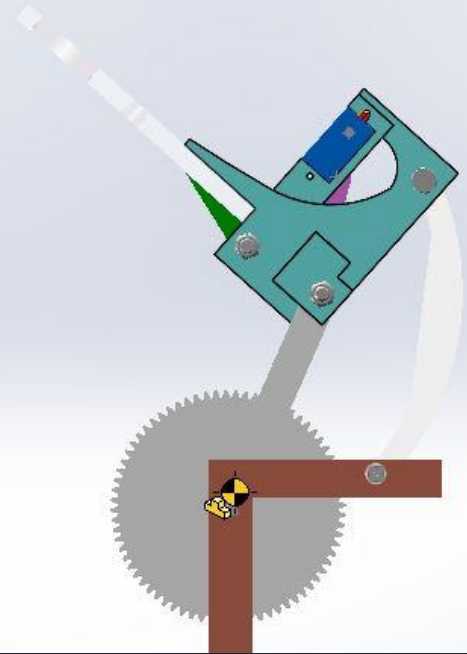
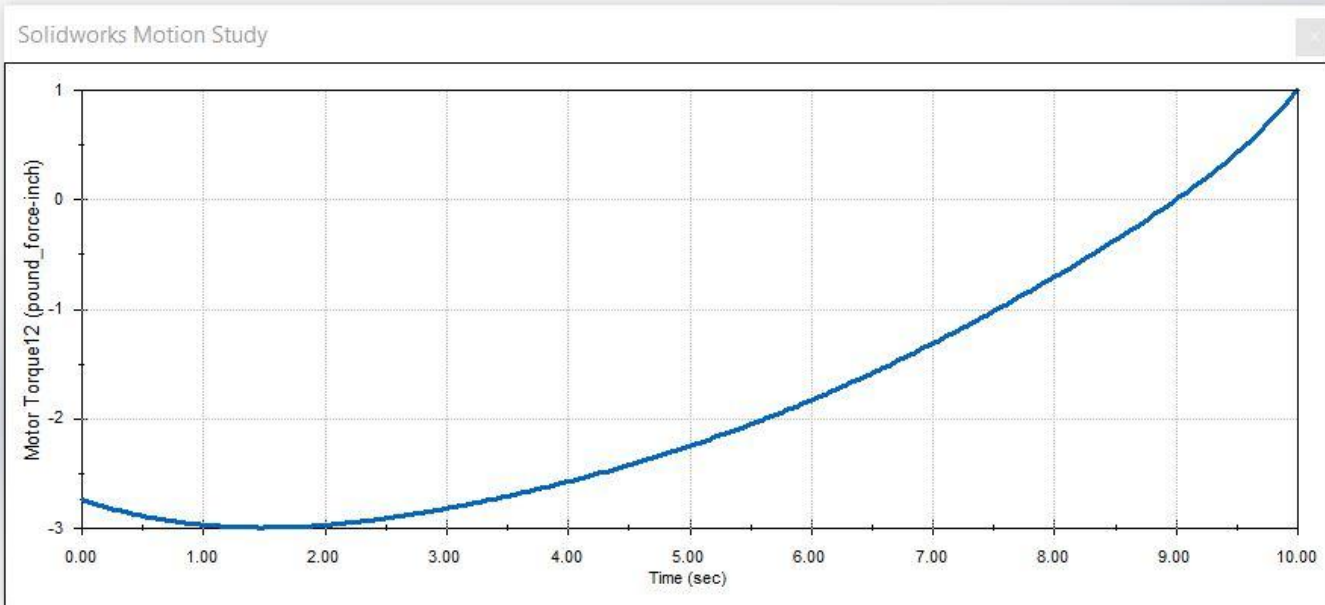




Video Demo of SolidWorks Motion Study: Crank Torque through Range of Motion

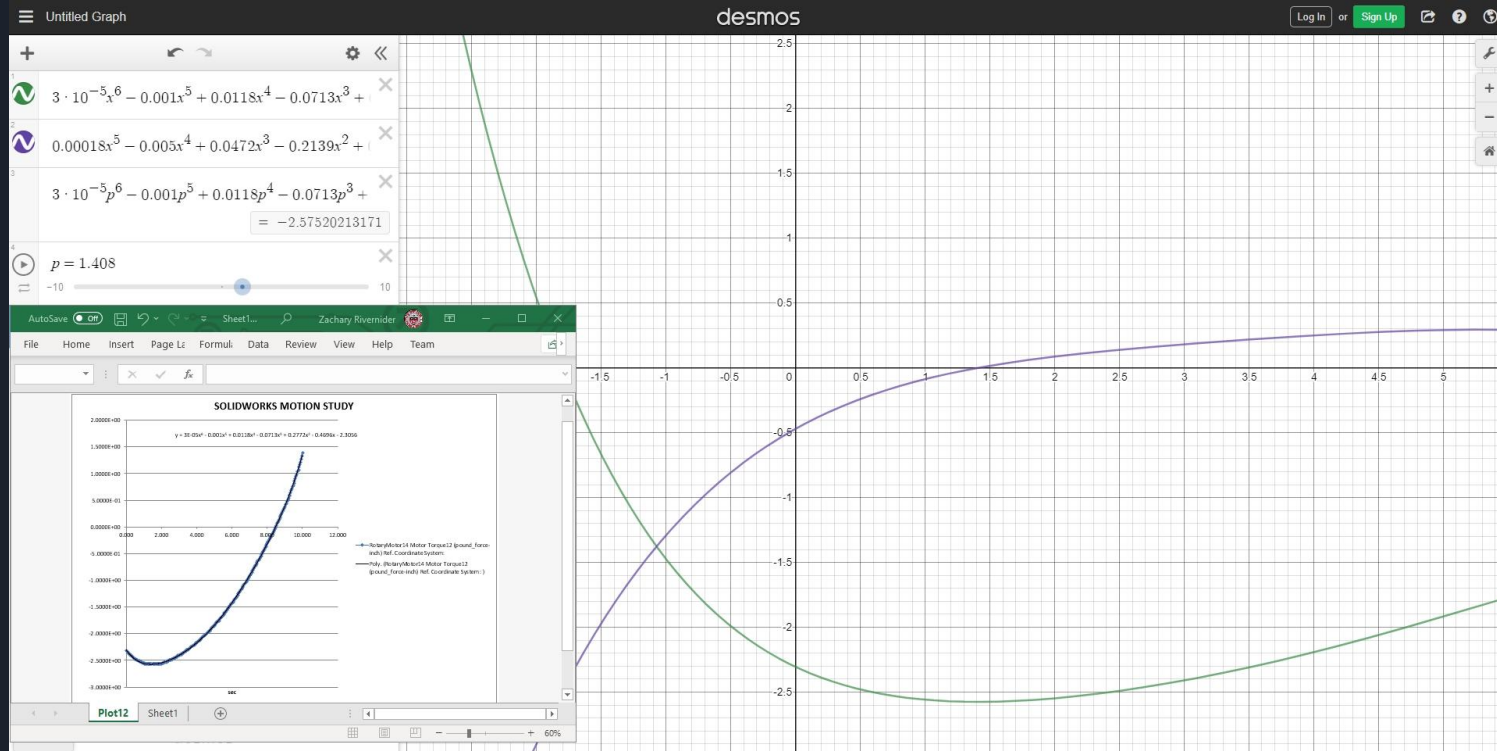


Solidworks Motion Study

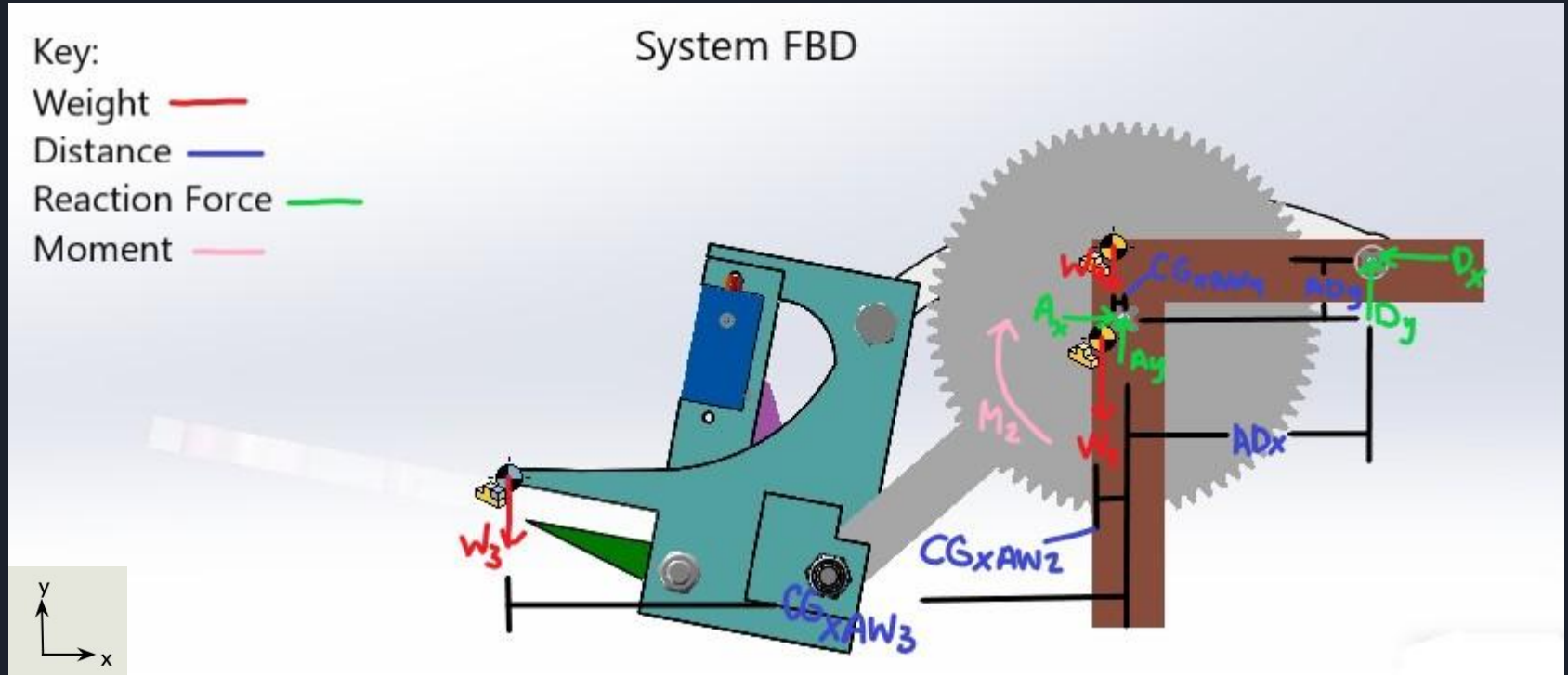


Evaluating Solidworks Motion Study

$$T_{\text{MAX}} = 2.575 \text{ in-lbf}$$



Lifting Mechanism Force Analysis: Crank Torque and Forces on Joints



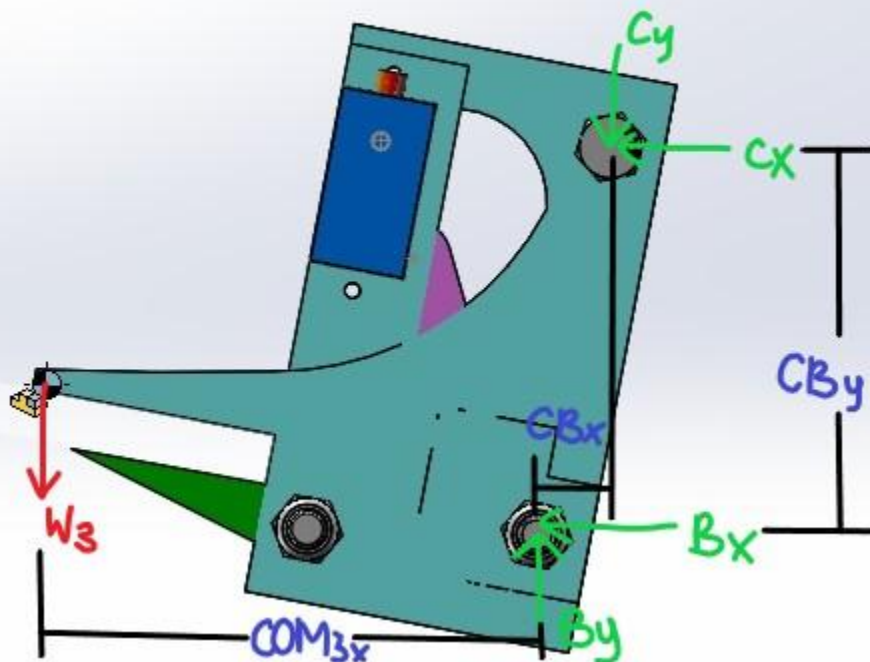
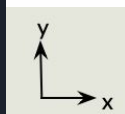
Key:

Weight —

Distance —

Reaction Force —

FBD Link 3



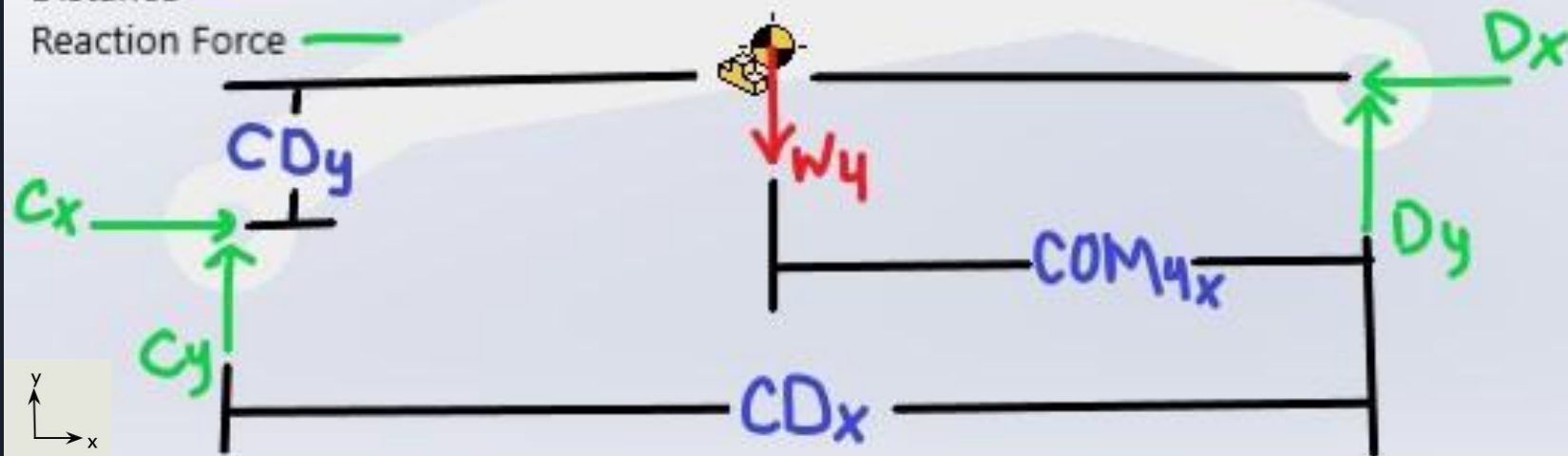
Key:

Weight —

Distance —

Reaction Force —

FBD Link 4



Known Parameters:

$$\begin{aligned} a &:= 3.053\text{in} & b &:= 2\text{in} & cc &:= 3.892\text{in} & d &:= 1.983\text{in} & W_4 &:= .02\text{lbf} & CG_{xAW2} &:= .169\text{in} & CG_{xAW3} &:= 4.785\text{in} & CG_{xAW4} &:= 0.062\text{in} & CB_x &:= .373\text{in} & CB_y &:= 1.965\text{in} \\ W_2 &:= .07157\text{lbf} & W_3 &:= 0.56\text{lbf} & \text{Theta}_2 &:= 47.20\text{deg} & \text{Theta}_4 &:= 79.67\text{deg} & COM_{3x} &:= 2.581\text{in} & COM_{4x} &:= 1.969\text{in} & AD_x &:= 1.933\text{in} & AD_y &:= .442\text{in} & CD_x &:= 3.862\text{in} & CD_y &:= .482\text{in} \end{aligned}$$

Supply initial guesses for unknowns:

$$\begin{aligned} A_x &:= 2\text{lbf} & A_y &:= 2\text{lbf} & B_x &:= 2\text{lbf} & B_y &:= 2\text{lbf} \\ C_x &:= 2\text{lbf} & C_y &:= 2\text{lbf} & D_x &:= 2\text{lbf} & D_y &:= 2\text{lbf} \\ M_2 &:= 4\text{in}\cdot\text{lbf} & M_4 &:= 4\text{in}\cdot\text{lbf} \end{aligned}$$

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:

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

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

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

From FBE of L_3 :

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

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

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

From FBE of L₄:

$$0 = W_4 \cdot \text{COM}_{4x} + C_x \cdot \text{CD}_y - C_y \cdot \text{CD}_x$$

$$0 = C_x - D_x$$

$$0 = C_y + D_y - W_4$$

$$\Sigma M_D := 0$$

$$\Sigma F_x := 0$$

$$\Sigma F_y := 0$$

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

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

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

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

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

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

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

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

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

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

Gear Teeth Force Analysis

Given

$$\underline{T} := 2.57 \text{ in lbf} \quad r := 1.5 \text{ in}$$

Guess

$$F_t := 2 \text{ lbf}$$

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

$$\text{Find}(F_t) = 1.713 \text{ lbf}$$

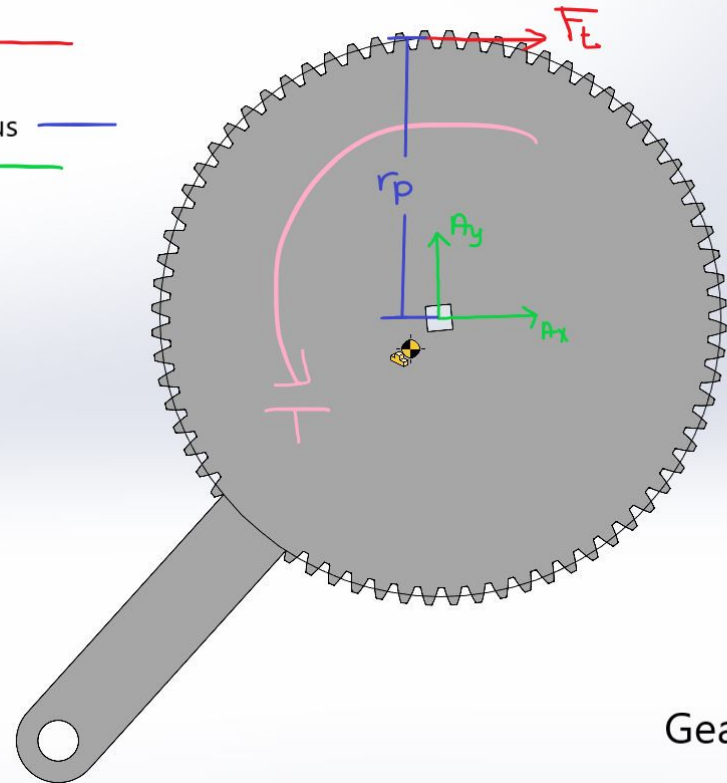
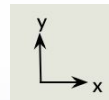
Key:

Force on Tooth ———

Torque ———

Pitch Circle Radius ———

Force on Axle ———



Gear FBD

Stresses and Factor of Safety of Gear Teeth

Stress Analysis

Factor of Safety

Given

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

Equations

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

$$\tau = 104.711\text{psi}$$

Given

$$\tau := 104.711\text{psi} \quad \tau_y := 2500\text{psi}$$

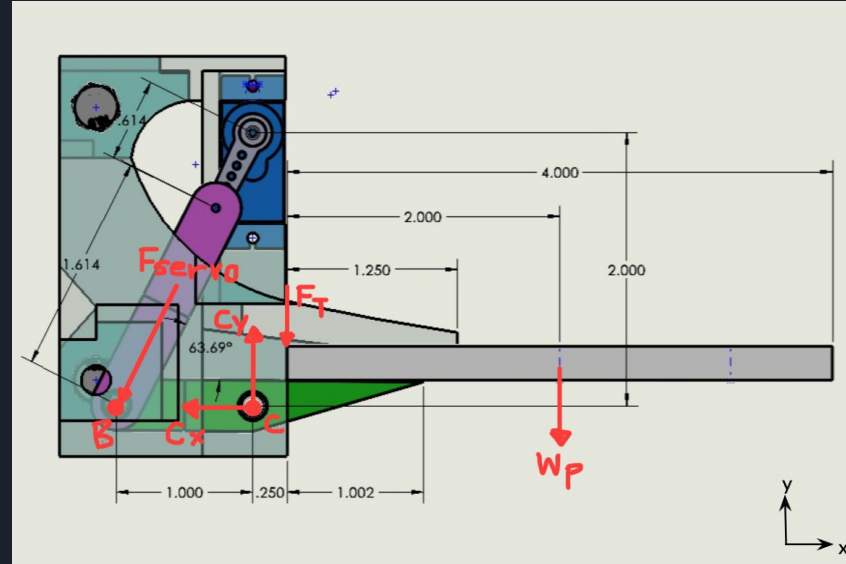
$$+FOS := \frac{\tau_y}{\tau} = 23.875$$

$$F_{\text{servo}} = 1.116 \text{ lbf}$$

$$C_y = 1.916 \text{ lbf}$$

$$C_x = -0.494 \text{ lbf}$$

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



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

Finding F_I

Knowns

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

Guesses for F_I and F_E

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

Given

$$0 = F_B \cdot d_{Fb} - W_P \cdot d_{wpl} \quad \Sigma M_{\text{pivot}} = 0$$

$$0 = F_B - F_T - W_P$$

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

Finding Forces on Joints

Knowns

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

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

Guesses for F_I and F_B

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

Given

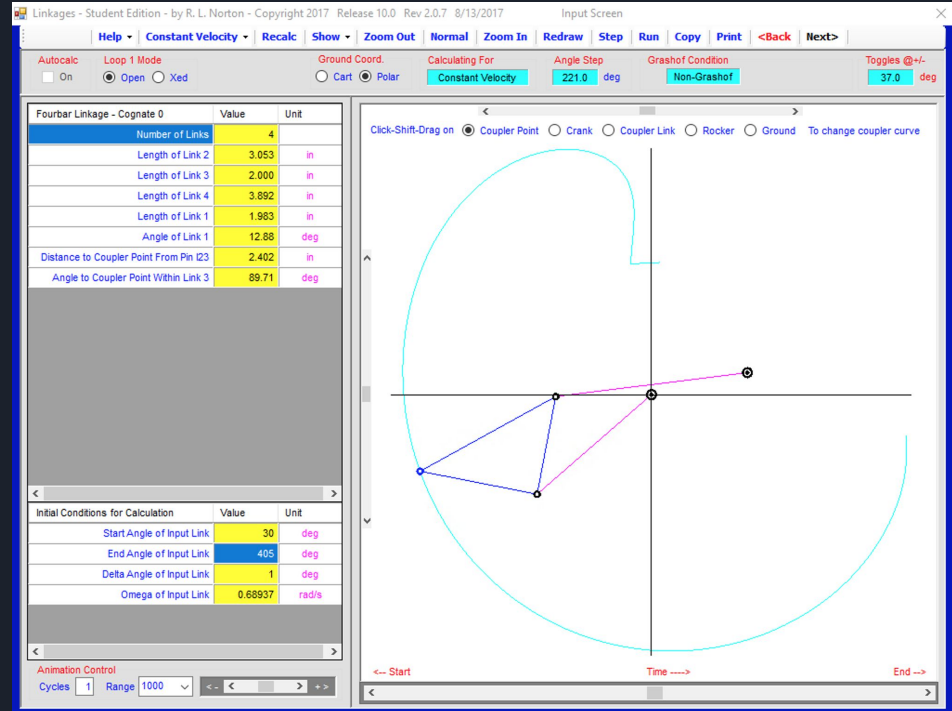
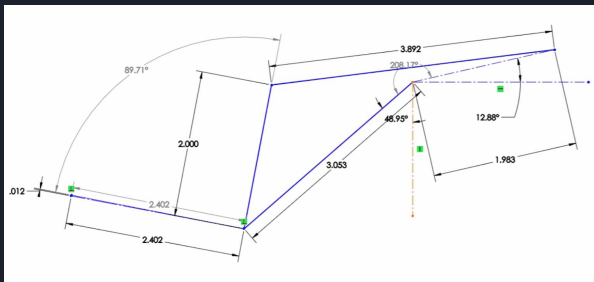
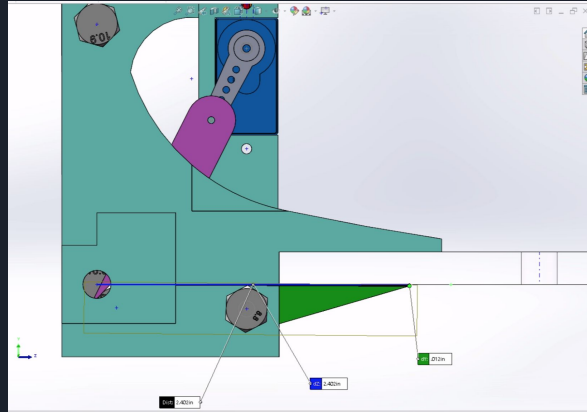
$$0 = F_{\text{servo}} \cdot \sin(\theta) \cdot d_{CB} - F_T \cdot d_{CFt} - W_P \cdot d_{CW} \quad \Sigma M_C = 0$$

$$0 = -F_{\text{servo}} + C_V - F_T - W_P$$

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

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

Four-Bar Component Speeds at Max. Torque Position



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

$$V_A = 2.105 \text{ in/s}$$

Linkages - Student Edition - by R. L. Norton - Copyright 2017 Release 10.0 Rev 2.0.7 8/13/2017 Print Screen

Print To Screen Veloc I 2,3 X 3 Veloc I 2,3 Y 3 Veloc I 2,3 Mag 3 Veloc I 2,3 Ang 3 Next >

Print Every 1 Set Angle Dec Plcs 3 Set Data Dec Plcs 3 Functions 1 2 4 Coordinate System Global Local Velocity of Instant Center 2-3 - X, Y, Mag, Ang Coordinates Refresh

Current Model Parameters			Input Angle (deg)	Veloc I 2,3 X (in/sec)	Veloc I 2,3 Y (in/sec)	Veloc I 2,3 Mag (in/sec)	Veloc I 2,3 Ang (deg)
Fourbar Linkage	Value	Unit	209.000	1.020	-1.841	2.105	-61.000
Links	4		210.000	1.052	-1.823	2.105	-60.000
Link 2	3.053	in	211.000	1.084	-1.804	2.105	-59.000
Link 3	2.000	in	212.000	1.115	-1.785	2.105	-58.000
Link 4	3.892	in	213.000	1.146	-1.765	2.105	-57.000
Pivot O4x	1.93	in	214.000	1.177	-1.745	2.105	-56.000
Pivot O4y	0.44	in	215.000	1.207	-1.724	2.105	-55.000
I23-CplrPt	2.402	in	216.000	1.237	-1.703	2.105	-54.000
CplrPtAng3	89.71	deg	217.000	1.267	-1.681	2.105	-53.000
			218.000	1.296	-1.658	2.105	-52.000
			219.000	1.324	-1.636	2.105	-51.000
			220.000	1.353	-1.612	2.105	-50.000
			221.000	1.381	-1.588	2.105	-49.000
			222.000	1.408	-1.564	2.105	-48.000
			223.000	1.435	-1.539	2.105	-47.000
			224.000	1.462	-1.514	2.105	-46.000
			225.000	1.488	-1.488	2.105	-45.000
			226.000	1.514	-1.462	2.105	-44.000
			227.000	1.539	-1.435	2.105	-43.000
			228.000	1.564	-1.408	2.105	-42.000
			229.000	1.588	-1.381	2.105	-41.000
			230.000	1.612	-1.353	2.105	-40.000
			231.000	1.636	-1.325	2.105	-39.000
			232.000	1.658	-1.296	2.105	-38.001
			233.000	1.681	-1.267	2.105	-37.001
			234.000	1.703	-1.237	2.105	-36.001
			235.000	1.724	-1.207	2.105	-35.001

Initial Conditions		
Start	30.0	deg
End	405.0	deg
Delta	1.0	deg
Omega2	0.7	rad/s

Veloc I 2,3 X	
Max	2.105 in/sec
Min	-2.105 in/sec
P - P	4.209 in/sec

Veloc I 2,3 Y	
Max	1.907 in/sec
Min	-2.105 in/sec
P - P	4.012 in/sec

Veloc I 2,3 Mag	
Max	2.105 in/sec
Min	0.000 in/sec
P - P	2.105 in/sec

Veloc I 2,3 Ang	
Max	269.000 deg
Min	-90.000 deg
P - P	359.000 deg

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10-01-2020
at 00:51:27
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Four-Bar Component Speeds at Max. Torque Position: Linkages Software Results

$$V_B = 1.368 \text{ in/s}$$

Linkages - Student Edition - by R. L. Norton - Copyright 2017 Release 10.0 Rev 2.0.7 8/13/2017 Print Screen

Print To Screen Functions ☐ 1 ☐ 2 ☒ 4 Coordinate System ☒ Global ☐ Local Velocity of Instant Center 3-4 - X, Y, Mag, Ang Coordinates

Current Model Parameters			Input Angle (deg)	Veloc I 3,4 X (in/sec)	Veloc I 3,4 Y (in/sec)	Veloc I 3,4 Mag (in/sec)	Veloc I 3,4 Ang (deg)
Fourbar Linkage	Value	Unit	209.000	0.020	-1.460	1.460	-89.219
Links	4		210.000	0.034	-1.451	1.451	-88.677
Link 2	3.053	in	211.000	0.047	-1.441	1.442	-88.137
Link 3	2.000	in	212.000	0.060	-1.432	1.434	-87.602
Link 4	3.892	in	213.000	0.073	-1.423	1.425	-87.069
Pivot O4x	1.93	in	214.000	0.086	-1.415	1.417	-86.539
Pivot O4y	0.44	in	215.000	0.098	-1.406	1.409	-86.012
I23-CplrPt	2.402	in	216.000	0.110	-1.397	1.402	-85.488
CplrPtAng3	89.71	deg	217.000	0.122	-1.389	1.394	-84.967
			218.000	0.134	-1.381	1.387	-84.449
			219.000	0.146	-1.373	1.380	-83.933
			220.000	0.157	-1.365	1.374	-83.420
			221.000	0.169	-1.357	1.368	-82.909
			222.000	0.180	-1.350	1.361	-82.401
			223.000	0.191	-1.342	1.356	-81.894
			224.000	0.202	-1.335	1.350	-81.390
			225.000	0.213	-1.328	1.345	-80.888
			226.000	0.224	-1.321	1.340	-80.387
			227.000	0.235	-1.315	1.336	-79.889
			228.000	0.245	-1.309	1.332	-79.392
			229.000	0.256	-1.303	1.328	-78.896
			230.000	0.266	-1.297	1.324	-78.402
			231.000	0.277	-1.291	1.321	-77.909
			232.000	0.287	-1.286	1.318	-77.417
			233.000	0.297	-1.281	1.315	-76.927
			234.000	0.308	-1.276	1.313	-76.437
			235.000	0.318	-1.271	1.311	-75.948

Initial Conditions		
Start	30.0	deg
End	405.0	deg
Delta	1.0	deg
Omega2	0.7	rad/s

Veloc I 3,4 X	
Max	23.570 in/sec
Min	-1.996 in/sec
P - P	25.566 in/sec

Veloc I 3,4 Y	
Max	4.379 in/sec
Min	-1.718 in/sec
P - P	6.096 in/sec

Veloc I 3,4 Mag	
Max	23.623 in/sec
Min	0.000 in/sec
P - P	23.623 in/sec

Veloc I 3,4 Ang	
Max	269.686 deg
Min	-89.765 deg
P - P	359.451 deg

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at 00:51:27
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Four-Bar Component Speeds at Max. Torque Position: Linkages Software Results

$$V_{\text{coupler}} = 3.234 \text{ in/s}$$

Linkages - Student Edition - by R. L. Norton - Copyright 2017 Release 10.0 Rev 2.0.7 8/13/2017 Print Screen

Print To Screen Veloc CP X 3 Veloc CP Y 3 Veloc CP Mag 3 Veloc CP Ang 3 Next >

Print Every 1 Set Angle Dec Pics 3 Set Data Dec Pics 3 Functions 1 2 4 Coordinate System Global Local Velocity of Coupler Point - X, Y, Mag, Ang Coordinates Refresh

Current Model Parameters			Input Angle (deg)	Veloc CP X (in/sec)	Veloc CP Y (in/sec)	Veloc CP Mag (in/sec)	Veloc CP Ang (deg)
Fourbar Linkage	Value	Unit	209.000	0.557	-3.040	3.091	-79.622
Links	4		210.000	0.599	-3.044	3.102	-78.863
Link 2	3.053	in	211.000	0.642	-3.047	3.114	-78.100
Link 3	2.000	in	212.000	0.686	-3.050	3.126	-77.333
Link 4	3.892	in	213.000	0.729	-3.052	3.138	-76.560
Pivot O4x	1.93	in	214.000	0.774	-3.054	3.150	-75.783
Pivot O4y	0.44	in	215.000	0.818	-3.054	3.162	-75.000
I23-CplrPt	2.402	in	216.000	0.863	-3.054	3.174	-74.213
CplrPtAng3	89.71	deg	217.000	0.909	-3.053	3.186	-73.420
			218.000	0.955	-3.052	3.198	-72.622
			219.000	1.001	-3.050	3.210	-71.819
			220.000	1.048	-3.046	3.222	-71.011
			221.000	1.096	-3.043	3.234	-70.197
			222.000	1.143	-3.038	3.246	-69.378
			223.000	1.191	-3.032	3.258	-68.554
			224.000	1.240	-3.026	3.270	-67.724
			225.000	1.288	-3.019	3.282	-66.889
			226.000	1.337	-3.011	3.294	-66.049
			227.000	1.387	-3.002	3.306	-65.203
			228.000	1.436	-2.992	3.319	-64.352
			229.000	1.487	-2.981	3.331	-63.495
			230.000	1.537	-2.969	3.343	-62.633
			231.000	1.588	-2.956	3.356	-61.765
			232.000	1.638	-2.943	3.368	-60.892
			233.000	1.690	-2.928	3.381	-60.014
			234.000	1.741	-2.913	3.393	-59.131
			235.000	1.793	-2.896	3.406	-58.242

Initial Conditions		
Start	30.0	deg
End	405.0	deg
Delta	1.0	deg
Omega2	0.7	rad/s

Veloc CP X	
Max	4.902 in/sec
Min	-2.004 in/sec
P - P	6.905 in/sec

Veloc CP Y	
Max	31.579 in/sec
Min	-3.054 in/sec
P - P	34.633 in/sec

Veloc CP Mag	
Max	31.646 in/sec
Min	0.000 in/sec
P - P	31.646 in/sec

Veloc CP Ang	
Max	269.464 deg
Min	-89.829 deg
P - P	359.293 deg

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Design No. 1
10-01-2020
at 00:51:27
File:

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.

$$\begin{aligned} a &:= 3.053\text{-in} & b &:= 2\text{-in} & c &:= 3.892\text{-in} & d &:= 1.983\text{-in} & \theta_2 &:= 208.17\text{deg} \\ p &:= 2.402\text{-in} & \text{angToC} &:= 89.71\text{deg} \end{aligned}$$

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

$$A_2 := \cos(\theta_2) - K_1 - K_2 \cdot \cos(\theta_2) + K_3 = -0.055$$

$$B := -2 \cdot \sin(\theta_2) = 0.944$$

$$C_2 := K_1 - (K_2 + 1) \cdot \cos(\theta_2) + K_3 = 3.007$$

$$\theta_{42} := 2 \cdot \text{atan}\left(\frac{-B + \sqrt{B^2 - 4 \cdot A \cdot C}}{2 \cdot A}\right) = -139.963\text{-deg}$$

$$\text{alternate_}\theta_{42} := \theta_{42} + 2 \cdot \pi = 220.037\text{-deg}$$

$$\theta_{41} := 2 \cdot \text{atan}\left(\frac{-B - \sqrt{B^2 - 4 \cdot A \cdot C}}{2 \cdot A}\right) = 174.236\text{-deg}$$

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

$$D := \cos(\theta_2) - K_1 + K_4 \cdot \cos(\theta_2) + K_5 = -2.578 \quad E := -2 \cdot \sin(\theta_2) = 0.944$$

$$F_2 := K_1 + (K_4 - 1) \cdot \cos(\theta_2) + K_5 = 0.485$$

$$\theta_{32} := 2 \cdot \text{atan}\left(\frac{-E + \sqrt{E^2 - 4 \cdot D \cdot F}}{2 \cdot D}\right) = -32.085\text{-deg}$$

$$\text{alternate_}\theta_{32} := \theta_{32} + 2 \cdot \pi = 327.915\text{-deg}$$

$$\theta_{31} := 2 \cdot \text{atan}\left(\frac{-E - \sqrt{E^2 - 4 \cdot D \cdot F}}{2 \cdot D}\right) = 66.358\text{-deg}$$

$$\text{alternate_}\theta_{31} := \theta_{31} + 2 \cdot \pi = 426.358\text{-deg}$$

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

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

$$\omega_3 := \frac{a \cdot \omega_2 \cdot \sin(\theta_{41} - \theta_{42})}{b \cdot \sin(\theta_{31} - \theta_{32})} = 0.617 \frac{\text{rad}}{\text{s}}$$

$$\omega_4 := \frac{a \cdot \omega_2 \cdot \sin(\theta_{42} - \theta_{31})}{c \cdot \sin(\theta_{41} - \theta_{31})} = 0.351 \frac{\text{rad}}{\text{s}}$$

$$V_{Ax} := a \cdot \omega_2 \cdot (-\sin(\theta_2)) = 0.994 \frac{\text{in}}{\text{s}}$$

$$V_{Ay} := a \cdot \omega_2 \cdot (\cos(\theta_2)) = -1.855 \frac{\text{in}}{\text{s}}$$

$$V_{Amag} := \sqrt{V_{Ax}^2 + V_{Ay}^2} = 2.105 \frac{\text{in}}{\text{s}}$$

Confirms V_A calculated previously

$$V_{Bx} := c \cdot \omega_4 \cdot (-\sin(\theta_{41})) = -0.137 \frac{\text{in}}{\text{s}}$$

$$V_{By} := c \cdot \omega_4 \cdot (\cos(\theta_{41})) = -1.36 \frac{\text{in}}{\text{s}}$$

$$V_{Bmag} := \sqrt{V_{Bx}^2 + V_{By}^2} = 1.367 \frac{\text{in}}{\text{s}}$$

V_B calculated result

$$V_{CAx} := p \cdot \omega_3 \cdot \sin(\theta_{31} + \text{angToC}) = -0.601 \frac{\text{in}}{\text{s}}$$

$$V_{CAy} := p \cdot \omega_3 \cdot \cos(\theta_{31} + \text{angToC}) = -1.355 \frac{\text{in}}{\text{s}}$$

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

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

$$V_{Cmag} := \sqrt{V_{Cx}^2 + V_{Cy}^2} = 3.234 \frac{\text{in}}{\text{s}}$$

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		Speed (RPM)	Torque (N)	Torque (in-lb)	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
Tstall (in-lbf)	0.7047	5	0.0771	0.682	0.292	0.040	1.538	2.624	2.584	0.253
wnoload (RPM)	158	7	0.0761	0.673	0.288	0.056	2.150	2.594	2.538	0.355
Inoload (A)	0.033	11	0.0741	0.656	0.281	0.085	3.369	2.533	2.447	0.558
Istall (A)	0.3	13	0.0731	0.647	0.278	0.099	3.975	2.502	2.403	0.659
Ref Voltage	9	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
R _A	30	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
V _T = R _A I _A + E _A		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, lift 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

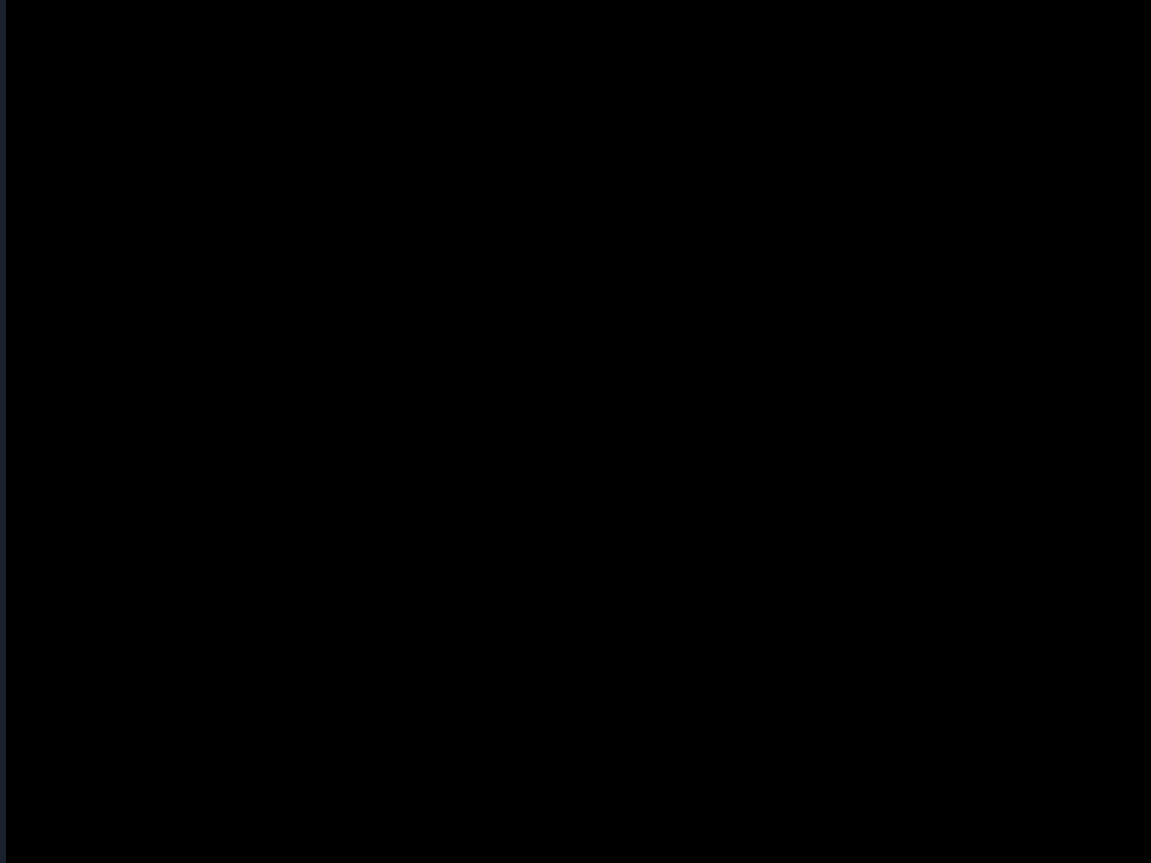
Pick up new plate and pause until given signal from IR sensor to continue

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

Release

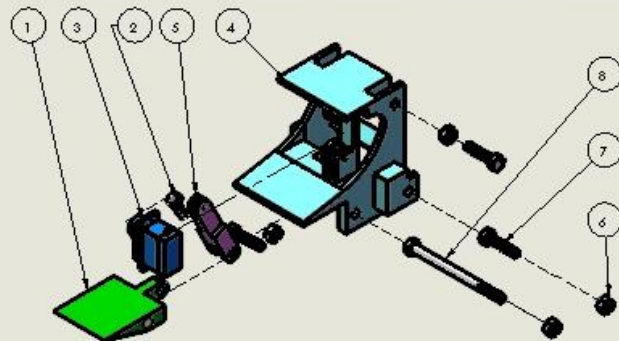


Assembly Video of Lifting Mechanism



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	\$0.24	\$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 LINKS	1	\$0.10	\$0.10	PLA	0.0076	0.0076
6	M5 NYLON INSERT LOCKNUT	6	\$0.04	\$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



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	DELRI	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

