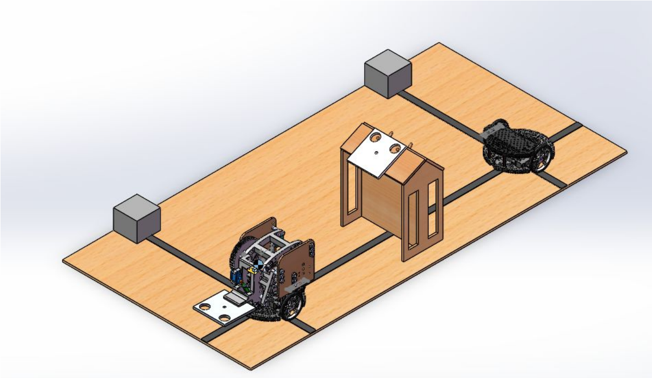
RBE 2001 Final Presentation

Team 9

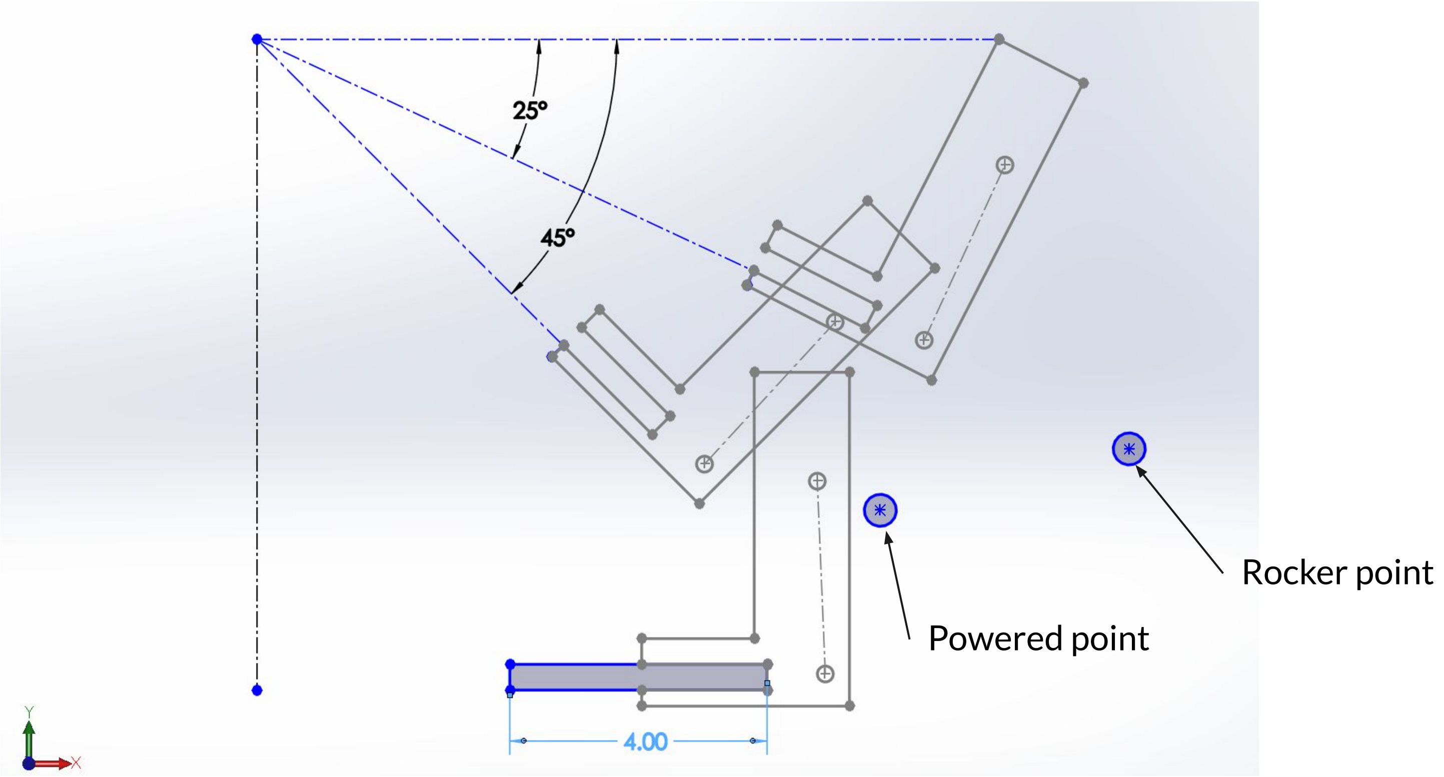
Overview of Challenge



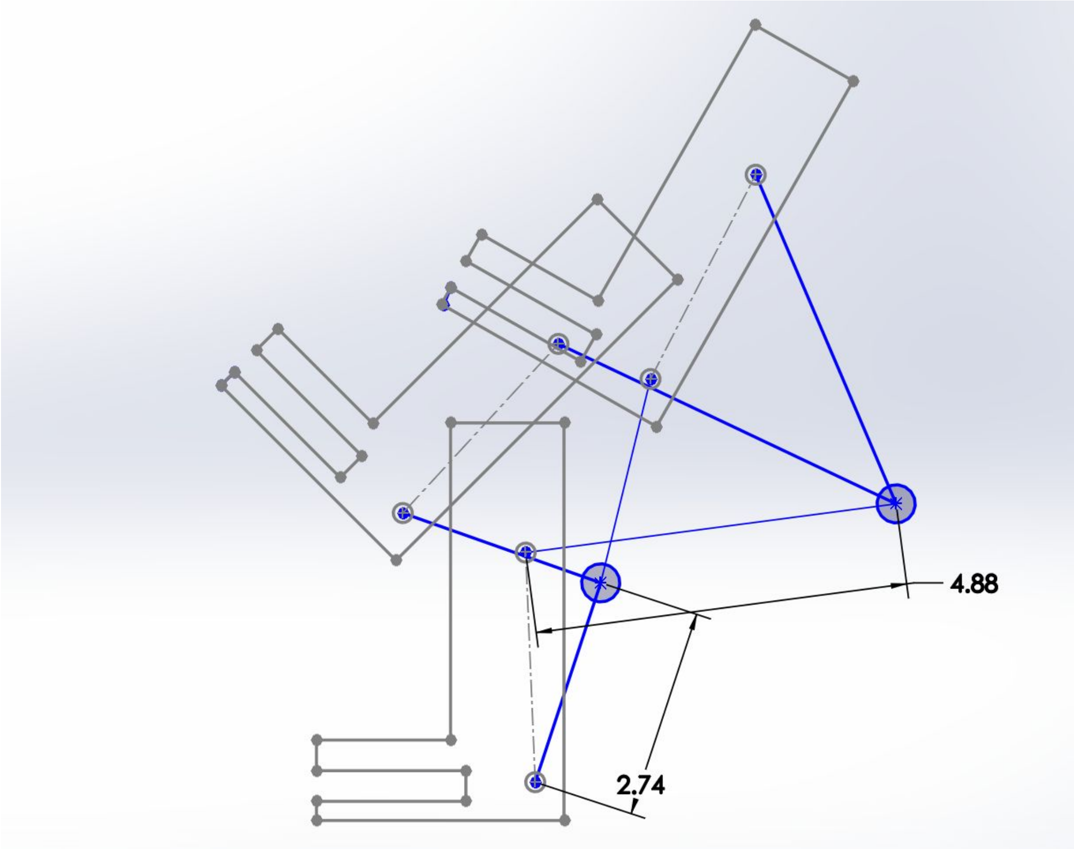
- Design a pair of robots to pick up and replace “solar collectors” mounted at two different angles
- The first robot must pick up a collector off of one side of the “house,” place it on a staging block, then replace it on the house, before the other robot does the same
- To do this, the robots will use two styles of grippers, four-bar assemblies, an infrared remote, an ultrasonic sensor, and a light sensor

Overview of Robot

Linkage Synthesis Design Solidworks Sketch

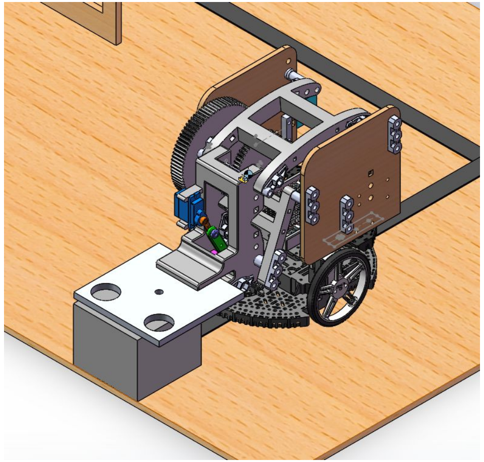


Linkage Synthesis Design Solidworks Sketch

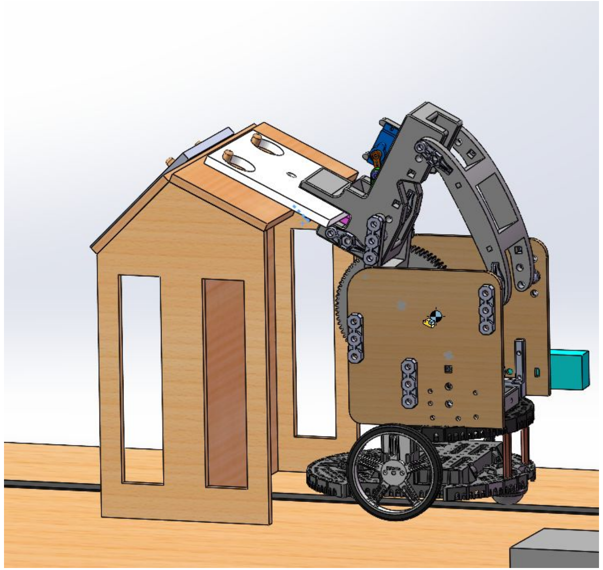


Aluminum Plates at 45˚, 25˚ and 0˚

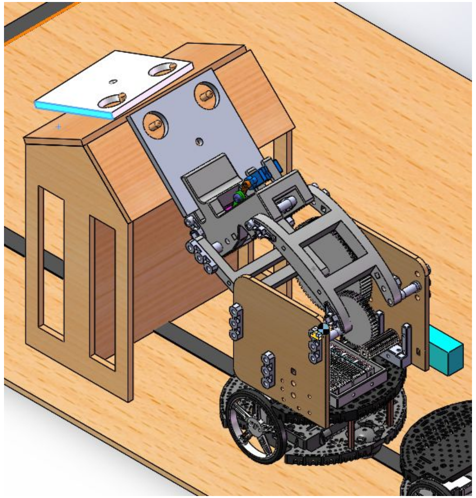
Position at 0°



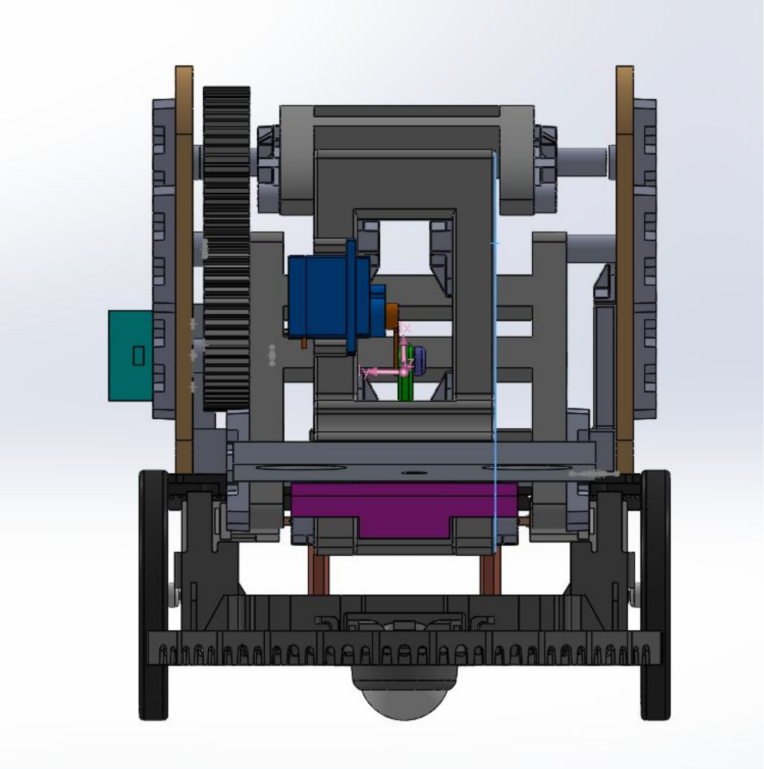
Position at 25°

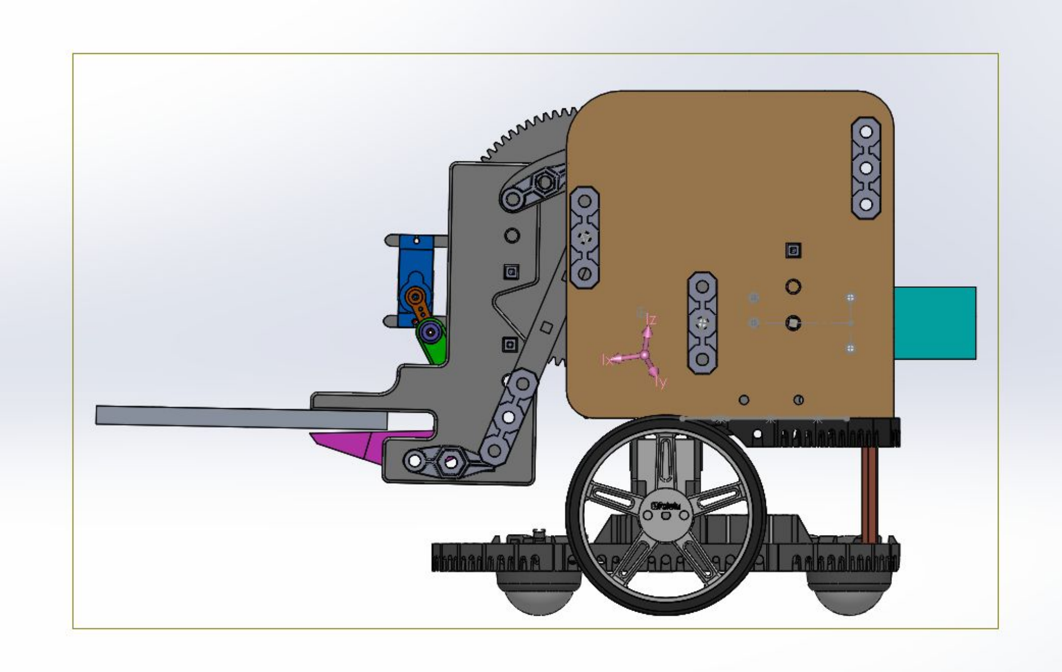


Position at 45°

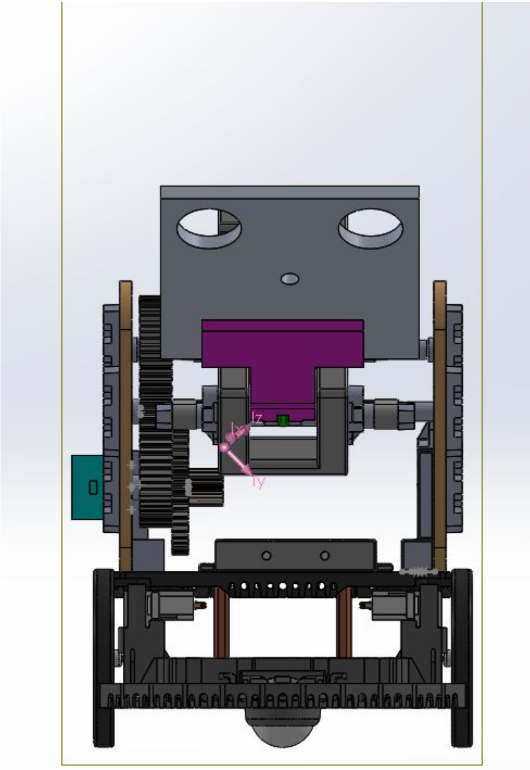


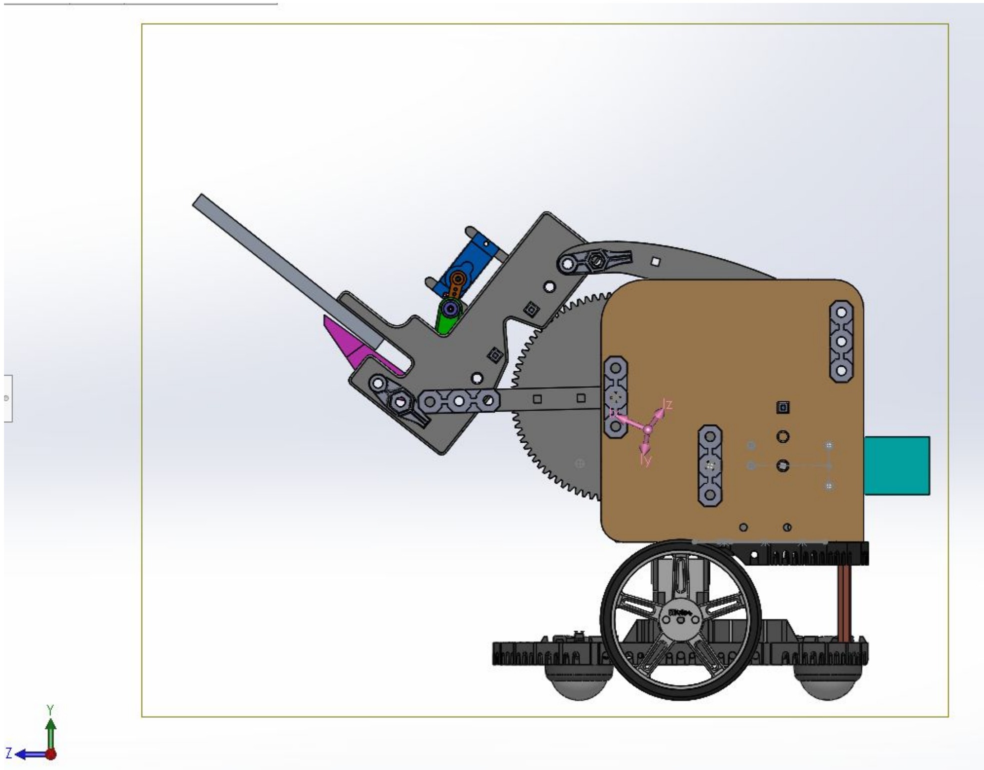
Center of Mass at 0°



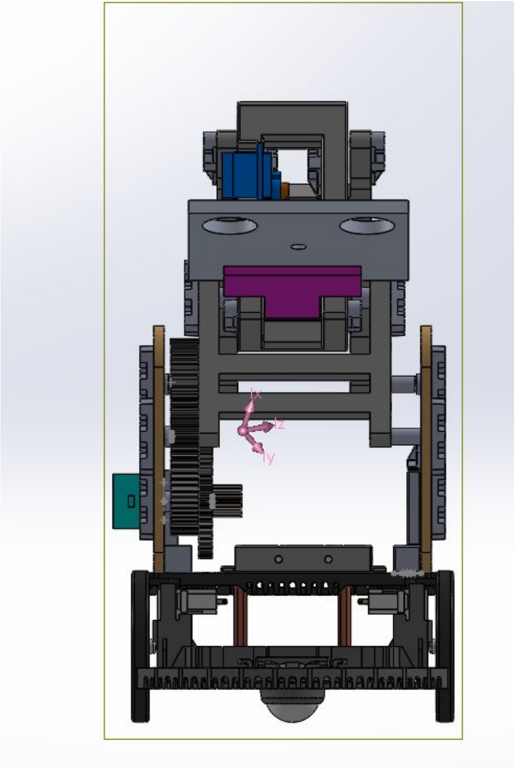


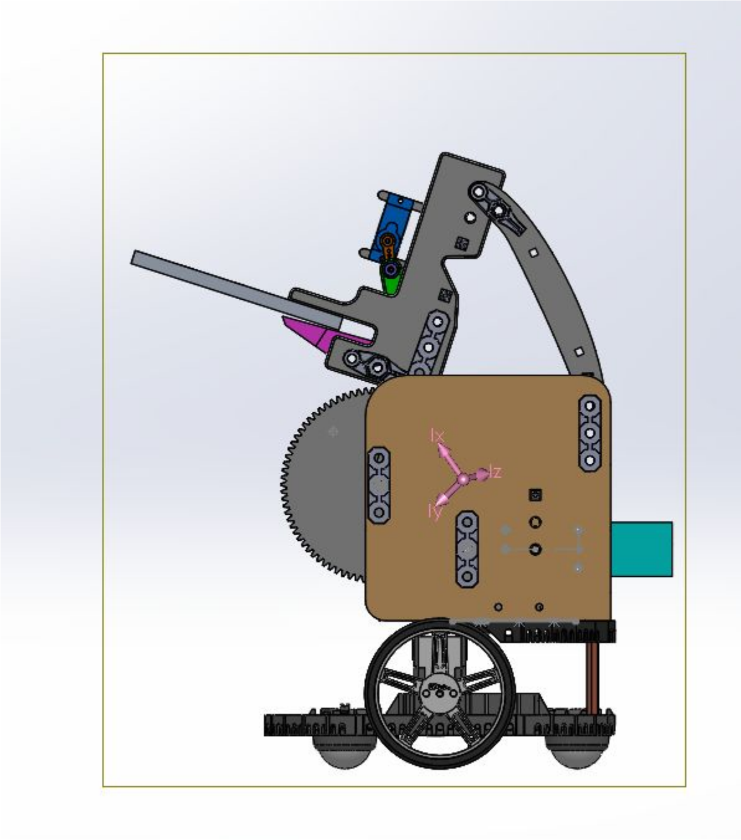
Center of Mass at 45˚



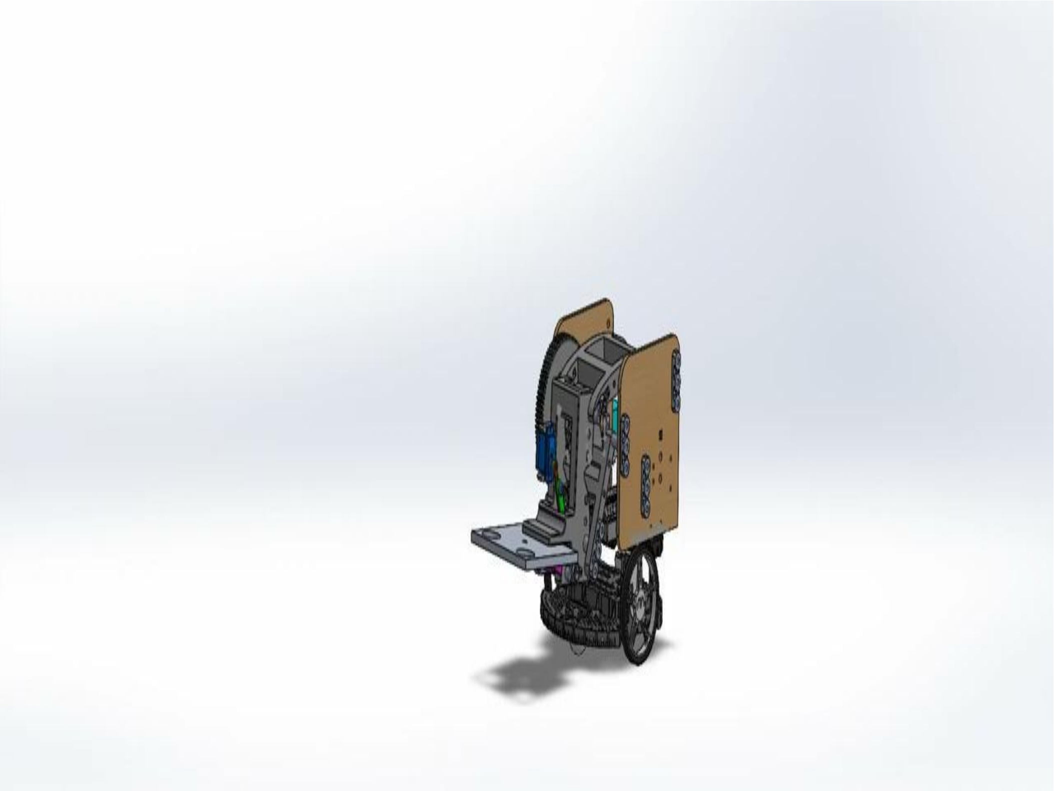


Center of Mass at 25°

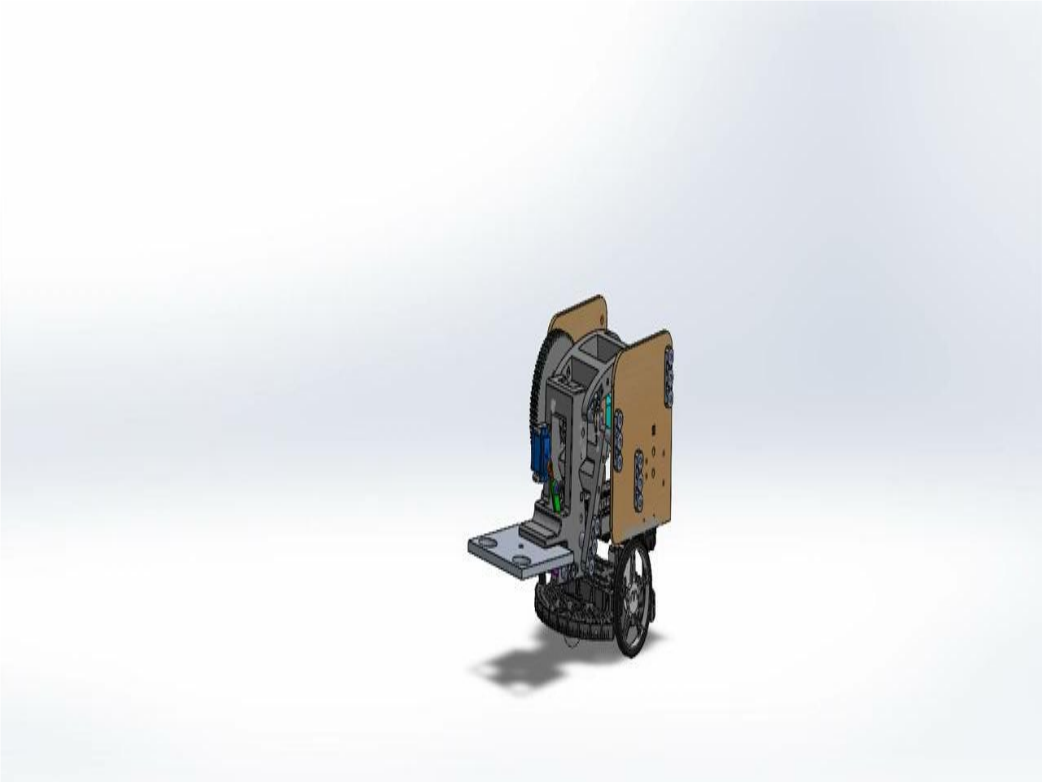




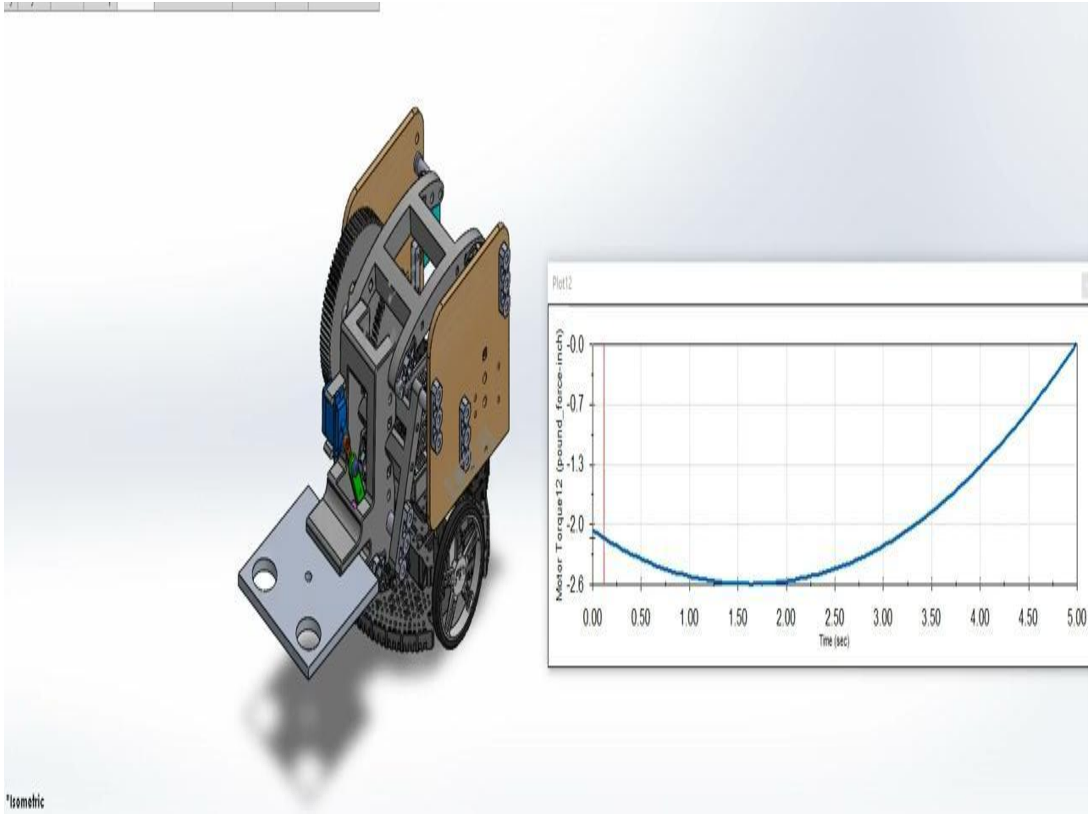
Moving Grabber from 0° to 25°



Moving Grabber from 0° to 45°



Motion Study

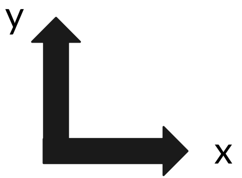


FBDs Of 4-Bar

Known Parameters:

$a := 2.68in$ $b := 3in$ $cc := 4.88in$ $d := 3.98in$ $ee := 2.7in$

$W_3 := 1.08lbf$ $Theta_2 := 205deg$ $Theta_4 := 186.24deg$

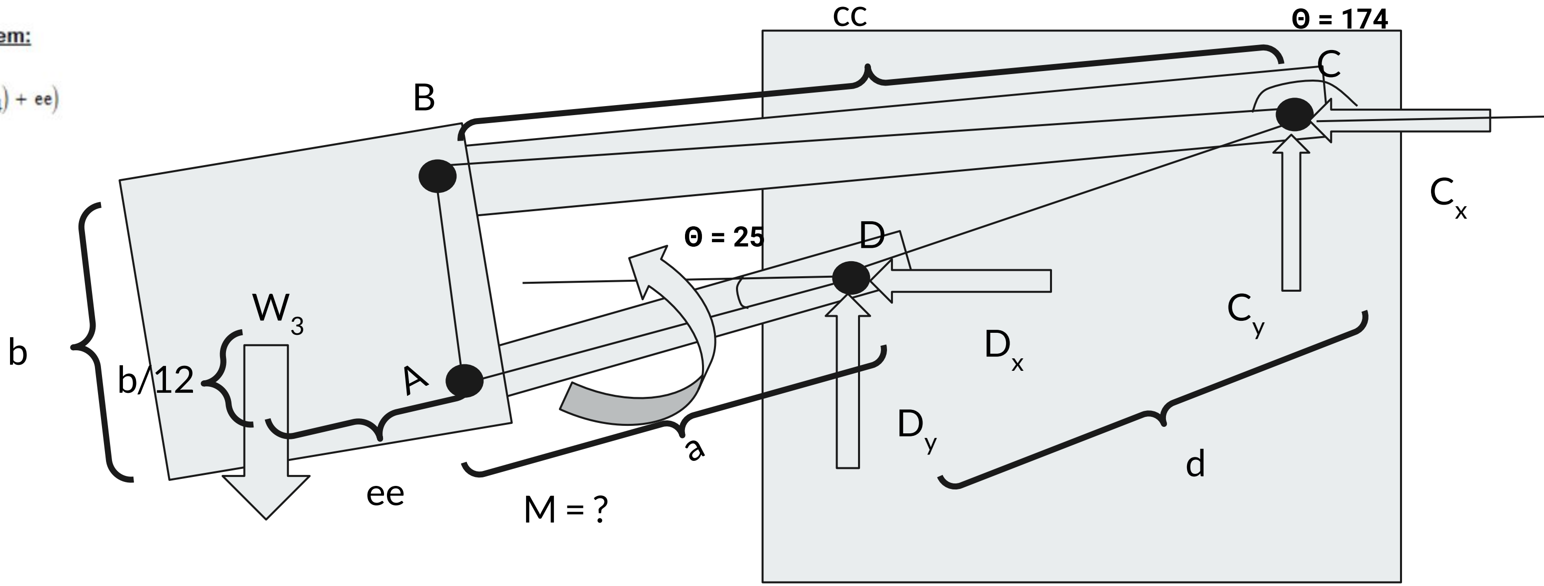


From FBE of L_2, L_3, and L_4 as a system:

$$0 = M_2 + C_y \cdot d - W_3 \cdot (d + cc \cdot \cos(Theta_4) + ee)$$

$$0 = C_x + D_x$$

$$0 = C_y + D_y - W_3$$



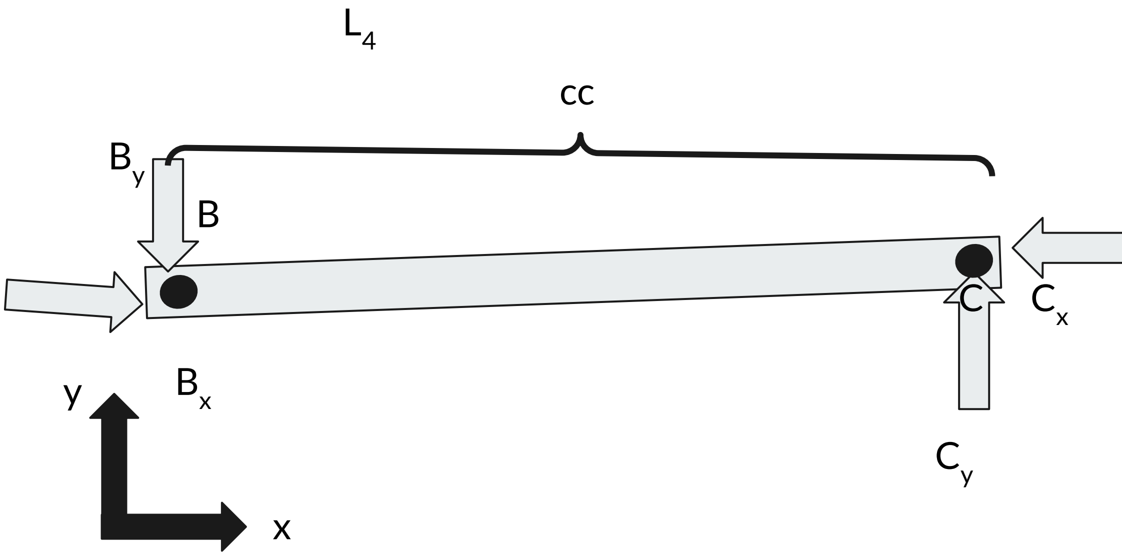
FBDs and equations of 4-Bar Continued

<u>From FBE of L_3:</u>

$0 = -B_x \cdot b - W_3 \cdot ee$ $\qquad \Sigma M_A := 0$

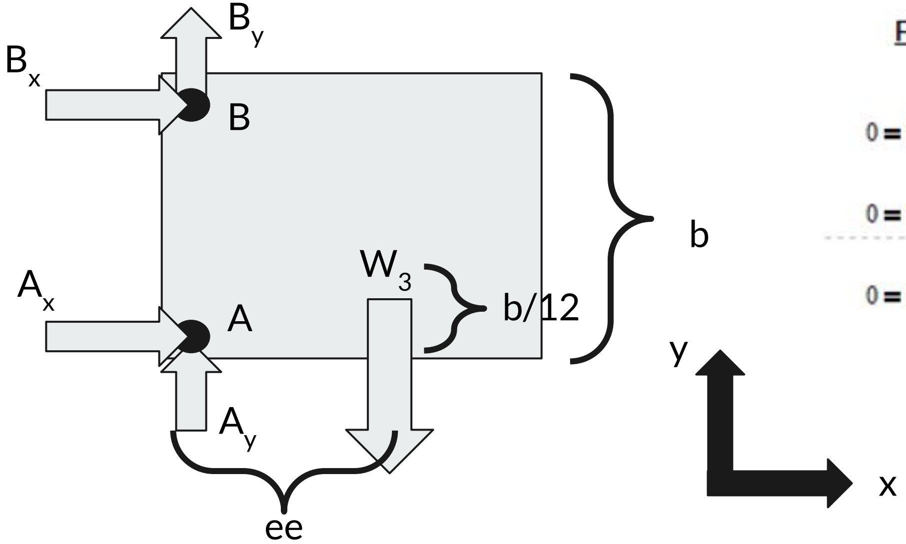
$0 = A_x + B_x$ $\qquad \Sigma F_x := 0$

$0 = A_y + B_y - W_3$ $\qquad \Sigma F_y := 0$



FBDs and equations Of 4-Bar

L_3 - Grabber



From FBE of L_4:

$0 = B_x \cdot cc \cdot \sin(Theta_4) - B_y \cdot cc \cdot \cos(Theta_4)$ $\Sigma M_C := 0$

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

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

Grabber Forces on Joints and Torque

$SA_x = 0.97\ \mathrm{lbf}$

$SA_y = 1.19\ \mathrm{lbf}$

$SB_x = -0.97\ \mathrm{lbf}$

$SB_y = -0.11\ \mathrm{lbf}$

$SC_x = -0.97\ \mathrm{lbf}$

$SC_y = -0.11\ \mathrm{lbf}$

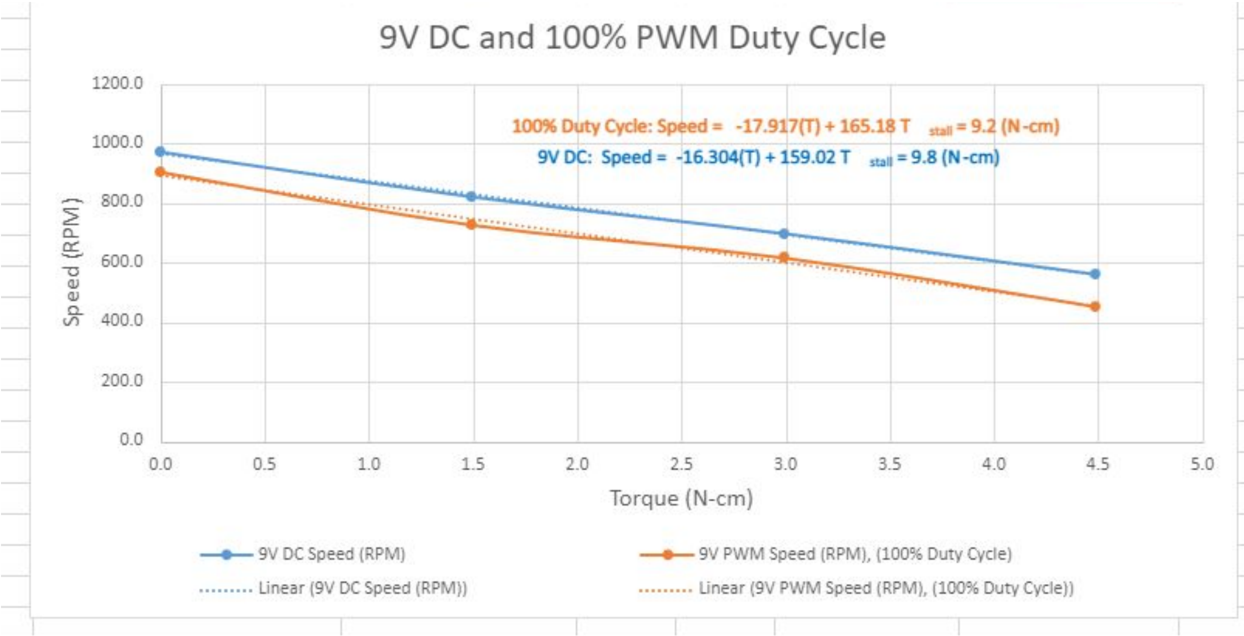
$SD_x = 0.97\ \mathrm{lbf}$

$SD_y = 1.19\ \mathrm{lbf}$

$SM_2 = 2.4\ \mathrm{in \cdot lbf}$

The calculated torque is 2.4in*lbf

Gear Ratio Calculations



2.4 in lbs = 27.12N * cm

Stall T = 9.2 N* cm

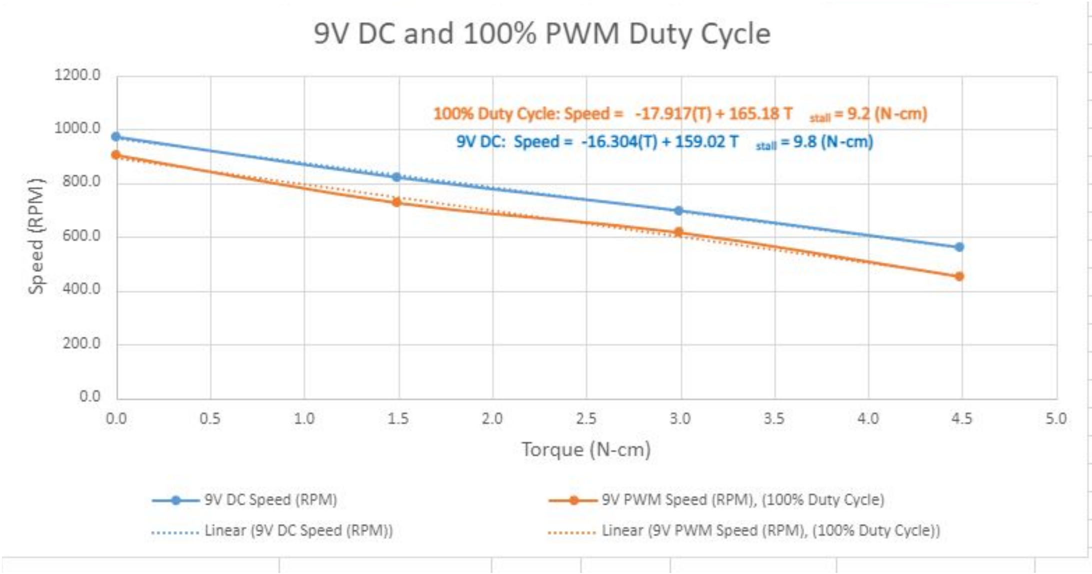
¼ stall T (what we run at) =

2.3 N * cm

27.12 : 2.3 = 11.79: 1

Minimum ratio: 12:1

Speed Analysis



Gear ratio = 28

Efficiency = .9

Running at 2.4 in lbs = 27.12 N*cm

27.12 N*cm/ 28(efficiency^2) = motor output = 1.2 N*cm

1.2 N*cm makes motor run at 750 rpm

750 rpm/28 = 26.79 rpm = 0.45 rps

.45 rps is fast enough for our robot to complete it’s challenges

Grabber Torque Analysis

$W := 0.3125\,\mathrm{lbf}$

$F_L := 0.368\,\mathrm{lbf}$

$d_6 := 2\,\mathrm{in}$

$d_2 := 1.7\,\mathrm{in}$

$d_3 := 1.44\,\mathrm{in}$

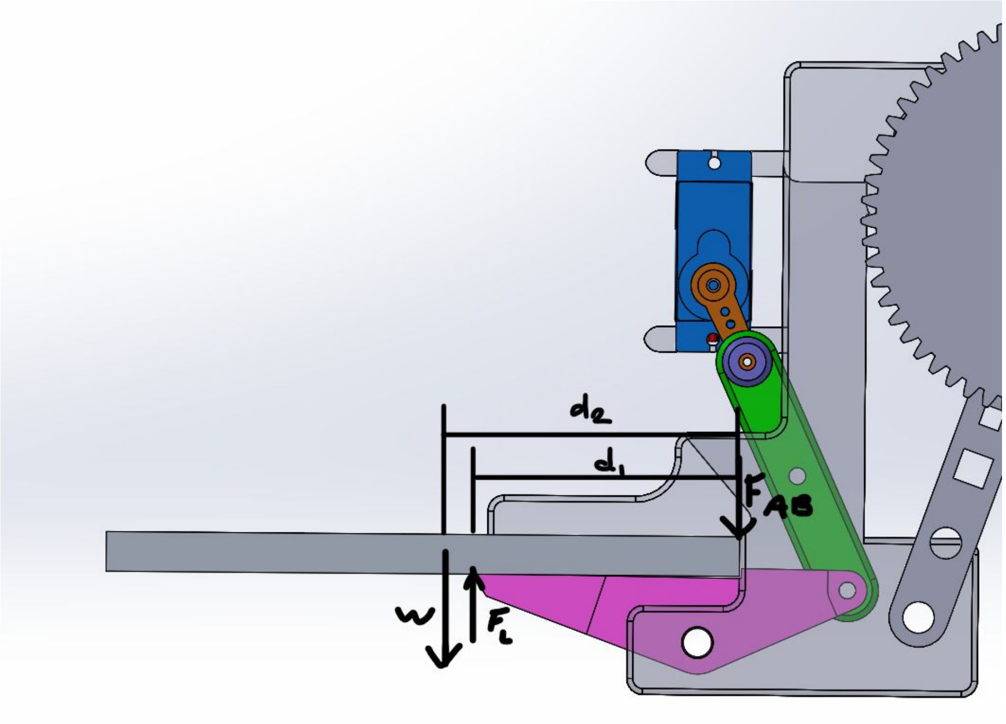
$d_4 := 1\,\mathrm{in}$

$d_5 := 0.53\,\mathrm{in}$

$\mathrm{theta1} := 70\,\mathrm{deg}$

$\mathrm{theta2} := 0\,\mathrm{deg}$

$\mathrm{theta3} := 63\,\mathrm{deg}$



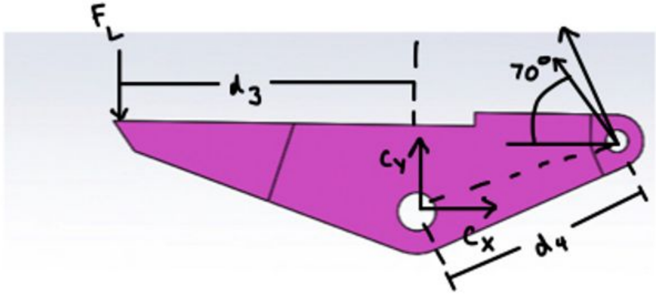
$$\Sigma M_F := 0 = W\,d_6 - F_L \cdot d_2$$

$$F_L := \frac{(W \cdot d_6)}{d_2} = 0.368\,\mathrm{lbf}$$

$$\Sigma M_C := 0 = F_L \cdot d_3 + F_{AB} \cdot \cos(\mathrm{theta2}) \cdot d_4$$

$$F_{AB} := \frac{(-F_L \cdot d_3)}{\cos(\mathrm{theta2})\, d_4} = -0.53\,\mathrm{lbf}$$

Grabber Torque Continued

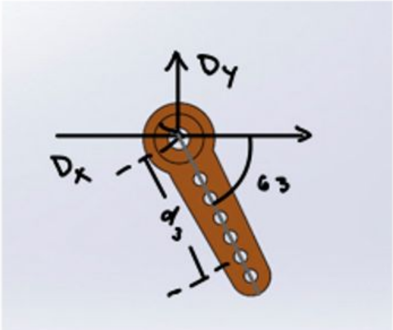


$$\Sigma F_x := C_x - F_{AB} \cdot (\cos(\text{theta1})) = 0$$

$$C_x := -0.18\,\text{lbf}$$

$$\Sigma F_y := 0 = -F_L + C_y + F_{AB} \cdot \sin(\text{theta1})$$

$$C_y := 0.866\,\text{lbf}$$



$$\Sigma F_x := 0 = D_x - d_5 \cdot \sin(\text{theta1})$$

$$D_x := 0.18 \cdot \text{lbf}$$

$$\Sigma F_y := 0 = D_y + d_5 \cdot \sin(\text{theta1})$$

$$D_y := -0.498\,\text{lbf}$$

Grabber Forces on Joints and Torque

$D_y = -2.215\,N$
$D_x = 0.801\,N$
$C_y = 3.852\,N$
$C_x = -0.801\,N$

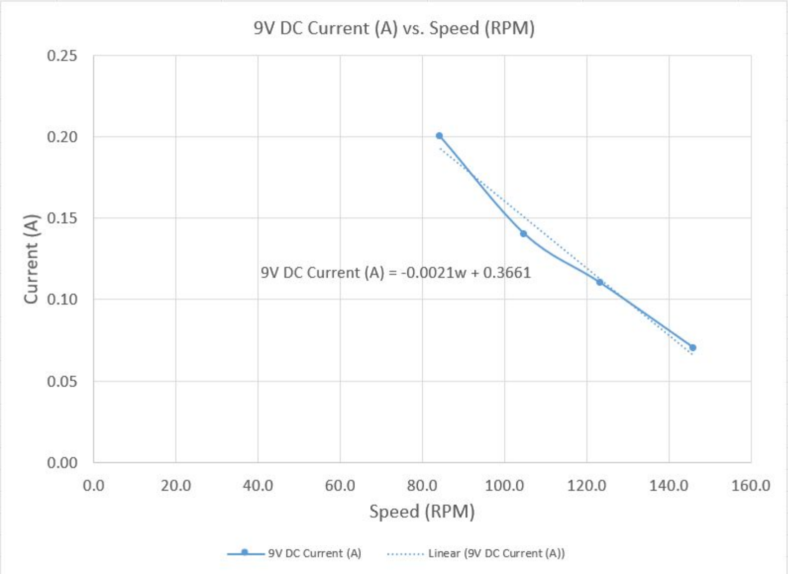
$$\Sigma M_d := F_{AB} \cdot \sin(\text{theta1}) F_{AB} \cdot \cos(\text{theta3}) - F_{AB} \cdot \cos(\text{theta1}) \cdot F_{AB} \cdot \cos(\text{theta3}) - T_1$$

$$\boxed{T_1 := 0.034\,\text{in} \cdot \text{lbf}}$$

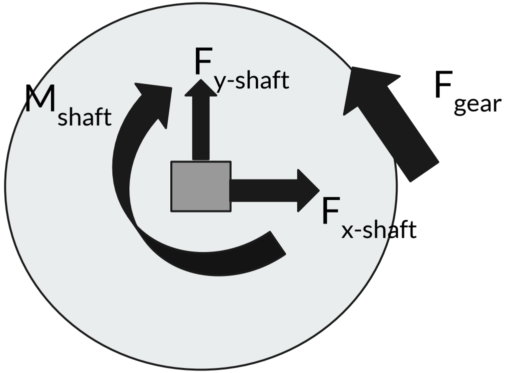
- ❏ Stall torque of Servo Motor = 1.12 in lbs
- ❏ 0.034/1.12 = .03
- ❏ Motor will run at 3% stall torque to lift plates

Blue Motor Current At Maximum Torque

- Stall current: .3661 A
- No-load torque: .07 A
- Max torque from motion study: 2.4 in-lb
- Max torque from blue motor = $2.4(e_1)(e_2)(\text{efficiency})^2$
- Max torque from blue motor = $2.4(.25)(.1429)(.95)^2$ = .07734 in-lb
- Speed from torque: -17.917(T)+165.18
- Speed at 2.4 in-lb: -17.917(2.4)+165.18 = 122.1792 RPM
- Current from speed: -.0021(w) + .3661
- Current at 2.4 in-lb: -.0021(122.1792) + .3661 = .11 A



Gear Free Body Diagram



$\Sigma M_{shaft} = F_{gear}$(pitch circle)(sin(pitch angle)) - $M_{shaft} = 0$

$\Sigma F_x = F_{x\text{-}gear}(\cos(20)) + F_{x\text{-}shaft} = 0$

$\Sigma F_y = F_{y\text{-}gear}(\sin(20)) + F_{y\text{-}shaft} = 0$

Pitch circle = 3.5 in, Pitch angle = 20°, M_{shaft} = 2.4 in-lb

F_{gear}(3.5 in/2)(sin(20)) = 2.4 in-lb

F_{gear} = 4.01 lb

$F_{x\text{-}shaft}$ = -3.768 lb

$F_{y\text{-}shaft}$ = -1.372 lb

Gear Stresses and Factor of Safety

$$\tau_{gear} = \frac{F}{A}$$

T = 2.4 (in-lb)

Diametral pitch = 24 (teeth/in)

N_{teeth} = 84 teeth

b = .5 (in)

$$d = \frac{diametral\ pitch}{N_{teeth}} = \frac{84\ (teeth)}{24\ (teeth/in)} = 3.5\ (in)$$

$$r = \frac{d}{2} = \frac{3.5\ (in)}{2} = 1.75\ (in)$$

$$F = \frac{T}{r} = \frac{2.4\ (in-lb)}{1.75\ (in)} = \frac{2.4\ (in-lb)}{1.75\ (in)} = 1.37\ (lb)$$

$$A = \frac{\pi}{2(diametral\ pitch)} * b = \frac{\pi}{2(24\ (teeth/in))} * .5(in) \quad = .033\ in^2$$

$$\tau_{gear} = \frac{F}{A} = \frac{1.37\ (lb)}{.033(in^2)} = \boxed{41.91\ (psi)}$$

$$FoS = \frac{\tau_{pla}}{\tau_{gear}}$$

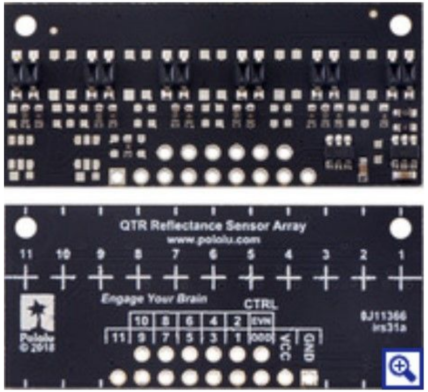
$$\tau_{pla} = 2500\ (psi)$$

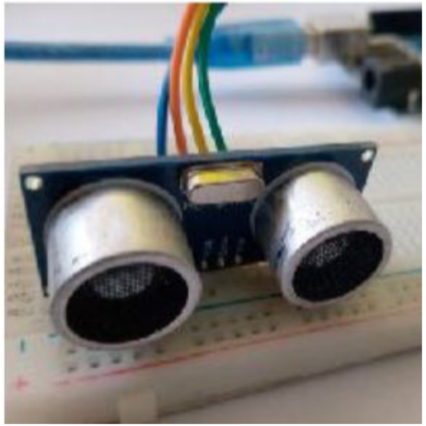
$$FoS = \frac{\tau_{pla}}{\tau_{gear}} = \frac{2500\ (psi)}{41.91\ (psi)} = \boxed{59.7}$$

Software

Summary of Sensors - External Inputs

- Light Sensor
  - Two outputs representing left and right
  - High when dark, low when light
  - Used to follow black lines on playing field by finding difference between two outputs
- Ultrasonic Sensor (range finder)
  - Two transducers - speaker and microphone
  - Calculates time between pulse sent from speaker and reception by microphone
  - Uses interrupts to constantly update distance values in front of robot
- IR Receiver
  - Used to receive inputs from the IR remote
  - Allows crew to interact with robot during the program to confirm that certain conditions have been met

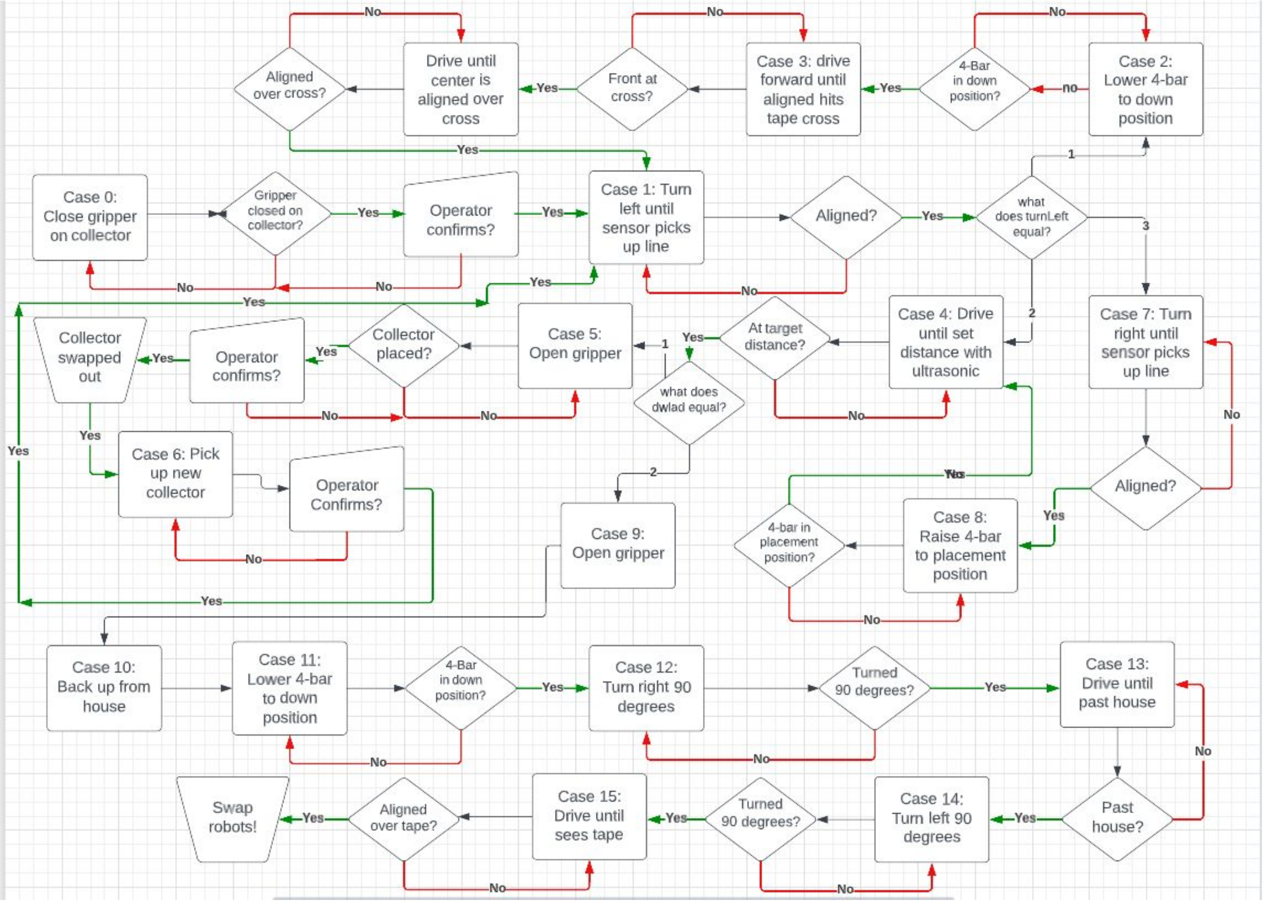




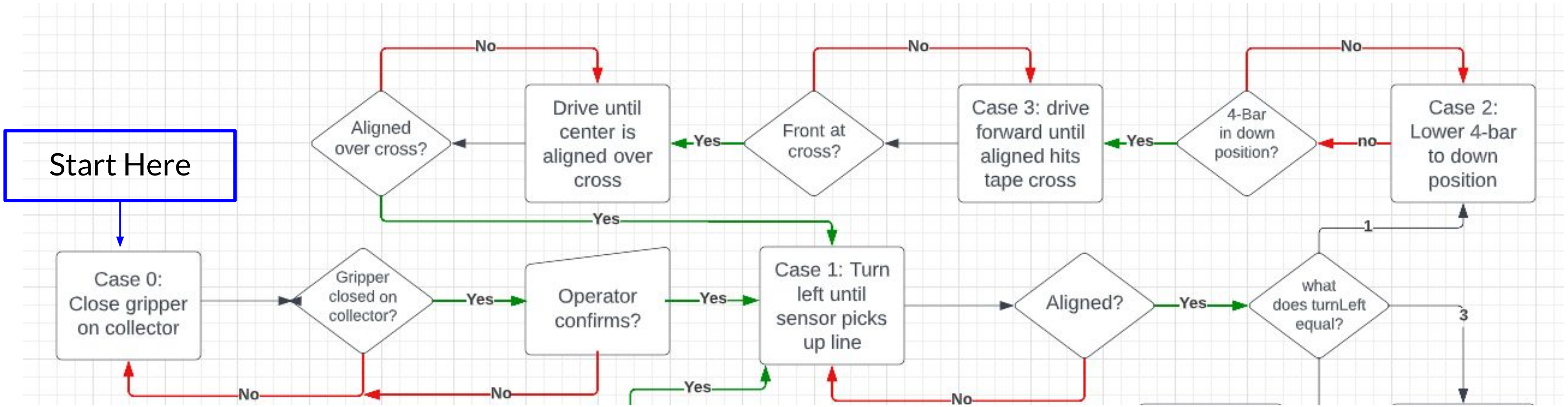
Summary of Sensors - Internal Inputs

- Drive motor encoders
  - Track rotations of drive motors
  - Allow for “dead reckoning” movement based on encoder ticks per revolution
- Blue motor encoders
  - Quadrature encoders to allow tracking of direction as well as speed
  - Uses interrupts to accurately track changes in the motor’s position
- Rotary Potentiometer
  - Allows for careful and accurate control of standard servo’s positions
- Linear Potentiometer
  - Used to track position and speed of continuous servo
  - Connected to bottom plate of linear slide gripper to give position of plate, and then translate that to control of servo

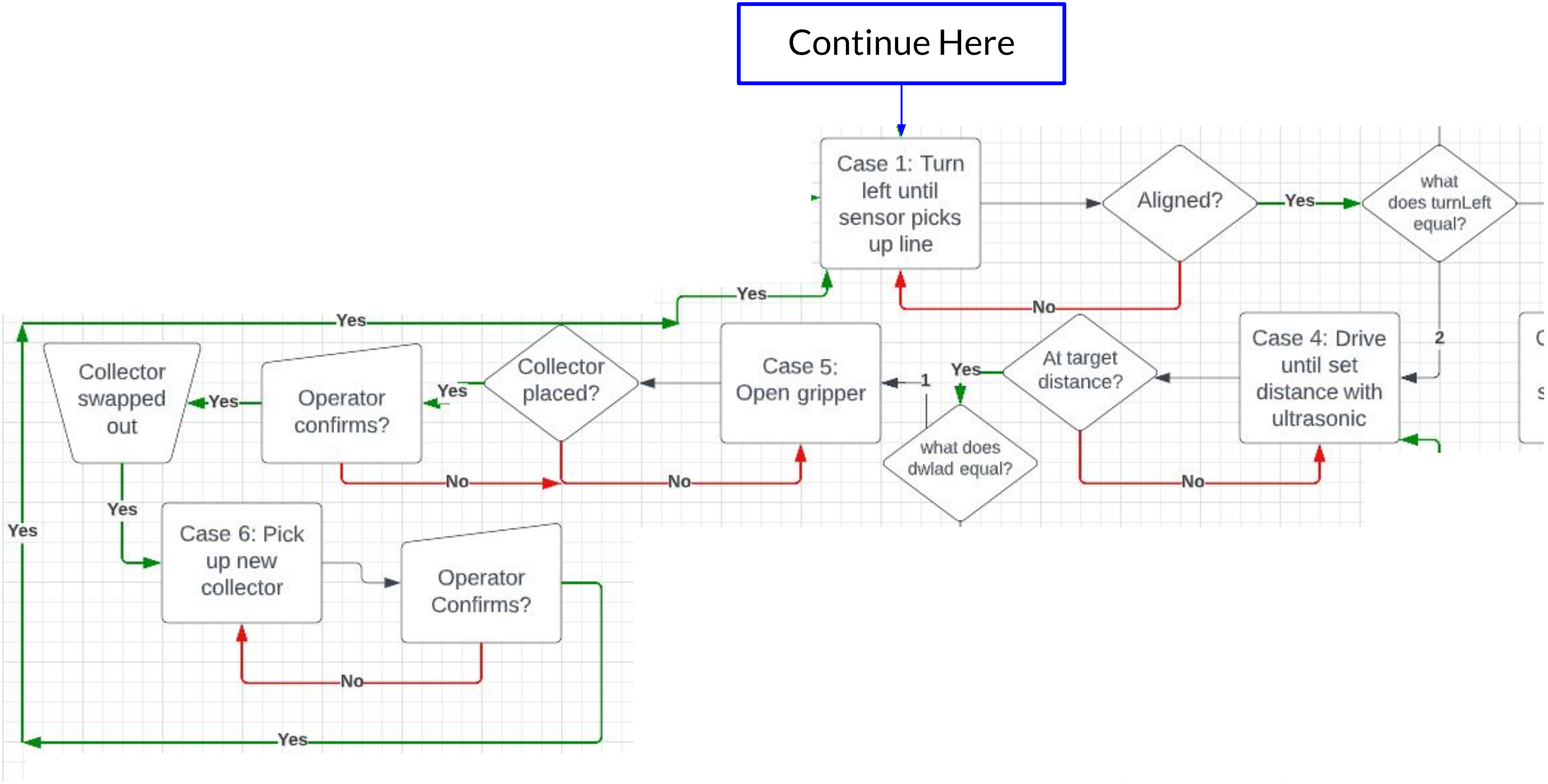
```
void isrA()
{
    if(digitalRead(ENCB) != digitalRead(ENCA))
    {
        direction = 1;
    }
    else
    {
        direction = -1;
    }
    count += direction;
}

void isrB()
{
    if(digitalRead(ENCA) != digitalRead(ENCB))
    {
        direction = -1;
    }
    else
    {
        direction = 1;
    }
    count += direction;
}
```



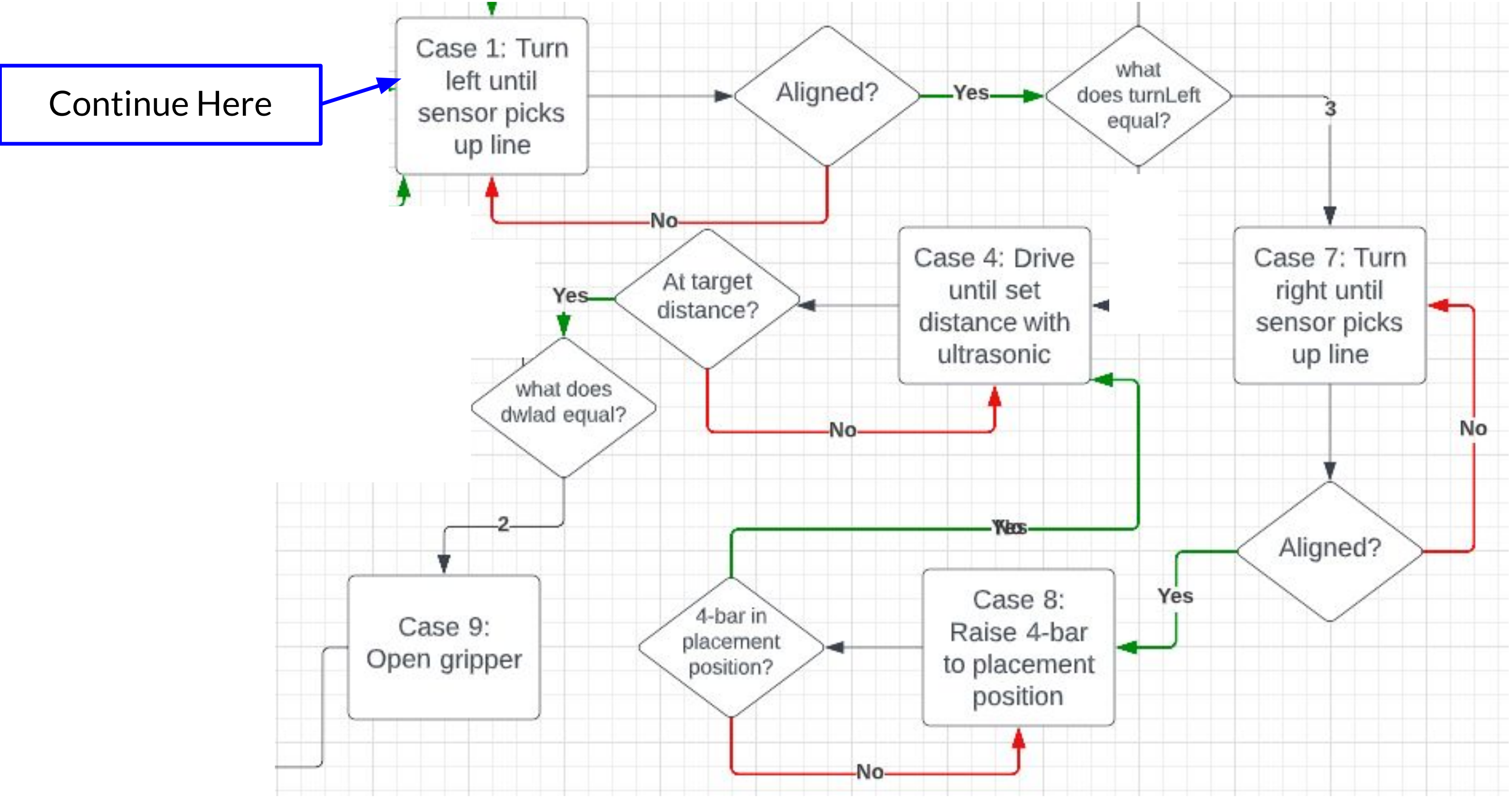
Program Flowchart - Overview



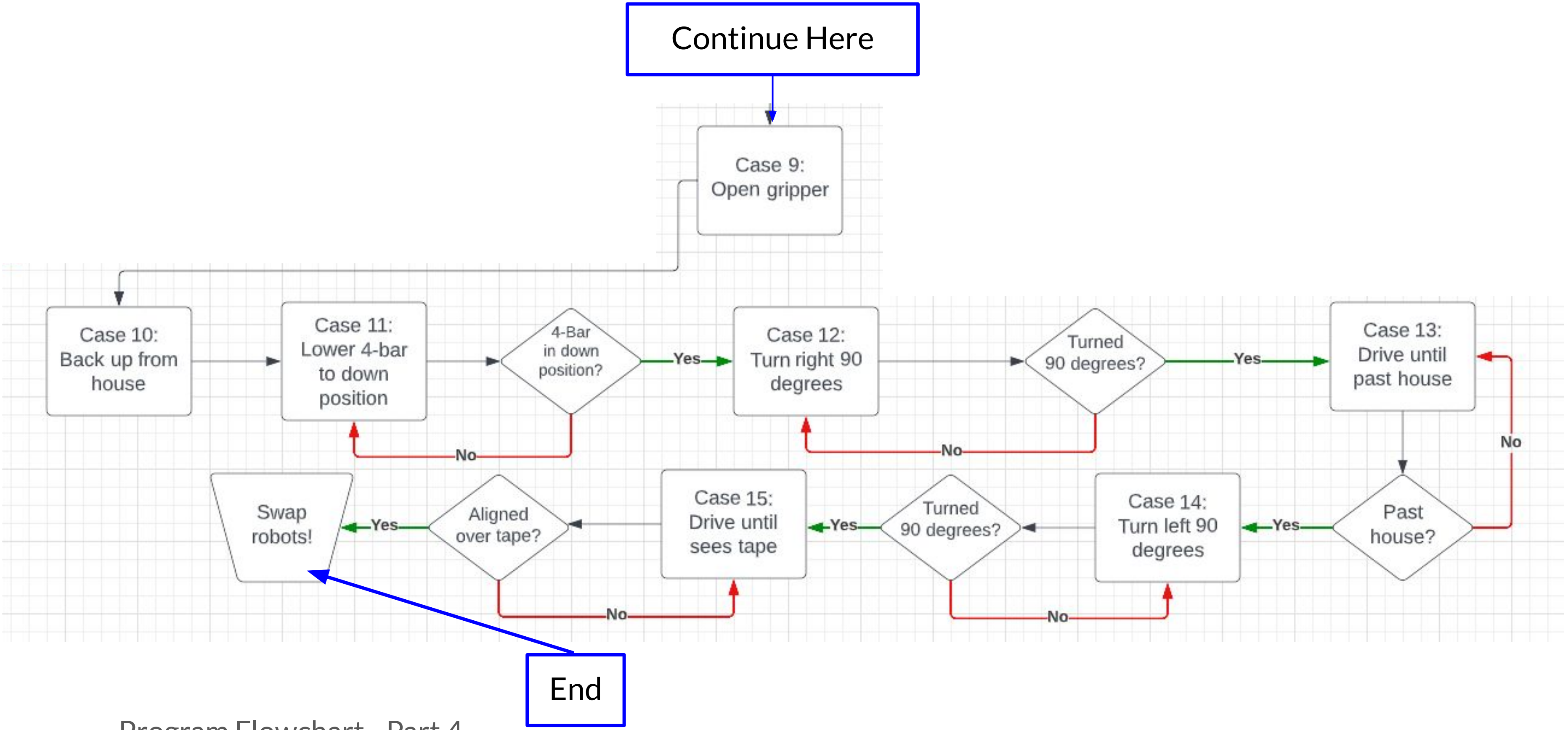
Program Flowchart - Part 1



Program Flowchart - Part 2

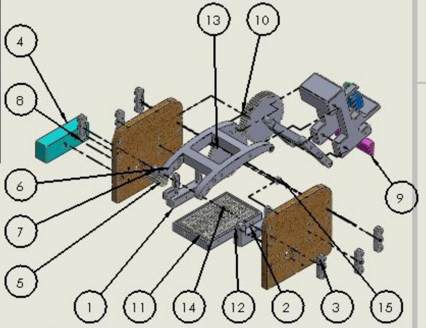


Program Flowchart - Part 3



Program Flowchart - Part 4

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	MATERIAL	UNIT WEIGHT	EXTENDED WEIGHT	UNIT COST	EXTENDED COST
1	2001.01	RIGHT CHASSIS MOUNT	1	PLA	0.0224	0.0224	0.15	0.15
2	2001.02	LEFT CHASSIS MOUNT	1	PLA	0.0224	0.0224	0.15	0.15
3	2001.03	LASER CUT MOUNT	2	PLYWOOD	0.0623	0.1245	0.37	0.74
4	2001.04	BLUE MOTOR	1	PROVIDED	--	--	--	--
5	2001.05	MOTOR GEAR	1	PLA	0.02127	0.02127	0.15	0.15
6	2001.06	TOP LINK	1	PLA	0.0587	0.0587	0.32	0.32
7	2001.07	1/4 INCH SPACER	2	PLA	0.0002	0.0004	0.05	0.10
8	2001.08	BEARING FLAT	6	PLA	0.0060	0.0036	0.10	0.60
9	2001.09	GRABBER ASSEMBLY	1	VARIOUS	--	--	--	--
10	2001.10	GEAR LINK	1	PLA	0.0890	0.0890	0.37	0.37
11	2001.11	POLOLU BREAD BOARD	1	PROVIDED	--	--	--	--
12	2001.12	BREADBOARD MOUNT	1	PLA	0.0347	0.0347	0.20	0.20
13	2001.13	COMBO GEAR	1	PLA	0.0435	0.0435	0.23	0.23
14	2001.14	1/8 INCH SPACER	1	PLA	0.0002	0.0002	0.05	0.05
15	2001.15	0.08 INCH SPACER	1	PLA	0.0002	0.0002	0.05	0.05
--	--	--	--	--	--	0.4423	--	3.11



WORCESTER POLYTECHNIC INSTITUTE

DRAWN JRM 10-8-2022

MATERIAL VARIOUS

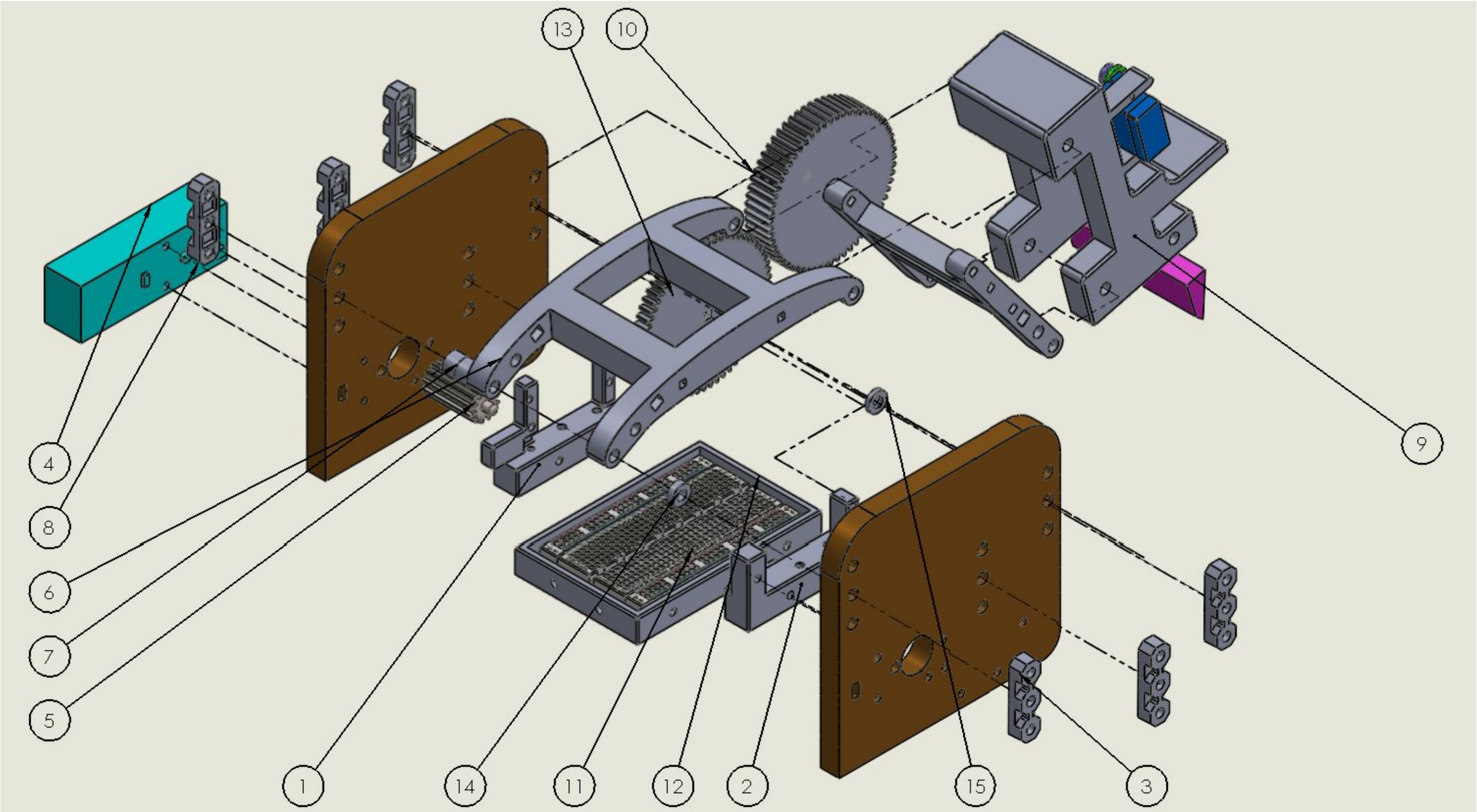
TITLE: Four Bar Assemby

SIZE B DWG. NO. 2001.01 REV

SCALE: 1:5 WEIGHT: SHEET 1 OF 2

Solidworks Bill of Materials and Exploded View

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	MATERIAL	UNIT WEIGHT	EXTENDED WEIGHT	UNIT COST	EXTENDED COST
1	2001.01	RIGHT CHASSIS MOUNT	1	PLA	0.0224	0.0224	0.15	0.15
2	2001.02	LEFT CHASSIS MOUNT	1	PLA	0.0224	0.0224	0.15	0.15
3	2001.03	LASER CUT MOUNT	2	PLYWOOD	0.0623	0.1245	0.37	0.74
4	2001.04	BLUE MOTOR	1	PROVIDED	--	--	--	--
5	2001.05	MOTOR GEAR	1	PLA	0.02127	0.02127	0.15	0.15
6	2001.06	TOP LINK	1	PLA	0.0587	0.0587	0.32	0.32
7	2001.07	1/4 INCH SPACER	2	PLA	0.0002	0.0004	0.05	0.10
8	2001.08	BEARING FLAT	6	PLA	0.0060	0.0036	0.10	0.60
9	2001.09	GRABBER ASSEMBLY	1	VARIOUS	--	--	--	--
10	2001.10	GEAR LINK	1	PLA	0.0890	0.0890	0.37	0.37
11	2001.11	POLOLU BREAD BOARD	1	PROVIDED	--	--	--	--
12	2001.12	BREADBOARD MOUNT	1	PLA	0.0347	0.0347	0.20	0.20
13	2001.13	COMBO GEAR	1	PLA	0.0435	0.0435	0.23	0.23
14	2001.14	1/8 INCH SPACER	1	PLA	0.0002	0.0002	0.05	0.05
15	2001.15	0.08 INCH SPACER	1	PLA	0.0002	0.0002	0.05	0.05
--	--	--	--	--	--	0.4423	--	3.11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