Western University of Canada

Faculty of Engineering

MSE 2202 – Introduction to Mechatronic Design

Team Project – Tesseract Robot

by

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Product Development File

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Date Submitted: April 11, 2018

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Specification and Planning

Problem Statement

Create an autonomous system that locates and retrieves a tesseract and places it under the pyramid that is emitting the correct signal.

Meeting Minutes #1

Date: February 15, 2018

Agenda:

- Define/ Understand Problem Statement
- Break down the problem into smaller tasks

Discussion:

1. **Problem Statement**
   a. create an autonomous system that locates and retrieves a tesseract and places it under the pyramid that is emitting the correct signal.

2. **Step by Step breakdown**
   - Locate the cube
   - Retrieve the cube
   - Locate the correct pyramid
   - Pick up pyramid
   - Place pyramid over cube

3. **Concerns:**
   - The robot's motion might not be able to effectively move over the conduits
     - Friction calculations required to select appropriate motors and wheels
     - Unsteady motion over the conduits may result in the loss of the location of the pyramid or tesseract when locating them
   - Cube might be pushed over the wall during cube retrieval

To be completed:

1. Brainstorm possible strategies for locating the tesseract
2. Compile several solutions for tesseract and pyramid retrieval
3. Research possible sensors that could be used in the products

Product Design Requirements

Meeting Minutes #2

Date: February 22, 2018

Agenda:

- Analyze field setup and discover specific problems that we feel we must overcome in our robot design.
- Define design requirements
- Begin sketching implementations of ideas and analyzing the plausibility and effectiveness of these designs.
- Generate a list of questions to be answered both internally and externally.

Discussion

Analyzing Field Setup

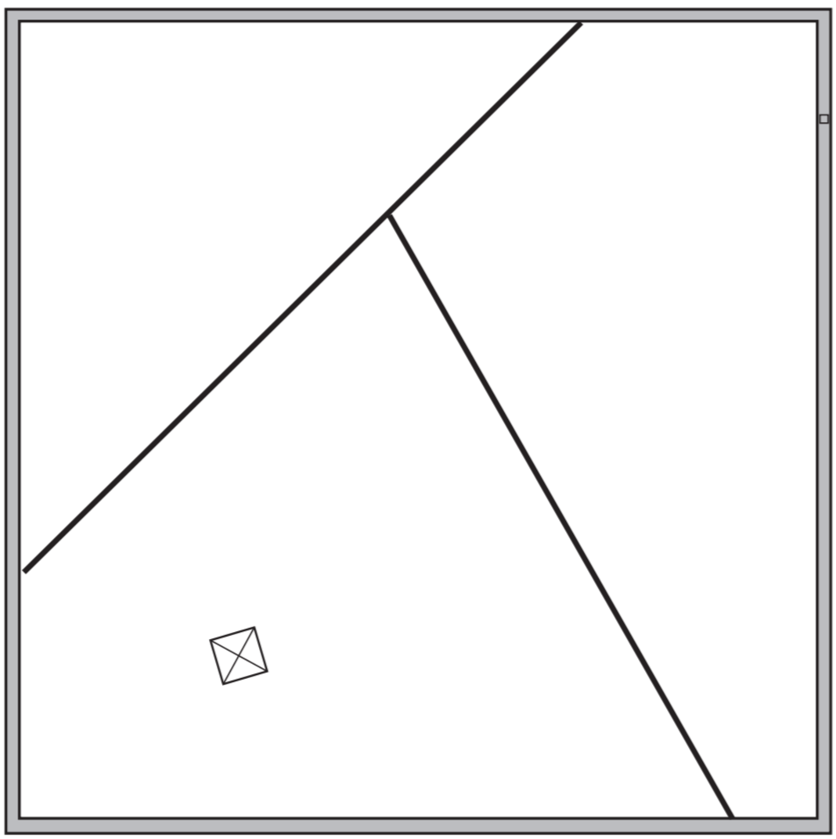


Figure 1: Field Setup

- Encoders, ultrasonic range finders and other sensors that give the robot a sense of placement will be vital for an autonomous period within the open field.

Questions

Question	Approach
How precise is pyramid hole size compared to cube?	Eugen
Angle of pyramid	Eugen
How much of our bot can be laser cut / 3d printed (within budget?)	Eugen
How do we use suction cups with arduino?	Google
Friction coefficients with lexan?	Google
Hall effect sensors	Google
Photosensitive (IR) sensors	Google
Ultrasonic sensors	Google
Can we use outsourced motors	Naish
What are the specs on the VEX sensors Prof. Naish has for us	Owl

Figure 2: Questions Table

To be completed:

- Analyze the implementation of various designs and begin discussing best choices for first prototype.
- Discuss financial budget and parts that are essential for building such designs.

Design Requirements/ Specifications:

Considering the Problem Statement a list of consumer needs was compiled. These consumer needs then lead to a set of engineering requirements that were used to set up a Quality Function Deployment (QFD).

The main goal of the robot being designed is to reliably and consistently locate and place the tesseract under the correct pyramid. To do this each of the tasks the problem is broken down into must be completed effectively. More specific requirements were then generated for each part of the task after the task was broken down into multiple steps. These task specific requirements were used to evaluate the validity of the concepts generated during the concept generation process. The following sub-requirements were generated:

1. being able to navigate the course without being hindered by the conduits
    a. Move straight forwards or backwards
    b. Do not slip over the conduits
    c. Be able to turn over the conduits
2. Locating and retrieving the tesseract
    a. Consistently locate the tesseract no matter the location
        i. modular
    b. Accurately locates the tesseract
    c. Does not push the tesseract somewhere unreachable during the locating process
    d. Does not lose/ drop the tesseract while navigating the course after retrieval
3. Locating the correct pyramid and retrieving it
    a. Consistently reads the signal from each pyramid
    b. Consistently selects the correct pyramid
    c. Does not lose the signal after locating the pyramid
    d. Effectively pick up the pyramid
    e. Do not drop the pyramid

Row Number	Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Weight / Importance	Relative Weight
1	Fast	4	13.33
2	Reliable	5	16.67
3	Inexpensive	2	6.67
4	Easy to maintain	2	6.67
5	Easy to set up	3	10.00
6	Aesthetically pleasing	1	3.33
7	Fuel efficient	2	6.67
8	Clean operations	5	16.67
9	Reasonably sized	4	13.33
10	Incorporate latest technology	2	6.67

Figure 3: Customer Requirements QFD

			Relationship Between Requirements: 9 - Strong 3 - Moderate 1 - Weak										
			Column Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
			Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9
			Requirement Weight	120	150	60	96.67	90	30	76.67	200	150	76.67
			Relative Weight	11.43	14.29	5.71	9.21	8.57	2.86	7.30	19.05	14.29	7.30
			Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)										
			Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▼	▲	▼	▲	▼	x	▼	▲
			Target or Limit Value	3	100	1000	10	2	75	10	0	25x50x80	2
Row Number	**Max Relationship Value in Row**	**Relative Weight**	**Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")** / **Demanded Quality (a.k.a. "Customer Requirements" or "Whats")**	Completes task within x minutes	Completes task x percent of the time	Final product costs x dollars	Needs to be maintained after x uses	Product begins operations after x inputs	x percent of surveyed individuals indicate that product is aesthetically pleasing	Product consumes x watts of power	Product does not drop any debris during operations	Product is within 25x50x80 cubic cm	Product incorporates latest technology in x areas
1	9	13.33	Fast	9									
2	9	16.67	Reliable		9		1				3		
3	9	6.67	Inexpensive			9							1
4	9	6.67	Easy to maintain				9						
5	9	10.00	Easy to set up					9				3	
6	9	3.33	Aesthetically pleasing						9				3
7	9	6.67	Fuel efficient				3			9			
8	9	16.67	Clean operations							1	9		
9	9	13.33	Reasonably sized									9	
10	9	6.67	Incorporate latest technology										9

Figure 4: Functional Requirements QFD

Correlations: Positive (+) or Negative (-)

Row Number	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Column Number	1	2	3	4	5	6	7	8	9	10
		Completes task within x minutes	Completes task x percent of the time	Final product costs x dollars	Needs to be maintained after x uses	Product begins operations after x inputs	x percent of surveyed individuals indicate that product is aesthetically pleasing	Product consumes x watts of power	Product does not drop any debris during operations	Product is within 25x50x80 cubic cm	Product incorporates latest technology in x areas
4	Needs to be maintained after x uses		-	-							
5	Product begins operations after x inputs										
6	x percent of surveyed individuals indicate that product is aesthetically pleasing			-							
7	Product consumes x watts of power	-			-						
8	Product does not drop any debris during operations	-	+	-	-						
9	Product is within 25x50x80 cubic cm		-	+			+	+	+		
10	Product incorporates latest technology in x areas	+	+	-	+		+	-	+	-	

Figure 5: Functional Requirements Roof QFD

Row Number	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Minimize (▼), Maximize (▲), or Target (x)	Target or Limit Value	Max Relationship Value	Requirement Weight	Relative Weight (Relative Importance)
1	Completes task within x minutes	▼	3	9	120.00	11.43%
2	Completes task x percent of the time	▲	100	9	150.00	14.29%
3	Final product costs x dollars	▼	1000	9	60.00	5.71%
4	Needs to be maintained after x uses	▲	10	9	96.67	9.21%
5	Product begins operations after x inputs	▼	2	9	90.00	8.57%
6	x percent of surveyed individuals indicate that product is aesthetically pleasing	▲	75	9	30.00	2.86%
7	Product consumes x watts of power	▼	10	9	76.67	7.30%
8	Product does not drop any debris during operations	x	0	9	200.00	19.05%
9	Product is within 25x50x80 cubic cm	▼	25x50x80	9	150.00	14.29%
10	Product incorporates latest technology in x areas	▲	2	9	76.67	7.30%

Figure 6: QFD Summary

Program Plan
Work Plan

Week	Deliverable
February 15	Stuff to do for reading week, general direction discussion
February 22	Prelim ideas, CAD of arm concepts, research
March 1	First design review ready, tasks assigned for prototype
March 8	Work on prototype build, most parts sourced
March 15	Work on prototype build and coding
March 22	Second design review ready, prototype complete
March 29	Final parts laser cut or otherwise created
April 5	Robot complete
April 11	Report complete

Figure 7: Work Plan

Conceptual Design

Meeting Minutes #3

Date: February 24, 2018

Agenda:

- Discuss strategies for locating the tesseract
- Discuss designs for cube and pyramid retrieval
- Discuss sensors and actuators that could possibly be used in the design

Discussion:

1. **Strategies for locating the tesseract**
    - Move to the center of the field and spin slowly and scan all four walls looking for the cube
        - Hall effect sensors have quite a short range so if this strategy is to be used, sensors with a longer range should be used.
    - Go around the entire field and scan the entire length of the wall until the cube is located
        - Hall effect sensors could be used
        - Must be mind full of not knocking the cube off the wall just before locating it as we got around the wall
    - Design a retrieval mechanism that picks up anything that is on the wall
        - No need to find the cube before retrieving it
        - We would just need to know if we have the cube
            - A limit switch or hall effect sensors could be used

2. **Possible Pyramid retrieval designs**
    - Each member brainstormed and sketched several ideas individually
    - The ideas were looked at by all the members and the duplicates were removed
    - Sketches or cad drawings of the pyramid pick up ideas are attached below

3. **Sensors:**
    - A document is created for the purposes of compiling a list of possible sensors that can be used for the product
        - This document contains the name of the product, locations where the product can be sourced from, the price of the products and a link to the spec sheet for the product
        - This file will be regularly updated as possible sensors are further researched and the group strategies for completing the task continues to evolve.

To be completed:

1. Finalize the pyramid pick up concepts
2. Complete the required concept selection processes for the pyramid pick up (i.e. Decision matrix …)

Conceptual Design Development

To generate design concepts, each team member developed sketches and models for each particular task or challenge.

Pyramid Manipulation

Flap Intake Mechanism Design Concept (CAD)

The flap design with a 30-degree angle ramp based on belts and rollers in factory production lines is developed to verify if the pyramid and cube can both be manipulated with one intake mechanism, or if separate claw-type mechanisms are needed for cube manipulation.

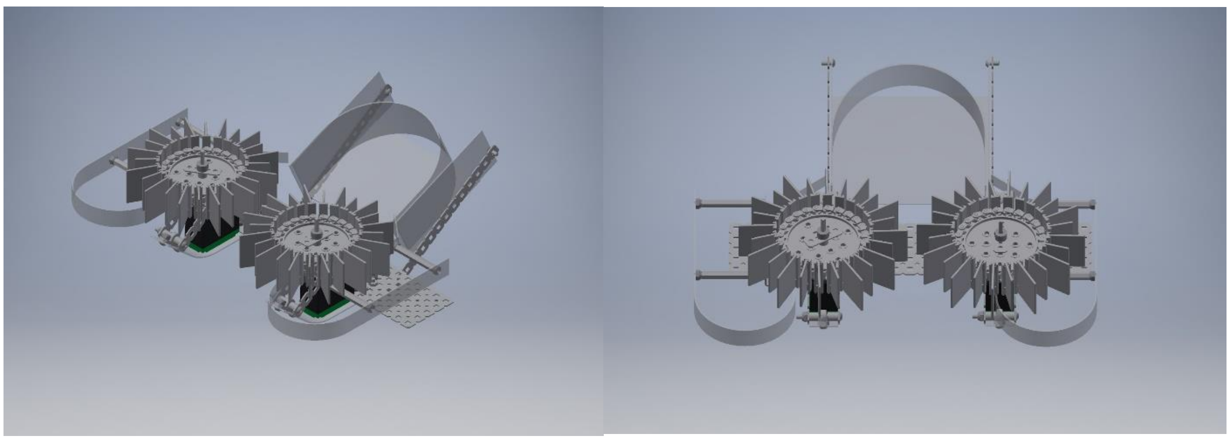


Figure 8: Flap Intake CAD Model

Roller Intake Design Concept

The pyramid roller intake aims to make direct contact with the upper walls of the pyramid, spin opposite to each other to use friction to push the pyramid into a ramp holder. Measures would need to be made to acquire the right type of material (possibly rubber) for the rollers.

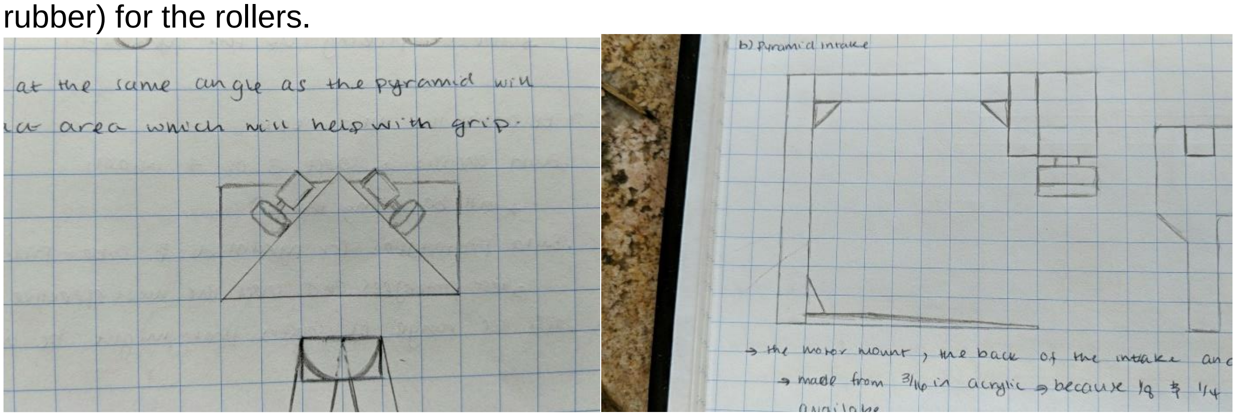


Figure 9: Roller Intake Sketches

Vertical Suction Cups
Using a single servo, two arm links rotate to close the vertical claw onto the pyramid, at which point the suction cups push onto the pyramid and lift it. To increase the clamping force, a gear train with a larger output gear can be pursued.

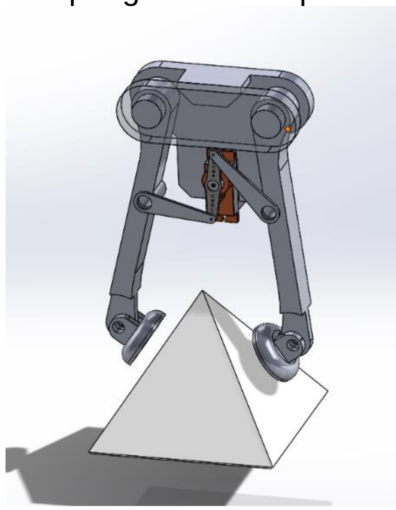


Figure 10: Vertical Suction Mechanism CAD Model

Pyramid Storage
It was decided that having the ability to store and move the pyramid would allow for more flexibility and reliability in design. Without storage, the robot would need to have retrieved the cube and transfer it underneath the pyramid immediately after the pyramid is retrieved, which would both limit design, programming, and marketability of the product. As such, each design is able to contain and maneuver the field through the use of an elevated ramp or suction cups.

Pyramid Location
As a design requirement is to identify the correct pyramid transmitting a code via IR, an IR sensor is necessary. In addition to searching for the pyramid through IR, an ultrasonic sensor may be used to verify the position of the pyramid.

Meeting Minutes #4

Date: March 2, 2018

Agenda:

- Discuss Designs for Cube retrieval
- Discuss possible chassis designs

Discussion:

1. **Designs for cube retrieval**
    - Each member brainstormed cube retrieval methods individually
    - The concepts generated by the members were examined and the duplicates were removed.
    - A drawing or cad model of the concepts generated are available on the next page.
    - The group originally considered modifying the pyramid retrieval mechanism to pick up the tesseract as well to simplify our design but this would require the pyramid intake to be able to become much smaller that it needs to be when intaking the pyramid. This design would also require the intake to reach above a wall.
        - Due to the above challenges, it was observed that although using one mechanism would decrease the number of components needed, it would increase the complexity of the intake design and lower its reliability.
    - The remaining designs are as follows
        - Magnetic Intake: **Figure 11**: Magnetic Intake CAD Model
        - Arm Claw: **Figure 12:** Arm Claw Sketches
        - Rail Claw: **Figure 13:** Rail Claw Sketches
    - **Note –** Depending on the design selected for cube retrieval our strategy from locating the cube might change
        - As described in meeting minutes #2 from February 24, 2018
2. **Chassis Design**
    - A four-wheel chassis design was selected over a two or three-wheel design to gain higher stability
        - This will allow the product to navigate the conduits in a more consistent and stable manner
            - A three-wheel design with a passive front wheel will be less consistent so the path of the robot would be harder to predict as it moves over the conduits
        - **Concerns:** The 4-wheel design might make it harder for the robot to turn in tight corners
    - One motor controlling each side would ensure that the two wheels on one side of the robot are moving in sync and are not fighting against one another at any point. This will make the product easier to program.
    - A chain can be used to drive the two wheels on each side using one motor.

        - The chain allows us to adjust the distance between the wheels to reach a balance between the consistency of the drive and the space required for the cube and pyramid mechanisms to be mounted on.
    - Calculations are required to find effective and efficient motors to use.

To be completed:

1. Research possible motors and wheels that can be used for the drive base
2. Complete the required concept selection processes for the cube retrieval mechanism (i.e. Decision matrix …)

Cube Manipulation

Magnetic Intake Design Concept

This design involves using a rotating mechanism with various flaps attached to it. A magnet would be attached to each of these flaps. As a result the mechanism can pick up the pyramid anywhere on the wall as the robot goes around the wall. This design does not require us to know where the tesseract is. With this design we would only need to know when the tesseract is retrieved by the robot. A secondary mechanism must then be used to remove the cube from the magnet.

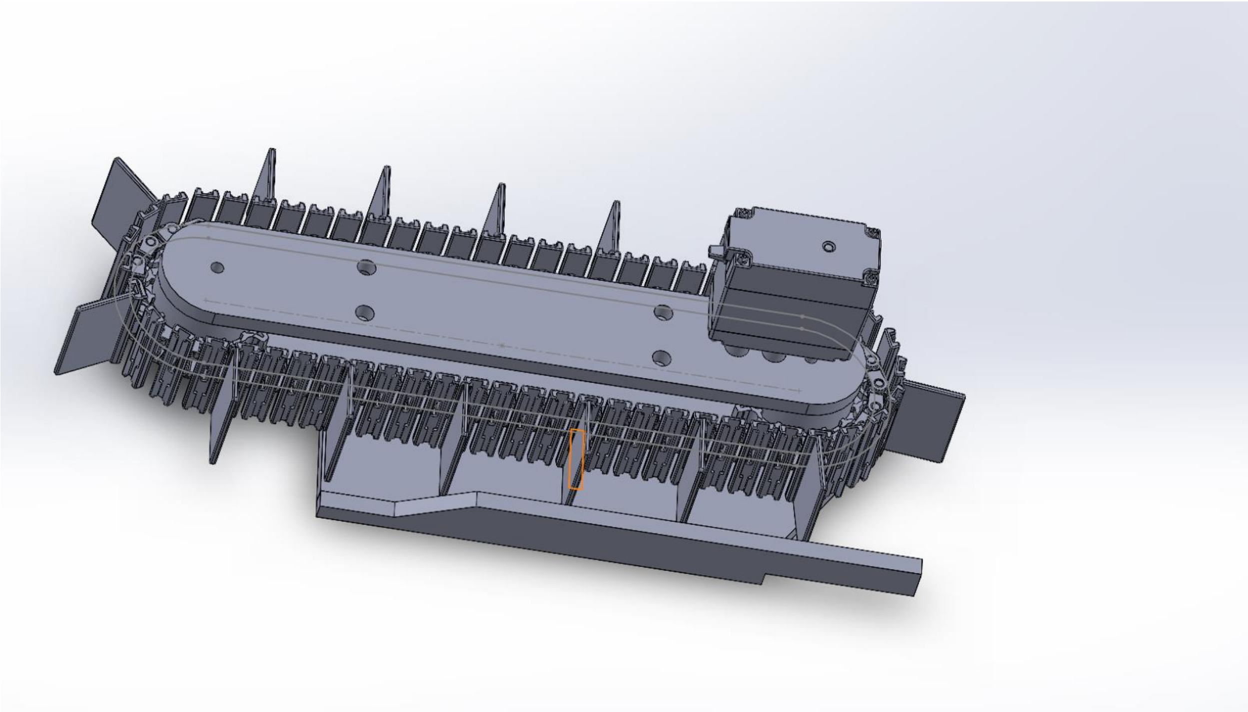


Figure 11: Magnetic Intake CAD Model

Arm Claw
The arm would be mounted on the robot at the same height as the wall, and can pivot to adjust for minor height deflections. The claw design is much more reliable than the intake for picking up and securing the tesseract, and the arm can rest over the wall while the robot drives along the perimeter of the arena.

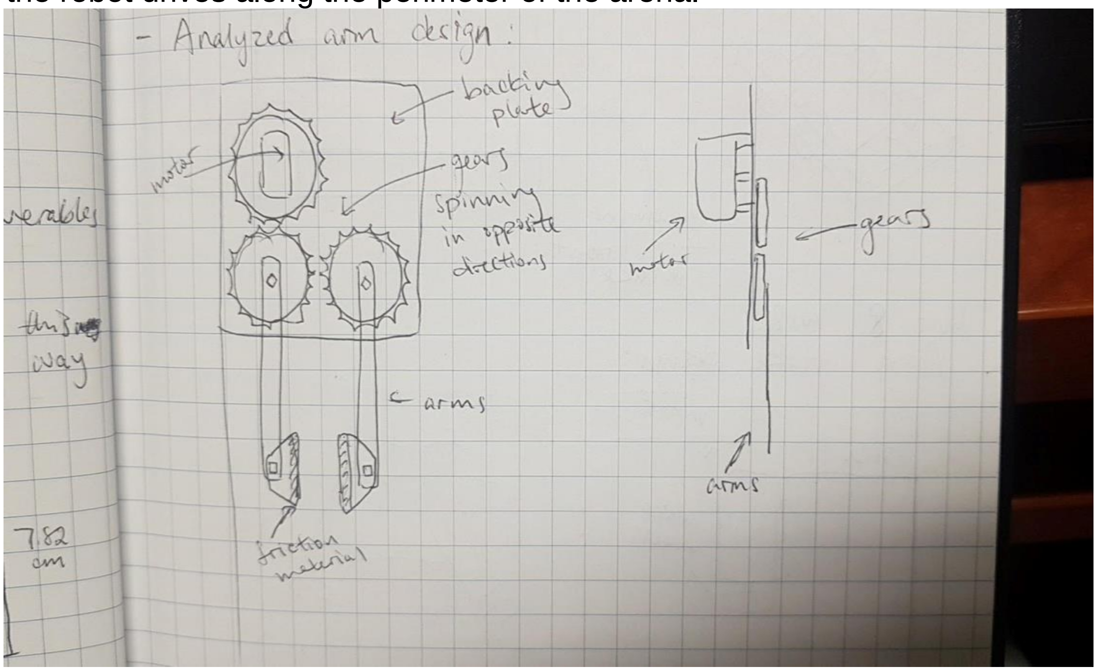


Figure 12: Arm Claw Sketches

Rail Claw:
Utilizes the same claw design as the arm claw, but retracts and extends the claw by mounting it at the end of a rack and pinion. The tesseract would be retrieved and controlled by retracting the rack and dropping it in a funnel on the robot. This eliminated the problems of powering a motor to hold horizontal position and the tesseract bouncing randomly, increasing the reliability of the entire procedure.

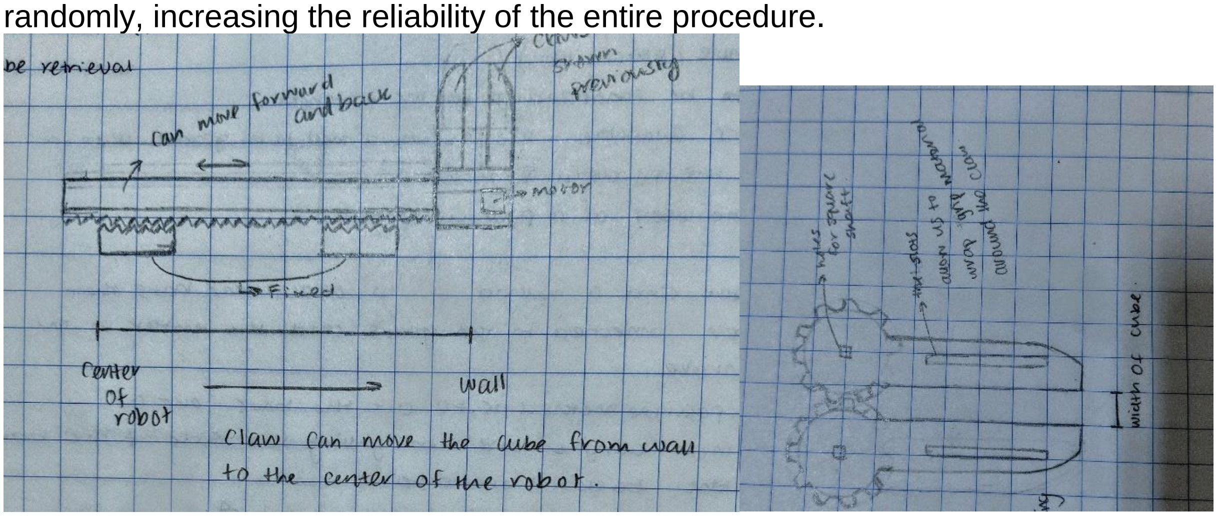


Figure 13: Rail Claw Sketches

Cube Storage and Release

To store the cube as the robot begins to search for the pyramid, all three retrieval mechanisms are able to keep the cube inside the mechanism. To release the cube, however, the magnetic intake requires a stopper or a motorized mechanism to remove the cube from the magnets. A ramp or a funnel can be used to direct the cube to the bottom of the robot, close to the pyramid mechanism (**Figure 14:** Ramp Sketches).

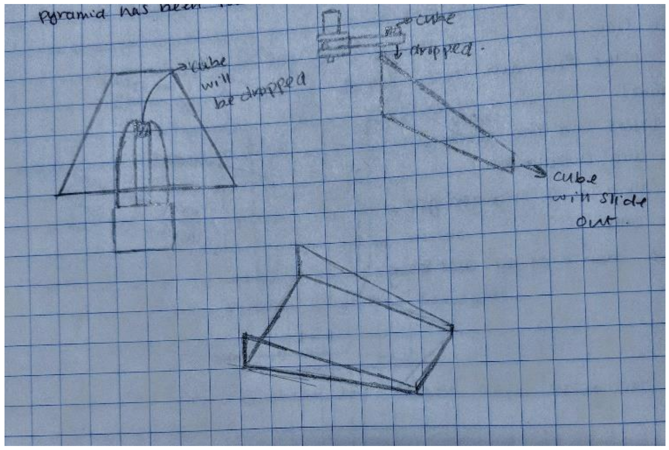


Figure 14: Ramp Sketches

Cube Location

Since the tesseract contains a magnet, a hall effect sensor can be used to detect the magnetic field created by the tesseract. In addition, a magnetometer or a compass can be used to take advantage of the magnet inside the cube. Both of these sensors, however, could pickup magnetic fields from other ferrous parts of the robot and so it must be ensured that the cube manipulation mechanism is built as nonferrous as possible. As the magnetic intake mechanism would inherently be problematic, the intake could constantly be rotating along the wall, and when the cube is retrieved, a limit switch or ultrasonic range finder could detect possession.

Note - The concepts modeled below were modeled to provide a clear visual basis for the ideas presented. This ensured that all members fully understood each concept. The use of VEX parts allowed the group to complete these models quickly which resulted in more efficient concept generation sessions. The models below are not a representation of the final product.

Drive Concepts

Chassis Heights

Low Chassis: Pros: Easier to implement. Gives you more space to build. Cons: Would need more wheels and perhaps more than 2 motors. May not go over the conduits.

High Chassis: Pros: Can go over the conduits with ease. Will at most require four wheels although more are possible. Cons: Loses some build space. More materials are required to elevate chassis.

Mecanum Drive Design Concept (CAD)

The four-wheel drive train proposed will be elevated >1 inch through the use of 4-inch wheels to be able to drive over the conduits in the power plant. A holonomic drive is preferred for the ability to drive in all directions without turning to best locate the cube, and will be experimented with to support this decision.

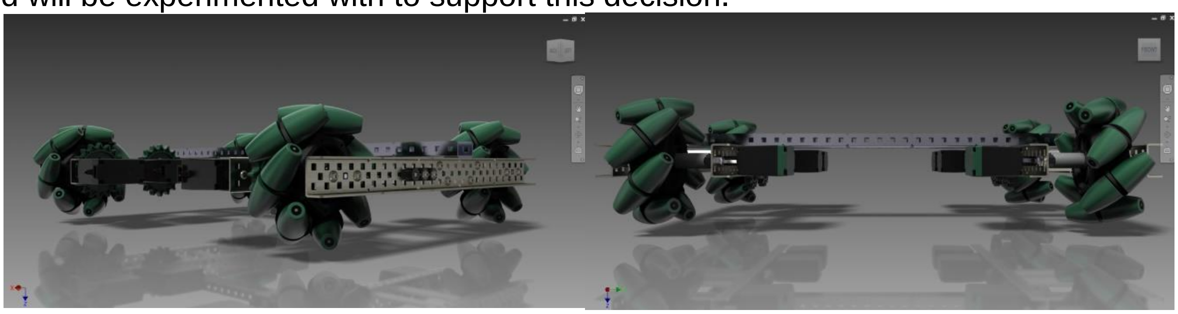
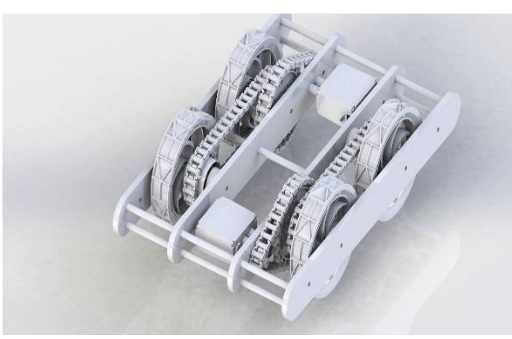
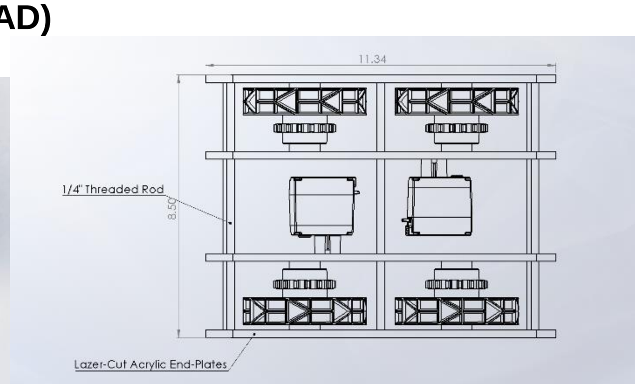


Figure 15: Mecanum Drive CAD Model

Tank Drive Design Concept (CAD)





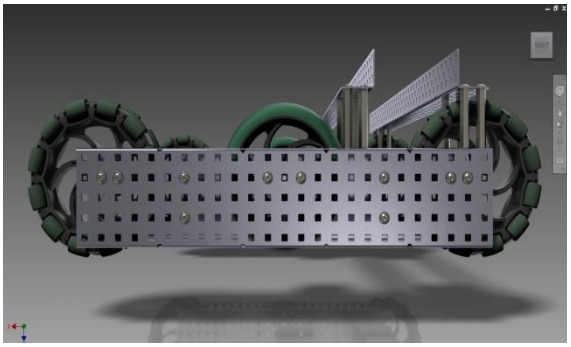


Figure 16: Tank Drive CAD Model

This chained tank drive allows the use of only two motors, with power distributed to both wheels on either side. This is a much simpler design that would make programming more reliable.

X-Drive Holonomic

A 4 motor drive with 4 wheels angled at 45 degrees allows for maneuvering forward and backwards, and left and right.

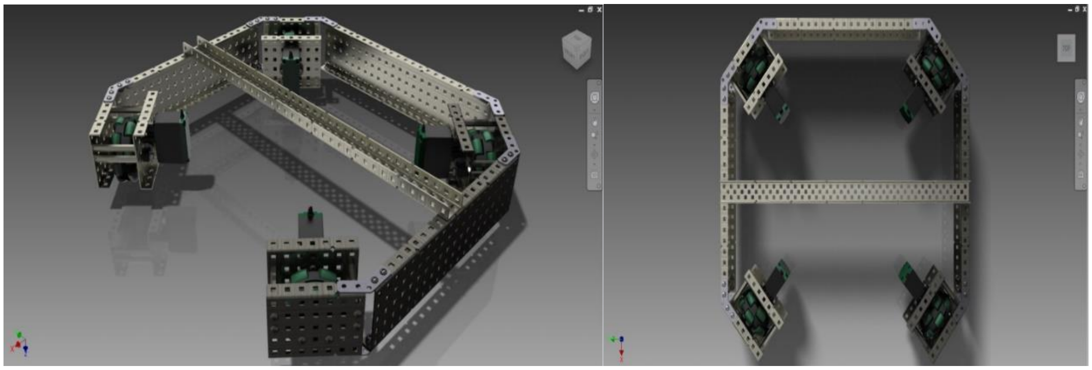


Figure 17: X-Drive CAD Model

H-Holonomic Drive

An additional motor powering a perpendicular wheel allows the robot to maneuver left and right. May compromise space.

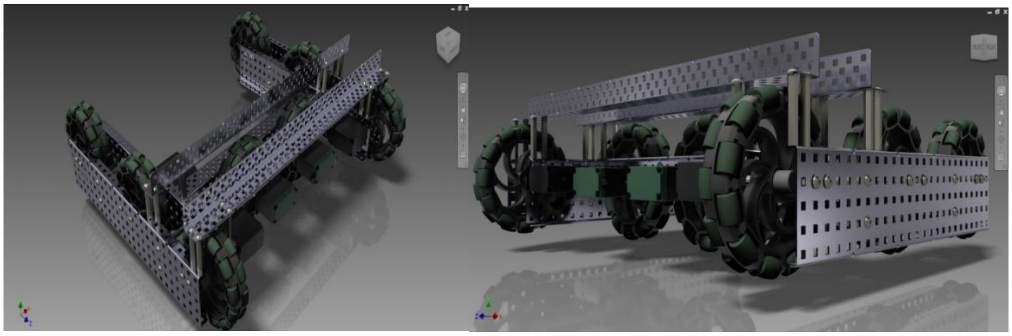


Figure 18: H-Holonomic Drive CAD Model

Lift Concepts

Lift Design Concept: If a need for a lift is found, it is suggested the lift be a linear lift to best maneuver the tesseracts and Pyramids autonomously, or a simple non-linear lift design for reliability.

Simple Lift

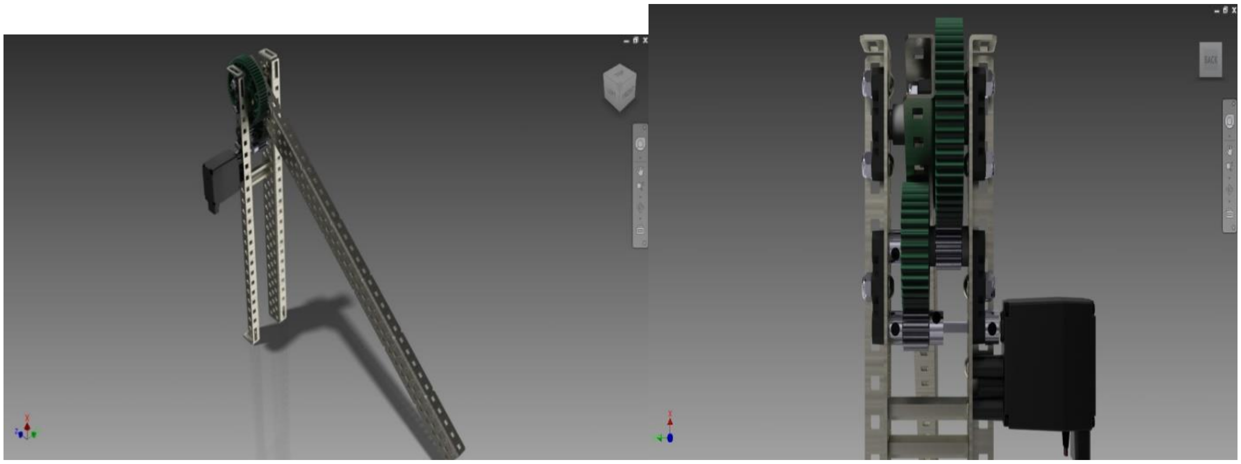


Figure 19: Simple Lift CAD Model

Chain Bar

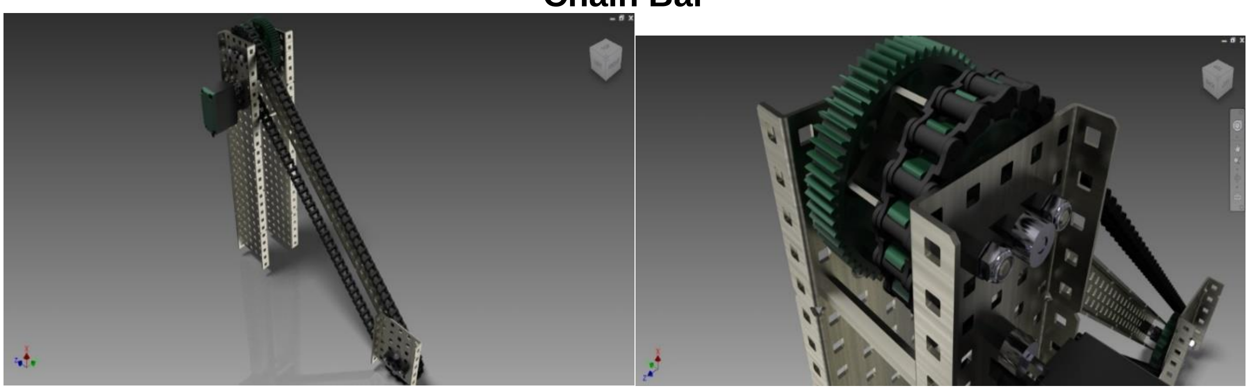


Figure 20: Chain Bar CAD Model

4-Bar Linkage

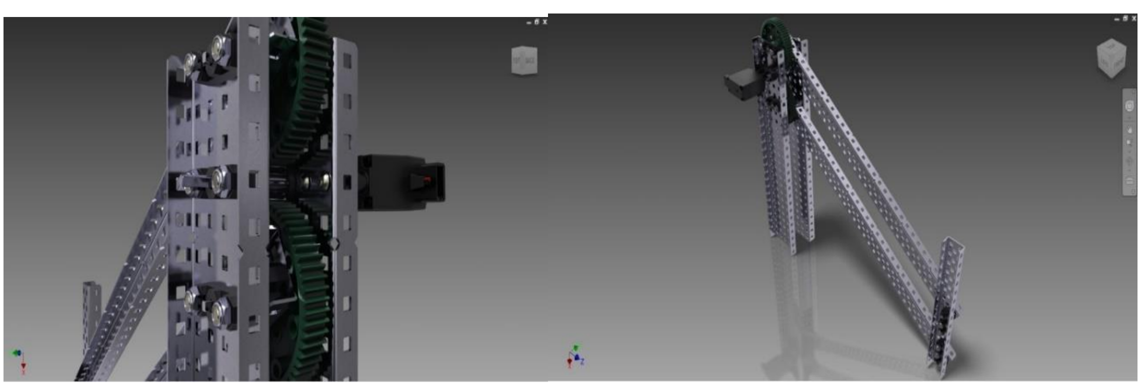


Figure 21: 4-Bar Linkage CAD Model

Concept Evaluation

After concepts were fully discussed and defined, they were objectively compared through decision matrices to select the best concept. Some design decisions were made during discussion or selected based on other concept selections.

Cube Manipulation

Decision Matrix - Tesseract Retrieval Mechanisms								Options			
	Reliability	Size	Complexity	Speed	Cost	**Total**	**Relative Weight**	Intake	Arm Claw	Rail Claw	Mag. Intake
Reliability	1	2	4	4	4	15	**0.44444444**	-1	0	1	1
Size	0.5	1	2	2	2	7.5	**0.22222222**	-1	0	0	-1
Complexity	0.25	0.5	1	1	1	3.75	**0.11111111**	-1	0	-1	-1
Speed	0.25	0.5	1	1	1	3.75	**0.11111111**	0	0	0	0
Cost	0.25	0.5	1	1	1	3.75	**0.11111111**	0	0	0	-1
Total						**33.75**	**1**	**-0.7777778**	**0**	**0.33333333**	**0**

Figure 22: Cube Manipulation Decision Matrix

Out of the three designs, it was decided through a decision matrix that the rail claw would be best for cube manipulation due to its ability to reliably retrieve the cube at large heights and lengths from the robot and bring it to a position underneath the robot. The Arm claw would require the cube to drop into an indeterminable position and the magnetic intake would result in a lack of sensor data, although possibly a quicker method.

Cube Storage and Release

The claw's servo closed position will be set greater than perpendicular to the cube and along with the use of a gripping material, the claw will be able to securely store the cube. A ramp at the center of the robot was chosen to best support the rail claw, which would utilize a rack and pinion rail to bring the claw and cube into the center and drop it through the funnel created by the ramp.

Cube Location

Since the cube retrieval mechanism will not use any magnets, a magnetometer will be used to detect the location of the cube. A compass magnetometer has the ability to detect magnetic fields in all three directions (x, y, z) which will give a much more accurate reading than a hall effect sensor, which only provides a reading within inches to the magnet, after initial tests.

Tesseract Sensor Tests

Distance Detected (cm)	10	5	3	2	1
Magnetometer	No	Yes	Yes	Yes	Yes
Hall Effect	No	No	No	Yes	Yes

Figure 23: Tesseract Sensor Tests

Pyramid Manipulation

Decision Matrix - Pyramid Retrieval Mechanisms								Options		
	Reliability	Size	Complexity	Speed	Cost	**Total**	**Relative Weight**	Claw	Roller Intake	Arm Intake
Reliability	1	3	4	3	4	15	**0.43902439**	-1	0	1
Size	0.33333333	1	2	1	2	6.33333333	**0.18536585**	1	0	1
Complexity	0.25	0.5	1	0.5	1	3.25	**0.09512195**	1	0	0
Speed	0.33333333	1	2	1	2	6.33333333	**0.18536585**	1	0	-1
Cost	0.25	0.5	1	0.5	1	3.25	**0.09512195**	1	0	0
Total						**34.1666667**	**1**	**0.12195122**	**0**	**0.43902439**

Figure 24: Pyramid Manipulation Decision Matrix

The decision matrix resulted in the Arm Intake to be selected. The Arm Intake has a reliable method of containing and releasing the pyramid with a large normal force. The claw may face issues with spontaneously dropping the pyramid if the suction cups were not strong enough and the roller intake's large nature would be unpredictable and would most likely require a wall to push up against.

Pyramid Storage

The pyramid would be stored in a forklift type ramp which has an indented cutout at the bottom to allow for the cube to be placed underneath the pyramid. When this is done, both the pyramid and cube could be released onto the field, with the challenge completed.

Pyramid Location

It was decided to use the IR sensor to detect the pyramid as determining which pyramid was the correct one is essential.

Drive Design

While several drive designs were developed, after the initial status report meeting, it was determined that holonomic drives would lead to several problems during the autonomous run, including the robot moving left and right without a good way of detecting this motion. As such, the tank drive using 4-inch wheels was selected, as this would be high enough to move across conduits and be a reliable drive to program. Two distance sensors on the side of the robot will be used to follow the wall at a distance to search for the cube, while a distance sensor at the front will be used to detect when a turn is to be made.

Lift Design

As the Arm Intake mechanism was pursued, a lift is required to elevate the pyramid above the cube and maneuver over the conduits without the intake hitting them. A horizontal four-bar design was selected due to its strength torque versatility.

Electronic Design

While the MSE-Duino provides functionality due to the two microcontrollers, other ARM and AVR based microcontrollers were also considered for higher speed of sensor computation and more I/O.

	STM32-F429ZI	STM32-F446RE	MSE-Duino	Arduino Mega		
Test:	ARM Cortex-M4 @ 180MHz	ARM Cortex-M4 @ 180MHz	AVR ATmega328p @ 16MHz	AVR ATmega2560 @ 8MHz		Arm Improvement over AVR
INT_LOOP(30000)	19.95	19.95	3.98		MIPS	**501.26%**
LONG_LOOP(30000)	19.99	19.99	2.24		MIPS	**892.41%**
FLOAT_DIV(30000)	2.22	2.22	0.21		MFLOPS	**1057.14%**
DOUBLE_DIV(30000)	2.05	2.05	0.21		MFLOPS	**976.19%**
FLOAT_MUL(30000)	1.63	1.63	0.21		MFLOPS	**776.19%**
DOUBLE_MUL(30000)	1.51	1.51	0.21		MFLOPS	**719.05%**
CoreMark		602.44		4.25	Points	**14175.06%**
Calculate PI as fast as possible	5000	5000	63000	80000	milliseconds	**1260.00%**
Specs:						
Architecture	32-bit ARM	32-bit ARM	8-bit AVR	8-bit AVR		
CPU Freq	180	180	16	8	MHz	
RAM	256	128	2	8	KB	
FLASH	2048	512	32	256	KB	
I/O Pins	144	64	28	64	Pins	
UART / USART Buses	8	6	1	4	Buses	
I2C Buses	3	3	1	1	Buses	
SPI Buses	6	4	2	5	Buses	
ADC	12-bit, 24-ch	12-bit, 24-ch	10-bit	10-bit	Bits	
Interrupts	All GPIO	All GPIO	2	?		

Figure 25: Microcontroller Considerations

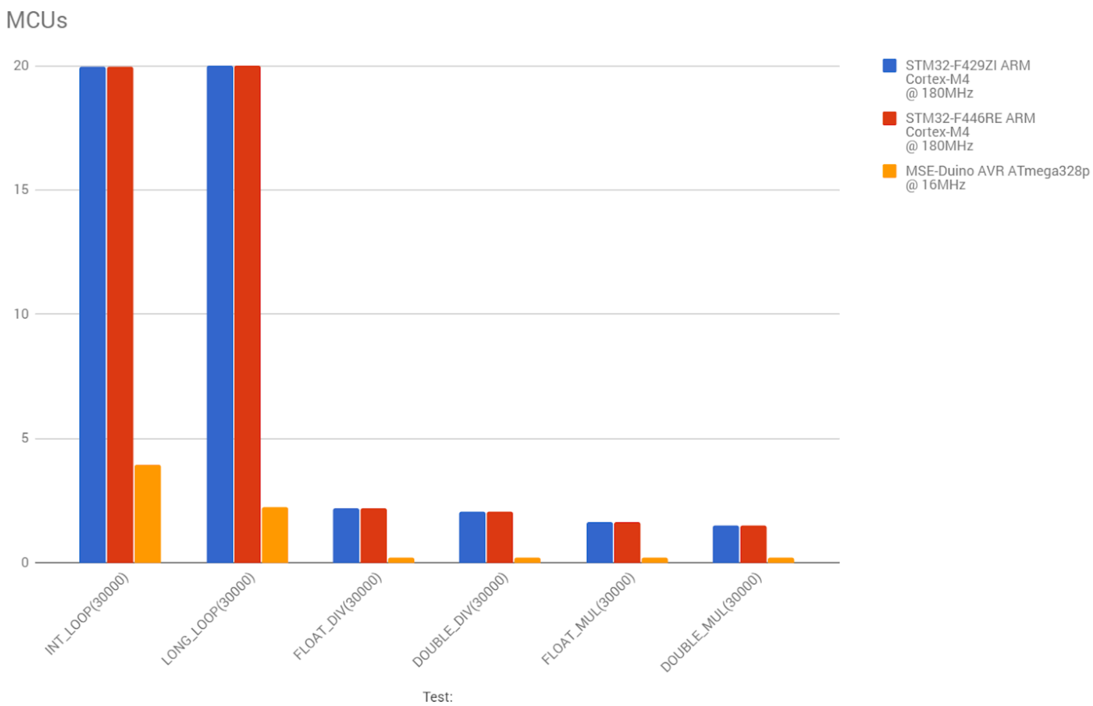


Figure 26: Microcontroller Considerations Graph

Product Design

Project Generation

Meeting Minutes #5

Date: March 9, 2018

Agenda:

- Select the materials to be used in the product
- Decide on methods to replicate the product as closely as possible using the materials available for the product

Discussion:

1. **Material Selection**
    - The materials used on the product should be non-ferrous
        - The tesseract has a magnet inside so it would stick to magnetic materials
        - This can disturb the process
            - If the cube sticks to a part of the robot the cube might not be able to be retrieved and placed under the pyramid correctly
        - Aluminum, carbon fibre, Lexand, acrylic and wood are some non-ferrous options
            - Aluminium components can be used for portions of the robot that are under a lot of loading and need to be relatively strong and non-brittle
                - Much lighter than steel and nonferrous
            - Acrylic is a good material to use for parts of the robot that are not under much loading
                - Acrylic can be laser cut easily so manufacturing different parts from it is very simple.
                - Light weight
                - Acrylic is brittle so it cannot be bent into different shapes
                - Glue with small connectors (also cut from acrylic) could be used to make 3 dimensional designs from the laser cut piece
                - **Concerns –** since acrylic is brittle the parts made from it would be easily damaged if they fall or are loaded in a non-favorable angle. Gluing the pieces will also result in mechanisms with low structural integrity as glue might not hold the pieces together securely enough
            - Lexand components would be stronger that those made out of acrylic and they can be bent to make the 3-dimensional mechanisms on the product.
                - Although they cannot be laser cut, they can be machined using plastic specific tools and machines.
                - Lexand is a good alternative for the cube and pyramid retrieval mechanisms.

2. **Prototype Design**

- The 4 inch VEX wheels available in the lab will be used on prototype instead of the 5” elastic wheels selected for the product.
    - These wheels are harder that the wheels selected for the product so they may have some traction problems when going over the conduits
        - Extra grip might need to be added to make the drive base more closely replicate the product
- VEX 393 motors with integrated encoders are used instead of the Nemo 23 motors selected for the drive base.
    - These motors are not as strong as the motors selected for the product and have different internal gearing so they will have to be geared differently
- Use laser cut acrylic pieces for the cube pick up and the pyramid intake
    - Must note that this will be less durable than the actual mechanisms since acrylic is more brittle than Lexan and aluminium.

To be completed:

1. Complete the CAD for the intake and cube pick up parts that need to be laser cut for the prototype
2. Complete the prototype
3. Finalize the Product materials and designs.

Cube Manipulation and Storage

Product

While the initial design was able to manipulate the tesseract promisingly, it would need to drop the cube from a high distance, resulting in bounce and roll. This would mean the robot would need to search for the cube again. As such, the rail design concept that was selected was pursued, that stores the cube within the claw, and when the pyramid is retrieved, drops the cube through the ramp (see Figure X for ramp).

In the final product all the parts for the rail design would be made from ⅛ inch aluminum to ensure that the parts are non-ferrous but durable and strong. The claws would be made out of acrylic since they are not under any great amount of loading. If manufacturing processes allow the claws could be made from 1 layer of ⅜ inch acrylic each (See **Figure 27:** Cube Retrieval Design), If testing proves ⅜ inch acrylic to be to brittle aluminium can be used instead. The ramp is also not under a great amount of loading however it does have corners that need to be bent upwards. Instead of using 3 pieces of acrylic and gluing them to one another a piece of ⅛ inch aluminum can be cut and bent to form the ramp.

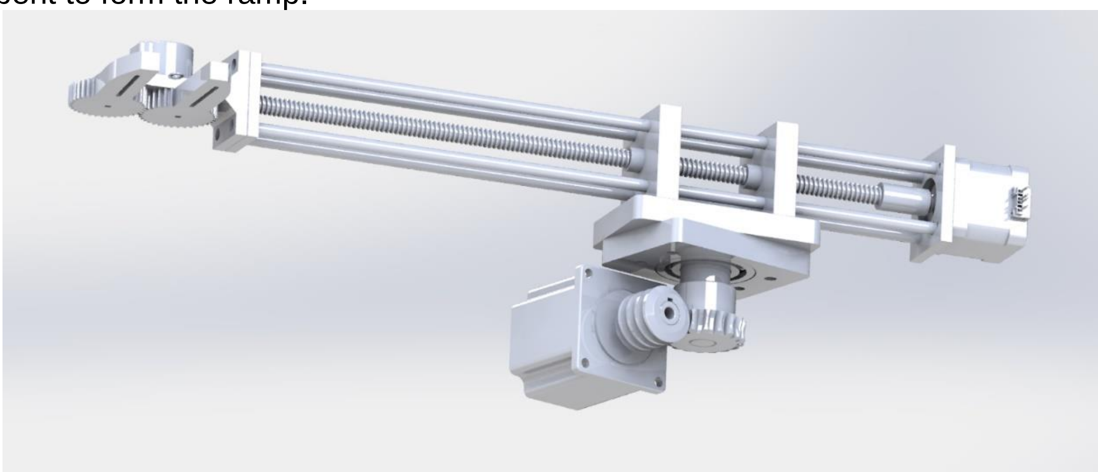


Figure 27: Cube Retrieval Design

Prototype

Initially, an arm claw prototype was built with VEX parts to refine the claw concept.

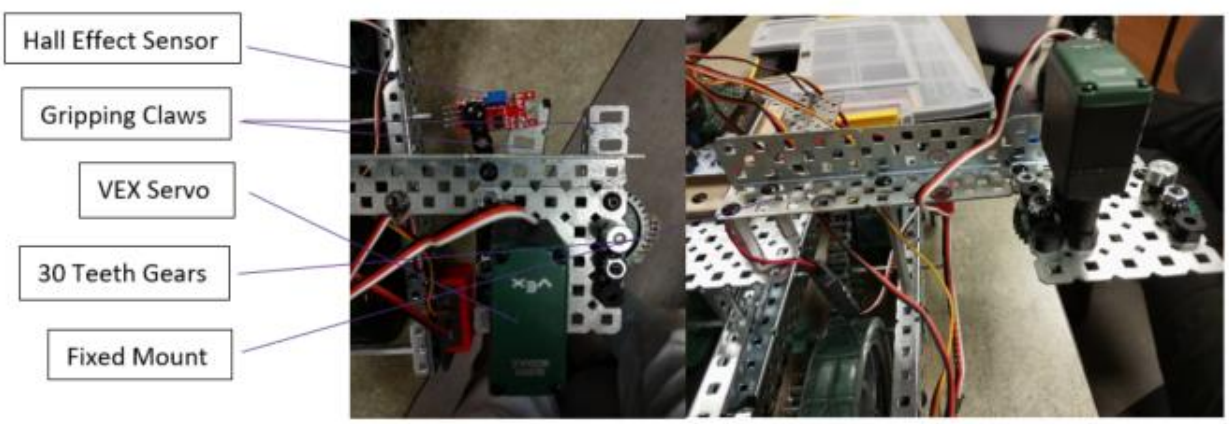


Figure 28: Cube VEX Prototype

The claw prototype served as a proof-of-concept for the claw to be a feasible solution for the product, and allowed us to pursue this design. The VEX parts, however, are ferrous and our custom solution was pursued.

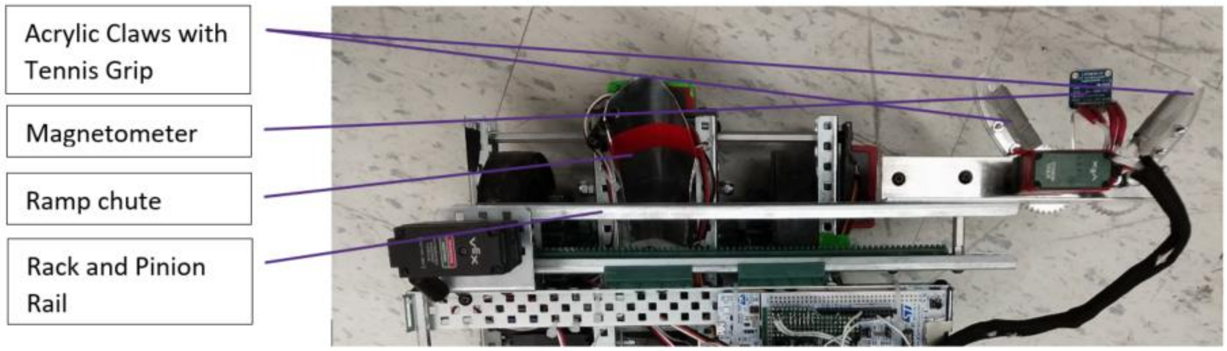


Figure 29: Claw Acrylic Prototype

Cube Location

The magnetometer that was selected provided better results than the hall effect sensor in the product. It was also used to prototype the programming logic to locate the tesseract. However, it was noticed that it still would only locate the cube within 5 cm. This meant the cube could not be located by the robot just turning and scanning the field from one location.

To ensure that the cube was retrieved every time, The robot would have to find a wall and track the wall as the magnetometer scans the top of the wall for the cube. This process would take longer than a randomized search in some cases but it is more consistent which is our most most important design requirement. The magnetometer will be mounted directly above the claws of the cube retrieval mechanism to ensure that the cube is located just as the claws are approaching it.

Pyramid Manipulation / Storage and Elevation

Product

The final product will consist of 2 motors, running in the opposite direction at all times. The motors will be inwards when the pyramid is being retrieved and running outwards after the pyramid is placed on top of the cube. The motors and wheels connected to them will be at the same angle as the pyramid to ensure that maximum contact surface area occurs the wheels and the pyramid.

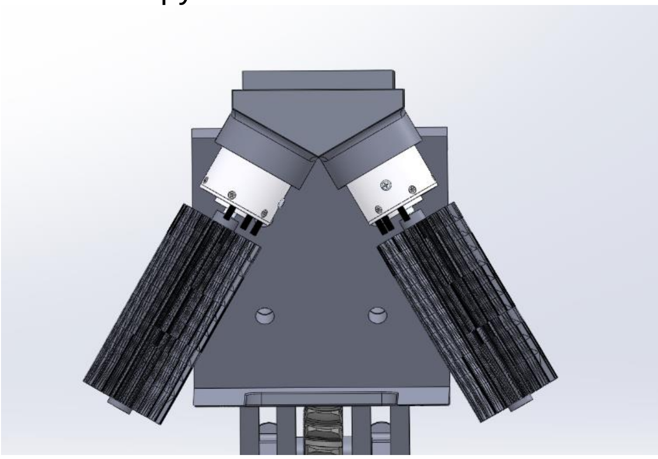


Figure 30: Front View of Pyramid Design

Tests conducted using various prototypes showed that a 10 degree incline for the bottom of the forklift is the most effective angle for intaking the pyramid. These test were conducted by putting the intake at 7 different angles and 10 trials were conducted per angle. As the result the intake is placed at a 10 degree incline.
The bottom of the forklift must be less than 1/32 in thick at the tip to ensure that the bottom of the pyramid does not get caught on it. 1.32 in thick carbon fibre will be used for this bottom piece. Carbon fibre is durable and despite being very thin in this case it will not break easily.

The carbon fibre will be connected to an aluminium piece at the bottom if this piece is too flexible to ensure that the pyramid would not slide off of the intake when being pulled up. The aluminum piece would only be half of the size of the bottom piece to ensure that the tip of the piece is thin enough.

The entire intake system will be lifted to lift the pyramid after the pyramid is retrieved. This is done through the use of a arm with 2 joints attached to a motor. The motors used will be discussed under the engineering analysis section. This arm will lift the pyramid and the intake so that the pyramid can be placed over the cube. This lift system will also keep the intake up when navigating the field to ensure that the intake does not get caught on the conduits.

Figure 31: Pyramid Retrieval Product Render

Prototype

The roller design was prototyped with VEX parts. Different gripping mechanisms were tested that included VEX intake wheels and LEGO wheels.

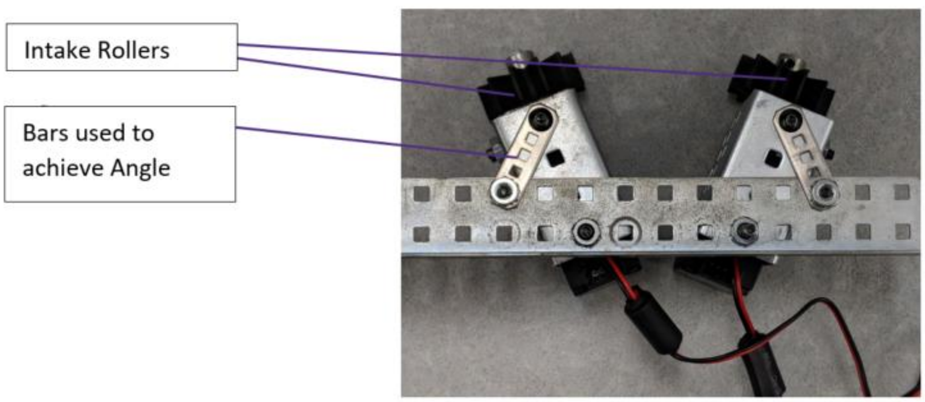


Figure 32: Pyramid Retrieval Prototype Top View

Testing this prototype allowed us to understand that the ramp needed to be thinner than 1/16in to reliably push the pyramid up the ramp. In addition, doubling the intake wheels on each side was found to be a better solution as it increased the contact surface area.

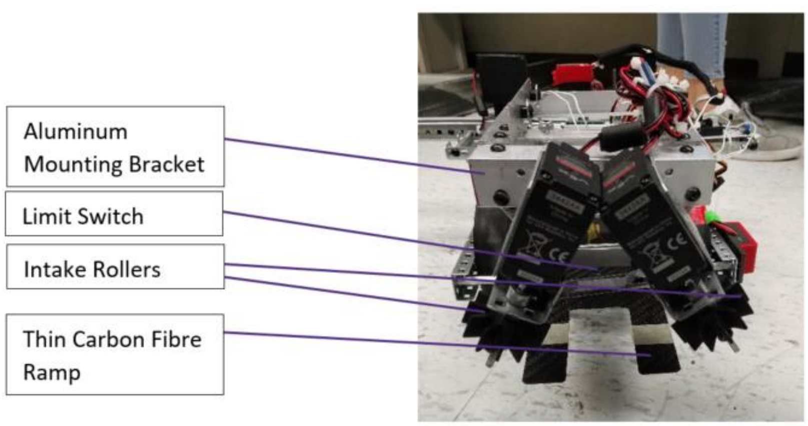


Figure 33: Pyramid Retrieval Prototype Front View

The selected design allows the pyramid to remain on top of the ramp, held in by the rollers. However, the carbon fibre sheet was not strong enough to hold the pyramid on its own when elevated, and so, 1/16in aluminum was mounted halfway underneath the carbon fibre sheet to maintain rigidity. The Aluminum piece mounted also allowed us to give the tip of the carbon fibre a downward angle which eased the intaking processes as the pyramid would not get caught on the tip of the bottom of the forklift.

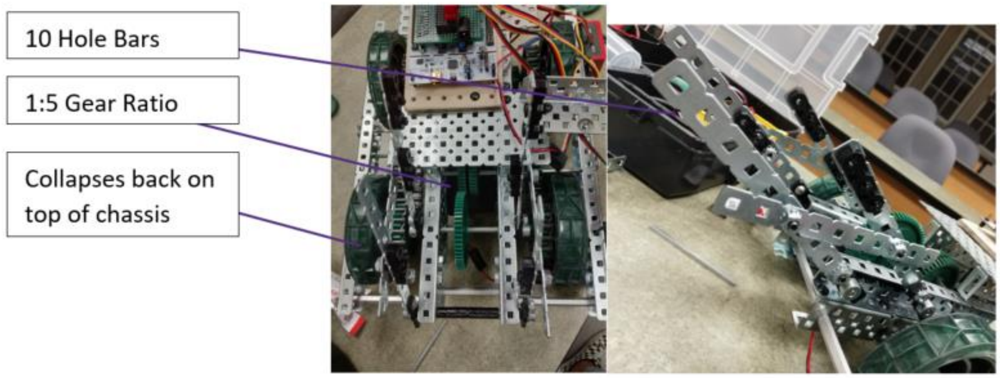


Figure 34: VEX Lift Prototype

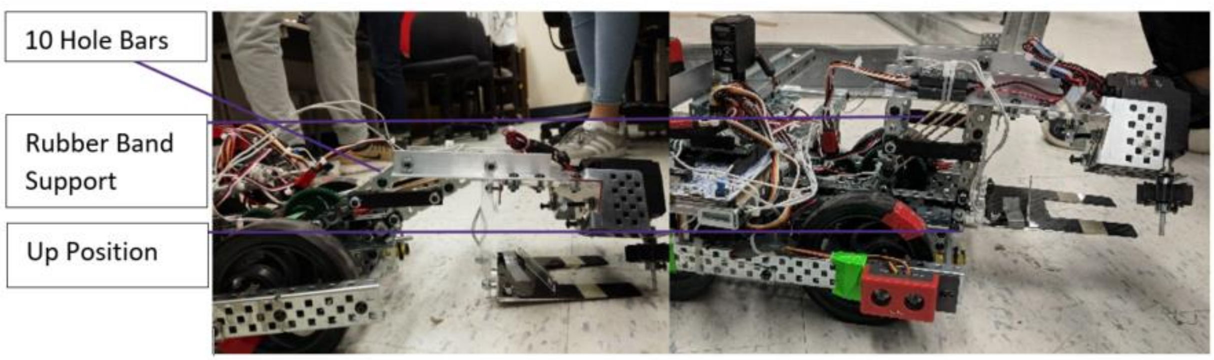
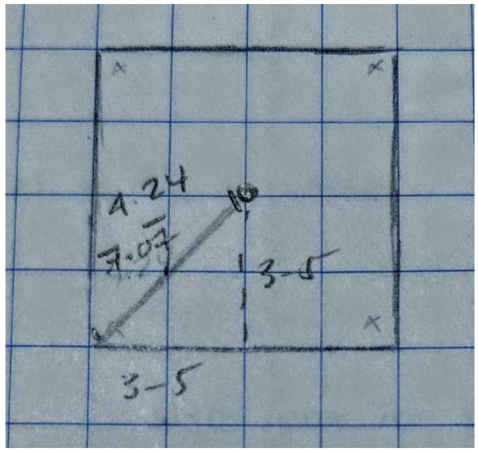


Figure 35: Final Lift Prototype

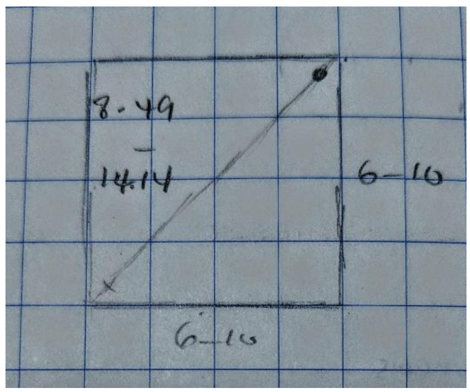
Pyramid Location

The IR sensors being used have at most a 28 inch range, undervaluing this range just to be safe would give results in a maximum range of approximately 2 ft for the wide (unshielded) IR sensor on the robot. This range is too small for the robot to be able to rotate at one pint of the course and pick up the signals from the two pyramids.

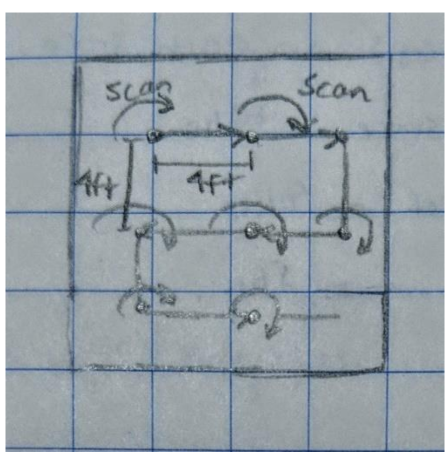
Using pythagorean theorem we see that if the robot is exactly in the middle of the field there is a distance of 4.24 ft to 7.07 ft between the orbot and the farthest corner of the field for a field ranging from 6ft to 10ft respectively.



Assuming the robot is at one corner of the field the largest distance increases to a range between 8.49 ft to 14.14 ft.



Since the distance between the pyramid and the robot can be more than 2 ft the robot must navigate through a path and search for the pyramid. This robot must rotate and scan the field every 4 ft. Although a systematic path being taken might not always be the fastest depending on where the pyramids are located, a systematic approach allows us to always, eventually locate the pyramid. A randomized approach might result in the pyramid being missed. The systematic path drawn below is suggested as the path to be taken.



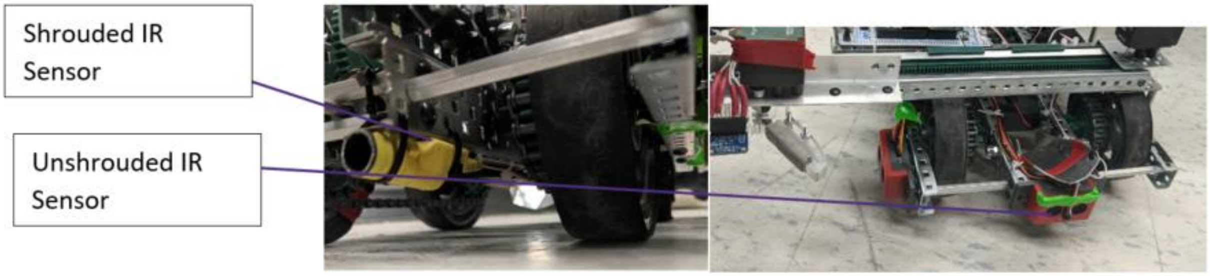


Figure 36: IR Sensor Mounts

Drive Design

Product

The base of the robot will be built out of aluminium to ensure that it is strong, light and non-ferrous. 4" elastic wheels from McMaster-Carr are being used as the 4 wheels of the robot. These wheels are very soft and have very good traction so they would not slip over the conduits. The two wheels on each side will be controlled by 1 motor. chain wil be used to connect the two motors. The length of the chain be modified in the wheels need to be farther apart or closer to one another.
Finally, the 4 wheel design offers stability for the robot as it navigates over conduits resulting in a smooth navigation.

Figure 37: Drive Product Render

Prototype

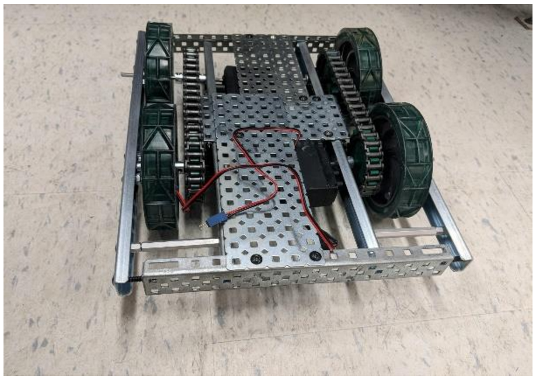


Figure 38: Drive VEX Prototype

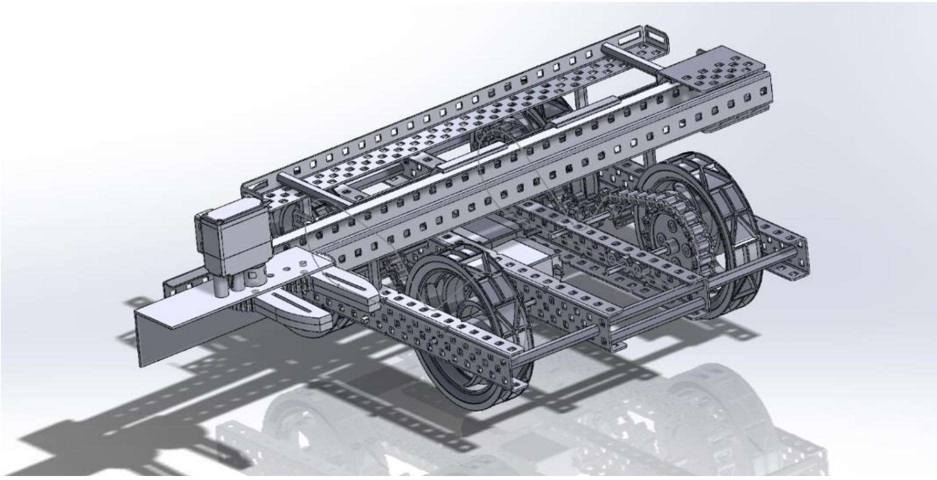


Figure 39: Drive CAD Assembly

The prototype was built using the materials available in the lab. 4” VEX wheels were used. The wheels were quite hard and as the result they slipped over the conduits. Tennis racket grips were added to the wheels to increase their traction so they could replicate the product more closely. VEX 393 motors were used instead of the motors selected for the product. Since these motors were weaker than those on the product additional gearing was required to replicate the product. This addition made the prototype larger than the actual product.

Full Product Design

As a whole, the Tesseract Robot has the ability to locate, retrieve and store both the tesseract and the pyramid. The rail claw provides degrees of freedom in both X and Y, and has a reliable nonferrous claw system to grip the tesseract. The pyramid intake with two large rollers are designed in the shape of the pyramid to maneuver it with ease. It is coupled with a strong 4-bar lift system to elevate the pyramid to finally place it above the tesseract. The Tesseract Robot is designed with a powerful drive system that is able to conveniently drive its low weight of 6.7kg.

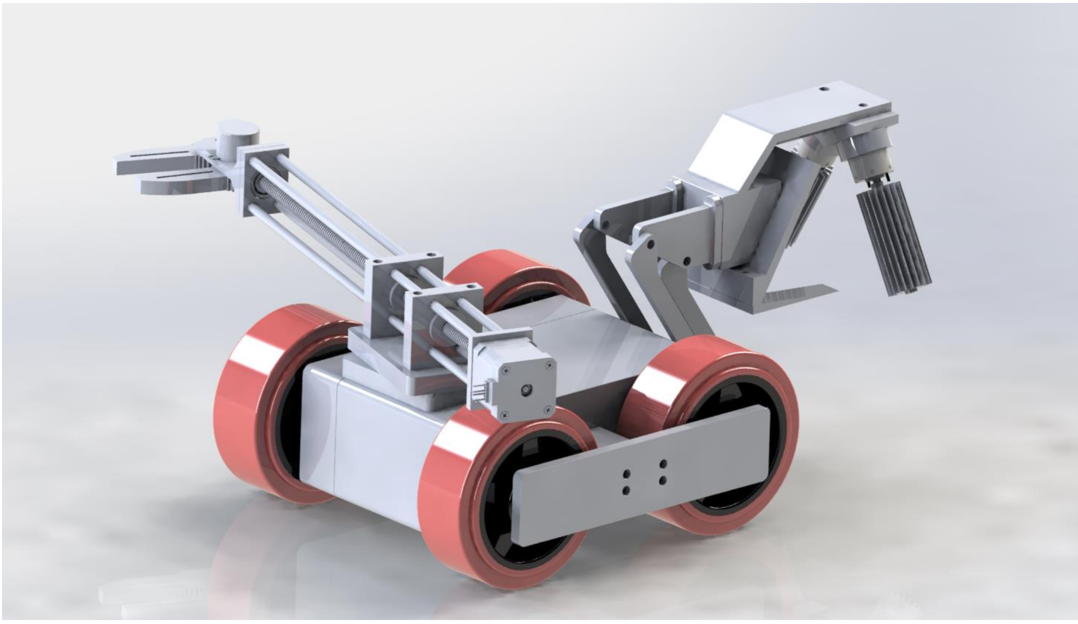


Figure 40: Full Product Render

Full Prototype Design

The prototype was developed with the product as a model with VEX, laser cut acrylic, aluminum, and carbon fibre parts.

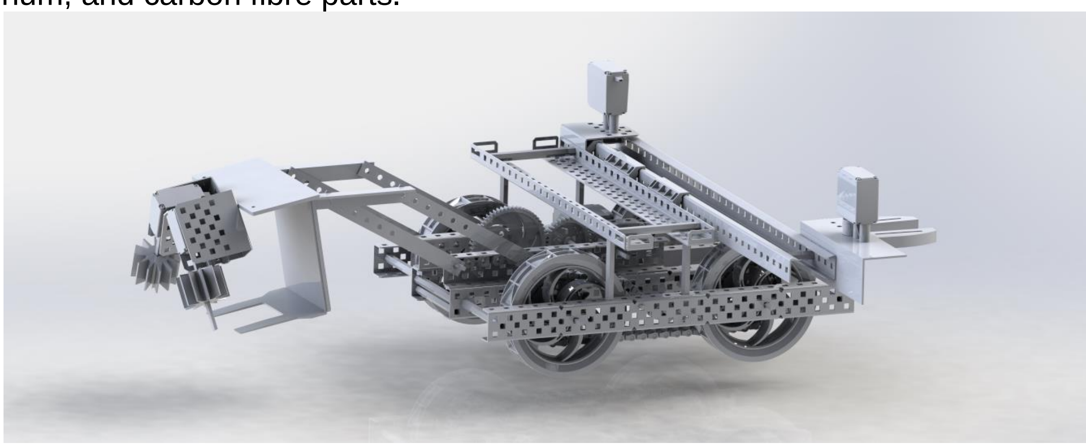


Figure 41: Full Prototype Render

MSE2202B Prototype Specification Document

- Electronics, Sensors and Actuators
    - Main MCU
        - Nucleo-64, STM32 - F446RE
        - 180 MHz ARM Cortex-M4
        - 512 kb flash, 128 kb RAM
    - Sensors
        - Magnetic
            - ST LSM303
                - 1x Located on claw for cube detection
            - NXP MAG3110
                - 1x Located on rear chassis for cube detection for accurate pyramid placement
        - Distance
            - VEX Ultrasonic Rangefinder
                - 2x located on left side for parallel wall following
                - 1x located on front side for turning
        - IR
            - TSOP32338
                - 1x located on rear for Pyramid detection
                - 1x located on rear for Pyramid detection (with focusing shroud)
        - DC Motors, All controlled via VEX 29 Motor Controller
            - VEX DC motor
                - 1x located on claw linear slice
                - 3x located on pyramid lift
            - Chinese 12V DC motor with gearbox
                - 1x for left drive
                - 1x for right drive
        - Servo Motors
            - VEX Servo
                - 1x located on claw
        - Wireless Communications
            - ESP8266 WiFi Module
                - 1x for user to issue start and stop commands via a phone of computer
        - Misc.
            - Limit Switches
                - 2x located on claw linear slide
                    - Connected as interrupts to GPIO ports
                - 2x located on pyramid lift
                    - Connected as interrupts to GPIO ports

Figure 42: Prototype Specification Document

Electronic Design

Discussion

A third-party microcontroller was usedh due to increased I/O and computational capabilities when compared to an ATmega238p. STMicroelectronics Nucleo development boards were selected for use on the prototype. Nucleo development boards are an Arduino alternative with superior capabilities when compared to AVR microcontrollers. Two appropriate boards were obtained for this project: a Nucleo-144 with an STM32-F429ZI MCU, and a Nucleo-64 with an STM32-F446RE MCU. STM32 is a line of industrial grade ARM Cortex-M based microcontrollers offered by STMicroelectronics. A summary of the specifications and a STM32 block diagram for these boards is listed below in Figure 1.

The main benefits for using this alternative microcontroller include:

- greater number of GPIO ports
- greater number of IRQ ports
- greater computational capabilities
- easier interfacing with I2C peripherals (does not require logic level shifter)
- multiple hardware UART buses
- theoretical higher polling rate for sensors

A Pinmux is provided below in Figure 2 for the Nucleo-64 which outlines how every peripheral is connected to the STM32 controller. Two Block Diagrams of the electronic components are listed below. Figure 3A is the initial planned peripheral layout. Figure 3B is the peripheral layout which was used on the prototype.

A Daughter board was developed to provide easy VEX plug-and-play capability to the Nucleo Controller Boards. See the schematic below. The pins on the final revision are separated into low and high-power tolerances. High power pins provide a GPIO pin with pwm capability for motors. These high-power pins are routed through a voltage regulator which provides high current directly from the battery. The low power pins provide GPIO communications for various basic sensors and interrupts. 5V is provided from the host board. Additional pins included UART 7, UART 8, and I2C1 for various peripherals. All pins and sockets are 0.1” pitch which complies with the Arduino UNO header standard, and the VEX sensor connectors.

A Three-axis magnetometer was solely used to detect the tesseract while on the wall. This sensor interfaces with the controller through an I2C bus. The firmware required to interface with this sensor sends initialization, resolution, and read commands over the I2C1 bus to the sensor, then listens on the bus for the response. Three 16-bit values are returned from the sensor; one for each axis. The the software simply calculates the Euler magnitude of the magnetic field via the three readings. If this magnitude is greater than a threshold, then the robot will intake the tesseract.

The two infrared sensors are connected to hardware UART buses. This allows the STM32 to receive UART Rx interrupts to identify pyramids, however due to a lack of software development time, this was not able to be implemented. The prototype in its demonstration state was polling the UART 7 and UART 8 buses in order to detect the pyramid. Using the hardware serial buses available on the STM32 eliminates the need to use a cumbersome software serial library to interface with the infrared sensors.

Limit Switches on both intake mechanisms are connected through interrupts to the STM32.

The Nucleo-64 was planned to be used to drive the prototype. 48 hours before the showcase was commenced, the Nucleo-64 board was rendered unusable due to neglect and was replaced with the Nucleo-144.

NUCLEO-144
STM32F429ZIT6 in LQFP144 package
ARM®32-bit Cortex®-M4 CPU with FPU
180 MHz max CPU frequency
VDD from 1.8 V to 3.6 V
2048 KB Flash
256+4 KB SRAM, including 64 KB of CCM (core coupled memory) data RAM
GPIOs (114) with external interrupt capability
16-stream DMA controller with FIFOs and burst support
12-bit ADCs with 24 channels (3)
12-bit DAC channels (2)
USART/UART (4)
I2C (3)
SPI (6)
Advanced-control Timer (2)
General Purpose Timers (10)
Watchdog Timers (2)
CAN 2.0B active (2)
SAI
SDIO
Random Generator (TRNG for HW entropy)
USB 2.0 OTG HS
USB 2.0 OTG FS
Camera interface

Ethernet
LCD-TFT

NUCLEO-64
STM32F446RET6 in LQFP64 package
ARM®32-bit Cortex®-M4 CPU with FPU
Adaptive real-time accelerator (ART Accelerator™) allowing 0-wait state execution from Flash memory
180 MHz max CPU frequency
VDD from 1.7 V to 3.6 V
512 KB Flash
128 KB SRAM System
4 KB SRAM Backup
Timers General Purpose (10)
Timers Advanced-Control (2)
Timers Basic (2)
SPI (4)
I2S (2)
USART (4)
UART (2)
USB OTG Full Speed and High Speed
CAN (2)
SAI (2)
SPDIF-Rx (1)
HDMI-CEC (1)
Quad SPI (1)
Camera Interface
GPIO (50) with external interrupt capability
12-bit ADC (3) with 16 channels
12-bit DAC with 2 channels

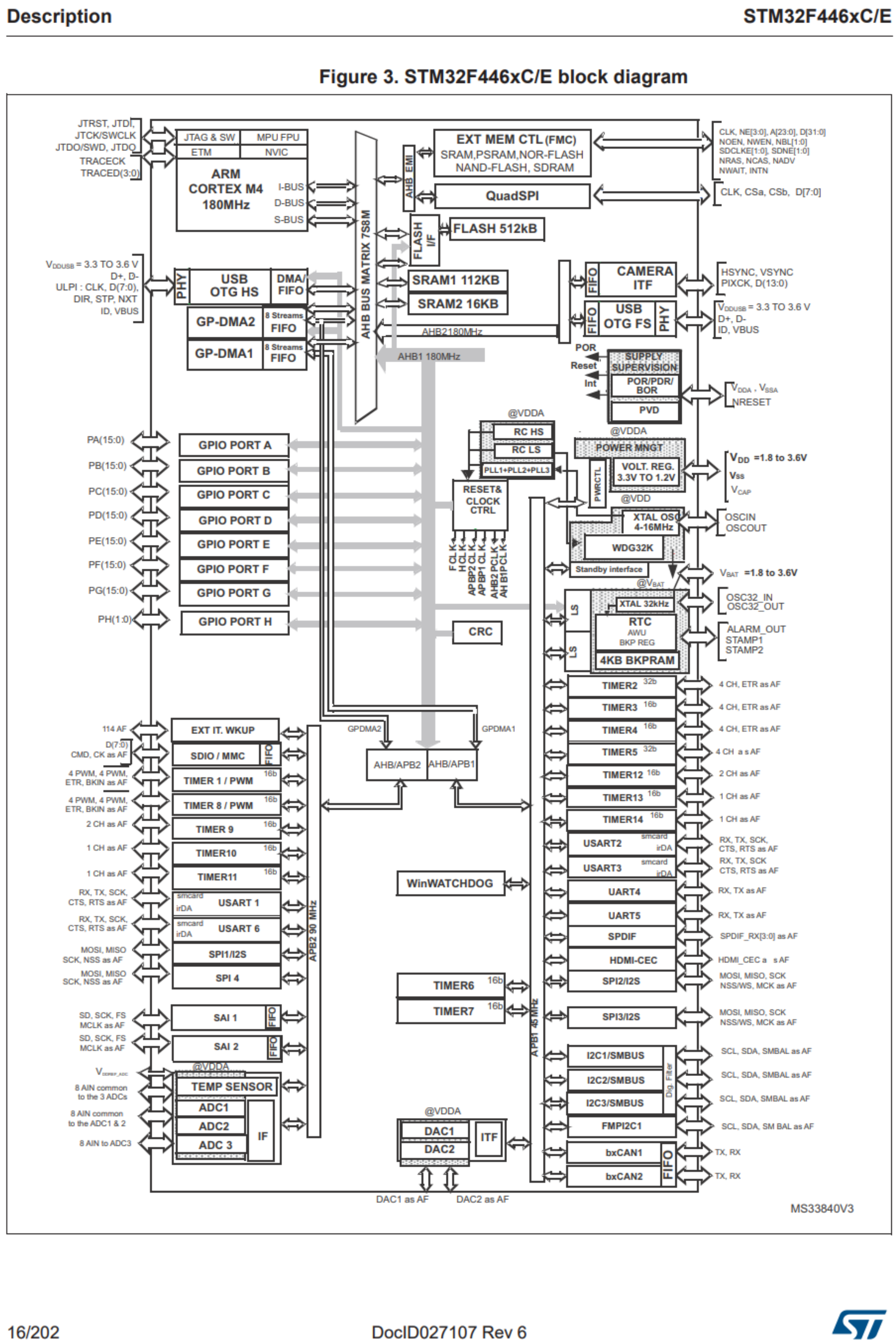


Figure 43: STM Block Diagram

Daughter Board

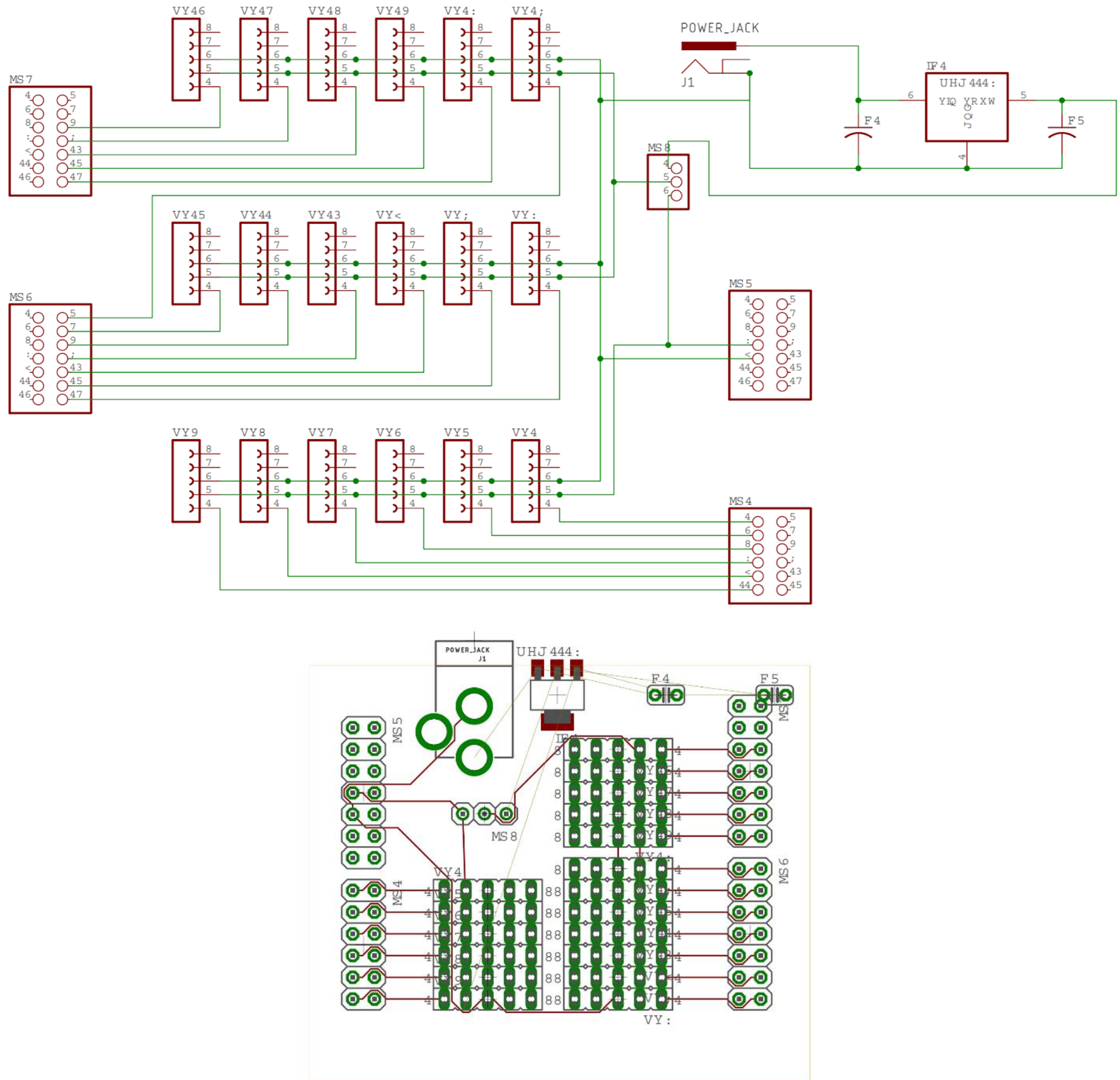


Figure 44: Daughter Board Layout

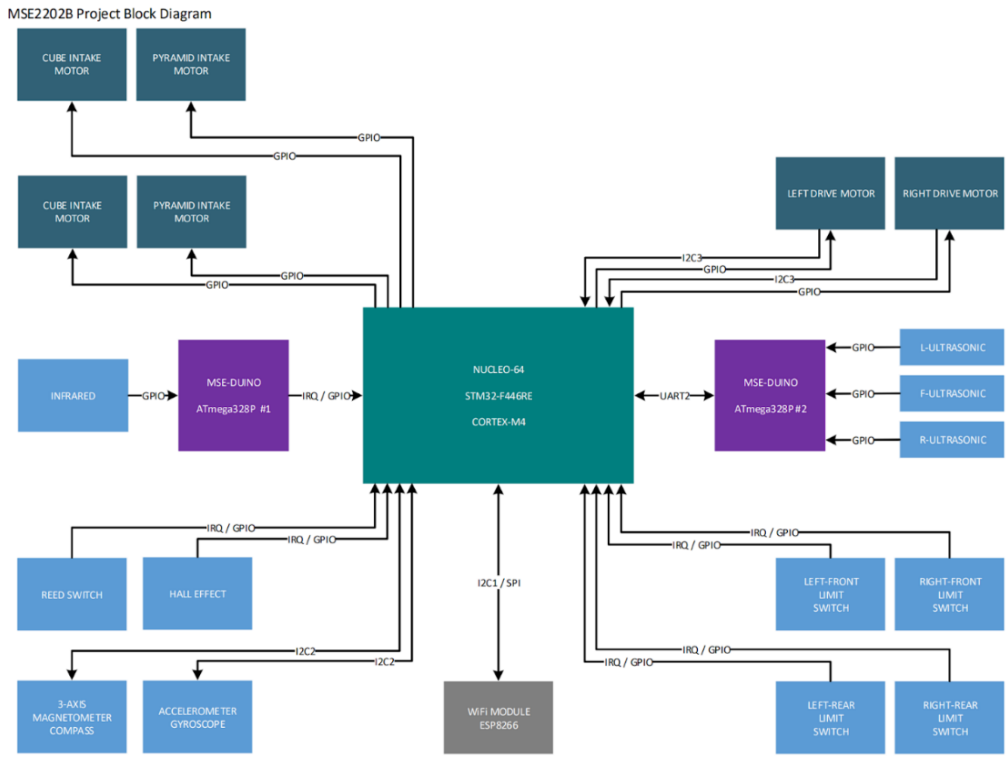


Figure 45: Planned Block Diagram

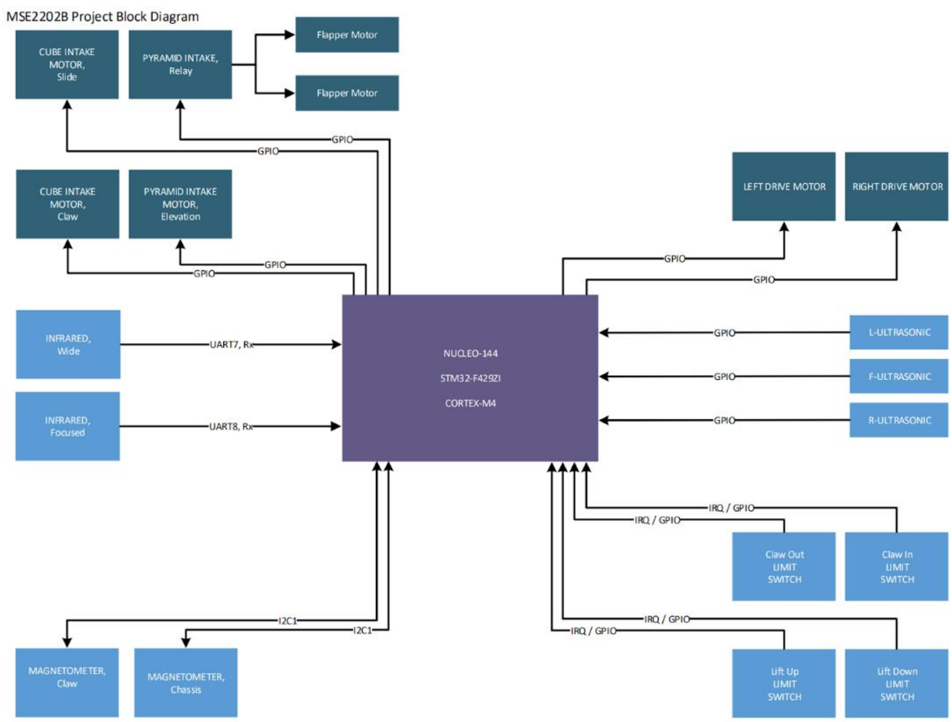


Figure 46: Block Diagram Used

Colour Legend		
Daughter Board Low Power	GROUND	I/O
Daughter Board High Power	POWER	OTHER

Positic	Name	STM Heade	Arduino UN	Type	Attached Device	I/O Structui	Voltage Tol	Signal	Label
2	PC13	CN7-1-12		I/O		FT	5 V	GPIO_EXTI13	B1 [Blue PushButton]
3	PC14	CN7-1-13		I/O		FT	5 V	RCC_OSC32_IN	
4	PC15	CN7-1-14		I/O		FT	5 V	RCC_OSC32_OUT	
5	PH0	CN7-1-15		I/O		FT	5 V	RCC_OSC_IN	
6	PH1	CN7-1-16		I/O		FT	5 V	RCC_OSC_OUT	
7	NRST	CN7-2-7	Reset	Reset					
8	PC0	CN7-2-19	A5	I/O	LR_ULTRA_OUT	FT	5 V		
9	PC1	CN7-2-18	A4	I/O	LR_ULTRA_IN	FT	5 V		
10	PC2	CN7-1-18		I/O		FT	5 V		
11	PC3	CN7-1-19		I/O		FT	5 V		
14	PA0	CN7-2-14	A0	I/O	F_ULTRA_IN	FT	5 V		
15	PA1	CN7-2-15	A1	I/O	F_ULTRA_OUT	FT	5 V		
16	PA2	CN10-1-18	D1	I/O	Default Serial	FT	5 V	USART2_TX	USART_TX
17	PA3	CN10-1-19	D0	I/O	Default Serial	FT	5 V	USART2_RX	USART_RX
20	PA4	CN7-2-16	A2	I/O	LF_ULTRA_IN	TC			
21	PA5	CN10-1-6	D13	Output	PYR INTAKE MOTOR	TC		GPIO_Output	LD2 [Green Led]
22	PA6	CN10-1-7	D12	I/O	LIFT MOTOR	FT	5 V		
23	PA7	CN10-1-8	D11	I/O	DRIVE MOTOR RIGHT	FT	5 V		
24	PC4	CN10-2-17		I/O		FT	5 V		
25	PC5	CN10-2-3		I/O		FT	5 V		
26	PB0	CN7-2-17	A3	I/O	LF_ULTRA_OUT	FT	5 V		
27	PB1	CN10-2-12		I/O	LIMIT_SW_2 LIFT DOWN	FT	5 V		
28	PB2	CN10-2-11		I/O	LIMIT_SW_1 LIFT UP	FT	5 V		
29	PB10	CN10-1-13	D6	I/O	UART3, RX IR SHROUDED REAR	FT	5 V		
33	PB12	CN10-2-8		I/O		FT	5 V		
34	PB13	CN10-2-15		I/O		FT	5 V		
35	PB14	CN10-2-14		I/O		FT	5 V		
36	PB15	CN10-2-13		I/O	LIMIT_SW_3 CHECK PYR	FT	5 V		
37	PC6	CN10-2-2		I/O		FTf	5 V		
38	PC7	CN10-1-10	D9	I/O		FTf	5 V		
39	PC8	CN10-2-1		I/O		FT	5 V		
40	PC9	CN10-1-1		I/O		FT	5 V		
41	PA8	CN10-1-12	D7	I/O		FT	5 V		
42	PA9	CN10-1-11	D8	I/O	CLAW SLIDE SERVO	FT	5 V		
43	PA10	CN10-1-17	D2	I/O	UART1, RX IR UNSHROUDED FR	FT	5 V		
44	PA11	CN10-2-7		I/O		FT	5 V		
45	PA12	CN10-2-6		I/O		FT	5 V		
46	PA13	CN7-1-7		I/O		FT	5 V	SYS_JTMS-SWI	TMS
49	PA14	CN7-1-8		I/O		FT	5 V	SYS_JTCK-SWC	TCK
50	PA15	CN7-1-9		I/O		FT	5 V		
51	PC10	CN7-1-1		I/O		FT	5 V		
52	PC11	CN7-2-1		I/O		FT	5 V		
53	PC12	CN7-1-2		I/O		FT	5 V		
54	PD2	CN7-2-2		I/O		FT	5 V		
55	PB3	CN10-1-16	D3	I/O	CLAW GRIP SERVO	FT	5 V	SYS_JTDO-SW(	SWO
56	PB4	CN10-1-14	D5	I/O		FT	5 V		
57	PB5	CN10-1-15	D4	I/O		FT	5 V		
58	PB6	CN10-1-9	D10	I/O	DRIVE MOTOR LEFT	FT	5 V		
59	PB7	CN7-1-11		I/O		FT	5 V		
60	BOOT0	CN7-1-4		Boot		B			
61	PB8	CN10-1-2	D15	I/O	I2C1	FT	5 V		
62	PB9	CN10-1-3	D14	I/O	I2C1	FT	5 V		

Alternate Functions

Name	AF0	AF1	AF2	AF3	AF4	AF5	AF6	AF7	AF8	AF9	AF10	AF11	AF12	AF13	ADC	DAC
PC13																
PC14																
PC15																
PH0																
PH1																
NRST																
PC0							SAI1_MCLK_B				USB_OTG_HS_ULPI_STP				ADC123_IN10	
PC1						I2S3_SD/SPI3_M	SAI1_SD_A	I2S2_SD/SPI2_MOSI							ADC123_IN11	
PC2						SPI2_MISO					USB_OTG_HS_ULPI_DIR				ADC123_IN12	
PC3						I2S2_SD/SPI2_MOSI					USB_OTG_HS_ULPI_NXT				ADC123_IN13	
PA0		TIM2_CH1/TIM2	TIM5_CH1	TIM8_ETR				USART2_CTS	UART4_TX						ADC123_IN0	
PA1		TIM2_CH2	TIM5_CH2					USART2_RTS	UART4_RX	QUADSPI_BK1_IO3					ADC123_IN1	
PA2		TIM2_CH3	TIM5_CH3	TIM9_CH1				USART2_TX							ADC123_IN2	
PA3		TIM2_CH4	TIM5_CH4	TIM9_CH2			SAI1_FS_A	USART2_RX			USB_OTG_HS_ULPI_D0				ADC123_IN3	
PA4						I2S1_WS/SPI1_N	I2S3_WS/SPI3_N	USART2_CK					USB_OTG_HS_S	DCMI_HSYNC	ADC12_IN4	DAC_OUT1
PA5		TIM2_CH1/TIM2_ETR		TIM8_CH1N		I2S1_CK/SPI1_SCK					USB_OTG_HS_ULPI_CK				ADC12_IN5	DAC_OUT2
PA6		TIM1_BKIN	TIM3_CH1	TIM8_BKIN		SPI1_MISO	I2S2_MCK			TIM13_CH1				DCMI_PIXCLK	ADC12_IN6	
PA7		TIM1_CH1N	TIM3_CH2	TIM8_CH1N		I2S1_SD/SPI1_MOSI				TIM14_CH1					ADC12_IN7	
PC4						I2S1_MCK			SPDIFRX_IN2						ADC12_IN14	
PC5								USART3_RX	SPDIFRX_IN3						ADC12_IN15	
PB0		TIM1_CH2N	TIM3_CH3	TIM8_CH2N				I2S3_SD/SPI3_M	UART4_CTS		USB_OTG_HS_ULPI_D1		SDIO_D1		ADC12_IN8	
PB1		TIM1_CH3N	TIM3_CH4	TIM8_CH3N							USB_OTG_HS_ULPI_D2		SDIO_D2		ADC12_IN9	
PB2		TIM2_CH4					SAI1_SD_A	I2S3_SD/SPI3_MOSI		QUADSPI_CLK	USB_OTG_HS_ULPI_D4		SDIO_CK			
PB10		TIM2_CH3			I2C2_SCL	I2S2_CK/SPI2_S	SAI1_SCK_A	USART3_TX			USB_OTG_HS_ULPI_D3					
PB12		TIM1_BKIN			I2C2_SMBA	I2S2_WS/SPI2_N	SAI1_SCK_B	USART3_CK		CAN2_RX	USB_OTG_HS_ULPI_D5		USB_OTG_HS_ID			
PB13		TIM1_CH1N				I2S2_CK/SPI2_SCK		USART3_CTS		CAN2_TX	USB_OTG_HS_ULPI_D6					
PB14		TIM1_CH2N		TIM8_CH2N		SPI2_MISO		USART3_RTS		TIM12_CH1			USB_OTG_HS_DM			
PB15	RTC_REFIN	TIM1_CH3N		TIM8_CH3N		I2S2_SD/SPI2_MOSI				TIM12_CH2			USB_OTG_HS_DP			
PC6			TIM3_CH1	TIM8_CH1	FMPI2C1_SCL	I2S2_MCK			USART6_TX				SDIO_D6	DCMI_D0		
PC7			TIM3_CH2	TIM8_CH2	FMPI2C1_SDA	I2S2_CK/SPI2_S	I2S3_MCK	SPDIFRX_IN1	USART6_RX				SDIO_D7	DCMI_D1		
PC8	SYS_TRACED0		TIM3_CH3	TIM8_CH3				UART5_RTS	USART6_CK				SDIO_D0	DCMI_D2		
PC9	RCC_MCO_2		TIM3_CH4	TIM8_CH4	I2C3_SDA	I2S_CKIN		UART5_CTS		QUADSPI_BK1_IO0			SDIO_D1	DCMI_D3		
PA8	RCC_MCO_1	TIM1_CH1			I2C3_SCL			USART1_CK			USB_OTG_FS_SOF					
PA9		TIM1_CH2			I2C3_SMBA	I2S2_CK/SPI2_S	SAI1_SD_B	USART1_TX						DCMI_D0		
PA10		TIM1_CH3						USART1_RX			USB_OTG_FS_ID			DCMI_D1		
PA11		TIM1_CH4						USART1_CTS		CAN1_RX	USB_OTG_FS_DM					
PA12		TIM1_ETR						USART1_RTS		CAN1_TX	USB_OTG_FS_DP					
PA13	SYS_JTMS-SWDIO															
PA14	SYS_JTCK-SWCLK															
PA15	SYS_JTDI	TIM2_CH1/TIM2_ETR			CEC	I2S1_WS/SPI1_N	I2S3_WS/SPI3_NSS		UART4_RTS							
PC10							I2S3_CK/SPI3_S	USART3_TX	UART4_TX	QUADSPI_BK1_IO1			SDIO_D2	DCMI_D8		
PC11							SPI3_MISO	USART3_RX	UART4_RX	QUADSPI_BK2_NCS			SDIO_D3	DCMI_D4		
PC12					I2C2_SDA		I2S3_SD/SPI3_M	USART3_CK	UART5_TX				SDIO_CK	DCMI_D9		
PD2			TIM3_ETR						UART5_RX				SDIO_CMD	DCMI_D11		
PB3	SYS_JTDO-SW(	TIM2_CH2			I2C2_SDA	I2S1_CK/SPI1_S	I2S3_CK/SPI3_SCK									
PB4	SYS_JTRST		TIM3_CH1		I2C3_SDA	SPI1_MISO	SPI3_MISO	I2S2_WS/SPI2_NSS								
PB5			TIM3_CH2		I2C1_SMBA	I2S1_SD/SPI1_M	I2S3_SD/SPI3_MOSI			CAN2_RX	USB_OTG_HS_ULPI_D7			DCMI_D10		
PB6			TIM4_CH1	CEC	I2C1_SCL			USART1_TX		CAN2_TX	QUADSPI_BK1_NCS			DCMI_D5		
PB7			TIM4_CH2		I2C1_SDA			USART1_RX	SPDIFRX_IN0					DCMI_VSYNC		
BOOT0																
PB8		TIM2_CH1/TIM2	TIM4_CH3	TIM10_CH1	I2C1_SCL					CAN1_RX			SDIO_D4	DCMI_D6		
PB9		TIM2_CH2	TIM4_CH4	TIM11_CH1	I2C1_SDA	I2S2_WS/SPI2_N	SAI1_FS_B			CAN1_TX			SDIO_D5	DCMI_D7		

Figure 47: STM32 Pinmuxing

GROUND	I/O
POWER	OTHER

Attached Dev	CN7		Attached Dev
	CN7-1-1	CN7-2-1	
	CN7-1-2	CN7-2-2	
	CN7-1-3	CN7-2-3	
	CN7-1-4	CN7-2-4	
	CN7-1-5	CN7-2-5	
	CN7-1-6	CN7-2-6	
	CN7-1-7	CN7-2-7	
	CN7-1-8	CN7-2-8	
	CN7-1-9	CN7-2-9	
	CN7-1-10	CN7-2-10	
	CN7-1-11	CN7-2-11	
	CN7-1-12	CN7-2-12	
	CN7-1-13	CN7-2-13	
	CN7-1-14	CN7-2-14	F_ULTRA_IN
	CN7-1-15	CN7-2-15	F_ULTRA_OUT
	CN7-1-16	CN7-2-16	LF_ULTRA_IN
#N/A	CN7-1-17	CN7-2-17	LF_ULTRA_OUT
	CN7-1-18	CN7-2-18	LR_ULTRA_IN
	CN7-1-19	CN7-2-19	LR_ULTRA_OUT

Attached Dev	CN10		Attached Dev
	CN10-1-1	CN10-2-1	
I2C1	CN10-1-2	CN10-2-2	
I2C1	CN10-1-3	CN10-2-3	
#N/A	CN10-1-4	CN10-2-4	
	CN10-1-5	CN10-2-5	
PYR INTAKE MOTOR	CN10-1-6	CN10-2-6	
LIFT MOTOR	CN10-1-7	CN10-2-7	
DRIVE MOTOR RIGHT	CN10-1-8	CN10-2-8	
DRIVE MOTOR LEFT	CN10-1-9	CN10-2-9	
	CN10-1-10	CN10-2-10	
CLAW SLIDE SERVO	CN10-1-11	CN10-2-11	LIMIT_SW_1 LIFT UP
	CN10-1-12	CN10-2-12	LIMIT_SW_2 LIFT DOWN
UART3, RX IR SHROUDED REAR	CN10-1-13	CN10-2-13	LIMIT_SW_3 CHECK PYR
	CN10-1-14	CN10-2-14	
	CN10-1-15	CN10-2-15	
CLAW GRIP SERVO	CN10-1-16	CN10-2-16	
UART1, RX IR UNSHROUDED FRONT	CN10-1-17	CN10-2-17	
Default Serial	CN10-1-18	CN10-2-18	
Default Serial	CN10-1-19	CN10-2-19	

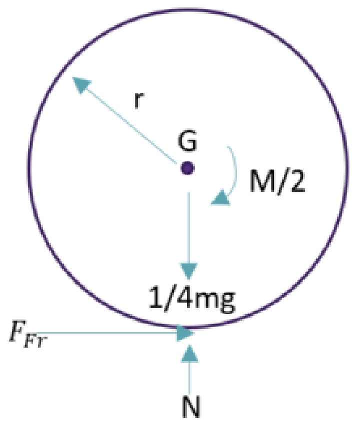
Figure 48: STM32 Custom Headers

Engineering Analysis

Drive

To allow the product to successfully navigate the field and maneuver conduits with no stalling, yet fast enough speeds, a strong motor with a high torque was required. As such, the NEMA 23 2250 Position-Control DC Motor from McMaster Carr was selected for its high stall torque of 23in-oz and peak power of 320W.

To verify the motor would satisfy torque requirements, a torque calculation was done on each wheel.



Assume even weight and torque distribution between wheels and a nominal u_s of 0.4

$$\sum F_G = N - \frac{1}{4}mg = 0$$

$$N = \frac{1}{4}mg \quad F = u_s N = \frac{1}{4}mgu_s$$

$$\sum M_G = F_{Fr} - \frac{M}{2} = 0$$

$$M = \frac{1}{2}mgu_s r$$

From SolidWorks mass and COG Analysis:

$m = 6.67kg \quad r = 0.1245m$

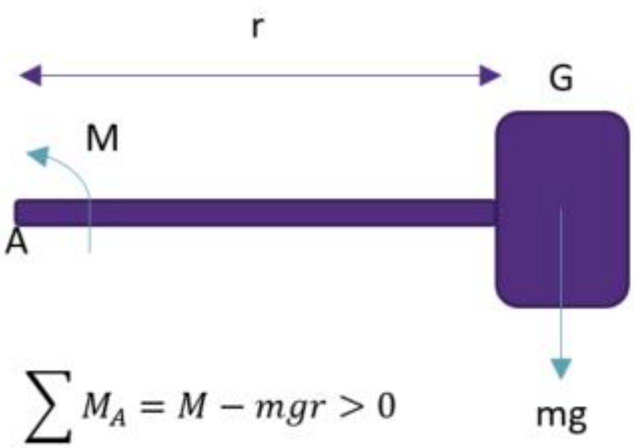
For a FOS of 2 and a 30 gearbox/chain reduction, motor stall torque should be greater than: **0.109 Nm**.

Figure 49: Drive Torque Calculations

As the NEMA motors provide 0.162Nm in stall torque, these motors satisfy the torque requirement with a factor of safety of 2.

Lift and Claw Arm

To develop a reliable lift for the pyramid that can consistently pickup and drop the pyramid, a high torque with a large margin of safety is required. A torque analysis was done to determine the largest torque requirement from the pyramid lift.



$$\sum M_A = M - mgr > 0$$

$$M > mgr$$

From SolidWorks mass and COG Analysis:

$m = \ 0.48kg \quad r = 0.33m$

For a FOS of 2 and the 50:1 gearbox reduction,
motor stall torque should be greater than **0.062 Nm**.

Figure 50: Lift Torque Calculations

Using the NEMO 14 with gearbox from McMaster Carr, it is seen that the torque requirement is met with a factor of safety of 2, as the motor has a stall torque of 0.07Nm. The same motor was selected for the Claw Arm due to similar torque requirements.

Pyramid Intake

The pyramid intake uses two rollers moving in opposite directions spaced out enough to let a pyramid through. Due to this nature, size is of utmost importance, along with a high RPM and a reasonable torque. The Compact Round-Face DC Gearmotor was selected for its small size of 3.75x1.25x1.25in and high speed of 202 rpm. One of these on both sides will prevent any torque issues.

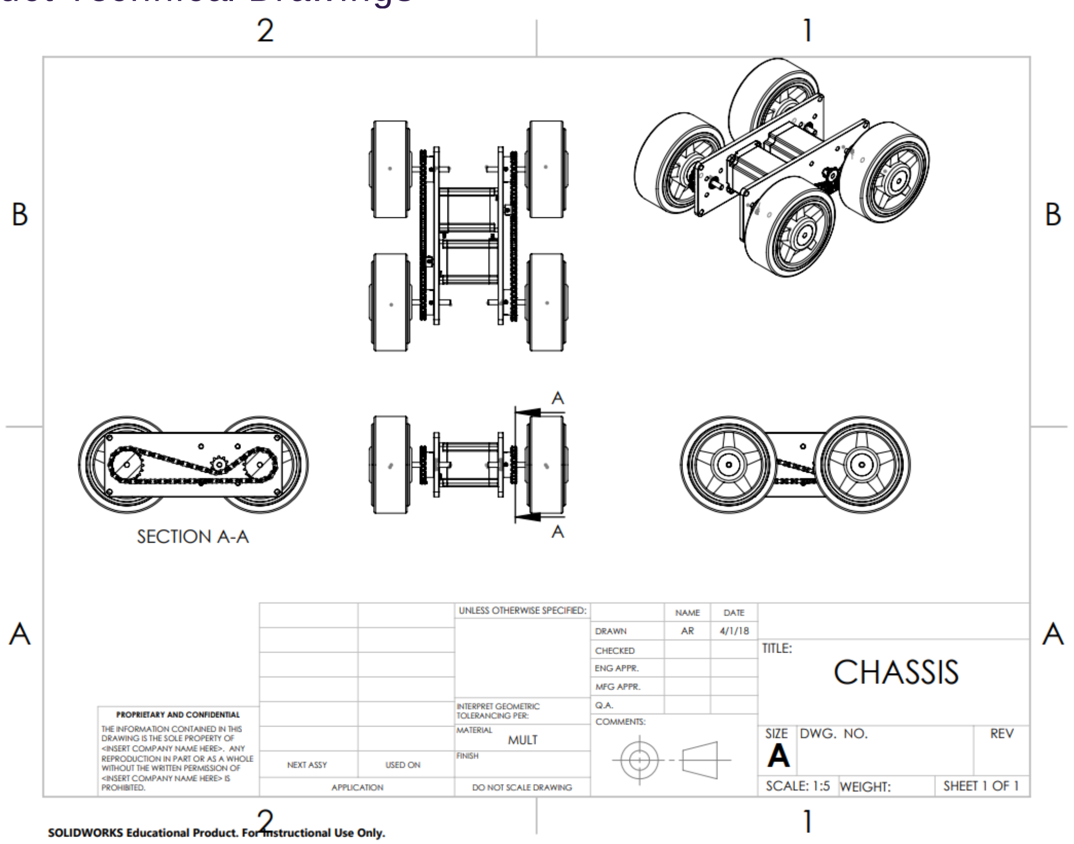
Detailed Documentation

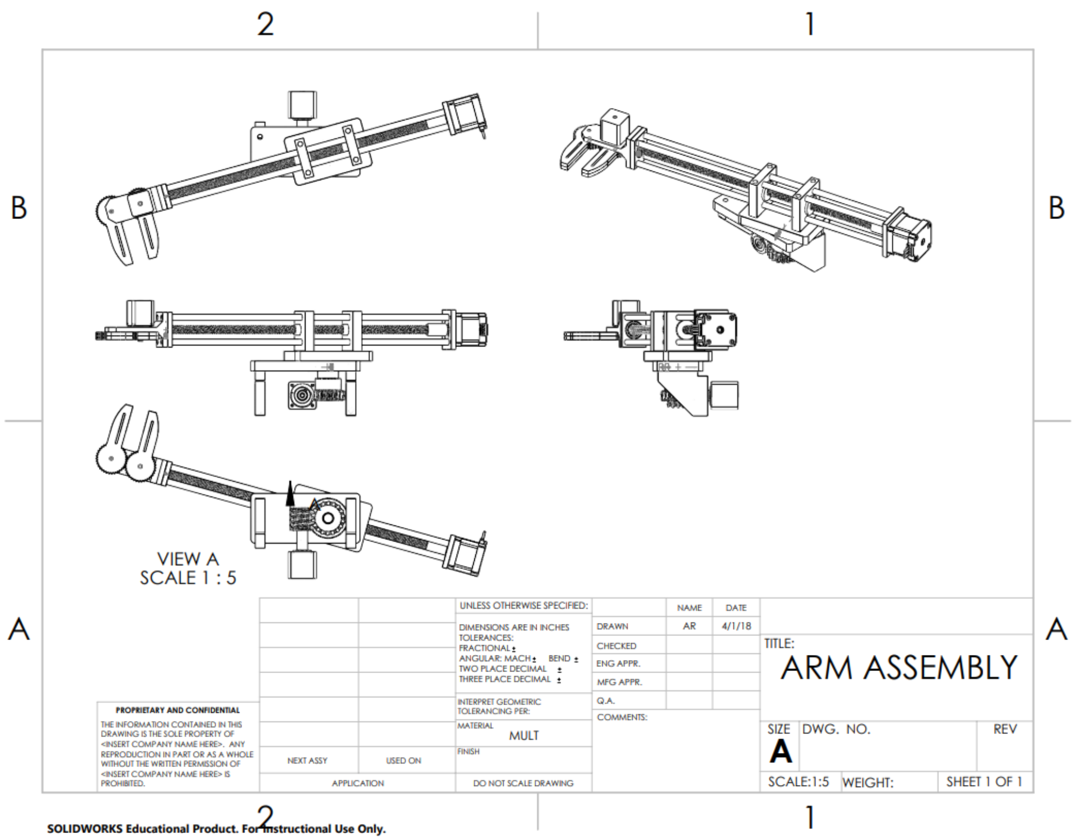
Product BOM

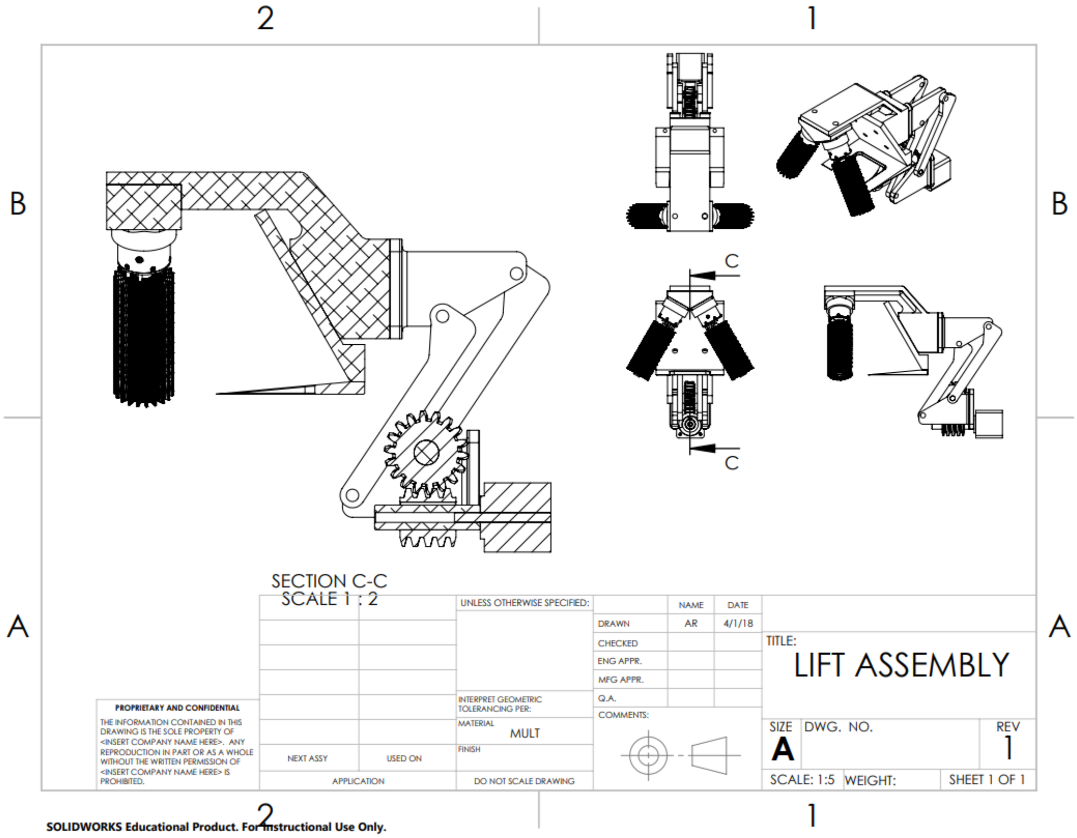
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ChassisSidePlate		2
2	DriveStepper		2
3	60355K503		4
4	1327K113		4
5	2737T131		4
6	6261K281		78
7	2737T2		2
8	Wheel_Bushing		4
9	CasterWheel_5in.ipt		4
10	ChassisSideCover		2
11	SideSensorEntension		2
12	SideSensorMount		2
13	ChassisMotorHousing		1
14	ClawArmBearingMount		1
15	60355K509		1
16	ArmRotate		1
17	RackStand		2
18	93410A912		1
19	95120A592		2
20	Rail		4
21	nema_17_motor		1
22	ClawWormCoupler		1
23	ClawRailMotorBracket		1
24	60355K504		1
25	ClawBracket		1
26	ClawMount		1
27	CLAW_L		2
28	CLAW_R		2
29	Step Motor 28BYJ-48		1
30	57545K511_SPEED-REDUCING WORM GEAR FOR 90 DEG TRANSFER		1

31	57545K527_SPEED-REDUCING WORM GEAR FOR 90 DEG TRANSFER	2
32	RotationBushing	2
33	6627T38	2
34	CubeArmMountBracket	2
35	LiftLinkageBaseMount	4
36	PyrIntakeAngledMount	1
37	PyrIntakeBacking	1
38	PyrIntakeForks	1
39	LiftLinkage	4
40	PyrIntakeFlapperMotor	2
41	PyrIntakeMotorMount	1
42	PyrIntakeRoller	2
43	57545K511_SPEED-REDUCING WORM GEAR FOR 90 DEG TRANSFER-cutoff	1
44	PyrIntakeLinkageRod	1

Product Technical Drawings







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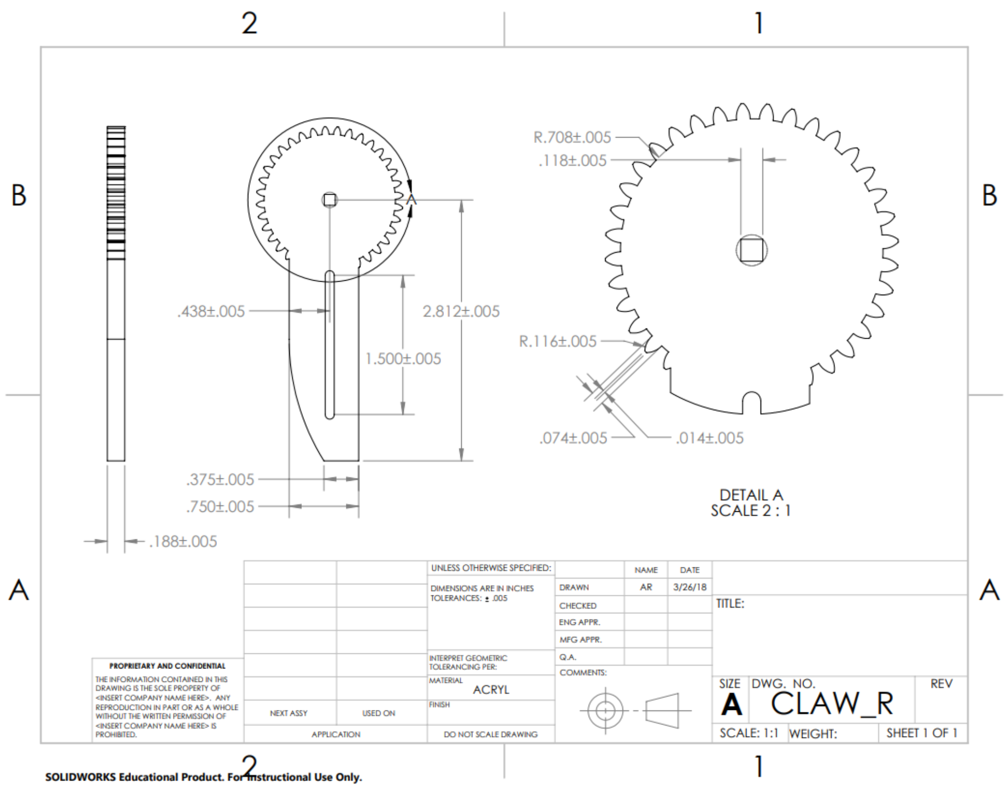

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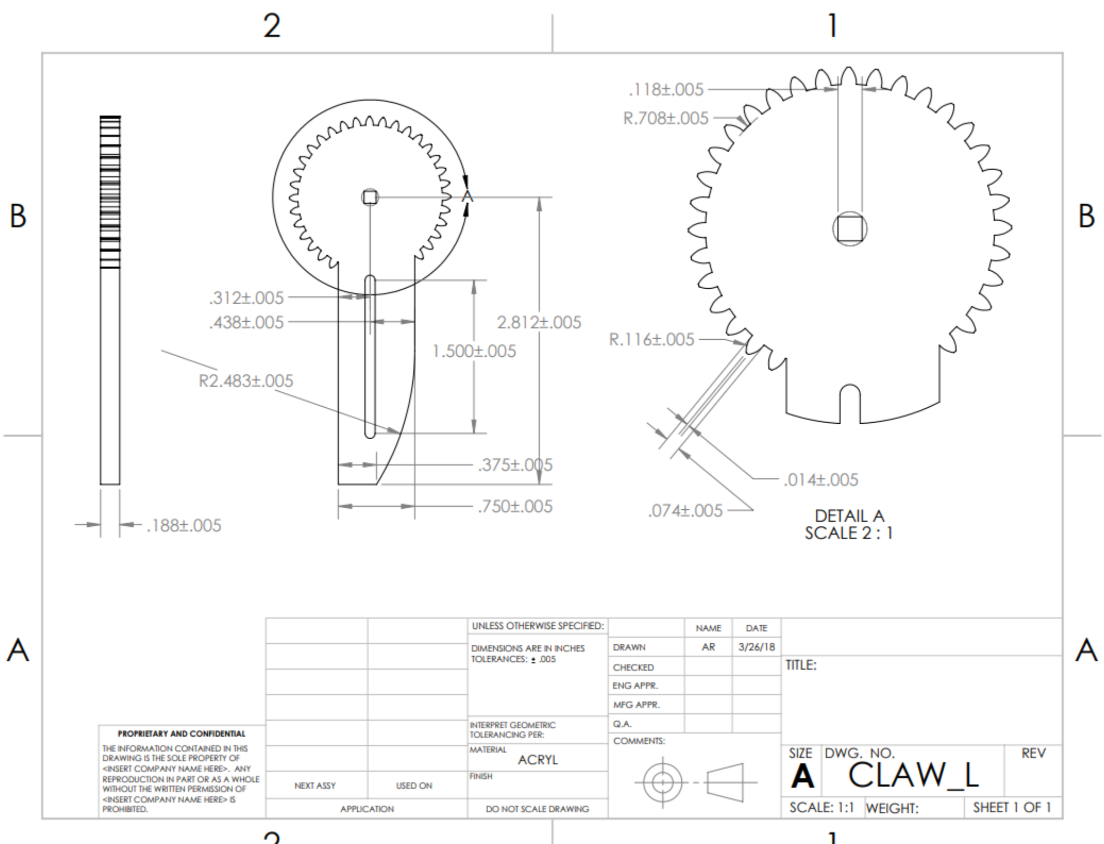
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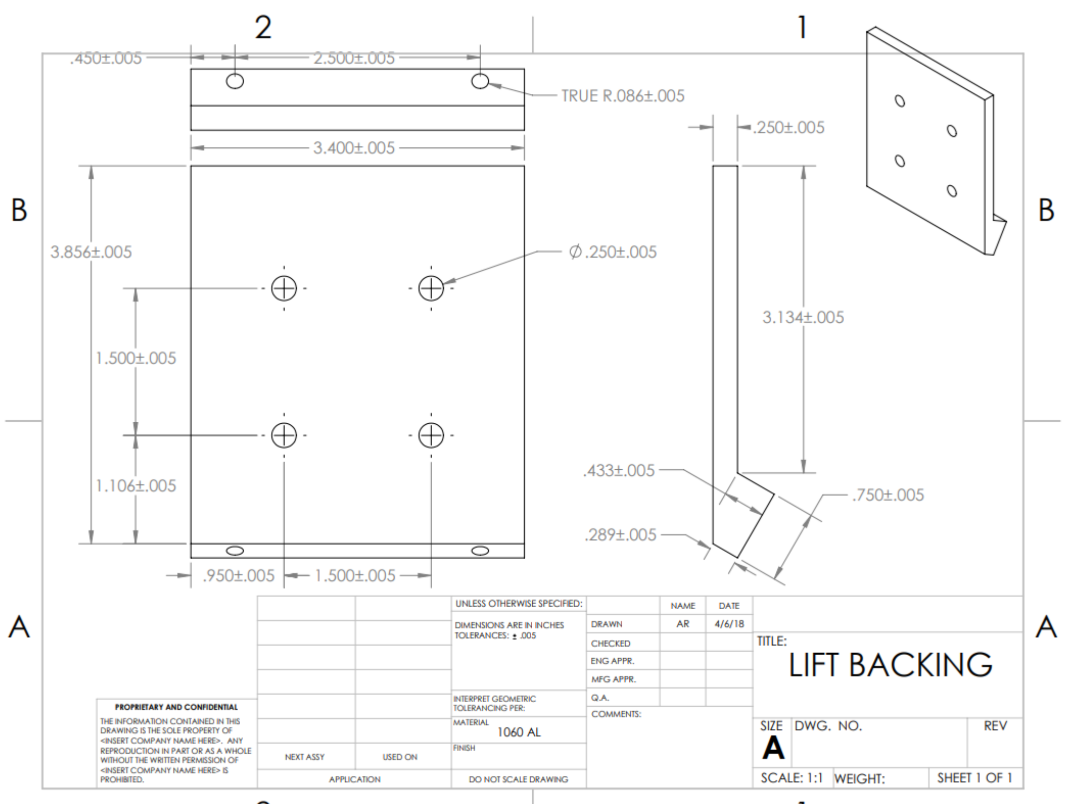
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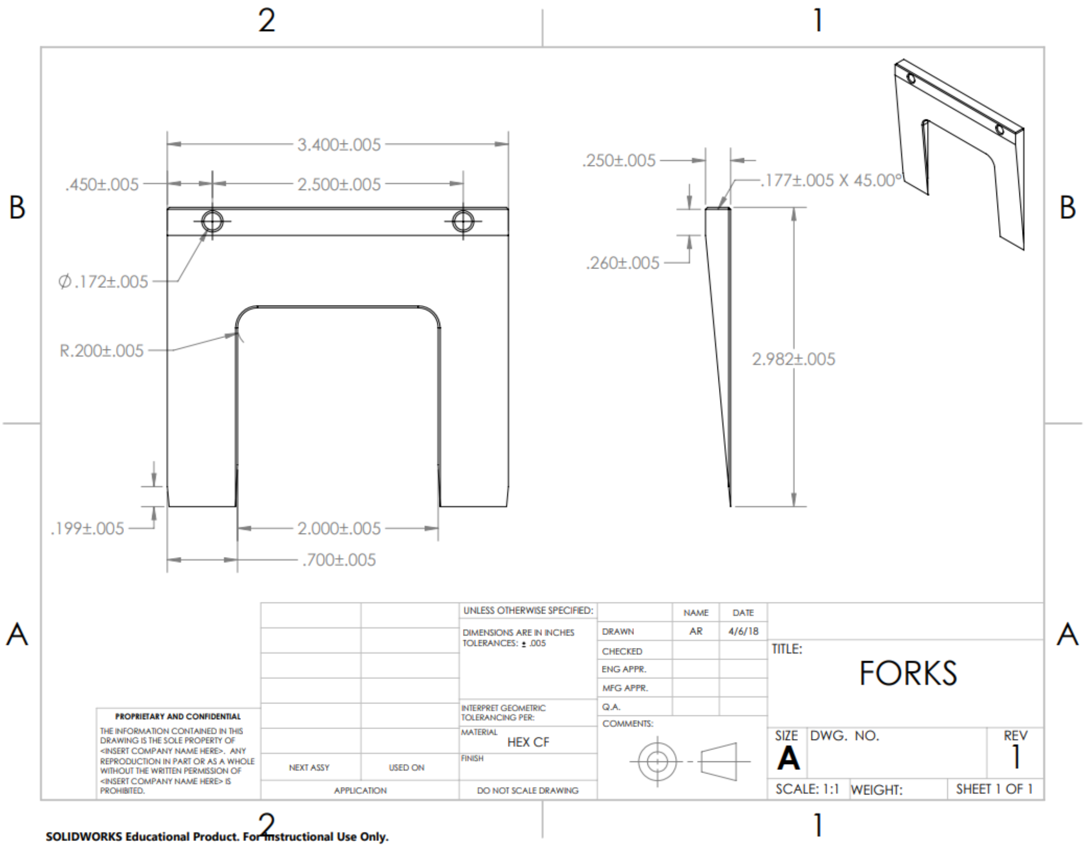
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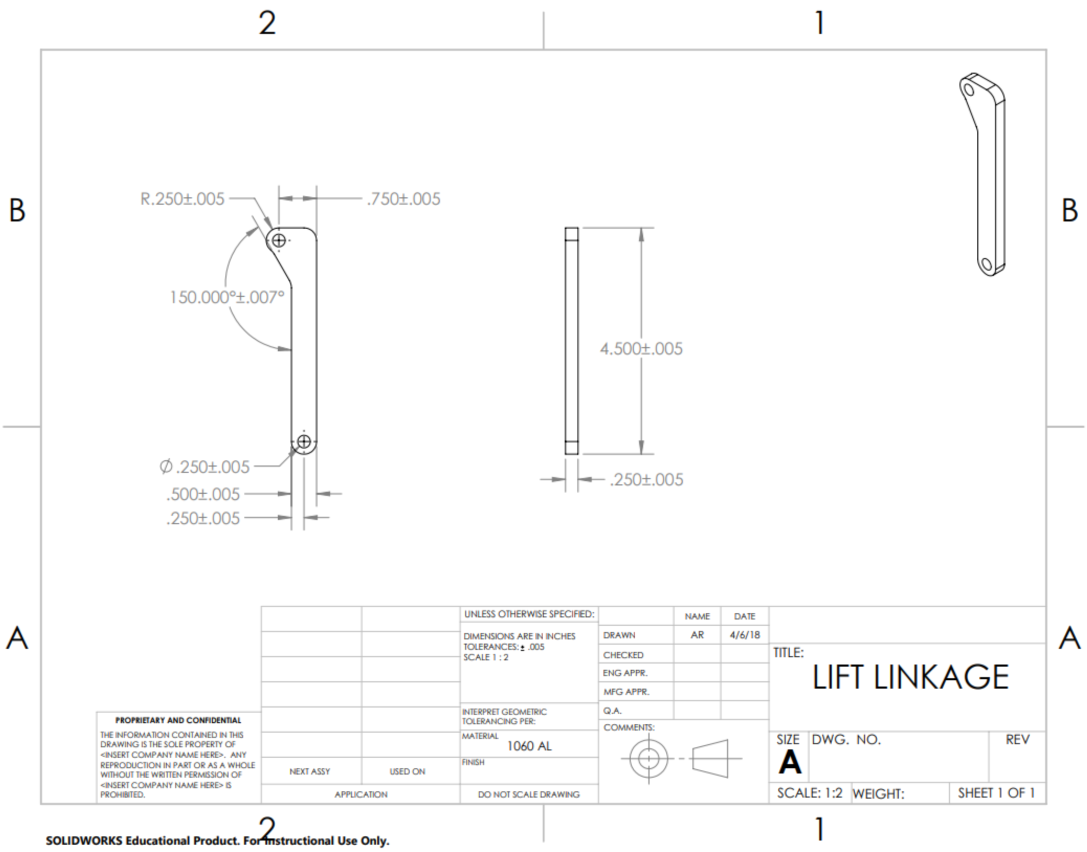
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.250±.005
4.500±.005
.250±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE 1 : 2
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
LIFT LINKAGE
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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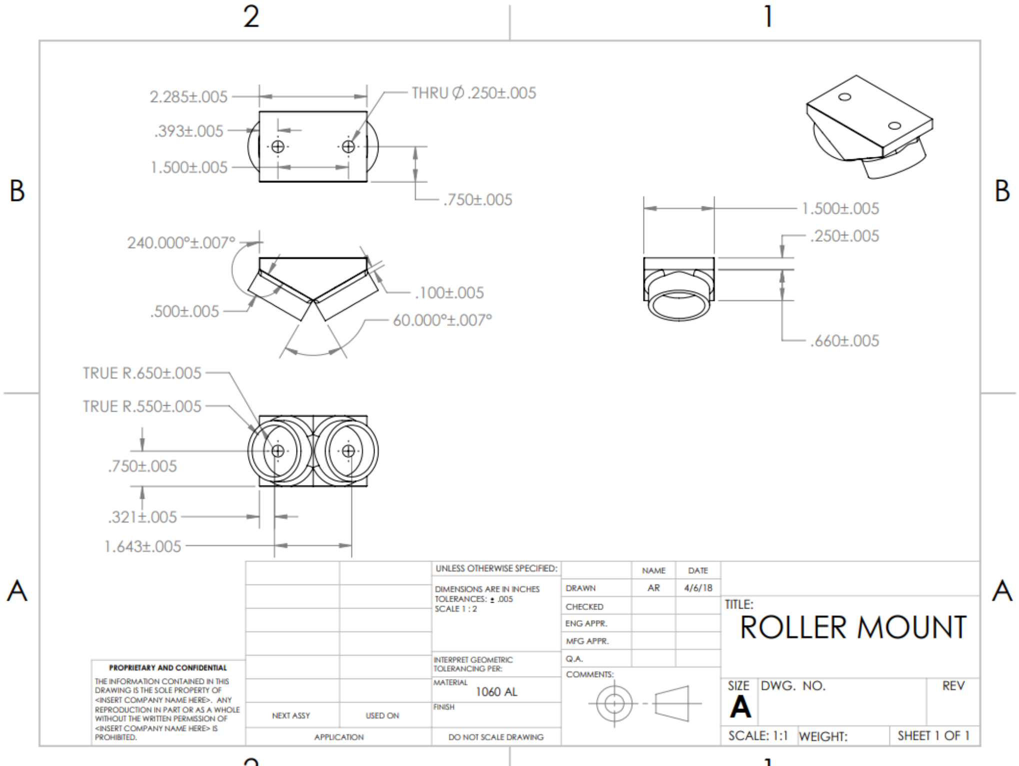
2.285±.005
THRU Ø .250±.005
.393±.005
1.500±.005
.750±.005
240.000°±.007°
.100±.005
.500±.005
60.000°±.007°
TRUE R.650±.005
TRUE R.550±.005
.750±.005
.321±.005
1.643±.005
1.500±.005
.250±.005
.660±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE 1 : 2
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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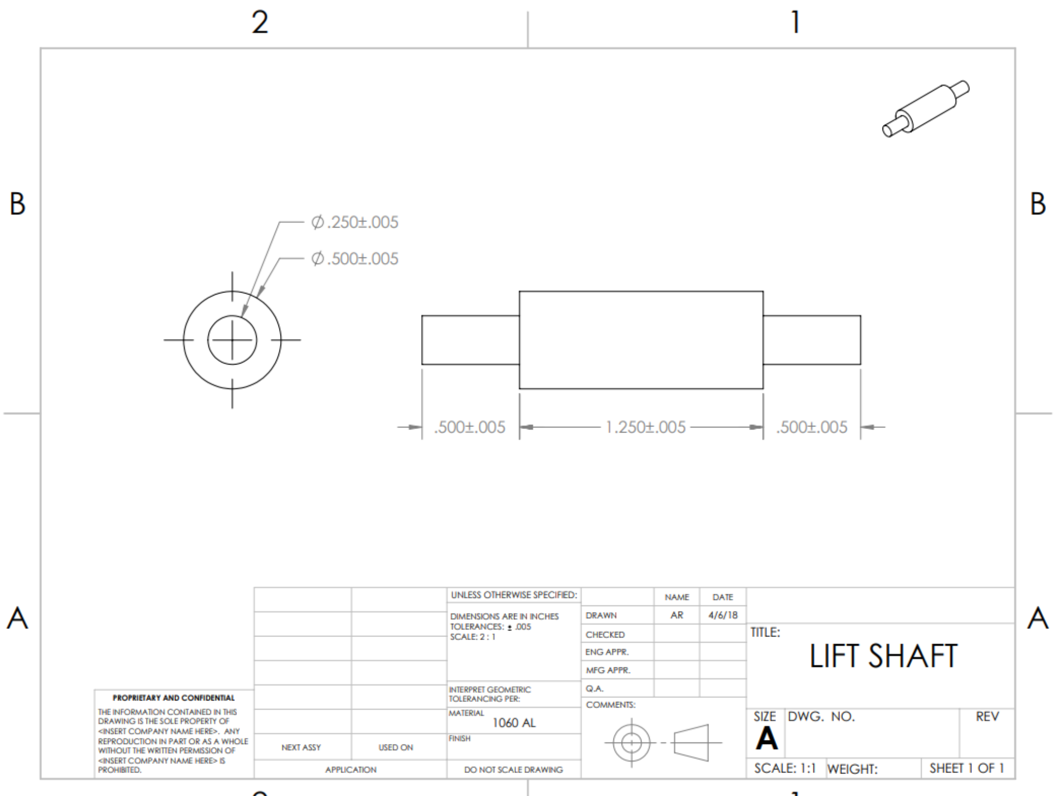
TITLE:
ROLLER MOUNT
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


Ø .250±.005
Ø .500±.005
.500±.005
1.250±.005
.500±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 2 : 1
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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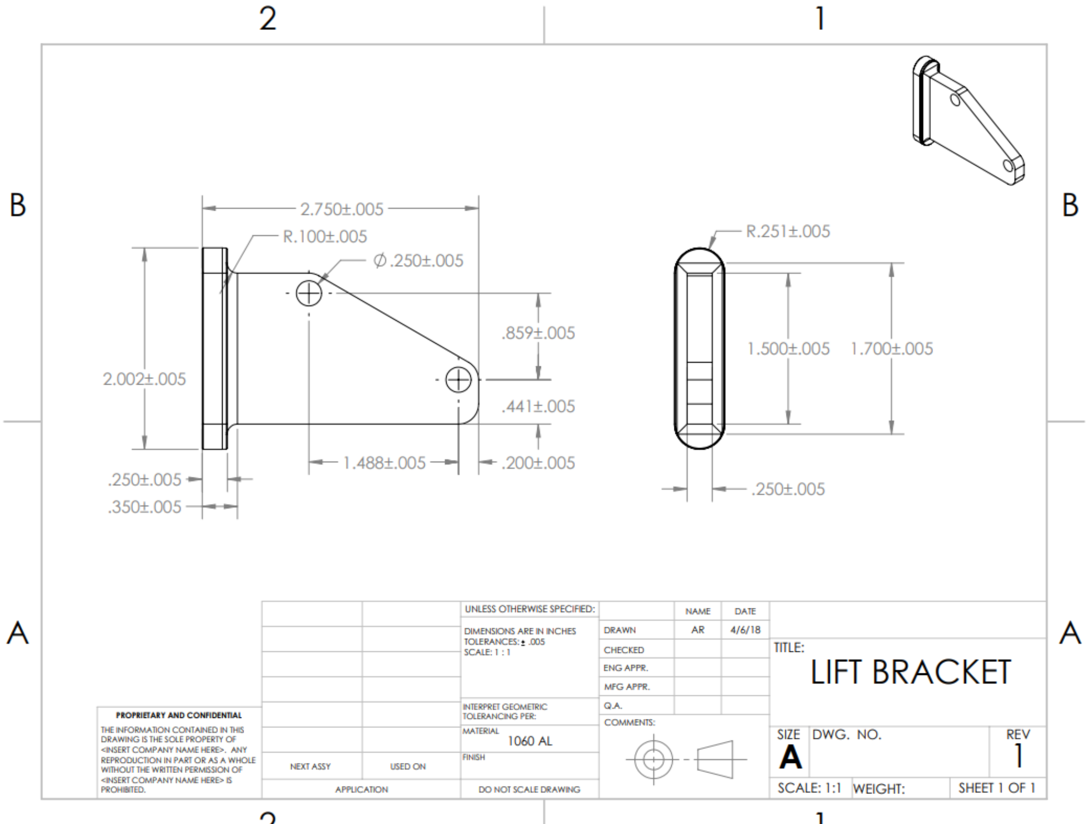
TITLE:
LIFT SHAFT
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1



2.750±.005
R.100±.005
Ø.250±.005
.859±.005
2.002±.005
.441±.005
1.488±.005
.200±.005
.250±.005
.350±.005
R.251±.005
1.500±.005
1.700±.005
.250±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 1 : 1
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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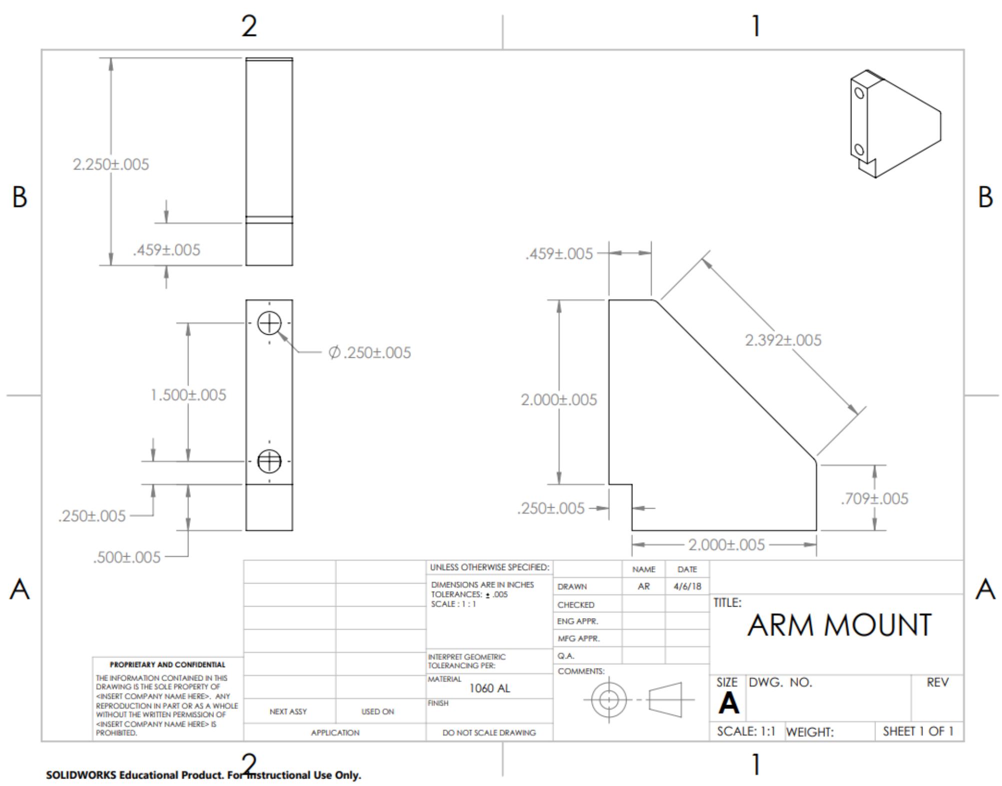
TITLE:
LIFT BRACKET
SIZE
A
DWG. NO.
REV
1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1



2.250±.005
.459±.005
Ø.250±.005
1.500±.005
.250±.005
.500±.005
.459±.005
2.392±.005
2.000±.005
.250±.005
.709±.005
2.000±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 1 : 1
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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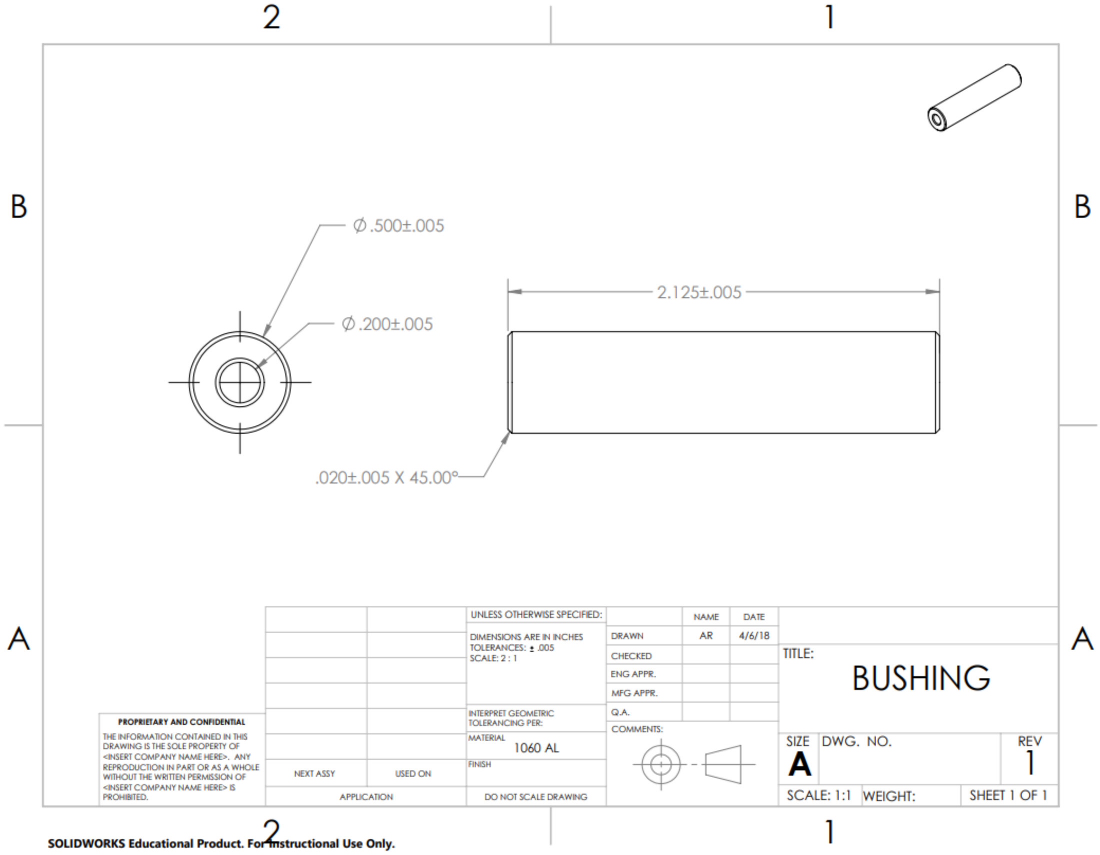
TITLE:
ARM MOUNT
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1



Ø .500±.005
Ø .200±.005
2.125±.005
.020±.005 X 45.00°
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 2 : 1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NAME DATE
DRAWN AR 4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
BUSHING
SIZE A
DWG. NO.
REV 1
SCALE: 1:1 WEIGHT: SHEET 1 OF 1
NEXT ASSY USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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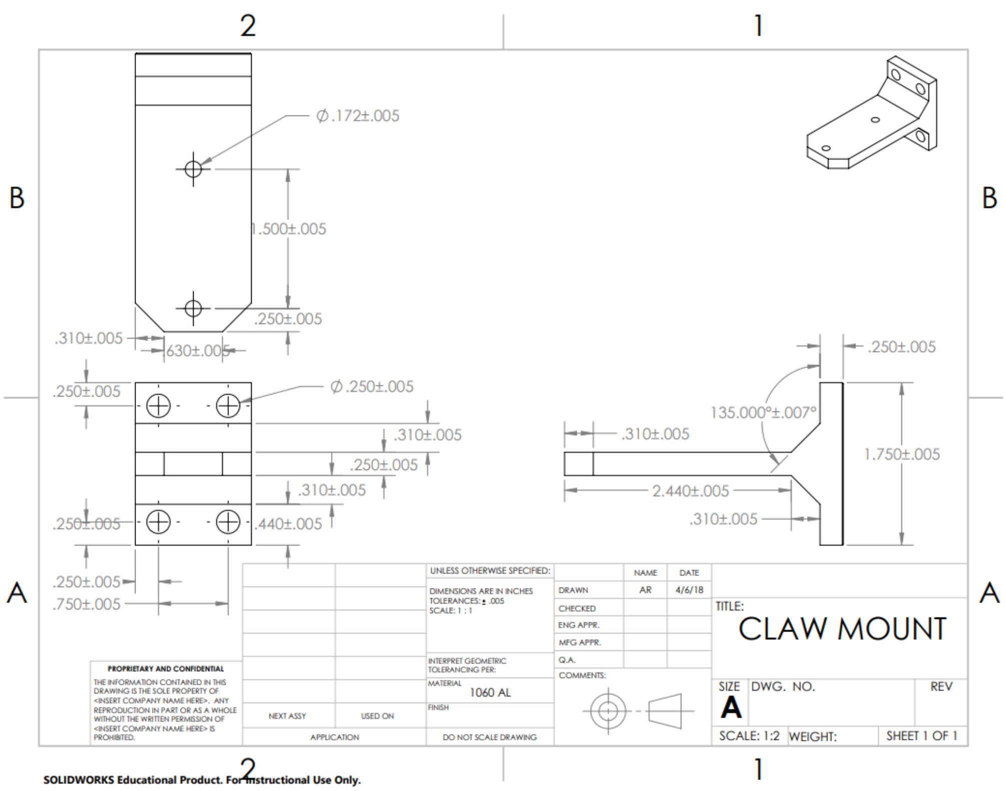

Ø .172±.005
1.500±.005
.250±.005
.310±.005
.630±.005
.250±.005
Ø .250±.005
.310±.005
.250±.005
.310±.005
.250±.005
.440±.005
.250±.005
.750±.005
.250±.005
135.000°±.007°
.310±.005
1.750±.005
2.440±.005
.310±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 1 : 1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NAME DATE
DRAWN AR 4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
CLAW MOUNT
SIZE A
DWG. NO.
REV
SCALE: 1:2 WEIGHT: SHEET 1 OF 1
NEXT ASSY USED ON
APPLICATION
DO NOT SCALE DRAWING
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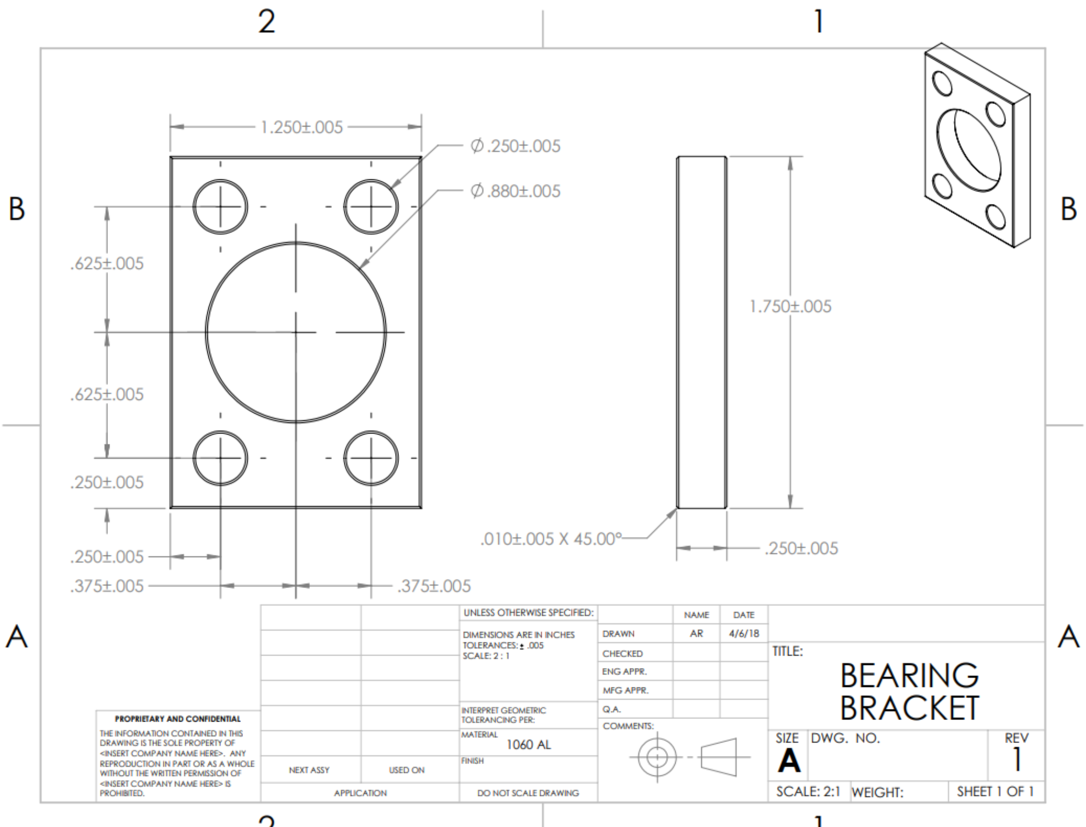
1.250±.005
Ø .250±.005
Ø .880±.005
.625±.005
.625±.005
.250±.005
.250±.005
.375±.005
.375±.005
1.750±.005
.010±.005 X 45.00°
.250±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 2 : 1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
BEARING BRACKET
SIZE
A
DWG. NO.
REV
1
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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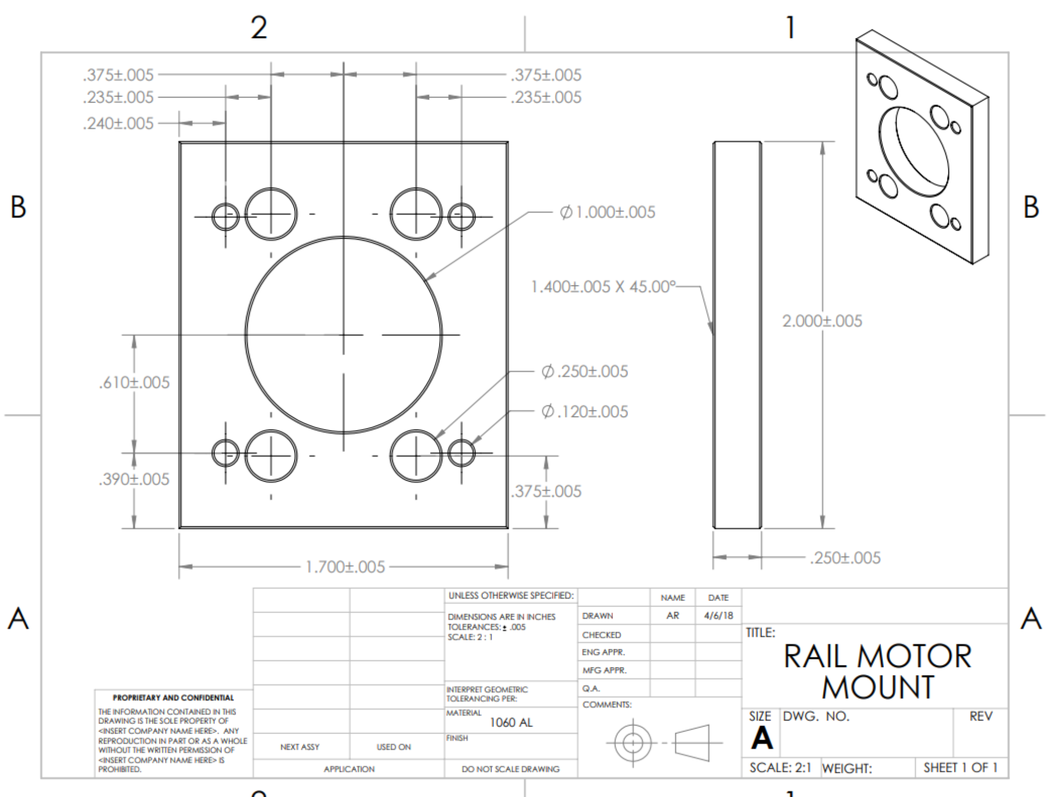
.375±.005
.235±.005
.240±.005
.375±.005
.235±.005
Ø 1.000±.005
1.400±.005 X 45.00°
2.000±.005
Ø .250±.005
Ø .120±.005
.610±.005
.390±.005
.375±.005
1.700±.005
.250±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 2 : 1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
RAIL MOTOR MOUNT
SIZE
A
DWG. NO.
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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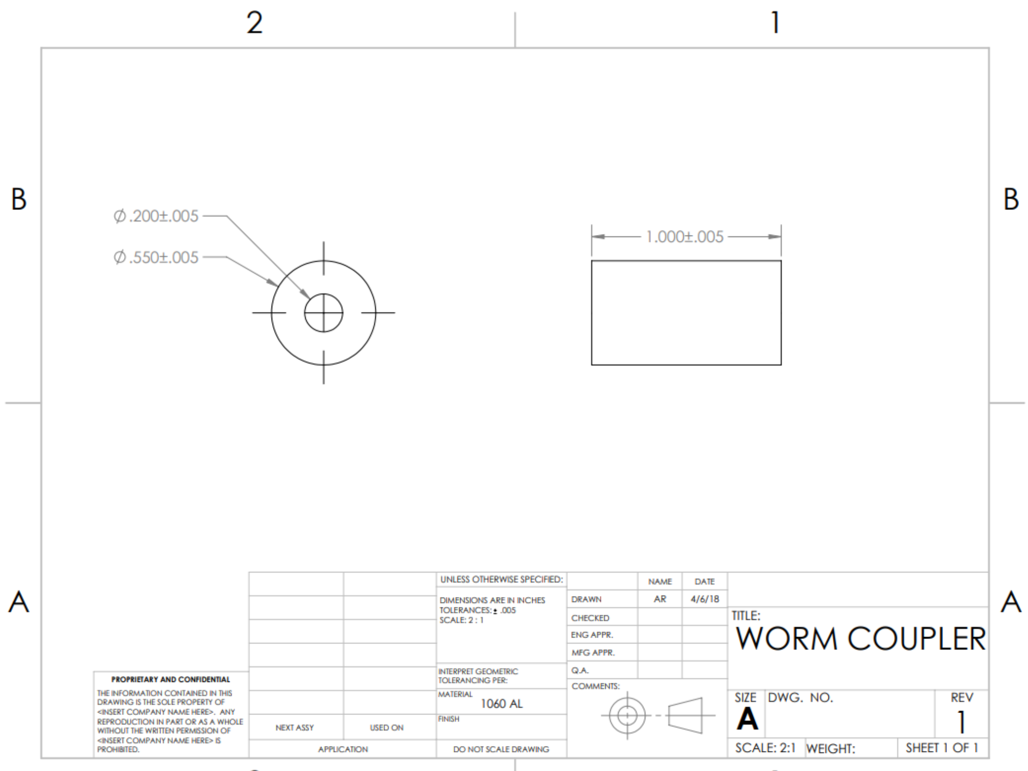
Ø .200±.005
Ø .550±.005
1.000±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 2 : 1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
WORM COUPLER
SIZE
A
DWG. NO.
REV
1
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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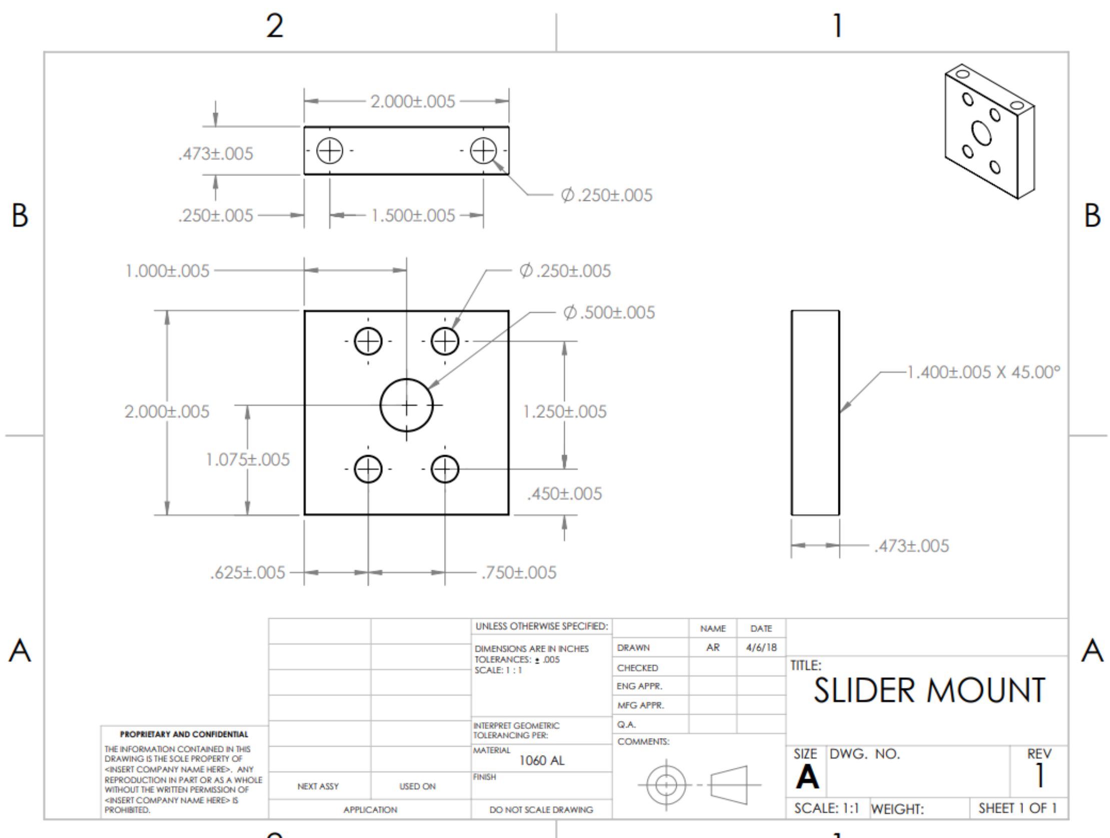
2.000±.005
.473±.005
.250±.005
1.500±.005
Ø .250±.005
1.000±.005
Ø .250±.005
Ø .500±.005
2.000±.005
1.250±.005
1.075±.005
.450±.005
.625±.005
.750±.005
1.400±.005 X 45.00°
.473±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 1 : 1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SLIDER MOUNT
SIZE
A
DWG. NO.
REV
1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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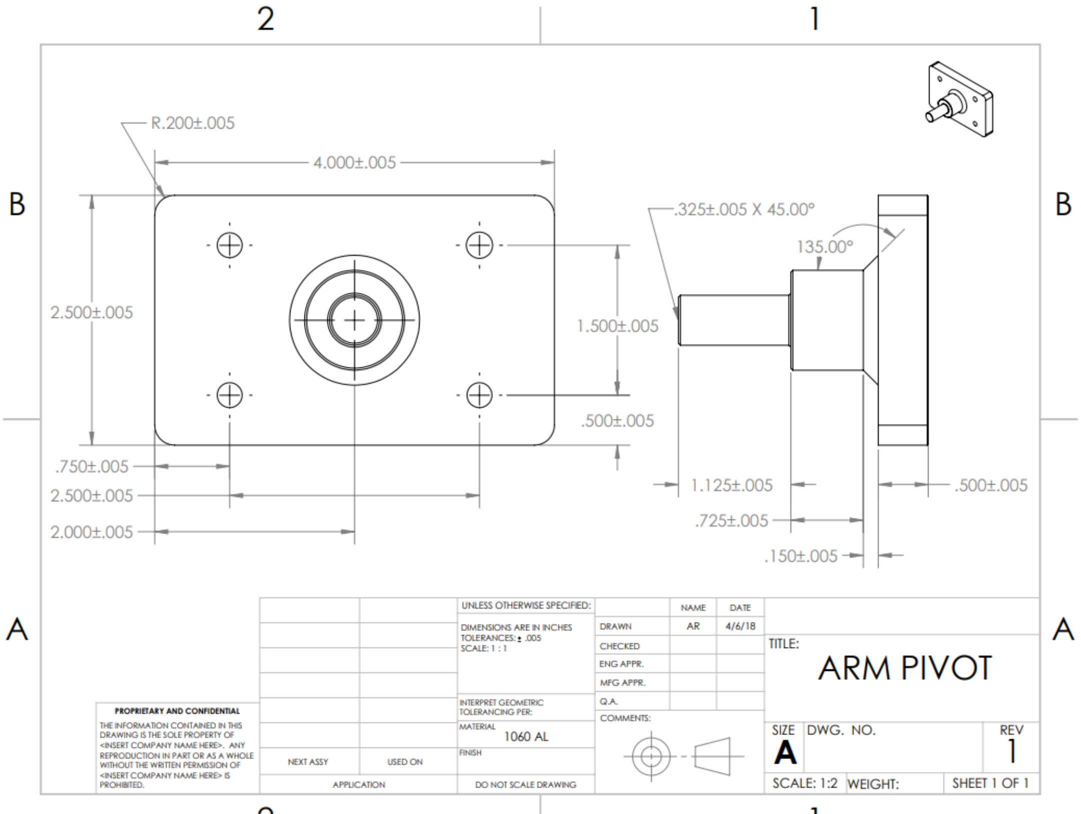

R.200±.005
4.000±.005
2.500±.005
1.500±.005
.500±.005
.750±.005
2.500±.005
2.000±.005
.325±.005 X 45.00°
135.00°
1.125±.005
.725±.005
.150±.005
.500±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 1 : 1
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
ARM PIVOT
SIZE
DWG. NO.
REV
A
1
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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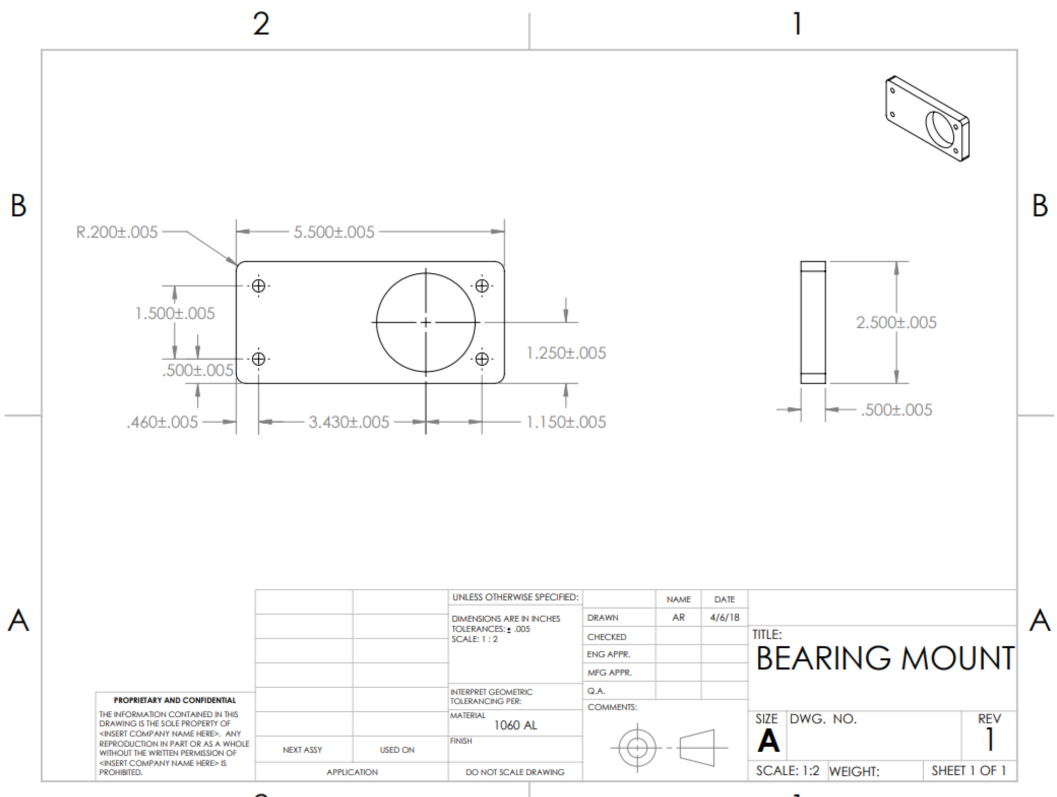

R.200±.005
5.500±.005
1.500±.005
.500±.005
1.250±.005
.460±.005
3.430±.005
1.150±.005
2.500±.005
.500±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 1 : 2
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 AL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AR
4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
BEARING MOUNT
SIZE
DWG. NO.
REV
A
1
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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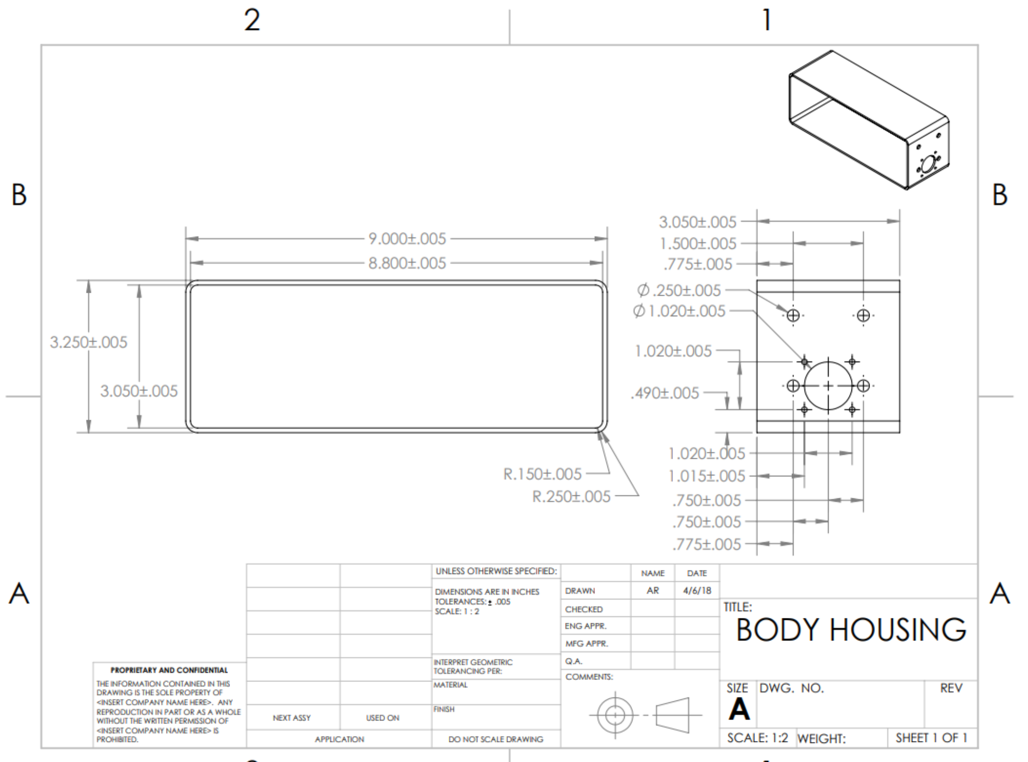

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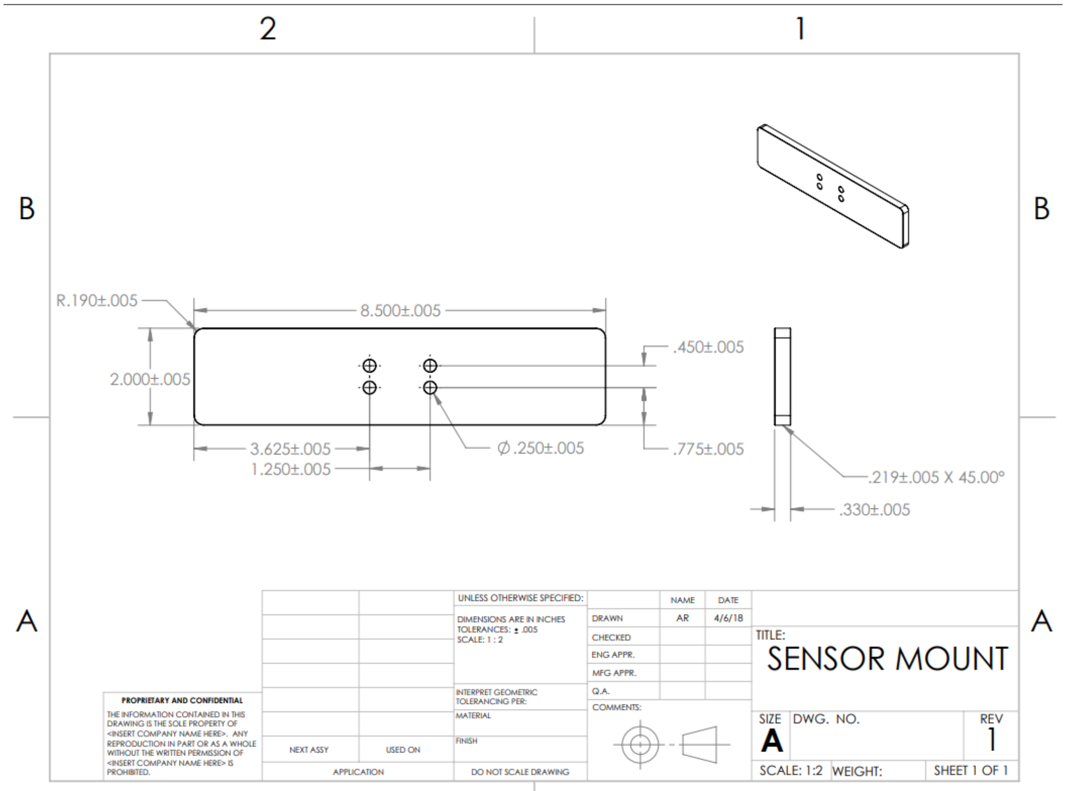
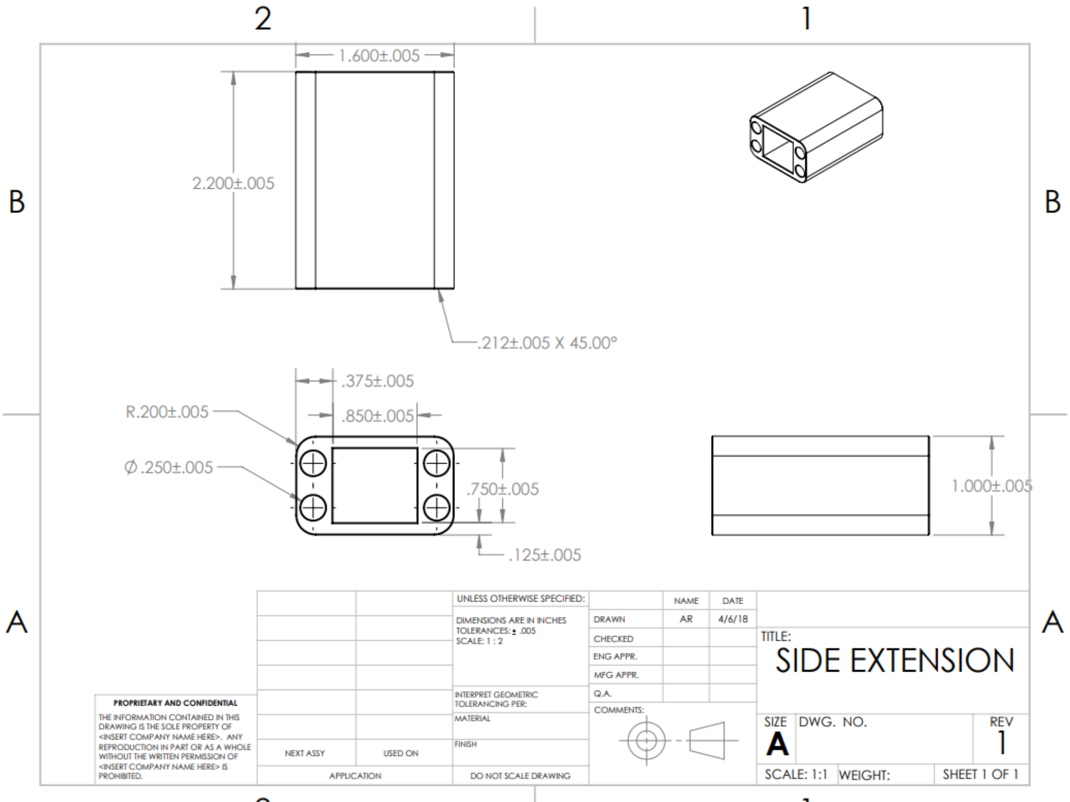


SOLIDWORKS Educational Product. For Instructional Use Only.


1.600±.005
2.200±.005
.212±.005 X 45.00°
.375±.005
.850±.005
R.200±.005
Ø.250±.005
.750±.005
.125±.005
1.000±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ± .005
SCALE: 1 : 2
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN AR 4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIDE EXTENSION
SIZE A
DWG. NO.
REV 1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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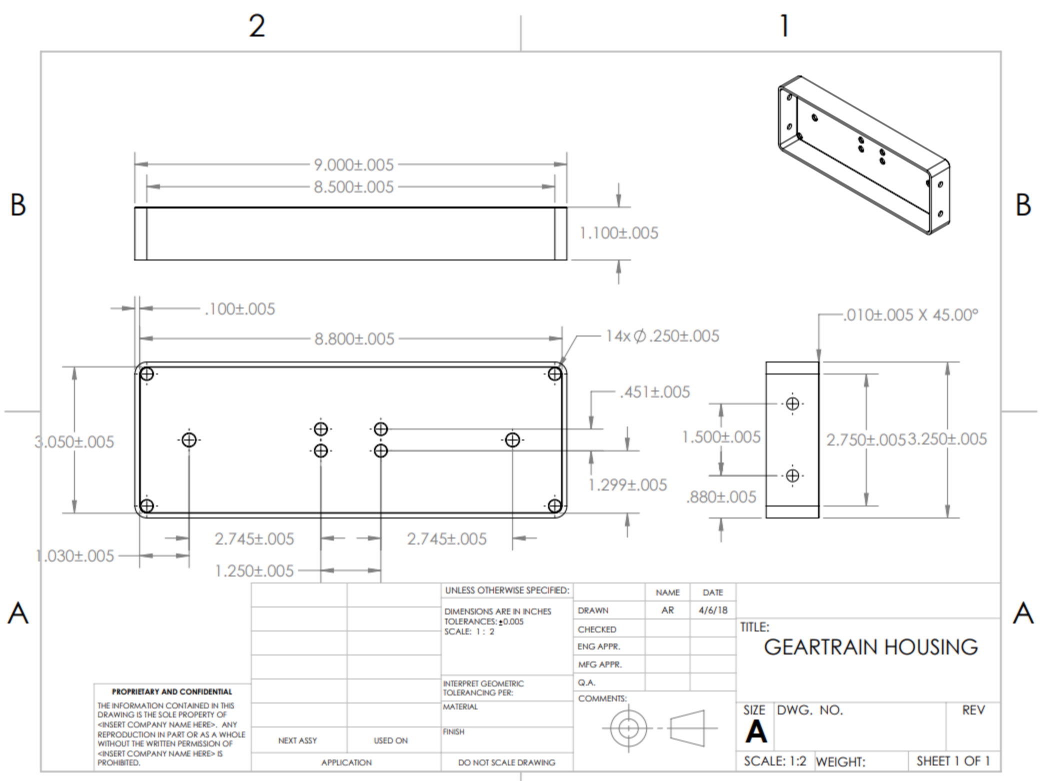
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING


9.000±.005
8.500±.005
1.100±.005
.100±.005
8.800±.005
14x Ø.250±.005
.010±.005 X 45.00°
.451±.005
1.500±.005
2.750±.005
3.250±.005
3.050±.005
1.299±.005
.880±.005
2.745±.005
2.745±.005
1.030±.005
1.250±.005
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: ±0.005
SCALE: 1 : 2
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN AR 4/6/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
GEARTRAIN HOUSING
SIZE A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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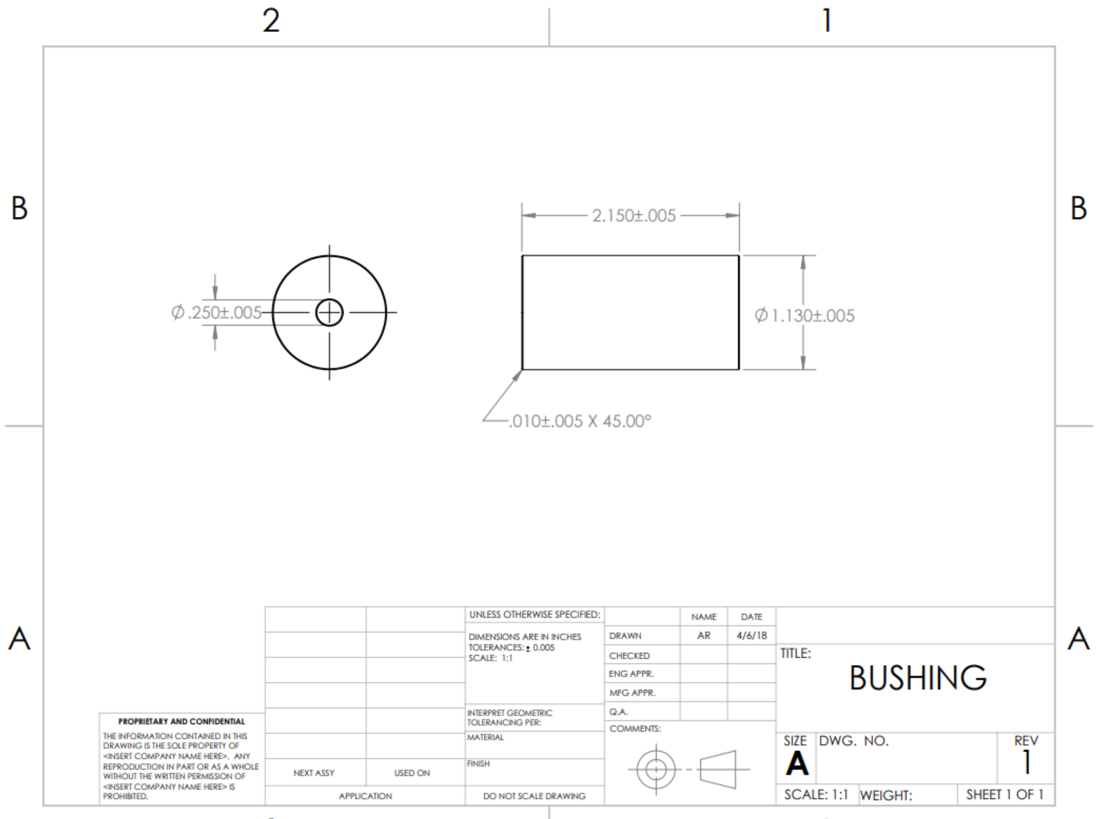
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING



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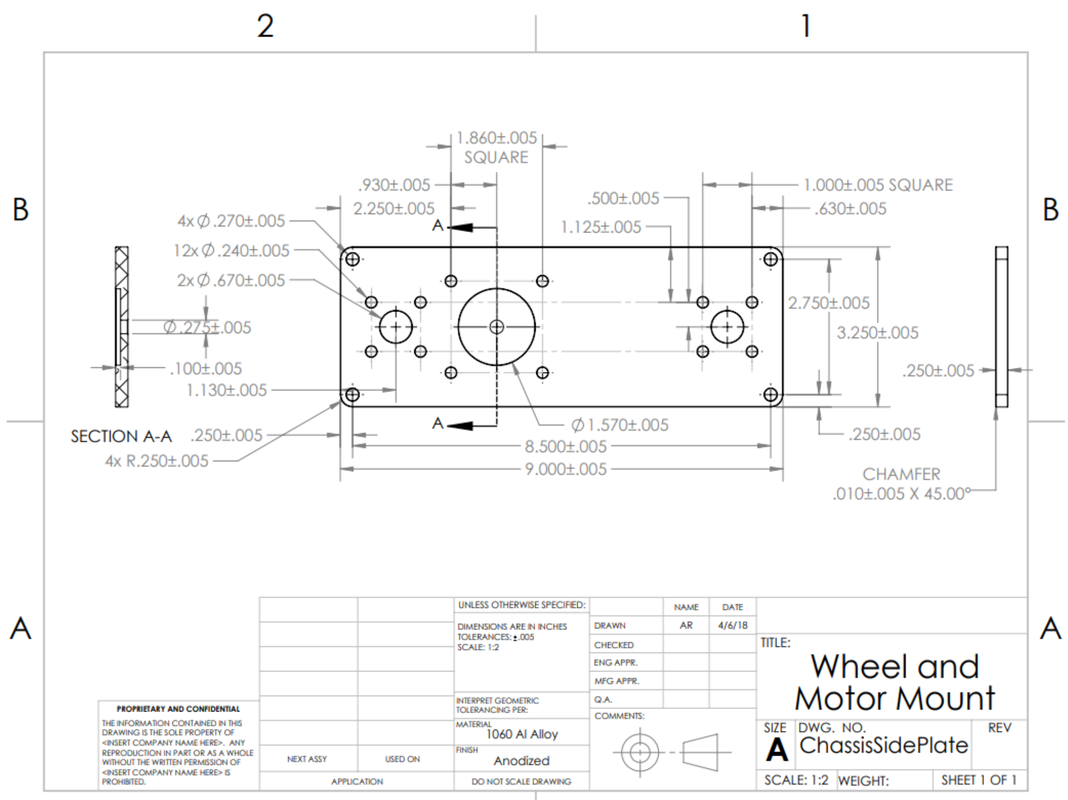

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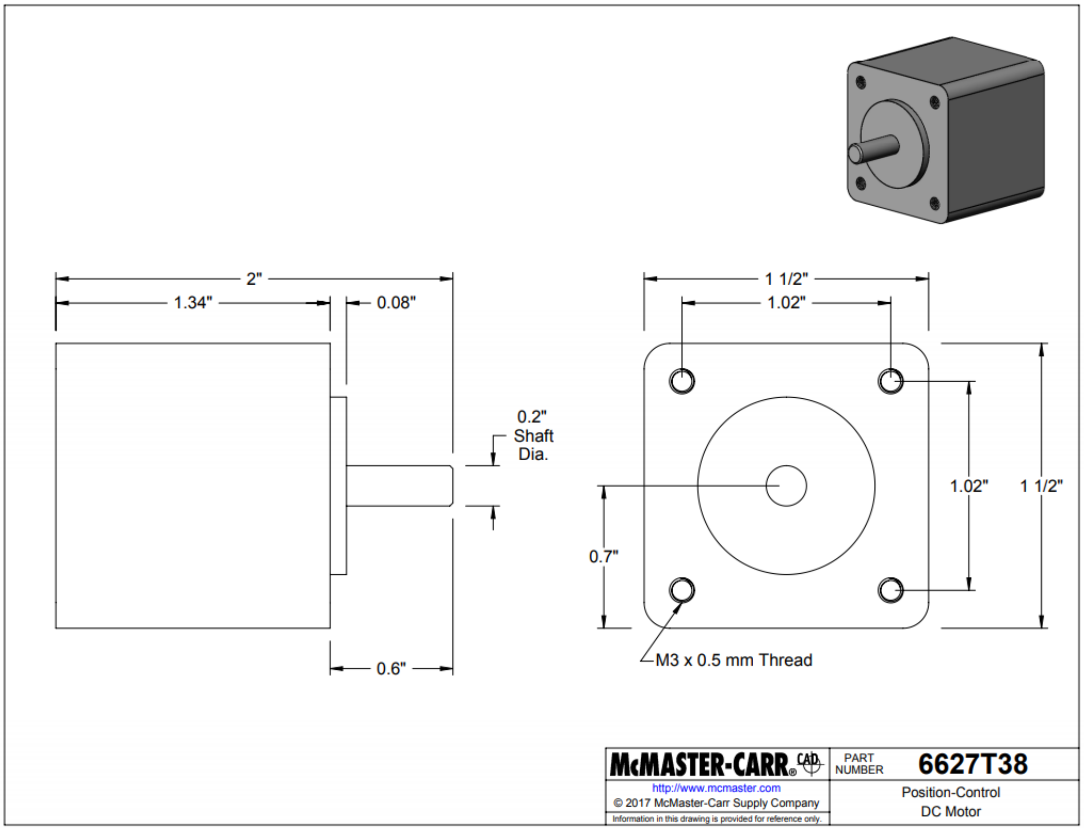
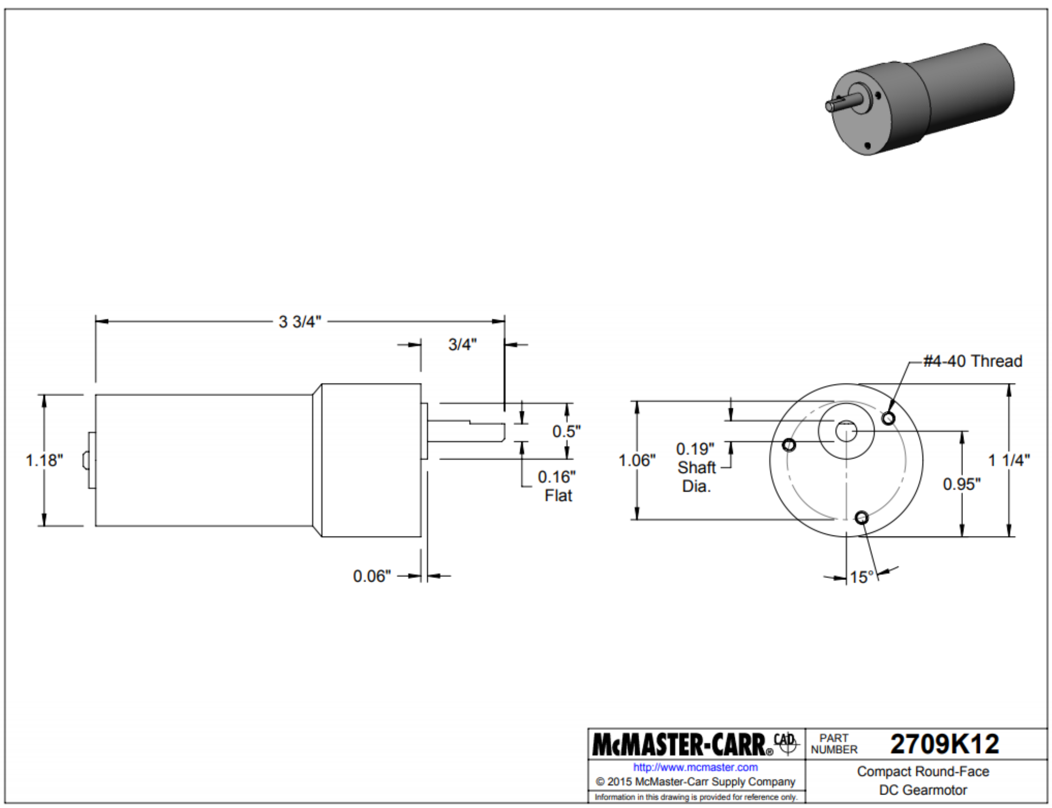


2"
1.34"
0.08"
0.2"
Shaft
Dia.
0.6"
1 1/2"
1.02"
1.02"
1 1/2"
0.7"
M3 x 0.5 mm Thread
McMASTER-CARR
PART NUMBER
6627T38
http://www.mcmaster.com
© 2017 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Position-Control
DC Motor



3 3/4"
3/4"
1.18"
0.5"
0.16"
Flat
0.06"
#4-40 Thread
1.06"
0.19"
Shaft
Dia.
1 1/4"
0.95"
15°
McMASTER-CARR
PART NUMBER
2709K12
http://www.mcmaster.com
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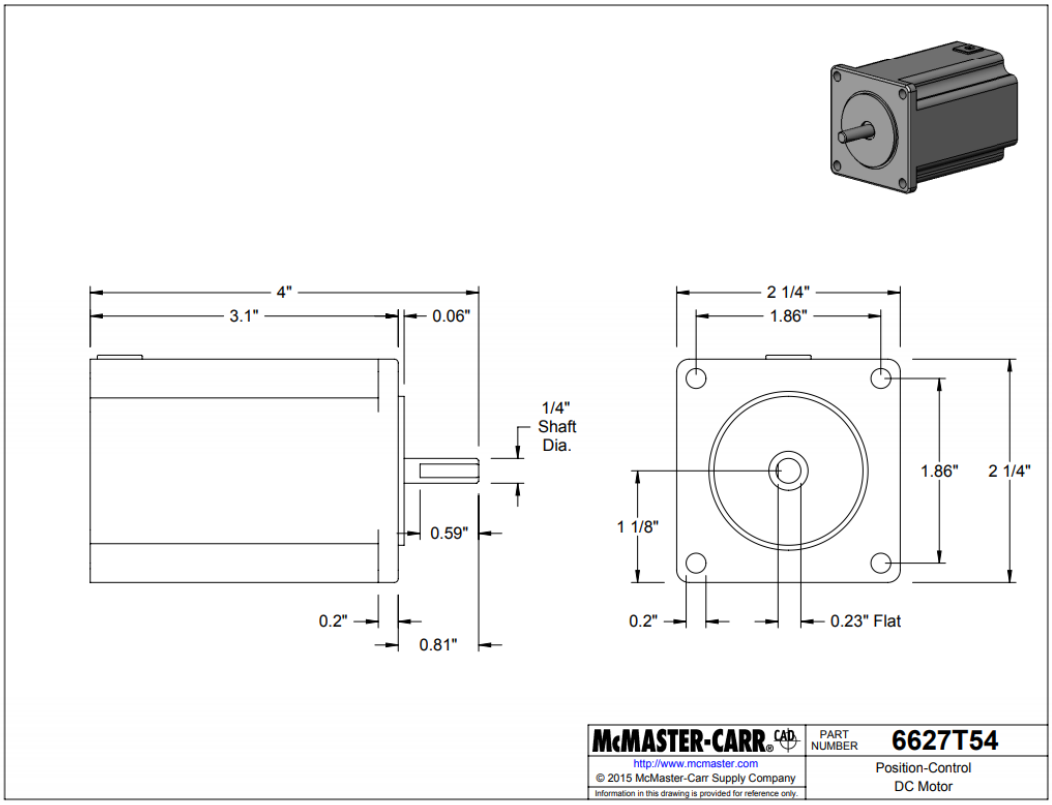
Compact Round-Face
DC Gearmotor



4"
3.1"
0.06"
1/4" Shaft Dia.
0.59"
0.2"
0.81"
2 1/4"
1.86"
1.86"
2 1/4"
1 1/8"
0.2"
0.23" Flat
McMASTER-CARR
PART NUMBER 6627T54
http://www.mcmaster.com
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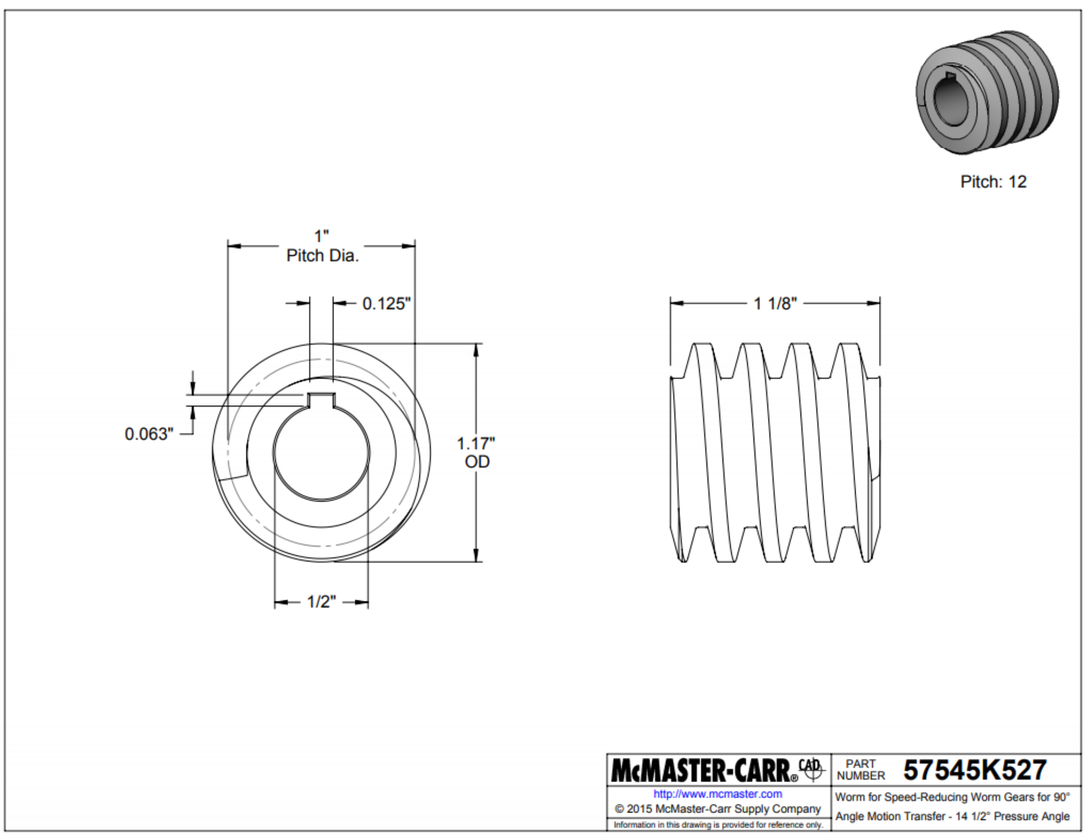
Position-Control DC Motor



Pitch: 12
1" Pitch Dia.
0.125"
0.063"
1.17" OD
1/2"
1 1/8"
McMASTER-CARR
PART NUMBER 57545K527
http://www.mcmaster.com
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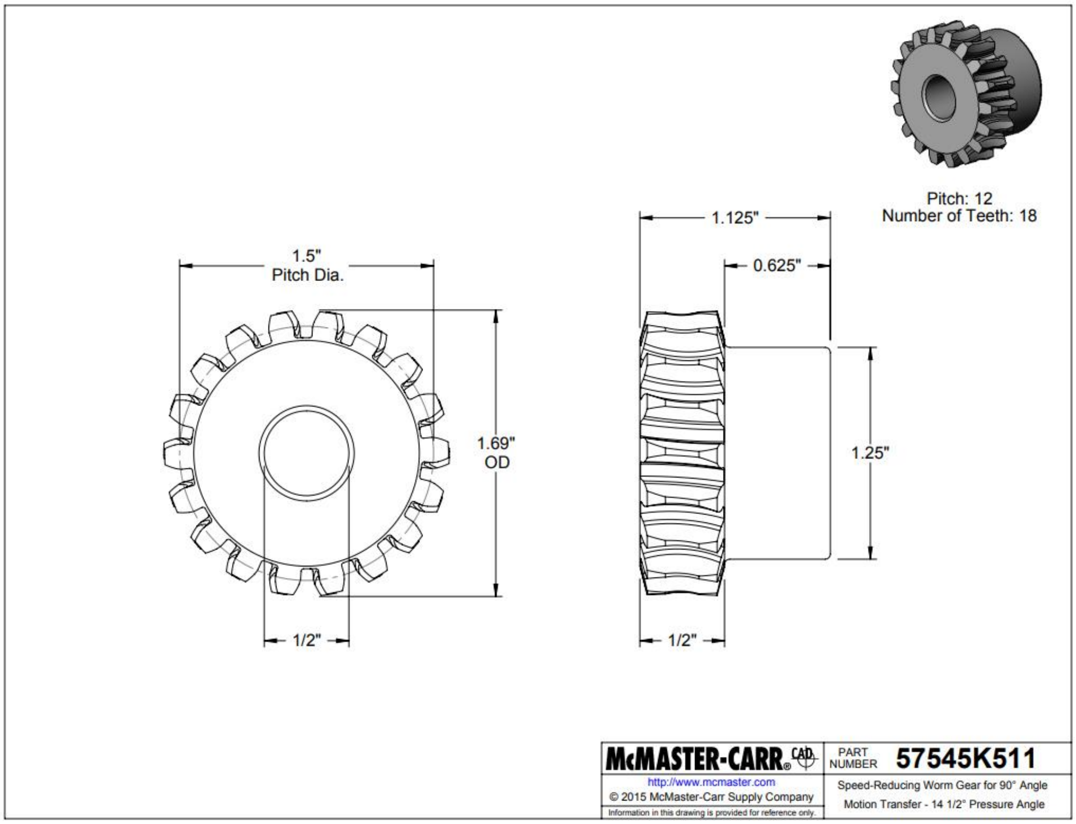
Worm for Speed-Reducing Worm Gears for 90° Angle Motion Transfer - 14 1/2° Pressure Angle



Pitch: 12
Number of Teeth: 18
1.125"
0.625"
1.5"
Pitch Dia.
1.69"
OD
1.25"
1/2"
1/2"
McMASTER-CARR
PART NUMBER 57545K511
http://www.mcmaster.com
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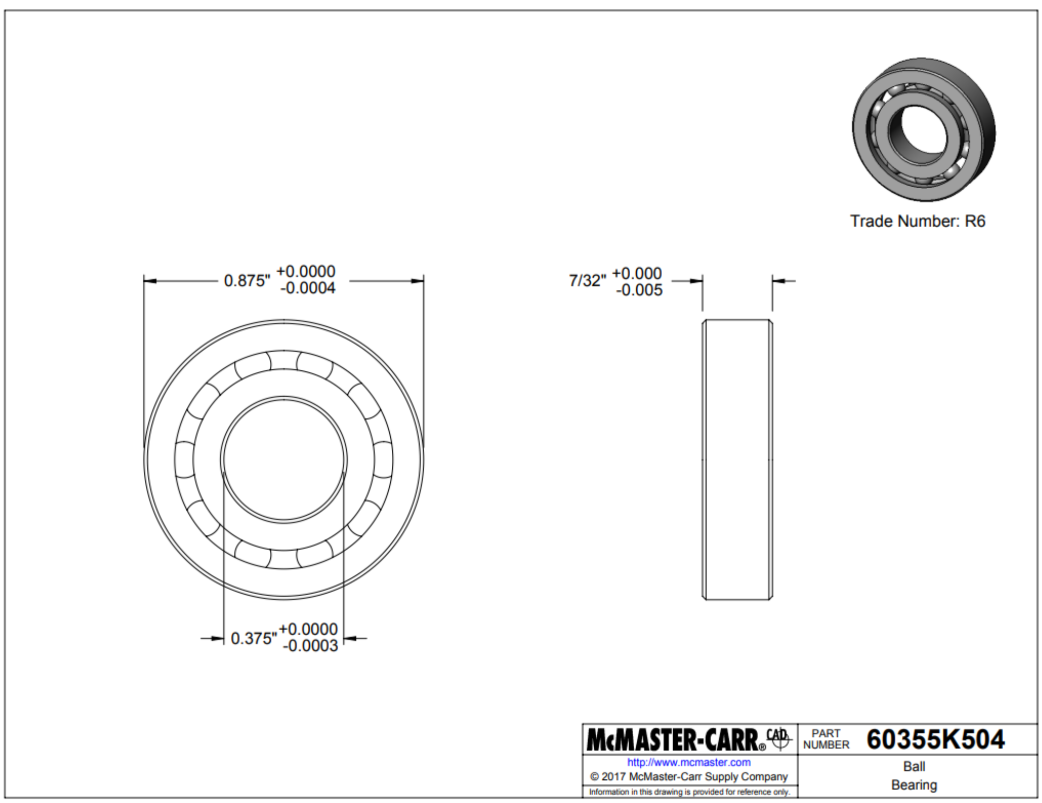
Speed-Reducing Worm Gear for 90° Angle
Motion Transfer - 14 1/2° Pressure Angle



Trade Number: R6
0.875" +0.0000 -0.0004
7/32" +0.000 -0.005
0.375" +0.0000 -0.0003
McMASTER-CARR
PART NUMBER 60355K504
http://www.mcmaster.com
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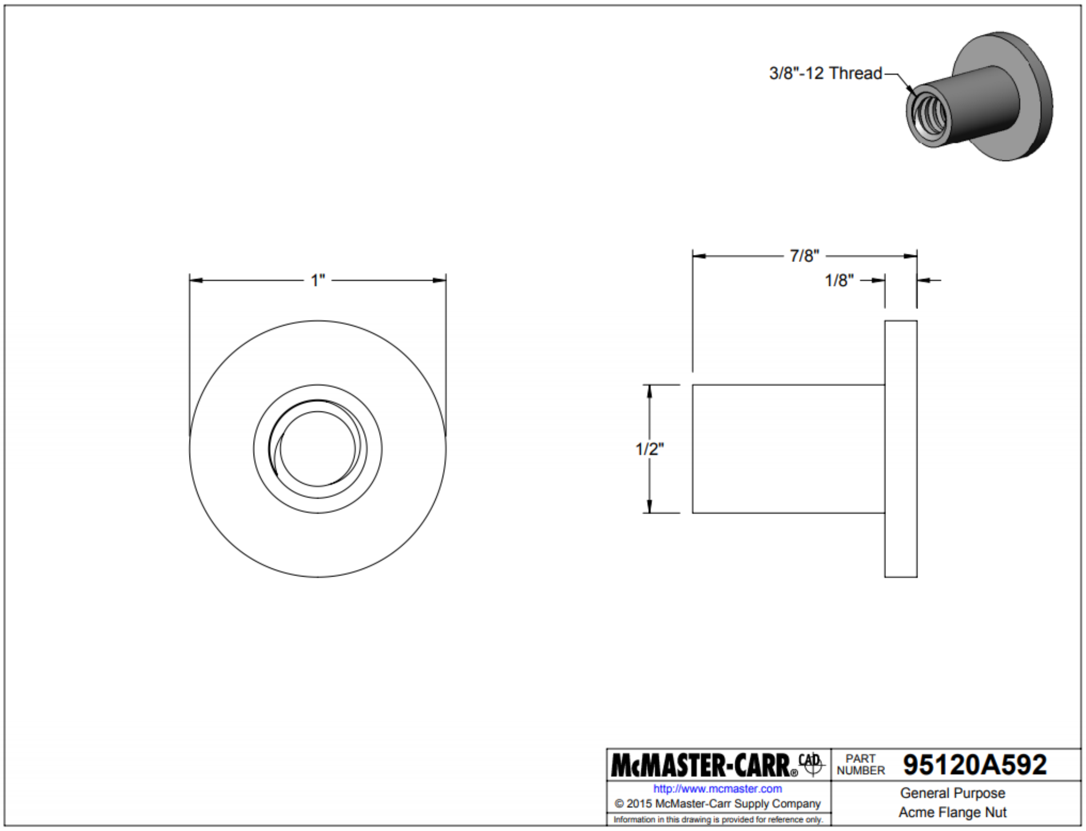
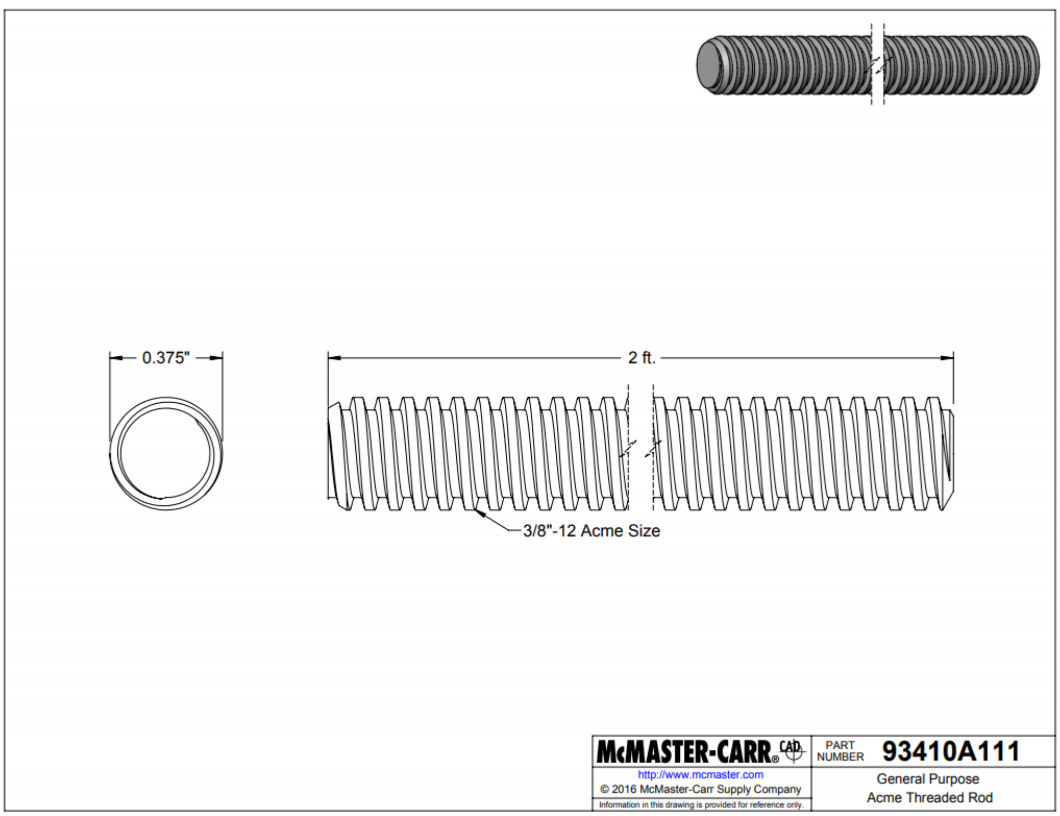
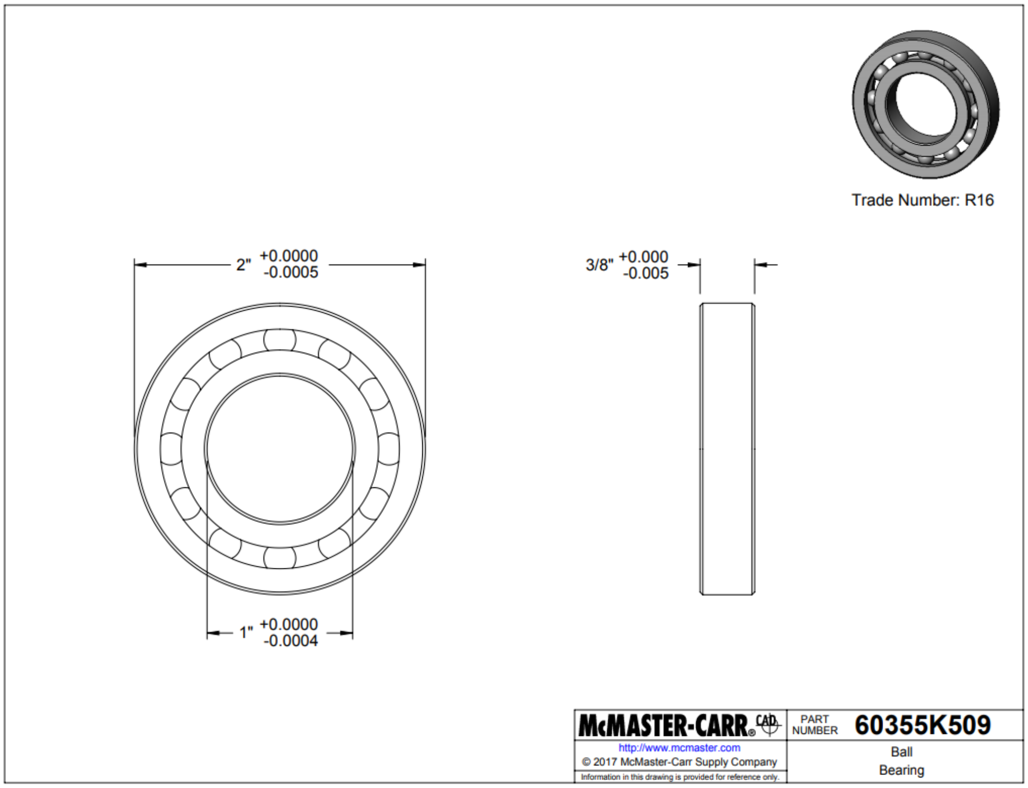
Information in this drawing is provided for reference only.
Ball
Bearing


3/8"-12 Thread
1"
7/8"
1/8"
1/2"
McMASTER-CARR
PART NUMBER 95120A592
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
General Purpose
Acme Flange Nut


0.375"
2 ft.
3/8"-12 Acme Size
McMASTER-CARR
PART NUMBER 93410A111
http://www.mcmaster.com
© 2016 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
General Purpose
Acme Threaded Rod


Trade Number: R16
2" +0.0000 -0.0005
3/8" +0.000 -0.005
1" +0.0000 -0.0004
McMASTER-CARR. CAD
PART NUMBER 60355K509
http://www.mcmaster.com
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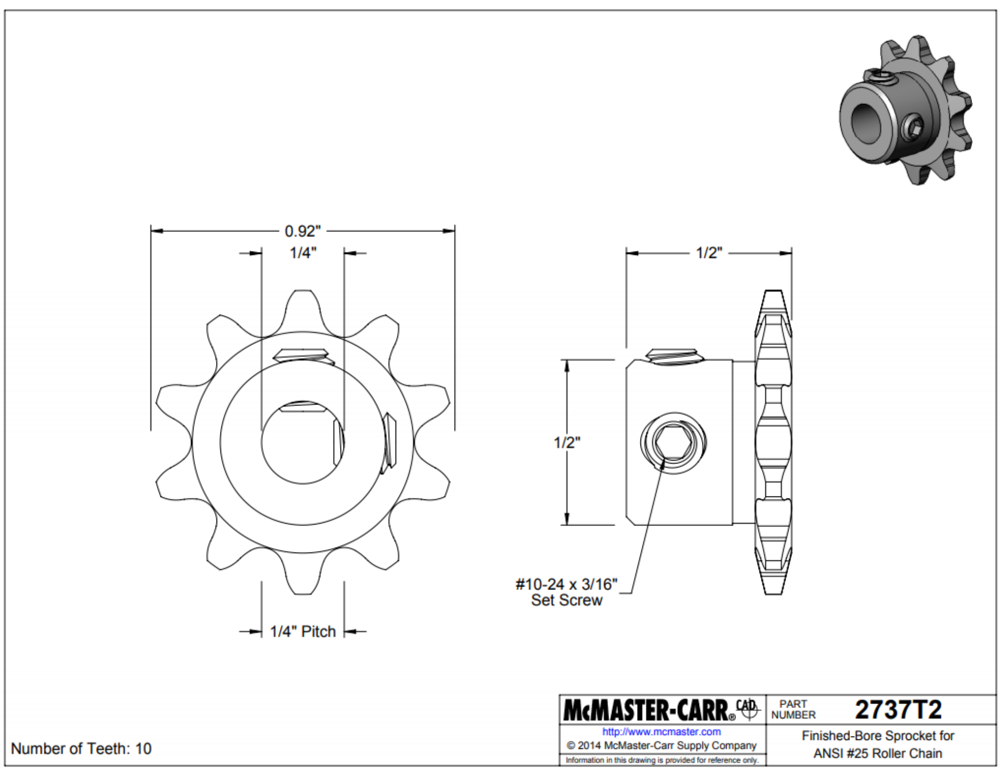
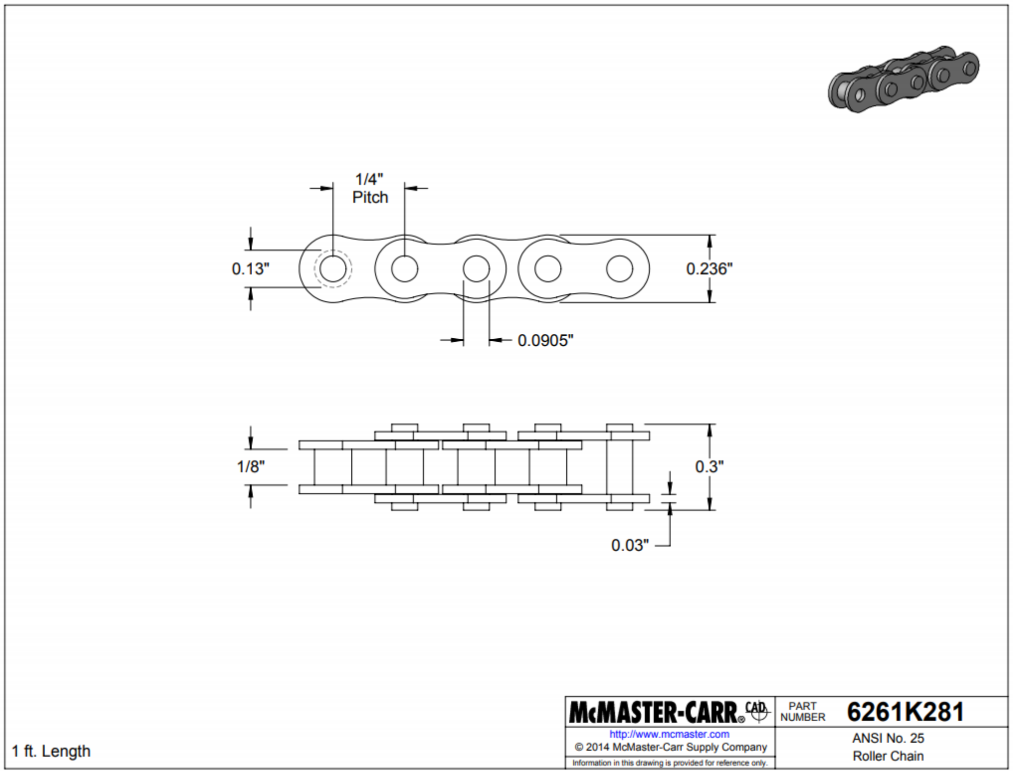
Information in this drawing is provided for reference only.
Ball Bearing


0.92"
1/4"
1/2"
1/2"
#10-24 x 3/16" Set Screw
1/4" Pitch
Number of Teeth: 10
McMASTER-CARR. CAD
PART NUMBER 2737T2
http://www.mcmaster.com
© 2014 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Finished-Bore Sprocket for ANSI #25 Roller Chain


1/4"
Pitch
0.13"
0.236"
0.0905"
1/8"
0.3"
0.03"
1 ft. Length
McMASTER-CARR CAD
PART NUMBER 6261K281
http://www.mcmaster.com
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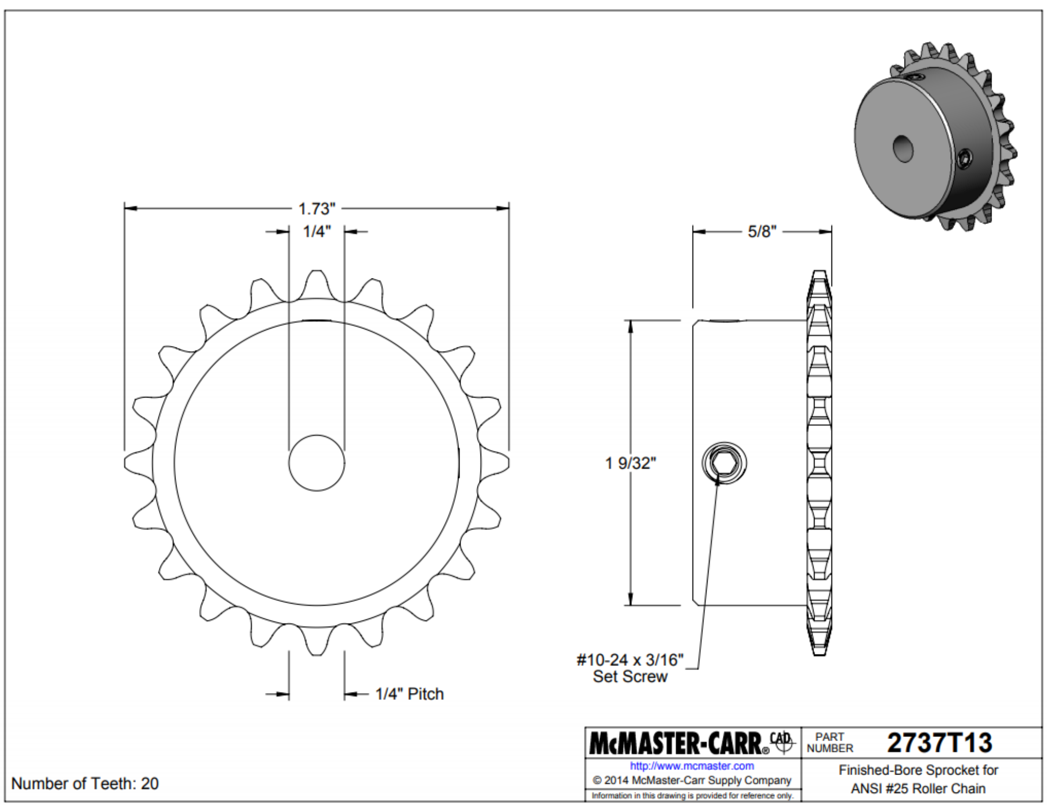
Information in this drawing is provided for reference only.
ANSI No. 25
Roller Chain


1.73"
1/4"
5/8"
1 9/32"
#10-24 x 3/16"
Set Screw
1/4" Pitch
Number of Teeth: 20
McMASTER-CARR CAD
PART NUMBER 2737T13
http://www.mcmaster.com
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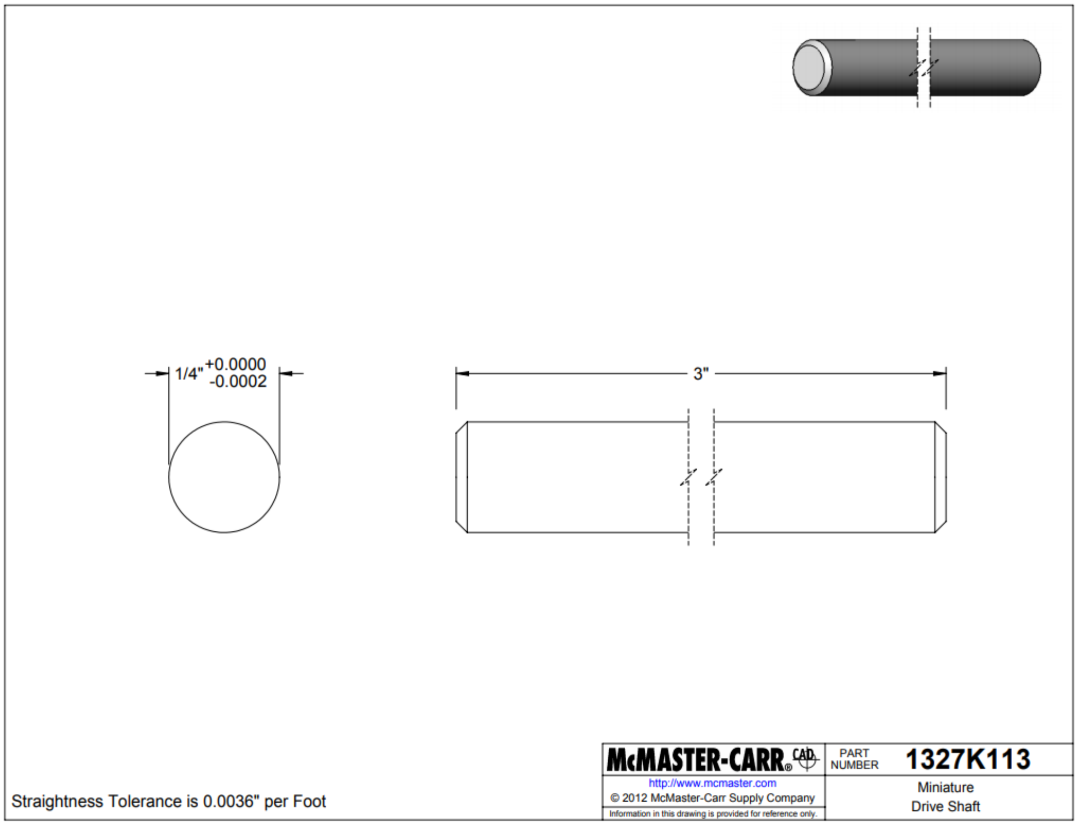
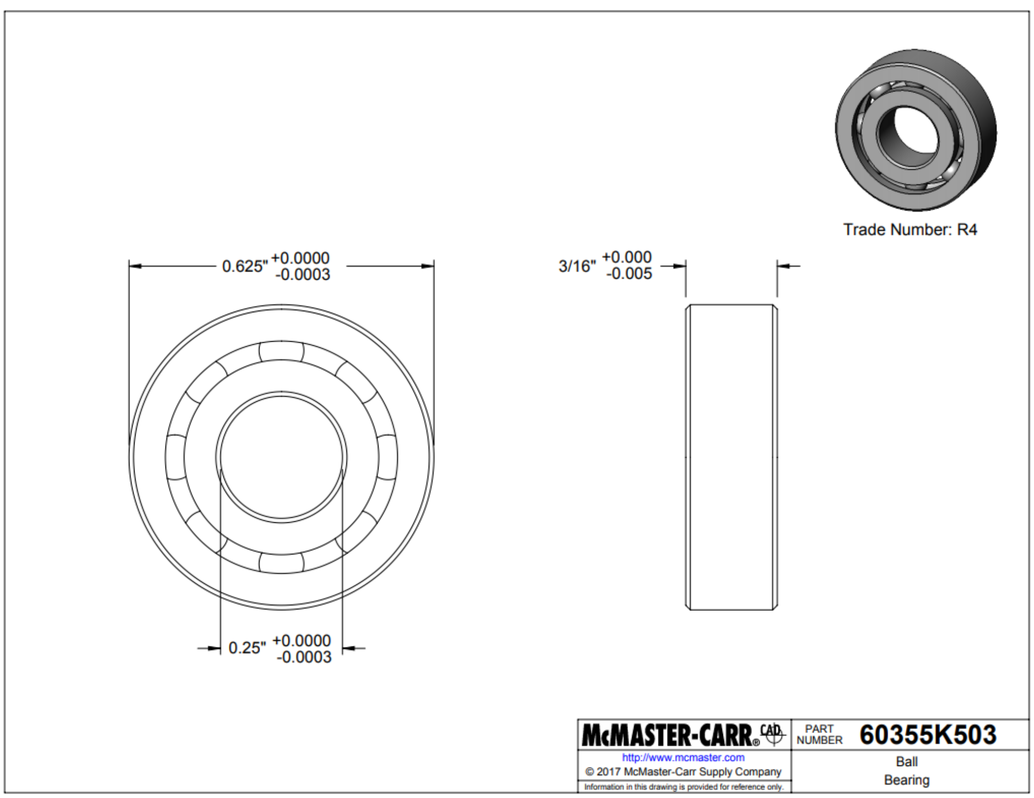
Information in this drawing is provided for reference only.
Finished-Bore Sprocket for
ANSI #25 Roller Chain



1/4" +0.0000 -0.0002
3"
Straightness Tolerance is 0.0036" per Foot
McMASTER-CARR CAD
http://www.mcmaster.com
© 2012 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
1327K113
Miniature Drive Shaft



Trade Number: R4
0.625" +0.0000 -0.0003
3/16" +0.000 -0.005
0.25" +0.0000 -0.0003
McMASTER-CARR CAD
http://www.mcmaster.com
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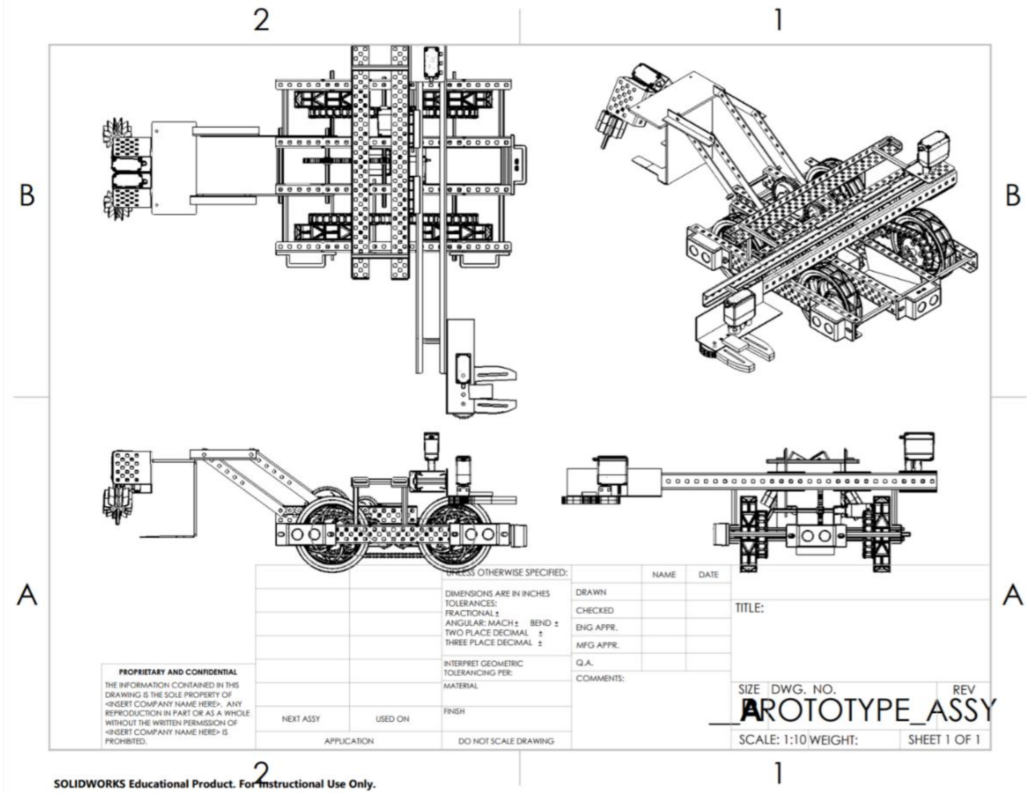
Information in this drawing is provided for reference only.
PART NUMBER
60355K503
Ball Bearing

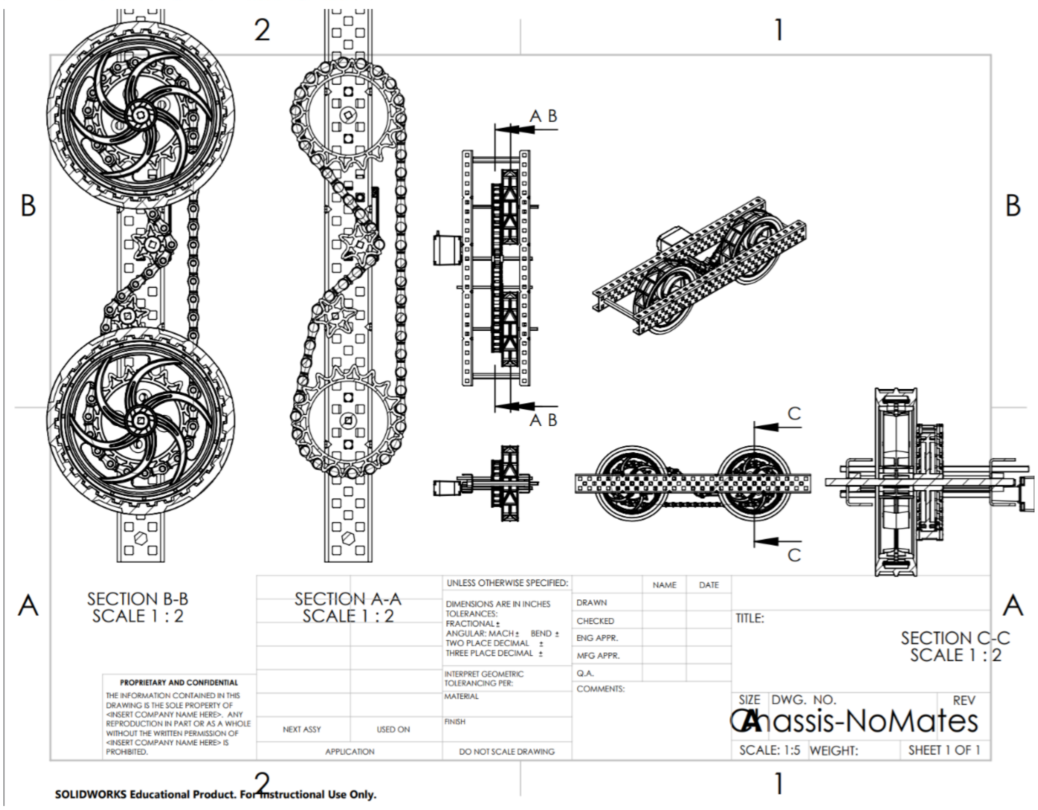
Prototype BOM

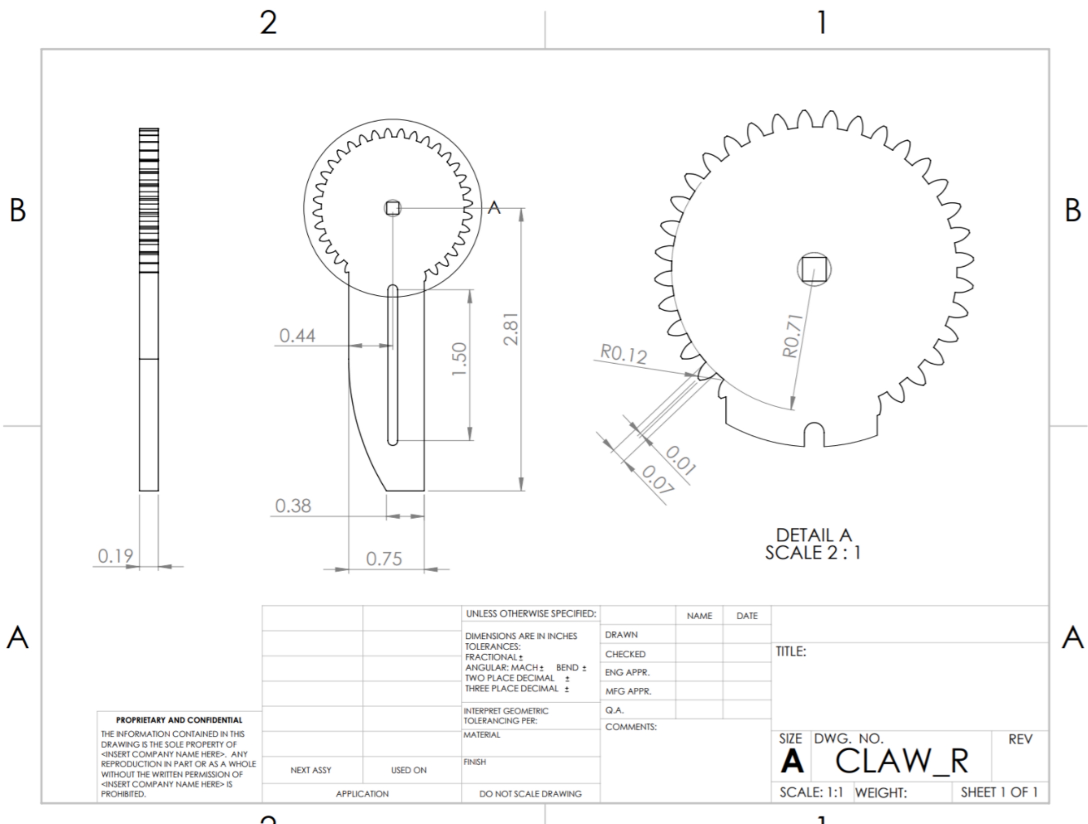
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	VL-CHAN-121-25 RevA	Chassis Structure	4
2	BEAM-3000	3" Standoff	10
3	BEARING-FLAT	Shaft Bearing	14
4	VEX-MEDIUM-WHEEL	4" Wheel	4
5	SHAFT-4000	4" Shaft	14
6	VEX-2WIRE-MOTOR	VEX DC Motor	6
7	sprocket-hs-06-tooth	6 tooth roller chain sprocket	4
8	sprocket-hs-18-tooth	18 tooth roller chain sprocket	4
9	chain-hs-link	Roller Chain Link	110
10	VL-RAIL-21-25 RevA	Liner Slide Rail	2
11	BEAM-2000	2" Standoff	4
12	276-1926-002 Rev1	Liner Slide Hardware	1
13	276-1926-004 Rev1	Liner Slide Hardware	3
14	276-1926-005 Rev1	Liner Slide Hardware	2
15	BEAM-1500	1.5" Standoff	2
16	Claw-Bracket	Bracket for claw	1
17	CLAW_L	Left Claw	2
18	CLAW_R	Right Claw	2
19	VEX-MOTOR	Vex Servo	1
20	magmount	mount for LSM303	1
21	VL-CHAN-121-15 RevA	Structure	2
22	VEX-12-TOOTH-GEAR	12 tooth gear	1
23	VEX-36-TOOTH-GEAR	36 tooth gear	1
24	VEX-60-TOOTH-GEAR	60 tooth gear	1
25	backForkLift	back of pyr intake	1
26	BottomForklift	bottom of pyr intake	1
27	Circles 5.5in Inch Shaft Bar	pyr linkage	4
28	Circles 3.5 inch Linkage	pyr linkage	1
29	topForkLift	top of pyr intake	1
30	VL-RACK-BRK RevA	Liner Slide Hardware	2
31	INTAKE-ROLLER	Pyr Hardware	4

32	Circles 3.5 inch Linkage-o	pyr linkage	1
33	rampCube	slide for cube	1
34	Ultrasonic_Range_Finder_276-2155	ultrasonic sensor	3
35	IR	IR Sensors	2
36	STM32F429ZI	Cortex M4 MCU	1
37	Daughter Board for MCU	Connect sensors and motors to MCU	1
38	Elastic Bands	stress relif of pyr intake	4
39	Limit Switches		3
40	Misc Hardware	Nuts and Bolts	...

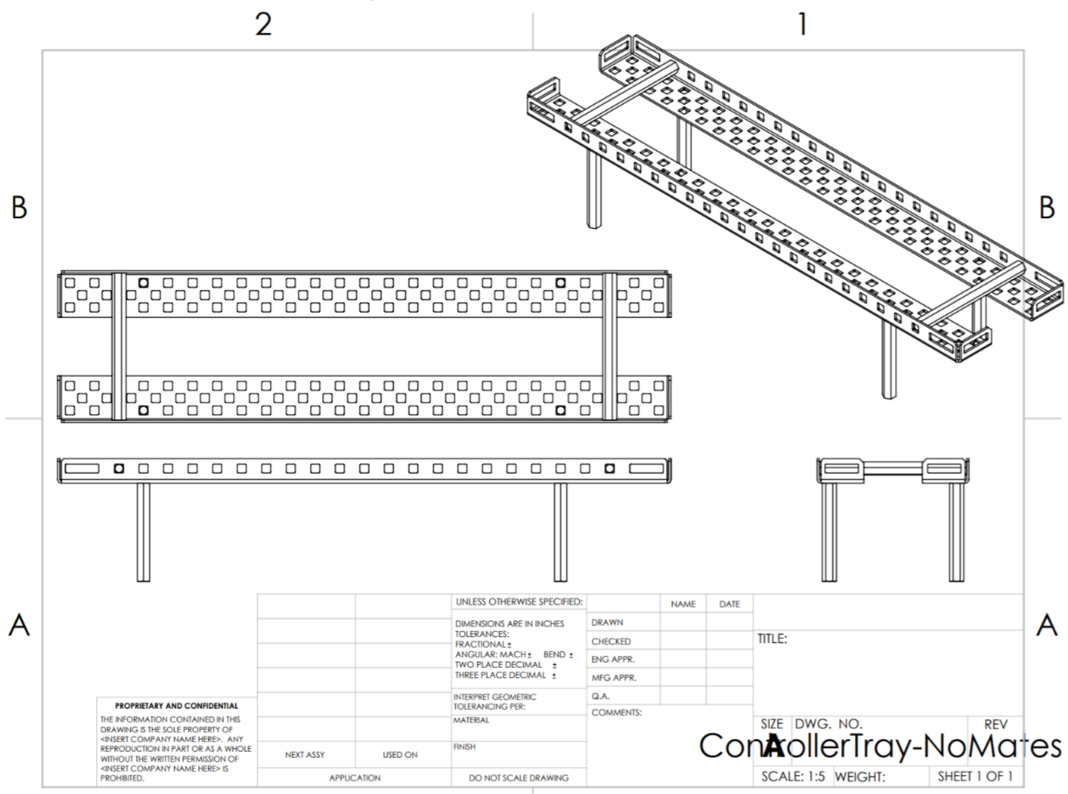
Prototype Technical Drawings







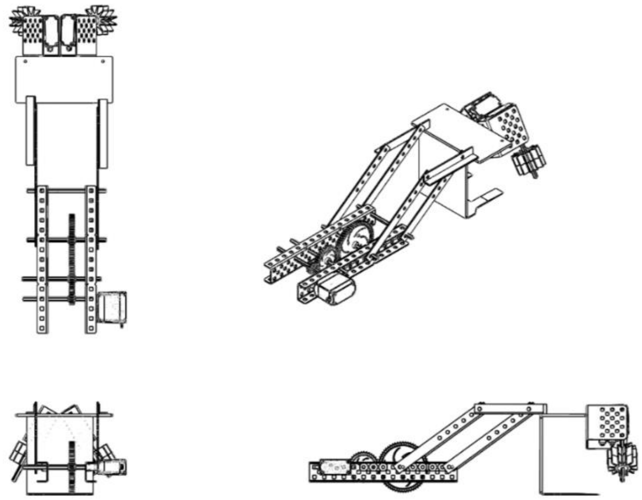
SOLIDWORKS Educational Product. For Instructional Use Only.



SOLIDWORKS Educational Product. For Instructional Use Only.

2 1

B B



A A

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

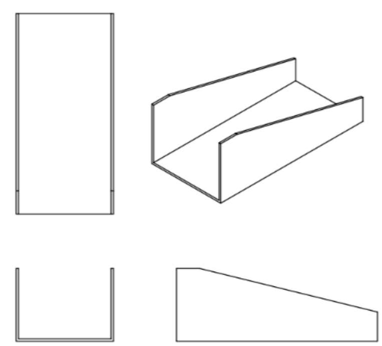
SIZE A | DWG. NO. LAtAssy-NoMates | REV

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

2 1

2 1

B B



A A

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE A | DWG. NO. ramp | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

2 1

Final Code

MSE-bot.h

```
//Main Class

//Compile Options and Reqs:
//  Board: Nucleo-64
//  Part Number: F446RE
//  Upload Method: STLink

#include <Wire.h>
#include <Stream.h>
#include <SPI.h>
#include <Servo.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_LSM303_U.h>
#include <math.h>

//pin assignments
#define LEFT_MOTOR              D10
#define RIGHT_MOTOR             D9

#define LR_ULTRASONIC_IN        A1
#define LR_ULTRASONIC_OUT       A0
#define LF_ULTRASONIC_IN        A3
#define LF_ULTRASONIC_OUT       A2
#define F_ULTRASONIC_IN         A5
#define F_ULTRASONIC_OUT        A4

#define CUBE_INTAKE_ARM         D12
#define CUBE_INTAKE_CLAW        D8
```

```
#define PYR_INTAKE_LIFT              D13
#define PYR_INTAKE_WHEELS            D3

//#define TARGET_PYR_SW              PB15
#define START_SW                     PC13
#define PYR_INTAKE_SW         PG0
#define LIFT_LIMIT_SW0               PB2   //upper switch for retracted position
#define LIFT_LIMIT_SW1               PB1   //lower switch for extended position

//Program Parameters
#define WALL_TARGET_DIST             13 * 58 // 11 cm * 58 = 638
#define WALL_TARGET_TOLERANCE        30 // 1cm
#define PARALLEL_TOLERANCE           60 // 1.5cm
#define TURN_THRESHOLD               600
#define SWERVE_DELAY                 2000
#define PING_MS                      10

#define FORWARD_SPEED_FAST           1800
#define REVERSE_SPEED_FAST           1200
#define FORWARD_SPEED_SLOW           1650
#define REVERSE_SPEED_SLOW           1350
#define STOP_VALUE                   1500

#define CUBE_MAG_GEN_THRESH          2000
#define CUBE_MAG_ACCURATE_THRESH     4500
#define IR_TIME_TOLERANCE            2000
#define CUBE_INTAKE_OPEN             65
#define CUBE_INTAKE_CLOSE            105


class MSEBot {
```

```
public:
  bool _speedMode = 1;

  unsigned int _LR_ultrasonic_dist;
  unsigned int _LF_ultrasonic_dist;
  unsigned int _F_ultrasonic_dist;
  unsigned int _LRecho;
  unsigned int _LFecho;
  unsigned int _Fecho;
  unsigned int _LastIRTime = 0;

  char _IRValues[4] = {'A', 'E', 'I', 'O'};
  bool _IRsw = 1; // 1 for AE, 0 for IO
  bool _ArmPosition = 0;
  bool _LiftPosition = 1;
  bool _TurnCount = 0; // counter for turn direction for finding pyramid

  int _compassHeading;
  int _compassMagnitude;

  sensors_event_t compassData;

  Servo _leftMotor;
  Servo _rightMotor;
  Servo _armMotor;
  Servo _clawMotor;
  Servo _liftMotor;
  Servo _intakeMotor;

  Adafruit_LSM303 AccelMag;
```

```
  public:
    void init();

    void findWall();
    void PingUltra();
    void PingFront();
    void TurnOnAxisL();
    void TurnOnAxisR();
    void goForward();
    void goReverse();
    void moveIn();
    void moveOut();
    void StopDrive();
    bool scanIRFocused();
    bool scanIRWide();
    bool hasPyramid();
    void readCompass();
    short checkForCube();
    void checkForPyramid();
    void parallelFollow();
    void scanField();
    void intakeOn();
    void placePyramid();
    void setSpeed(bool speed);
    void closeClaw();
    void openClaw();
    void moveArmIn();
    void moveArmOut();
    void moveLift(bool position);

};
```

MSE-bot.cpp

```
#include "MSE-Bot.h"


void MSEBot::init(){
  //Robot Initialization Function, Call this in setup() of the Arduino Sketch
  int initTime = millis();

  //Initialize Buses
  Serial.begin(9600);
  Serial7.begin(2400);    //UART7 for pyramid IR sensor
  Serial8.begin(2400);    //UART8 for front IR sensor
  Wire.begin();           //I2C1 for Compass and Accel
  Wire.setClock(400000);

  //Initialize GPIO Pins
  //pinMode(13, OUTPUT);
  pinMode(LR_ULTRASONIC_IN, OUTPUT);
  pinMode(LF_ULTRASONIC_IN, OUTPUT);
  pinMode(F_ULTRASONIC_IN, OUTPUT);
  pinMode(LR_ULTRASONIC_OUT, INPUT);
  pinMode(LF_ULTRASONIC_OUT, INPUT);
  pinMode(F_ULTRASONIC_OUT, INPUT);
  pinMode(LEFT_MOTOR, OUTPUT);
  pinMode(RIGHT_MOTOR, OUTPUT);
  pinMode(CUBE_INTAKE_ARM, OUTPUT);
  pinMode(CUBE_INTAKE_CLAW, OUTPUT);
  pinMode(PYR_INTAKE_LIFT, OUTPUT);
  pinMode(PYR_INTAKE_WHEELS, OUTPUT);
  pinMode(PYR_INTAKE_SW, INPUT);
  digitalWrite(PYR_INTAKE_SW, HIGH);
```

```
  pinMode(LIFT_LIMIT_SW0, INPUT);
  pinMode(LIFT_LIMIT_SW1, INPUT);
  pinMode(START_SW, INPUT);

  //Initialize Actuators
  _leftMotor.attach(LEFT_MOTOR);
  _rightMotor.attach(RIGHT_MOTOR);
  _armMotor.attach(CUBE_INTAKE_ARM);
  _clawMotor.attach(CUBE_INTAKE_CLAW);
  _liftMotor.attach(PYR_INTAKE_LIFT);
  _intakeMotor.attach(PYR_INTAKE_WHEELS);
  _clawMotor.write(CUBE_INTAKE_OPEN); // open position

  //Initialize Sensors
  AccelMag.begin();

  _liftMotor.writeMicroseconds(1600);
  Serial.print("Initialized in "); Serial.print(initTime-millis()); Serial.println("ms! Starting operation
on request!");

  //Wait for start button to be pressed
  while(!digitalRead(START_SW)) {}

  Serial.println("Starting...");

  //Initialize Intake Positions
  //moveLift(0); // up position
```

```
  /*
  digitalWrite(13, HIGH);
  digitalWrite(START_SW, HIGH);
  */



}

void MSEBot::PingUltra(){ // Ping ultrasonic sensors and record values in member variables
  digitalWrite(F_ULTRASONIC_IN, HIGH);
  delayMicroseconds(PING_MS);
  digitalWrite(F_ULTRASONIC_IN, LOW);
  _Fecho = pulseIn(F_ULTRASONIC_OUT, HIGH, 10000);
  if(_Fecho) _F_ultrasonic_dist = _Fecho;

  digitalWrite(LF_ULTRASONIC_IN, HIGH);
  delayMicroseconds(PING_MS);
  digitalWrite(LF_ULTRASONIC_IN, LOW);
  _LFecho = pulseIn(LF_ULTRASONIC_OUT, HIGH, 10000);
  if(_LFecho) _LF_ultrasonic_dist = _LFecho;

  digitalWrite(LR_ULTRASONIC_IN, HIGH);
  delayMicroseconds(PING_MS);
  digitalWrite(LR_ULTRASONIC_IN, LOW);
  _LRecho = pulseIn(LR_ULTRASONIC_OUT, HIGH, 10000);
  if(_LRecho) _LR_ultrasonic_dist = _LRecho;

  //Serial.print(" F: "); Serial.print(_F_ultrasonic_dist); Serial.print(" LF: ");
Serial.print(_LF_ultrasonic_dist); Serial.print(" LR: "); Serial.println(_LR_ultrasonic_dist);
}
```

```
void MSEBot::PingFront(){
    digitalWrite(F_ULTRASONIC_IN, HIGH);
  delayMicroseconds(PING_MS);
  digitalWrite(F_ULTRASONIC_IN, LOW);
  _Fecho = pulseIn(F_ULTRASONIC_OUT, HIGH, 10000);
  if(_Fecho) _F_ultrasonic_dist = _Fecho;
}

void MSEBot::TurnOnAxisL(){ // Set speeds for turning left
  if(_speedMode){
    _leftMotor.writeMicroseconds(FORWARD_SPEED_FAST);
    _rightMotor.writeMicroseconds(REVERSE_SPEED_FAST);
  }
  else{
    _leftMotor.writeMicroseconds(FORWARD_SPEED_SLOW);
    _rightMotor.writeMicroseconds(REVERSE_SPEED_SLOW);
  }
}

void MSEBot::TurnOnAxisR(){ // Set speeds for turning right
  if(_speedMode){
    _leftMotor.writeMicroseconds(REVERSE_SPEED_FAST);
    _rightMotor.writeMicroseconds(FORWARD_SPEED_FAST);
  }
  else{
    _leftMotor.writeMicroseconds(REVERSE_SPEED_SLOW);
    _rightMotor.writeMicroseconds(FORWARD_SPEED_SLOW);
  }
}
```

```
void MSEBot::StopDrive(){ // Set speeds to stop
  _leftMotor.writeMicroseconds(STOP_VALUE);
  _rightMotor.writeMicroseconds(STOP_VALUE);
}

void MSEBot::goForward(){ // Set speeds to go forward
  if(_speedMode){
    _leftMotor.writeMicroseconds(FORWARD_SPEED_FAST);
    _rightMotor.writeMicroseconds(FORWARD_SPEED_FAST);
  }
  else{
    _leftMotor.writeMicroseconds(FORWARD_SPEED_SLOW);
    _rightMotor.writeMicroseconds(FORWARD_SPEED_SLOW);
  }
  //Serial.println("Forward");
}

void MSEBot::goReverse(){ // Set values to go in reverse
  if(_speedMode){
    _leftMotor.writeMicroseconds(REVERSE_SPEED_FAST);
    _rightMotor.writeMicroseconds(REVERSE_SPEED_FAST);
  }
  else{
    _leftMotor.writeMicroseconds(REVERSE_SPEED_SLOW);
    _rightMotor.writeMicroseconds(REVERSE_SPEED_SLOW);
  }
    //Serial.println("Reverse");
}
```

```
void MSEBot::moveIn(){ // Move in towards right side
  if(_speedMode){
    _leftMotor.writeMicroseconds(STOP_VALUE);
    _rightMotor.writeMicroseconds(FORWARD_SPEED_FAST);
  }
  else{
    _leftMotor.writeMicroseconds(STOP_VALUE);
    _rightMotor.writeMicroseconds(FORWARD_SPEED_SLOW);
  }
    //Serial.println("in");
}

void MSEBot::moveOut(){ // Move out away from right side
  if(_speedMode){
    _leftMotor.writeMicroseconds(FORWARD_SPEED_FAST);
    _rightMotor.writeMicroseconds(STOP_VALUE);
  }
  else{
    _leftMotor.writeMicroseconds(FORWARD_SPEED_SLOW);
    _rightMotor.writeMicroseconds(STOP_VALUE);
  }
    //Serial.println("out");
}

void MSEBot::moveArmOut() {
  Serial.println("Moving Arm");
  _armMotor.writeMicroseconds(1100);
  delay(5000);
  _armMotor.writeMicroseconds(STOP_VALUE);
}
```

```
void MSEBot::moveArmIn() {
  Serial.println("Moving Arm");
  _armMotor.writeMicroseconds(1800);
  delay(5000);
  _armMotor.writeMicroseconds(STOP_VALUE);
}

void MSEBot::moveLift(bool position) {
  if(position) { // if we want lift down
    if(!_LiftPosition) { // if lift up
      //while(!digitalRead(LIFT_LIMIT_SW1)) {
        _liftMotor.writeMicroseconds(REVERSE_SPEED_SLOW); // move down until hits outer
switch
        delay(2000);
      _liftMotor.writeMicroseconds(STOP_VALUE);
      _LiftPosition = 1;
    }
  }
  else { // if we want lift retracted or up
    if(_LiftPosition) {
      //while(!digitalRead(LIFT_LIMIT_SW0)) {
        _liftMotor.writeMicroseconds(FORWARD_SPEED_SLOW); // move up until hits inner
switch
      delay(2000);
      _liftMotor.writeMicroseconds(STOP_VALUE);
      _LiftPosition = 0;
    }
  }
}
```

```
bool MSEBot::scanIRFocused(){ // Scan using rear shrouded IR
  char value = Serial7.read();
  int idx1, idx2;
  if(_IRsw){
    idx1 = 0;
    idx2 = 1;
  }
  else{
    idx1 = 2;
    idx2 = 3;
  }
  if(value == _IRValues[idx1] || value == _IRValues[idx2]){
  _LastIRTime = millis();
    return 1;
  }
  else{
    return 0;
  }
}

bool MSEBot::scanIRWide(){ // Scan using front unshrouded IR
  char value = Serial8.read();
  int idx1, idx2;
  if(_IRsw){
    idx1 = 0;
    idx2 = 1;
  }
  else{
    idx1 = 2;
```

```
    idx2 = 3;
  }
  if(value == _IRValues[idx1] || value == _IRValues[idx2]){
  _LastIRTime = millis();
    return 1;
  }
  else{
    return 0;
  }
}

bool MSEBot::hasPyramid(){ // Read if we have pyramid using limit switch
  return digitalRead(PYR_INTAKE_SW);
}

void MSEBot::readCompass(){ // Obtain magnetometer readings
  AccelMag.read();
  _compassMagnitude = sqrt(pow(AccelMag.magData.x, 2)+pow(AccelMag.magData.x,
2)+pow(AccelMag.magData.x, 2));
  //_compassHeading = atan2(AccelMag.magnetic.x, AccelMag.magnetic.y)*180/3.14159;
}

short MSEBot::checkForCube(){ // Compare magnetometer readings to see how close cube is
  readCompass();
  if(_compassMagnitude > CUBE_MAG_ACCURATE_THRESH) return 1;  //return 1 if the mag
field exceeds the threshold of the cube being held in the claw
  if(_compassMagnitude > CUBE_MAG_GEN_THRESH) return 2;       //return 2 if the mag field
exceeds the threshold of the cube being in the vicinity of the claw
  else return 0;                                              //return 0 if the cube is not near by
}
```

```
void MSEBot::checkForPyramid(){ // Checks previous instance of IR reading to see if robot is still pointing towards pyr
  while(_LastIRTime - millis() > IR_TIME_TOLERANCE) {
    scanIRFocused();
    TurnOnAxisL();
  }
}

void MSEBot::findWall(){
  PingUltra();
  goForward();
  while(_F_ultrasonic_dist > TURN_THRESHOLD) {
    PingUltra();
  }
  StopDrive();

}

void MSEBot::parallelFollow(){ // Follow walls at a set distace, parallel to wall, turn as necessary
  PingUltra();

  if(_F_ultrasonic_dist < TURN_THRESHOLD) {
    StopDrive();
    /*
    while(_LR_ultrasonic_dist > WALL_TARGET_DIST){ //Turn until Front Ultrasonic is measureing a large distance
    TurnOnAxisL();
    PingUltra();
    }
    */
```

```
    TurnOnAxisL();
    delay(100);
  }

  unsigned int parallel = abs(_LF_ultrasonic_dist - _LR_ultrasonic_dist);
 /* unsigned int distance = abs(_LF_ultrasonic_dist - WALL_TARGET_DIST);

  if(parallel < PARALLEL_TOLERANCE && distance < WALL_TARGET_TOLERANCE){
//Everything is fine and dandy
    goForward();
  }
  else if(_LF_ultrasonic_dist > PARALLEL_TOLERANCE + _LR_ultrasonic_dist){ //Distance is
ok, Robot is not parallel
    moveIn();
  }
  else if(_LF_ultrasonic_dist + PARALLEL_TOLERANCE < _LR_ultrasonic_dist){ //Distance is
ok, Robot is not parallel
    moveOut();
  }
*/
    if(parallel < PARALLEL_TOLERANCE){
    goForward();
  }
  else if(_LF_ultrasonic_dist > _LR_ultrasonic_dist){
    moveIn();
  }
  else{
    moveOut();
  }
}
```

void MSEBot::scanField() { // Swerve and scan field for pyramid as robot drives across it back andforth

```
TurnOnAxisL();

delay(300);

goForward();

delay(300);



/*
       if(scanIRWide()) {
         StopDrive();
         return;
        }
        PingUltra();
  if(_F_ultrasonic_dist < 3 * TURN_THRESHOLD) { // turn at walls
    if(_TurnCount) {
      TurnOnAxisR();
      unsigned long triggerTime= millis(); // turn 160 degrees
      while(millis() - triggerTime < 3000) {
        if(scanIRWide()) {
          StopDrive();
          return;
        }
        if(scanIRWide()) {
          StopDrive();
          return;
        }
        if(scanIRWide()) {
          StopDrive();
          return;
```

```
      }
    }
    _TurnCount = 0;
  }
  else {
    TurnOnAxisL();
    unsigned long triggerTime= millis(); // turn 160 degrees
    while(millis() - triggerTime < 3000) {
      if(scanIRWide()) {
       StopDrive();
        return;
      }
      if(scanIRWide()) {
        StopDrive();
        return;
      }
      if(scanIRWide()) {
        StopDrive();
        return;
      }
    }
    _TurnCount = 0;
  }
}

if(scanIRWide()) {
        StopDrive();
        return;
      }
```

```
  if((int)(millis() / SWERVE_DELAY) % 2) { // alternate between swerving left and right in real
time
    _leftMotor.writeMicroseconds(FORWARD_SPEED_FAST);
    _rightMotor.writeMicroseconds(FORWARD_SPEED_FAST);
  }
  else {
    _leftMotor.writeMicroseconds(FORWARD_SPEED_FAST);
    _rightMotor.writeMicroseconds(FORWARD_SPEED_FAST);
  }

  if(scanIRWide()) {
        StopDrive();
        return;
      }
      */
}

void MSEBot::intakeOn() { // get intake in position for retrieving pyramid
  _intakeMotor.writeMicroseconds(REVERSE_SPEED_FAST);
  moveLift(1);
}

void MSEBot::placePyramid() { // routine for putting cube in pyramid
  _intakeMotor.writeMicroseconds(STOP_VALUE);
  delay(1000);
  moveLift(0);
  openClaw(); // drop cube into funnel
  delay(1000);
  goReverse(); // back up a bit
  delay(2000); // test this value so cube under pyr
```

```
  StopDrive();
  delay(1000);
  moveLift(1);
  delay(1000);
  goReverse();
  _intakeMotor.writeMicroseconds(FORWARD_SPEED_FAST); // push pyramid back out with cube underneath
  delay(2000);
  StopDrive();
}

void MSEBot::setSpeed(bool speed){
  if(speed){ //speed == 1: FAST
    _speedMode = 1;
  }
  else{ //speed == 0: SLOW
    _speedMode = 0;
  }
}

void MSEBot::closeClaw(){ // close claw
  _clawMotor.write(CUBE_INTAKE_CLOSE);
}

void MSEBot::openClaw(){ // OPEN CLAW
  _clawMotor.write(CUBE_INTAKE_OPEN);
}
```

Main.ino

```
#include "MSE-bot.h"

MSEBot Robot;


void setup() {

  Robot.init();

  Robot.moveLift(1);

  Robot.moveArmOut();

  Robot.openClaw();

  Robot.findWall();

}


void loop() {

  bool hasCube= 0;

  bool hasPyr= 0;


   while (!hasCube) { //Loop until robot finds the cube

        Robot.parallelFollow(); // Follows walls of arena and scans for cube

         Robot.readCompass();

         Serial.println(Robot._compassMagnitude);

            if (Robot._compassMagnitude> 5000) { // Finds cube within gripping distance

              delay(500);

              Robot.StopDrive();

              delay(1000);

                Robot.closeClaw(); // Pulls cube into robot

                delay(500);

                Robot.moveArmIn();

                hasCube = 1;

                break;

            }
```

```
    }
    while(!hasPyr){
bool focused, wide;

    //Loop until finds the pyramid
    while(!wide || !focused) {
      wide = Robot.scanIRWide();
      focused = Robot.scanIRFocused();

      Robot.TurnOnAxisL();
      delay(300);
      Robot.goForward();
      delay(300);

      if(focused){
        Robot.intakeOn();
        delay(100);
        Robot.goForward();
        delay(500);
        Robot.StopDrive();
        Robot.moveLift(0);
        Robot.openClaw();
      }
      if(wide){
        Robot.TurnOnAxisL();
        delay(7500);
        Robot.intakeOn();
        delay(100);
        Robot.goForward();
        delay(500);
```

```
    Robot.StopDrive();
    Robot.moveLift(0);
    delay(100);
            Robot.openClaw();

  }



}

Robot.StopDrive();



// Slowly pinpoint pyramid with shrouded IR
while(!Robot.scanIRFocused()) {
  if(Robot.scanIRFocused()){
      break;
    }
    Robot.TurnOnAxisL();
    if(Robot.scanIRFocused()){
      break;
    }
    if(Robot.scanIRFocused()){
      break;
    }
}

Robot.StopDrive();
Robot.intakeOn();
```

```
    delay(500);

    // Push into pyramid with intake until it's in the intake
    while(!Robot.hasPyramid()){
      Robot.goForward();
      delay(10000);
      break;
    }

    Robot.placePyramid();

    }
/*   */
}
```

Product Evaluation

The performance of the prototype and the product can not be equated as many of the factors that negatively affected the performance of the prototype will not be present in the actual product. This is because in spite of our best efforts several aspects of the product were not accurately replicated and represented on the prototype. For example the motors used on the prototype are much weaker that those used of the product. The motors are also bulkier which limit the space on the robot. The wheels on the prototype are also poor representations of those that were selected for the product. The 4” rubber wheels being used on the product are soft and offer much more traction than the VEX wheels used on the prototype, even with the added traction from the racket grip tape.

Most of the components of the prototype functioned individually. However, our prototype had difficulty locating the correct pyramid. Testing various components and mechanisms on the robot showed that the mechanical design of the prototype was functional. Unfortunately, problems with the code and the IR sensors used resulted in inconsistent results when the robot was navigating the course.

Overall, spending more time debugging and refining the code would allow the prototype to function as intended.

The final product designed meets most but unfortunately not all of the design requirements specified by the group. The rubber wheels would allow for effective navigation of the field, however the large turn radius due to the larger size of the robot and the 4 wheel drive results in wide turns around the corners of the course which would cause the tesseract to be missed if it was placed close to a corner. The cube is picked up and held on to firmly by the claws designed due to the addition of the grip material as required by the specifications stated at the beginning of the project. Finally, the intake used for the pyramid was proven to be able to pick up the pyramid from different angles as long as the bottom of the forklift intake is at a 10 degree incline and the intake is free to open up more when the pyramid is being picked up from it’s wide side. The addition of the elastics to the intake also allows the wheels to apply enough force to the pyramid to intake it when it is being picked up from its thinner side. Finally, the product might take longer than three minutes to complete the task depending on the location of the pyramid due to the fact that the IR sensors have around a 2 ft effective range so the robot must navigate the field looking for them.

To ensure that the product is consistently meeting all requirements when in the field, the code must be refined to include safety checks in case a step is not completed properly. Aspects of the code must also be debugged to ensure that locating the correct pyramid is done is consistently, no matter the location of the pyramid.

Cost of External Parts sourced for Prototype

Name	Sourced from	Cost	Quantity	Total Cost	Receipt/ Proof of sale
Microcontroller (STM32 F429ZI)	ST Microelectronics	25	1	25	Contated ST Sales office
Tennis Racket Grips (Head Hydrosorb)	Sport Check	11.99	1	11.99	Receipt
Tennis Racket Overgrip (Wilson Pro)	Sport Check	7.99	1	7.99	Reciept
1/2 inch aluminum L braket	Home Depot	6.48	1	6.48	Screenshot
1 inch aluminum L braket	Home Depot	10.58	1	10.58	Screenshot
Magenetometer	DigiKey	20.33	1	20.33	Receipt
Nuts and bolts	Home Depot	10.48	1	10.48	Receipt
Total				92.85	

Figure 51: Prototype Cost Breakdown

Sourcing of External Parts

Part Category	Chosen?	Part	Part Manufacturer	Currently on hand	Source	Source SKU	Value	Price Paid	CAD/USD	Specs:
Main Controller	1x	STM32 F429ZI	ST Microelectronics	yes	ST Sales rep	497-16280-ND	$25.00	$0.00	USD	ARM®32-bit Cortex®-M4 CPU with FPU, 180 MHz
	0x	STM32 F446RE	ST Microelectronics	yes	ST Sales rep		15	0		ARM®32-bit Cortex®-M4 CPU with FPU, 180 MHz
	0x	Arduino Mega 2560	Atmel	yes			20			16 MHz
Secondary Controller?	0x	MSE Duino	Atmel	yes						16 MHz
Drive Motors	5x	Vex Integrated Encoder	...							
Stepper Motors	0x	Stepper	Adafruit Industries LLC	no	Digikey	1528-1062-ND	14	14	USD	1.645"x1.645", 330mA, 12V, 1.8deg stepper, Driver needed
Servo Motors	1x	Vex Servo	...							
Magnetic Sensors	0x	STEVAL-MKI181V1	ST Microelectronics	in transit	ST Sales rep		?	0		
	1x	LSM303	Adafruit Industries LLC	yes	Digikey	1528-1173-ND	20.53	20.53	CAD	
	0x	MAG3110	Sparkfun	yes	Digikey	1568-1030-ND	20.53	20.53	cad	
Photosensitive Sensors	2x	The IR one they give us		yes	naish		0	0		
Ultrasonic Sensors	3x	The VEX one they give us		yes	naish		0	0		
Arduino WiFi shield	0x	EXP8266		no	sparkfun	WRL-13678		7		
Misc Hardware	...	1.5" Standoffs		no						
Suction Cup	0x			no			10			
Suction Cpu Vaccum Pump	0x			no			3			
Sensor Moduled	0x					1528-1173-ND	15		USD	

Figure 52: External Parts Sourcing

Receipts

701 Brooks Ave South,
PO Box 677
Thief River Falls, MN 56701-0677

www.digikey.ca
Orders 1-800-344-4539
Fax 218-681-3380

Invoice # 61915590
Completed Salesorder CANADIAN $

Bill To:
ANDREW RANDELL
1140 WESTERN RD
351B LONDON HALL
LONDON ON N6G0A3
CANADA

Ship To:
ANDREW RANDELL
1140 WESTERN RD
351B LONDON HALL
LONDON ON N6G0A3
CANADA

Buyer:
ANDREW RANDELL
534 SANDBANKS CRESCEMT
WATERLOO ON N2V2K2
CANADA

Ship From:
DIGI-KEY
701 BROOKS AVE. SOUTH
P.O. BOX 677
THIEF RIVER FALLS MN 56701-0677

Salesorder / Packlist:	54121411 / PL1
Customer:	10773995
Payment Terms:	AMER EXPRESS / 2002
Shipping Method:	XF1D
Tracking #:	430759290844
Order Source:	INTERNET
Order Date:	16-Mar-2018
Invoice Date:	19-Mar-2018
Ship Date:	19-Mar-2018
Document Date:	19-Mar-2018/AUTO

Line Item	Ordered	Cancelled	Shipped	Item Number/ Description	Unit Price CANADIAN $	Amount CANADIAN $
1	1	0	1	**PART:** 1528-1173-ND **DESC:** BOARD ACCEL/COMPASS 3AXIS LSM303 **COO :** UNITED STATES **ECCN:** EAR99 **HTSUS:** 8473.30.1180 LEAD FREE ROHS COMP REACH UNKNOWN **Mercury:** Cert on File. For more information contact RoHS@DigiKey.com	20.53000	20.53 T
2	1	0	1	**PART:** 1568-1030-ND **DESC:** EVAL BOARD FOR MAG3110 **COO :** UNITED STATES **ECCN:** EAR99 **HTSUS:** 8473.30.1180 LEAD FREE ROHS COMP REACH UNKNOWN **Mercury:** Cert on File. For more information contact RoHS@DigiKey.com	20.53000	20.53 T
3	1	0	1	**PART:** 1528-1223-ND **DESC:** ESP8266 HUZZAH BREAKOUT BOARD **COO :** CHINA **ECCN:** 5A992C **HTSUS:** 8473.30.1180 LEAD FREE ROHS COMP REACH UNKNOWN **Mercury:** Cert on File. For more information contact RoHS@DigiKey.com	13.66000	13.66 T

Total Invoiced	54.72
Shipping charges applied	8.00
** Charges subtotal **	62.72
HST on taxable amount: 54.72 Tax Rate: 13.00	7.11
Total charged to credit card	69.83

CANADIAN $
Incoterm 2010: DDP LONDON, ON, CANADA
T indicates taxable amounts

* One or more items on this order are controlled for export.
* NO EEI 30.36
* These items are controlled by the U.S. Government and authorized for export only to the country of ultimate destination for use by the ultimate consignee or end-user(s) herein identified. They may not be resold, transferred, or otherwise disposed of, to any other country or to any person other than the authorized ultimate consignee or end-user(s), either in their original form or after being incorporated into other items, without first obtaining approval from the U.S. Government or as otherwise authorized by U.S. law and regulations.

Box(es):

1	**XIPR**	**430759290844**	**0.17 kg / 6 oz**
	1	1528-1173-ND	
			Continued...
	1	1568-1030-ND	
	1	1528-1223-ND	

Claims for pricing errors, shortages, and defective product must be reported within 30 days of invoice date.
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PO Box 677
Thief River Falls, MN 56701-0677

www.digikey.ca
Orders 1-800-344-4539
Fax 218-681-3380

Invoice # 61915590
Completed Salesorder CANADIAN $

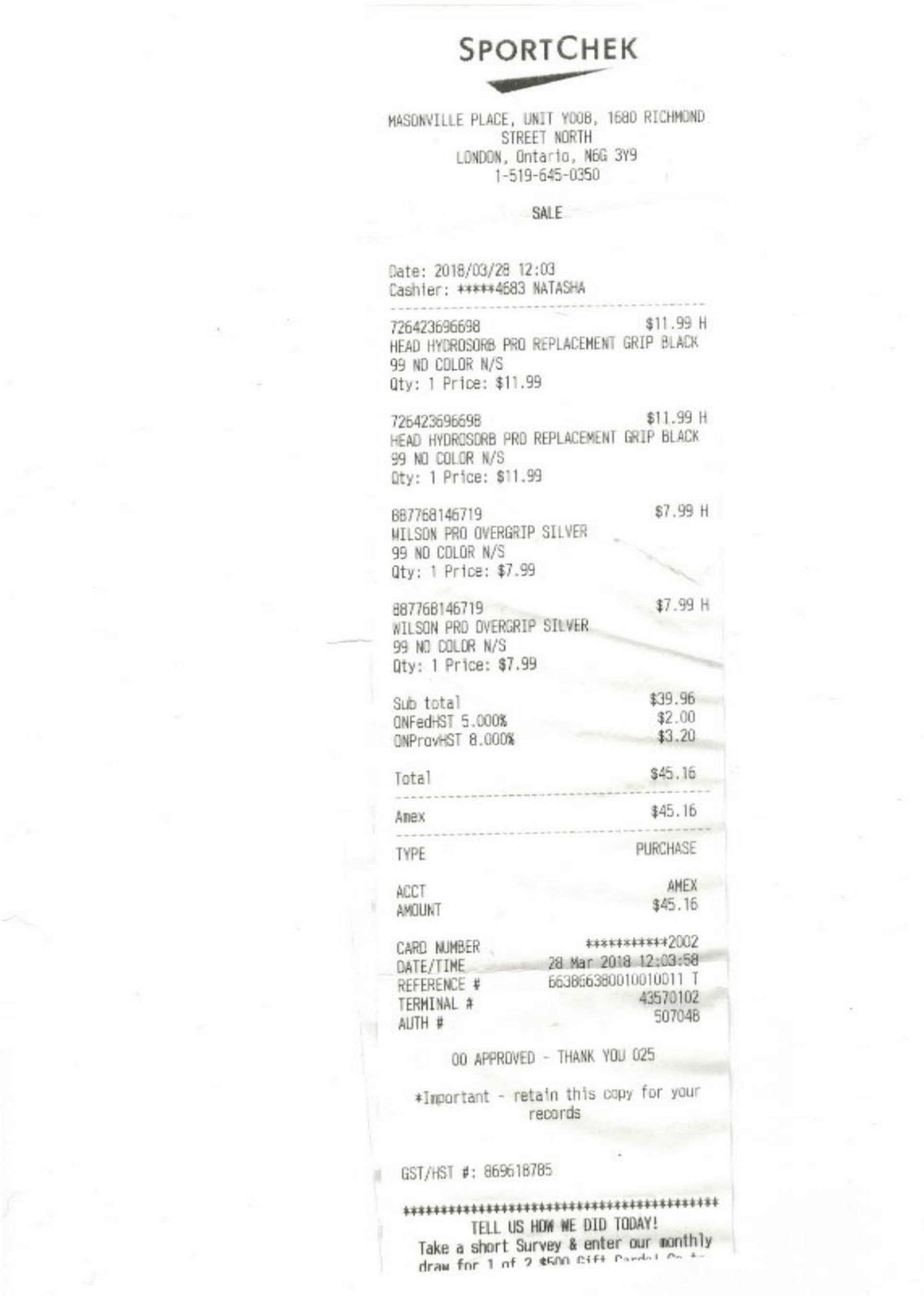
General - WEB ORDER ID: 187457872
CUSTOMER 10773995 INDICATED THAT PRODUCT WILL NOT BE EXPORTED OUTSIDE OF CANADA. A0FX

CERTIFICATE OF COMPLIANCE:
The Digi-Key components included in the above shipment are genuine components and were provided by the applicable manufacturer to Digi-Key. Test reports (chemical, physical, electrical, etc., together with results of any tests performed by the manufacturer) are on file (either here or in the plant of the manufacturer) and will be made available upon request. These components have been handled in accordance with the requirements of applicable quality standards. This certification is valid only to the original customer and is not transferable. Contact Customer Service at 800-858-3616 if you have any questions.

Kim Gilbert

Kim Gilbert, Director, Customer Service

Figure 53: Digikey Receipt



SPORTCHEK

MASONVILLE PLACE, UNIT Y00B, 1680 RICHMOND
STREET NORTH
LONDON, Ontario, N6G 3Y9
1-519-645-0350

SALE

Date: 2018/03/28 12:03
Cashier: *****4683 NATASHA

726423696698 $11.99 H
HEAD HYDROSORB PRO REPLACEMENT GRIP BLACK
99 NO COLOR N/S
Qty: 1 Price: $11.99

726423696698 $11.99 H
HEAD HYDROSORB PRO REPLACEMENT GRIP BLACK
99 NO COLOR N/S
Qty: 1 Price: $11.99

887768146719 $7.99 H
WILSON PRO OVERGRIP SILVER
99 NO COLOR N/S
Qty: 1 Price: $7.99

887768146719 $7.99 H
WILSON PRO OVERGRIP SILVER
99 NO COLOR N/S
Qty: 1 Price: $7.99

Sub total	$39.96
ONFedHST 5.000%	$2.00
ONProvHST 8.000%	$3.20
Total	$45.16
Amex	$45.16
TYPE	PURCHASE
ACCT	AMEX
AMOUNT	$45.16
CARD NUMBER	***********2002
DATE/TIME	28 Mar 2018 12:03:58
REFERENCE #	663866380010010011 T
TERMINAL #	43570102
AUTH #	507048

00 APPROVED - THANK YOU 025

*Important - retain this copy for your records

GST/HST #: 869618785

****
TELL US HOW WE DID TODAY!
Take a short Survey & enter our monthly

Figure 53: SportsChek Receipt

More saving.
More doing.

600 Fanshawe Park E., N. London, ONT
KATHLEEN FAULKNER 519-850-5900

7009 00057 87015 03/04/18 12:45 PM
SELF CHECK OUT

771878737113	PAPC 1/16X1X <A>	10.48
771878737670	PAPC 1/16X3/ <A>	12.46
	SUBTOTAL	22.94
	GST/HST	2.98
	TOTAL	$25.92
XXXXXXXXXXXX9050	DEBIT	
		CAD$ 25.92

AUTH CODE 153012
Chip Read — Verified By PIN
AID A0000002771010 — Interac
TVR 0280008000
IAD 1504850400A10000040094000400000000000
000000
TSI F800
ARC 00

7009 57 87015 03/04/2018 0305

13% HST R135772911

RETURN POLICY DEFINITIONS

POLICY ID		DAYS	POLICY EXPIRES ON
A	1	90	02/07/2018

THE HOME DEPOT RESERVES THE RIGHT TO LIMIT / DENY RETURNS. PLEASE SEE THE RETURN POLICY SIGN IN STORES FOR DETAILS.

KEEP YOUR RECEIPT FOR FASTER RETURNS
SHOP ONLINE AT WWW.HOMEDEPOT.CA
More saving. More Doing.
****

ENTER FOR A CHANCE TO WIN A $3,000 HOME DEPOT GIFT CARD!

Tell us about your store visit! Complete our short survey and enter for a chance to win at:

www.homedepot.com/survey

You will need the following to enter on-line:

User ID:
2PX2 181328 174376

Password:
18203 174319

Entries must be completed within 14 days of purchase. Entrants must be 18 or older to enter. See complete rules on website. No purchase necessary.

(Le sondage est également offert en français sur le Web.)

Figure 53: Home Depot Receipt