CyberTooth robotics team

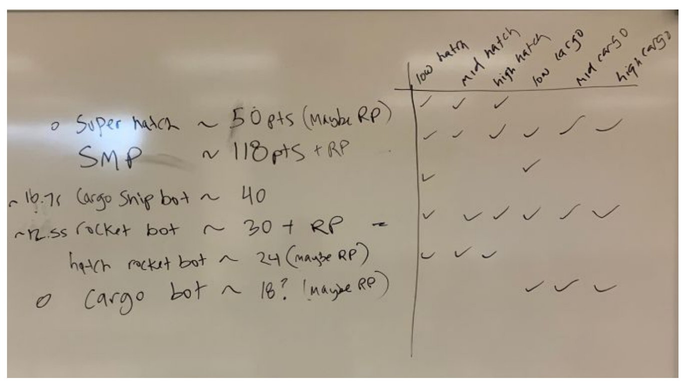
2019 Engineering Process

CyberTooth Build Process

Build Timeline: CyberTooth uses a strategic design process to plan out the whole robot before final fabrication. Below are the basic steps the team goes through during the build and competition season.

Kickoff: On kickoff the team gets together to watch the game reveal. The team refrains from designing robot mechanisms at this point, and takes the rest of the day to read and comprehend the rules.

Game Analysis: The team uses the game and scoring rules to figure out all of the possible ways to score points and does some math to figure out details like maximum scoring potential.



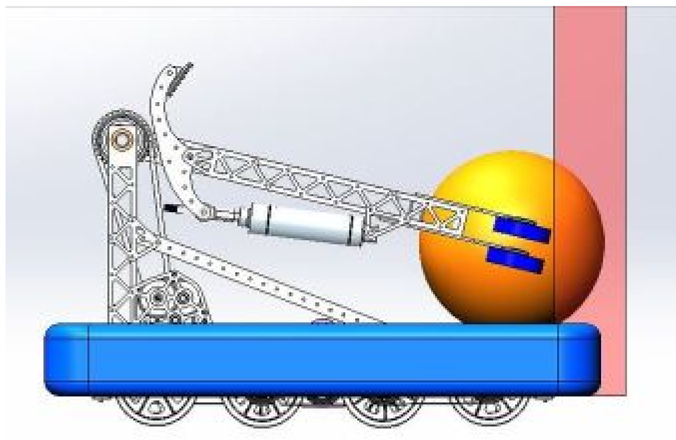
Priority List: After game analysis, the team comes up with a list of robot actions and their priority for the year. This list is based on logic based discussions with the goal of competing the game challenge, and performing well at our events.

Priority List 2019		
	PA= Programming Assisted	
1	Drive	☑
2	Drive off hab 1	☑
3	Blind Drive off Hab 1	☑
4	Get on Hab 1	☑
5	Get on Hab 3	☑
6	Retrieve Panel from HP	☑
7	Hold Panel Securely	☑

Robot in a Sentence: The team understands that in order to have an effective robot - the robot likely will not be able to do every possible task we've defined on the list. The robot in a sentence helps define what the CyberTooth robot will do for the year and what tasks are likely not going to be a part of the robot.

Prototyping: After the robot and priorities are defined, the team splits into groups based on individual robot mechanisms and start brainstorming solutions to the design challenge. CyberTooth prototyping is done in a number of ways from cardboard mock-ups to rough CAD sketches to working mechanisms. Each group tries a variety of different designs before settling on a solution.

CAD: All parts of the robot are put into CAD where a mass system integration takes place. If a specific design must be compromised in order to fit with the other mechanisms, the design may need to go back for more prototyping. Once a design is complete, the parts will either have prints made or be prepared for CNC equipment. Additional parts are purchased as well.



Fabrication: CyberTooth has the use of an in-house router and CNC mill. Additionally, a manual mill and lathe are used for other part fabrication. Each part designed in CAD has its own unique part number to help keep track of inventory and application. The final step in fabrication for most of the aluminum parts is purple powder coating.

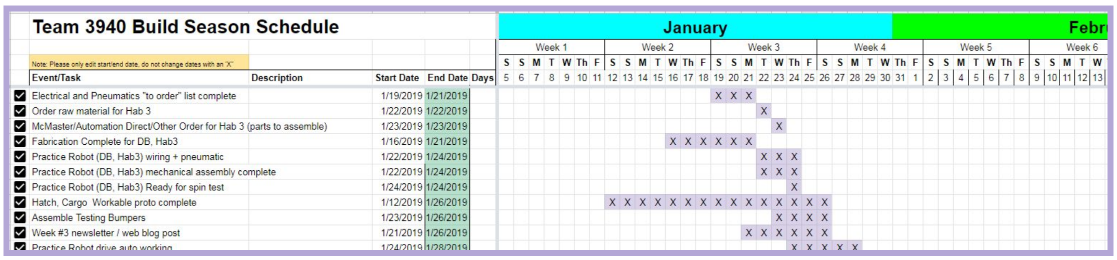
Assembly: After parts are fabricated the team assembles them into the final robot. Additional exploded view prints, or assembly guides may be used in order to ensure everyone knows how the parts fit together.

Testing: It is important that there is time left for programming and testing each mechanism. The team needs to make sure that each item functions as intended. It's helpful at this point to use the priority list as a guide as to which mechanisms are the most important to get working first.

Competition: The robot is finalized and ready for competition. During the event repairs and changes may take place in order to optimize performance on the playing field, but unless something catastrophically breaks or needs changing most of the design will stay the same.

Review: After each competition a review will take place to assess the "pluses and deltas" of each event. From here the team can make a plan to prepare for the next competition, which may involve taking a mechanism all the way back to the prototyping stage.

Specific Timeline: One of the main issues identified in previous seasons was not finishing the robot on time. This year, prior to the season we made very aggressive timeline goals and kept track of them via a Gantt Chart (Appendix A).



	Team 3940 Build Season Schedule					January																											Febr												
						Week 1							Week 2							Week 3							Week 4							Week 5							Week 6				
	Note: Please only edit start/end date, do not change dates with an "X"					S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W
	Event/Task	Description	Start Date	End Date	Days	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13
☑	Electrical and Pneumatics "to order" list complete		1/19/2019	1/21/2019																X	X	X																							
☑	Order raw material for Hab 3		1/22/2019	1/22/2019																			X																						
☑	McMaster/Automation Direct/Other Order for Hab 3 (parts to assemble)		1/23/2019	1/23/2019																				X																					
☑	Fabrication Complete for DB, Hab3		1/16/2019	1/21/2019													X	X	X	X	X	X																							
☑	Practice Robot (DB, Hab3) wiring + pneumatic		1/22/2019	1/24/2019																			X	X	X																				
☑	Practice Robot (DB, Hab3) mechanical assembly complete		1/22/2019	1/24/2019																			X	X	X																				
☑	Practice Robot (DB, Hab3) Ready for spin test		1/24/2019	1/24/2019																					X																				
☑	Hatch, Cargo Workable proto complete		1/12/2019	1/26/2019									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																		
☑	Assemble Testing Bumpers		1/23/2019	1/26/2019																				X	X	X	X																		
☑	Week #3 newsletter / web blog post		1/21/2019	1/26/2019																		X	X	X	X	X	X																		
☑	Practice Robot drive auto working		1/24/2019	1/28/2019																					X	X	X	X	X																

This spreadsheet was a tool that we looked at during the start of each meeting to see what tasks could be worked on and to keep track of deadlines.

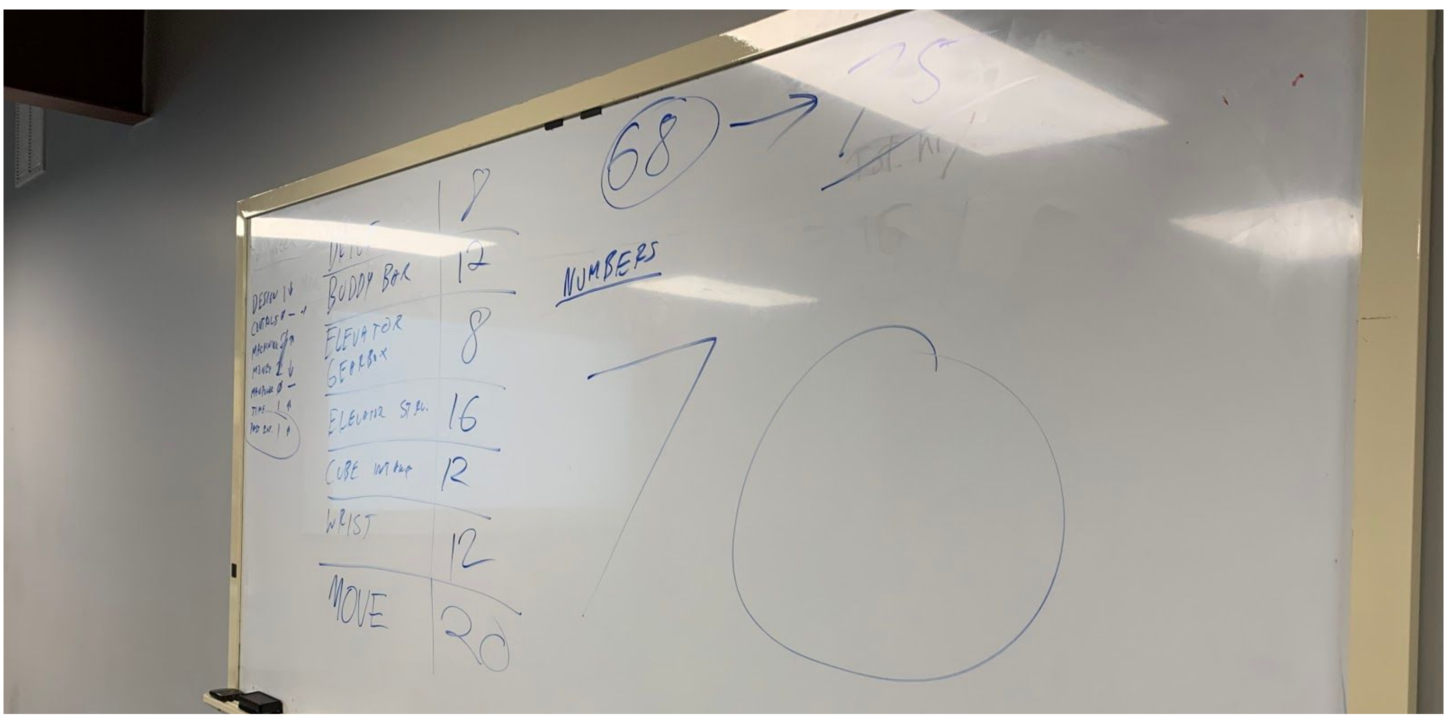
Resource Tokens: CyberTooth uses the concept of resource tokens to help balance robot build aspirations and team resources. Resource tokens are a unitless number to measure our ability to “do the thing” based on team abilities such as:

- Available student time
- Available mentor time
- Machining capabilities,
- Financial assets
- Design and Controls skills and talent
- Previous experiences

Like all teams, CyberTooth has a finite number of resources to produce an attractive and competitive robot for the season; and we strive to make the most out of the tokens we have. This system also keeps us in check, and pushes us to find and execute on simpler solutions for mechanisms without significant compromises to our priority list.

As a rule of thumb, and individual mechanism cannot cost more than 20 tokens; for example designing and building our first swerve drivetrain during build season would be a 20 point mechanism, whereas a stock AM14U4 chassis with no modifications would be a 4 point mechanism. No mechanism is free, and we understand that even the simplest of implementations cost resources.

Prior to build season, we complete a group exercise to review our previous season to determine how many resource tokens we spent, and compare it to our original allotment of tokens set during the Priority List segment of our build season. We then evaluate with a plus/delta method to determine whether or not we have grown or need improvement in certain areas that make up our resource tokens numbers. We then set an overall budget for the entire season based on whether or not we have a majority gain, loss or no change in these areas:



This whiteboard exercise outline indicates how we felt we spent our resources for the 2018 FIRST Power Up season. After tallying up the individual resources that were used per mechanism, (plus a 20 point adder for moving build sites mid-build season,) we agreed that we spent 68 tokens in 2018. Prior to the 2018 season, we said we had 75 tokens available. After evaluating our tokens usage and skills changes for 2019, we set a limit of 70 points for this season.

2019 Game Analysis

Initial Thoughts: CyberTooth spent a few days analyzing this year's game Destination Deep Space Presented by the Boeing Company. In or initial analysis we came to a few general conclusions.

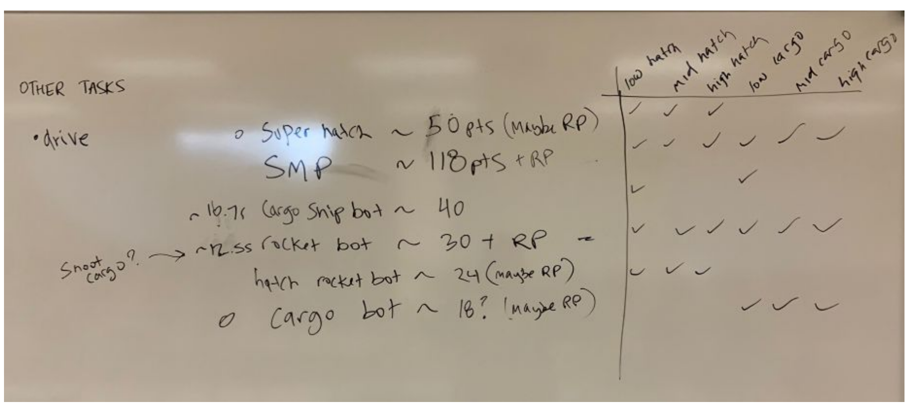
- The team has never had a climbing challenge like this
- The cargo ball is similar to other game pieces we've seen
- The hatch panel is a new type of game piece
- Scoring only requires a robot to go to half field
- We think ~10 teams in Indiana will be able to climb to level 3

How to score points: During our initial brainstorming, we identified all the ways that a robot could score points.

- Sandstorm cross hab line (3 or 6 pts)
- Place Hatch (2 each)
- Place Cargo (3 each)
- Fill Rocket Ship (1RP)
- Climb HAB 1
- Climb HAB 2
- Climb HAB 3
- Hold a Partner above level

Game Piece Scoring Analysis

The team then as a thought exercise estimated what scoring potential specific fictional robots could achieve. For instance, a robot that can only do hatches in a match, but can place them at all levels would score ~50 points and maybe contribute to an RP. A robot that could score both hatch panels and cargo balls on the cargo ship could score ~40 in a perfect match.



A "SMP" robot that is capable of doing every task on the field in a perfect match with unlimited time would score ~118 points plus a ranking point by themselves. Realistically, when match time was considered, the team believed this mythical robot would not be possible. Additionally, the team came to the conclusion that based on team resources we did not want to build a robot that could do absolutely everything on the field.

Robot Abilities Analysis

The team expanded on this thought and made a spreadsheet that listed robot tasks with what function the robot would be required to have to complete those tasks. The more checkboxes checked per row - the more complicated that task is. Additionally "robot concepts" were added to the bottom of the chart to combine different ideas.

		Drive/Hab			Panel				Cargo				Blindness		
		☑	☐	☑	☑	☑	☐	☑	☑	☐	☑	☑	☑	☑	☑
		Drive	Drive +	Hab Mechanism	Panel Obtainer	Panel Retention	Panel Elevation	Panel Put	Cargo Retention	Cargo Put	Cargo Elevation	Cargo Obtainer	Blindness	Contribute to Rocket RP	Contribute to EG RP
Drive off level 1 & cross line	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐
Drive off level 2 & cross line	☑	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐
Put Hatch Lower rocket	☑	☑	☐	☐	☑	☑	☐	☑	☐	☐	☐	☐	☐	☑	☐
Put Hatch Mid rocket	☐	☑	☐	☐	☑	☑	☑	☑	☐	☐	☐	☐	☐	☑	☐
Put Hatch Upper rocket	☐	☑	☐	☐	☑	☑	☑	☑	☐	☐	☐	☐	☐	☑	☐
Put Hatch Lower ship	☐	☑	☐	☐	☑	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐
Put Cargo Lower rocket	☑	☑	☐	☐	☐	☐	☐	☐	☑	☑	☐	☑	☐	☑	☐
Put Cargo Mid rocket	☐	☑	☐	☐	☐	☐	☐	☐	☑	☑	☑	☑	☐	☑	☐
Put Cargo Upper rocket	☐	☑	☐	☐	☐	☐	☐	☐	☑	☑	☑	☑	☐	☑	☐
Put Cargo Lower ship	☐	☑	☐	☐	☐	☐	☐	☐	☑	☑	☐	☑	☐	☐	☐
	☐														
Own bot scored on Hab 1	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
Own bot scored on Hab 2	☑	☑	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
Own bot scored on Hab 3	☑	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
Assist one on same hab	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
Assist one on higher hab	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
Assist two on same hab	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
Assist two bot on higher hab	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
	☐														
Concept 1: Place Cargo, Hatch in all rocket levels. Hab 2	☐	☑	☑	☐	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐
Concept 2: Place Cargo, Hatch in lower levels of rocket and cargo ship. Hab 3	☑	☑	☐	☑	☑	☑	☐	☑	☑	☑	☐	☑	☑	☐	☐
Concept 3A: Place OR Cargo, Hatch in all rocket levels. Hab 3	☐	☑	☐	☑	☐	☐	☐	☐	☑	☑	☑	☑	☑	☐	☐

With the understanding that not every task should be attempted. The team came to 3 reasonable concepts for our "Robot in a Sentence"

1. A robot that can place cargo and hatches in all rocket levels and climb to HAB level 2.
2. A robot that can place cargo and hatches in lower levels of both the rocket and cargo ship, climb to HAB level 3
3. Place on game piece (Cargo OR Hatch) in all levels, climb to HAB 3.

With a few concept ideas, the team redid the scoring analysis to calculate maximum scoring potential, maximum number of moves, and predicted cycle time to achieve a perfect game. Additionally a "points per move" could be calculated to help see which design has a better yield per second in points. While these numbers are mostly theoretical, they help to understand how the robot will perform throughout the game.

	Votes	SCORE SUM	Cycle Time	Moves	PPM
SMP		**118**	**3.75**	**40**	
Super Hatch BOT		**46**	**7.50**	**20**	
Super Cargo BOT		**66**	**7.50**	**20**	
ALL Cargo Ship Only		**46**	**9.38**	**16**	
ONE Rocket Only		**36**	**12.50**	**12**	
Drive Base		**6**	**#DIV/0!**	**0**	
Concept 1: Place Cargo, Hatch in all rocket levels. Hab 2	**0**	**88**	**4.69**	**32**	2.75
Concept 2: Place Cargo, Hatch in lower levels of rocket and cargo ship. Hab 3	**13**	**78**	**6.25**	**24**	3.25
Concept 3A: Place Hatch in all rocket levels, as well as Cargo Ship . Hab 3	**5**	**58**	**7.50**	**20**	2.90
~~Concept 3B: Cargo in all rocket levels. Hab 3~~		**54**	**12.50**	**12**	4.5

Using the above complexity chart and our scoring analysis, the team debated which concept would be most effective in the game. Some points were made during discussion to help guide the decision.

- Climbing to HAB 3 potentially yields the most points in the shortest amount of time
- Climbing to HAB 3 is a complex mechanism, assisting a partner sounds harder
- If we climb to HAB 3, we only need one partner to drive to level 1 to get the RP
- Hatches have to be scored first, before a cargo ball can be scored
- Hatches and Cargo are worth the same amount of points regardless of scoring location
- Relying on partners can be unpredictable
- We built an elevator last year
- Cargo is worth more points per piece than hatch panels.

The team decided that “Concept 2” was the best solution for the team to pursue. Concept 1 was good, but the point potential of the HAB 3 climb was too enticing. Additionally, the team agreed that it would probably be more valuable to score both types of game pieces as opposed to all levels. Therefore, the Robot in a Sentence was as follows:

> *The robot has the ability to score hatch panels and cargo at level 1 locations around the field, and ascends to HAB 3 at the end of the match.*

Priority List: With a concept defined, the priority list could take shape:

Priority List 2019		
	PA= Programming Assisted	
1	Drive	☑
2	Drive off hab 1	☑
3	Blind Drive off Hab 1	☑
4	Get on Hab 1	☑
5	Get on Hab 3	☑
6	Retrieve Panel from HP	☑
7	Hold Panel Securely	☑
8	Put Panel on Cargo Ship Hatch	☑
9	PA scoring panel on front face cargo ship	☐
10	PA scoring panel on side of cargo ship	☐
11	Cargo Floor Pickup	☑
12	Transport Cargo	☑
13	Cargo to Cargo Ship	☑
14	PA scoring cargo on cargo ship	☐
15	Put Panel on Rocket Hatch	☐
	Score hatch during sandstorm	☐
16	PA scoring panel on rocket	☐
17	PA scoring cargo on rocket	☐
18	Traverse cable cover	☑
19	Cargo to Lower Rocket	☑
20	Pick Panel from Floor	☐
21	Cargo HP Station Retrieval	☑
	Drive off hab 2	☑
	Blind Drive off Hab 2	☐
	Get on Hab 2	☐

The team came to conclusions to help guide the order of this list:

- Having a drivetrain is essential to all tasks and #1 on the list
- HAB3 at the end of the match has a high points per second potentially
- HAB3 has a large percentage contribution to a ranking point.
- Hatch Panels because they are required to hold in the cargo balls.
- A majority of the game could be played effectively without a floor hatch mechanism.
- Elevation to the higher levels of the rocket are not part of our Robot in a Sentence
- Cargo retrieval from the HP station is not essential because of all of the floor cargo
- Cargo floor pickup is important because it could reduce cycle times and they are staged on the floor
- Scoring a hatch on the front face of the cargo ship would be a valuable skill
- If effective at climbing to HAB3, we do not need to climb to HAB 2

The entire team has gone through this priority process and used analysis and logic to come to these conclusions. The priority helps to decide which parts of the robot were most important to the team and we kept our list to help guide throughout the build process.

Design Mechanism Groups

CyberTooth mentors and students split into 5 groups to further prototype and design the robot.

1. Drivetrain
2. Hab3 Mechanism
3. Cargo Mechanism
4. Hatch Mechanism
5. Controls/Blindness

Drivetrain:

Qualities and Abilities: After we completed our Robot in a Sentence *(The robot has the ability to score hatch panels and cargo at level 1 locations around the field, and ascends to HAB 3 at the end of the match.)* and our Priority List, we evaluated what skills our drivetrain needed to have in order to effectively achieve as many aspects as possible on our Priority List. We then created a list of:

- Must have qualities
- Nice to have qualities
- Must have abilities
- Nice to have abilities

The robot has the abilties to score hatch panels and cargo at level 1 locations around the field, and ascends to HAB 3 at the end of the match.			
Qualities (Must)	**Qualities (Nice)**	**Must Have Abilities**	**Nice To Have Abilities**
is legal for 2019 competition	simple	Allows us to traverse the field	Drive off HAB 2
it moves	easy to program	Allows us to drive to scoring locations	Drive on HAB 2
reliable	is straightforward to drive	Does not prevent us from getting on HAB3	hard to defend against
makes efficient use of resource tokens	is easy to maintain	Allows us to drive onto HAB1	is good at playing defense
robust	quick bumper changes	Allows us to traverse the cable cover	
is stable when moving around the field	easy to wire	Does not get stuck on the cable cover	
supports the rest of the robot at all times	innovative	Does not get stuck on a Hatch Panel	
well thought out	pretty	Does not get stuck on a Cargo Ball	
makes efficient use of time (to build)	wins awards		
robust bumper attachment	cheap		
Survive a fall off level 3			
We can drive it well with minimal practice			

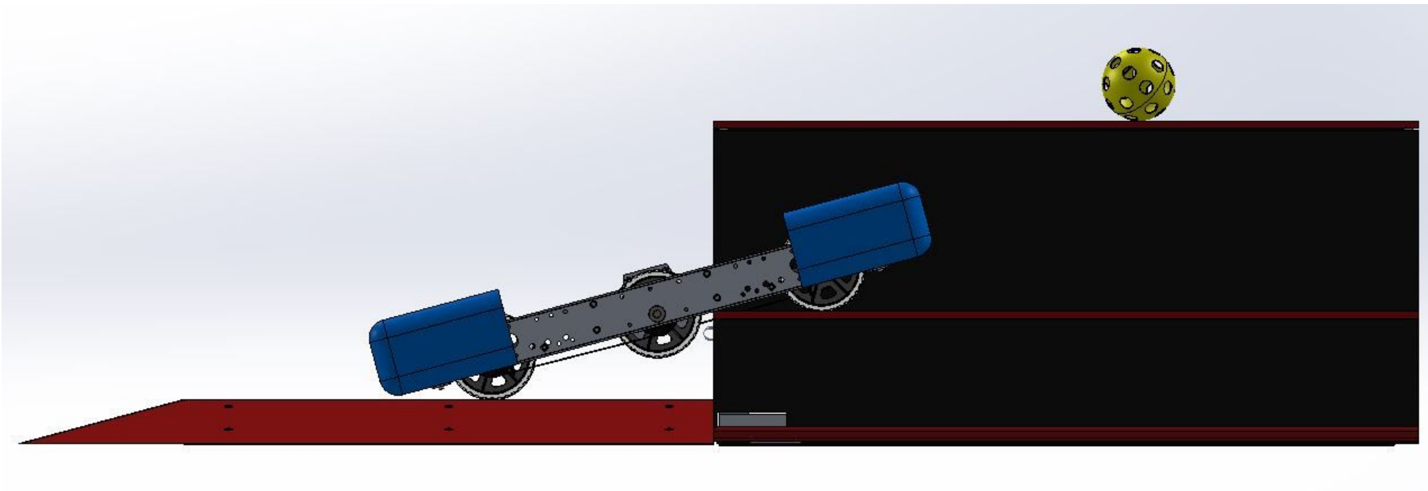
One of the most important things we considered is that we would be having a new drive team this season, after having the same driver for the previous three seasons. This is why we listed *We can drive it well with minimal practice* as a Must have Quality.

After this exercise, we noted a few specific abilities and qualities that were not a part of this list, including:

- Moving sideways
- Pushing other robots
- Be as small as possible

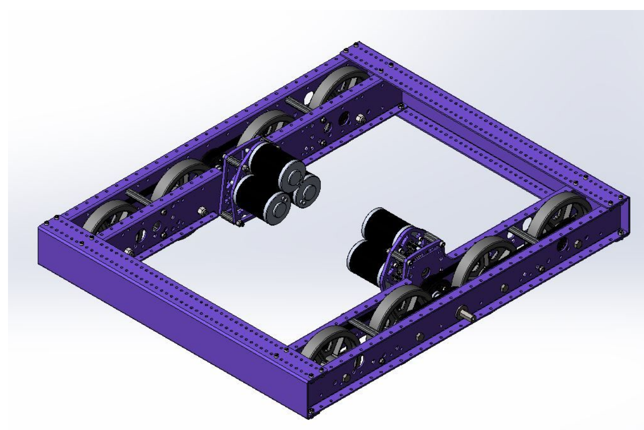
While sideways translation of the robot may have been a 'nice to have' for alignment, we noted that it was not a requirement of the Drivetrain group to solve; and we would consider misalignment concerns in the specific mechanism groups. This allowed us to significantly narrow our choices to a few skid-steer configurations. We knew that a stock AM14U4 with no modifications (at a cost of four points) would check all of the Must Haves, we considered a few upgrades that would check of more of the Nice to Haves. We also noted that we liked the performance of our 2018 drivetrain, which was an AM14U3 in an 8WD configuration with EVO Slim gearboxes with 2 CIM motors each. We also concluded that quick acceleration would be an asset to reduce cycle times for 2019, given the maximum 20ft sprint distances between game pieces and scoring locations.

We noted that a long AM14U4 with bumpers can theoretically get stuck if it is driven too slowly off the hab.



Concepts: We focused on checking off the ‘Drive off Hab 2’ ability when making these decisions, as we knew that we didn’t necessarily need to drive **on** to Hab 2 because of our plans to climb to Hab 3. We also focused on being difficult to defend against, so we investigated higher-traction wheels as compared to the stock white HiGrip wheels that came in the kit. We utilized lessons learned from our 2018 robot, as well as used it to physically prototype driving off of Hab 2 to choose our drivetrain:

- AM14U4 Frame
- 8WD with 60A 6” AndyMark SmoothGrip Wheels
- 6 MiniCIM Drive
- 7.56:1 AndyMark EVO Slim drive gearboxes
- ~32 x 27”



We chose this 8 Resource Token drivetrain as it checked the most amount of boxes per resource token on our Qualities and Abilities list for the drivetrain. In addition, there were other desirable features for the team.

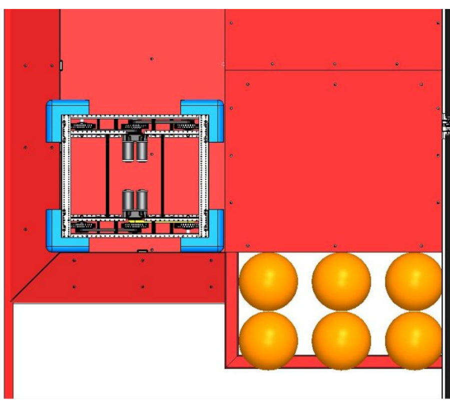
- It did not require significant custom machining of the drivetrain
- Allows us to optimize our drive wheel and gearbox combinations
- Allows for quick acceleration and speed to reduce our cycle times
- 8WD configuration is also a little more forgiving to drive for a new driver, as it does not rotate as quickly as a comparable 6WD setup.
- SmoothGrip wheels also offer higher traction on both carpet and HDPE surfaces based on our testing.
- Climb style needed a robot that was as long as possible, as our HAB3 climb arm needed to extend onto the HAB as much as possible.

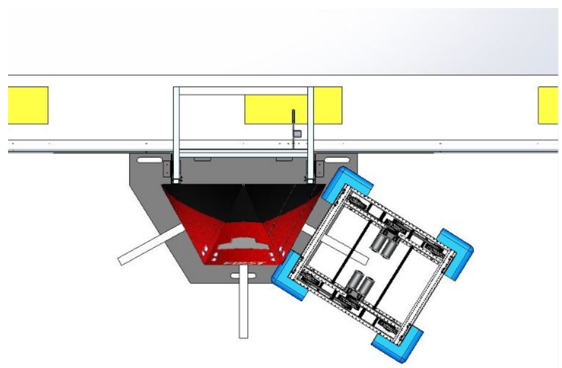
Motor Selection: We specifically chose a 6 MiniCIM drive motor configuration over our previously used 4CIM drive as we knew we wanted just a little more acceleration, but also from our testing in 2018 found that MiniCIM motors dealt with heat soak better than the full size CIM motors, giving us a more consistent drive performance throughout the match. They also are shorter in length which gave us a little more room to place electronics between the motors on our belly pan. We also optimized our drive gearing around a 20-25ft sprint, or approximately the distance from the Depot to the furthest Cargo Ship bay.

1-Speed Drivetrain

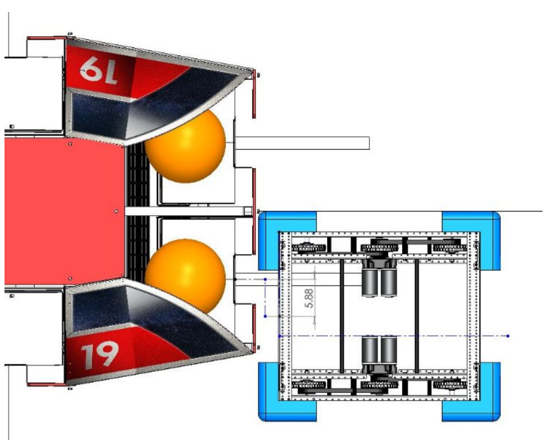
	Free Speed (RPM)	Stall Torque (N*m)	Stall Current (Amp)	Free Current (Amp)		Speed Loss Constant	Drivetrain Efficiency
Mini CIM	5840	1.41	89	3		81%	90%
# Gearboxes in Drivetrain	# Motors per Gearbox		Total Weight (lbs)	Weight on Driven Wheels		Wheel Dia. (in)	Wheel Coeff
2	3		154	100%		6	1.2
Driving Gear	Driven Gear		Drivetrain Free-Speed	Drivetrain Adjusted Speed		"Pushing" Current Draw per Motor	
1	7.56		20.22 ft/s	16.38 ft/s		96.59 Amps	
1	1		7.56 : 1	<-- Overall Gear Ratio			
1	1		772.48677				
1	1		625.71429				

Testing: For the drivetrain, we knew enough about the performance of these parts to not need to build up a full prototype. The largest concerns to test were how the frame size with bumpers lined up with different field components. The frame size fit nicely on HAB1 and is able to align with the rocket as shown below.





The only concern was alignment with the front face of the cargo ship. With the robot centered on the bay opening, the robot overhangs past the centerline. This would keep two robots from scoring at the same time. This issue was not a big enough deal to change the drive, but just leave as a note to the hatch group for consideration while they completed their designs and strategy.



Hab 3 Climb:

Qualities and Abilities: Just like we did in our Drivetrain group, we used the Robot in A Sentence to guide us through creating our Qualities and Abilities list:

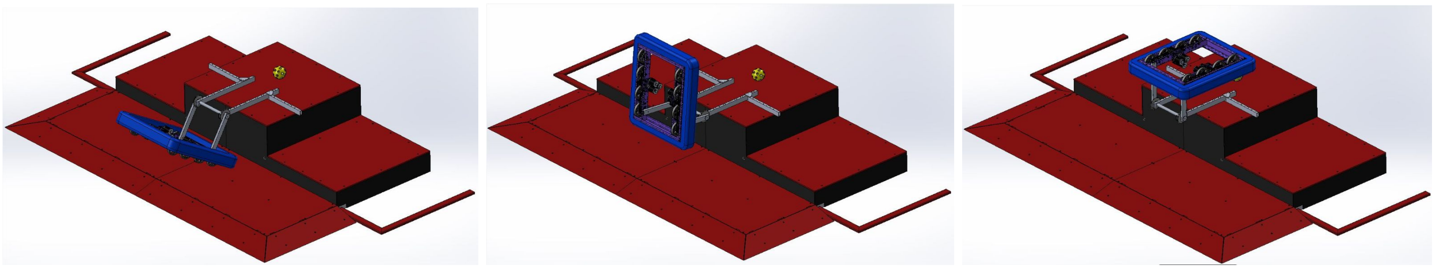
The robot has the abilties to score hatch panels and cargo at level 1 locations around the field, and ascends to HAB 3 at the end of the match.			
Qualities (Must)	**Qualities (Nice)**	**Must Have Abilities**	**Nice To Have Abilities**
is legal for 2019 competition	simple	Allows us to get on HAB 3	Allows other robots to be scored on HAB 3
reliable	easy to program	From anywhere on the field, we can be ascended to HAB3 in less than 30s	Drive on HAB 2
makes efficient use of resource tokens	is easy to maintain	Allows other robots to get onto HAB2	Takes less than 3 seconds
robust	easy to wire	Not impacted by some misalignment	Not impacted by significant misalignment
well thought out	innovative		Not impacted by moderate misalignment
makes efficient use of time (to build)	pretty	robot obviously looks like it has climbed to level 3 (no "paper tests")	
consistent	wins awards		move off edge of platform
	cheap		unable to be touched by robots on level one or two

After this exercise, we noted we had two different performance criteria goals baked into our abilities list. We said that our minimum level of performance must allow us to be climbed to HAB3 in less than 30 seconds, regardless of where we are starting that process on the field. By that logic, if we're starting from the very edge of the opponent's HAB zone tape line, which is approximately 40 feet away from the HAB, we'll spend at least 4-5 seconds driving from there to the HAB (with some factor built in for acceleration.) That left us 25 seconds to complete the process once we are in position. Our nice to have stretch performance goal was to be able to complete the climb process in less than 3 seconds.

Concepts: After setting the boundaries of performance and characteristics, we had two leading concepts - a stilts style climber that elevates the robot linearly and has us drive onto the platform, and a climbing arm that grips the sides of the hab and flips us up onto our back. We weighed the Pros and Cons of each:

Flip Climb		Stilts Climb	
Pros	**Cons**	**Pros**	**Cons**
● Good experience and understanding of high-load rotary mechanisms (2018) ● Can use some resources spent to elevate other game pieces ● Can be designed to allow for some misalignment ● Could be compatible with a stilts climber, provided they climb first ● Could be a quick single step motion to climb. ● Simple to program and operate	● Can be difficult to allow space for other robots to climb after us ● Significant care and design effort required to ensure a robust and reliable powertrain and structure ● Could potentially be a high-weight cost, even if up integrated to other scoring mechanisms	● Can be made into a compact independent system ● Can allow us to drive around and potentially make room for other robots on HAB3 ● Could be designed to allow us to climb to HAB2, but not a necessary feature.	● Previously had reliability issues with high-load linear systems (2018) ● If made as an independent system, is an additional weight cost ● Initially thought to be a slow process to complete, as our concepts required more steps as compared to our flip climb ● Could be complex to program and operate

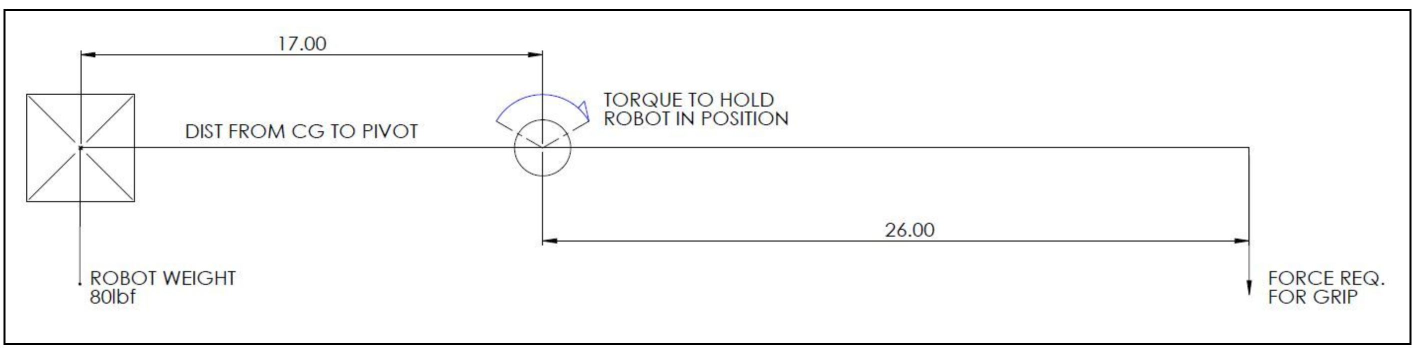
After careful consideration of these pros and cons, we felt the potential ability to integrate our flip climb into other mechanisms and simplicity of operation pushed us to pursue this method. We knew that it may have a lower points ceiling (as it may be difficult to climb with additional robots on HAB3,) but felt it would be a more efficient use of our resource tokens for the same requirement of getting at least our own robot onto HAB3. We then drew up a quick crayola CAD of what we thought the climbing process should look like, taking advantage of the real-to-life CAD models of the field in Solidworks.



Motor and Gearing Selections:

At this point during the build season, the Cargo group had determined that the ability to elevate the cargo from the floor up to the height of the opening on the Cargo Ship was a requirement based on our Robot in a Sentence and our Priority List. These positions, along with the several positions required by our climbing sequence led us down a path of utilizing some sort of continuous rotation motor+gearbox solution to power the arm.

We first considered the physical geometry of the robot, and identified the worst case scenario: when the bumpers of the robot are perpendicular to the floor, as that is the maximum distance of the Center of Gravity of the robot to the pivot point. We boiled it down to a fairly simple free body diagram, and found our geometry and estimated the mass of the components that would be beyond the pivot point. We also used this same diagram to determine the amount of grip force that was required based on the length of the arm itself, which is covered in more detail in a later section. For simplicity, we considered this as simple 2D geometry:



After we drew this diagram, we used it to determine how much torque we needed our motor solution to produce, and by extension, what ratio we would need once we've picked a motor and gearing combination. We used some simple statics to model the robot (box on the left) as a point in space to determine the amount of holding torque was required when the robot was at Max Q (bumpers perpendicular to the ground). We knew that the robot obviously needed to go past this point to climb, so we built in some safety factors for calculation error, the efficiency of the system and reliability purposes. We ended up at a safety factor of 2.7, which gave us our target output torque required at the pivot point, as well as our maximum weight that the system could handle.

Weight of thing to lift	80
Distance from Pivot	17
Force in In/Lbs	1360
Force in Ft/Lbs	113.33
SF	2.7
Force in Ft/Lbs Target	306
Force in IN/Lbs Target	3672
MAX WEIGHT TO LIFT	216

Once we had our torque targets, we considered combinations of CIMs, MiniCIMs and RedLine 775 motors. We considered the system as a whole, and used the specs of the motors to determine what ratio was needed between the motor shaft and the pivot point, considering gearbox options, sprocket setups and belt runs. **We did our calculations at the 'Max Power' rating of the motor** to give us additional overhead safety factor, but also to design the motor to run at the speed of which it can produce the most power - a good balance of speed and torque. If we had designed everything to the **stall torque** of the Motors, we would likely be underpowered as the system would technically be designed to the point of where it is no longer moving.

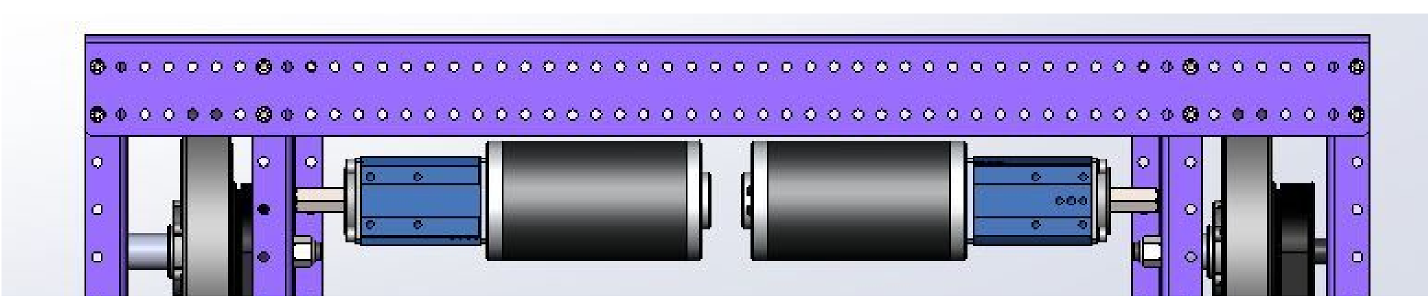
	MINICIM MOTOR		
	Max Speed	5840	rpm
1.41 Nm	Stall Torque	1.039963	Ft/lbs
	Max Power	215	Watts
	Speed at Max Power	2920	RPM
0.7 Nm	Torque at Max Power	0.5162935	Ft/lbs
	Req ratio for 1 motor	592.6861369	
	Req ratio for 2 motor	296.3430684	
	sys RPM	9.853444575	
	sys RPS	0.1642240763	
	sys MAX RPM	19.70688915	

	CIM MOTOR			
N/M lol	Max Speed	5310	rpm	
2.42	Stall Torque	1.7849	Ft/lbs	
	Max Power	336	Watts	
	Speed at Max Power	2655	RPM	
1.21	Torque at Max Power	0.8924502	Ft/lbs	
160	Req ratio for 1 motor	342.8762748		15-42
114.2336256	Req ratio for 2 motor	171.4381374	2.678720897	
1.400638377	sys RPM	15.48663582		
	sys RPS	0.2581105971		
	sys MAX RPM	30.97327165		

	REDLINE A MOTOR		
	Max Speed	21020	rpm
0.7	Stall Torque	0.5162935	Ft/lbs
	Max Power	382	Watts
	Speed at Max Power	9875	RPM
0.4	Torque at Max Power	0.2950249	Ft/lbs
	Req ratio for 1 motor	1037.200589	
	Req ratio for 2 motor	518.6002944	
	Req ratio for 3 motor	345.7335296	
	Req ratio for 4 motor	259.3001472	
	sys RPM	19.04163979	
	sys RPS	0.3173606631	
	sys MAX RPM	40.53217907	

We also considered what the maximum rotation speed of the arm was going to be when it was being used in 'cargo' mode as it would have the ability to run much faster, and we didn't want it to be uncontrollably fast. We thought that a speed in excess of 40RPM was going to be uncontrollable, so we set this as a bit of a speed limit. Because of this use case, we also knew that we needed motors that would survive for long periods of being stalled at a low voltage, so they would need to have enough thermal mass to support this. Based on these considerations, we chose to utilize **2 CIM Motors** with a target design ratio of approximately 171.44 :1.

From here, we began to explore physical solutions to achieving this desired ratio target. We decided that we wanted the output stage to be made from 2 runs of #35 chain, both for it's high tensile strength but also its ability to soak up some of the shock loads that the arm would produce while the robot was driving around the field. We first considered using 100:1 AndyMark CIM Sport gearboxes with an external chain reduction of 1.86:1 for an overall ratio of 186:1:



We ultimately decided that this solution would not quite fit our needs. Knowing we wanted to keep the 2x2 box tube towers between the drive rails, and mount the gearboxes between them, servicing these gearboxes was going to be a challenge. We also noted that these gearboxes are rated for 140 ft/lbs, and we would be putting nearly 190ft/lbs through them in a worst case scenario. We investigated a combination of these with an external gear pair, but they too did not fit.

We began to investigate what it would take to create a set of custom arm gearboxes that would provide the following:

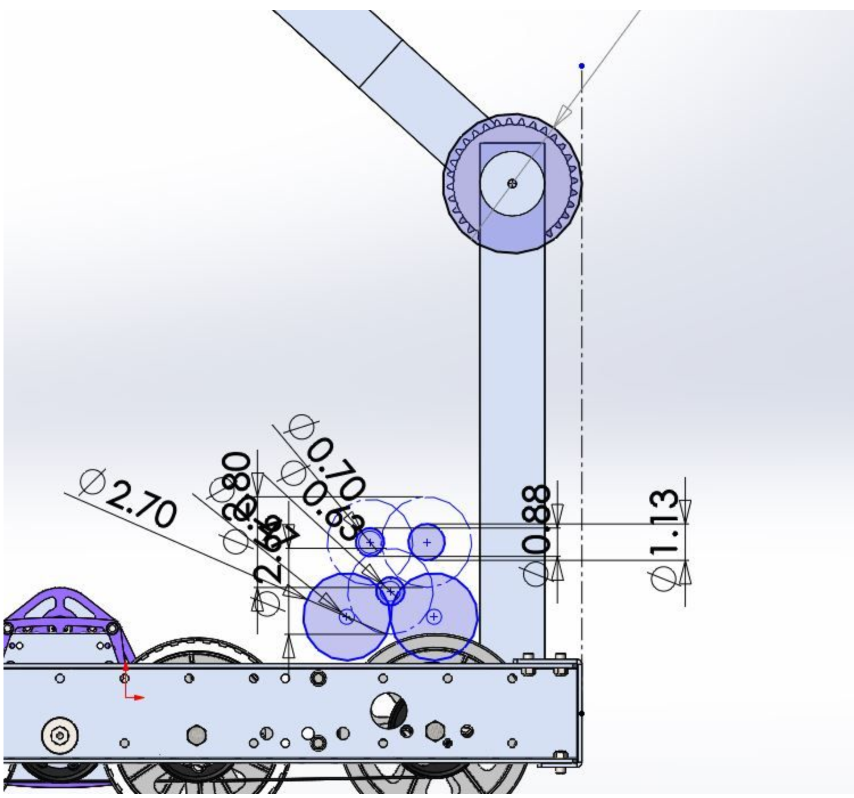
- Be robust enough to handle the torque required from the system
- Be compact enough to easily fit within our robot design
- Be easily serviceable in case of a catastrophic failure
- Offer the ability to fine tune their ratio later

Knowing that we have access to many COTS gears and parts, we opted to utilize as many COTS gears and shafts as we possibly could when designing this gearbox. We considered the following system ratio:

		CUSTOM GEARBOX			
		Input	Output	Stage Ratio	Stage Tooth Spacing
32dp	Motor Cluster	15	85	5.666666667	100
32dp	1st Cluster	20	85	4.25	105
20dp	2nd Cluster	14	56	4	70
35chain	Chain Reduc	15	28	1.866666667	43
			Output Ratio	179.8222222	

This configuration met all of these criteria, as the steel gears available would be strong enough in this application. The 20DP gear stage is also the same tooth spacing as an AndyMark EVO Slim gearbox, which has several ratios and compatible gears that would let us fine tune the gear ratio as needed. Additionally, every sprocket and gear was a COTS item, meaning we did not have to machine them from scratch. It also was very close to our desired ratio target of ~171:1.

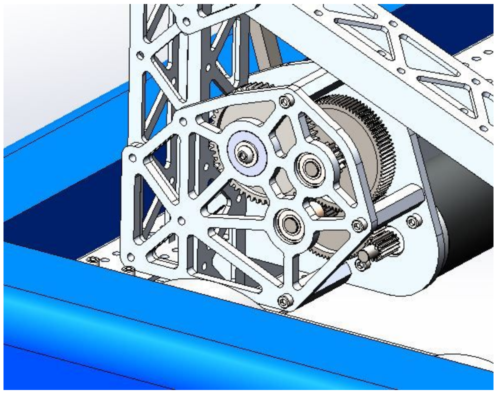
From here, we began to layout the gearbox packaging on the robot.

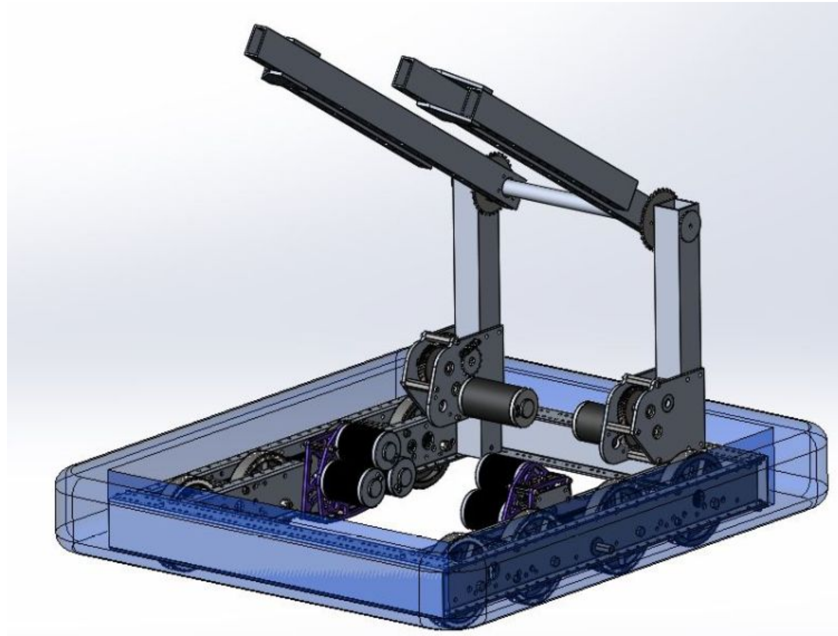


This crayola CAD sketch shows that the gearbox would be compact enough to fit in our desired location of in front of the vertical supports of the arm, as low to the ground as possible to keep the Center of Gravity of the robot low.

We also at this point decided that it would not be too difficult to integrate mounting for two CIM motors into each gearbox. This gave us the option to add more motors if needed to the arm, or potentially only run one gearbox with two motors into it if we ran into weight issues down the line.

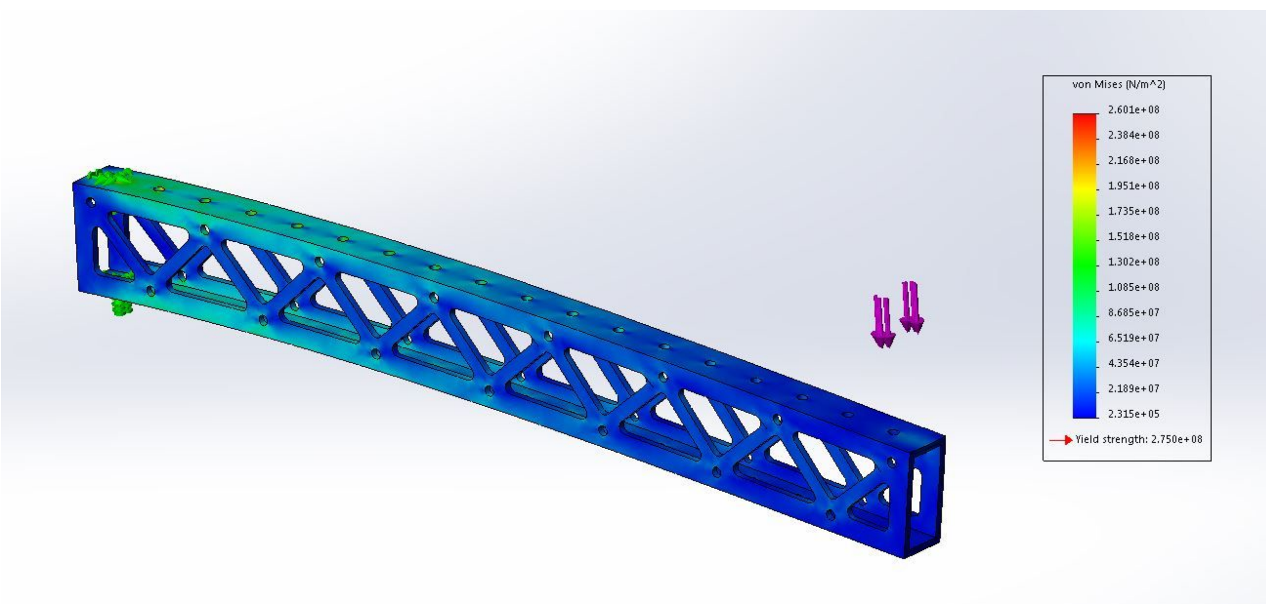
We also concluded that we could take advantage of the 2x2 box tube as part of the structure of the gearbox, and chose to extend the plates over them and fit the entire gear train within a 2” wide space. At this point, the design was mature enough to begin to lighten the gearboxes to complete powertrain design:





Structure:

Our team resources lend themselves to be able to take advantage of the strength box extrusions, as we can create custom components from them with the use of a CNC Mill. We knew we wanted the strength of ⅛” wall tubing to prevent bearing and bolt tear out, but needed to ensure it was lightened enough to be of comparable weight to a thinner wall tube. We drew up a couple designs in CAD, but settled on a triangular truss pattern that removed almost 40% of the weight of a given tube. We utilized Solidworks Simulation to see if it was strong enough in our worst case scenario; the weight of a robot hanging off of one end:



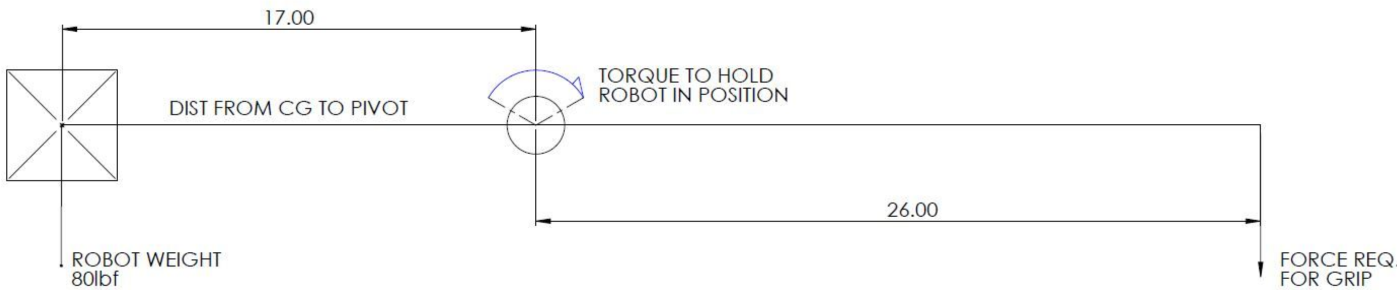
We found that our choices had a safety factor of nearly **3.5:1** and felt we could move forward with utilizing this pattern as much as possible throughout the robot.

Gripping Device:

Once we had the basic structure and powertrain of the arm figured out, we needed to design our actual gripping mechanism. We knew from our requirements list that we needed to be able to deal with some misalignment, and wanted to be able to deal with moderate misalignment. We also noted that the robot needed to let go of the sides of the HAB in an obvious way to demonstrate to the referees that the robot was indeed only supported by the top surface of the HAB.

We briefly discussed both suction devices and pure grip devices, but ultimately decided that a suction device would cost too many resource tokens to perfect, and also hypothesized that putting a pure suction device in straight shear would be difficult to maintain suction with. We ultimately decided to investigate grip pad materials first.

Through less-than-empirical methods, we did some pretty basic grip-feel tests of a wide variety of grip materials we had samples of. We ultimately found that Apache SBR Tan V-Top was the grippiest material we could find, and (based on CoF of other known friction tests on HDPE of wheel materials,) estimated it's Static CoF on the textured HDPE to be somewhere between 0.3 and 0.4. This allowed us to backsolve how much grip force we needed:



If we now reconsider this previous diagram as a class 1 lever, where the weight of the robot can cause the entire beam to pivot around the center, we need to solve for how much force is required to hold the robot in place on the right hand side of this diagram. We can break this diagram down to help us solve it easier - we know that in order to hold the robot weight stationary, we'd need to have at least ~113 ft/lbs (1360 in-lbs) of force at the centre pivot. In order to balance the right hand side of the system, we need to solve how much force is required to set the system to zero. **This number will be the maximum force of friction required to hold the system steady,** which we can use to solve how much grip force is required:

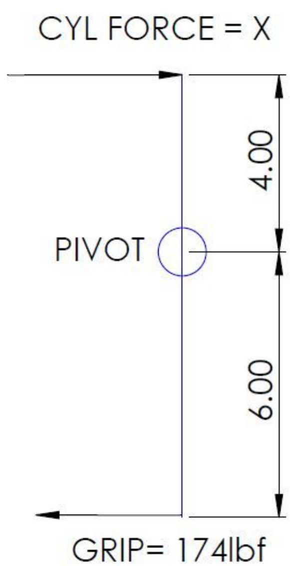
$$Torque = Force * Distance\ from\ Pivot$$
$$Force = X$$
$$Torque = 1360inlbs$$
$$Distance\ from\ Pivot = 26in$$
$$Force = \frac{Torque}{Distance\ From\ Pivot}$$
$$Force = \frac{1360inlbs}{26in}$$
$$Force \approx 52lbf$$

$$Force_{Friction} = \mu_s N$$
$$Force_{Friction} = 52lbf$$
$$\mu_s \approx 0.3$$
$$N = X$$
$$N = \frac{Force_{Friction}}{\mu_s}$$
$$N = \frac{52lbf}{0.3}$$
$$N \approx 174lbf$$

This means that based on this material, we need the gripping device to exert **174 pounds of force** at the point of contact in order to hold the robot steady. This model actually only accounts for one side, and we knew that we would have one gripping device per side, this already builds in a **safety factor of 2.** We also based this math on a worse-case 0.3 CoF, which builds in a little more safety factor.

Gripper Geometry and Cylinder Sizing

At this point, we need to consider the balance of being able to exert enough force on the hab to grip, but also have enough stroke to make it obvious that we have let go of the hab at the end of the climbing sequence. We played with several geometry types, but it can be boiled down to another simple class 1 lever diagram. This in conjunction with a similar static analysis, we checked to see if this 2D geometry was possible with air cylinders @50psi.



$$\frac{Req\ Cylinder\ Force}{Cylinder\ Distance\ to\ Pivot} = \frac{Grip\ Force}{Grip\ Distance\ to\ Pivot}$$

$$Req\ Cylinder\ Force = \frac{Grip\ Force}{Grip\ Distance\ to\ Pivot} \times Cylinder\ Distance\ to\ Pivot$$

$$Req\ Cylinder\ Force = \frac{174lbf}{6in} \times 4in$$

$$Req\ Cylinder\ Force = 116lbf$$

$$2in\ Diameter\ Cylinder\ Force = \pi r^2 \times Pressure$$

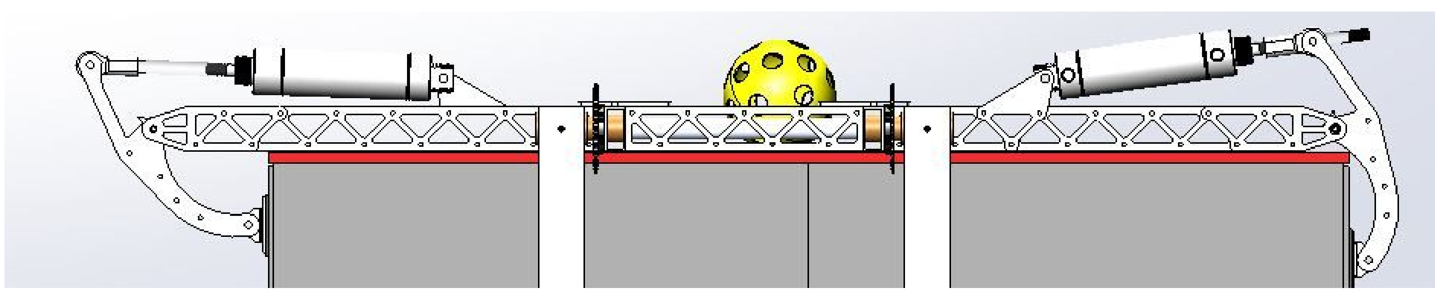
$$2in\ Diameter\ Cylinder\ Force = \pi 1^2 \times 50psi$$

$$2in\ Diameter\ Cylinder\ Force \approx 157lbf$$

$$Safety\ Factor = \frac{157lbf}{116lbf} * 2\ Cylinders$$

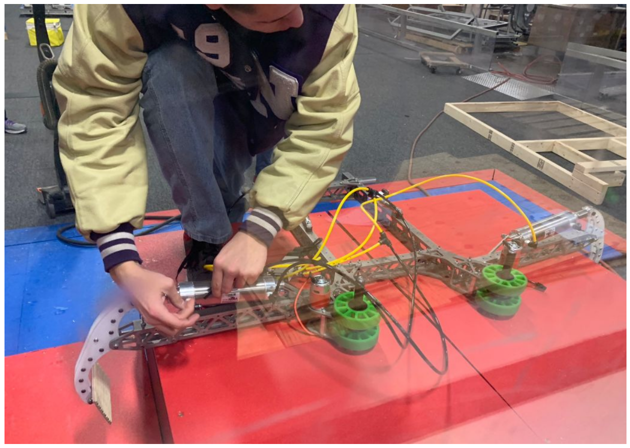
$$Safety\ Factor = 2.7$$

This concluded that we can use 2” bore cylinders and have enough grip strength to curl the robot. We estimate our safety factor is big enough to deal with the shock loads that the grip mechanism may see during climbing sequences. We now need to check if this geometry can allow for enough misalignment (approximately +/- 3” on either side):



This geometry worked. It allowed for about 3 inches on either side for misalignment room, and still allowed us to grip. Because of the safety factor we built in, we could also ignore some of the weird force vectors that become present when put into a real life scenario with the forces not quite perpendicular to the clamp devices.

Testing: Prototyping the climber to exact specifications would be a difficult challenge. The team instead decided to build production level parts as soon as possible to assemble and test to ensure that the climb would function as expected. Testing was done using shop air at 40psi.



The testing was successful and the grip was enough to support our mentor, Nick standing on the edge of the arm to simulate the weight of the robot cantilevered off the edge of the platform. Although, we understand there would be some variability between this test and final robot operation, the success gave us the confidence to move forward with the design without making major changes.

Cargo:

Qualities and Abilities

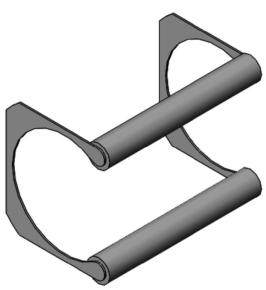
True to our process, we created our list of Must haves and Nice to haves specifically for the Cargo game piece.

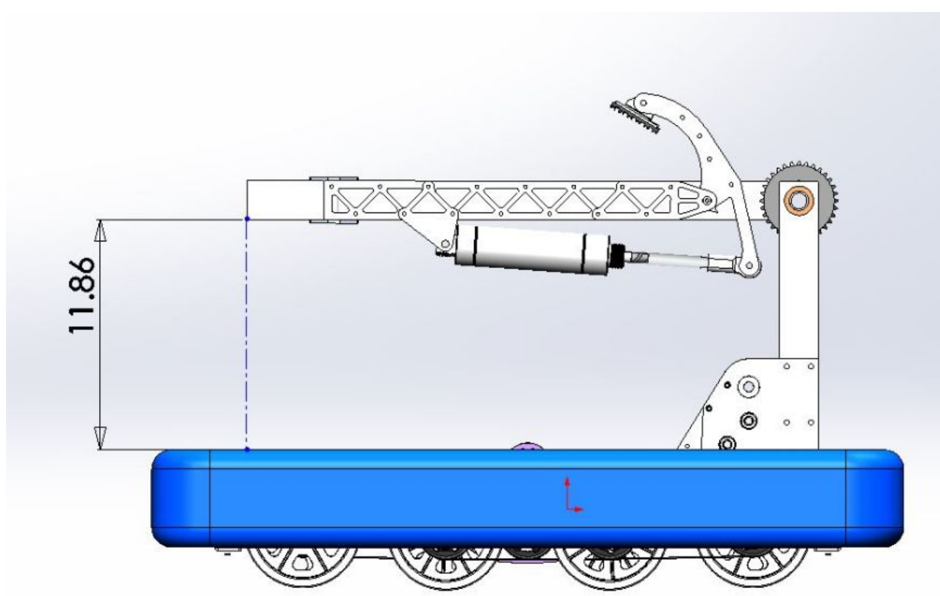
The robot has the abilties to score hatch panels and cargo at level 1 locations around the field, and ascends to HAB 3 at the end of the match.				
Qualities (Must)	**Qualities (Nice)**	**Must Have Abilities**	**Nice To Have Abilities**	**Bored so we have it**
is legal for competition	Light weight	Retrieve cargo from the floor	Acquire cargo from the HP	Score LVL2 of the rocket
Securely holds Cargo	Compact	Score cargo in the cargo ship	Choose which side of the rocket the cargo lands in	Score LVL3 of the rocket
Quick Cycle Time	Easy to operate with little practice	Score cargo in LVL1 of the rocket	Integrated with HAB3 mechanism	Pass cargo to partner
Quick acquisition	Easy to integrate sensors	Does not drop cargo while traversing the field	Score without turning around	
Quick Deposit		Doesn't get stuck on other robot parts	Score out both sides	
Easily deals with all legal sizes of Cargo		Can retract quickly if being defended		
Efficient use of resource tokens		Can retract completely within frame perimeter to play defense		
Robust				
Makes efficient use of time to build				
Difficult to acquire two game pieces at once (no fouls)				

Ideas

We had to main concepts; a wrist joint that holds a top/bottom/both roller claw that extends outside the bumpers to acquire the Cargo at the end of the HAB3 mechanism, and two separate systems - articulated Over The Bumper (OTB) intake that hands off to a fixed side-by-side roller claw on the HAB 3 mechanism. We hypothesized both of these would physically work, but would come down to how much room we have to package these mechanisms based on our qualities and abilities requirements. We gravitated pretty quickly to roller style mechanisms as they have a proven track record in the *FIRST Robotics Competition* as compared to other designs, such as moving claw arms, etc. In the interest of resource token management, we also needed the wrist style mechanism to pivot via air cylinders, to lighten the load on our controls group.

Before prototyping we started first with our roller claw crayola CAD, however, we identified a problem pretty quickly:





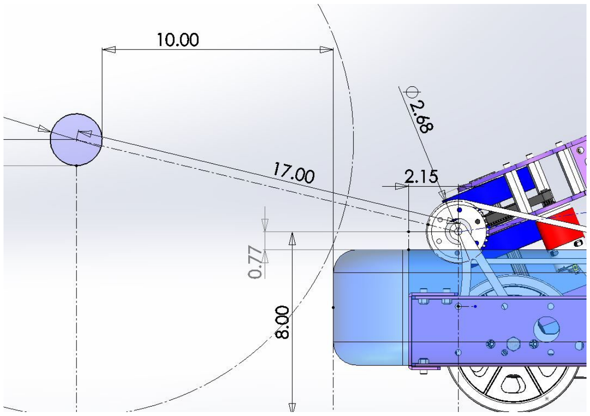
With the cargo ball being 13” in diameter, there was very little room to integrate this style of mechanism without making serious compromises to it’s effective collecting width, and the structure of the robot to get it to fit within the frame perimeter. Additionally, the range of motion desired appeared to require the usage of a motor for the wrist, which we didn’t feel we had the resource tokens to spend on.

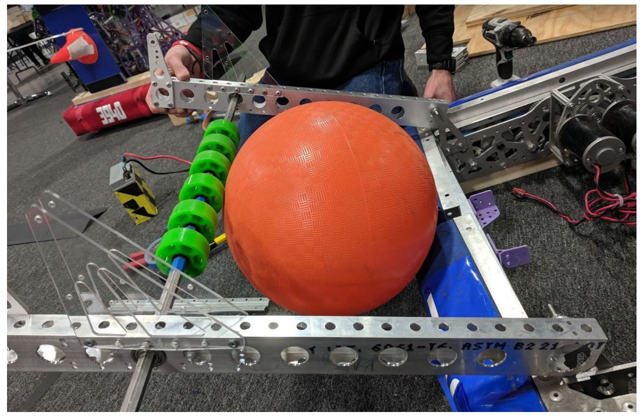
At this point, we focused on our concept of a top-roller OTB intake with a secondary roller set on our HAB3 mechanism.

Prototyping:

OTB Intake:

We spent most of our physical prototyping time on our over the bumper (OTB) intake as we thought that was the biggest challenge. We utilized an older drive base as our testing platform, and tested various small wheel types and spacings. We ultimately settled on 35A 2.25” AndyMark HD Compliant wheels, in addition to some slight compliance at the pivot point of the intake. This combination of components made for a pretty consistent positioning of the CARGO up to the top of the bumper, primed for our upper mechanism to acquire it.

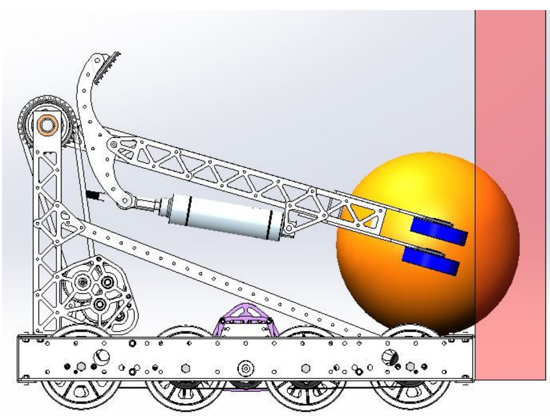


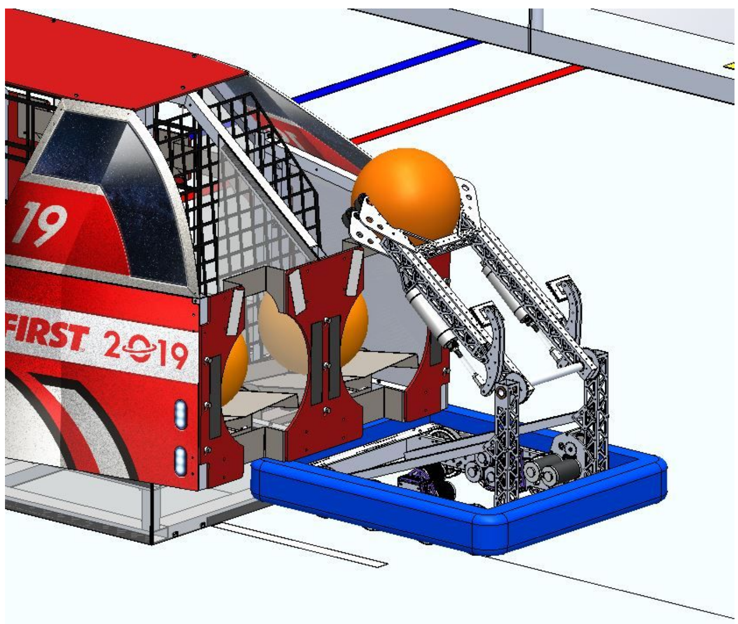


Upper Intake

We spent most of our CAD prototyping time focusing on figuring out if it was possible to integrate a roller claw at the end of our HAB3 arm, without compromising anything about our higher-priority climbing ability. We did some physical prototyping to prove that we wanted 4” 35A AndyMark Compliant Wheels, with some ability to adjust how much compression we have on the ball. We played with a few different motor layouts, trying to get it to package nicely.

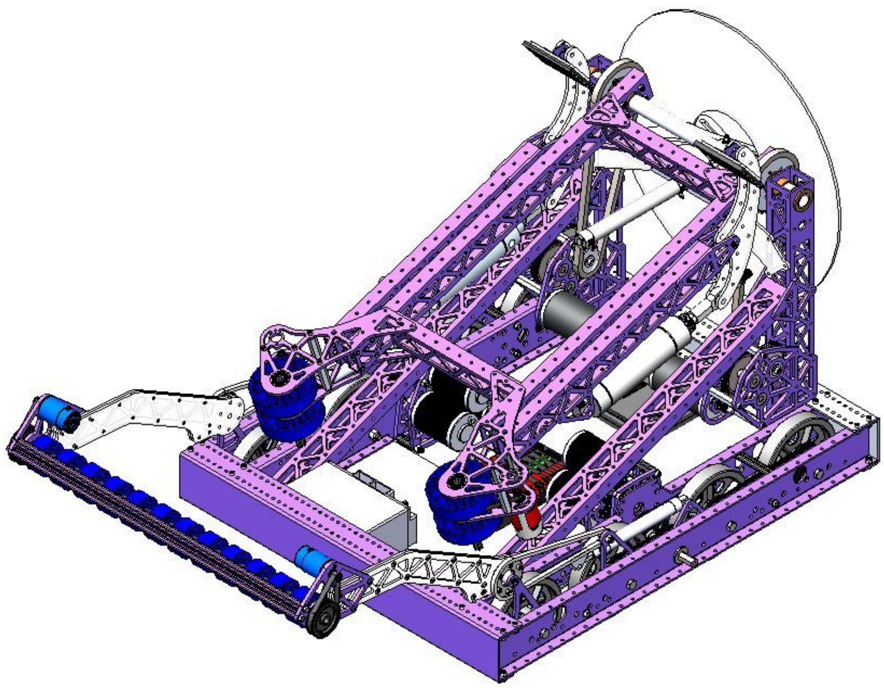
Packaging a 4” wheel at the end of the arm was the biggest challenge, as we wanted to have our ‘collapsed’ state to be with the arm down, so that we could be as compact as possible with the arm down if we ever needed to play defense.

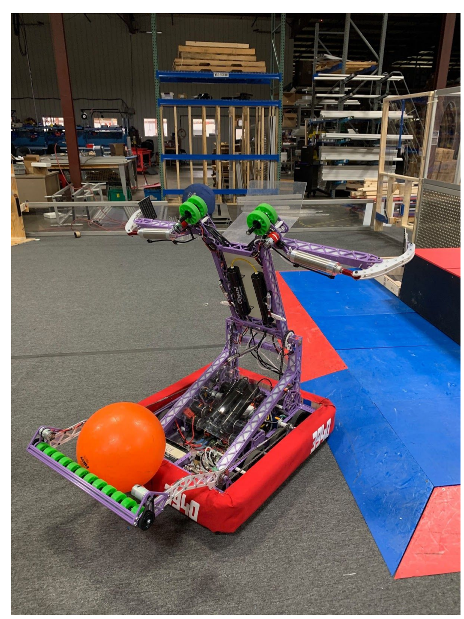




Integration and Testing:

After finalizing geometry with the aid of physical prototyping and CAD, we built our practice robot's worth of components to test before committing to the full run of parts for both the competition robot as well as spares. We also deeply considered how our OTB intake would interact with the field and other robots, and opted to make the primary structure of the extension from Polycarbonate, so that it would flex out of the way when it was impacted, rather than permanently bend and be unusable mid-match.





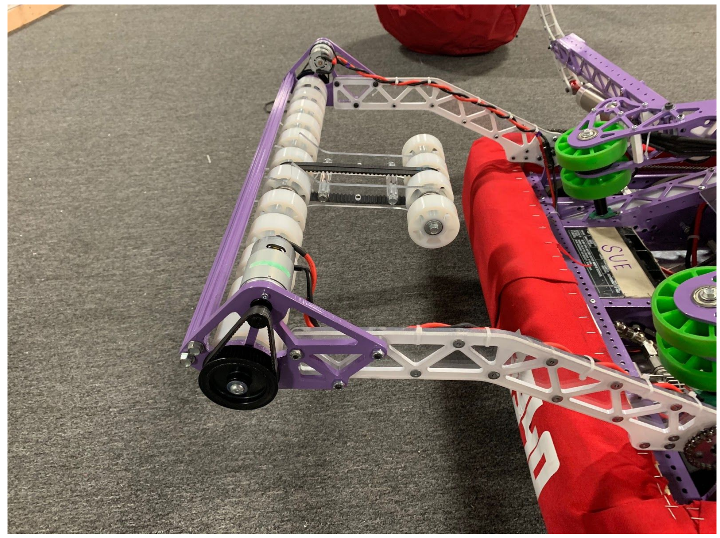
Initial testing of the mechanisms individually was really promising. Each system worked very well independently; the OTB intake could easily acquire balls from the floor and bring them up the bumper without issue, and the rollers on the HAB3 arm could easily acquire and release the Cargo ball. The HAB3 roller set also had plenty of grip on the Cargo ball so that it would not be dropped when traversing the field or moving the arm.

Once the two were integrated into the robot, we discovered a small dead zone that would frequently cause the cargo to sit between the OTB intake and the HAB3 roller set, causing the ball to be stuck in the robot and not be held by the HAB3 mechanism. The picture on the right demonstrates where the ball would sit, even with the arm all the way down.

Secondary Roller Set:

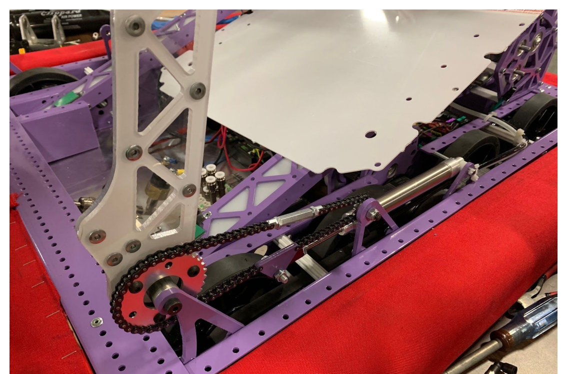
We brainstormed several ideas to alleviate the ‘dead ball’ problem, including extending the HAB3 roller set further forward on the robot, changing the OTB intake, removing the OTB intake and only using the HP station to acquire cargo, etc. We eventually settled on trying to add a secondary floating roller as part of the OTB intake behind the leading robot-wide roller set to keep the Cargo ball in contact with the OTB intake for longer, for a more direct pass to the roller set on the HAB3 mechanism.

This proved to solve our ‘dead ball’ solution in relatively short order. This roller set is both powered by and supported by the main leading roller axle, via a timing belt connecting the two roller sets. It can also pivot up and down to allow the ball to pass up through the OTB intake and over the bumpers, but has a lower stop to act as a ‘check valve’ to prevent the ball from coming back in or resting in the previous ‘dead zone’.

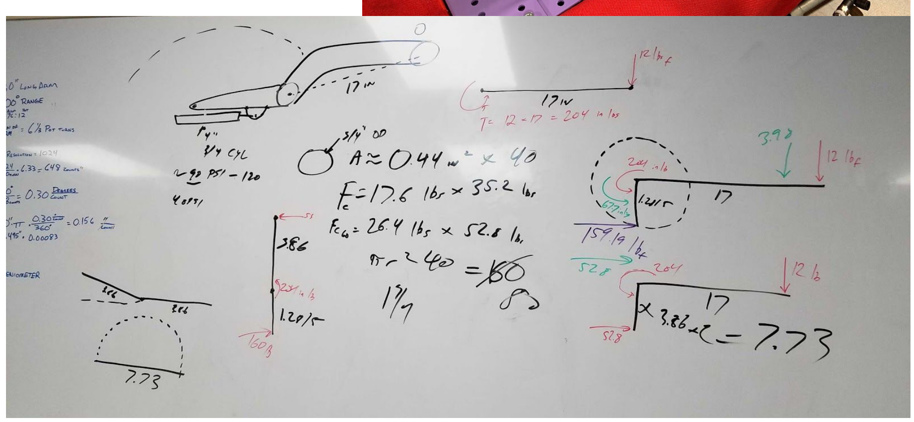


Pivot Power Redesign:

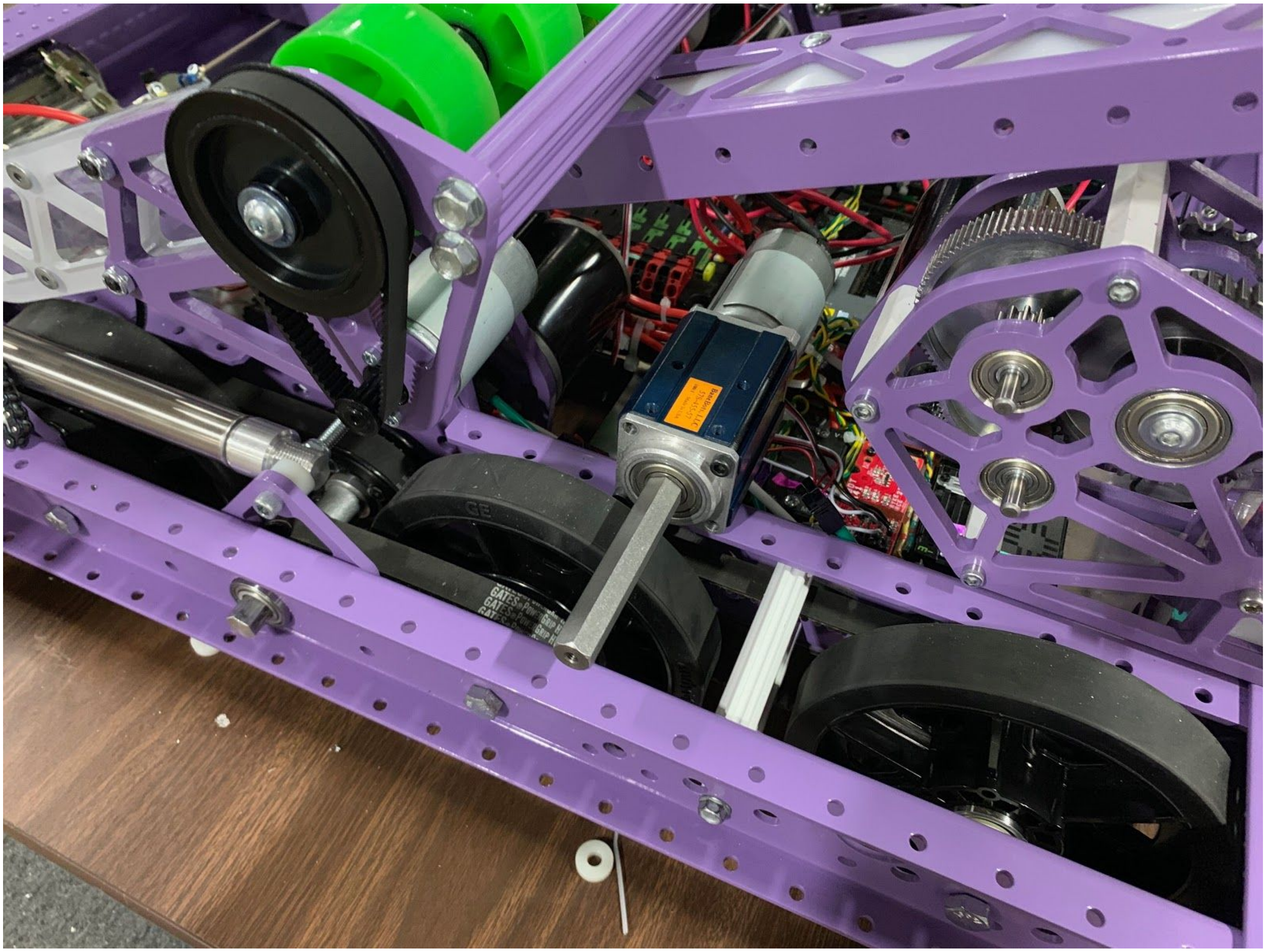
Analysis of current state: When we initially designed our OTB intake, we intended to power it with an air cylinder that drove a chain to increase the range of motion it had. We initially chose an air cylinder setup because we knew this mechanism only needed to be used fully extended, or fully collapsed, meaning it only needed two positions. We also had a packaging constraint, so we chose a compact solution with air cylinders to power it in and out. Unfortunately, when we attempted to test this motion, the cylinders seemed to be way underpowered and could not move the mechanism. We went back and reanalyzed the forces at play:



We mathed out the maximum force that our cylinders could exert, and found we were limited to approximately 35 pounds of force; whereas the system needed 159 pounds of force to move the intake with our given geometry. Realizing that this was not going to work, we evaluated our options for moving this mechanism.



Motor Pivot Power Solution: Once we realized that our current solution was way underpowered, and there was no way to step up the bore size of the cylinders in order to gain more force into the system because of packaging constraints, we considered a motor+planetary solution to power the rotation of the mechanism via a chain drive. Because we had already completed the analysis of the system at current state, it was easy to find a motor and gearbox pairing that fit our needs. We elected to use 775 motors in combination with 100:1 57 Sport gearboxes, as it was the right speed and torque to move the mechanism, and the gearbox would be able to take the extreme shock loads we were going to see under defense. The long run of chain also helped mitigate the shock load concerns we had.



This solution worked out great, and was actually a minimal resource token usage solution too. We also integrated some hall effect sensors at the ends of travel for the mechanism, and essentially treat it like a two position system - it drives each direction until the magnet trips the hall effect sensor, which tells the robot to stop driving the motors.

Hatch:

Qualities and Abilities: From prior analysis, we know that the hatch group needed to acquire from the loading station, and deliver to the level one locations. Secondly, it would be nice to score a hatch in sandstorm. Before prototyping, the team defined which qualities and abilities were important for the hatch mechanism.

The robot has the abilties to score hatch panels and cargo at level 1 locations around the field, and ascends to HAB 3 at the end of the match.				
Qualities (Must)	**Qualities (Nice)**	**Must Have Abilities**	**Nice To Have Abilities**	**Bored so we have it**
is legal for competition	lightweight	human player retreival	floor pickup	Remove existing panels
Secure Hold	compact as possible	place on lower areas	integrated with cargo	second level placement
Smooth Release	not reliant on setup variance	do not drop	integrated with hab3	move panel from horizontal to vertical
Quick Cycle Time	Easy Operation	not get stuck on floor	automatically released	
Quick Retrieval	Doesn't stick out far	doesn't launch panels	automatically picked up	
Quick Deposit		doesn't get stuck on other robot parts	only one game piece (guarantee)	
Consistant Placement		doesn't interfere with other systems	Score without turning around	
Secure Placement			Score out both sides	
Low Mantenance				
efficient use of resource tokens			Pass to partner	
			Pick up off opponent floor - (diff rules)	
no fouls from accidentaly moving hatch panel			move panels along the floor	

Ideas: The hatch group then came up with a list of ideas to try for prototyping.

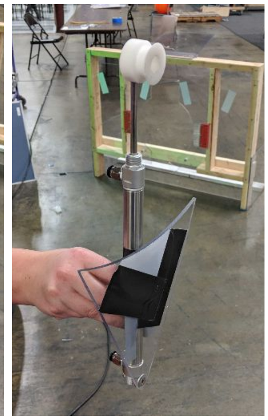
- Envelope clasp style with prongs that open and close
- Flat Velcro pickup
- Velcro Wheel pickup
- Scissor Arm
- Pancake Flipper Arm
- Vacuum Pickup
- Tongs Pickup

Prototyping:

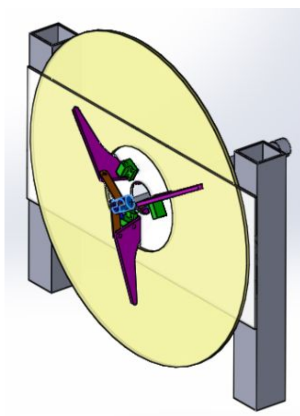
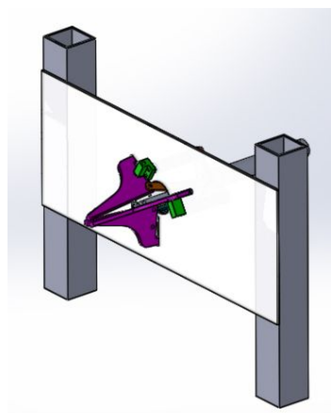
Velcro concept - One of the main concerns with velcro was how it would perform over time after a number of uses or if the velcro got dirty. The group working on this velcro concept did over 100 stick and release tests on test velcro and also took the hatch panel and covered the velcro with dirt and debris to simulate a long event.

Additionally, a velcro prototype was mounted to a previous year's robot to test. A cone was added to help with alignment during loading station pickup.

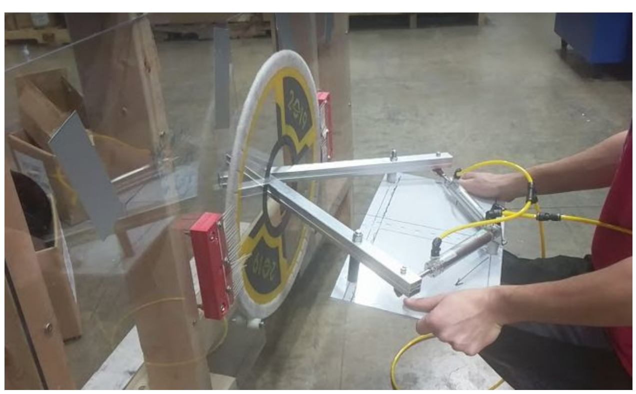
Edge Grabber - This group played with different shapes and sizes of parts that can hold onto the hatch panel. One of the largest concerns with this group was ensuring that the hatch panel could be held securely. Early tests with one tab on the inside did not hold as well as multiple contact points. The final iteration of this concept included a concave white spacer securely held the center of the hatch.

3 Prong Grabber: This idea was mocked-up in CAD. It features 3 fingers that reach inside the hatch panel center circle and expand to hold in the center. Being made up of small precision parts this design was hard to make by hand and was created in CAD.

Scissor Style Grabber: One of the most promising tests was with a scissor style grabber. This mechanism could grab and release with one actuation. When the hatch panel was held, it was very secure and could not be pulled off. The prototype would need to be more refined in order to fit within the confines of the robot.

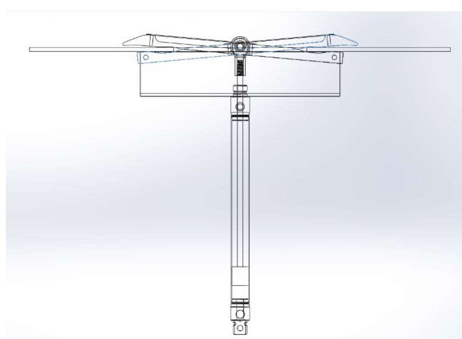
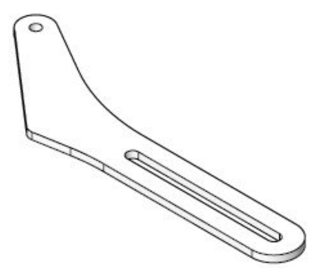


All of the prototypes had potential, but we needed to proceed with one design. Pros and Cons were listed for each design in order to fairly evaluate.

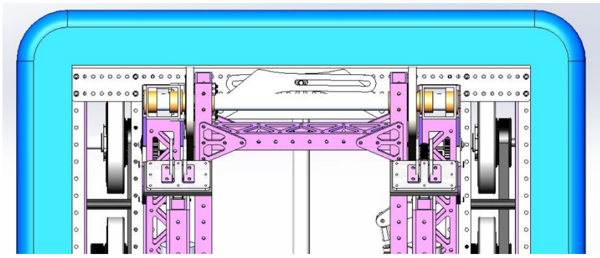
Velcro		Edge	
Pros	**Cons**	**Pros**	**Cons**
-Velcro sticks well -Non-moving grip	-Velcro could deteriorate over time -May need to clean velcro -Needs something to help with alignment -Needs release mechanism	-Secure hold -Could potentially pick up off the floor	-Many moving parts -Complex Design
3-Prong		**Scissor**	
Pros	**Cons**	**Pros**	**Cons**
-Secure hold -	-Many moving parts -Complex Design	-Secure Hold -Small footprint -One actuation.	-Floor pickup more difficult

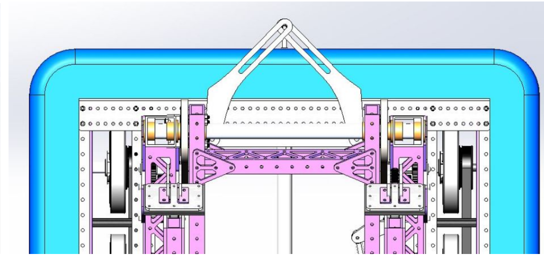
From initial prototyping, the group decided to proceed with a scissor style mechanism due to its compact size and shape, it's robustness, and it's simplicity of one actuation.

Refinement of Hatch Arms: The group made initial designs in CAD and made more refined arms that were small and light. The shape was made in CAD and then hand-cut for initial prototyping. The final versions were refined and cut on our CNC router.

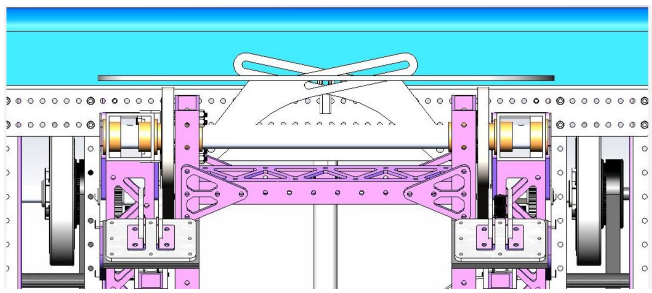




Integration and Testing: One of the largest difficulties with the hatch mechanism was integrating with the rest of the robot. We felt that this mechanism could be very compact in size and therefore we attempted to fit this mechanism on the back of the robot. A refined arm design could be used and fit within the frame perimeter of the robot.

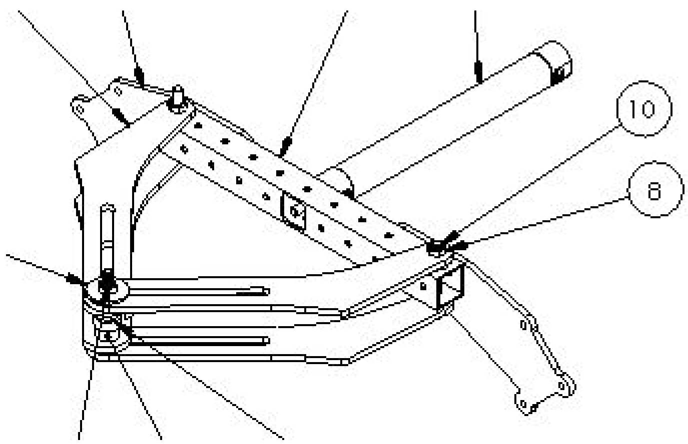




One major issue with this design was that when holding a Hatch Panel, the arms would stick outside of a frame perimeter. By rule, this would keep the team from being able to start a match while holding a panel with this mechanism. To resolve this issue, the team decided on an alternative holder for during the Sandstorm period.

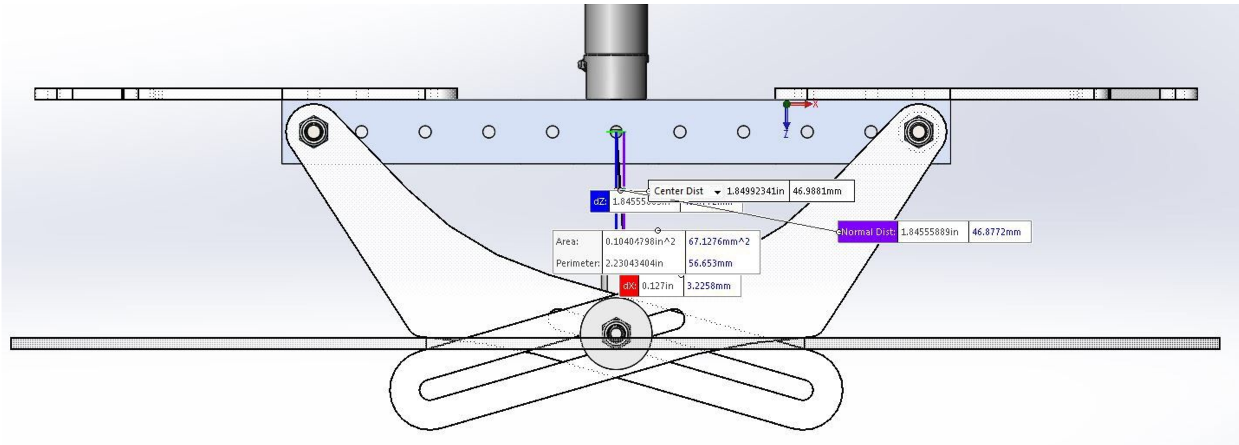


Initially the design called for a 4-arm layout in two layers. This provided a good hold on the hatch panel in prototyping. Unfortunately, this design interfered with the vision system on the robot and required a switch to a 2-arm design.



Issues and Resolutions: At the competition, we found that the hatch mechanism was not as effective as we wanted it to be. Using our scouting data and match video footage, we found that we were frequently dropping hatch panels during placement and at the loading station causing us lost match time and hurting our overall scores. After analysis we determined the following issues:

Old Geometry:



- **Hatch catching on bumper** - Hatch panel would sag on the mechanism as we drove
- **Skewed hatch panels** -The “arms” were too flimsy to firmly grasp a hatch panel and keep it from sliding around
- **Red grease caused problems with the limelight** - Limelight would reflect off of the red grease and white paint due to its opacity
- **Geometry problems** - The geometry of the previous design did not grip the hatch panels tightly enough

After Tippecanoe, we decided to troubleshoot the original hatch panel mechanism

- We did 20 timed trials that each involved obtaining hatch panels from the loading station and placing them on both sides of the rocket and the front and side of the cargo ship
- Original cycle time = 18.231 seconds
- We had 5 hatch panel drops, most of which occurred at the loading station

Solutions:

- The new geometry of the arms holds the hatch panel higher, so it no longer catches on the bumper
- Now, rather than one “layer” of arms, the new design has two. This makes the arms more robust and prevents hatch panels from becoming skewed on the mechanism due to flimsiness
- Instead of using red grease to lubricate the mechanism, we now use multi-purpose oil, which is translucent. This solution fixed the issues we were having with the hatch mechanism interfering with limelight
- The new geometry of the arms include protrusions that tightly grip the hatch panel

We ran the same 20 timed trials with the newly designed hatch mechanism, and the consistency of obtaining and scoring panels improved

  - New cycle time = 16.279 seconds (that’s a 10.7% improvement!)
  - Only two drops, and none occurred at the loading station

New Geometry: