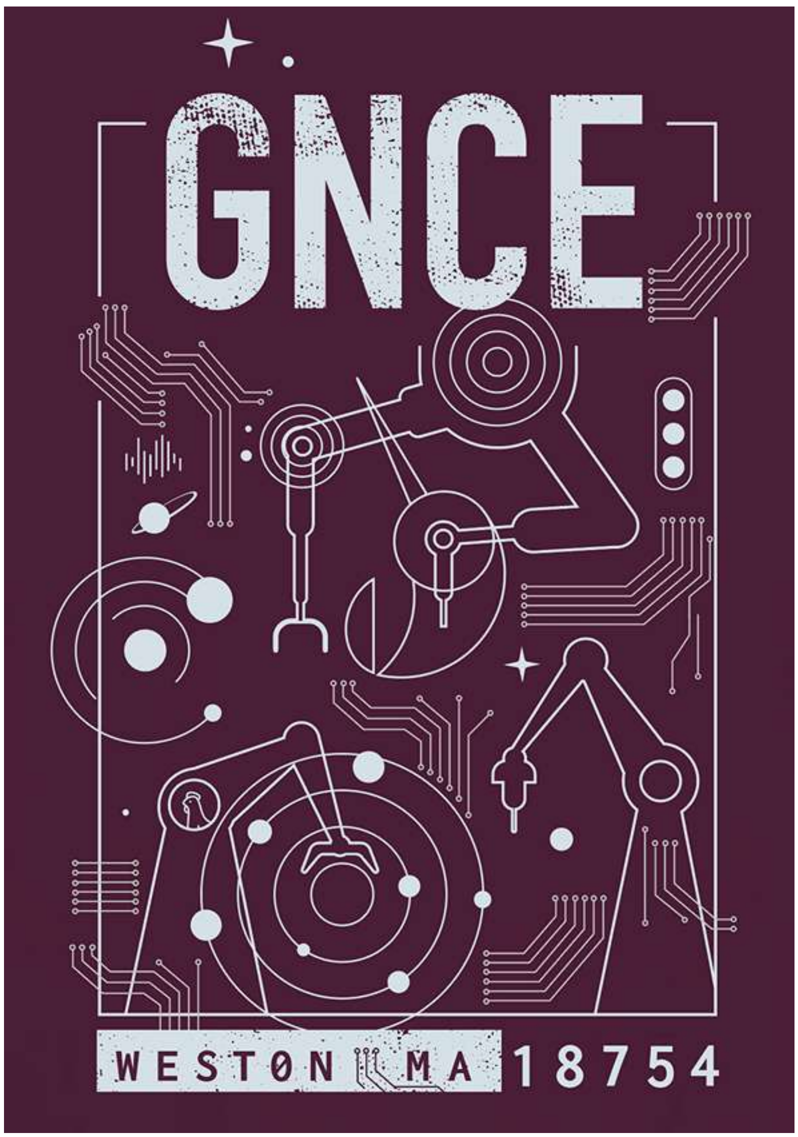
Galactic Narwhal Chicken Effect
G N C E

Engineering Portfolio
Team 18754



Team Overview

We are a third-year FTC team from Weston High School, started as two separate teams in 6th grade: The Butterfly Effect and Aquatic Chickens. In 7th grade, the teams combined to form Galactic Narwhal Chicken Effect (GNCE). At the 2023 Massachusetts State Championship, we were the Inspire Award winner.

One of GNCE's key goals is that **every member designs, builds, and programs**, since we strive to have every member to understand the entirety of the design process. However, to ensure effective workflow and division of labor, each member has one or more primary concentrations when not working on other projects.

Alex
Build/programming

Henry
Scouting/programing

Zack
Build/drive

Zach
Drive

TJ
Build

Ellie
Build/documentation

Jonathan
Build

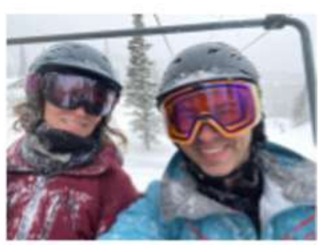
Jessica
Build

Sam
Outreach/documentation

Arjun
Outreach/build

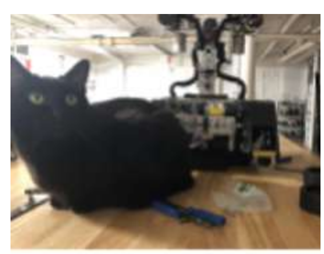
Finley
Documentation/
Testing

Rex
Programming



Cary and Cynthia
Coaches

Bear
Emotional support



Hotdog
Bodyguard

Motivate Award

Started	- FTC team 22489 with 10 members (6 girls, 4 boys), recruited 4 new members to 18754 - 3 FLL teams who competed at qualifying events. Team numbers 54604, 54605, 28140
Mentored	**- ~270 hrs total of mentoring throughout the team** - Team 22489 several hours per week (126 hrs total), qualified for the MA state championships - 30 Weston Middle School FLL students 4 hours per week (144 hrs), one qualified for state champs
Assisted	- BTI to secure facilities for the BTII FTC event - Provided design feedback and 3D printed parts for Lupine, Wolfpack Machina, and Tech Tigers - FLL team 55734 for several hours each month and donated a large number of LEGO bricks and our EV3 to help them get started
Published	- Weston Arts and Innovation Center presentation, broadcasted by local media center
Ran	- Robot demonstration at 2022 Weston Town Celebration, inviting Brainstormers to join us - Organizing a summer program targeted toward girls in FLL in partnership with the Weston High School Chapter of Girl Up (a United Nations non-profit organization)
Supported	- Volunteered at the Cambridge Science festival FTC robot zoo exhibit and demonstration
Reached	- We estimate that we have reached more than 2,400 people this season - 400+ people out of 640 students at our high school through demonstrations and events - 600+ people out of the 100,000+ who attended the Cambridge Science Festival - 400+ people watched our demonstration at a Weston Town Celebration - 1,000+ people via fundraising efforts through WEEFC boosters and Weston Owl (local news). Raised $100,000 in February via donations from nearly 600 families. - Hosted aspiring young engineers at practices, introducing them to FIRST programs
Advocated	- For a new school GNCE Robotics and Engineering Lab - GNCE proposed the idea to school administration and helped them to craft the proposal that was unanimously approved by WEEFC and School Board in February. Will be completed this summer.

GNCE's long-term goal is to establish and grow a top-ranked FIRST organization that is sustained after its original members graduate from high school. To accomplish this mission, we have developed a multi-year plan to expand robotics in our small town of Weston, Massachusetts.

Year 1 (2019): Proposed a Town Robotic Center

To allow more students to participate in FIRST programs, our FLL project was a proposal for the preservation of unused town historical buildings by transforming them into a community robotics center.

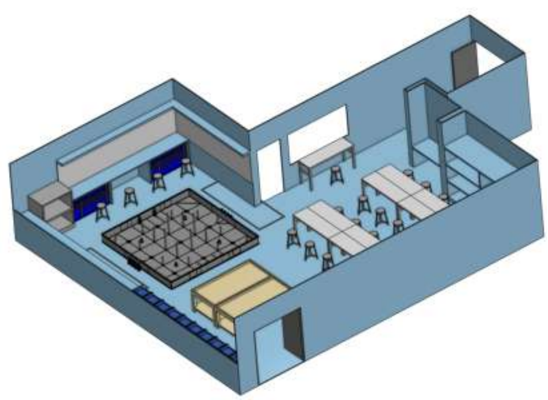
Year 2 (2020): Raised Community Awareness
Partnered with the Weston Arts and Innovation Center to demonstrate accessibility of FIRST using both our FLL and FTC robots. Worked with Weston Media Center, our town's local community communication service, to produce a public online recording.

Year 3 (2021): Started and Mentored Two FLL Teams
- Advocated for school funding of FLL teams
- Recruited and formed two teams **(20 students and 4 parent coaches).** Mentored several times per week, and both teams competed at a qualifier competition
- Introduced FTC to FLL teams via robot demonstrations

Year 4 (2022): Started/Recruited New High School FTC Team
- Advocated for school funding of FTC teams
- Recruited **10 new members for the team (6 girls, 4 boys)** and mentored them during their weekly practices
- Started **3 new FLL teams (30 students and 8 parent coaches)**
- Recruited 4 new members for our team

Year 4 & 5 (2022-2023): Transitioning to the Next Generation

- Designed and advocated for creation of new **FTC and FLL GNCE Robotics and Engineering Lab**
- Provide dedicated space for FIRST fields and equipment to support up to **3 FLL and 4 FTC teams** (one team per grade).
- **Approved unanimously** by school board and WEEFC academic boosters program
- **Raised $100,000 from nearly 600 families in February**
- Will be completed during summer 2023
- This summer we plan to create a playbook with our proposal and fundraising strategies to help other teams to build support for creating their own FIRST Engineering Lab based on what we learned from our experience



Outreach Events:

GNCE acts as an ambassador for *FIRST* by holding events with our community to raise awareness of *FIRST.* Through various demonstrations and events this season, **GNCE has reached over 1,400 people.** One way we have cultivated the next generation of *FIRST* is by inviting aspiring young engineers to our practice space to introduce them to the opportunities *FIRST* provides and the number of ways in which they can become involved.

During a town celebration for the completion of a major town center renovation, GNCE organized and ran a booth to promote FIRST in the community. We invited fellow MA FTC team #8644, The Brainstormers, and held practice matches and demonstrations where people from all backgrounds had the opportunity to drive our robot and learn about FTC. At this event we reached several hundred people.

At MIT's 2022 Cambridge Science Festival, we volunteered to be a part of the full day FTC exhibit with several fellow MA FTC teams. We demonstrated our robots from last season and talked to parents and their kids about FIRST programs. In the end, we reached more than 600 people who attended the festival that week.

In order to raise awareness about the new *FIRST* robotics programs in our school, we held recruiting events during lunch period and at our school's activity fair where we could reach the entire school at once, allowing us to present our robot and educate the student body about FTC. At these combined events we reached 400 people.

Financial Plan

Our families agreed to annual dues of $400 per family for the regular season. We agreed that additional dues would be charged based on the actual costs of the postseason events team members attend. Our team and team 22489 share a combined budget, avoiding the administrative burden of dividing parts and money between the two teams. We anticipate staying within our operating budget.

Income (2 teams)	Per student	Total
Rollover prior season		(247)
Sponsors		1,118
Regular season dues	400	9,600
Event dues		6,000
Season Income		**16,471**

Expenses (2 teams)	Budget	As of 3/3/2023
Fees	590	590
Robot	8,000	9,078
Field	700	795
Events	5,000	2,788
Other	1,000	821
Season Expenses	**15,290**	**14,073**

In addition to our operating budget, we also assisted our school academic boosters (WEEFC) and school board with raising $100,000 in February 2023 from nearly 600 families in a focused campaign to support the GNCE Engineering and Robotics Lab that we proposed to our school administration. A copy of the proposal and infrastructure budget are available in our pit for review.

Connect Award

Skills development
Many of our team members completed an engineering course to learn CAD/Onshape principles; those who did not take this course were taught CAD by Coach Gumbert and the other members of the team. We also studied online resources such as ohhgm0.org, Automatic Addison and Robo Grok to help us determine motor sizing and calculate whether the torque of the motor and worm gear were adequate.

Mentors and sponsors
A team goal was for our new members to learn how to create 3D printed custom parts that were better than those from purchased kits in terms of size and strength requirements. To support this goal, we toured Markforged's facilities and labs. We invited several other MA FTC teams to join us, allowing them to also learn from the experience. Travis Norris, mentor for FRC team 2423 and Markforged engineer, sponsored our request to print our chassis on one of their industrial printers.

Wayne Penn from Boston Tech Initiative helped us early this season with defensive and offensive driving strategies. Based on his tough questions we improved our design and strategy. Particularly, his advice to thoroughly consider game strategy led us to create our own scouting program, an asset for tracking team data during important playoff matches. Additionally, we are thankful for Mr. Penn's help in connecting us with FIRST team 5298 from The Bronx, NY during the offseason, expanding our reach within the FIRST community.

To learn from the technical community, we held design reviews with experts from our community, including Stephen Boardman (WHS Engineering Teacher), Dr. Boris Korsunsky (WHS Physics Teacher), Vahid Atefi (Software Engineer), and Mads Schmidt (Robotics Engineer). After presenting our robot, they gave us incredibly valuable feedback about possible future improvements. Some of the most notable suggestions include using sensors to update our position on the field while driving autonomously, adding a second worm gear to reduce stress on the shoulder, adding a second servo for the turret, and transitioning from procedural to object-oriented programming.


Meeting MarkForged Engineers


Design Review with Mads Schmidt


Strategy Review with Wayne Penn

Design / Think Award

Autonomous Period Strategy

- Cycle starting cone plus five stacked cones on high junction (5 points per cone * 6 cones = **30 points excluding the points also scored for TeleOp by these cones**)
- Detect custom signal cone and park in correct zone (**20 points)**
- Minimize turns and driving to limit errors
- Use distance sensors to measure and dynamically adjust for errors

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Total autonomous points: 50 points scored

TeleOp Period Strategy

- By running simulations with humans acting as robots, we determined that alliances in which both robots focus solely on cycling cones or focus solely on setting up circuits do not perform as well as alliances which have one bot setting up circuits and the other cycling cones. We also found the greatest **net points** were gained by controlling as many junctions as possible by flipping the opposing alliance's junctions in order to secure our circuit. In other words, we aim to **flip 3 points away** from the other alliance and create a net score change of **6 points for every cone flip**.
- We start by flipping the highest opposing controlled junction (not including ground junctions). Once all of the opposing controlled junctions are flipped, we then switch to the tallest available empty junctions (not including ground junctions). Once we own all the reachable low junctions, we then add more cones to the tall junctions. This strategy led us to design a robot that could flip many junctions without moving its chassis at all.
- Estimation of junctions flipped:
  - 4 high junctions: 11 net points per flip * 4 junctions = **44 net points (32 points)**
  - 2 high junctions: 5 net points no flip * 2 junctions = **10 net points (10 points)**
  - 2 mid junctions: 9 net points per flip * 2 junctions = **18 net points (12 points)**
  - 2 low junctions: 8 net points per flip * 2 junctions = **16 net points (10 points)**
  - 1 terminal: **1 net point (1 point)**
- Cones previously scored during Autonomous Period:
  - 6 cones on one high junction * 5 points each = 30 points

End Game Period Strategy

- Use one or both beacons to prevent the opponent's circuit
  - Our completed circuit + preventing opponents' circuit = 20 + 20 **= 40 net points (20 points)**
  - One beacon = 10 points flip ownership = **13 net points (10 scored)**
- Terminal parking bonus not worth the extra two points – instead, we will focus on continuing to cycle cones until the end of the match unless we run out of cones and then we can park by extending the arm

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Total TeleOp and end game points: 172 net points, 125 points scored

In a traditional event our strategy target is 222 net points including flips (175 scored points), not including points scored by our alliance partner. In a controlled solo match (no alliance partner or competing teams) our current robot design is able to score 175 points consistently.

Design Process

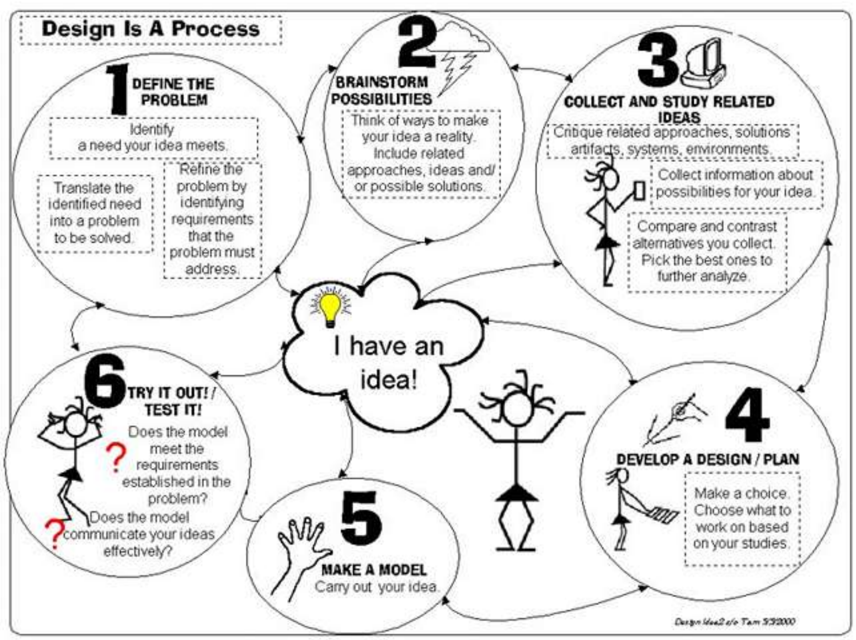
We chose to use an iterative design process as illustrated in the figure from Stems Robotics below.

- **Step 1 (defining the problem):** developing overall strategy, listing constraints which the robot would need to follow (size constraints to avoid penalties, intake constraints to avoid picking up more than one cone, constraints to allow for navigation between junctions, etc).
- **Step 2 (brainstorming):** generating mechanical and programming concepts we thought might work best for the challenge, taking into consideration the requirements defined in Step 1.
- **Step 3 (collecting ideas):** expanding upon step 2 concepts, determining parts required for each approach.
- **Step 4 (developing a design):** specifying the required parts, sensors, and programs needed to execute the concept, creating hand drawing/CAD renderings for 3D-printed parts, writing the control programs.
- **Step 5 (building phase):** creating rough prototypes of essential design components before 3D printing.
- **Step 6 (testing):** concluding which parts of the designs were the most effective, often combining the best concepts to create the most effective overall design.

We often returned to earlier steps to rethink our approaches based on lessons learned. This iterative design process is most visible within the chassis, intake mechanism, and arm designs, described in detail below.

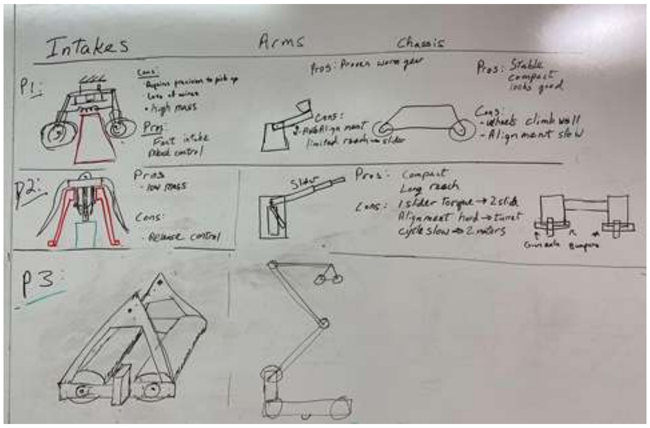
Arm Design Process

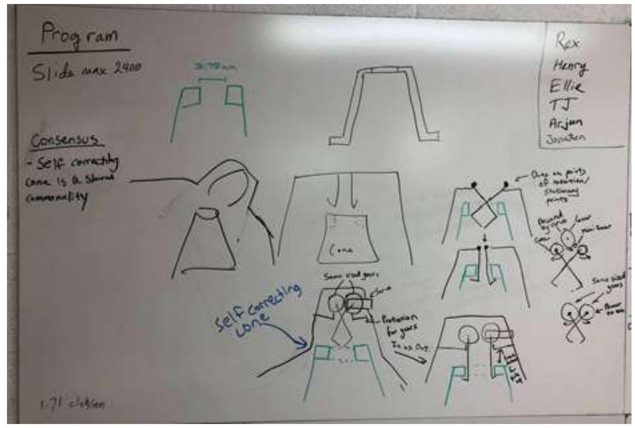
(Following the steps of the iterative design process diagram)



Step 1: We first planned to allow the robot to reach all four junction levels, as well as to pick up and deposit cones with minimal driving to maximize cycle speed. Flipping junctions while minimizing driving was a key catalyst of our design.

Step 2: We then brainstormed five alternative arm designs– the elevator, the diagonal elevator, the two linear slides handing off to each other, reverse four bar linkage, and the swinging arm (with and without multiple joints and pivot base)– weighing the pros and cons of each. We considered factors such as precision, complexity of programming, robustness, wire management, and consistency.





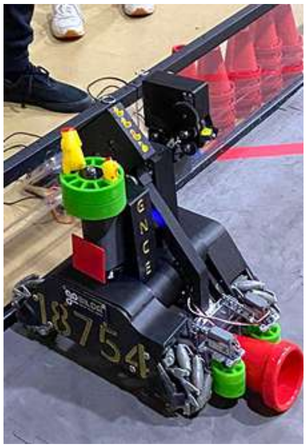
Step 3: We researched components vital to the function of each arm design, such as linear slides, and how to best use them in the elevator design. We also drew inspiration from mechanisms used in previous VEX competitions. The construction of the turret and arm complex also required focused research in topics including steel vs. aluminum slides, servo blocks, and double motor worm gears.

Step 4: Factoring in time constraints, we planned on designing the simplest mechanism first, i.e. the swinging arm with one joint, as it would be the fastest to design and prototype.

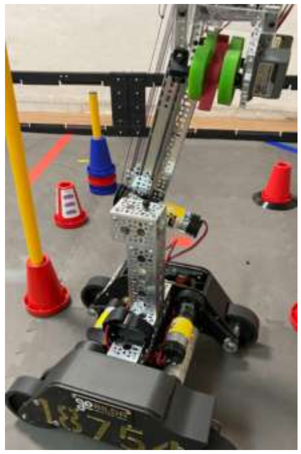
Step 5: Our first prototype was the single pivot arm from last season's robot. However, it was unable to reach the medium or tall junctions, so we began prototyping a pivot arm with linear slides. We went through multiple iterations - such as adding a second linear slide for greater strength and stability and attaching the arm to a turret for greater range of motion - as well as various materials.

Step 6: During prototype testing, we ran into tipping issues caused by the heavier steel linear slides and the extended reach. We redesigned the slides to use aluminum draw slides and added 28 lbs to the chassis to lower our center of gravity. We also added protective extrusions for the base of the turret to prevent wires from catching in the gears.

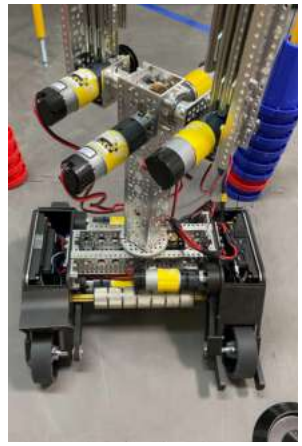
Just before our first qualifier during testing we experienced a worm gear failure from the stress brass teeth of the gear. We quickly added an additional gear to our worm gear mechanism at the recommendation of our high school's engineering teacher during a design review. This halved the strain on the brass gear and should help to prolong its lifespan. A further iteration of the design added linking gears on the outside of the tower to synchronize the two motors and enables us to manually move the shoulder without power.



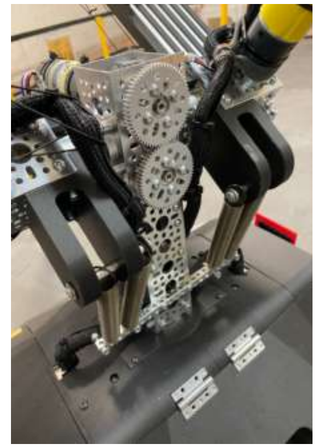
Earliest arm prototype



Single motor worm gear, slide and no turret



Dual motor worm gear and steel slides

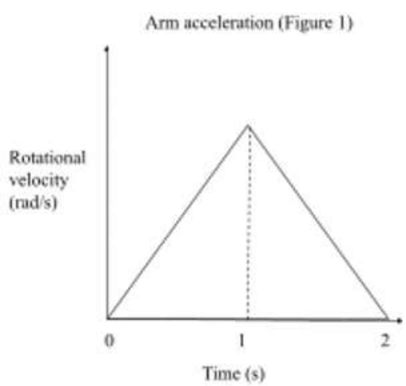


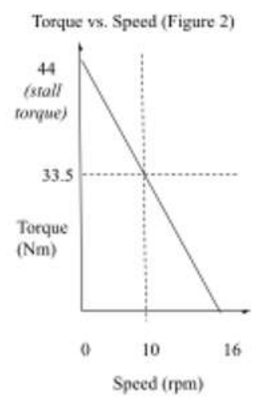
Current design

Several of our technical mentors and team 18438 Wolfpack Machina suggested we add springs as a counterbalancing force. We custom designed and 3D printed the mounting mechanism pictured above. Through additional modeling and testing we determined it was possible to replace our previous 435 RPM motors with lower torque but faster 1150 RPM motors. This decreased our autonomous cone cycle time from 5 seconds to under 4 seconds per cone which is fast enough to deposit 6 cones and park during the 30 second autonomous period and empty the substation of the remaining 18 codes during the 2 minute manual period.

Arm Motor Sizing Calculations

We set a goal of moving 120 degrees in two seconds (10 rotations per minute). We modeled a load torque to move the slides, claw, and cone in that time assuming linear acceleration and deceleration (Figure 1) and added the torque needed to offset gravity when the arm is fully extended in a horizontal position (maximum load torque on arm).





We realized in prototype testing that a single arm would twist with the weight of the intake so we added a second arm to stabilize. We also modeled steel and aluminum slides to reduce the mass of the slider by 32%. The aluminum slides decreased the maximum load torque by 20%.

Table 1: Load Torque from Gravitational + Angular Acceleration

	Steel slides			Current Design	
	Mass (kg)	Torque (Nm)		Mass (kg)	Torque (Nm)
Springs	0	0.00		0	-7.26
2 Slides	2.8	19.66		1.9 (aluminum)	13.34
Claw	0.7	10.56		0.59 (new design)	8.89
Cone	0.07	1.10		0.07	1.10
Total		**31.3**			**24.8**

We modeled multiple motors with different gear ratios to determine the optimal combination of speed and torque. To solve for the available motor torque at a goal of 10 RPM, the free speed of the motor is plotted against the motor stall torque specification from the manufacturer (example of current design shown in Figure 2).

For example, our calculations (Table 2) showed that the goBILDA worm gear paired with one 435 RPM motor only provided 58% of the required torque and was unable to lift the dual steel goBILIDA slides fully extended. When a second motor was added, the stall torque doubled and increased the output to 117% of the required torque, meaning that our goal was barely achievable and was quite slow in testing. When modeling the lower mass aluminum sliders, they provided a safety margin of 147% of the load torque.

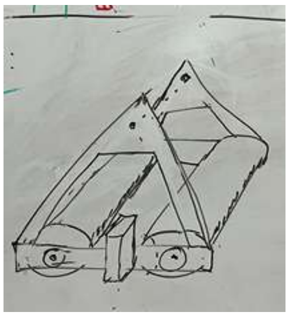
Our technical mentors suggested a torque ratio of 200% or more is a good rule of thumb. To achieve this we modified our control software to retract the sliders from 1.22m to 0.5m while lifting the shoulder joint from the maximum torque horizontal position when possible. This increased the motor to load torque ratio to over 400%. After we added springs and redesigned the claw to be lower weight this further increased the ratio allowing us to lift the fully extended arm with more than the recommended 200% torque ratio. We continue to use the software to retract the arm before lifting when fully extended to provide extra margin and reduce the wear on the gears.

Table 2: Motor Sizing

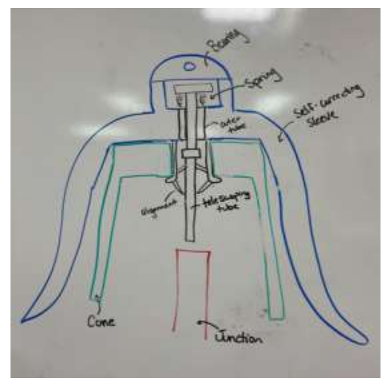
Motor Options	Stall Torque (Nm)	Free RPM	Motor Torque (Nm)	Load Torque (Nm)	%
Steel + 1x 435 RPM and worm gear	51	16	18.3	31.3	58%
Steel + 2x 435 RPM motors	102	16	36.5	31.3	117%
Aluminum + 2x 435 RPM motors	102	16	36.5	24.8	147%
Alum + 2x 435 RPM motors (retracted)	102	16	36.5	9	406%
Alum + 2x 1150 RPM + springs (extended)	44	41	33.5	16.1	208%

Intake Design Process
(Following the steps of the iterative design process diagram above)

Step 1: We defined the required characteristics of the intake at the end of the arm, including low mass to reduce weight of the arm, quick collection without precise aim, reach of large portions of the board with limited chassis movement, grip on the cone even through violent vibrations, and ability to prevent cones from falling over on the ground junction when removing the arm quickly. In later iterations, we returned to this step and defined that the intake should be able to lift cones from the autonomous stack against the wall without knocking the stack over.



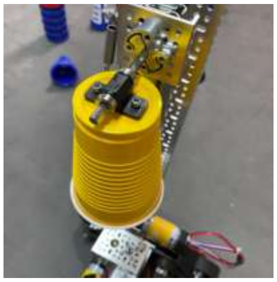
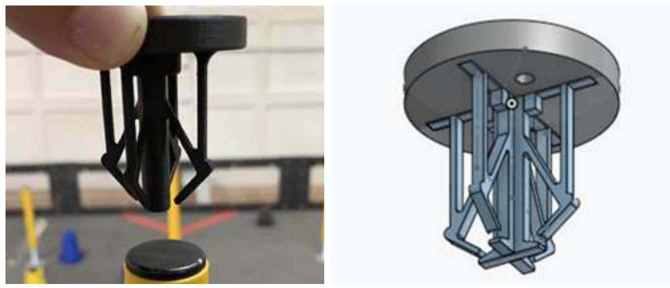
Step 2: Before brainstorming any new intake designs, we first tested our intake from last year's robot, and found that the compliant wheel roller design worked very efficiently. We brought our previous year's robot to the 2 week scrimmage at the start of the season, and this intake allowed us to win first place overall. In addition to continuing to tweak this roller intake, we brainstormed a variety of new intake designs. These newly brainstormed intake designs included 'roller intake,' the 'sticky intake,' the 'octopus intake,' and the 'claw intake,' each approaching our goals from very different angles:



- **Sticky intake:** By hooking a tape-coated plastic cup to a free-rotating axle and connecting it to the slider arm, this intake grips cones using friction and double sided tape rather than mechanically grasping them.
- **Octopus intake (shown at right):** Also known as the self-correcting sleeve, this intake features telescoping tubes attached to stabilizing pincers that take advantage of the force pressed upon the pincers by the junction being capped.
- **Roller intake:** This intake features long compliant wheels or wheels with multiple rubber bands that then allow for less driver accuracy and lower cycle time when intaking cones.
- **Claw intake:** Although a claw mechanism vertically sandwiches cones similar to a roller intake, it limits the weight at the end of sliders by eliminating the need for wheels. An over-centered linkage holds the claw closed without constant servo power. The design also allows the robot to reach the stack of cones near the field's edge during autonomous without hitting the wall.

Step 3: We then researched the types of compliant wheels available online for our roller intake, noting differences in wheel length, weight, and shape. We also looked into previous FTC and VEX challenges, taking inspiration from previous successful designs.

Step 4: We planned to create a prototype of each intake using experimental materials in order to confirm the measurements and figure out how to attach the intakes onto the arm.

		
Sticky Intake	Octopus Intake	Roller Intake

Step 5: After we created the prototypes, we narrowed down the number of intakes we wanted to continue pursuing and created the first metal and plexiglass iterations of the intake design. Notes on each intake prototype:

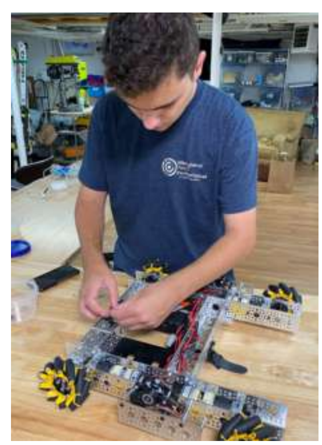
- **Sticky intake:** discarded due to difficulty unsticking the cup once grasped by the outer plastic. We also determined later this design is illegal due to residue left on cones, which is considered field damage.
- **Octopus intake:** discarded after CADing and 3D printing four iterations. Although functional, all of them were too stiff or too weak to be efficient intakes.
- **Roller intake:** discarded, as the cones consistently caught and stuck in the bands, and the surgical tubing was slippery and would not pick up cones.
- **Claw intake:** our current and most successful intake. Matched the efficiency of the roller intake but better for picking up cones stacked against the wall.

Step 6: Lessons learned testing multiple prototypes:

- The intake must lift vertically to avoid knocking over the stack of cones.
- We tested multiple types of surgical tubing and rubber bands for our claw intake. Thick rubber bands that are not too stiff are the best gripping mechanism.
- **Improvements:** After our intake broke at the Robostorm 7.2 qualifier in a hard hit with another robot, we designed a lighter and compact version using 3D printed brackets and accessible servos that can be swapped out by removing only 4 screws.

Chassis Design Process

(Following the steps of the iterative design process diagram above)



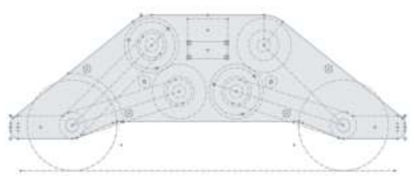
Step 1: A key aspect of our chassis design was the size constraint; the robot must be small enough to navigate and turn between junctions without hitting them or getting caught. We also wanted the robot to stay relatively stationary, maximizing depositing range while limiting turns necessary.

Step 2: We brainstormed whether a modified version of our 3D printed chassis from last year could accomplish these goals, deciding to test both the 3D printed chassis and a kit chassis with mecanum and odometry wheels.

Step 3: Before prototyping, we researched wheel alternatives to the Gobilda mecanum wheels, such as Rhino wheels which would allow us to have more traction while defending against other robots. While conducting research, we also found that our robot could become very top-heavy; we decided that a good solution to this would be to add weights to the bottom of the robot.

Step 4: We planned to test if the kit design with odometry wheels would meet our goals for the chassis.

Step 5: When building the chassis kit, we noticed that its size made it hard to traverse between junctions and the odometry wheels were frequently caught on the ground junctions while driving. This confirmed our decision to continue developing the custom chassis which showed more promise due to its compact and raised design.

 Refined design/geometry of the 3D-printed custom motors and pulleys	 Printing of the custom chassis with fiberglass layers to stiffen the parts	 Center protective covers to conceal space between pontoons

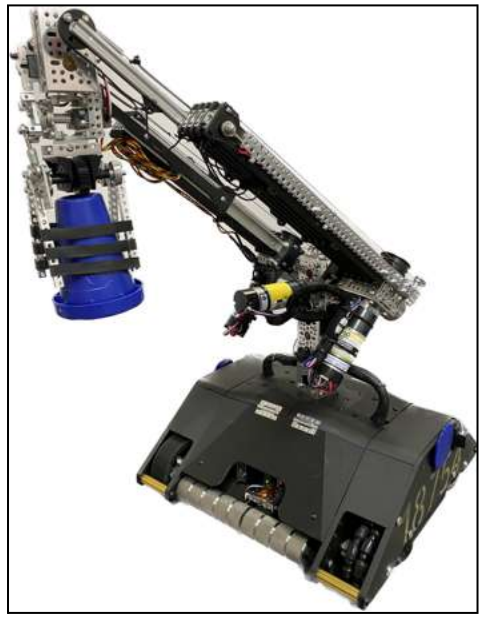
Since our custom chassis incorporates innovative motor geometry and a pulley system allowing it to elevate its middle section (as pictured above), we were able to attach a 20-pound weight to the bottom of the chassis in order to lower our center of gravity, both solving our tipping problem and making us more resistant to being pushed by other robots.

Step 6: Lessons learned by testing multiple prototypes:

- The chassis must be sufficiently heavy and have a low center of gravity to prevent the robot from tipping.
- Due to their traction, rhino wheels provided better traction than the mecanum wheels.
- That said, if the rhino wheels have too much grip, the robot has difficulty turning and is difficult to quickly align to new positions or make micro position updates to pick up cones.
- After our state championship, we arranged to test our robot's pushing capability against the Brainstormers and Wolfpack robots in a scrimmage. Based on that testing we settled on mecanum wheels for our current design. Mecanum wheels when combined with the heavier weight of our robot and lower drive gear ratios provided plenty of pushing power and more flexibility to rapidly reposition.

Once the chassis design was finalized, we designed and printed center protective covers between the chassis pontoons where the battery and sensors are located.

Industrial Design and CAD



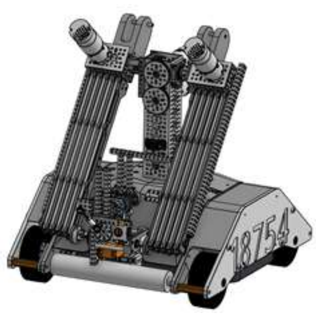
We decided to 3D print as much of our robot as possible to allow more creative design freedom so we could create a high performance robot that is aesthetically unique.

All printed parts of our robot were printed using Onyx (chopped carbon fiber) with layers of continuous carbon fiber or fiberglass, and by layering these elements in our parts, we increased the amount of strain our parts could withstand, making them as rigid as aluminum.

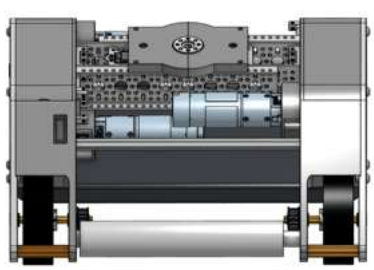
We applied industrial design principles to create a robot that is both visually pleasing and industrially sound. The robot's look was inspired by companies like Ferrari and Apple Computer, both of which create products that deliver high performance coupled with aesthetically pleasing designs by using clean lines and smooth curves.

The symmetric sloping front and rear panels protect the battery and sensors, but also prevent cones from becoming trapped on the robot which is a common source of penalties. The panels are hinged to provide rapid tool-free access to those areas. The two main side 'pontoons' are the primary structural backbone of the robot. The pontoon design consists of 4 custom 3D-printed parts held together by a handful of bolts and threaded inserts embedded into the printed part. Minimizing the number of fasteners supports a sleek look and improves our reliability, as we have fewer fasteners that become loose over time.

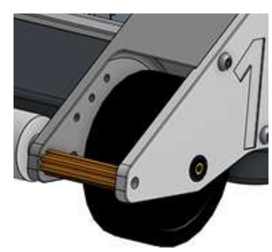
After an early qualifier where our alliance partner broke our claw mechanism, we realized we needed to incorporate more modularity into our design. We redesigned our arm assembly so that both the claw and sliders could be easily detached and replaced, constructing duplicate subassemblies.



CAD assembly of our robot

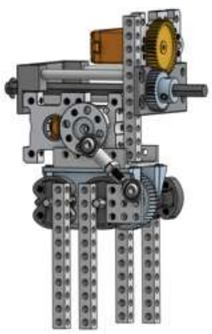
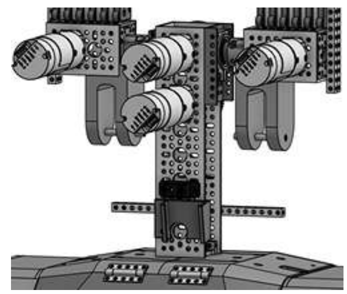


Front view of assembly



Updated chassis with bumpers

Other design highlights include front and rear stainless steel bumpers which enhance our look and add 8 lbs of counterweight for the extended arm while providing protection against collisions. An additional 20-pound black cast iron counterweight is attached to the bottom of the chassis and seamlessly blends into the design. The result is the 60+ pound robot appears much lighter than it is. Almost every team member designed at least one part of the robot.

 Center protective covers	 Top cover	 Turret covers
 Wrist and claw with access for rapid repairs	 Linear slides	 Camera mount, tower, turret, and spring mounting additions

Innovate Award

The arm assembly is unique and innovative compared to common designs that employ vertical or horizontal slides or four-bar linkages. The combination of a turret, shoulder, slides, wrist, and claw has proven to be highly effective. Extending up to five feet in any direction, the arm allows our bot to collect and deposit cones while remaining stationary, taking under two seconds from collecting a cone to reaching the far tall junction.

This provides drivers the ability to reach a zone of nine separate junctions with the push of 2 buttons. Our robot can flip the opposing alliance's junctions while maintaining control of our own, supporting the central principle behind our original game strategy.

Key arm assembly innovations (greater detail found in Design/Think):

- **Turret:** The turret is driven by redundant high torque servos and gears for 360 degree reach.
- **Double worm gear shoulder:** The shoulder leverages a worm gear powered by two redundant motors.
- **Dual slides:** Dual aluminum drawer slides with custom designed 3D printed spacers are lightweight and have integrated wire management. The slides will continue to operate if one of the redundant motors fails or the 200 lbs rated string breaks.
- **Claw and wrist:** The claw is designed to pass through the two slides with a cone. It lifts stacked cones without knocking them over. An over-centered linkage keeps the claw closed without power.