Mechanical Design & Game Analysis: Part 2

2024 FRC Kick-off: CRESCENDO

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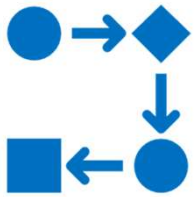
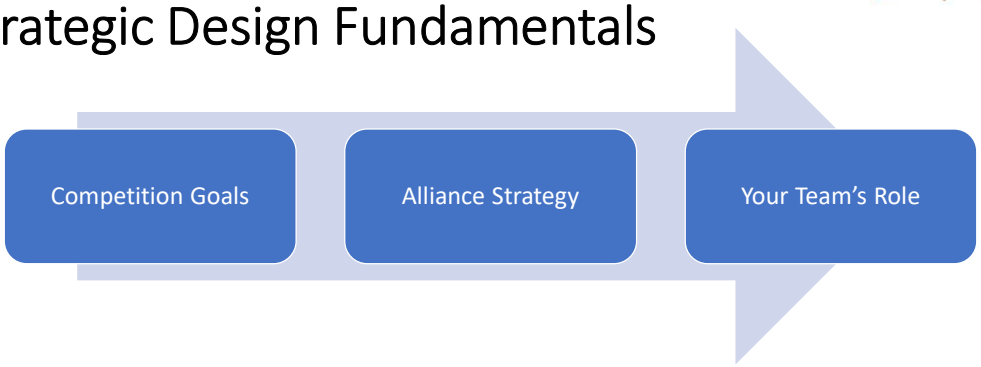
Design Process



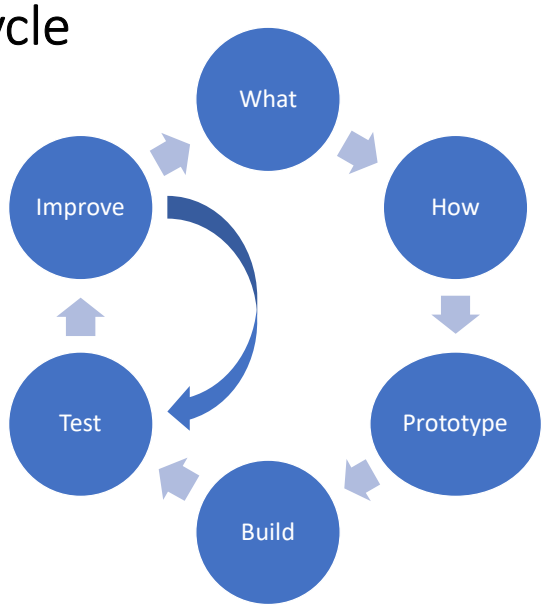
Strategic Design Fundamentals



Goals drives strategy
Strategy drives design
Performance target drives improvement

This is a review of the previous part 1 class that covered FRC Game analysis. Goal setting for the season and competition is important to help selecting your team's strategy.

Design Cycle



This is a typical design cycle that also describes an approach to FRC robot design.
What: This is the list of tasks your team chose to perform as part of your game strategy analysis.
How: This is the beginning of how you will build the robot to complete the game tasks.
Prototype: You might choose one or more ways to accomplish the task. Some of these methods will require testing through prototypes.
Build: Building phase is not one step. For example, you should build your drive base as early as possible and not wait for every subsystem to be prototyped first.
Test: Testing of the 1st version of the robot would ideally be about 4 weeks after kickoff.
Improve: Improving never stops, especially now we are in the "District" model with multiple events. It is very difficult to pick out and solve all issues in the design/prototype phase. Get it built and tested fast, then improve.

The "What": 2023 Example

- What is our selected game strategy / game role?
- What are our scoring targets? How much / how fast?
- What game tasks are high priority?

- Season Goal
  - Make District Champs
- Competition Goal
  - Be 1st pick or Alliance Captain at both district events
- Alliance Role / Strategy
  - Be a high-volume cube specialist scoring 9 game pieces per match.
- Rank Point Skills
  - Auto Balance
  - Focus on creating links on the floor level nodes
  - End Game Balance with partners

Period	Task	Needs / Wants
Auto	Score Mobility Points	MUST
	Score Charge Station Balance	MUST
	Score Preload Cube	MUST
	Floor pick up second cube	Want to have
	Score second or third Cube	Stretch goal
Tele-op	Collect cube from Double Station	NO
	Collect cube from Single Substation into top of robot	Maybe
	Collect Cube from floor	MUST
	Score Cube low	MUST
	Score Cube mid	Want to have
	Score Cube high	Want to have
	Collect and score Cones	NO
Endgame	Balance Charge Station solo	MUST
	Balance Charge Station with partner	MUST
	Balance Charge Station with 2 partners	MUST

More review of the preceding game analysis presentation. This is a specific example of a team's goals and how that impacts the game analysis and tasks selected. The above task list example was a real task list for 4451's offseason robot built to compete at SCRIW in October 2023. The "season goals" represent what this robot task list could achieve.

Please note: There are some hard choices made in this strategy decision. There are two game pieces available in the 2023 Charged Up game. This task chose the "CUBE" game piece only since it is easier to grab and score. We also focused primarily on low goals. Charged Up had a ranking strategy that included an alliance scoring "links" of three game pieces in a row. Being faster by scoring a simple game piece low gives our alliance the opportunity to complete enough links for a rank point bonus. However, someone on the alliance needs to score at least 2 "CONES" to have enough links for the rank point. That is very reasonable for most qualification alliances.

End game – and its associated rank point – was easy in Charged Up. Essentially this could be accomplished with a drive base, low center-of-gravity, and an autonomous routine to balance the "CHARGE STATION".

The "How": FIRST and Team Resources

FIRST Provided Kit Bot Design

Team and Vendor Resources

- Open Alliance / Robot in 3 Days
  - Find through ChiefDelphi.com
  - SC Teams: 342, 1102, 6366
  - Other Teams:
    - 3847 Spectrum
    - 4481 The Rembrandts
    - 6328 Mechanical Advantage
- Robonauts Everybot
  - https://www.118everybot.org/
- Vendors
  - REV Starter Bot
  - WestCoast Products Competive Concept

For the first time ever, FIRST is publish a full "kit bot" capable of driving AND scoring game pieces. The kit bot drive bases have been around many years and is always a solid, robust choice. The kit of parts will also include a design and some of the parts needed to make a simple scoring section. Teams will have to provide some raw building materials.

I HIGHLY recommend teams with limited experience build this robot first. I believe it could be built and running in 1 week! That's a huge advantage to get it running then focus on improving the design or coming up with an alternate design. My team will build this as a second robot using some of new students as a great learning experience.

There are four other sources of design inspiration available to everyone: "Robot in 3 Days", "Open Alliance", "Everybot" by team 118 "The Robonauts", and past games.

- Robot in 3 Days: There are several groups of mentors and students that quickly build a fully functional robot in 3 days to complete most of the game tasks.
- Open Alliance: There are LOTS of FRC teams that openly publish everything they are doing including prototypes and CAD drawings. The "Open Alliance" is a subset of those teams that have also agreed to document daily / weekly progress reports through the website "ChiefDelphi" and potentially be interviewed by the "FUN (FIRST Updates Now)" YouTube team.

- Vendors: There are two vendors, WestCoast Products and REV, that build robots using items they sell as good example of how to use their build system.
- Past Games: More on the next slide…

NOTE: 4451 uses all these resources to guide our build and prototyping process. For example, we usually have limited time to test and prototype a wide variety of designs. We only prototype a few choices. We can monitor other teams for items would don't have time to chase.

The "How": Use Game History & Prior Robots

Game History

- Pick and Place Games…
  - 2011, 2015, 2017, 2018, 2019
- Shooting Games…
  - 2012, 2013, 2014, 2016, 2017, 2020, 2022
- Climbing / Lifting End Games…
  - 2007, 2010, 2013, 2016, 2017, 2018, 2019, 2020, 2022
- Driving over items on the field…
  - 2012, 2016, 2020
- Driving up ramps
  - 2006, 2007, 2012, 2018, 2019

"Steal from the best :: Invent the rest"

Using past games is a great way to get a start on design. Game tasks are usually repeated with some variations. The above list of games grouped by type of task.

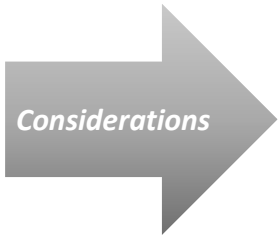
Use Theblue alliance.com to see videos and matches of past games.

Mechanical Systems: Drive base

DRIVE RULES

If you can't drive, you can't play.

Can't play well without practice.



- Do not experiment with drive trains. Use a go-to solution.
- Wiring must be PERFECT.
- Radio must be protected, well mounted and use Power Over Ethernet.
- Bumpers must be well built and not fall off.

If something fails on your robot during a game, you can always switch to playing defense and contribute to the alliance. If your drive train fails…. Not good.

Practicing with robot that might not have a perfect scoring system is better than not practicing. Practice is critical to good game play and improving the design.

Kit Bot Drive Base from AndyMark

Recommendations

- Kit bot drive base with 4 motors minimum. May need wheel upgrade depending on game.
- Kit bot upgraded to brushless motors
- Kit bot upgraded with brushless & gyro

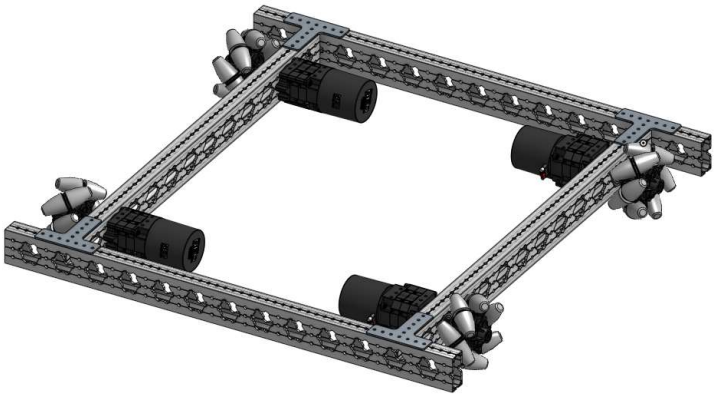
Kit bot drive is mechanically sound chassis for most teams. Recommend this is the first thing you build after review the FRAME PERIMETER rules and selecting the appropriate chassis size. The full size chassis will be too big. I recommend you leave the length the same and make it slightly narrower.

Recommendations:

- Rules allow 4 drive motors total. Do not build the chassis with only 2 motors. Typical FIRST will supply the kit bot with brushed CIM motors.
- Upgrade 1: If possible upgrade the drive system to brushless motors such as the REV Vortex or NEO motor. These motors provide power more efficiency. They also include encoders which gives you the possibility of more autonomous control.
- Upgrade 2: Add a gyroscope such as the NavX2 that can be purchased through AndyMark. This really upgrades the software possibilities to program autonomous "path following" modes for improved auto scoring.

Mecanum

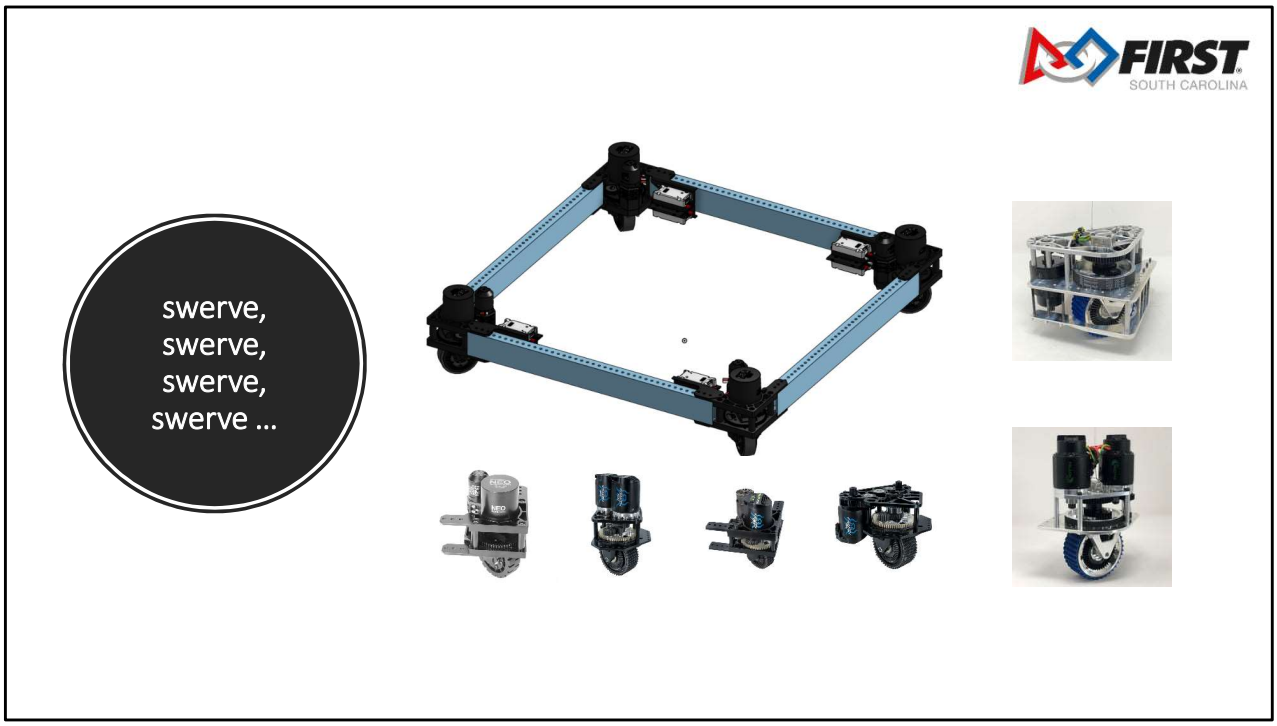
- Go-to omni-directional drive train prior to COTS swerve revolution.
- Need to drive it like an omni-directional drive base.
- *NOTE: The kitbot can be upgraded to mecanum but would require 4 gearboxes. AndyMark has instructions for this upgrade. The picture drive base is a custom built system.*



Mecanum drive system have a love / hate relationship with FRC. This is a good option for simple omni directional driving.

Key issues to consider:

1. A lot of teams may not pick a mecanum drive robot during alliance selection. It does not hold up well against heavy defense.
2. Can do simple autonomous driving with mecanum. It is difficult to implement more complex routines such as path following.
3. In my observations, most people are not well practiced enough to take advantage of the omnidirectional features and simply drive it more like a tank drive.



Recently FRC vendors have started to sell very robust swerve modules and include software libraries to control them. This has made swerve accessible to a lot of teams. In my opinion, this would only be considered if you team goals are to win district championships as the alliance captain or 1st pick. Other teams are welcome to use it with the following STRONG cautions:

- Swerve is expensive – about $2500 to $3000 dollars, plus you will need to buy spare parts. Fortunately, these modules, if maintained, will last several seasons.
- You should build the system in the offseason to get use to it.
- You should also have some confidence in your software team to implement swerve. You still need to understand code enough to adjust parameters and control loop tuning values.
- You MUST have good gyro to make this work. The CTRE Pigeon 2.0 and NavX2 are standard FRC options.
- You should have at least one backup module fully assembled and tested to use as a replacement unit during competitions.

NEWTON'S RULE

Gravity is not your friend.

Considerations:

- Low center of gravity is critical for "drive-ability".
- Can compensate with software ramping of the motor controllers.

A well placed and low center of gravity (COG) make any drivetrain better performing and more controllable for the driver. High COG will show up as a tippy or unstable robot especially when starting or stopping. COG should also be near the center of the robot. If one end is heavy, it will be easy for the drive base to pop a wheelie.

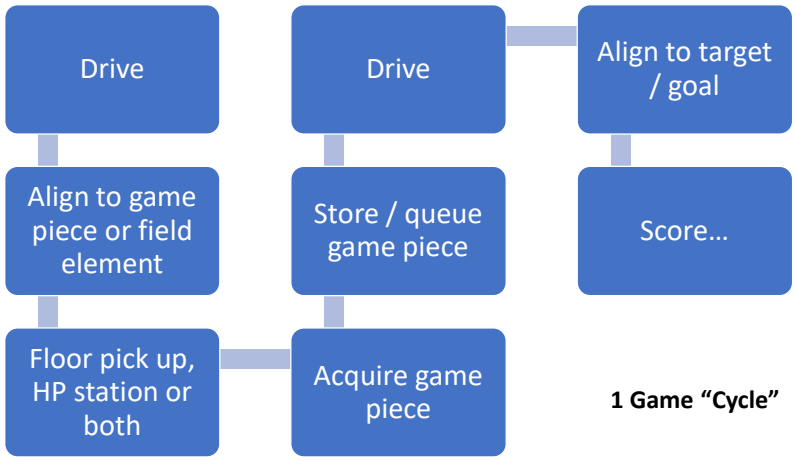
Fixes:

- This should be a key consideration in the design process to prevent the issue.
- If the robot is under weight, add solid sports weight as low as possible. Secure tightly to the drive base.
- Most motor controllers are now equipped with a "ramp rate" function. This allows the driver to use the joystick without having to manually control the tippiness. We typically use 0.5 to 0.75 seconds ramp from 0 to full power.

Mechanical Systems:

Intakes / Game Piece Acquisition

Basic Game Process



This simple flow chart describes a full cycle from collecting game pieces to scoring. Consider EVERY step above in the design instead just focusing on the last box --- "score."

INTAKE RULES

*Always motorize game piece acquisition.**

Drive Train

- Pick up game piece while driving
- Don't drive over the game piece and get stuck
  - Need something "under" the game piece to lift it (bumper/bar/roller)
- Don't stop short of the game piece

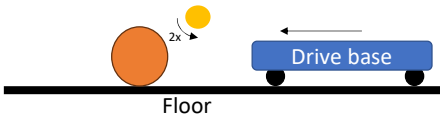
Alignment

- Wider is better
- Self centering if needed

Sight Line

- Does the robot block your view?
- Can you add some type of indication that you acquired the game piece?

Roller surface speed = 1.5 to 2x drive speed



** Unless you are dumping game pieces into a hopper from above.*

This page is mainly referring to picking up game pieces off the floor.

Wheels, Wheels, Wheels & Rollers

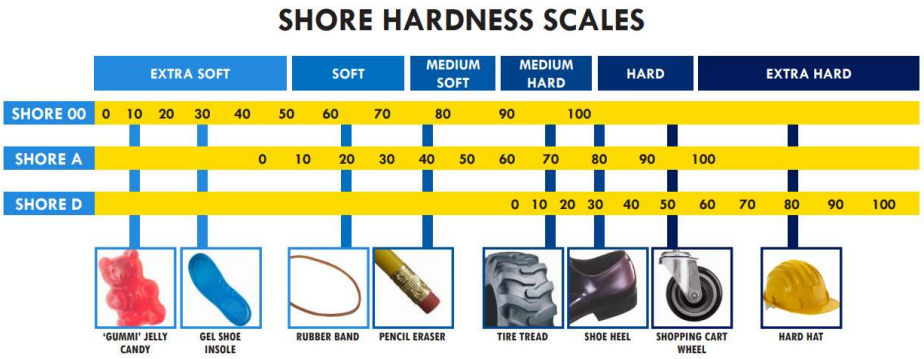
Compliant Wheel

Non-Compliant Wheel

General rule of thumb:
If the game piece is hard – use squishy wheels. If the game piece is squishy – use hard wheel for intaking. It also makes if a difference if you also going to use the wheel to either secure the game piece while driving and/or using the same wheels to “shoot” the game piece.

Rubber hardness

Shore "A" scale for molded rubber



Most of the wheels used in FRC are rubber or rubber coated. The Shore A scale can be used to select good wheels for the game piece and task.

Most of the FRC range from 35A durometer to 90. You will need replacement wheels if using the softer wheels like 35A. They are literally like a pencil eraser and will wear out.

Wheels, Wheels, Wheels & Rollers

Mecanum

Omni Wheels

For intake or conveying systems, omni and mecanum wheels can be used to help the game move sideways compared to the rotation of the axle.

Omni example: The game piece needs to move from a wide zone to a narrow chute or conveyor in the robot. Use omni rollers to prevent the ball from binding if it needs to slide left or right.

Mecanum example: These are usually used outside the robot to actively move the game piece to the left or right while collecting. FYI… these wheels come in a “left” or “right” version. You will need both types to be effective.

Wheels, Wheels, Wheels & Rollers

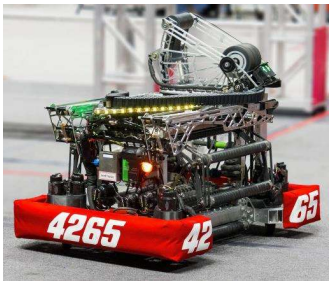
Continuous Roller

VersaRoller Easy Drop Example

Full width rollers are also good for intakes and/or conveyors. Typically, these are hollow polycarbonate tubes. Team will cover the smooth rollers in grip tape or rubber to make them a bit more sticky.

Ball Pick Up

Thru Bumper - Serialize Outside



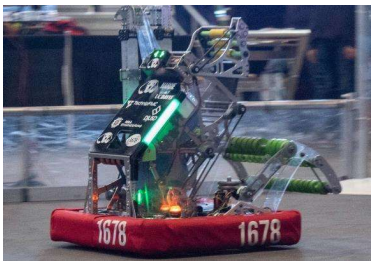
These robots “centered” the game piece while it was still on the floor before entering the robot internal conveyor system.

Robots on the left and right are using sets of mecanum wheels to active center the ball to central bumper cut out.

The robot in the middle used their swerve drive to align to a single ball and brought it through the bumper.

Ball Pick Up

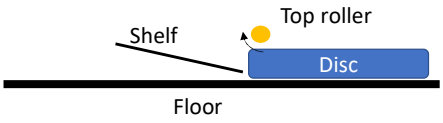
Over Bumper Serialize Inside

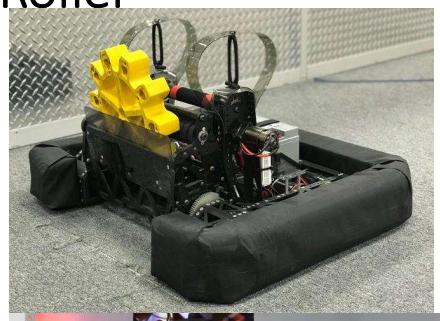


Another design approach is to bring balls in the robot over the bumper. PLUS: A wide intake zone makes it easy to pick up one or more balls without a lot of drive maneuvers. CON: One the ball is inside the bot, you need a hopper system to serialize the balls in a line before scoring.

It is also very important to consider the height of the bumper compared to the ball. You want to use the top roller to pull the ball up and over the bumper. But you need something “under” the ball to pinch against. Most cases, the bumper works. There are situations where you would need a pinch bar or second powered roller under the ball to aid pickup.

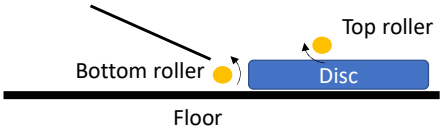
Disc Pickup – Shelf and Roller





Flat objects definitely need an over/under approach for pick up. Typically this would be a piece of polycarbonate as a shelf / spatula and a powered roller on top to pull the piece toward the robot.

Disc Pickup – Over/Under Rollers

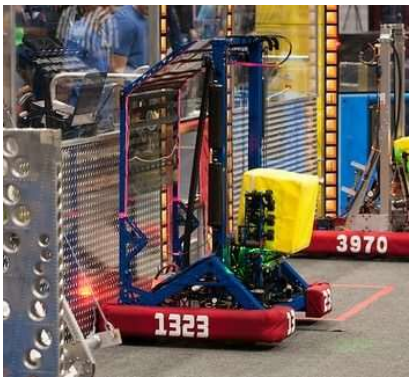


It is also possible to use an over / under roller combination.

Box Pick Up - 2018

Over/under roller & scoop

Side rubber wheels



Side compliant wheels

Over / under roller & scoop: This was 1619's robot. I asked them about this configuration which was unique for the year. It gave them a wider pick up zone for autonomous modes that captured several game pieces over the course of several steps.

Side rubber wheels: These are hard-ish, not compliant rubber wheels. However, they used a pneumatic cylinder to open up the intake and clamp the piece. The wheels pulled toward the robot for consistency.

Side compliant wheels: Compliant wheels are usually a good choice for a harder object than needs grip. Again, this also used a pneumatic clamping claw.

Inflatable Tube Pickup – 2011 Logomotion

Over/under paddles

Over/under roller

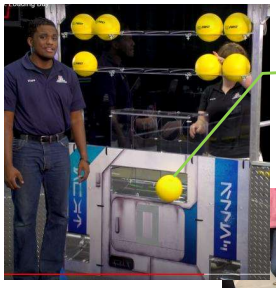
Over/under wheels

Over/under paddles: This violates the powered roller concept. But it worked fine for this game since most pick up zones were protected from defense.

Over/under roller: Nice wide pick up zone.

Over/under wheels: They emphasized a lightweight roller system.

Human Station Pickup – 2017 & 2020



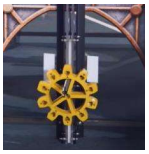
High level HP ball feeder

Shelf/hopper to receive foam balls

1758 Technomancers

Sloped HP feeder

Hopper to receive "Gear"

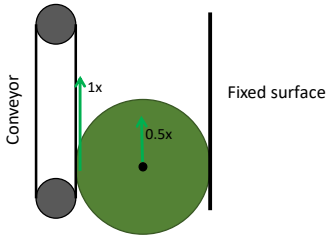


These are examples of human loaded machines. 1758's machine could also pick up balls from the floor through a bumper cutout. The foam balls were shoved up through the bottom hopper.

Mechanical Systems:

Hoppers and Conveyors

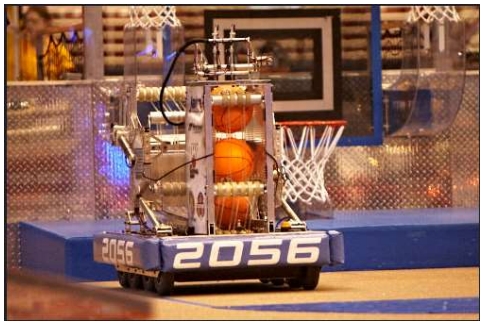
Conveyor
One side fixed – One side moving

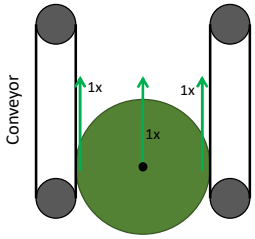


Game object moves at
½ the surface speed of the conveyor belt.

You have to consider that the single sided conveyor system needs to move fast.

Conveyor
Both sides moving





Both conveyors and the game object move at the same speed.

In both conveyor systems, please make sure the spacing between the belts is slimmer than the ball. It needs a little squeeze to hold it in the air. Usually an inch of compression should be fine.

Conveyor Belting Types

Polycord in Grooved Pulley	Flat Polybelt on Crowned Pulley	Timing Belt with Timing Pulleys
		

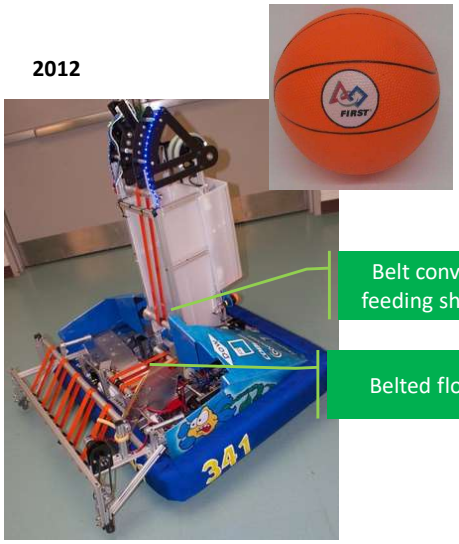
Polycord in grooved pulley: This is rounded poly cord you can buy from McMaster Carr or even some place like WestCoast products. NOTE: The round belt can jump out of the groove if there is side force on the cords. This system can be finicky.

Flat polybelt: This runs on a crowned pulley to keep it centered. The trick here is to make sure the belt is stretched tight to remain engaged. These belts have to be cut and heat fused. AndyMark now sells the belt and fusing system for reasonable cost.

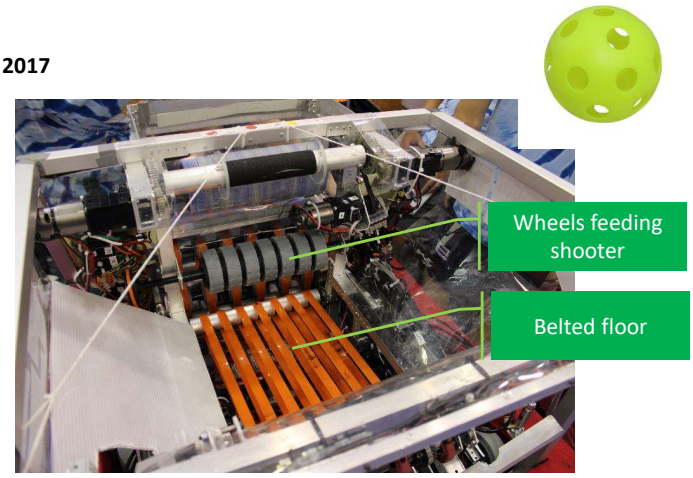
Timing belt: This requires precise spacing between the pulleys to properly tension the belt. Once set, the belts will transmit power very well and never jump off. This system is very reliable but pricy. A way to reduce the cost in low load applications is to 3D print your own pulleys.

Ball hopper to shooter

2012



2017

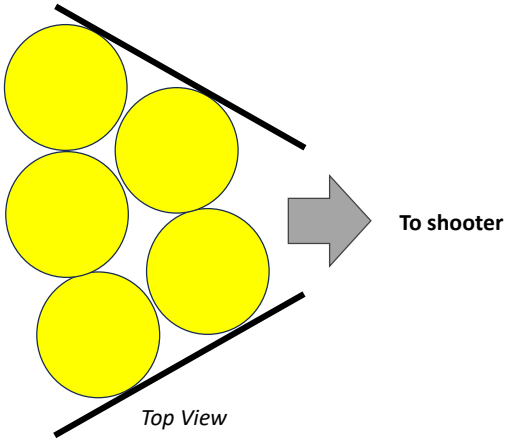


*** Hopper floors can be sloped instead of belted – depending on the game piece and hopper size.*

Serializing balls from a hopper into a linear conveyor to feed a shooter is a very common system in FRC. A completely gravity fed hopper usually is not effective. Using powered belts on the floor and/or sides of the hopper is needed.

Ball hopper “Bridging”

Top View



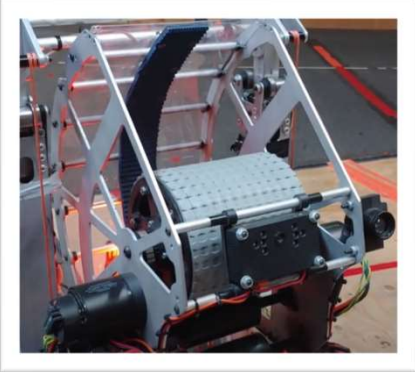
Top View

Gravity only may cause the balls to “bridge” where multiple balls can touch the hopper sides and get stuck without an active agitator. In the picture, a belt on one of the walls is used to prevent bridging.

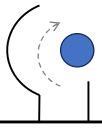
Mechanical Systems:

Shooters / Launchers

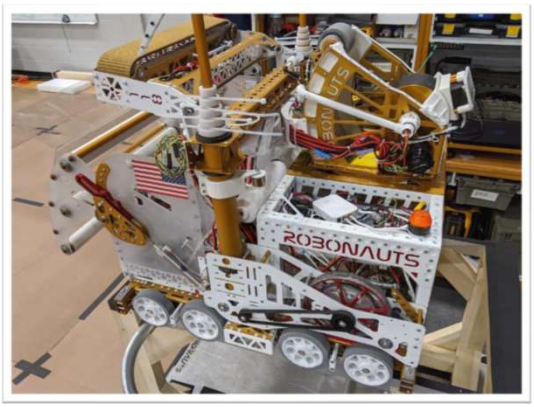
Hood ball shooter



Fixed hood



Variable hood

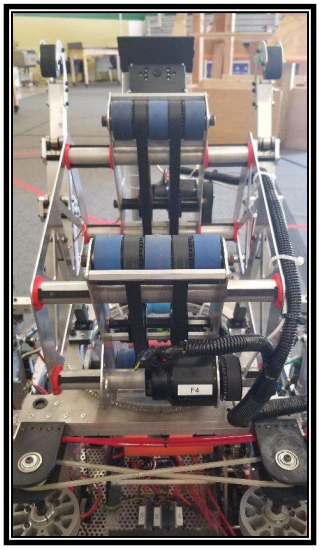


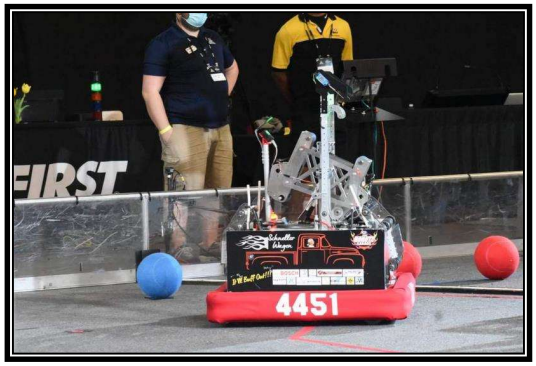
Variable hood and top acceleration wheel

Shooting balls is also a common task in FRC. In all cases, I recommend using brushed DC motors like a NEO or Falcon with a closed-loop velocity control of the speed. This will be more accurate than only setting a specific percent output.

All shooting hoods need some amount of compression between the ball, shooter flywheel and back wall. For example, the 2020 game had a squishy 7" foam ball. Most shooter compressed the ball through a 5" or 5 ½" gap. (1 ½ to 2" of compression.) Prototyping will help with determining this number plus you could look at the "Open Alliance" teams and see what they tested.

Over / Under wheels or belts



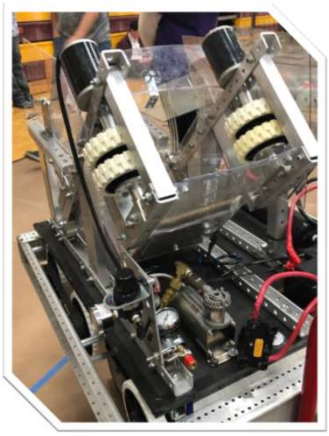


It is also possible to use over/under wheels or belts to shoot. Please note: This will produce a knuckle ball shot. If the game needs back spin on the object, this is not a good approach.

The example shown is 4451's shooter from 2022. It was not good to have backspin on the ball that year. Backspin is basically extra kinetic energy that must be dissipated in the goal.

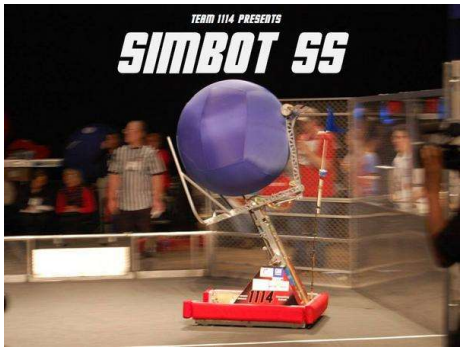
We "thought" it would need much ball compression between the belt. The prototype seemed OK. The production robot shot very inconsistent with low compression. We increased ball compress from 1" to 2" and greatly improved consistency for our second competition.

Side Wheels

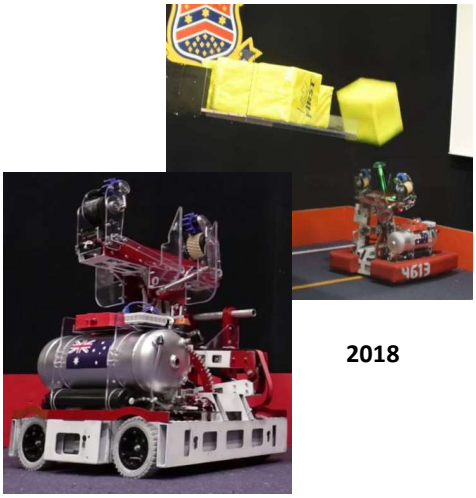


Side wheels can also be used to shoot a knuckle ball. Here, you need to be careful that both sides are running the same speed, or you could have inconsistent aim.

Linear launchers



2008

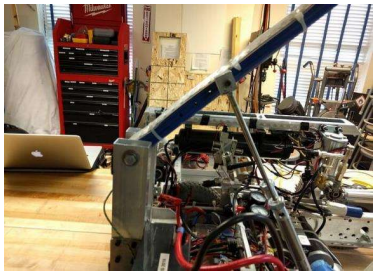


2018

Another type of knuckle ball shooter is a linear puncher. This is usually powered by springs or rubber surgical tube. The 2018 example was a very unique solution that year since most teams used an elevator to score the game piece. Linear punchers were also used heavily in 2014 which had a similar yoga ball that 2008 used.

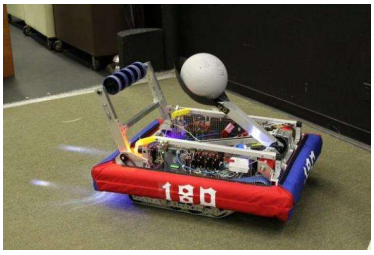
Catapults

Surgical Tubing Spring



Pneumatic Cylinder

Motorized

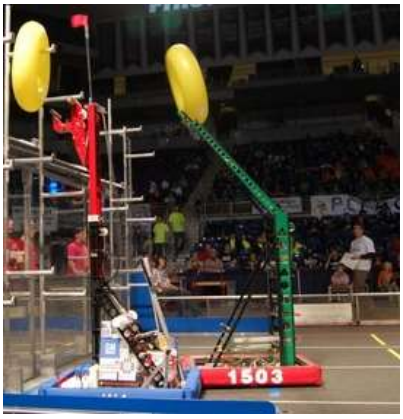


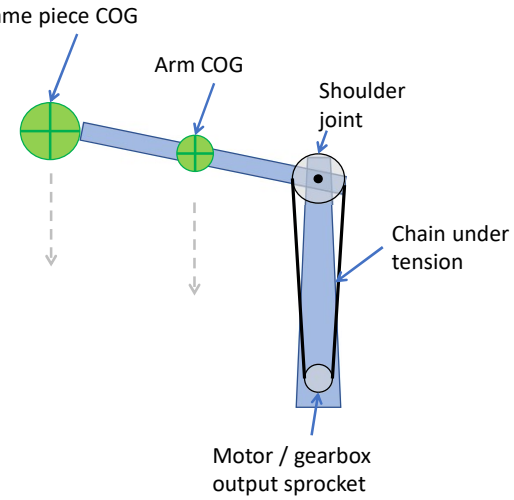
And the last knuckle ball shooter…. Is the catapult! There are several ways to power catapults. The trick is usually a catapult to vary its shooting distance. That's why some teams used a motorized catapult.

Mechanical Components:

Wrists / Arms / Elevators

Rotating Arms

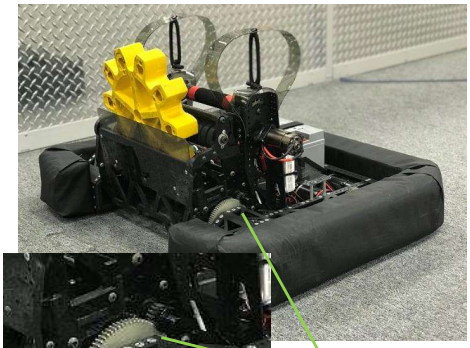




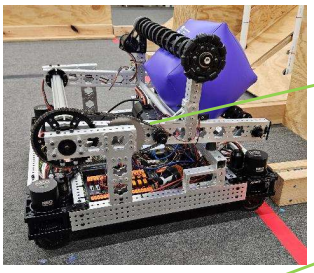
Rotating arms are also very common subcomponents of an overall system. This used as a big pivot (like above) or a small wrist joint or an intake pivot.

The trick here is to make sure the chain is tensioned. There is a picture of a tension system on the next slide.

Pivot / Wrist Joint



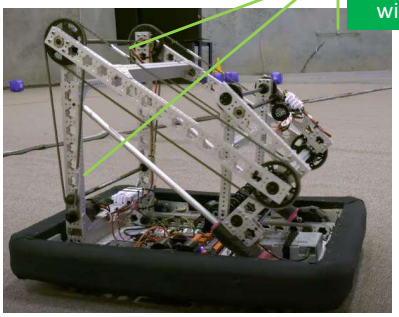
Gear to gear pivot



Trapped sprocket tensioner

DO NOT RECOMMEND

Sprocket/Chain with tensioner



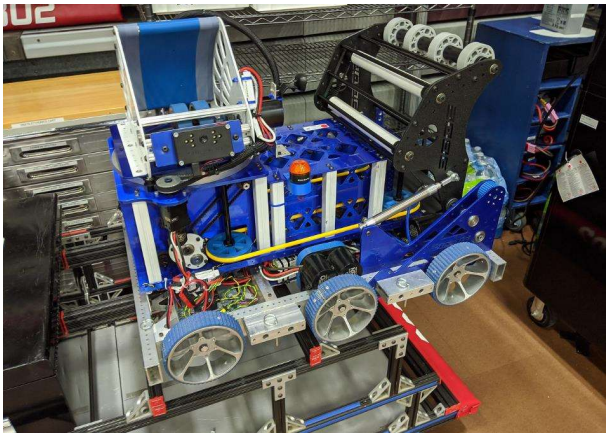
Inline turnbuckle chain tensioner.

Pivots are usually chain powered as well. If the chain is short, it may be difficult to fit an inline tensioner. You can also do this with accurate center-to-center bearing spacing and not have to actively tension.

I have seen low-load pivots done with gear teeth. You have to be careful with this application. There are very few teeth engaged to move that pivot. You may snap off a few teeth!

Pivot with Pneumatic Cylinder

- Pneumatic cylinders are good for two position system.
- Downside: Extra weight and complexity of compressor system.
- Need to protect cylinder rods and tubes from getting bent or dented.



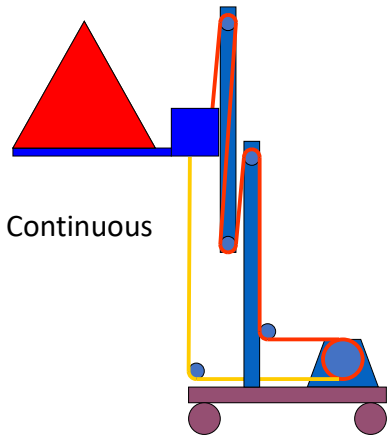
A pneumatic cylinder system is great for two position intake systems.

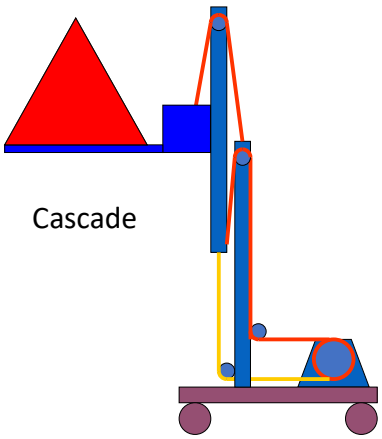
Telescoping Arm

- Limited COTS solutions for 2-way powered arms
- Several COTS solutions for “climber in a box.” (Extend with constant force springs / Retract with winch)

Telescoping arms can be hard to build. There a few COTS solutions available. Be sure to look at how these will be accurately moved through the full length. Brushless motor control is a great choice.

Elevators: Extension - Rigging

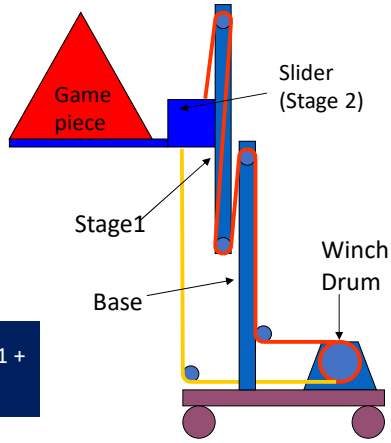




There are two primary ways to “rig” an elevator system.

Extension: Continuous Rigging

- Cable goes same speed for up and down
- Intermediate sections sometimes jam
- Low cable tension
- More complex cable routing
- The final stage moves up first and down last



Winch load = (weigh of game piece + stage 1 + stage 2 + friction) * drum radius

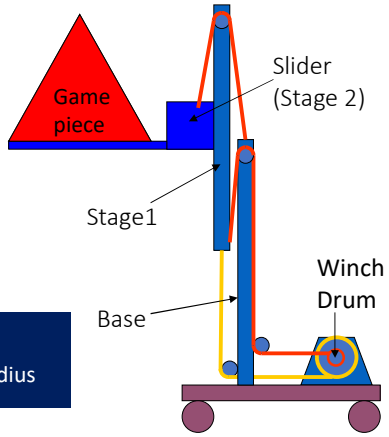
Method 1: Continuous rigging. There is one continuous cord (or belt) to go from the spool to the final stage. You can let gravity drop the elevator, but it is best to have a return pull down cable.

If you look at the diagram it may be hard to detect how the lift works. Essentially your are pulling up the final stage (with the game piece) until it slams into the top of the next stage, then the cable will lift that stage. This also means the weight load on the cable changes as it picks up the weight of the next stage. The software may need compensation to handle the variable load.

Since the stages hit each other, you will need bumper / hard stops to take the load. Also be aware that the shock load could bend thin metal tubing.

Extension: Cascade Rigging

- All sections move together
- Stage 2 moves twice the speed of Stage 1 (relative to the ground)
- Much more tension on the lower stage cables
- Needs lower gearing to deal with higher forces

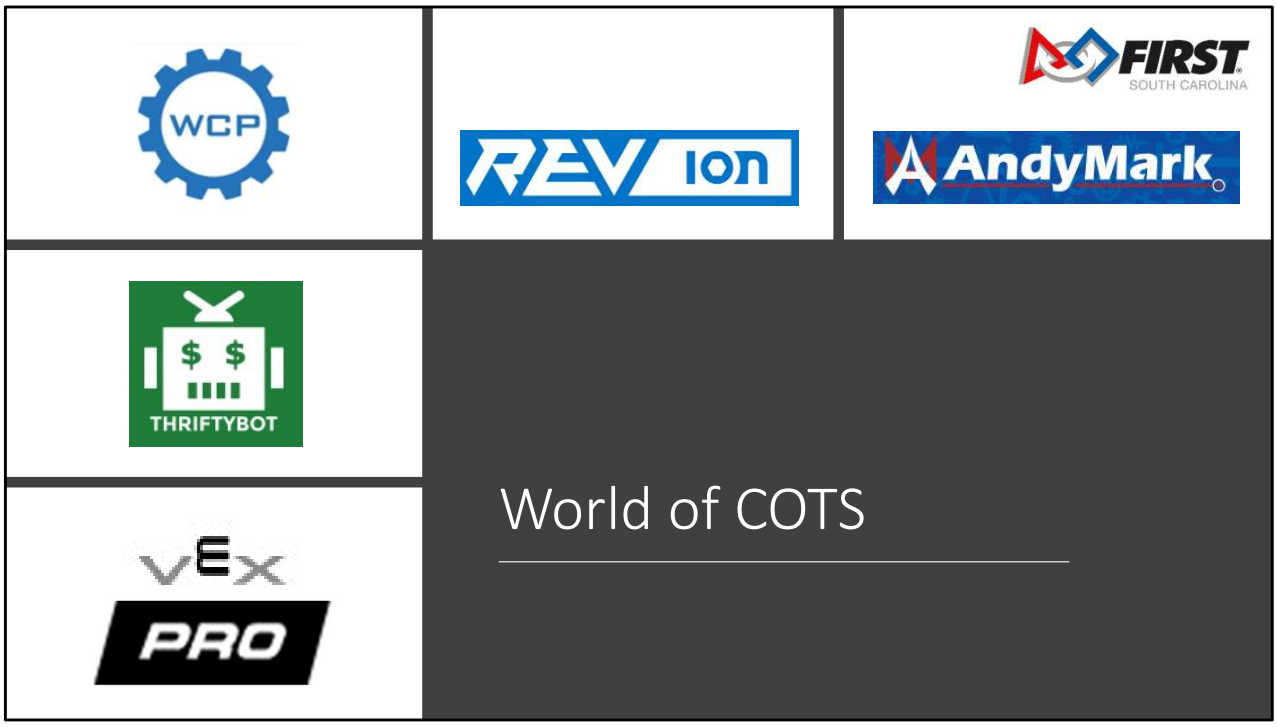


Winch load = (weigh of stage 1 + 2*(stage 2+ game piece) + friction) * drum radius

Cascade rigging is very popular choice. You only have to power the first stage. The other stages are rigged to move at the same time. WestCoast Products and ThriftyBot sell kits and will show you how to rig and tension the system.

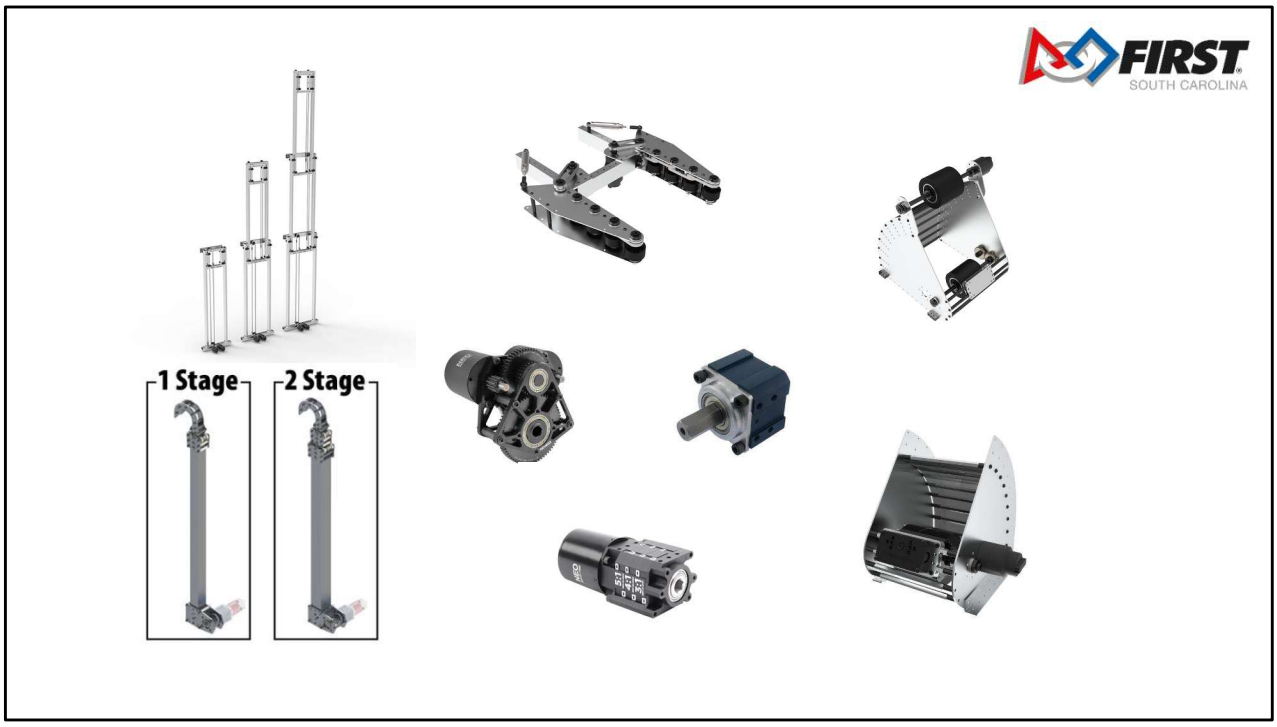
Mechanical Components:

COTS Assemblies



FRC has come a long way over time. Now there are a bunch of vendor systems you buy instead of building everything yourself. This has brough parity and better play over time.

This has also happened with software libraries such as WPI Lib.



Do make when you can buy it! Unless you set up to do it. Gearboxes and elevator systems take good manufacturing.

QUESTIONS?