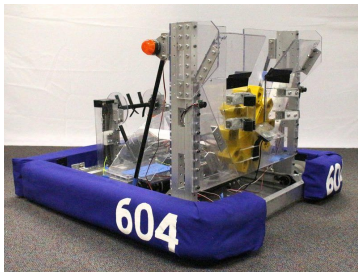
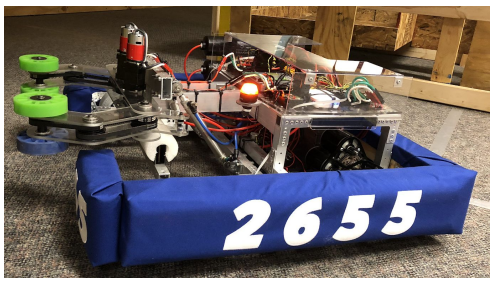
Guide to the FRC MCC

(Minimum Competitive Concept)





What is an MCC?

An MCC is a robot designed for FRC games that uses the fewest resources possible (money, time, equipment, knowledge, etc) to play the game at a level where the robot is valuable on any playoff alliance. When tuned, the MCC is often an alliance a captain due to its robust and consistent nature. These robots often have a lower potential score ceiling than some of the super star robots but are key contributors to their alliances.

MCC Principles

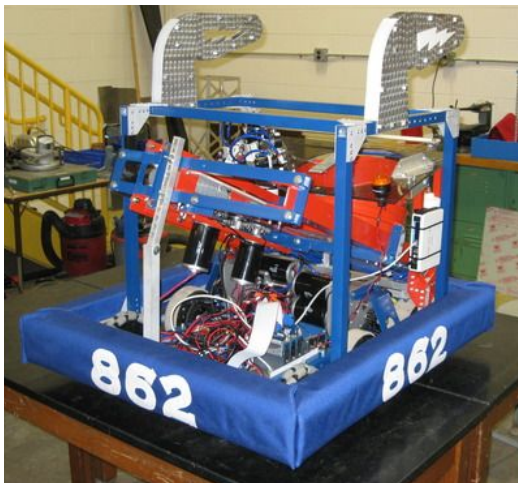
1. **Keep it Simple**
    a. Most MCCs have only a few moving parts above the drive train.
    b. 3 or fewer motors and 2 or fewer pneumatic actuations.
    c. Golden Rule #1: Always build within your team's limits
2. **Don't do everything!**
    a. Every MCC leaves some game tasks unaccomplished, and that helps make them great. By avoiding the most complicated tasks in any game the MCC builders are able to focus on the rest of the game and make their robots more effective at what they do accomplish.
    b. Choose early what you aren't going to do and don't comprise. 2017 Example: "Maybe we'll shoot fuel later if the gear and climber stuff is working," is almost as bad as focusing on fuel from the beginning. You will make sacrifices to the gear mechanisms to allow for the addition of fuel in the future and that will hurt your performance.
    c. Karthik's Golden Rule #2: If a team has 30 units of robot and functions have maximum of 10 units, better to have 3 functions at 10/10 instead of 5 at 6/10
3. **Drive train**
    a. Don't drive sideways (mecanum, swerve, etc). It's never needed to be competitive.
    b. Use the kit chassis or another proven and tested chassis design
        i. Most teams should use the kit of parts chassis (AM14U?) but other COTS chassis options are acceptable if you have the experience to build them.
4. **Avoid Linear Mechanisms**
    a. Rotary mechanisms are easier to make robust and efficient. It's harder to properly constrain linear system, meaning that you end up with systems that jam and more energy is used to overcome frictional forces. Use rotating and pivoting mechanisms in the majority of your mechanisms.
5. **Driver Practice and Tuning**
    a. Quickly get your robot to a state that you can start driving it and tuning it. Small iterations that improve your consistency and speed up your game task can dramatically improve your performance.
6. **Autonomous Mode**
    a. In most games moving in Autonomous mode is an absolute most.
    b. There is often a less difficult autonomous task, such as scoring in a low goal or hanging a gear that MCC robots should be able to do.
7. **Clean, Organized, Robust Wiring and Pneumatics**
    a. The most effectively engineered MCC will fail to have success if the wiring is messy and causes field disconnects or has trouble being maintained.

MCC Robot Examples

2013 - Ultimate Ascent - CD 2013 MCC Thread

3313 - Mechatronics

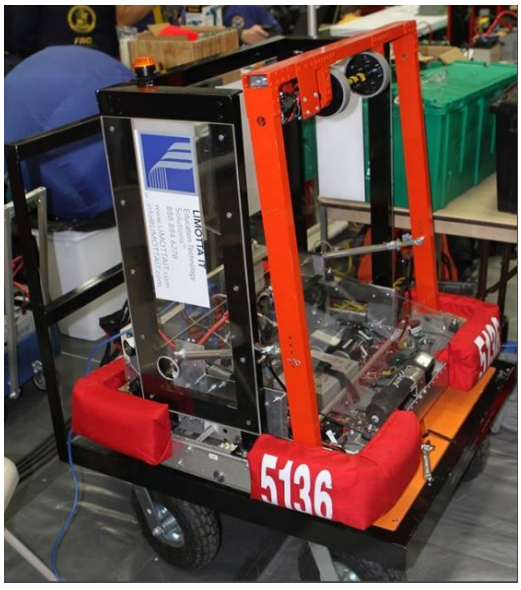
1. Simple design to get disks from the feeder station, score them in the high goal, and hang on the pyramid for 10 points. These were the same tasks that many Einstein robots were able to accomplish.
2. What it took to build it
    a. 2 pneumatic actuations
    b. 1 spinning wheel
    c. Plywood and a bucket
3. How'd they do?
    a. Rank 3



862 - Lightning Robotics

1. Fixed Angle Shooter, Passive 10 point climber, simple alignment for high goal shot. Expertly executed simple design.
2. What it took to build it
    a. 2 spinning wheels
    b. 1 pneumatic actuation for feeding disks.
3. How'd they do?
    a. Ranks 2, 1, 14, 12
    b. 2 District Wins, Championship Division Win

2014 - Aerial Assist - CD MCC 2014 Thread



5136 - Mechapirates

1. Simple robot built to be an inbounder or low goal scorer. Well practiced drive team.
2. What it took to build it
    a. KOP Chassis
    b. 1 pneumatic actuation
    c. 1 spinning shaft with wheels
3. How'd they do?
    a. Ranks 15, 26
    b. Championship Division Winner as 4th pick.

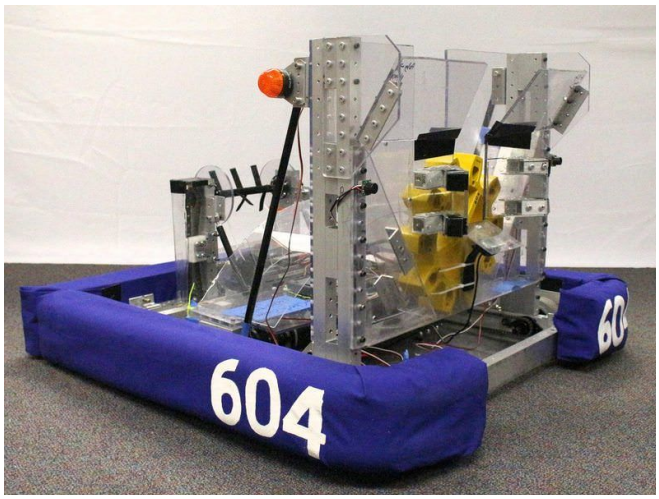
2016 - Stronghold

1257 - Parallel Universe

1. Single joint arm and intake. Able to go over defenses and score in the low goal. Added another motor driven wedge for the portcullis later in the season.
2. What it took to build it.
    a. KOP Chassis with Pneumatic wheel upgrade
    b. 1 motor for arm
    c. 1 spinning shaft for intake
3. How'd they do?
    a. Ranks 10, 1, 52, 10
    b. District Winner, District Finalist, District Championship Winner

2017 - Steamworks

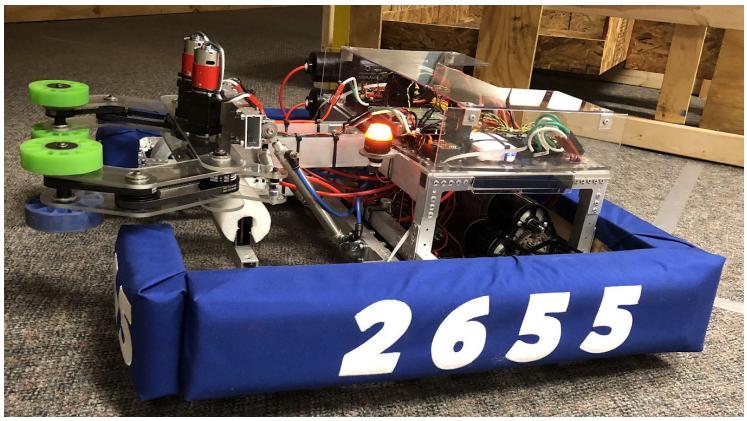
604 - Quicksilver



1. Passive Gear pocket, and velcro climber. Side gear auto modes.
2. What it took to build it.
    a. Lexan and aluminum extrusion for the human gear mechanism, no moving parts
    b. 1 Motor powered shaft with velcro on it.
3. How'd they do?
    a. Ranks 3, 3, 4
    b. Regional Finalist, Regional Winner, Championship Division Winner

2018 - Power Up

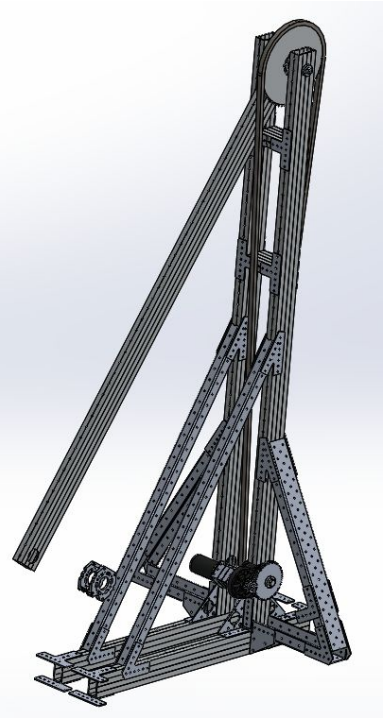
2655 - The Flying Platypi - 2018 CAD



1. Single joint with an intake, "claw on a stick". Awesome switch autonomous modes. Great at the vault and defending the home switch.
2. What it took to build it
    a. Pneumatic actuation for the arm uses a door hinge.
    b. Intake 2 motors + belts and pulleys. Designed based on public CAD.
3. How'd they do?
    a. Ranks 6, 7, 1, 5, 55
    b. Excellence in Engineering Award, District Event Winner, Championship Division Winner

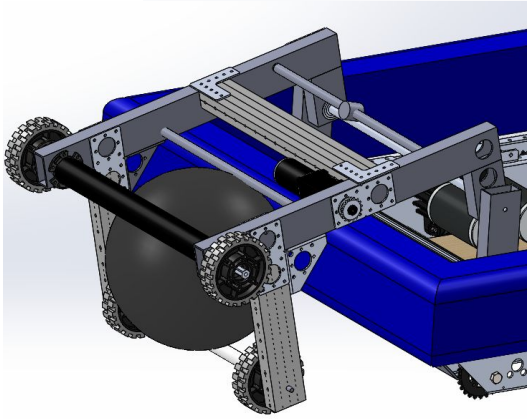
MCC Mechanism Examples

VEXpro Versaframe Arm Example



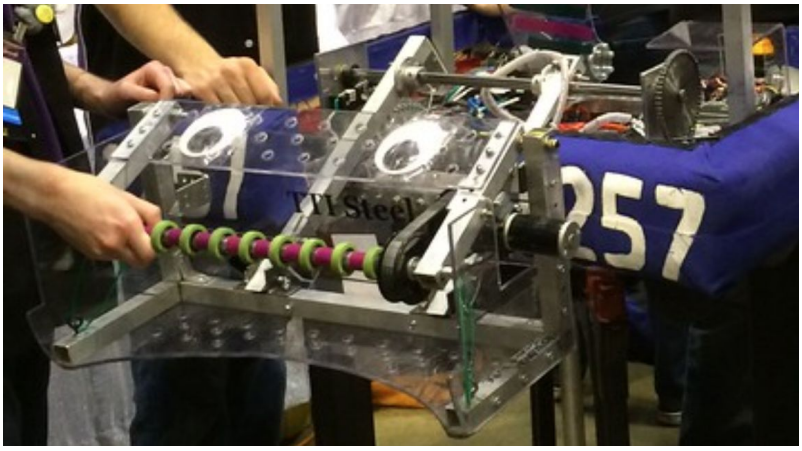
- Uses a planetary gearbox (likely 50:1 or more), then a 20DP gear stage on a VEXpro clamping gearbox. That is connected to a 12t #35 sprocket and a chain runs up the arm to a 60t sprocket and a VEXpro VersaBlock on the rube.
- You can recreate this easily using similar components but you can replace many of the gussets with cheaper options from Home Depot. You can use regular aluminum extrusion instead of much of the VersaFrame since you don't need all the holes.
- The VEX VP gearbox can be replaced by a large reduction Dual or 57 sport gearbox and directly connect to the 12t sprocket for driving the large sprocket on the arm.That would work just as well.
- You should look at adding limit switches and an encoder or a potentiometer to this arm.

5908 Intake / WCP 2016 MCC



- Simple Ball Intake used for defense crossings.
- Able to be deployed and retracted using pneumatics
    - (not shown)
- Simple thru tube mounting of a VersaPlanetary Gearbox (could be a VP lite gearbox) using a Versaframe bearing mount gusset or a Sport gearbox mounted on top of the rail.
- Chain connects the motor to the roller shaft.
- Lower wheels are free spinning on ½" Tube axle, could be polycarbonate ½" tube.
- Many of the Versaframe gussets shown could have been home depot steel or any other gusset. In fact some of the steel corner Ls or Keystone 4337 brackets would work better here.

1257 - 2016 Intake



- Simple Intake with VP and belt drive.
- Hex shaft with small wheels (banebots) and spacers
- Shaft is able to flex up which gives compliance on the ball. Elastic cord at the front of the intake pulls it down.
- Simple lexan and square tube construction.
- Arm powered by a simple gear on a hex shaft. May want to use steel hex here.

MCC Details, Tips, and Tutorials

Use CAD sketches to design pneumatic linkages

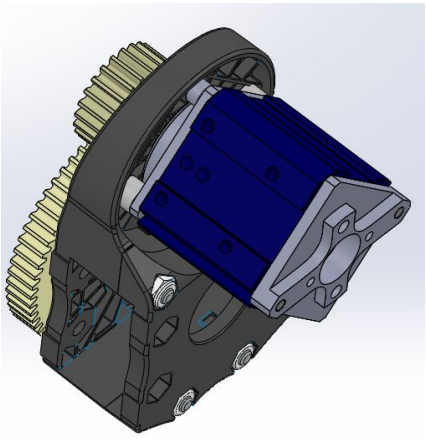
It's often a struggle to find the correct mounting points for a pneumatic cylinder to actuate your mechanism in the path that you want. This FRC#973 RAMP video explain a simple process for getting the right spot every time. DesignSheet.Spectrum3847.org has a tab devoted to pneumatics that lets you get the correct lengths.

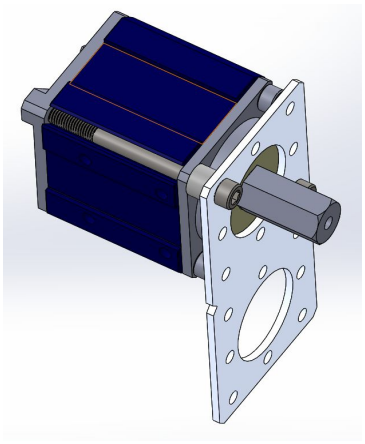
Use 1:1 Scale paper print outs when you don't have CNC tools

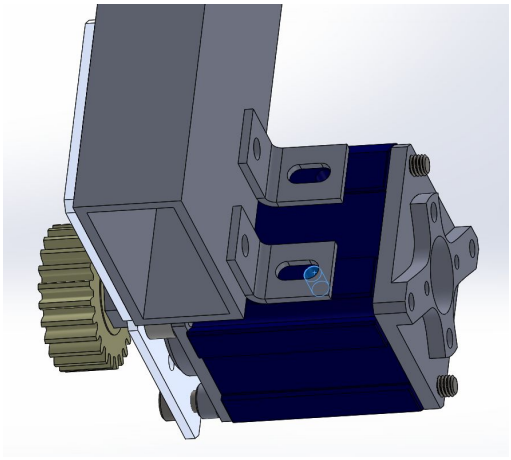
You can still take advantage of CAD programs (Onshape, Solidworks, Fusion 360, etc) even if you don't have CNC machines. FRC#558 details this method in a youtube video. This is useful for getting chain or belt spacing correct or finding the right place to put a pivot for your pneumatic cylinder.

Face mounting an AndyMark Sport

You can use two .25" thick #10 nylon spacers to be able to face mount a AndyMark Sport gearbox in many of the mounts for a CIM. Including Versaframe Bearing plate and VEXpro Single Speed Gearbox. Bonus when used with a flat plate on the far side of a 1x1" tube, a Keystone 4337 L Bracket can be used on the other side to mount into the side mounting holes of the motor. You could just mount to the side hole by drilling clearance holes in the tube to match the mounting holes on the gearbox, the Keystone L brackets could still be used in that configuration for support. The angle bracket prevents the single gusset from bending.

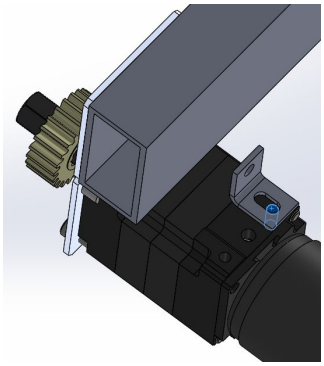




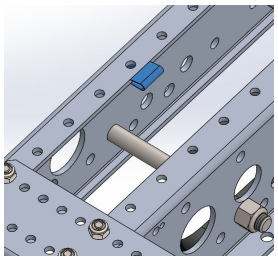


Face mounting a VersaPlanetary v2 Gearbox

A similar feature can be created with a VP v2 but you will need to space off the Keystone 4337 from the tube. .125" spacer is used for one stage and add a 0.5" for each stage over 1. A two stage gearbox is shown below.



Clip Nuts or Rivet Nuts



Clip Nuts (McMaster 94850A129) and Rivet-Nuts are useful in allow you to quickly bolt things to sheet metal without needing access to the other side of the plate for the nut. Here is a video on installing Rivet Nuts into the kitbot to use as bumper mounting fasteners.

Drill Templates for normal extrusion.

Garnet Squadron "WorseAFrame" Hole Guides

Used to drill 1” hole patterns in to normal 1” rectangular or square tube, to make it similar to VersaFrame.

Drilling 1.125” Bearing Holes on a Drill Press

Triple Helix Video Guide

Drilling correctly sized bearing holes is a difficult process for most teams without a mill or CNC equipment. Triple Helix did some testing to find the best cutting tool to use.

They suggest purchasing these two tools to use on a drill press.

1. Cutter: https://www.mscdirect.com/product/det… - $32.40
2. Arbor: https://www.mscdirect.com/product/det… - $50.12

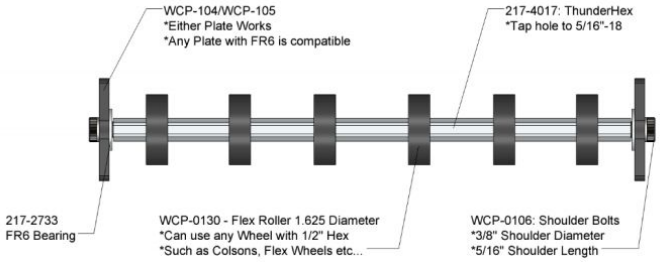
How to strip and crimp wires for FRC

Buy the correct wire crimpers for the terminals you are using.

- ▲ Code Orange Wiring Tutorial
- ▲ Spectrum 3847 Electrical Guide - Includes what and where to buy items.
- ▲ WPI Wiring the FRC Control System Official Guide

Shoulder screws in bearings allow for easy shaft removal

The Versaroller System is based on using shoulder screw to easily remove rollers from your robot. The same process can be used with hex shaft if you drill and tap the ends to 5/16-18”. Shoulder Bolts can be purchased from multiple sources Grainger is by far the cheapest source right now.



The VersaRoller User Guide explains the system thoroughly.

Suggested MCC Build Items

Items to use from the KOP - Kit(aka: Kollection) of Parts

1. **KOP Chassis** - whichever version of the AM14U is provided for you in the KOP is by far your best option for building an MCC. You can assemble it in multiple configurations to best suit your strategy and build it quickly using the provided instructions and videos.

2. **Pneumatics** - The rookie kit comes with most everything you need for one solenoid and the bimba voucher allows you to get two cylinders. Use FIRST Choice credits to get more fittings, air tanks, tubing, etc. A full pneumatic system requires an FRC legal Compressor, a Pressure relief valve connected via legal rigid fittings, a Nason pressure switch, At least one Pressure vent plug, “Stored” pressure gauge, “Working” pressure gauge and a “Working” pressure regulator.

3. **Motors** - The 2018 KOP comes with 2-4x CIMs, 1xMini CIM, 1x BAG Motor, 1x AM RedLine Motor. Those are some of your best motor options in FRC. Try to avoid using the window motor, throttle motor, or other Automotive motors, they are low wattage and hard to adapt to FRC robots. The 2018 KOP include a 4:1 57 Sport gearbox, this is a great option for intakes, etc. If you have it from last year you can reuse it. Local teams may be willing to give you theirs as well.

4. **Aluminum Extrusion** - The 2018 KOP include 4x 1”x1”x4’ aluminum tubes. These are useful building blocks for your robot. You can use gussets and brackets to assemble intakes or other assemblies.

5. **Electronics** - The kit comes with almost all of the electrical components your MCC will need, including wire, connectors, the FRC control system, and 2-6 motor controllers. Take advantage of all of these things. You can often get spares and additional motor controllers in FIRST Choice. Vouchers will allow you to purchase sensors (such as the Armabot encoder) and electronics

6. **Latex Tubing** - Great for using as a spring to assist in raising mechanisms, or spring loading intakes.

7. **Other Items** - other parts of the kit have various uses but often teams will attempt to find a solution with a KOP item because they have it on hand instead of looking to spend a few more dollars and purchasing the correct component for the task. So when designing parts for your final robot be sure that the KOP item actually fits the task at hand and that you will be able to have spares of it incase it breaks.

Items to Have

Pneumatics

Pneumatics should be included in most MCCs. They are free in the rookie KOP and many FIRST Choice credits and vouchers can be used for pneumatics. It is often to get old pneumatic components from local teams that have stock piled over the years.

- ▲ **Solenoid Valves**
    - Ideally you will have enough solenoid valves from your Rookie Kit and FIRST Choice. If you don’t it’s likely that a local team has solenoid valves they will give you.
    - If you do need to buy solenoid valves there are several cheap options though they are larger and heavier than those supplied by common FRC suppliers.
        i. Automation Direct AVS-5111-24D ($20)

- ▲ **Pneumatic Cylinders**
  - **Purchase:** 2 x 6” Stroke - 11/16” Bore Pneumatic Cylinders - AD Link ($31.50 each)
    i. Be sure to add 2 of the clevis ($3.50 each) to your cart as well.
  - These cylinders are large enough to be used to move an intake in and out of your robot in most cases. It may be ideal to purchase different cylinders if you are trying to package in a specific applications but it is likely that you can find a solution that allows these to work.
  - While these may be too large, you can use your regulator to lower pressure below 60 psi to allow them to use less air, but generating less force.
  - It’s possible you may be able to get these using the BIMBA Voucher if it is in the 2019 kit of parts, but they are slow to ship, so purchasing them is required.
- ▲ **McMaster Pre-set 125 psi Pressure relief valve**
  - **Purchase:** McMaster 48435K71 $5.26

Motors and Gearboxes

- ▲ **Purchase: 1x Dual Sport Gearbox (117:1 or 156:1- $118)**
  - Video showing Greasing Sport Gearboxes
  - Can be used for a large mechanism like an arm or climber
  - Or can be separated into a two motor gearbox (3.25:1) and a 57 sport(36:1 or 48:1) for intakes or shooters with a few optional accessories from AndyMark.
  - Optional accessories
    i. 1x 57 Sport Motor Block $10
    ii. 1x 2 Motor Sport ⅜” Hex Output Shaft $8
- ▲ **Purchase: 2x Redline A motors ($27) with the Sport Pinion already pressed on,**
  - These will save you a step in the assembly. Buy 2 of these.
- ▲ **Purchase: 1x 4:1 CIM Sport $64 - CIM Sport Guide**
  - The 2018 KOP included a 4:1 57 Sport with the addition of a CIM Sport Adapter Kit $15 you can modify it to mount a Mini CIM Motor.
  - Mini CIM’s have pre-attached wire leads so you don’t need to solder, and they are very hard to damage.
  - You can use this motor and gearbox combination to drive an intake or shooter. This setup with a 1:1 15t #35 Chain would make a very robust intake.
  - Try to support the back of the Mini CIM motor when mounting this gearbox combination.

Shafts

Hex shaft allow you to easily transfer torque to items such wheels and rollers so that they can move game pieces. **Note: Aluminum Hex shaft sold by non-FRC vendors is often oversized and that prevents them from easily interfacing with FRC gears and wheels.*

- VEXpro 1/2" 7075 ThunderHex Stock - $16 per 3ft
  - Can be tapped to ¼”-20 which often allows you avoid shaft collars
  - Read the bottom of the product page for an explanation of Thunderhex
- AM 7075 Hex Shaft - $16 per 3ft
  - Doesn’t have the tapped hole but if you are ordering from AM it works as well.
- REV Ultra Hex - $7 per 3 ft - Note: 6063 Aluminum is weaker than 7075
  - Not recommend for drive shafts, useful for light duty applications
  - Can be tapped to ¼”-20 which can allow you avoid some shaft collars

    - Inexpensive for a variety of applications
- 1/2” Steel Hex Shaft from McMaster - $11 for 3ft
    - Steel hex shaft is often cheaper than aluminum but it is harder to work with.
    - If you are using hex under heavy load using a piece of steel hex is a good idea.

Recommend Purchase: 3x Thunderhex, 2x REV Ultra Hex

Hubs

Hex hubs let you mount wheels, sprockets, and gears to hex shafts. The majority of FRC wheels are supplied with the same 1.875” bolt circle so you can use VEX or Andymark wheels with either hubs but they don’t work perfectly unless you match the vendor parts.

- ▲ **Purchase:** 2x 1/2 in. Hex Hub am-0096a $11.00
    - Used for mounting AM wheels to hex shafts.
- ▲ **Purchase:** 4x 1/2” Hex Bore Plastic VersaHub (217-4009) $2.99
    - If you are using VEXpro wheels/sprockets these work very well for lower load applications, such as shooters and intakes. You may want to buy some for prototypes since they are so cheap.

Wheels

- ▲ Compliant Wheels
  These wheels are able to deform around objects so they work great for intakes and shooters with hard objects. They are very soft and grip most game pieces well.
    - **Purchase:** 4 x ½” Hex 2.25” 35A AM Compliant Wheels $6
        - For intakes
    - **Purchase:** 2 x ½” Hex 4” 35A AM Compliant Wheels $9
        - For shooters or intakes
- ▲ **Purchase:** 2x Colson Performa (4" x 1.5", 1/2" Hex Bore) 217-4052 $14.99
    - Colsons have been used in FRC for decades
    - Great for shooters or intakes

Chain/Sprockets and/or Belts/Pulleys

Many successful robots have been built using only #35 chain and sprockets as the main method of transferring torque. Lighter options such as #25 chain or timing belts can be used but more care needs to be taken with their design, assembly, and maintenance as they are less resistant to misalignment and wear. We recommend teams stay with using #35 chain for most system until they are confident they can use the other systems effectively.

If you have access to a 3D printer you can print timing belt pulleys for many of the applications you’d need them for on FRC robots. You can purchase inexpensive timing belts from sources such as Vbeltguys.com. This makes timing pulleys and belts a very cost-effective option for FRC robots. FRC uses mostly 5mm HTD Timing belts. From most vendors, belts are given a product ID based on their diameter, tooth profile, and width. To get the diameter of a belt from its tooth count, multiply the tooth count by the pitch of the belt. So if you wanted a 60 tooth, 5mm HTD belt that was 9mm wide. You would do 60 teeth multiplied by 5mm and get 300. Then you would search for 300-5M-09. Don’t use 3D printed timing pulleys in high load applications such as drive trains or arm joints.

DesignSheet.Spectrum3847.org provides several useful calculators for determining chain and belt spacing. Make a copy of the document in your google drive and use it to help design your robot.

- **#35 Chain and Sprockets**
  - **Purchase:** 2x 12T Double Sprocket (#35, 1/2" Hex) 217-2658 $15
    - These double sprockets are a great value, you can design systems with two chain runs off a single motor, or you can cut them in half and get two sprockets for a $1 more than the cost of one.
  - **Purchase:** 2x 36T Plate Sprocket (#35) 217-2649 $16
    - A 36T sprockets is a good size for many systems. If you are building a large arm, using a larger sprocket such as the 60t is often needed but for many intakes, climbers, small arms, a 36T is reasonable and you can an easy 3:1 reduction when combined with the 12t Hex sprockets.
  - **Purchase:** #35 #35 Roller Chain (10') 217-2776 $12
  - **Purchase:** #35 #35 Chain Tool 217-5838 $30
    - When using this tool you don't need to purchase master links. Make sure all your chain runs are an even number of links to avoid the need for half-links.
    - Working with Chain Video

Shaft Collars

- ▲ **Purchase:** 6x ½" Hex Shaft Collar from AM
  - Used to hold item in place on shaft collars. You can substitute spacers or tapped screws in the end of shafts in place of shaft collars in many applications.
- ▲ 3D printing shaft collars is a good option for prototypes and light duty applications. As $5 each quickly adds up if you are using a lot of collars.

Bearings and Bearing Blocks

You are going to need Hex bearings. They have become one of the most common items on FRC robots since they allow the use of hex shaft without needing a lathe to turn the ends. You don't need to use them exclusively on every mechanism but they do make a lot of tasks easier especially when you have limited machining resources.
For many non-hex applications that have lower speeds (< 500RPM) you can use a plain bearing (aka bushing) instead of a bearings. This is especially useful for large diameter shafts/tubes ⅞" and above.

- ▲ **Purchase:** 2x ½" Hex Bearings 217-6717 12 for $54.99
  - You will always want more bearings, and they don't go bad.
- ▲ **Purchase:** 2x VEX Plastic VersaBlocks 217-4155 $8
  - These allow easy mounting of bearings on to 2"x1" tube
  - You can slide them for chain tensioning.
- ▲ Plain Bearings (Bushings)

Spacers

- ▲ PVC
  - ½" PVC works as easy spacers for ½" hex shaft

- You can cut a slit into them and snap them over shaft if you need

▲ 3D Printed Spacers
- Many hex and round spacers can be 3D printed for less money than you would purchase them. If you have access to any 3D printer they can print off dozen of spacers a day.

▲ Nylon Spacers
- **Purchase:** McMaster sells them in packs of 100 for around $0.10 each
  i. https://www.mcmaster.com/nylon-spacers
  ii. ¼" and #10 sizes in 1/2" and 1/4" are some of the most used
- Very useful as bolt standoffs and assembling structures.

▲ Hex Spacers
- **Purchase:** Andymark and VEX both sell hex spacers now. Having them stocked in various sizes 1/16" to 1" is a good idea. BE SURE TO SELECT ½" HEX
- AM Hex Spacers $6 for 10
- VEX Hex Spacers $6 for 10 up to 1" Then $7 for 10 for 1" and 2"

Fasteners

Multiple sources will have fasteners. We mainly buy our fasteners from zoro.com but Andymark prices are reasonable when compared to other vendors such McMaster.com

▲ 10-32 Socket Head Screws and Locknuts
- Socket Head Cap Screws - Alloy Steel - **Purchase:** Various Sizes 200 each: ½", ¾". 1.75"
- Locknuts - **Purchase:** 400-600 AndyMark - Don't vibrate loose like normal nuts
- Washers

▲ Self Drill 10-24 Screws
- **Purchase:** **2x** $8.43 for 100 - https://www.mcmaster.com/90064a480
- These screws provides a secure grip with a wrench and a flange reduces the risk of crushing thin metal. They save you time and effort by drilling their own holes and fastening in a single operation. Quickly attach guessets to aluminum tubing or wood.

▲ ¼-20 Socket Head Screws and Locknuts
You will need fewer of these than 10-32 but you will need some.
- Socket Head Cap Screws - **Purchase:** ~100 each Various Sizes: ⅝", ¾", 1.25" 3"
- Locknuts - **Purchase:**300 AndyMark
- Washers - **Purchase:** Regular - 100 AndyMark Fender Washer - 25 AndyMark

▲ **Optional:** 3/16" Rivets
Used instead of bolts, very useful fastening to tube so you don't have to put a bolt all the way through it and crush the tube.
- Rivets - Harbor Freight - 100 for $5
- Rivet Guns
  i. Harbor Freight Hand Riveter $5 - Not the best but it's cheap
  ii. Drill Rivet Attachment $20 - Amazon - We have had good luck with this one.

▲ **Optional:** ¼-20 Clip Nuts, lets you easily attach bumpers or structure to the kit bot chassis by addin't nuts to the bottom of the holes. https://www.mcmaster.com/94850A129
- If you are buying these from McMaster you can buy other fasteners such as bolts and rivets from there as well. Note that they add a shipping charge to every order after you place the order.

Aluminum Rectangular Extrusions

The mostly widely used material to build FRC robots is common aluminum square and rectangular extrusion. 6063 Al will be good enough for most MCC robots. 6063 is often cheaper than 6061 but it is weaker and harder to machine.

Ask local suppliers if they have any scraps you can have, many times 1 ft or less pieces is all you need for a part of your robot.

- ▲ **Purchase:** ~20ft of 1x2 and ~20ft of 1x1 aluminum extrusion is a good place to start.
- ▲ Purchase from a local metal supplier if possible. It will be far cheaper than buying from VEXpro or Home Depot.
    - 1x1 - 1/16” Wall
    - 1x2 - 1/8” Wall (Example price 21’ for $50)

Wood

Don’t be scared to use plywood on your robot. Many teams have the resources to work with wood easily (saws, drills) and it can be very useful in the right applications. If possible buy higher quality plywood and lumber, the sanded or cabinet grade panels are going to be stronger, have fewer knots, and will be flatter than the cheapest grades.

Spectrum’s belly pan has been 6mm Baltic Birch Plywood for the past 4 seasons and we have never had an issue with. It’s easy to drill, you can tap holes in it for bolts to mount electronics and it’s very rigid.

- ▲ **Purchase:** ¼” Plywood and ½” plywood + some 2x4 and 2x2 lumber
- ▲ Using plywood as the bellypan (Bottom plate for electronics) on your kit bot chassis, is strongly recommended.
    - Teams will try to use perforated polycarbonate or some other more expensive option and that will be to detriment of the rigidity of your robot.

Plastics

Plastic can be a great material to use on your robot. Note there are a wide range of plastics that can be used well on robots and sometimes it’s not easy to tell them apart. Please don’t use Acrylic/Plexiglass anywhere on your robot, it is very brittle and will likely crack and shatter. Polycarbonate, ABS, PET(G), Acetal(Delrin), are all okay to use. Polycarbonate is just the most common.

- ▲ Polycarbonate (commonly known as Lexan)
    - 1/16” and ⅛” polycarbonate is extremely adaptable to multiple uses on an FRC robot.
    - It can be cut cleanly using aircraft snips, so you don’t need power tools.
    - Used to make mounting brackets, lightweight gussets, spacers, etc.
    - ⅛” sheets are useful for stronger items.
    - Polycarbonate can be bent easily in a vise to make various angles as well.
    - Purchase from a local plastics distributor.
        - Example price 4’x8’x1/8”’ sheet for $85
    - **Purchase:** 1x 4x8x1/8” Sheet of polycarbonate

- ▲ PVC
    - Can be used for prototyping and in areas of your robot that will not see any impact.
    - PVC is very brittle so if you mount it on the exterior of your robot, it's possible it will shatter when hit.

Brackets

They allow you to connect parts together to build up frames and mechanisms. VersaFrame is a great system but it can be expensive. You can approximate many of it's gussets/brackets from other cheaper sources.

Other common items at home stores can be repurposed for your robot. Many FRC robots have used hinges, springs and many other items to great effect.

You can print out the drawings for a gusset/bracket that you need on paper than cut it out of a sheet of metal or plastic. You may ask local teams if they can help make a few of these for you on CNC equipment which is cheaper than purchasing them.

- **Angle Brackets, gussets, hinges**
    - Digikey/Mouser
        - Keystone 4337 90 degree aluminum bracket - Digikey - Mouser
            1. Video on how to use them
            2. **Purchase:** 100 for ~$18, you can use your digikey voucher that you will get on kickoff
    - Home Depot (Lowe's, etc often have similar brackets)
        - Note: Steel brackets are harder to modify and heavier than aluminum but they are inexpensive and you can buy them locally.
        - **Purchase:** A variety of these to have on hand, you may be able to ask Home Depot or lowes to donate them or donate gift cards to your team. They are great for prototypes.
        - 3 in. Zinc-Plated Flat Corner Brace (4-Pack)
        - 2-1/2 in. Zinc-Plated Flat Corner Brace (4-Pack)
        - 3 in. x 3 in. Zinc-Plated T-Plate (2-Pack)
        - 2"x0.625" Steel Angle Bracket (4-Pack)
        - Home Depot 2"x2.75" Zmax Steel Angle Bracket
        - Home Depot 1.5"x2" Zmax Steel Angle Bracket
        - 1.75" x 5" Tie Plate
        - Door Hinge - Used on 2566's 2018 Arm
        - 2-1/2 in. Non-Removable Pin Hinge - $1.29 For mounting flaps, etc.
        - 7.25" x 7.25" Angle bent sheet 90 degree Support (only get if you have a specific use)
    - VEXpro Versaframe Gussets
        - Very common in FRC, lightweight aluminum parts, smaller holes are easier to rivet to aluminum tubing.
    - AndyMark Gussets
        - AndyMark carries several brackets designed to mount to the AM14U series of drive trains.
    - REV 1 in guessets

Additional Options

Structure

- **Versaframe**
  a. Versaframe is product family from VEXpro that allows you to quickly and easily build robot mechanisms.
  b. The gussets and stock can be riveted together quickly and easily.
  - This is a more expensive option but it can save you a lot of time.
  - Brackets/Gussets = $3.50 to $10 each
    i. In many cases Home Depot steel brackets can replace versaframe for less money.
  - 1" x 2" x 0.050" Pre-Drilled VersaFrame Aluminum Tube Stock (59") = $30

- **AndyMark *Nut Extrusion**
  Can be bolted together at 90 degree angles using ¼-20 thread forming screws.
  - Peanut Extrusion 1”x1” $25 for 6ft
    i. Stronger than normal 1*1 box tube since it have ribs running in the middle that prevent it from collapsing.
  - Walnut Extrusion 1”x2” $29 for 6ft
    i. Similar to Peanut Extrusion but with a larger 1x2 profile
- **AndyMark C-Channel** - 6ft for $37
  - This C-Channel can be bolted around a 1”x1” or 1”x2” aluminum extrusion to make various brackets or components.
  - Regular 1.25”x1.25”x1/8” U Channel may be substituted but you would need to drill your own holes.
- **REV 1 in Extrusion**
  - Strong 1” extrusion with additional features for linear motion and holding panels. Can tap the end of the extrusion to mount to flat structures or other tubes.
  - Can slide 10-32 low profile lock nut into the slots.

- **Aluminum Round Tube**
  - There are many designs that can use round tube instead of square or rectangular tube. Espelly for support elements that won’t be mounting motion items.
  - Use press in tubing connectors to connect tubes to flat plates or rod ends
  - Common FRC Sizes
    i. 1.25” OD x .06 Wall - Allows 1.125” Bearings and hubs to be pressed in.
    ii. ⅞” OD - Roughly the same size as ½” PVC pipe

Additional Gearbox Options

1. **VP Lite Gearbox - $18 or $25**
   - Used for intakes and light duty applications.
   - Comes with ⅜” Hex shaft or Universal output that can connect to ½” hex
     i. Can use VersaHex Adapters to convert ½” parts to ⅜” hex shaft.
   - Need to add Ring Gears $2 each
     i. Plastic ring gears are not as strong as aluminum but ⅛ the cost, when used for intake

they work well.
    - Need to add Gear Reductions $15 each
        i. Recommend 7:1 reductions to start (10:1 reductions have a small sun gear that may break.)
    - Can be combined with Versablock lites and 1”x1” for easy mounting
    - Doesn’t have side mounting holes
    - $18 + $2 + $15 = **$35** 7:1 gearbox with ⅜” hex output (Up to 10:1)
    - $18 + $4 + $30 = **$52** 20:1 gearbox with ⅜” hex output (Up to 100:1)
2. **AM 57 Sport Gearbox - $59 to $96**
    - Can’t change configuration like you can with VPs
    - The Dual Sports (we suggest the 156:1 kit or 117:1 kits) are a good value if you need the power of two motors, this would be for an arm joint, etc.
    - **$84** for 20:1 gearbox with ½” output shaft
3. **VersaPlanetary V2 Gearbox - $40 to $45**
    - Buy with ½” Output shaft
    - Need to add Ring Gears $10 each
        i. Can substitute plastic ring gears ($2) for light duty applications
    - $40 + $20 + $30 = **$90** for 20:1 gearbox with ½” output (Up to 100:1)
4. **VEXpro Clamping Gearbox - $15**
    - Needs a pinion gear, output gear, and bearings to to work. Look at drawings on website for instructions on how to use these.
    - 72 tooth ½” hex spur gear $25
    - 2x ½” Hex Bearings $10
    - 10,11, or 12 tooth CIM Pinion $10
    - $15 + $25 + $10 + $10 = **$60** for max 7.2:1 gearbox with ½” Hex output
5. **8mm to ½” Hex Adapter or Pulley for CIM Motors +** AM CIM Mount Bracket $9
    - VEXpro $10 - AndyMark $11 OR WCP CIM HTD 12t pulley $10
    - These are used to directly adapt a CIM style motor to ½” hex. This allows you to mount a ½” hex bore sprocket/pulley directly to the output shaft and drive a simple mechanism that way.
    - Combine with the CIM Mount for quickly mounting your CIM Motor to the robot.
    - For ~$20 you have a hex shaft spinning at ~5000RPM that you can use for your mechanisms.
    - You likely have a spare CIM motor, or a veteran team near you can give you a few for free.
    - Be sure the adapter isn’t rubbing on the boss of the motor, use a bronze washer or a 8mm retaining ring to prevent them from rubbing.
    - Using an 18t to 36t Belt reduction to a shaft spinning 2.25” compliant wheels would be a good intake in many games. Larger wheels need more reduction, a smaller roller needs less reduction. You can even 3D print Timing Belt Pulleys if you have the ability to do that.
    - WCP sells a 12t pulley $10 that directly mounts to a CIM so you don’t even have to use the hex adapter.

Additional Shaft Options

- VEXpro 1/2" 7075 Hex Stock - $15 per 3ft
- McMaster ½” x ¼” 6061 Hex Tube - $10 per 3ft
- AM ½” Churro Shaft - $12 per 3ft - Note: 6005A Aluminum is weaker than 7075
    - Not recommend for drive shafts, useful for light duty applications
    - Can be tapped to ¼”-20 which often allows you avoid shaft collars