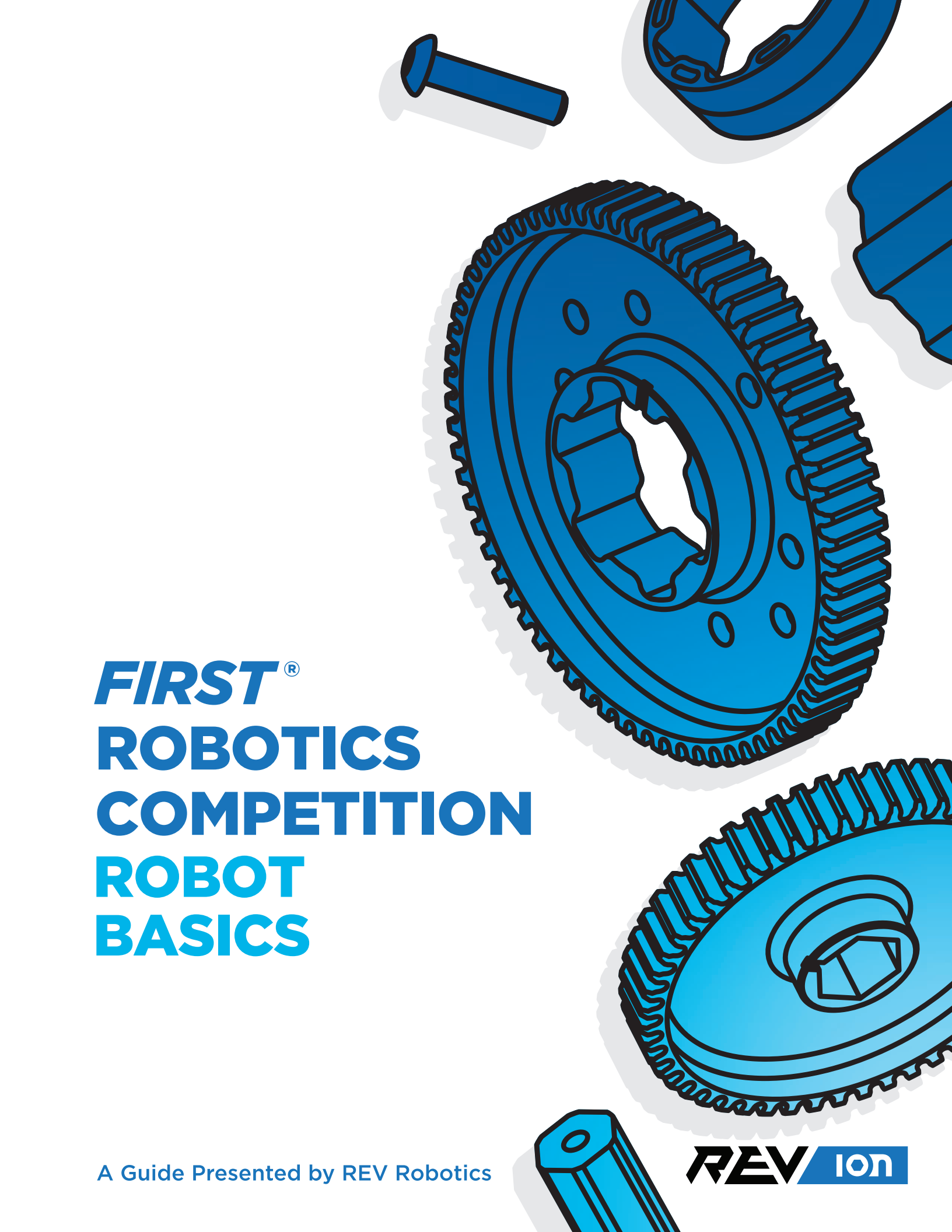




FIRST[®] **ROBOTICS** **COMPETITION** **ROBOT** **BASICS**

A Guide Presented by REV Robotics

REV **ION**

Table of Contents

Categories of Robot Parts	3
Hardware and Tools	4
Structure	5-9
Structure Application Examples	9-11
Transmitting & Transforming Motion	12-19
Supporting Motion	20-21
Constraining Motion	21
Stopping Motion	22
Motion Application Examples	23
Wheels	24-26
Drivetrains	27
Swerve Basics	28
Mechanisms	29
Mechanism Actions	30
Designing a Mechanism	31
Common Mechanisms	32-36
Mechanism Application Example	37-38
Actuators	39-40
What's Next?	41

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Categories of Robot Parts

A robot is built from many various types of parts. All the parts on a robot can be broken down into the following categories. This guide will explain each category, as well as provide some suggestions for building sturdy structures and simple mechanisms.

Hardware and Tools

Hardware refers to the fasteners used to hold the structure together, such as screws, bolts, nuts, rivets, etc.

Structure

Structural parts are the framework to which all other parts are attached. Strong geometry, like triangles, are a great foundation for a sturdy robot.

Transmitting and Transforming Motion

Sprockets, chain, belts, pulleys, and gears are used to transfer motion on the robot. Differences in the sizes of gears and sprockets allow for changes to speed and torque.

Wheels

Wheels come in many varieties, each with their own unique features that make them useful not only for robot propulsion, but also for mechanisms like intakes and manipulators.

Supporting, Constraining, and Stopping Motion

Parts, such as shaft collars and spacers, help restrict or constrain motion to the intended direction. Unwanted motion hurts the accuracy and repeatability of the robot's actions. Other parts, like ratchets or hard stops, work to stop or constrain a robot's movement, in line with the intended direction.

Drivetrains

Drivetrains are the base of most *FIRST* Robotics Competition robots. They are generally made of wheels, gearboxes, motors, and structure. There are many different styles of drivetrains featuring different components that will affect the maneuverability of the robot.

Mechanisms

A mechanism is a mechanical assembly that transmits motion or force to perform a specific task.

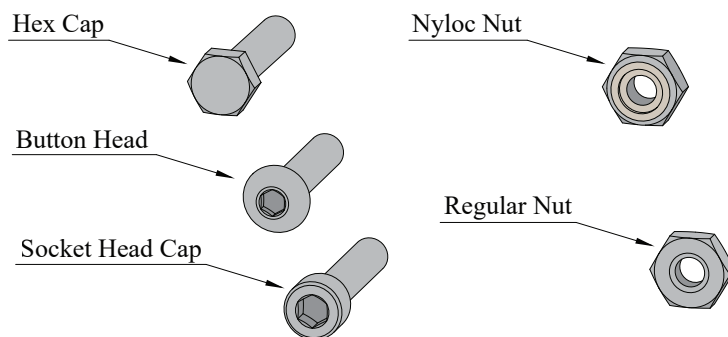
Actuators

Actuators, like motors, servos, and pneumatic cylinders, create motion on the robot.

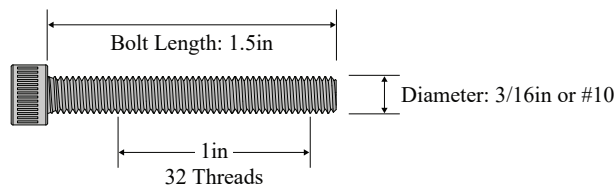
There are other types of parts that go into creating a robot that won't be discussed in this guide. For more information on those parts, please see the "What's Next?" section at the end of this guide.

Hardware and Tools

Teams participating in the *FIRST* Robotics Competition use hardware to connect, or fasten, brackets and structure together on a robot. Different applications require different lengths and/or profiles of screws. When attaching a bracket to aluminum extrusion, shorter screws with a low-profile head, like a button head screw, are generally required. Longer screws are used to connect Control System components and other thicker materials. Locking nyloc nuts are suggested to prevent the screws from loosening due to vibrations as the robot moves.



Many different build systems, such as the ION Build System, have standardized hardware sizes in order to cut down on the amount of hardware and tools teams need to keep on hand. Hardware is generally sized by bolt diameter and number of threads per inch. For example, #10-32 hardware has a #10-sized, approximately 3/16in diameter, bolt with 32 threads per inch, and a #1/4-20 bolt has a 1/4in diameter with 20 threads per inch. Consider picking a standard for your team, like #10-32, and using it throughout your robot.



See the “Structure Application Examples” section on pages 9-10 of this guide to find some ‘best practice’ tips for working with hardware.

We recommend these tools to start building your team’s toolbox:

- Using Hardware and Fastening Parts
 - Screw Drivers
 - Nut Driver Set
 - Hex Key Set
 - Combination Wrenches
 - Ratcheting Wrenches
 - Handheld Riveter with Pop Rivets
- Creating Holes
 - Power Drill
 - Drill Bit Set
 - Tap and Die Set
- Shortening and Shaping Material
 - Hack Saw
 - Metal Files

For more information on recommended tools, check out the *Suggested Tools for FIRST Robotics Competition Teams Guide*, which can be found on the technical resources web page:

www.firstinspires.org/resource-library/frc/technical-resources

Structure

This section goes over all of the basic structure elements used in *FIRST* Robotics Competition. Here, we give a comparison between T-Slot Extrusion and Patterned Extrusions, as well as a few tips and tricks for anyone choosing to build with REV ION.

The majority of a robot’s structural elements can be divided into two main categories:

- **Extrusion**
 - Patterned
 - T-Slot
 - Plain Stock
- **Flat Stock**
 - Plywood
 - Metal
 - Plastics
- **Brackets**
 - Motion
 - Structure

Extrusion

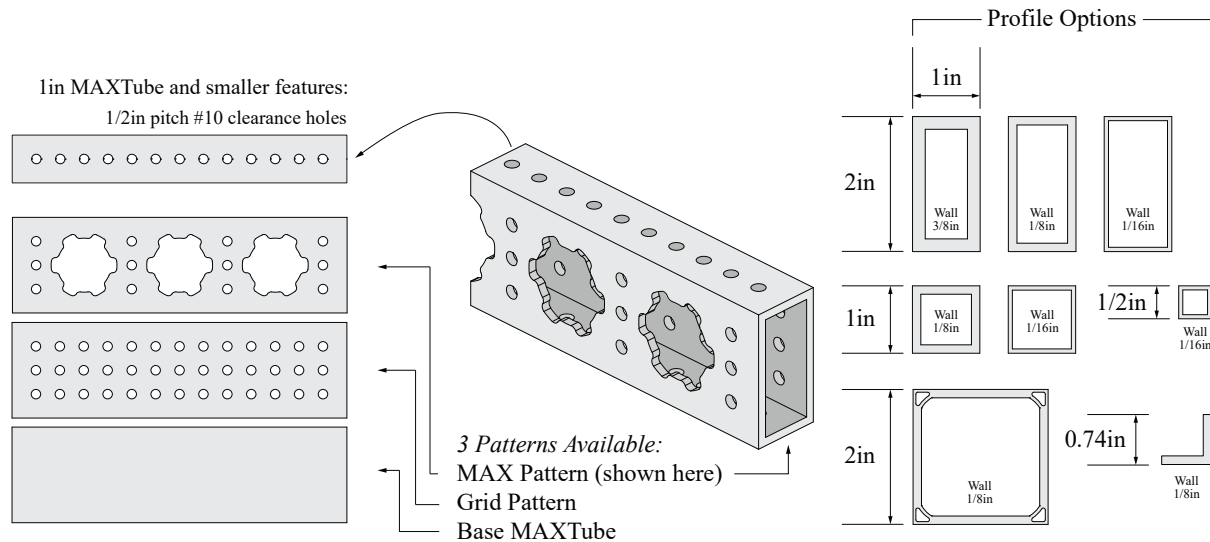
There are three primary types of structure pieces used when building a robot: T-Slot Extrusion, Patterned Extrusion, and Plain Extrusion Stock. While they all have a few similar features, they each have applications best suited for them.

Patterned	T-Slot	Plain Stock
• A fixed pattern of mounting holes • Locations for mounting structure, gears, sprockets, bearings, shafts, motors, and servos • Good for a robot drivetrain • MAXTube accepts standard #10-32 Hardware on 1/2in pitch	• Slots allow for brackets to be placed anywhere • Adjust design with ease • Good for linear motion • ION 1in Extrusion accepts standard #10 Nuts and #10 Low-Profile Nyloc Nuts	• Available in many profiles, including square/ rectangular tube, and C-channel • Ultimate choice for customization, but it requires precise machining

Patterned Extrusion

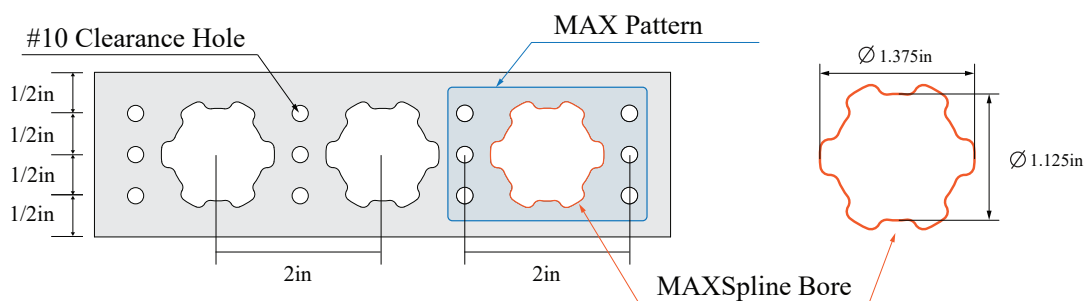
Using patterned extrusion to build a sturdy drivetrain is a great start to building a robot. Pre-drilled holes, often in a grid pattern, allow for the rapid iteration of a design without needing to machine a new part. A wide variety of different patterns exist, each one with its own set of standards. REV Robotics is just one of many manufacturers of patterned extrusion. Each team should evaluate the different patterns available and decide which design best suits their robot based on the desired features. Making sure that any types of patterned extrusion your team uses are compatible with each other will save you time in the long run.

The ION Build System has three options for patterned extrusion within the MAXTube line: MAXTube with no pattern, MAXTube with Grid Pattern, and MAXTube with MAX Pattern. All 1in and smaller sides of the MAXTube extrusion have #10 clearance holes on a 1/2in pitch to allow for easy attachment to almost any other part.

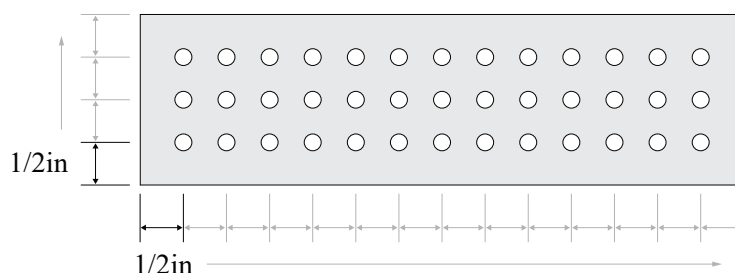


MAXTube with MAX Pattern features a combination of #10 clearance holes and a MAXSpline Bore patterned every 2in. The #10 clearance holes are arranged on a common 1/2in pitch grid. MAX Pattern frees teams from cutting and drilling, with easy installation of bearings for different live axle applications, as well as correct center-to-center distances for simple 1:1 power transmission with #25 chain or RT25 belts. MAX Pattern is featured on 2x1 and 2x2 MAXTube.

MAXSpline is a shape unique to the ION System and is featured on many ION components. Learn more about power transmission with MAXSpline in the motion section of this guide.



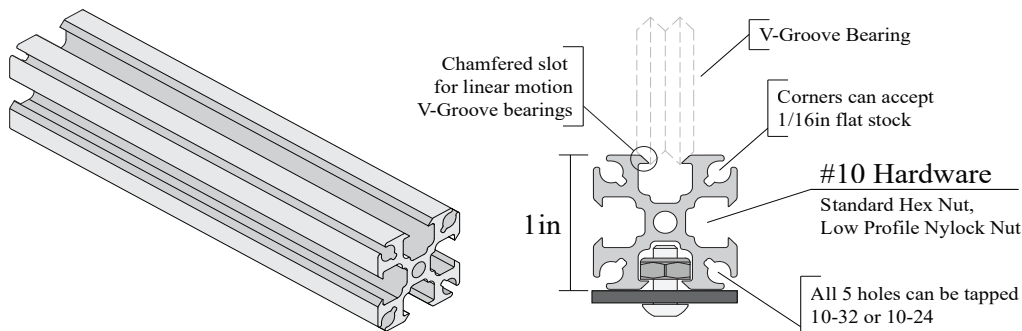
MAXTube's Grid Pattern is featured on all available sizes of MAXTube: 1/2x1/2, 0.74x0.74 angle, 1x1, 2x1, and 2x2. A grid of #10 clearance holes is spaced along each side of the MAXTube on a 1/2in pitch.



T-Slot Extrusion

The flexibility of T-Slot Extrusion makes using it a great option for builds that won't fit on the pitch of your patterned extrusion. Teams are not locked into a pitch, so there are virtually infinite options for mounting other components. T-Slot Extrusion is also a great option for adding linear motion to your robot. T-Slot Extrusion is available in many sizes from different manufacturers, including REV Robotics, 80/20, and Bosch. Each brand of T-Slot Extrusion has different features, such as compatible hardware sizes, extrusion profiles, and linear motion guides.

When using ION 1in Extrusion, standard #10 Hex Nuts or #10 Low-Profile Nyloc Nuts will fit in the slots, allowing teams to use a more commonly available option than specialized T-nuts.



Flat Stock

When extrusion is too rigid a shape to build what you need for your robot, or it is not available in a size with the surface area that your design requires, flat sheets of material may provide the flexibility you need. The flat stock used for FRC is generally made of wood, metal, or plastic.

Wood

Plywood and cardboard are great for prototyping because of how widely available they are, but may not be strong enough for competition. Many teams will check that their assembly or mechanism fits correctly with prototypes before building it out of a final material to save on the cost of iteration. Additionally, 3/4in plywood is often required to build the robot's bumpers.

Metal

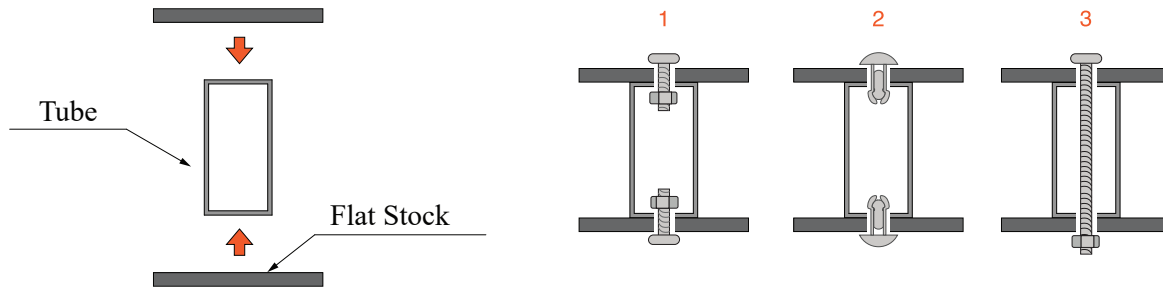
Pre-Cut Plates similar to patterned extrusion are widely available. Within the ION Build System, there are MAXPattern Plates, which feature the pattern on an aluminum plate. Since the plate is thin, structure can be added in tight spaces or plates can be stacked using standoffs to create custom widths of MAXPattern rails. Plain stock of steel and aluminum sheets is also widely available for custom machining parts in a variety of sizes and thicknesses.

Plastics & Composites

Polycarbonate is a popular **Plastic** that is also used to make safety glasses. It is strong, flexible, and available in many different sizes. Because it does not conduct electricity, it is an ideal material for mounting your control system. **Composite Plastics**, like MAXComposite or self-reinforced polypropylene, are known for their durability and light weight. This material is made of woven plastic fibers fused together so it must be cut in a way that melts the edges so that it does not fray.

Joining Flat Stock or Brackets to Tube

There are three ways to attach flat stock or brackets to tube: (1) bolting through each wall of the tube separately, (2) using rivets to attach each piece to the tube, or (3) using one bolt to attach all pieces.



Brackets

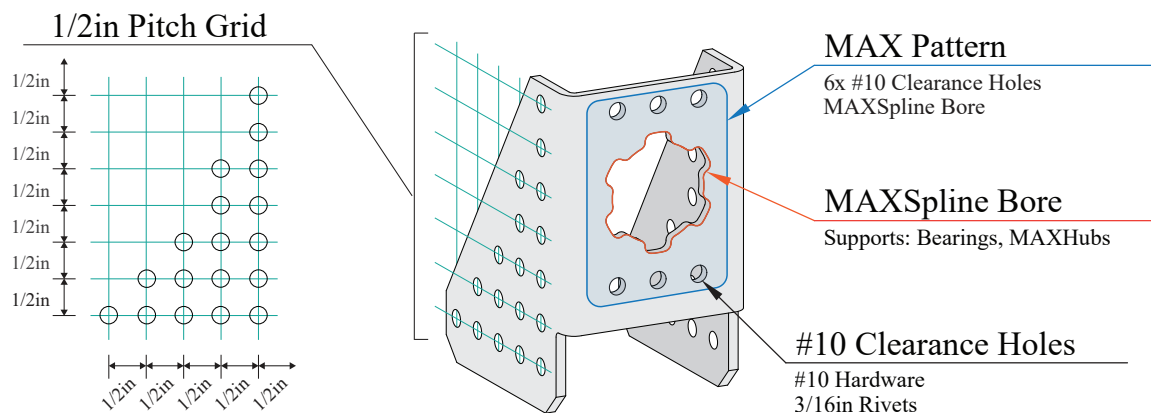
Brackets are used to join different parts of the robot together. Most brackets can be divided into two categories: **Motion** and **Structure**. Motion brackets help create strong attachment points for your motion components and any parts of your robot that move. Structure brackets are designed to hold pieces of extrusion, flat stock, and other structural material together.

Motion Brackets

Many motion brackets have features specific to the components they are designed to work with, and they often include special hole patterns for motors or different bores. The motion brackets you use will heavily depend on the motion components you design into your robot. Be sure to check the compatibility of your brackets with any other structure or components you are using on your robot.

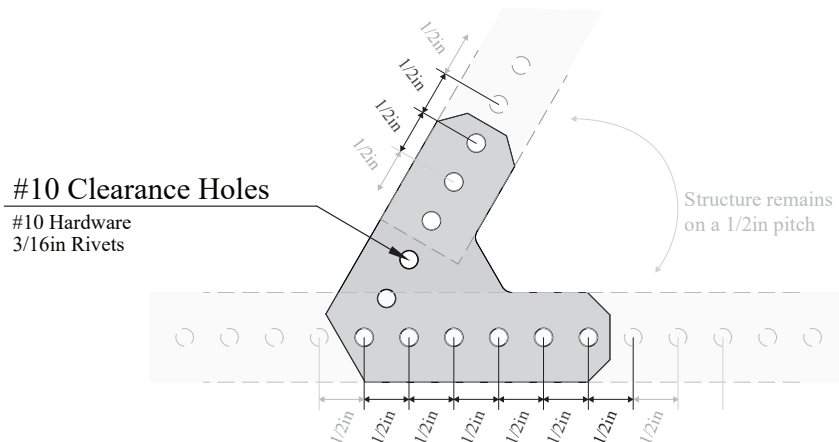
In the ION Build System, motion brackets are referred to as MAXSpline Brackets. These brackets feature the ION System's signature MAXSpline shape, the core to transmitting motion. The major distinguishing feature of MAXSpline Brackets are a MAXSpline Bore, or a full MAX Pattern to support bearings and MAXHubs.

MAXSpline Brackets that feature the MAX Pattern are designed to keep the pattern on pitch.

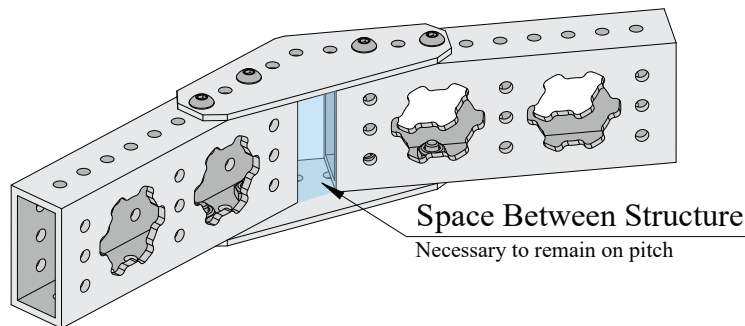


Structure Brackets

Structure brackets are designed to secure pieces of structure together at varying angles. There are different hole patterns available to accommodate the different extrusion types and patterns. Within the ION Build System, structure brackets are any bracket that does not have a MAXSpline Bore. ION 1in Brackets are hole-aligned to maintain the pitch grid between your MAXTube.



When building a robot with hole-aligned brackets, you may notice an open space between the structure ends, where they do not touch at the corner. This is expected and will not affect the strength of the joint.



Structure Application Examples

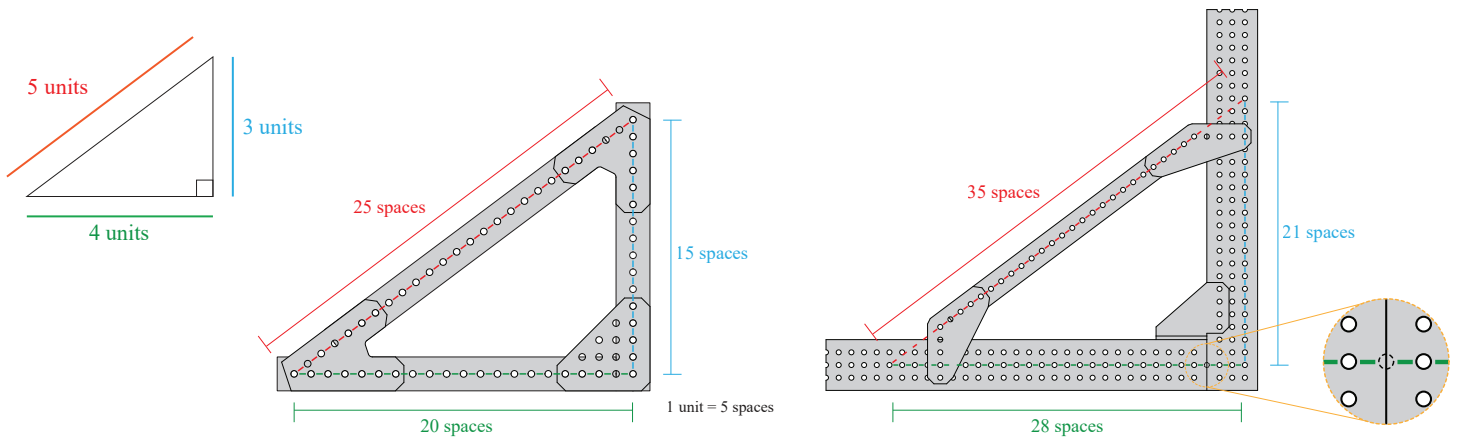
Check out the following tips and tricks, so you can quickly become a master robot builder.

3-4-5 Brackets

Triangles are a sturdy structural shape, commonly used on robots to support many types of mechanisms. Vertical structures are very common and can be supported with a 90 degree, or “right” triangle.

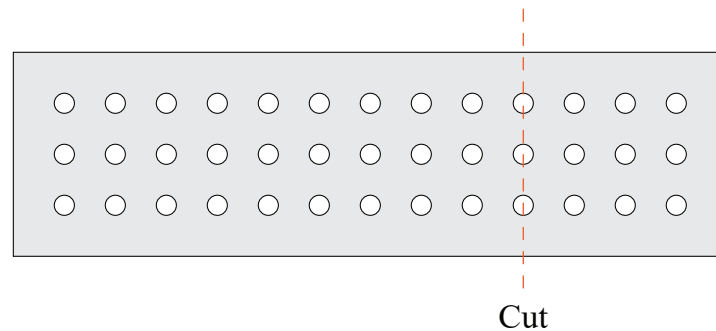
Building a triangle out of patterned extrusion with a fixed pitch hole pattern can be difficult when trying to ensure the holes remain on pitch across all sides and all angled brackets. For example, a simple right triangle can be made with a set of 45, 45, and 90 degree brackets. However, the required lengths of structure to form the triangle sides are irrational numbers, and therefore, the holes of the hypotenuse will not align with the pattern of the other sides.

The ION Build System features 3-4-5 brackets specifically designed to have the exact angles to make up a triangle with sides that are multiples of 3, 4, and 5 length units. In other words, the holes on all sides of a triangle built with 3-4-5 brackets will line up on pitch. Count the number of spaces between holes for each side of the triangle, and roughly cut the structure to length. In the example, each side is a multiple of five spaces (1 unit), but that base unit will depend on the overall desired dimensions of the triangle.



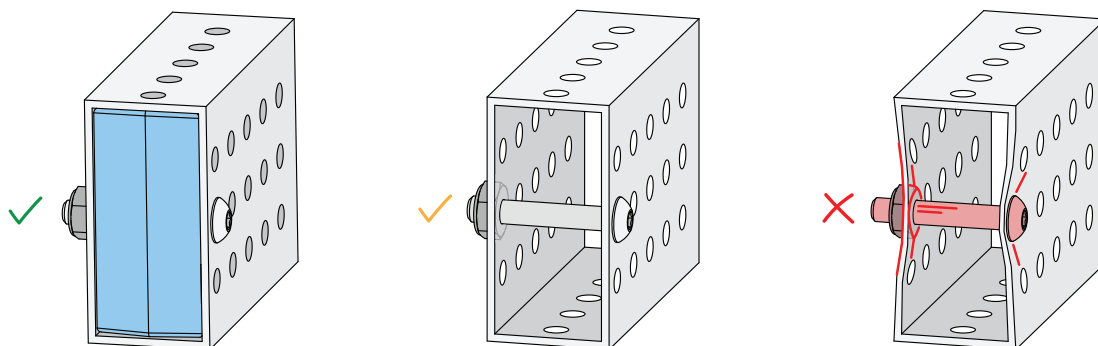
Cutting MAXTube on Pitch

To ensure that your MAXTube has been cut on pitch and will maintain the 1/2in grid throughout your entire robot's assembly, measure the length you need from the factory edge or from the center of a hole. When the tube is cut near the center of a punched hole in the grid, the tube will have space to attach with a bracket and maintain pitch.



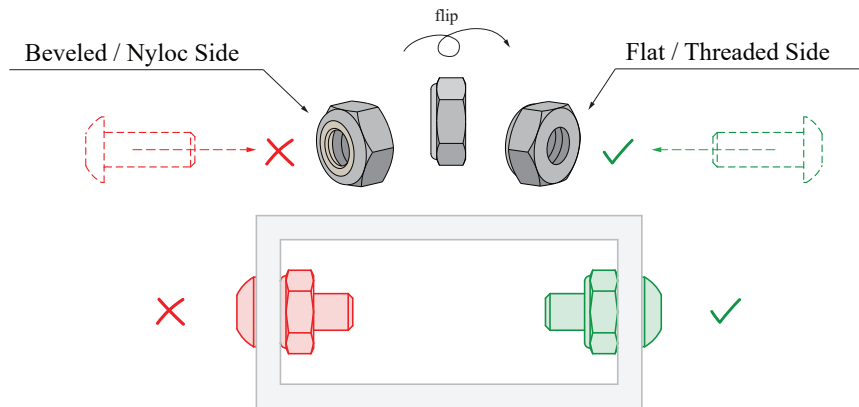
How to Bolt Through a Tube

When bolting through a tube, be careful not to over-tighten the bolt. Doing so can cause the tube to crush or deform. If you need to tighten the bolt for heavy-duty applications, be sure to support the tube from the inside, similar to as shown with the MAXTube Internal Support.



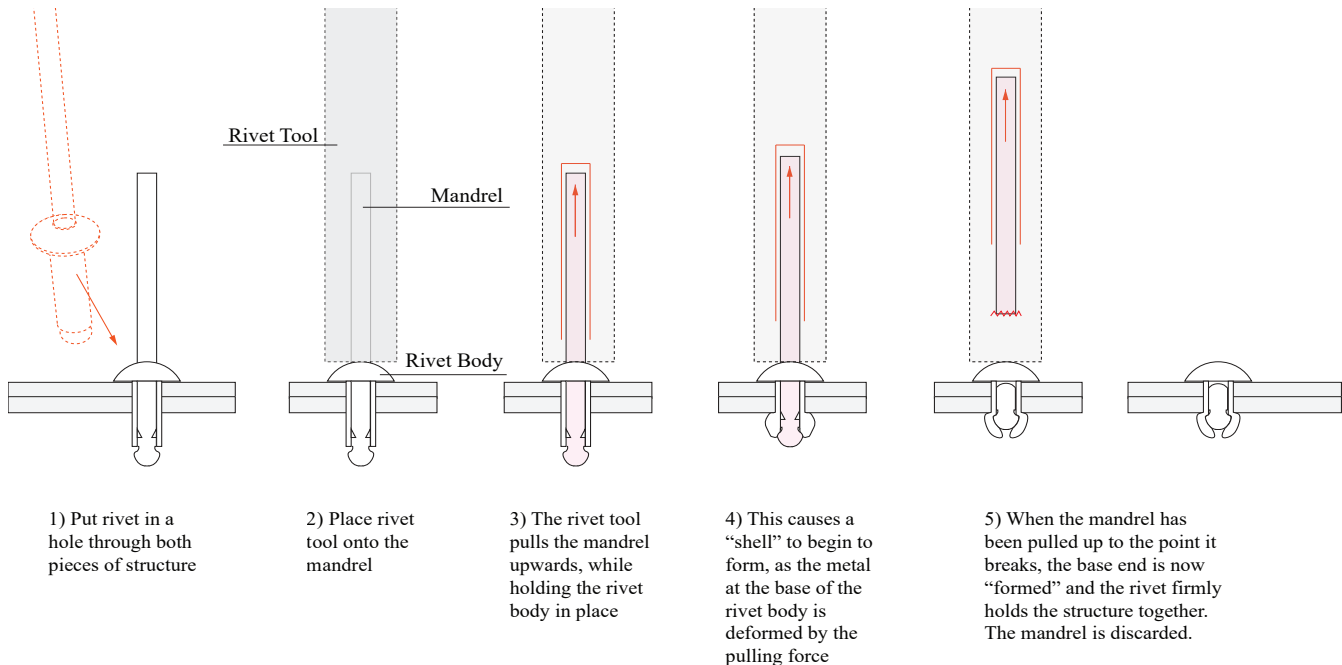
Nut Direction Matters

Nyloc nuts have a built-in nylon collar that secures a screw with friction. As the nut is tightened, the nylon collar deforms around the threads, creating a lock that is vibration-resistant. When using nyloc nuts, make sure to thread the screw through the flat, threaded side first. This ensures that the nylon collar of the nyloc nut will engage with the threads properly.



Rivets

Rivets are a popular alternative to nuts and bolts. By using a handheld riveter, you can secure brackets and other components to a robot with one item.



Transmitting and Transforming Motion

Transmitting Motion is the act of getting motion from one part of the robot to another using shafts, sprockets, gears, belts, pulleys, etc.

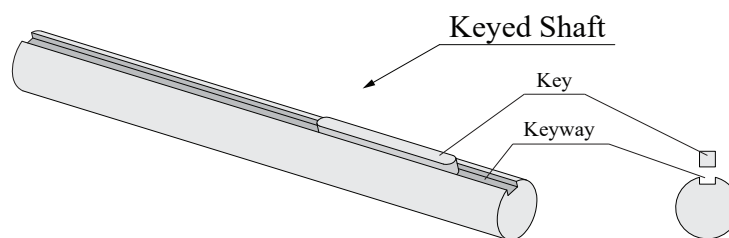
Transforming Motion is the act of changing the turning force (torque) and speed. Torque and speed are inverse to each other, meaning when one increases, the other decreases. Several of the same components that *transmit* motion are also used to *transform* motion (sprockets and chain, belts and pulleys, and gears).

Shafts

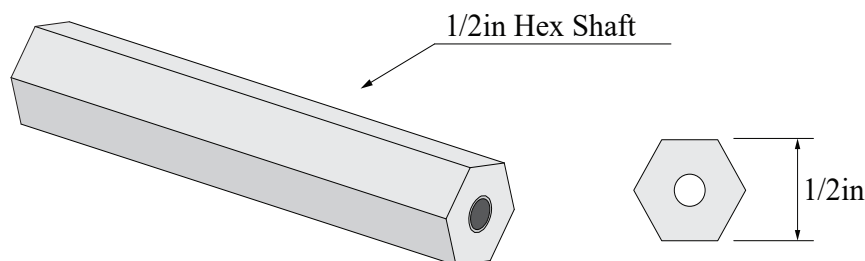
The core component for transmitting motion on a robot is a shaft. They come in many shapes and styles, but the goal of each shaft is to transmit motion to other components.

One of the oldest and least commonly used shaft types is a D-shaft - a round shaft with one flat side that makes a D shape. To transmit motion with a D-shaft, shaft collars and motion components are secured to the flat side of the shaft using a set screw. Transferring torque through a set screw can cause failure in high-torque applications, and the set screws require re-tightening under the best of circumstances, so this method is generally not recommended.

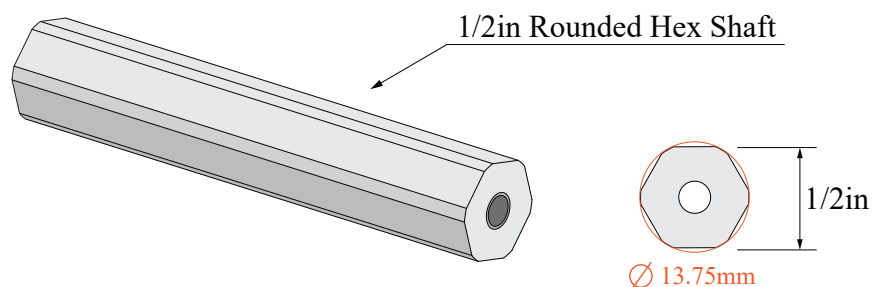
Another shaft type commonly found on motors and gearboxes are Keyed Shafts. These consist of two parts: a round shaft with a groove called a keyway, and a key that fits into that groove. Components attached to keyed shafts will also have a keyway, as the key is how torque is transferred from the shaft.



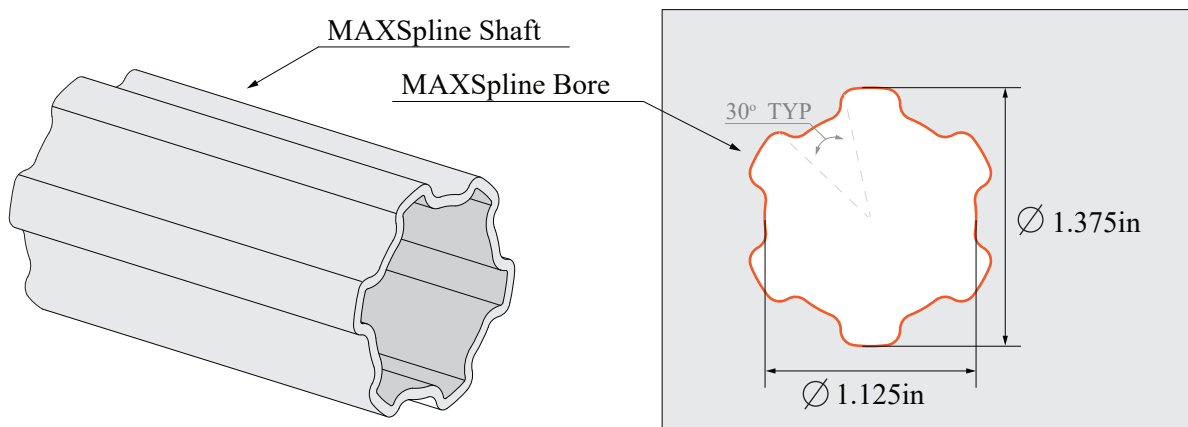
A 1/2in Hex Shaft is the most common way to transmit motion in the *FIRST* Robotics Competition. The six-sided shape provides reliable torque transfer and is commonly used with wheels, gears, sprockets, and more.



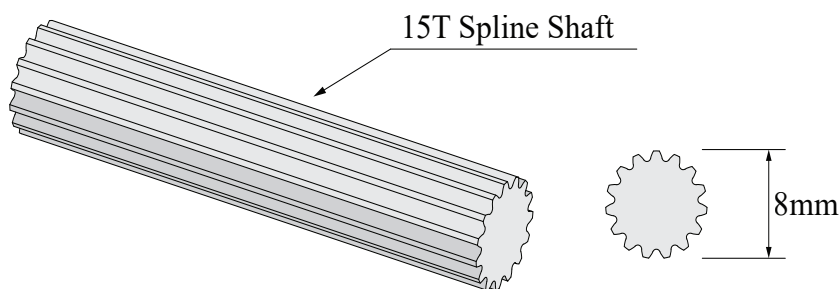
Sometimes when building with 1/2in hex shaft, it can be difficult to line up the shape within hex bore elements because the corners must be perfectly aligned. 1/2in Rounded Hex Shaft is a popular variation of 1/2in hex shaft. With the corners rounded to form a 13.75mm circle, 1/2in rounded hex shaft pilots smoothly inside 1/2in hex bore components as well as standard 1.125in flanged bearings for an easy assembly experience.



The last common shaft style are spline shafts. Spline shafts are identified by the shape of their spline, often consisting of grooves or teeth that run down the length of the shaft and interlock with other motion pieces. An example of a spline is the MAXSpline from the ION Build System. This unique spline shape combines internal and external bearing support with torque transfer features for added configurability of motion components. It is incorporated into various motion components in the ION System; sprockets, gears, wheels, shafts, etc.

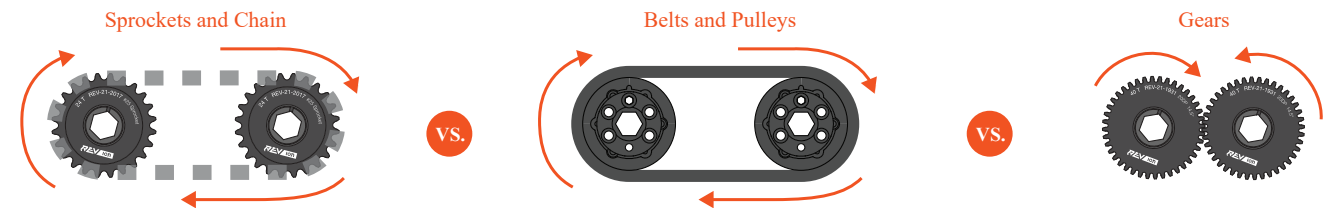


Another common shape used for spline shafts is the 15T spline, which is becoming a popular option for *FIRST* Robotics Competition applications. Its 8mm outer diameter makes it ideal for 8mm motor outputs, like on a NEO 2.0, or in gearboxes where 8mm inner diameter bearings are already being used. On a 15T spline shaft, the load is equally distributed across 15 teeth, allowing for better distribution of stress, more efficient torque transmission and increased durability when fitted correctly compared to regular 1/2in hex shafts.



Motion Transmission Systems

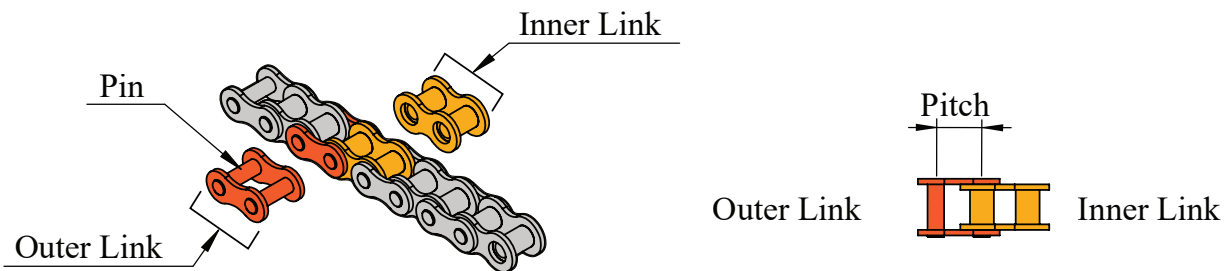
The three primary motion systems used to transmit motion are: sprockets and chain, belts and pulleys, and gears. Additionally, these systems are often configured in ways that simultaneously transmit and transform motion.



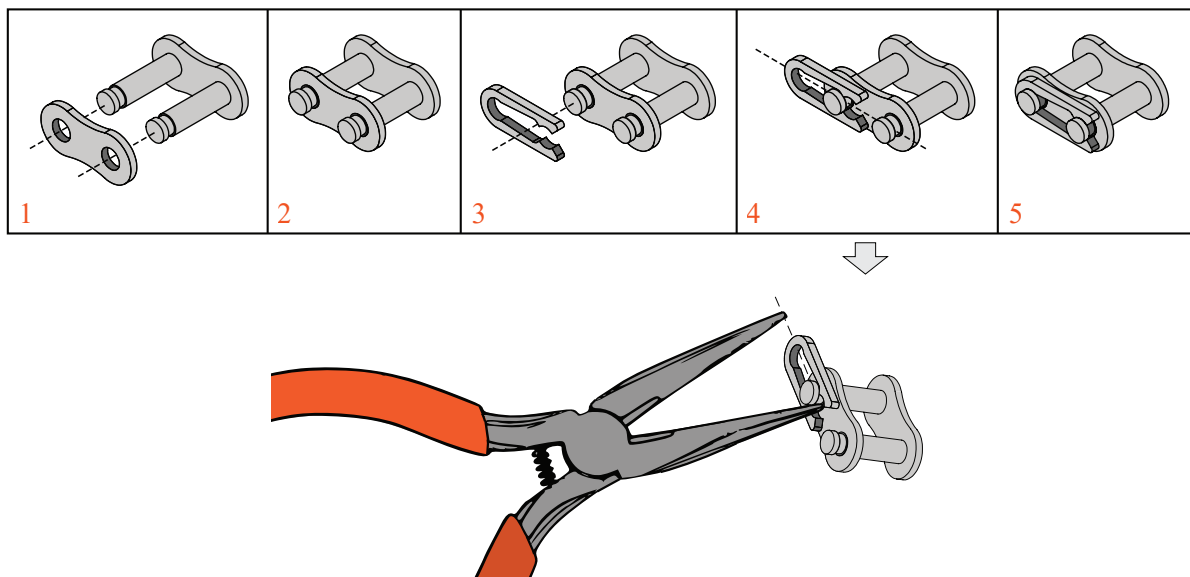
Sprockets and Chain	Belts and Pulleys	Gears
• Good for transmitting motion over long distances • Changing sprocket sizes requires changing the chain length and/or spacing • Chain is forgiving in construction accuracy • Chain tension and wrap are important	• Smooth and efficient • Can be lighter than gears or sprockets that are traditionally made of metal • Changing pulley size and/or spacing needs a new belt length • Belt tension and wrap are important	• Can be used for changing rotation direction • Compact • Flexible in adjusting speed and torque • Gear spacing is important

Sprockets and Chain

Sprockets and Chain are ideal for transmitting motion over long distances. A chain consists of a continuous set of links that ride on the sprockets to transmit motion. The two most commonly used sizes of chain in the *FIRST* Robotics Competition are #25 and #35. When choosing between chain sizes, it is important to consider the pitch of the chain and the weight and forces that your mechanism will be experiencing. The ION System is designed around #25 chain using compatible #25 sprockets.

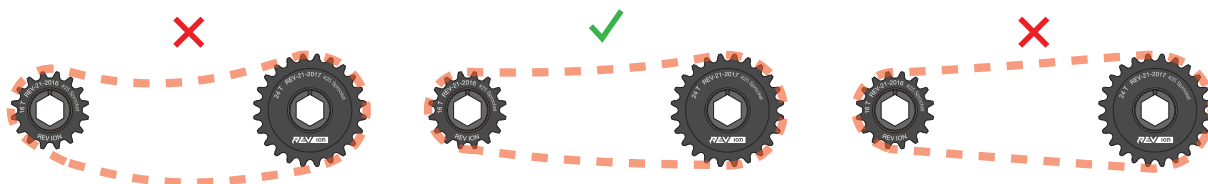


Creating a loop of chain requires breaking off the correct number of links by removing a specific chain pin and joining the ends together. Chain can be broken using many methods, including a chain tool or various steel cutting devices, like a rotary tool. Once you have counted the number of links necessary for your application, the chain can be joined using a master link or by replacing a pin. The diagram below shows how a master link is assembled to replace an outer link joining two inner links.

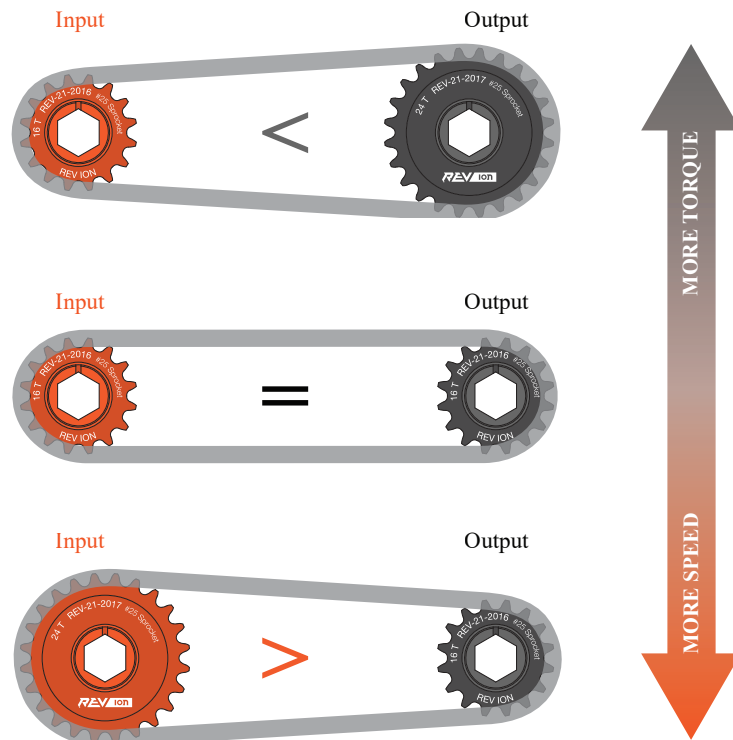


Instead of using a master link, a #25 Chain Tool can be used to push out a pin and then push the pin back in once the link has been formed for a stronger, but more difficult, joining method. For instructions on how to break and reassemble the chain using this method, see the *Chain Tool User's Manual* and 'How-To' video found on its product page on our website.

When creating your loop of chain, remember that properly tensioned chains should not be tight. If the chain is too tight on your sprockets, it can waste energy, making your actuators work harder while causing premature wear and damage. If the chain is too loose, it can slip off or skip teeth on the sprockets.



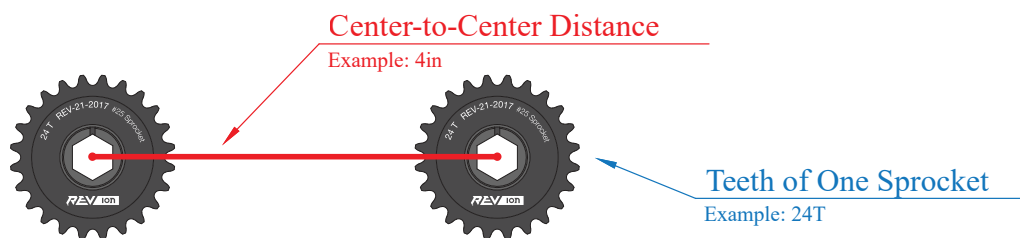
Transforming the torque and speed of motion with sprockets and chain is accomplished by changing the size of the sprockets.



Chain Loops can be used with ION Sprockets and structure featuring the MAX Pattern. Any 1:1 ratio will have the correct center-to-center distance for a properly tensioned chain, without the need for tensioning bushings. To calculate how many links you will need, multiply the center-to-center distance by eight, and add the number of teeth on one sprocket.

Links of #25 chain = (Center-to-Center Distance x 8) + Teeth in one sprocket

$$(\text{Center-to-Center Distance} \times 8) + \text{___T} = \text{Links of \#25 Chain}$$



$$(4\text{in} \times 8) + 24\text{T} = 56 \text{ Links of \#25 Chain}$$

ION Ratio Plates are available as a part of the ION Build System to accommodate ratios other than 1:1 that would not usually fit on pitch. The ION Ratio Plates provide an offset from the standard MAX Pattern that creates the correct center-to-center distance.

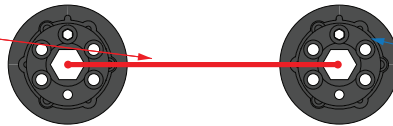
Belts and Pulleys

Belts and pulleys are a great, lightweight option for building a smooth-running mechanism. They are very similar to chain and sprockets, with the belt replacing chain and pulleys replacing sprockets.

The biggest difference is that belts are a set size and cannot be adjusted. If you want to change the spacing of your pulleys or use a different size pulley to increase speed, you will likely need a different sized belt.

$$(\text{Center-to-Center Distance} \times 8) + \text{Teeth in One Pulley} = \text{Belt Size of an RT25 Belt}$$

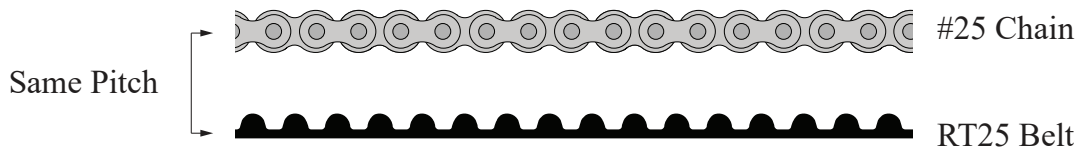
Center-to-Center Distance
Example: 4in



Teeth in One Pulley
Example: 24T

$$(4\text{in} \times 8) + 24\text{T} = 56 \text{ Tooth RT25 Belt}$$

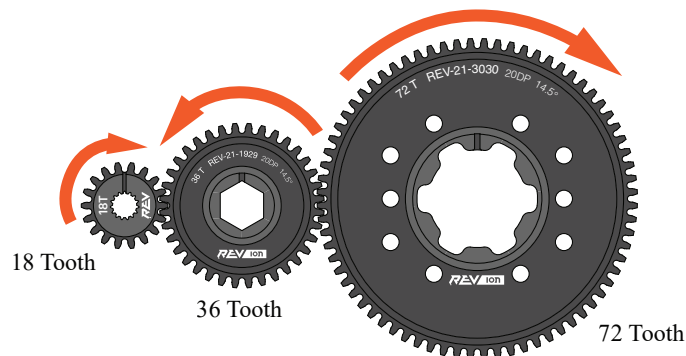
In the ION Build System, we created a new standard of belt called RT25. Unlike many common metric belt standards, RT25 Belts have a 1/4in pitch just like #25 chain. With this pitch, both RT25 Belts and #25 chain work natively within the ION Build System. The matching 1/4in pitch allows both systems to be swapped out 1:1 for rapid prototyping and iteration of designs. The pitch compatibility with MAX Pattern also makes it easier to swap in different belt lengths when you want to make changes. These belts are comparable in strength to the belts that teams are accustomed to using while working on the same pitch as the ION Build System.



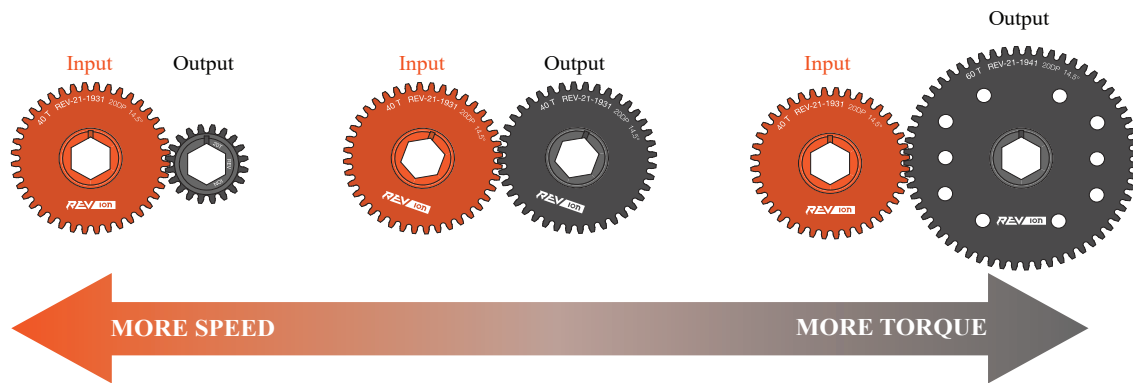
Gears

Gears have teeth that mesh together in order to transmit motion. Gears offer more flexibility in transforming motion than sprockets and chain or pulleys and belts because there are a larger variety of gear sizes available.

Gears are ideal for use in more compact spaces and are also used for changing the direction of rotation.



Transforming the torque and speed of motion can be accomplished by changing the size of the gears.



To ensure that you have a proper amount of gear teeth mesh, it is important to calculate the center-to-center distance in between your gears. You can do this by first calculating the pitch diameter (PD) of each gear using some combination of module (M), number of teeth (N), or outside diameter (OD). You can usually find these parameters in documentation specific to the manufacturer and type of gear.

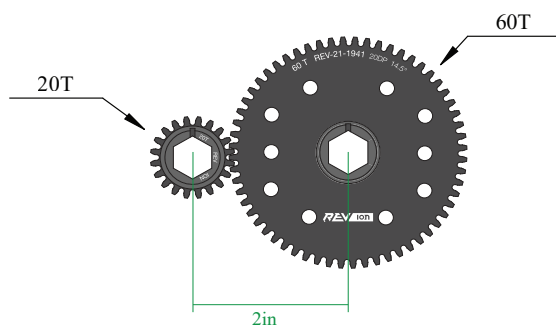
- $PD = M \times N$
- $PD = (OD \times N) / (N + 2)$
- $PD = OD - (2 \times M)$

Then, use the pitch diameters to calculate the center-to-center distance (CCD)

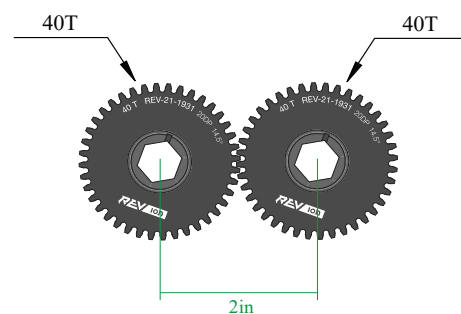
- $CCD = ((PD1) / 2) + ((PD2) / 2)$

Any two ION Gears that add up to 80 teeth will fit center-to-center on structure elements featuring the MAX Pattern and have a center-to-center distance of 2in.

$\underline{\quad} T + \underline{\quad} T = 80$



$$\underline{20} T + \underline{60} T = 80$$

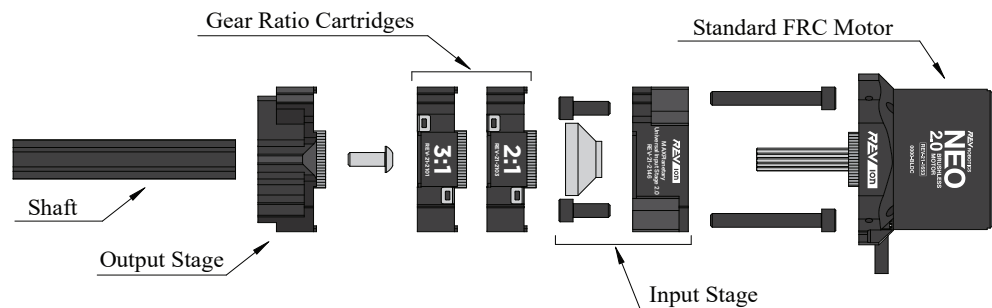


$$\underline{40} T + \underline{40} T = 80$$

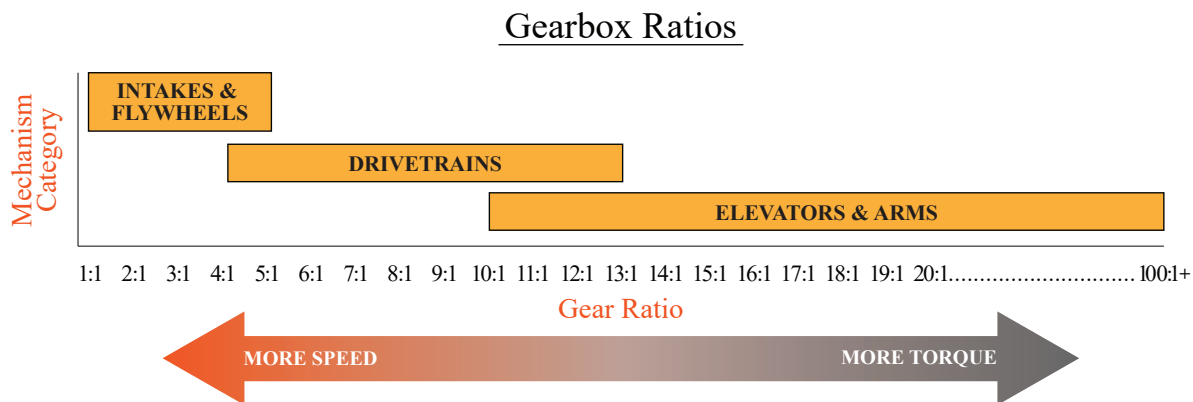
Gearboxes

Gearboxes are a very common way to transform motion in the *FIRST* Robotics Competition. They are generally compact and modular, able to be mounted on your robot wherever they're needed. Some have fixed gear ratios, and some can be easily changed for the needed application. A popular style of gearbox is the adjustable, modular, planetary gearbox. In this style of planetary gearbox, cartridges of different gear ratios are stacked to create an overall reduction. This is a fantastic option for teams to prototype with because they can quickly change the gear ratio without needing to redesign the entire mechanism.

One example of this kind of planetary gearbox is the MAXPlanetary Gearbox. The MAXPlanetary System consists of pre-assembled and lubricated gear cartridges, available in 2:1, 3:1, 4:1, 5:1, and 9:1 gear ratios. Teams can easily adjust torque and speed for different applications by configuring different combinations of cartridges. When assembling the MAXPlanetary Gearbox or any other planetary gearbox, it is important to place the highest gear ratio cartridge next to the motor. Additional cartridges should then be mounted in descending order.



A wide range of gear ratios are possible with the available cartridges. When combining up to three cartridges, multiply each cartridge gear ratio to find the overall gear ratio. For example, a combination of the 4:1 and 5:1 cartridges make a 20:1 overall gear ratio. The chart below shows a suggested range of gear ratios for common mechanisms driven by a NEO 2.0 and MAXPlanetary Gearbox. While this table is a good starting point, be sure to consider the type of motor you will use in your build as this gearbox is transforming the motor's original output to add torque.



The MAXPlanetary Gearbox section of our documentation has detailed information about the system features and limitations that is very useful when designing a robot. The Load Ratings section has information about how the type of motor used will affect what ratios are effective.

docs.revrobotics.com/maxplanetary

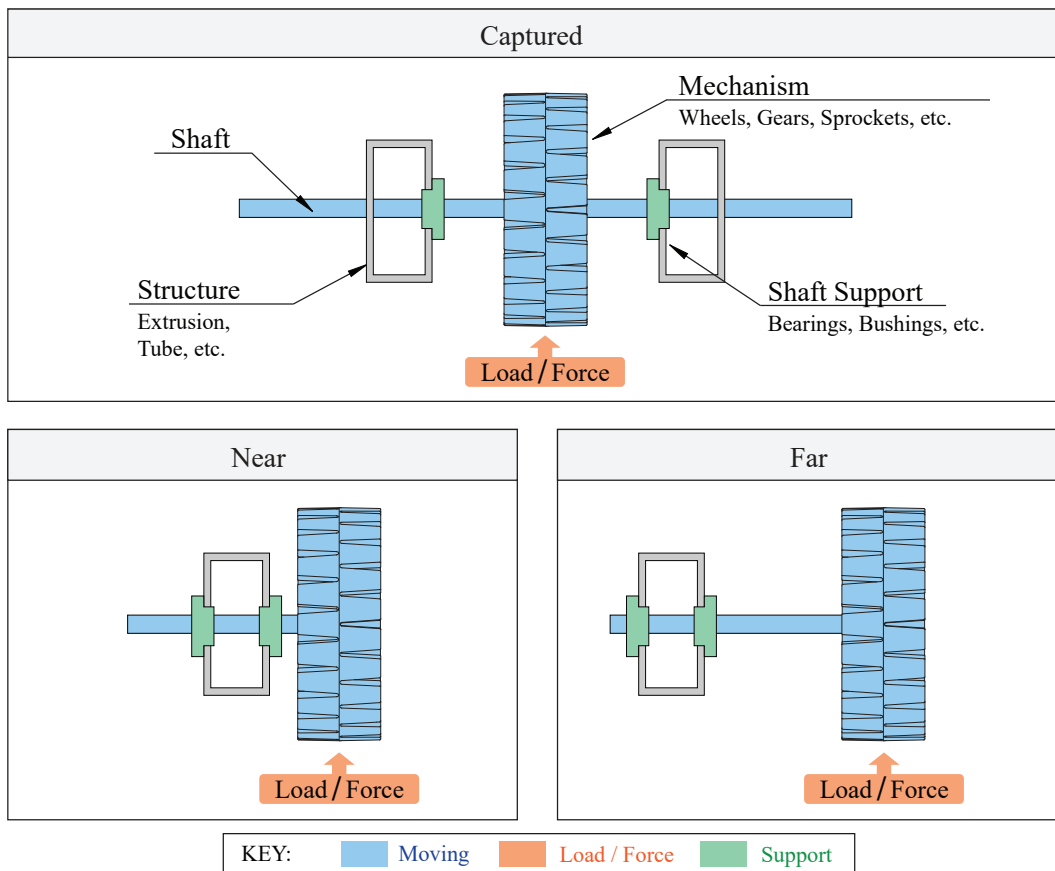
Supporting Motion

Supporting the mechanisms that move on the robot is very important. Without planning proper supports, shafts may not be able to spin and your mechanisms and actuators could be damaged.

Forces, or “loads”, that are at a right angle, or “normal” to the shaft, are the most important forces to counteract. The floor pushing on a wheel or two gears pushing against each other are two examples of normal forces.

A shaft should be supported with two points of contact. Without two support points, the shaft can pivot in the direction of the force. Ideally, those two points of contact should “capture” the mechanism under load. In other words, the support points are on either side of the mechanism. If a mechanism can’t be captured, it is important to keep the load as close to the two support points as possible.

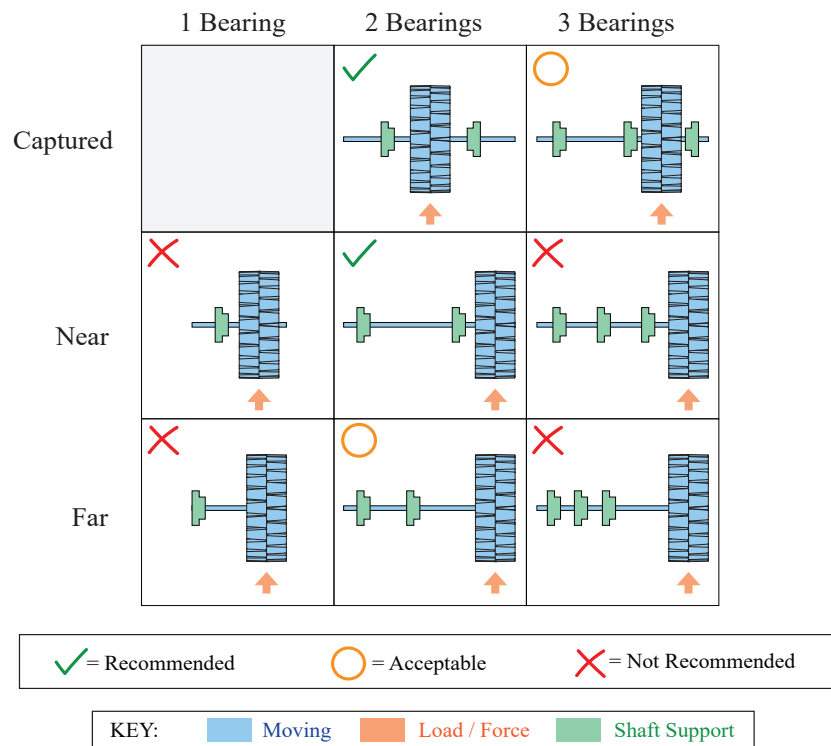
Below are some examples of the three major supported load configurations: Captured, Near, and Far.



Additionally, the further apart the two support points are from each other, the better it can resist effects of a normal force. As the supports move closer together, they begin to act more like a single support.

Supporting a shaft is important, but adding more than two support points can have diminishing returns. Each bearing that the shaft passes through adds a constraint to that shaft. You need to balance having the appropriate amount of constraints to keep the shaft from moving due to normal forces, but not so many that the shaft becomes “overconstrained.” Overconstrained mechanisms can bind and make rotation difficult, causing stress on the actuators and even damaging components of your robot.

The diagram below gives an overview of how bearing quantity and arrangement can impact the stability of load configuration (Captured, Near, and Far).

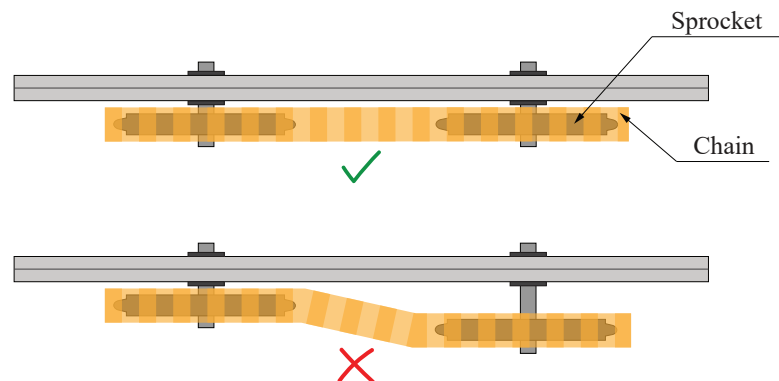


Constraining Motion

Robots need movement to accomplish goals; arms must pivot, wheels must turn, etc. However, movement that isn't directly related to those actions can affect the accuracy and precision of the robot mechanisms. This unintended motion must be properly restricted, or "constrained."

Long and thin structures can flex and deform, making it difficult to interact with objects and operate in a repeatable manner. Strengthen and constrain these structures by making use of brackets and extrusion.

Gears and sprockets must stay aligned to work properly. For example, if two sprockets are not perfectly aligned with each other, the chain between them will run off the sprockets. Keeping parts aligned on a shaft and keeping the shaft itself from sliding out is critical for reliably working robot mechanisms. Use a combination of spacers and shaft collars to align and constrain these parts into place.

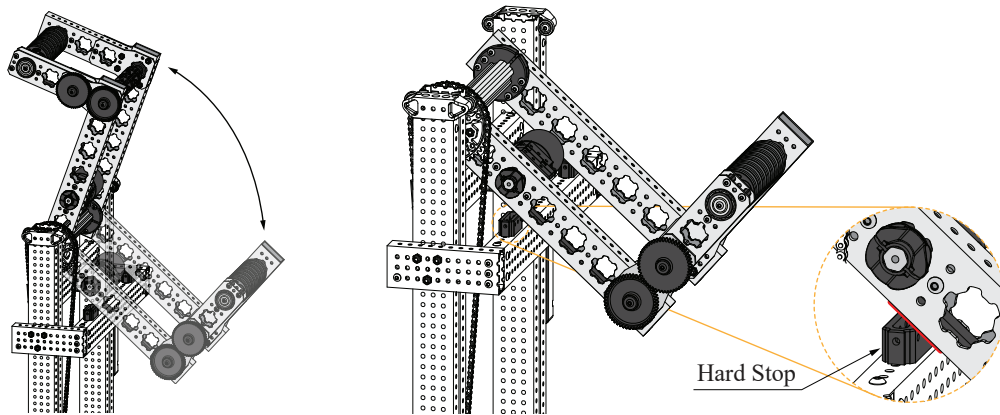


Stopping Motion

When non-structural elements of the robot are acted on by an outside force, motion begins. Outside forces can be anything from constant forces like gravity to forces generated by actuators controlled via code, like a motor that spins a gearbox. It is ideal to design your robot to work with these forces to support and constrain the motion you need, but these forces can also cause unwanted motion. To ensure your robot only moves as intended, it is important to understand how to stop motion. Two common ways to stop motion on an *FIRST* Robotics Competition robot are Hard Stops and Ratchets or Brakes.

Hard Stops

A hard stop is a structural feature of the robot that blocks the movement of the robot. Hard stops can be very effective at creating limits to the range of motion of a mechanism, but can cause mechanical parts to break, safety hazards such as pinch points, and potential electrical damage to motors and motor controllers. It is a best practice to use hard stops as a backup to stopping motion through programming methods.

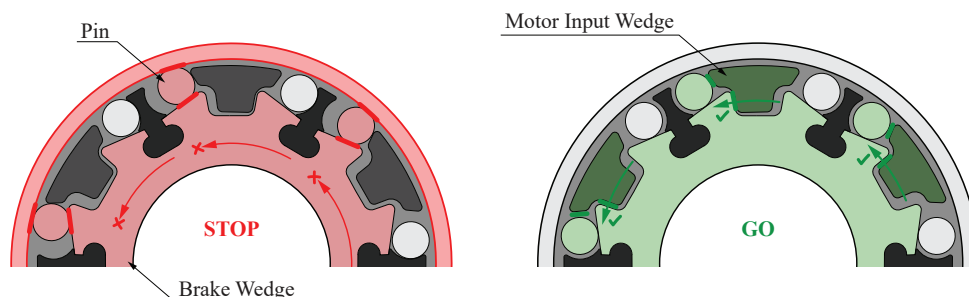


Brakes and Ratchets

Ratchets and brakes are specialized mechanisms that limit or stop rotational motion. A ratchet allows for motion in a single direction by using a pawl and gear. The outside edge of the pawl allows the gear to rotate, while the inside edge will wedge between the gear teeth and stop motion. Most ratchets have a physical switch that allows a user to switch which direction the ratchet's pawl will allow to rotate.

There are many types of brakes, including but not limited to friction, spring, and tooth brakes. It is common to find friction brakes in cars and bikes.

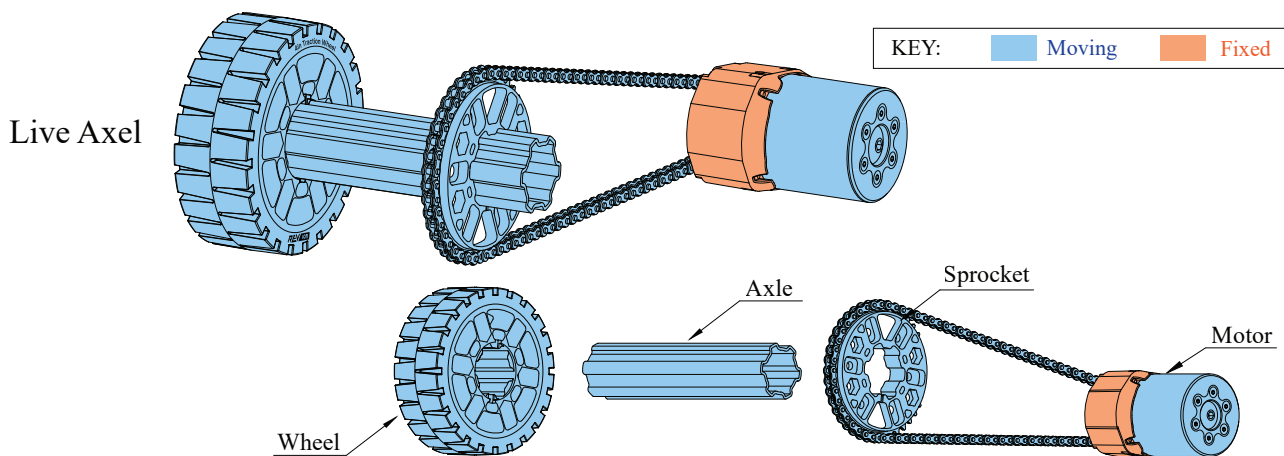
The MAXPlanetary 1:1 Brake Cartridge is a bi-directional, unpowered brake that is easily added to any MAXPlanetary Gearbox stack. Inside, a set of pins and brake wedges work together to keep your mechanism in place the moment the motor stops rotating. As soon as the mechanism is purposefully driven again, the motor input wedges knock the pins loose to disengage the brake and cause movement to continue.



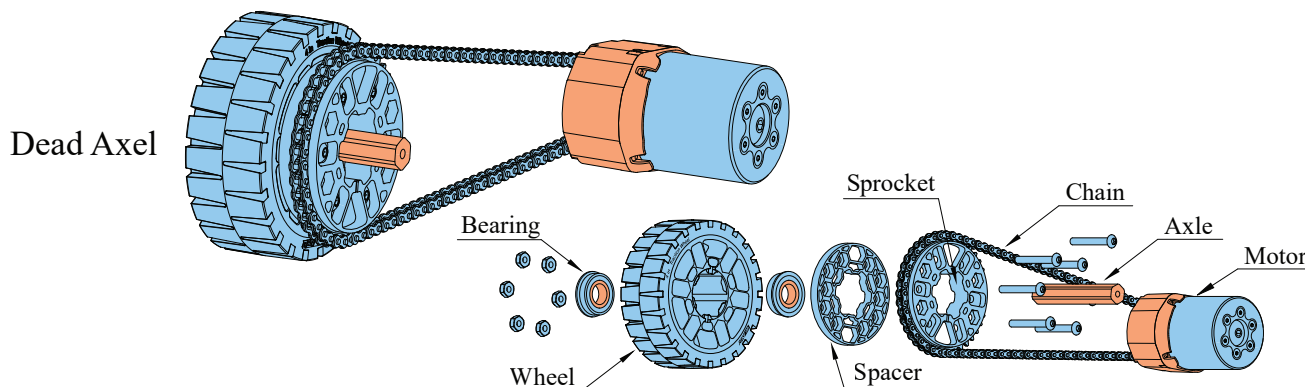
Motion Application Examples

The two main methods of attaching wheels to a robot are to create *Live* and *Dead* Axles.

A *Live Axle* is an axle that transmits torque to a wheel. This can be done through a 1/2in hex hub, gear, pulley, or sprocket. In a live axle assembly, the axle will rotate along with the wheel. Live axles are commonly used in drivetrains or as a flywheel.



A *Dead Axle* is an axle that only supports the wheels and does not move. Generally, bearings are used to support the wheel on the dead axle so it can spin freely. Dead axles remain stationary while the supported wheel is in motion. Some applications include free-spinning intake rollers and non-powered drivetrain wheels.



In the ION Build System, the MAXSpline shape provides many opportunities for mounting wheels and other motion components. MAXHubs provide a way to transfer torque to a MAXSpline Bore from shafts of various shapes and sizes. MAXHub variants allow for other bores or mount holes to populate within an existing MAXSpline Bore. The MAXSpline Bore can also accept standard 1.125in bearings directly. This allows teams to quickly switch between live and dead axles while prototyping.

A MAXSpline Shaft also fits smoothly inside any MAXSpline Bore whether in a wheel, sprocket, MAXTube, or motion bracket. The inside of a MAXSpline Shaft, while smaller than a MAXSpline Bore, can also support specialized bearings, hubs to convert the bore, and more! MAXSpline Shaft enables rapid prototyping of sturdy structures that utilize a dead axle, when paired with a way to transfer motion like a sprocket, as shown above.

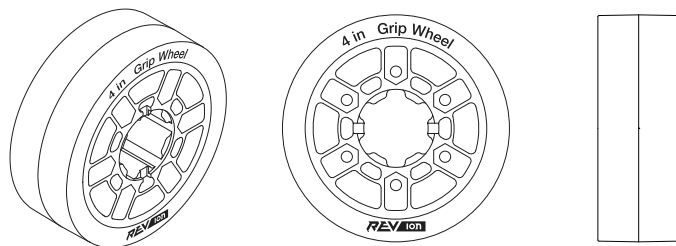
Wheels

Most wheels used in the *FIRST* Robotics Competition can be divided into four categories; Standard, Omni, Compliant, and Mecanum. Each manufacturer makes slightly different wheels, with varying materials, sizes, durometers, and colors. One element to consider when choosing a wheel is the bore size, and if you will need any additional hubs to convert your wheel to the needed input or output.

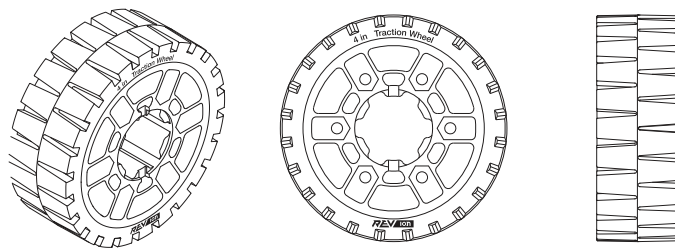
Most sizes of ION Wheels feature a MAXSpline Bore, while some smaller wheels feature 1/2in hex bore. Larger sizes of ION wheels have spokes with a bolt circle of #10 clearance holes. They also have a 3/8in-wide nut groove that eliminates the need for a wrench when utilizing the holes on the spokes.

Standard Wheels

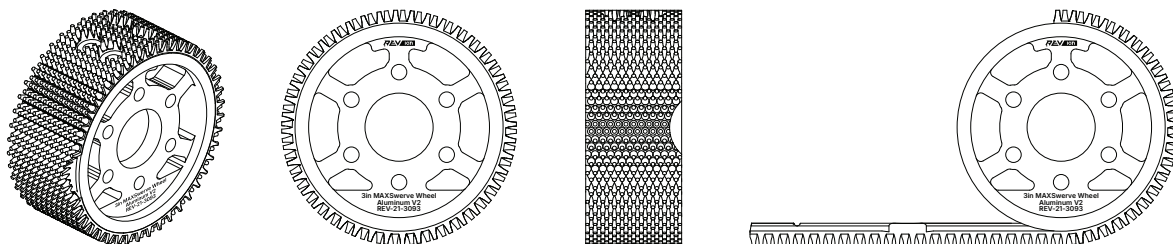
Standard wheels feature smooth or grip-textured tread. These wheels are versatile, being a great option for drivetrains, as well as intakes or flywheels. Standard wheels without a tread pattern are designed for optimal grip in situations where the material the wheel is interacting with is compliant, like carpet, foam objects, and squishy game pieces.



Standard wheels that have a tread pattern are designed for increased traction. They are good for drivetrains when you need a lot of pushing force.

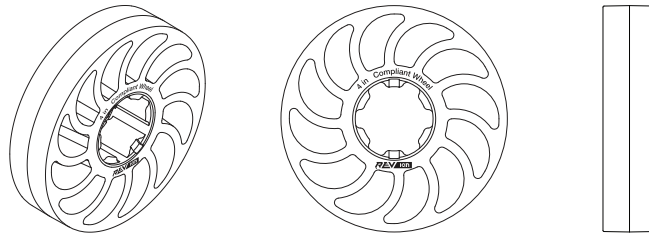


Some grip patterns provide more traction than others. Wheels that have a spiky textured tread are a great option for drivetrains that need a lot of pushing force or resistance to pushing. Most often, spiky tread wheels have replaceable tread and a metal hub so that as the tread's spikes wear down, you only need to purchase new tread, not an entire new wheel.

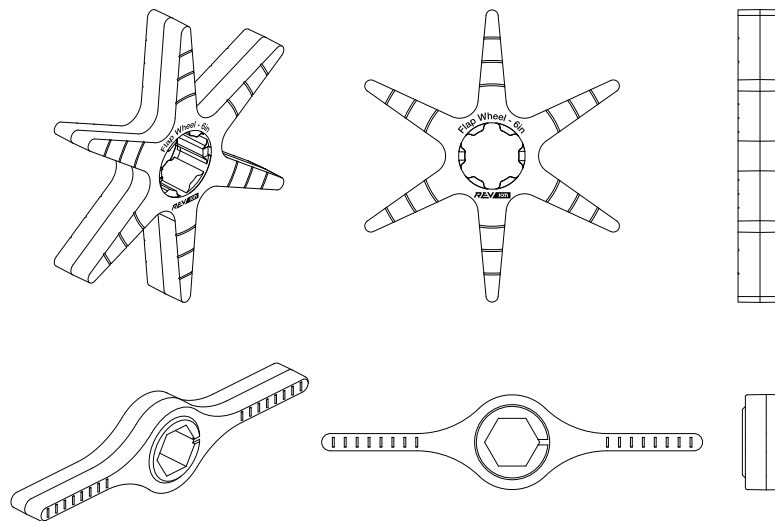


Compliant Wheels

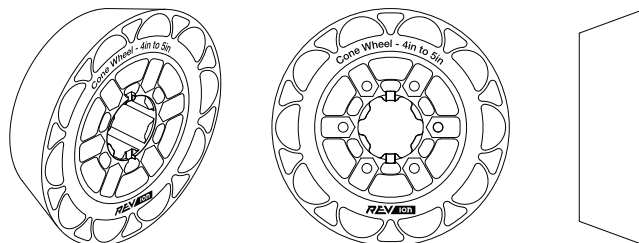
Compliant wheels are ideal for intakes and conveyor systems where a bit of “give” is needed. These wheels come in many sizes and are available in multiple durometers. As the tread durometer increases, the compliant wheel gets harder, which will change the wheel’s traction, wear, and compliance. Many compliant wheels feature “hurricane” or other shaped cutouts to ensure even compliance across the rotation of the wheel.



Other compliant wheels called flap wheels feature flexible flaps that are ideal for designs that need more compliance than the tread of the wheel alone can provide. This additional compliance is provided by the spacing of the flaps and introduces intentional slip, or added space, between the wheel and the game element.

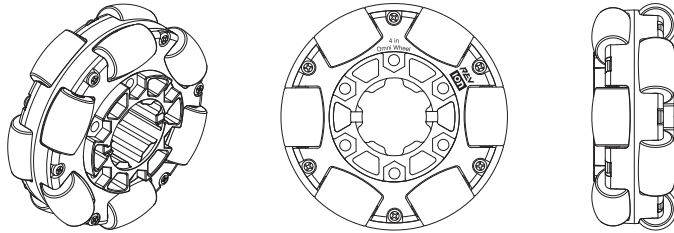


Cone wheels are another type of compliant wheel that direct or center game elements in a consistent, predictable path. They are often used to straighten, funnel, or shift objects laterally.



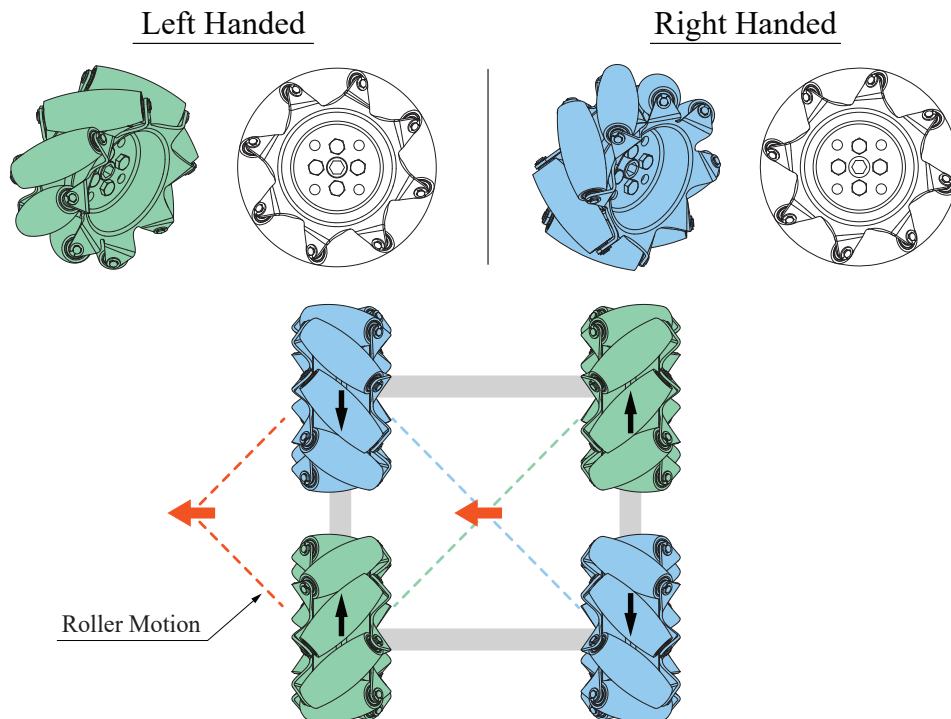
Omni Wheels

Omni wheels have smaller rollers around the circumference of the wheel. These rollers can passively roll perpendicularly to the direction the wheel is driven. Using omni wheels in conjunction with each other can create more maneuverable robots in advanced drivetrain applications. This wheel makes it easier for a robot with a differential drivetrain to turn.



Mecanum Wheels

Mecanum wheels, when properly setup on a drivetrain, allow for omni-directional movement. A set of mecanum wheels used in a drivetrain include two left-handed wheels and two right-handed wheels each made up of rollers that are angled at 45 degrees. When the mecanum wheels are set up to create an “X” pattern from above, the robot can strafe side to side in addition to driving in standard ways. Strafing is made possible by driving each pair of same-handed wheels in opposite directions. The opposing forces from the left-handed and right-handed wheels cancel out and are transformed into side to side movement of the drivetrain.



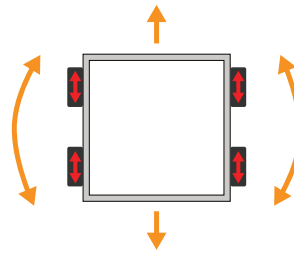
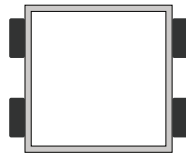
Mecanum wheels can also be used to create vectored intakes. By using the 45-degree angle of the rollers to your advantage, you can funnel game pieces towards a specific point on your robot, such as the opening of a conveyor.

Drivetrains

One of the first considerations when designing a robot is identifying what kind of drivetrain will be built. A good starting point for most drivetrain styles is the Drive Base Kit, available in the *FIRST* Robotics Competition Kit of Parts. In this section, we will focus on drivetrain styles, not drivetrain kits.

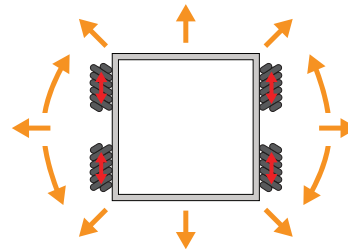
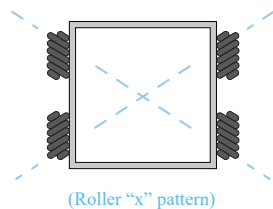
Differential Drivetrain

Differential drivetrains, also known as West Coast or Tank drivetrains, control the left and right sides individually. This simple type of drivetrain is easy to design and build but can be less maneuverable than other types. To help improve maneuverability, omni wheels can be used on the front or back, so wheels slide across the floor while turning. If your design uses six or more wheels, lowering the middle wheel of the drivetrain will cause less friction because not all wheels are touching the floor at one time.



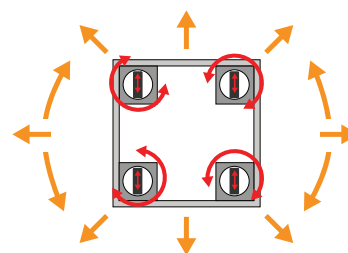
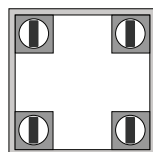
Mecanum Drivetrain

Mecanum drivetrains require four motors and a full set of mecanum wheels for operation. When the mecanum wheels are set up to create an “X” pattern from above, you can program the drivetrain to strafe side-to-side, move diagonally, and drive like a differential drive would. This maneuverability is of great benefit to teams. However, because your wheels are made of rollers, your robot is more susceptible to being pushed.



Swerve Drivetrain

Swerve drivetrains use standard wheels mounted on their own pivoting mechanisms called modules. Most swerve drivetrains require two motors per wheel; one to rotate the wheel, and one to control the direction the wheel points. Your robot can move in any direction because the drive wheels pivot without changing the orientation of the drivetrain, but this type of drivetrain is very technically complex.

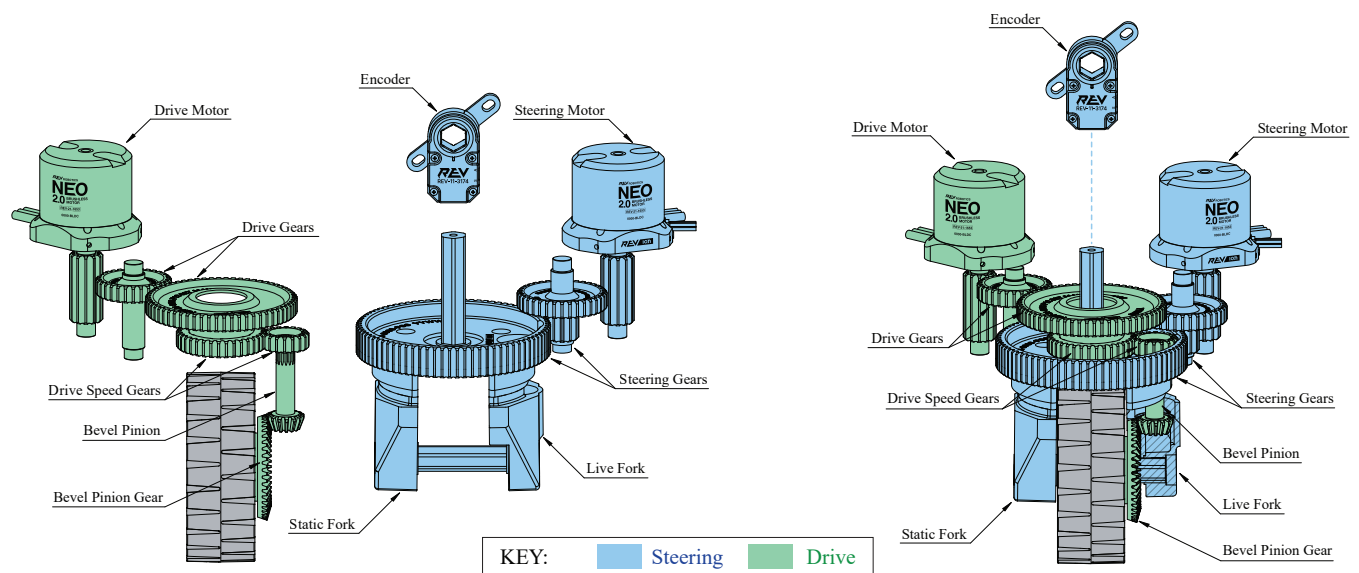


Swerve Basics

Maintaining a swerve module's complex gearing and writing the code necessary to control the drivetrain can seem like daunting tasks when using swerve for the first time. Many kits and code templates are available for swerve drive that can make the mechanical and software aspects more approachable, including MAXSwerve, EasySwerve, and more. Swerve module kits vary in their ability to be customized, so it is important to ensure that you evaluate all of the features of each module before committing to a system. Some features to consider include speed options, compatible motor types, the size and weight of the module, how much maintenance is needed, and how easily it can be repaired if there is an issue.

To achieve the unique movement that a swerve drivetrain offers, most swerve modules use a concentric gear system to independently drive and steer each wheel. This means that there are two separate gear systems that share a single axis. While each swerve module will have a different arrangement of the gears and unique part names, many of the core concepts are very similar to EasySwerve. Below we show the important parts of the driving and steering gear systems on an EasySwerve Module.

Like a gearbox, motion is transformed as it passes through the gears from the motor's output to the wheel. In some modules these gears are a fixed ratio and in others you can choose what works best for your needs.



In the drive portion of the EasySwerve module the drive and drive speed gears have clearance to allow a shaft to pass through for an encoder to connect to the steering system. This encoder measures the angle that the wheel has pivoted and reports it back to the code. The steering system also includes clearance for the drive's bevel pinion to transmit motion to the wheel, passing through the large steering gear. This steering gear is attached to two structure pieces, or forks, that hold the wheel and its shaft. The final output of the swerve module comes from the forks providing steering motion and the bevel pinion gear driving the wheel.

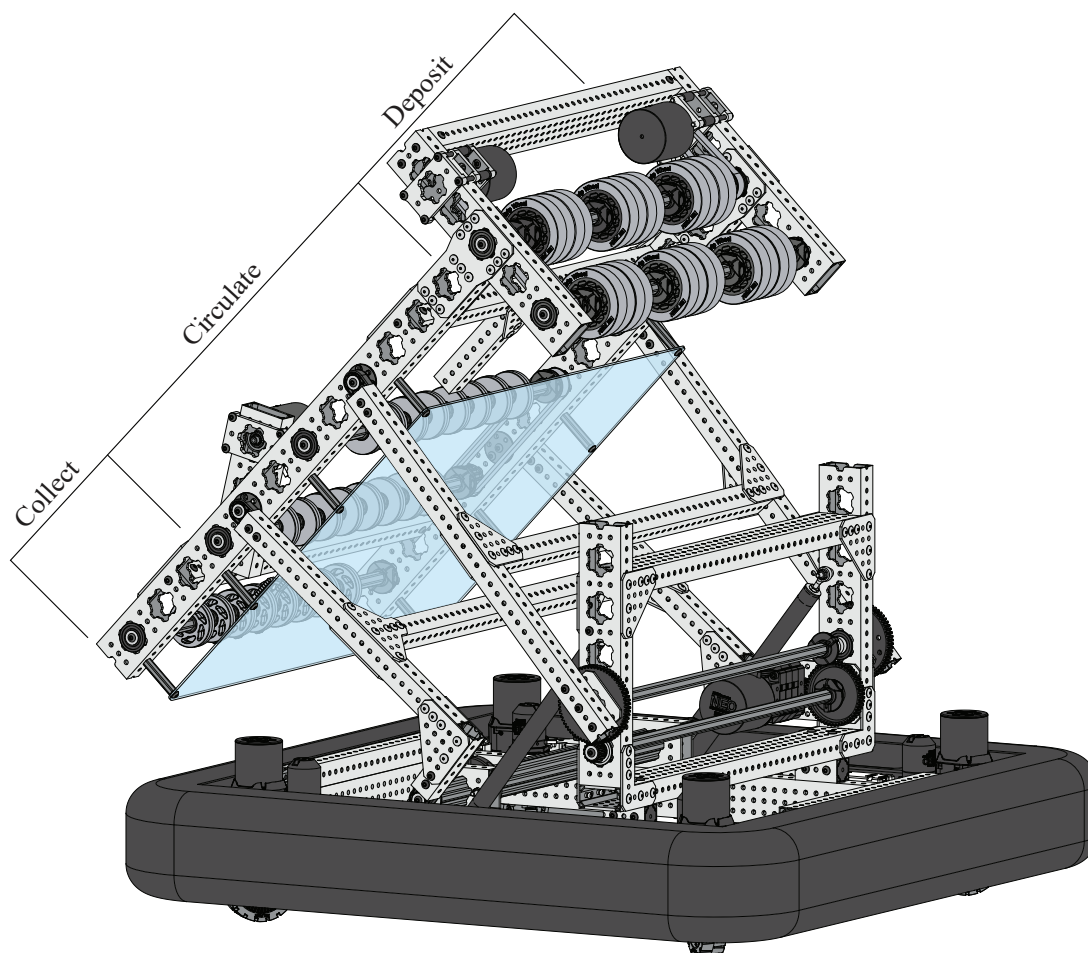
Mechanisms

A mechanism is a mechanical assembly that transmits motion or force to perform a specific task. Designed to interact with the field and game elements each year, most mechanisms mount directly to your robot's drivetrain or via a sturdy structure. Generally, any mechanism can interact with the field and game elements in one or more of the following ways: Collecting, Circulating, or Depositing.

Collecting is when the robot first touches an object with the intent to hold onto or use it. Collecting includes actions like gathering things off of the floor, retrieving a game element from a human player, receiving an item from another robot, or precisely picking things up one at a time.

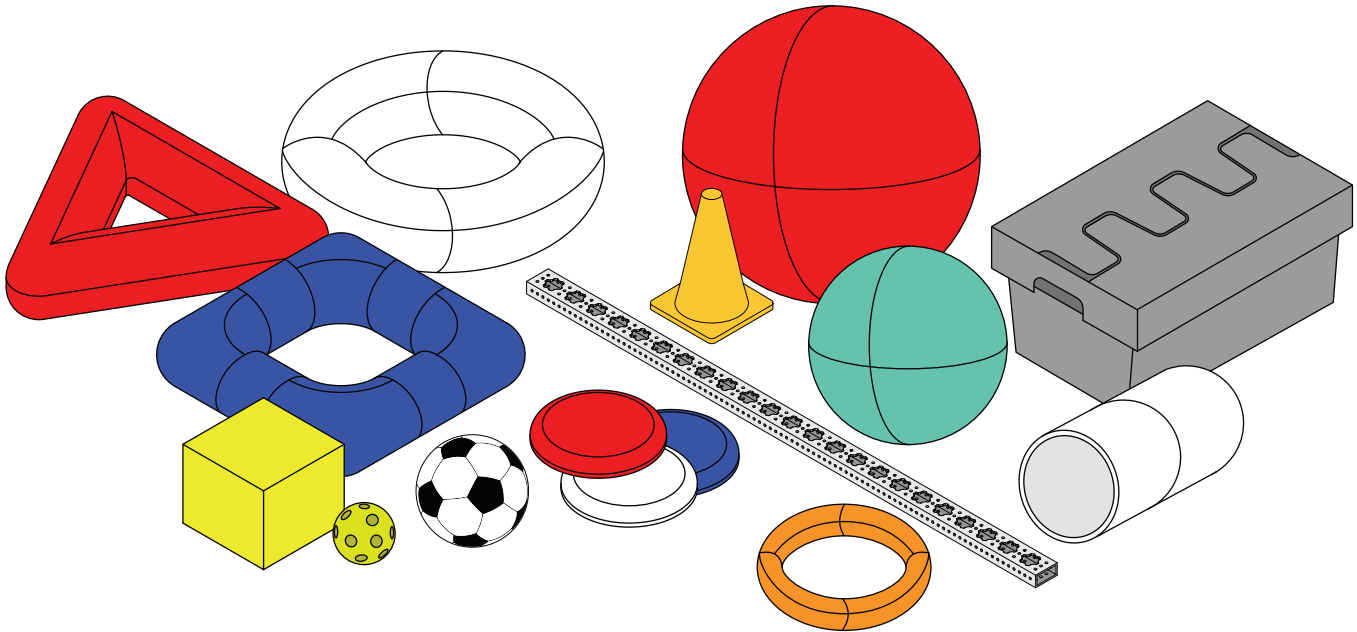
Circulating is the act of the robot manipulating things within itself. Circulating looks like the robot storing things, transporting game elements within the robot from a collecting mechanism to a depositing mechanism, or using a mechanism to turn the game element to a specific position, like ensuring a cone is pointing upward.

Depositing is when a robot scores a game element or leaves it at its final destination. Sometimes, the game element is in contact with the robot up until it is placed, dropped, dumped, or stacked directly in a specific location, but actions where the robot launches game elements are also considered depositing.



Mechanism Actions

Becoming familiar with the range of actions a mechanism is able to do can help you and your team quickly identify good options for your robot's design. It is also important to become familiar with the type of object you will be interacting with. Historically, *FIRST* Robotics Competition has used many types and sizes of game elements ranging from balls and discs to cones, inner tubes, and more.



2x1 MAXTube is to scale with game elements, measuring at 47in long.

Using the game elements shown in the graphic, here are examples of brainstorming ways for your robot to **Collect**, **Deposit**, and **Circulate**:

Collecting

- Using a roller to pick up foam rings from the floor
- Parking near a robot with some sort of funnel to catch a large ball
- Gently grabbing an inner tube from a human player
- Using a ramp to direct and stack totes as they are added to the field

Circulating

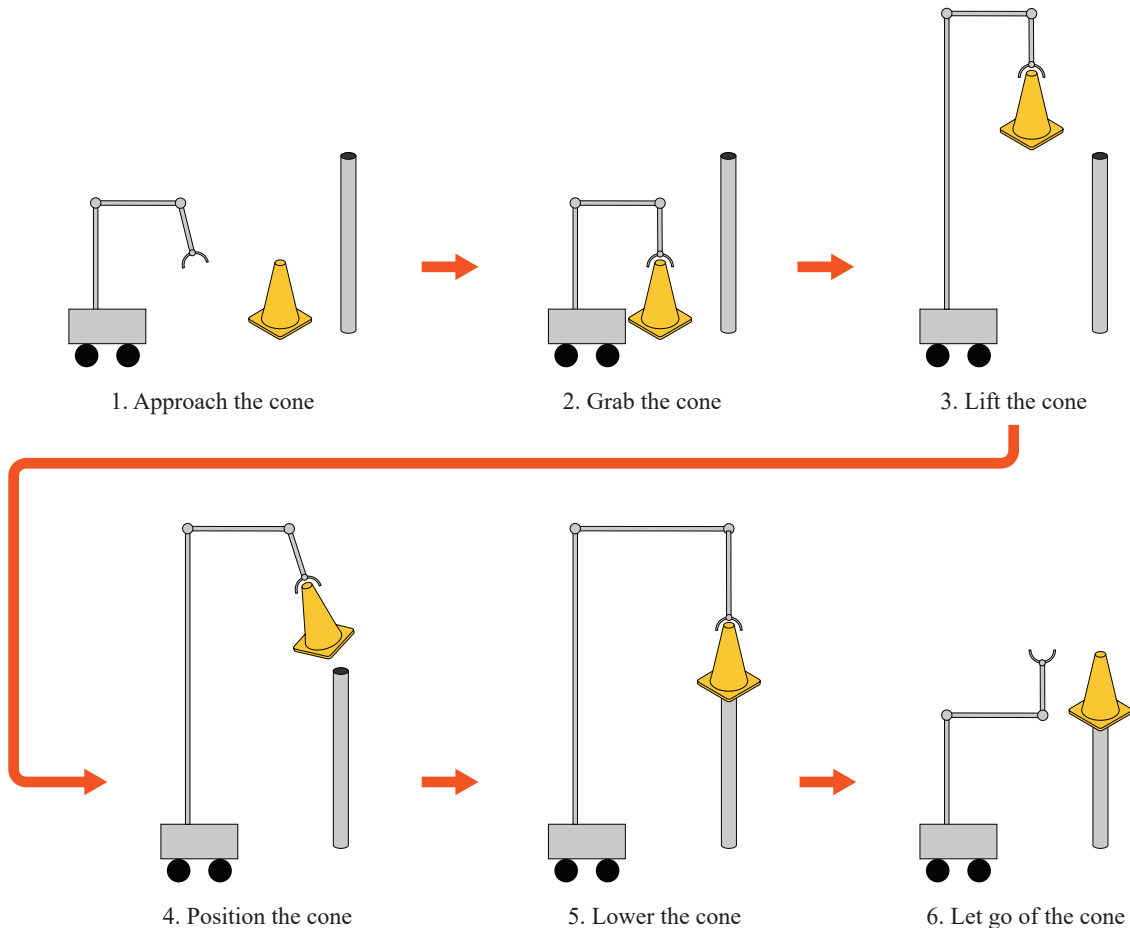
- Holding game elements in a hopper or bucket
- Moving balls from a hopper to a launcher
- Lifting a gear to align it with the scoring location
- Flipping a PVC tube to the correct orientation without letting go

Depositing

- Placing a cone on a pole
- Passing a cube to the human player through a tunnel
- Launching frisbees into a goal
- Tossing a large ball to another robot
- Pushing a stack of totes to a specific location

Designing A Mechanism

Before designing a mechanism, it is a best practice to define the task that needs to be done. When defining these tasks, start with broad statements like “the robot needs to put a cone on top of a pole to score points,” then start adding more detail. For example, scoring a cone becomes:



These simplified steps help us better understand our criteria for the design. As you continue the design process, be sure to revisit these criteria to ensure that you are meeting your goals.

Once the criteria for your design have been defined, we can start thinking about more specific aspects of mechanism, game, and robot construction rules that will affect, or constrain, the design:

- What size can the mechanism be?
- Are there relevant restrictions on height or how far the robot can reach?
- Where does the mechanism need to be located on the robot?
- Can it gather and hold multiple game elements or only control one at a time?
- Are there any special properties that the game element has? (i.e., Is it compliant?, weight, size, etc.)

Some constraints will come from the game rules, while others will be determined by other things such as budget, access to materials, other aspects of the robot, and more. While designing, consider the trade-offs of each option while taking into account your team’s constraints and the design’s criteria.

Common Mechanisms

This section contains brief descriptions of the most common mechanisms used in *FIRST* Robotics Competition. This is not a complete list, but a good place to start learning about the many types of mechanisms and how to describe them.

Launchers

Launchers are a category of high-energy mechanisms that propel objects through the air, requiring only a brief moment of physical contact with the game piece to transfer power.

Catapults

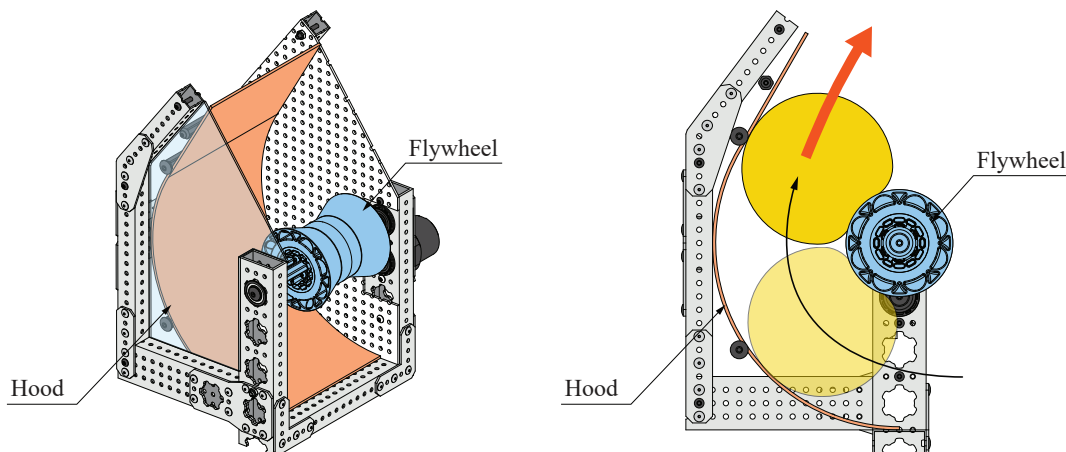
Catapults use a lever and fulcrum as a base to a system that launches objects. Generally, a cam or mechanical switch is used to rapidly release potential energy that was stored in a type of spring. While their simple, low-part design makes them easy to build and maintain, the storage of potential energy can be dangerous and must be done safely.

Flywheels

Flywheels launch game elements by transferring kinetic energy to the game element from one or more high-speed wheels, sometimes also referred to as a drum. As game elements are launched and energy is transferred, the flywheel will slow down so it is crucial to consider momentum conservation in your design. This can be compensated for by adding mass to the flywheel, like using heavy wheels, or through software control methods such as Closed Loop Control (PID Control).

There are two main varieties of Flywheel Launcher:

- Single Flywheel Launchers feed game elements between one rotating wheel or drum and a stationary backer board, often called a “hood”. The amount of space between the hood and flywheel controls the compression, or amount of “squish” a game element receives when being launched. The amount of compression, speed of the flywheel, and angle of the hood are the main factors affecting the flight path of the launched object.
- Double Flywheel Launchers send game elements between a pair of spinning wheels or drums. In addition to adjusting the compression, varying the speeds of each individual flywheel can generate a higher velocity or provide a ball with a specific type of spin, such as backspin.



Hoods

Often paired with single flywheel launchers, a hood acts as a guide for a launched object as it is fed through the flywheel and released. Hood shapes range from flat, or tangent to the flywheel, to curved to launch the game element at a specific angle. Hoods that are tightly fastened to the robot's structure will limit extra movement in the mechanism, ensuring that the maximum amount of energy from the flywheel is transmitted to the game element.

In some cases, it may be an advantage to have a hood that can move. Like other mechanisms, Adjustable Hoods can be passive, adjusted manually by a team member while the robot is off, or active and able to be driven by an actuator on the robot.

Turrets

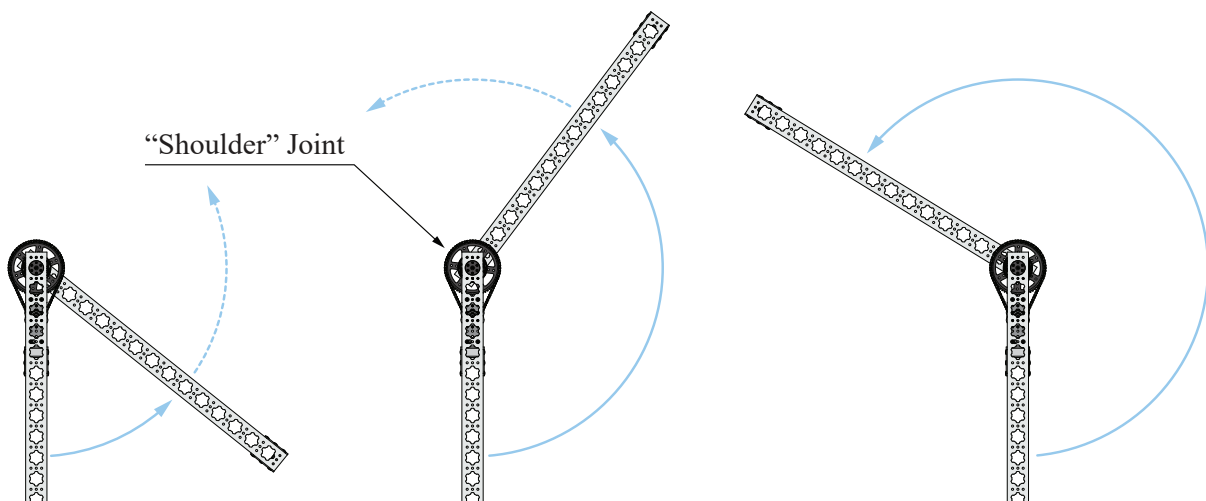
Turrets allow the operators to pan left and right independently of the robot's drive base. This makes the mechanism more complex but can make aiming for a precise target easier.

Arms & Lifts

Arms & Lifts are used to raise game pieces to higher elevations. Because there are multiple ways to achieve vertical reach, choosing the right mechanism depends heavily on your specific design constraints.

Jointed Arms

Jointed arms lift objects by moving through an arc, uniquely allowing them to reach over obstacles that vertical elevators cannot bypass. Joints are generally named based on their location: the base pivot is the shoulder, the middle is the elbow, and the joint nearest the mechanism collecting and depositing is the wrist. Because these joints withstand a lot of rotational torque, they require robust structural construction and a powerful, well-supported gearbox to operate reliably.

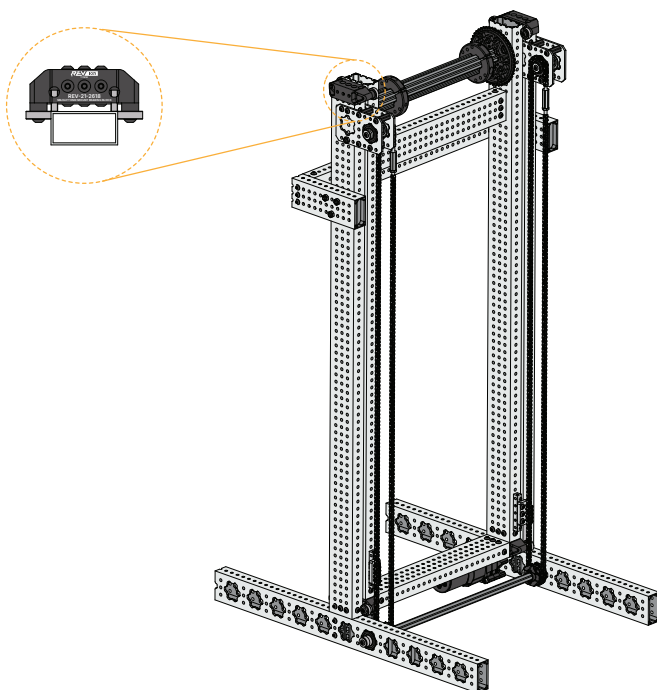


Scissor Lift

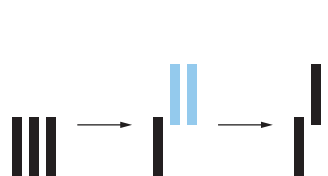
Scissor lifts use a folding structure to move straight up and down. While they may appear to be a simple solution, they are generally heavier, slower, and much more complex to assemble and maintain than other vertical lifts.

Elevators

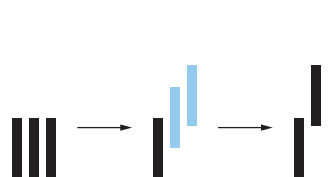
Elevators provide vertical lift by raising and lowering structural segments called stages, similar to a forklift. They rely on three core components: rigid base structures, bearing blocks to let the stages slide, and the rigging that drives the lift. Elevators can have multiple stages to reach greater heights, but most *FIRST* Robotics Competition elevators have 1-3 stages.



Continuous Lift Example



Cascading Lift Example



Stages extend using one of two mechanical patterns:

- **Continuous:** Extends one stage completely before starting the next. This guarantees precise height tracking, making it easy to target specific scoring levels.
- **Cascading:** Deploys all stages simultaneously. Position tracking becomes an estimate because of mechanical tolerance stack-up.

Manipulators

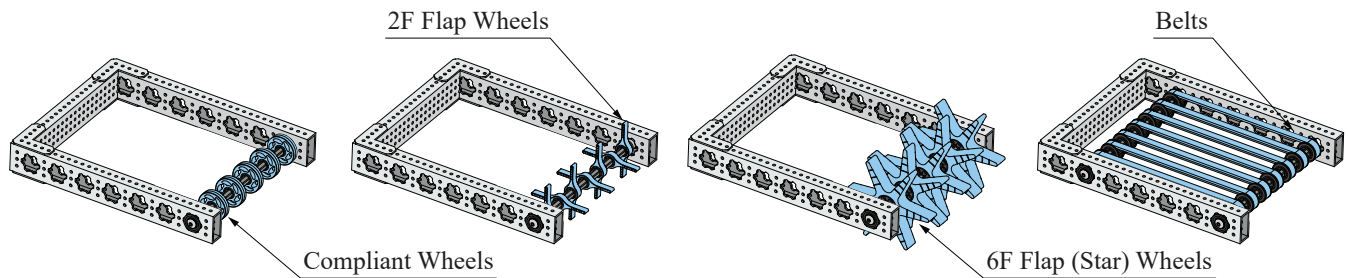
Manipulators are a type of mechanism designed to carefully handle and place individual game pieces. They fall into two categories: passive systems, which operate without power by relying on gravity or friction, and active systems, which are driven by powered components like servos or pneumatics.

Passive Mechanisms

Collecting or depositing objects doesn't need to be complicated, and sometimes thinking of a way for the robot to perform a task without power is a great exercise. Using common items found around the workshop to hold or pick up things can help spark ideas for an effective and reliable mechanism. Some examples of passive holders and grippers are: buckets, hooks, wedges/ramps, a claw/grabber that uses springs instead of an actuator to open and close, or an unpowered joint that deploys a part of the robot using gravity.

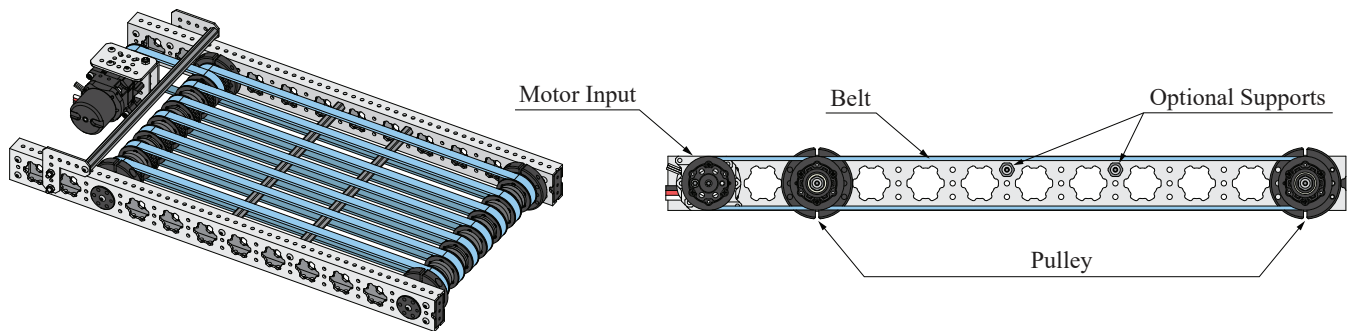
Rollers

Rollers are simple rotating shafts designed to move game elements. Easily built using compliant wheels, belts, flap wheels, or brushes, they can mount directly to the robot's frame or onto other mechanisms like lifts. While their basic purpose is to intake, hold, or release objects, they can also handle more advanced tasks: moving multiple items quickly using wide brushes, guiding pieces from collection to deposit, and indexing, or sorting and staging elements for the next mechanism.



Conveyors

Conveyors use a system of rollers, belts, or wheels to transport game elements. Conveyors are often seen moving items through the robot's interior, but can be added to claws or other mechanisms to help grab game elements.

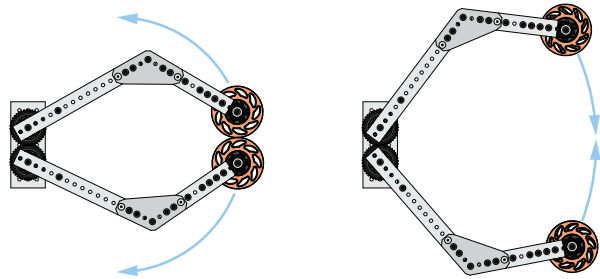
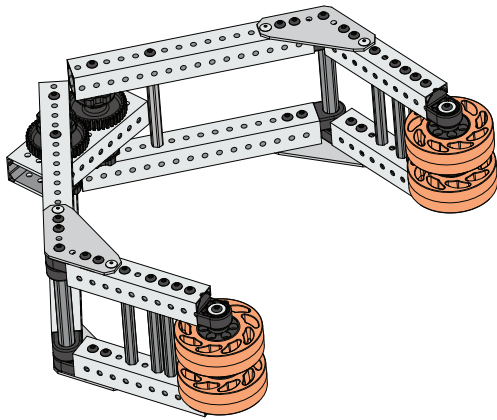


Rotating Indexers

Rotating Indexers regulate the flow of game pieces, funneling them into the next mechanism at a controlled speed. Much like a gumball machine dispensing one candy per turn, they separate and release items individually using a roller equipped with brushes, flaps, or slotted materials.

Pinch Claw/Grabber

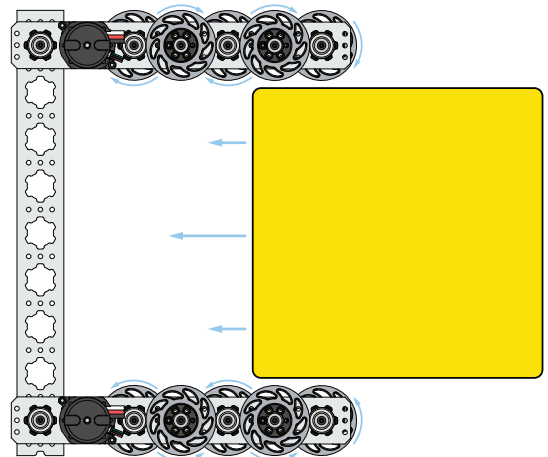
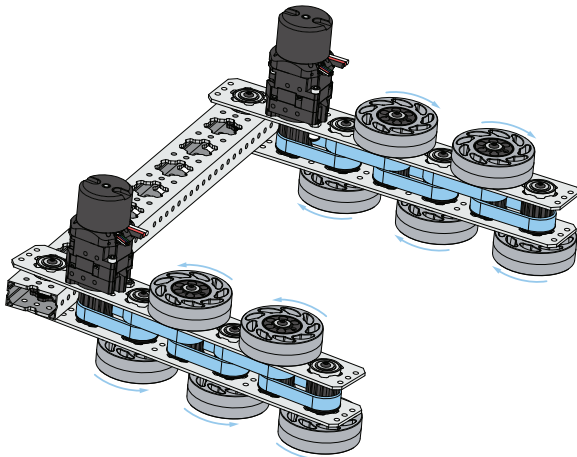
Pinch claws, or pinch grabbers, act like robotic hands, using two or more fingers to grasp objects. Operating much like a pair of chopsticks, they are designed for precision over volume, making them ideal for accurately handling a single game piece at a time.



*compliant wheels used for gripping

Roller Claw/Grabber

Roller Claws are a good solution for picking up one size of game elements from consistent orientations. The fingers, or arms, of the claw are static and hold small rollers that will grab or release the game elements when spun. It is recommended to use compliant wheels/rollers for firm objects and harder wheels for objects with more squish



Mechanism Application Example

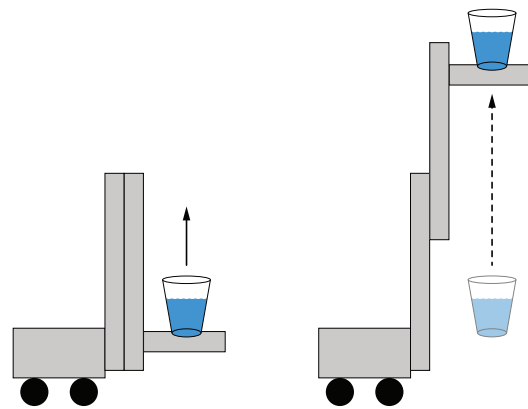
These examples will focus on the criteria that a robot needs to raise and lower a bucket of water without spilling it.

When actually designing a lift for your robot and its mechanisms, it is crucial to take into account the design constraints. The constraints being used for these examples have been simplified but when designing a robot for *FIRST* Robotics Competition the constraints will be more rigid and defined. Some important general constraints for lifts to consider include:

- Starting configuration size, maximum height, maximum weight, and other size limitations
- Horizontal extension limits and how far the robot can reach outside of its frame
- Quantity of motors available to use for driving your mechanism
- The complexity of building, wiring, and programming your team wants to take on
- Anything else that is season specific

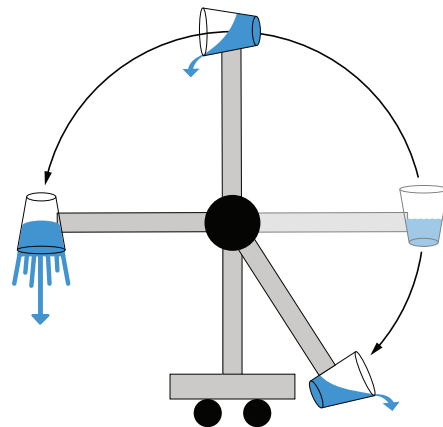
Elevator

Both continuous and cascading elevators provide smooth linear motion that will lift a platform that can carry the bucket of water. Because this lift only moves along one axis, it is perfect for holding the bucket steady and avoiding spills. However, it may not be best if there are any additional horizontal reaching or depositing aspects to the challenge. The modular, compact nature of an elevator lift create an excellent base structure to add on additional mechanisms when needed.



Single Joint Arm

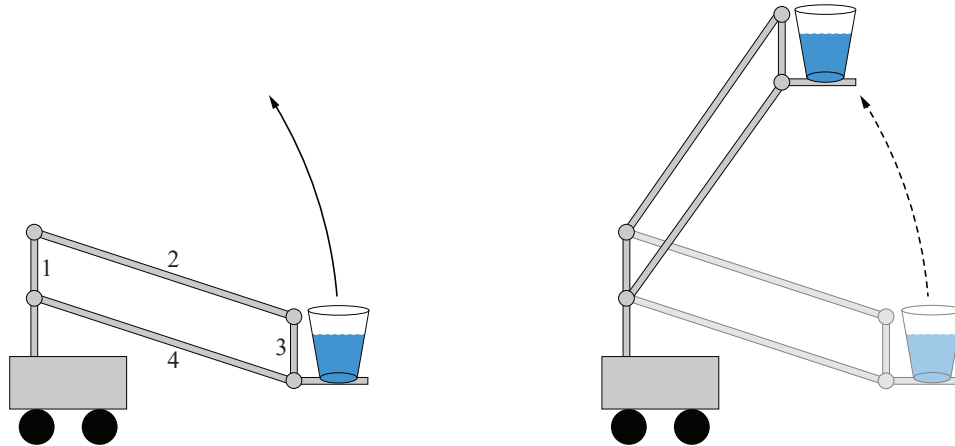
Rotating around a single pivot point, a single joint arm has a limited range of positions where the bucket of water will not spill. This arm has the ability to extend out horizontally from the robot more than an elevator, or the other mechanisms in this section. If the additional reach is an advantage to other aspects of the design, there may be a way to steady the bucket with another mechanism, or slightly modify the arm to be compatible.



Adding additional joints to an arm can provide the control needed to not spill the bucket, but adds additional complexity. In the example below, the position of both the shoulder and the wrist joints must be perfectly in sync to keep the bucket level and water contained. If the joints become out of sync, the water will spill.

Four Bar Arm

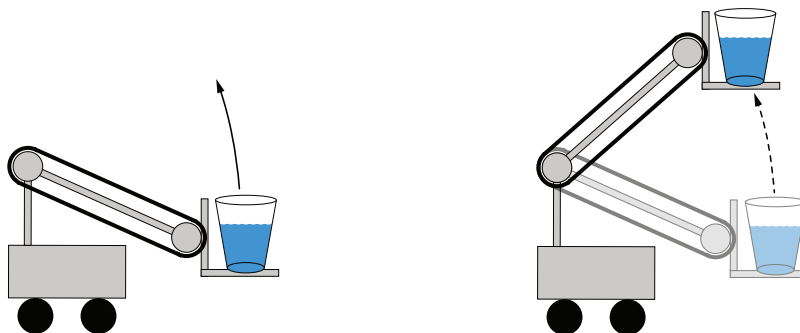
A Four Bar Arm, also referred to as a four bar linkage, is named for the four bars that create its structure. Two sets of parallel bars are mounted so that the opposing bars stay parallel to each other and the corners are able to pivot to maintain the parallel orientation. These arms are known for being sturdy and provide a consistent, small arc for vertical reach. This arm has an end that remains parallel to the main support, which is usually vertically mounted to the robot. This means that anything mounted to the end of the arm, such as the bucket of water, will not tip or spill.



If more height is needed, two sets of four bar arms can be stacked similar to a scissor lift, to create a more complex and further reaching lift called a double reverse four bar arm.

Virtual Four Bar Arm

Much like a standard four bar, a Virtual Four Bar Arm moves the bucket in a small arc while maintaining the orientation so no water spills. Virtual four bar arms get their name from the fact that part of the linkage is replaced with a chain or belt, separate from the one that drives the arm, that runs between the two ends of the arm. Since this fourth side of the arm is not technically a “bar”, the word virtual gets added to the name. Virtual four bar arms can be ideal when the arm needs to be lighter because chain or belts generally weigh less than extrusion.



Actuators

Actuators, such as motors, servos, and pneumatic cylinders, are devices used to create movement on the robot. When designing a robot, selecting the correct actuator for the application is important.

Servo Motors

Servo Motors are a specialized kind of motor that can be controlled to move to a specific angle. Some servo motors can be programmed to run continuously as well, but not all servo motors can do this. Servos have an output spline and are often paired with servo horns to transmit motion to mechanisms.

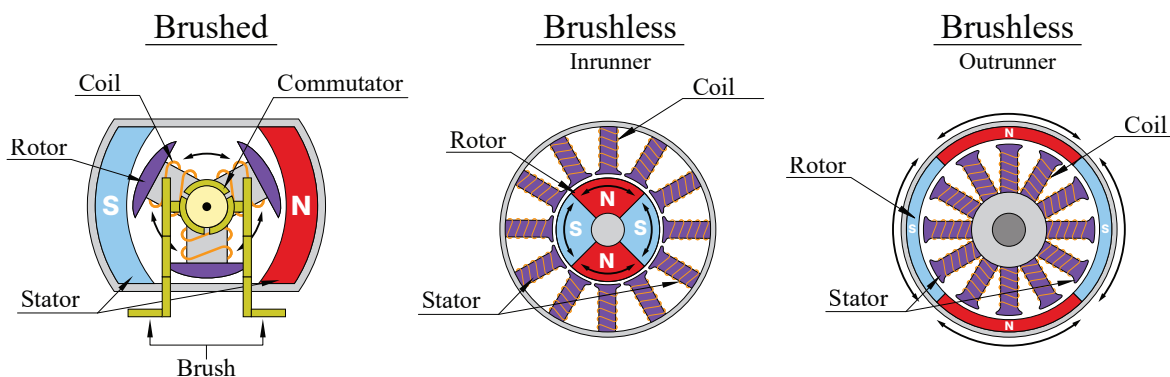
DC Motors

DC Motors consist of two major parts, the part that rotates, or the “rotor”, and the part that is stationary, or the “stator”. A DC motor uses these parts to convert electrical energy into rotational mechanical energy using electricity and permanent magnets.

Two types of DC motors are used in the *FIRST* Robotics Competition: Brushed DC Motors and Brushless DC motors. Both types are useful in various robot applications, and both have their trade-offs.

Brushed vs. Brushless

Operating a brushed DC motor is simple; provide DC electrical power and the motor spins. In a brushed motor, the rotor consists of coils of electrical winding wire, and the stator consists of permanent magnets. Since the electrical part is spinning, there needs to be a way to connect the external power wires to the spinning rotor. This is accomplished through conductive “brushes” that make contact with the stator, automatically sequencing (commutating) the power to make the rotor spin. Brushes make it easy on us, but they produce extra friction which reduces the efficiency of the motor.



As the name suggests, brushless DC motors don’t have brushes. They still have both electrical winding wires and permanent magnets, but the locations are flipped. The stator now consists of the electrical parts, and the spinning rotor consists of the magnets. This means there is no more brush friction within the motor, making a brushless motor more power-efficient. However, you can’t just provide DC power and expect the motor to spin. Without the brushes doing the sequencing for us, you must use a specialized motor controller that is designed for brushless motors to properly sequence the power and get the rotor spinning.

Power Classes

Traditionally in the *FIRST* Robotics Competition, there are two major power classes of motors: **Workhorse** and **Racehorse**.

Workhorse class motors are well-suited for applications that require a lot of torque or speed. They are not only high-power, but are resilient in high-load situations. This makes workhorse class motors ideal for drivetrains, flywheels, and arms. Common workhorse motors include the CIM, NEO, NEO Vortex, Kraken X60, Kraken X44, and RS-775 style motors, but the available motors can change from season to season.

Racehorse class motors are generally smaller and more lightweight than workhorse class motors. Great for intakes, conveyors, and tight spaces, these motors are very versatile. Common racehorse class motors include the NEO 550, Minion, RS-550 style motors, and several other lower power motors.

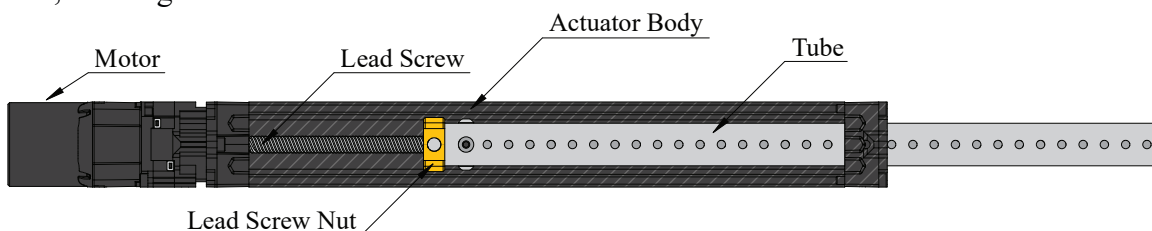
Linear Actuators

There are two main types of linear actuators used in the *FIRST* Robotics Competition: Motor Powered Linear Actuators and Pneumatic Cylinders.

Motor Powered Linear Actuators

Linear actuators that convert rotational motion into linear motion are generally known as motor powered linear actuators. These linear actuators come in many different sizes and often have both DC motor and servo motor versions. Motor powered linear actuators are great for mechanisms where the linear motion needs to be varied, like raising or lowering the angle of a launcher.

The REV ION Linear Actuator uses a lead screw for quick and powerful movements. A lead screw converts motion by using a motor to rotate the lead screw, which moves a specialized nut linearly along the lead screw that is mounted to a piece of MAXTube. As the lead screw nut moves, so does the MAXTube, creating the linear motion.



Pneumatic Cylinders

Pneumatic cylinders are actuated by moving pressurized air through a closed system. They can either be retracted or extended- the output is binary with no in-between. These are ideal for when you need to extend part of your robot to the same length repeatedly, like deploying an intake.

For more information, check out the *Pneumatics Manual* which can be found on the *FIRST* Robotics Competition technical resources webpage:

www.firstinspires.org/resource-library/frc/technical-resources.

What's Next?

The methods outlined here in our *FIRST Robotics Competition Robot Basics Guidebook* are a great way to start building a robot that is ready to drive.

So, what's next? Check out the following websites for information on how to get your robot moving by wiring and programming your control system.

***FIRST* Robotics Competition Resource Library**

Technical resources to help with building, programming, and wiring a robot, as well as tips on running a *FIRST* Robotics Competition team.

www.firstinspires.org/resource-library/frc/technical-resources

Control System and Programming Documentation (WPILib)

Resources to help with wiring your control system and programming your robot.

docs.wpilib.org

REV Robotics Documentation

Resources for help using REV products, including the REV Power Distribution Hub, SPARK MAX, NEO Brushless Motors, REV ION Build System, and more.

docs.revrobotics.com



Have a question for us?

The best way to get answers about REV Robotics products is to email us at:
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For questions about *FIRST* Robotics Competition within your area visit:

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FIRSTRoboticsCompetition@firstinspires.org

