# Hardware Team Cheat Sheet

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## Vendors

| | |
|---|---|
| McMaster | They sell literally everything mechanical: bolts, springs, gears, bearings, etc. They also have CAD for every part they sell, so use McMaster to get CAD for parts even if you're not buying the part from them. |
| Gobilda | Great for FTC-specific stuff. Their products are based around a metric pattern of M4 holes. They sell channels, meccanum and compliant wheels, lots of servos, and the ubiquitous 1xN square beams. They also sell motors and mounts and generally useful hardware. |
| Misumi | Everything slidey! Namely the SAR series of slides. |
| Amazon | Everything else: random bearings, steel wire, etc. Amazon, and other general online sellers, are good places to find miscellaneous parts. |
| Savox | Savox sells high-power, high-quality servos. Their servos are very expensive, but often useful. |
| Hitech | Hitech sells lots of servos. We have use their HSB-9360TH servo, but that is too expensive when compared to other companies like gobilda, or savox. |
| ProModeler | Recommended by Cuttle, ProModeler makes servos for military use. Their servos are very powerful and cheap. They sell some servos on par or better than the Savox Monster servos, for cheaper. |
| MKS servos | mksservosusa.com sells high end servos. |
| Actobotics | The imperial version of Gobilda. Generally, stick to gobilda, as metric is better. |

## Design for CNC

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|---|---|
| Minimum arc internal diameter | 0.125" absolute min, try to stay at or above 0.14"- this applies to fillets too! |
| Geometric limitations | Only 2D, 0.125" (1/8)" thick sheets. |
| #6-32 hole diameter | 0.148" |
| M4 hole diameter | 4.5mm/0.177" (or just 4mm and drill later) |
| M4 tap diameter | 3.3mm/0.129" (don't click "modeled" when making threads) |

## Design for CNC (cont)

| | |
|---|---|
| Countersinks | chamfer 2.75mm, or leave 10mm Dia. space around the hole |
| Tolerances | add 0.1mm to all dimensions where fit is neccessary |
| minimum thickness around hole (for strength) | aluminum: 2-3mm, other: 3-4mm, depends on load! |
| maximum dimensions | 12"x19" |

## Design for 3dp

| | |
|---|---|
| Countersunk holes | chamfer 2.75mm |
| self-threading holes | by making slightly undersized holes, screws will bite into the plastic on their own. This gives screws a little bit of strength without needing a nut. Useful when space is at a premium and strength is not required, like when mounting side panels or electronics. |
| M4 hole diameter | horizontal printing: 4mm will be threaded, 4.5 will not. vertical printing: 3.8 will be threaded, 4.2 will not. |
| #6-32 hole diameter | Horizontal printing: 3.3 will be threaded, 3.85 will not. Vertical printing: 3.1 will be threaded, 3.5 will not. |
| large holes (8+ mm dia.) | make them teardrop shaped, with a 90 degree top point. this removes the need for supports. |
| overhangs | maximum 65 degree overhangs to print without supports, unless the gap can be bridged (non curved bridge, less than ~5 cm) |
| supports | painful to remove, and decreases precision a lot. Don't expect smooth surfaces. |
| part strength | 3dp parts are plastic, so they aren't super strong. however, they are much weaker when forces work to tear layers apart, like bending a vertically printed cylinder. try to avoid making parts that will be stressed similarly. |

## Design for 3dp (cont)

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| nut traps | by making hexagonal cutouts, nuts can be inserted flush with a face or in the middle of a part. see nyloc dimensions, and add some (0.2mm each side) tolerance. |

## common assemblies

| | |
|---|---|
| plate and standoff | 2+ plates connected by screws with spacers to hold the plates apart. Spacers can be store bought metal ones or custom 3dp. Useful for basically everything, and surprisingly rigid. The thicker the standoffs, and the more of them there are, the stronger it'll be. Useful for gearboxes, arms, things with belts going through them, top bars, etc. |
| gobilda beams | gobilda 1106 and 1109 beams are super useful as general purpose 90 degree angles where 3d printed parts are too weak or large. The ends are also threaded which is nice. |
| linear slides | we use misumi slides (SAR series, mostly) or any old steel drawer slides for linear extension. You can stack them back to back to create more extension. To read about how to string them, search for 'rigging' on gm0. |
| axles with stuff on them | Always support shafts from both sides with bearings. Most commonly, you can use flange bearings on the insides of two parallel plates. On the shaft, use a hub (probably a sonic hub) to mount the part you want to rotate. This could be a gear, pulley, arm, etc. Then use 3dp spacers to fill the rest of the space on the axle, so the bearings are held in place. |

## common assemblies (cont)

| | |
|---|---|
| one way door | gravity- or spring-loaded mechanism that can be pushed open one way to allow things through, but locks and becomes rigid the other way, like a check valve or rachet. See the Ultimate Goal hopper. |

## tools/names

| | |
|---|---|
| hammerhead | t-shaped 2.5mm (countersunk m4 or socket head m3) |
| ergo | yellow and black ball nose hex drivers, for 6-32 screws. |
| golden | a smaller ergo, for countersunk 6-32 screws. |
| Big boi | red and black ball nose hex driver. It looks like a larger ergo. |
| needlenose | Needlenose pliers. The long skinny ones. Useful for holding nuts on while screwing, and other random grabbing-related tasks. |
| flush cutters | The red and black cutters. Mostly used for cutting zip ties, wires, or tabs on cnc'd parts. |
| vice grips | the fancy pliers. When closed, they clamp down on whatever you're holding, and stay there.Used for when you need high strength, or when you don't want to hold onto pliers for a long time. |
| wire stripper | a simple tool to remove the insulation from wires. |
| screw cutter | orange (metric) or red (imperial) tools that look like wire strippers. To cut a screw, screw it in from the threaded side of the tool all the way up to the place you want to cut it at, then squeeze. |

## Wheels!

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|---|---|
| Meccanum wheels | These are the wheels we normally use on our drivetrain. 45 degree rollers allow these to power movement parallel to their axis of rotation. |

## Wheels! (cont)

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|---|---|
| Omni wheels | Omni wheels are like meccanum wheels, except their rollers are perpendicular to the drive shaft. We use them in our odometry pods. The rollers allow them to roll side to side freely while being driven forward or backward. |
| Colson wheels | Hard rubber wheels with a glass-fiber filled plastic hub. Very common in FRC, they are robust traction wheels. We used a large one for our shooter in Ultimate Goal. |
| Compliant wheels | Soft silicone wheels, often made with a center hub connected to an outer tire by many silicone spokes. Compliant wheels come in many different shapes and sizes and colors, all with different properties. We used them in our Skystone intake. |
| Gecko wheels | Gobilda's gecko wheels are like compliant wheels, except the spokes are bent into s- or c- shapes. This makes them the most squishy compliant wheels available (at the moment). |
| Stealt-h/Rhino wheels | Stealth (Andymark) and Rhino (gobilda) wheels are traction wheels, like colson wheels. They have a flat outer tread, and are available in many sizes with different tread softness. |

## CAM

| | |
|---|---|
| Endmill | 0.125" flat endmill |
| Work Coordinate System | Z axis/plane, stock box point in top right, all arrows pointing away from parts |
| Stock tab | Top offset = 0 |
| cut ordering | first cut small holes (pockets), then large holes (contours), then outer contour. |
| 2d Pocket | Cut pockets first. Meant for small holes. Select bottom edge of cutout for geometry. |
| cutting feedrate (2d pocket) | 750 mm/min |

## CAM (cont)

| | |
|---|---|
| cutting feedrate (2d contour) | 400 mm/min |
| cutting feedrate (outer contour) | 350 mm/min |
| Max roughing stepdown (aluminum) | 0.5mm |
| Max roughing stepdown (other: pc, delrin, wood) | 1.5mm |
| ramp type | plunge |
| stock top offset | 0 |
| stock bottom offset | from -0.5 to 0 mm |
| tabs | (contours only) tabs at points, place at extrem-eties for better support. |
| 2d contour | To be cut second. For larger holes. Select bottom edge of cutout for geometry. |
| outer contour | To be cut last. Also a 2d contour. Cuts the part out from the stock. |
| Export gcode | Select all toolpaths, right click them, click postpr-ocess, select the postprocessor, set units to mm, then name the file and save it. |
| Probing (ALUMINUM ONLY) | Connect the probe alligator clip to the endmill, press the end of the audio cable onto the aluminum, and press the probe button in UCCNC. |

All of this CAM stuff (the numbers and things) is already entered in the operation templates. Search for the templates in slack. To use the templates, right click on your setup in the browser -> New from Template -> [whatever operation you want]

## common parts

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|---|---|
| flanged bearings | These bearings have a flange around one edge so they don't fall through the hole they are installed in. Our bearings are 14mm OD x 5mm thick, 6mm D bearings are |

## common parts (cont)

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| Thrust bearings | When dealing with high load in the direction of the shaft, use thrust bearings. They are like tiny lazy susans. We used these to support our ultimate goal turret. |
| V-bearings | These bearings have a v shape, which allows them to be used as pulleys. Make sure to put 3d printed cages around them if you use them as pulleys. (CAD for cages is in someone's scratch space) |
| 6mm D shafts | These shafts are smaller and therefore weaker than REX shafts, but are still plenty strong for most use cases. They have a flat section on their side, giving them a D-like profile, which allows the use of set screws. That said, don't use set screws unless absolutely necessary. Use sonic hubs instead, as they are far more secure. |
| 8mm REX (aka REX or 8REX) shafts | These shafts are both 8mm Round and 7mm hEX (REX), making them very versatile. They are also larger and stronger than 6mm shafts. You can use set screws, but use clamping/sonic hubs when possible. |
| Sonic hubs | These are gobilda's funny looking hubs with two clamping screws. They are very strong and sit very centered on the shaft. They are generally the best choice for attaching something to a shaft. |

## common parts (cont)

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| shaft spacers | Shaft spacers fill space along a shaft. For REX shafts, search the parts library for "REX spacer (break link)". When you import it, BREAK THE LINK, then extrude the side to make it whatever length you want. Generally, you should fill the entire shaft with spacers so that the bearings on either side are held between the spacer on one side and the flange pressing against another part on the other side. |
| weird brackets/90 degree connections/odd spacers | look around the gobilda structure page to see if something exists that would work for your needs. They have a lot of mounts and brackets and such. If they don't, 3d print one. |
| round linear shafts/bearings | linear bearings can slide and rotate around smooth round shafts. They are available for shaft sizes anywhere from 4-12mm, but the largest we usually use are around 8mm. To find these online, search for lmXuu, where X is the diameter you want. The shaft/rod must be supported at both ends; gobilda has some nice mounts. |

## common parts (cont)

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| linear rails | More expensive than linear rods and round bearings, linear rails are far more precise, and are much stronger as they can be mounted to a surface along their entire length. They are also often easier to use and mount, as the bearings come with threaded holes. We used these on our horizontal odometry pods during freight frenzy. |

## Motors

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| Motors | "motors" mean larger, 12v motors that are plugged into the 12v motor ports on the rev hub. They have more power than servos, and can do some position control with their builtin encoders, but are generally less precise. |
| Servos | Servos are smaller motors with gearboxes that are plugged into the 3-wire servo ports on the rev hub (or SPM). They have power than motors, but have precise position control. Most servos can rotate between 180 and 270 degrees, with hard stops at the ends. Continuous rotation servos can rotate indefinitely, but cannot be position-controlled, making them essentially tiny motors. |
| Red servos | Red servos are decent general-purpose servos. They're not fast, but they get the job done most of the time, and have 20 kg-cm of torque. However, we have mostly abandoned red servos in favor of gobilda servos. |

## Motors (cont)

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|---|---|
| Gobilda servos | Gobilda servos are dual-mode, meaning they can be set to position control or continuous rotation mode. They are available with three different gearing options: Torque, Speed, and Super Speed. There's also a 5-turn torque servo, for some niche applications. Gobilda servos are our go-to general-purpose servo. |
| Fan-model (blue) servo | These servos are slightly faster than gobilda speed servos, with more than 2.5 times the torque, all at the same price. The only downside is that their range of motion is only 180 degrees, compared to gobilda's 300. |
| Savox Monster servo | The god-servo. At around $150-200, these servos are expensive! Only use them when absolutely necessary, and be very careful to not break them. They are extremely fast, and have lots of torque. We used them to flip the bucket on our Freight Frenzy robot, and to raise the hopper in Ultimate Goal. |
| Promodeler servos | The better-than-god servo. These are similarly priced to Savox servos, but they are generally higher quality and higher spec. See the intake arm and claw on the Power Play robot. |

There are many other types of servos. The ones I've listed here are our most commonly used or referenced. See the 'vendors' section for other servo vendors.

## Power transmission

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|---|---|
| Belts/-pulleys | Belts are strong, quiet, and durable chains. We commonly use Gobilda's 5mm HTD belts for high-power applications like the drivetrain. Pulleys can be 3d-printed, and cad can be generated using the tools pinned in slack. Other common belt sizes are GT2 and 3mm HTD (for finer control) and T5, which is similar to 5mm HTD, but with backlash. |

## Power transmission (cont)

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| Gears | Gears can be used to transfer power between two shafts. They are very useful for increasing torque or speed, or combining multiple motors to get more power (see gearboxes on Ultimate Goal turret and intake, or spool gearboxes on Skystone and Freight Frenzy linear slides). However, it is often easier and better to use belts, when possible. Gears must be lubricated and protected from dust and stray fingers, which could get munched. |
| Miter/-bevel gears | Miter and Bevel gears transfer power at right angles. Miter gears have a 1:1 ratio, while bevel gears are available in multiple different ratios. For usage examples, see our Skystone intake gearboxes, Ultimate Goal intake, or Freight Frenzy Carousel. |
| Lead screws | Lead screws can be used to create powerful (but slow) linear motion. They are essentially large screws whose nuts have mounting holes. They must be lubricated well to prevent wear. |
| Linkages | Linkages are one of the most common mechanisms we use. They convert rotational motion to linear motion, with a very compact footprint. See our Skystone outtake, Ultimate Goal hopper, or Freight Frenzy outtake and intake. |
| Chains/sprockets | Chains and sprockets are metal belts and pulleys. While stronger, they have more backlash, are louder, and are very stiff, meaning that they aren't able to absorb heavy impacts very well. They are also harder to assemble, because you have to make the chain the exact size you want. See our skystone intake and all of our drivetrains before Ultimate Goal. |

## Nuts and Bolts

| | |
|---|---|
| Major Diameter | the outside diameter of the screw thread |
| counte-rsunk screws | By cutting out a cone from the top of a hole, a screw with a matching cone-shaped head can fit in perfectly, sitting flush with the surface of the material. Not only is this beneficial for making parts fit in tight spaces, it's also actually stronger. To create countersunk holes, we have to drill them out with the countersink bit on the drill press after they've been cnc'd. |
| socket head screws | Socket head screws just have a cylinder at the top with a hex bore. They are good general-purpose screws, and have the benefit that they use a larger hex than counte-rsunk or button head screws, which helps resist stripping. |
| button head screws | [do not use] Button head screws have flatter, rounded heads. They have a lower profile than socket head screws, but if you need clearance, just use countersunk screws. Button head screws are bad because if they strip out, there's no way to get them out, because you can't grab the head like a socket head screw. Button heads have all the problems of countersunk screws, without any of the benefits. |
| plain nut | a hexagonal piece of metal with a thread. Don't use these unless it's needed due to space constraints. When using plain nuts, you MUST put |
| lock nut | a nut with a lock washer, which helps prevent loosening. Loctite is still necessary though. If you need clearance, use a plain nut, and otherwise, use a nyloc. Lock nuts are somewhat useless. |

| Nuts and Bolts (cont) | |
|---|---|
| Nylon lock nut (nyloc) | a nut with a little nylon insert, which grabs onto the screw and prevents loosening. These are our standard general purpose nuts. |
| M4 | The gobilda standard, M4 bolts are our most commonly used size. M4 means that the major diameter is 4mm. |
| M3 | M3 screws are smaller and typically only used in niche usecases, like attaching servo horns or mounting misumi slides. They have a 3mm major diameter. |
| #6-32 | These screws are the tetrix standard, and we used to use them everywhere. However, we have mostly converted to metric. These still have some uses, such as screwing into the rev hubs' threaded holes, but try to avoid their use otherwise. The name means that they are #6 screws (aka major diameter is 9/64") with 32 threads per inch. |