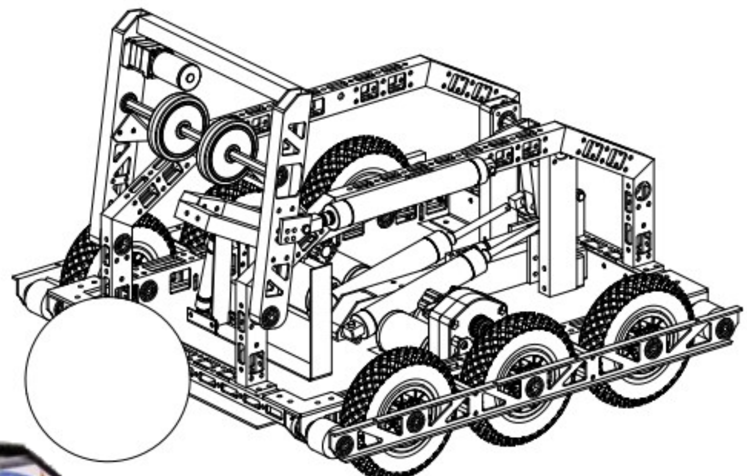
The Highlanders

FRC Team #4499

Engineering Design Document

MAGNETAR



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FRPC
PTC
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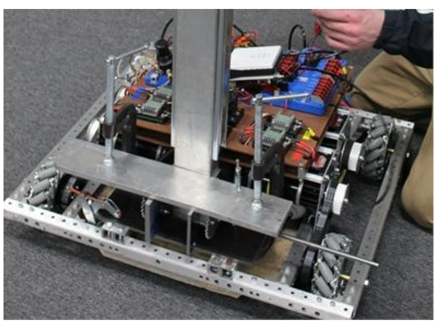
PEAK RESOURCES, INC.
LOCKHEED MARTIN
FIRST ROBOTICS COMPETITION
Neaera Consulting
FIRST STRONGHOLD

The Highlanders

Chassis — Engineering Design

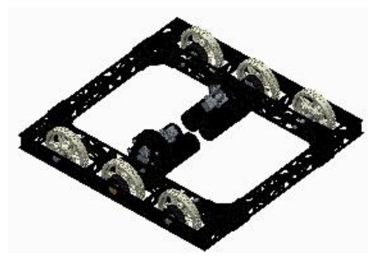
History:
Our team's chassis has been a long process that has taken many months of design work both before and during the build season. This year's design has been inspired and influenced by our prior years' efforts, successes and failures.

2012-2013
In our first year's competition we used the standard AndyMark chassis with C-Channels and Toughboxes. Our team's twist on the design was our use of mecanums with the AndyMark chassis, but this had a number of drawbacks. First, the frame wasn't sturdy enough for mecanum wheels and because of this we couldn't maneuver like we had expected the mecanum wheels to be able to. Usually one wheel was higher off the ground than the other three and when we tried to move sideways the robot either didn't move at all or just turned in circles. We also learned that we needed to use shifting gearboxes with our robot in order to gain both an advantage in speed and torque with our robot.



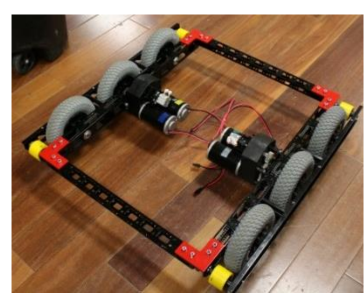
2013-2014
The first big step in creating our team's first custom chassis occurred at the end of summer break 2013 when our team purchased a CNC mill. One of the first things that we tried to do with it was to cut out a truss pattern into the side of an aluminum tube.

After the challenge was released for 2014, we eventually settled on a six wheel drive base with two-CIM ball-shifters, and we decided to make our own. Our CAD team then designed the full chassis with shifters and all from scratch and by the end of week two we had done it.

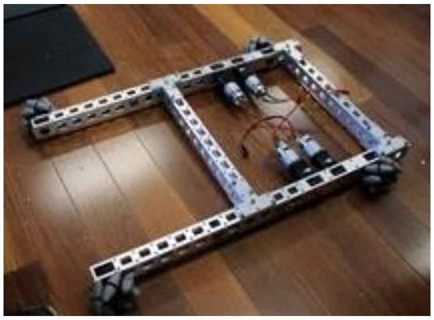


We wound up with the wheel configuration of the standard AndyMark chassis, using a live axle from the gear box for the center wheels and dead axles for the front and back wheel to reduce the complexity of the overall design. We put the wheels and belts in the same place as on the AndyMark chassis and used dropped center wheels to increase our maneuverability. We had aluminum tubing comprising most of the structure and Vex Pro Ball-Shifting gearboxes providing power to each side of the robot.

2014-2015
The Recycle Rush challenged seemed to scream 'mecanum' at our whole team; the maneuverability (if the frame is done right) would allow us to move around all of the obstacles on the field with ease. We had learned in year 1 that we needed a strong frame for mecanums, but now we knew how to do that – build our own!

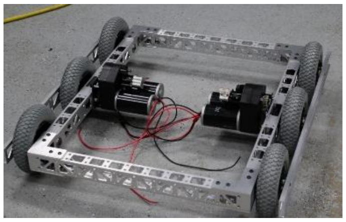


As we prototyped tote and recycle container handling systems, we realized that, while an H-frame chassis would allow us the space to take in totes, we didn't believe it would be stable enough to withstand the forces the mecanum drivetrain would put on it. We decided to add a cross-piece at the back of the robot, making it a (square) A-frame base.



We took advantage of the space available inside the square tubing to protect the belts that connect the motors to the wheels; by running them inside the tubes we save space and protect the system. Those belts connect each Vex wheel to its own RS-775 motor with a VersaPlanetary gearbox.

2015-2016



We started prototyping for Stronghold with a modified version of our 2014 chassis; tank drive with shiftable gearboxes driving 3 wheels on each side. We used belts again, as well, sticking with what we knew how to do well.

As we tried driving over obstacles, it quickly became apparent that our chassis needed adjustments. The three-wheel system was getting stuck going over the moat and could not scale the rock wall. We moved the three pneumatic wheels together on each side to remove the gap between them. We also raised our front beam and added smaller wheels at the front and back to help boost us over obstacles. We switched to a chain drive to prevent slipping under high torque and extended it to power the mini-wheels.

The modifications worked, and we are now able to drive over all of the obstacles with relative ease.

Design Guidelines:

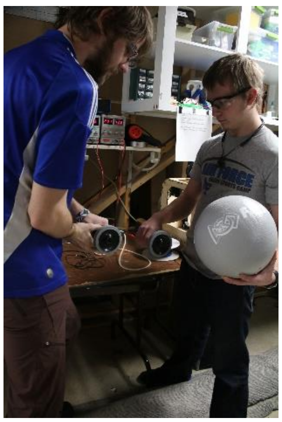
Our original chassis was designed with the equipment that we have in our shop in mind. Everything is either made from aluminum tubing or plate, a lot of it bought from a sponsor in town. We used 6061-T6 aluminum for its superior structural properties and its ease of machining. The tubes are held together at the corners with ¼ in. gusset plates that we machined using the HAAS CNC machine. While heavy, the gusset plates add a superior level of rigidity to our robots that we couldn't have otherwise gotten with lighter plates. We put weight-saving trusses and squares on all four sides of the tubes and we even put a standard hole-pattern on the top of all the beams in order to make mounting our robot subsystems easier. Our wheels were held in place using 3D printed spacers that both saved weight on the robot and reduced the time that we had to spend using more work-intensive machines like the mill and lathe.

All of our sequences for running the CNC machine have been made using the NC package of Creo provided by PTC. We used a variety of end mills to machine the beams, ranging from 3/8" roughing bits to ¼" finishing bits in order to reduce our machining time. After each of the parts for the chassis was done we sent them to another local sponsor who powder-coated them for us.

The Highlanders
Catapult
Engineering Design

Based on experience using a kicking mechanism in 2014's Aerial Assist, the team decided early on to explore two different solutions for throwing boulders: a wheeled shooter and a catapult.

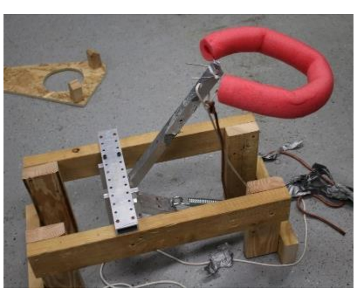
Wheeled Shooter



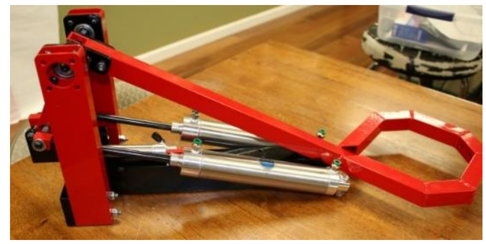
We started prototyping a wheeled shooter mechanism on the day after kickoff. With two hand-held motors we were able to make the ball move very well, but not very reliably. Increasing the stability of the system didn't help us, though. Once we had the wheel stabilized, we had difficulty making the sets of wheels move at the same speed; as the ball compressed, the motors slowed down under the larger load. We created many different prototypes to try to find the right balance between ball compression (distance between the motors), speed and force. In the end we determined that it was not a solution we could make work.

Catapult

Like the wheeled shooter, we started prototyping the catapult on day 2 of build season. This design appealed to us because so many teams had used it so successfully in Aerial Assist. We started out trying to use pistons, but found they could be slow. We switched over to using springs (leftover from an old trampoline) and a lever arm to supply the force. To add more force, we tried combining springs and pistons, but found that the pistons actuated slowly, and our distance actually decreased.



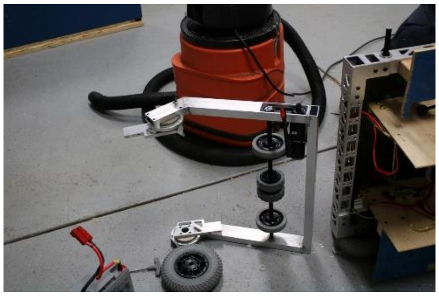
The design we have decided to use has pistons (no springs) and ballast tanks to supply the needed influx of air.



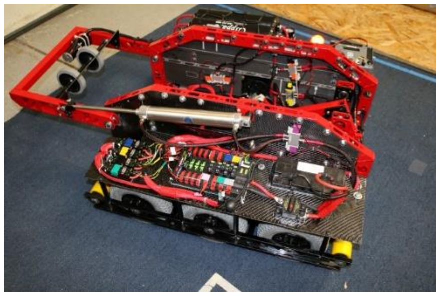
The latching mechanism for the catapult arm was another engineering design challenge. For safety reasons we needed something very secure to hold the arm even when the pistons were primed. We started with a gate latch, but found it had too much slop to be reliable. We designed a latch system in CAD and were able to mill it on the HAAS. It is able to latch reliably when the catapult is retracted, hold it securely when it is primed, and release it quickly when it is triggered.

Intake Design Evolution

Because we had such a good experience with our wheeled intake on our Aerial Assist bot, Quasar, we decided to pursue a similar design of using a main axle and several wheels. We prototyped a mechanism to experiment with how much compression worked with the boulders. Returning to cad to make the design allowed us to be sure of our sizing, and we created our first version with two smaller wheels close to the center of the bot and two slightly larger wheels further from the center.

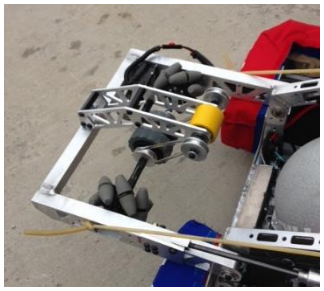


After initial testing, we revised the design to have only 2 wheels. While we were at a late-build-season scrimmage we discovered that, in the heat of battle, balls would frequently get carried up and over the wheels, popping out the top of the robot and not into the catapult's basket. There were two other problems with the intake/catapult interaction: the ball wasn't be held well, and so would sometimes bounce out of the basket as we went over defenses, and we had no way to get it out of the basket and back to the intake to put it into the low goal on the castle.



Initially we created designs to solve all three of these problems separately. A sheet metal guard on the intake prevented balls from coming out of the top of the intake. A lever and small piston clamped down on the ball when it was in the basket and prevented it coming out while driving. And a design was in process to have a piston poke a ball out of the basket and back to the intake wheels.

Two design changes made all of these mechanisms into one. First, mechanum wheels were added to the intake axle to help gather balls in from a wider angle. Adding an arm attached to the intake, with a McMaster-Carr wheel on a small axle, driven by polycord and the main axle, solved the three ball control problems. By having a drive wheel located where it is, we are able to

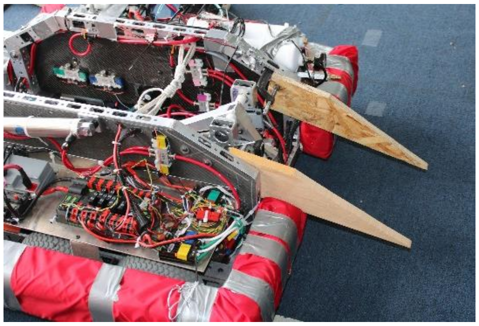


- Stop the ball going out the top
- Stabilize the ball when driving (the mechanism touches the ball when the intake is up)
- Push the ball out back into the intake wheels.

The Highlanders
Front Manipulator Engineering Design

Front Manipulator

We put off prototyping of manipulator arms until we were already well into our chassis, catapult and intake designs. At this point we started looking at arms to open the sally port and drawbridge. While we had many good ideas, we did not find them feasible for operating in the time we allotted ourselves to cross those barriers. It was only just before bag and tag that we started looking at wedge-like arms to lift the portcullis. We prototyped it with a window motor, and discovered that the motor would not be enough to lift the 5 lb. barrier. We bagged the robot without any arms for manipulating the defenses.

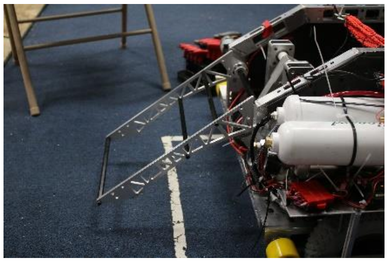


After bag and tag we realized that the same wedge shape might be enough to lift the gate. While our wood prototype would not slide along the bottom of our wooden portcullis, a metal wedge might be able to boost the plastic barrier enough to get it over the robot. This idea was reinforced by watching tournaments in week 0.5 and week 1; the portcullis seemed to move up easily and take a while to settle back down again.

We designed an actuated arm, made up of two pieces of sheet metal connected with an aluminum bar. This was lifted and lowered with a ½ inch bore piston; up to start the match, down to wedge under the portcullis and force it up. It was also able to press down on one of the pieces of the cheval de frise, allowing us to cross that barrier.

We used the device successfully until our last qualifying match in the Northern Arizona Regional, when we jammed the mechanism, breaking the bottom stop and bending the piston actuator.

After the Arizona tournament, our manipulator underwent another design improvement. Instead of sheet metal, we designed the arms to be out of 1/4” aluminum plate for increased strength, and switched to a RS-775 with a 40:1 conversion. The variable positioning available through the use of the motor will be valuable in defeating both the cheval de frise and the portcullis.



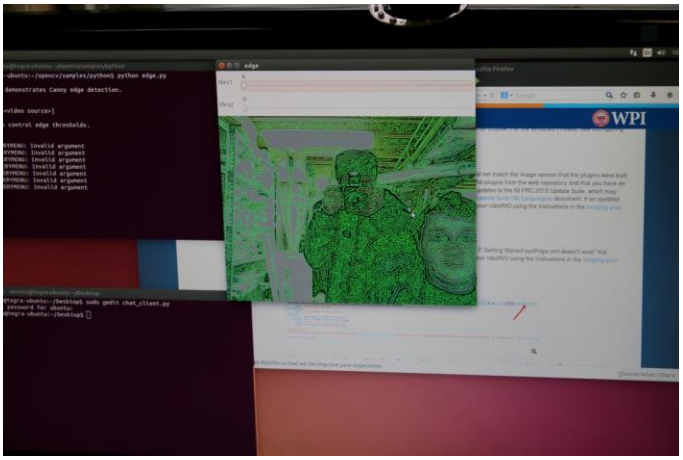
Programming for the 2015-2016 season

This year we decided to use Java as our primary programming language.

The Vision System

Unlike previous years this year's game field is often equipped with numerous obstructions that block the drivers' line of sight to the robot. Therefore we worked to create a system that would maximize the efficiency of cameras on board the robot. Initially we tested using the camera support built in to WPILib, however, low resolutions, slow frame rates, and high data usage made this solution infeasible. Therefore we developed a more comprehensive vision system based upon an on board Nvidia Jetson TK1. This year the Jetson board serves two purposes.

First of all the Jetson does high speed vision processing on the reflective tape on the castle. This allows the robot to be able to automatically adjust its range and angle when firing at the castle and improves the accuracy of the drivers. The vision code is written in python using opencv.

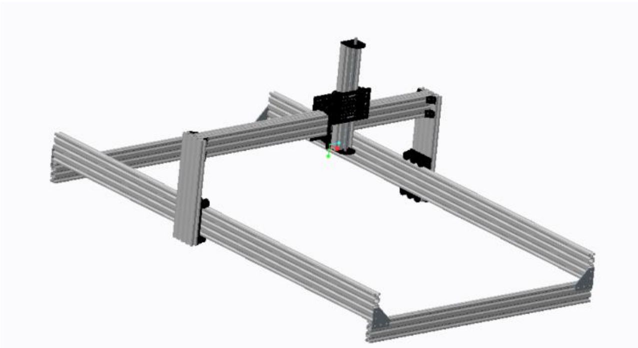


The second main function of the Tegra is to host a web server and to continuously serve the image data from 3 cameras to the driver station. The advantage of this system is that it can transfer 3 different video feeds with minimal latency. Additionally, it can append the images with targeting information for the drivers. The web server is hosted using python flask and is also capable of rapidly calibrating the vision code using a series of sliders programmed into the web-page.

The Highlanders
CNC Plasma Cutter — Engineering Design

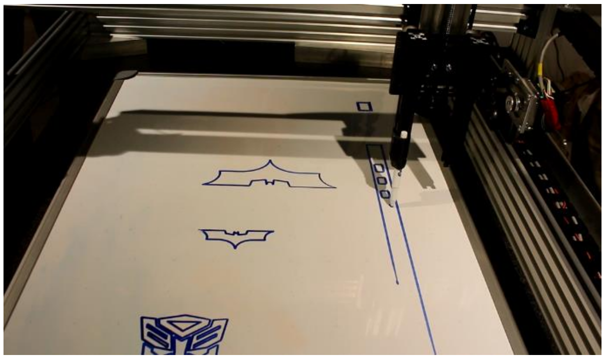
Our off-season project in 2014 was to build our own plasma cutter. Completed just before the 2015 build season started, it was a journey of discovery through the fall.

CAD Design
Designed on our own, based off of other designs we saw on the internet. We customized it for the type of plasma cutter we already had and for the dimensions we wanted.

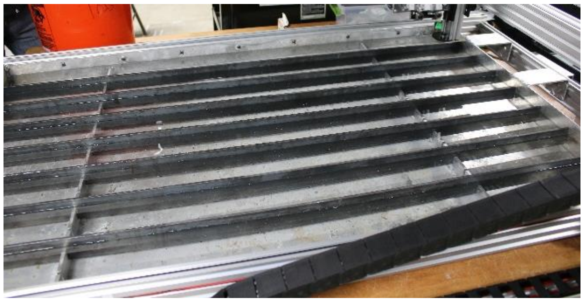


Initial Build Steps
The build started in September, once team members were back in town for school.

CNC Expo Writer
Once the super structure was complete, we tested the functionality by attaching a dry erase marker to the head. This let us verify that the control mechanisms were working, that the limit switches functioned as necessary, and that all 3 axes of control worked.



Basin
We were able to bend the metal to make the basin on our own metal brake. We welded the corners, then tack welded aluminum strips widthwise on the bed. Stainless steel strips that run across the aluminum ones support the metal to be cut and are sacrificial; cutting the part will also cut the steel, but these can be easily replaced.

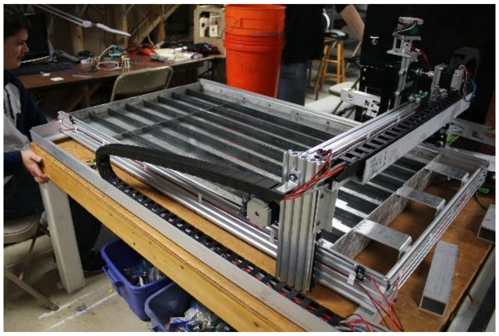


Software
When we started using the plasma cutter instead of the expo marker, we realized that the software we had created lines, not tool paths. The difference is that, since a plasma stream is wider than a single point, the cutter needs to have offsets that are different for inner and outer cuts. The software we use now is SheetCam, who is also a sponsor for the team.

CNC Plasma Cutter, p2

Final Product

We have used our CNC Plasma Cutter successfully for cutting robot parts as well as some fun items.



This is a part cut on the plasma…

…and the bracket it became.

Go Highlanders!

The Highlanders

Carbon Fiber

Engineering Design

With no prior experience, the team started working on the idea of using carbon fiber parts in January 2014. The team did a great deal of online research about carbon fiber. Our research included both how to create carbon fiber parts from raw carbon fabric and epoxy as well as how to safely handle, cut and machine finished carbon fiber parts. We particularly did our homework on the safety aspects including: handling and cutting raw carbon fiber fabric, layup and epoxy construction (and cleanup) in a small shop, safe handling, cutting, drilling and sanding of finished parts.

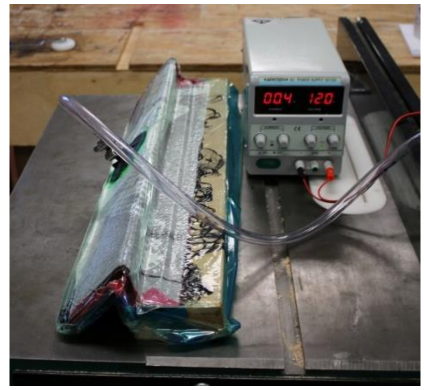
We have constructed carbon fiber tubing, solid carbon fiber sheets and carbon fiber sandwich sheets (plywood core and foam core) from raw carbon fiber fabric and epoxy in our own shop.

Once we felt we had the basics, we were interested in 'stepping up our game' and making parts that looked more professional than those we had created before.

To do this, we began using a vacuum system for forming the parts. Run off of the shop's compressor and a Raspberry Pi computer, the vacuum:

- Creates parts with greater strength to weight ratios, decreasing voids in the parts as well. as removing any unnecessary epoxy.
- Allows us to create formed parts with complex contours.

We have used carbon fiber sheets as electronic boards, skirting and side shields on our robots. We've used some tubing but have especially taken advantage of the forming capability to make right angles, including shelves for our electronics.



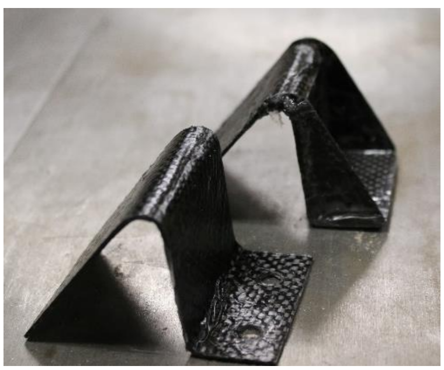
Carbon Fiber Applications

Solid Carbon Fiber Plate:
Some of the applications of solid carbon fiber plates for various applications on our robots:

- The base board and vertical boards of our 2016 bot are made of solid carbon fiber plate. The light weight of the parts allows us to add in more complex mechanisms to overcome obstacles without exceeding weight limits.
- The intake wheel assemblies on 2015's robot are supported by carbon fiber 'springs' – rectangular pieces cut from carbon fiber plate that allow the intake to flex horizontally without any flex vertically or any noticeable twist.
- A large plate of sandwich construction carbon fiber plate was created to hold electronics components and the kicker foot at the back of our robot in 2014. The plate was vertically oriented and bolted along its outer edges to two vertical aluminum rectangular tubes which themselves were bolted securely to the base of the robot.

Molded Carbon Fiber Plate:
With the vacuum system we have been able to create carbon fiber pieces formed to spec.

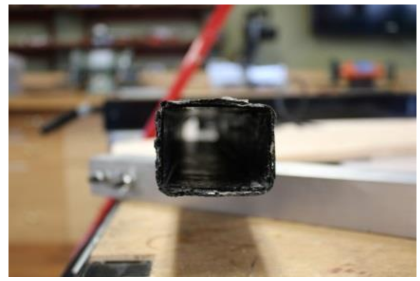
- For the 2016 robot, the protective outer verticals on the robot are carbon fiber plate formed with a 90 degree offset, as are the electronics shelves.
- In 2015 we prototyped hooks for picking up totes. This was a complex shape, but the parts came out in the proper dimensions. Unfortunately the material wasn't suited to the application, and the carbon fiber couldn't withstand the impact required.



Rectangular carbon fiber tube:
We created three pieces of carbon fiber rectangular tubing for the intake mechanism of our 2014 robot.

The "intake arm" on our early prototype robot was made by welding three 28" pieces of aluminum tubing together. In our final robot we replaced approximately 20" of the aluminum tubing (from the middle of each of the three pieces) with custom built carbon fiber tubing.

Carbon fiber tubing was constructed with an inner cross-sectional dimension equal to the outer dimensions of the aluminum tubing. Each carbon fiber tube was about 26" long and each replaced approximately 20" of aluminum by overlapping aluminum lugs at each end.



The Highlanders
3D Printing

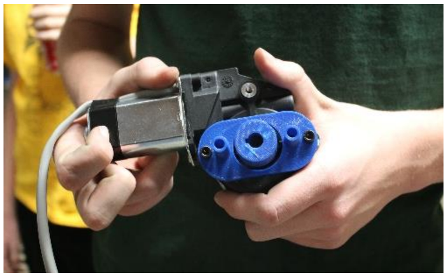
Engineering Design

3D Printed Parts Design

Many of the parts on our robot are 3D printed because the 3D printer can make parts faster than the manual machines when strength and dimensional tolerances are not of extreme importance.

We choose to design and 3D print parts when we can because it is simply faster to do them on the 3D printer, and they do not need the strength gained from aluminum or steel. 3D printing also allows us to use complex shapes that we could not make any other way. We received a printer from a sponsor during our 2013 season, and have recently added a second, dual-head printer. Our robot is cooler-looking and easier to make because of our use of this technology.

We did see the limits of the capability of a 3D printed part in 2013 when we used ABS to make a mount for a window motor. While the printing could easily deal with the complexity of the part, the torque applied to it exceeded its capacity, and it failed. We redesigned with a metal part, and learned a valuable lesson.



Each year we have printed many spacers for our robot as well as mounts for our cameras, router, and robot signal light.

In 2015 we printed complex gear shapes to allow us to mount encoders on the robot. The gears were designed to prevent slippage and allow the encoders to maintain accuracy even though they could not be mounted directly to the axle.

For the 2016 season we have designed and printed camera mounts as well as a jetson board/robo rio mount. We have once again used the technology to print made-to-order spacers as well as a router mount.