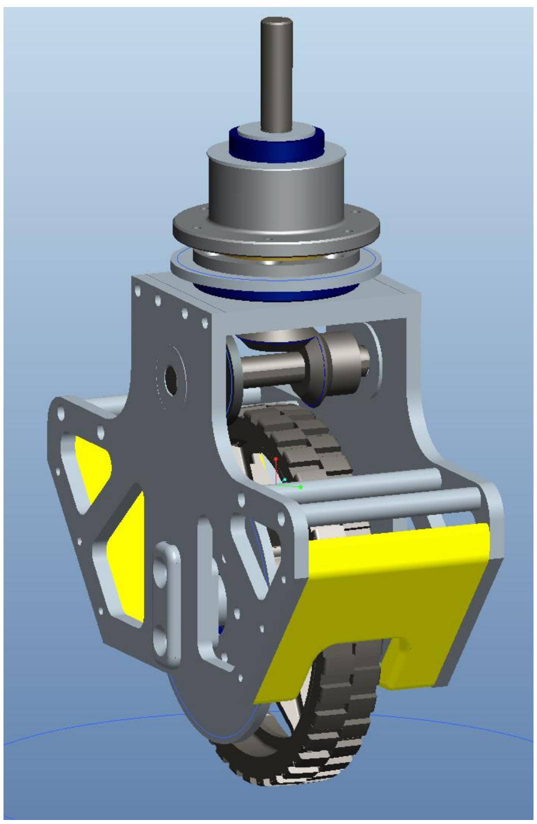
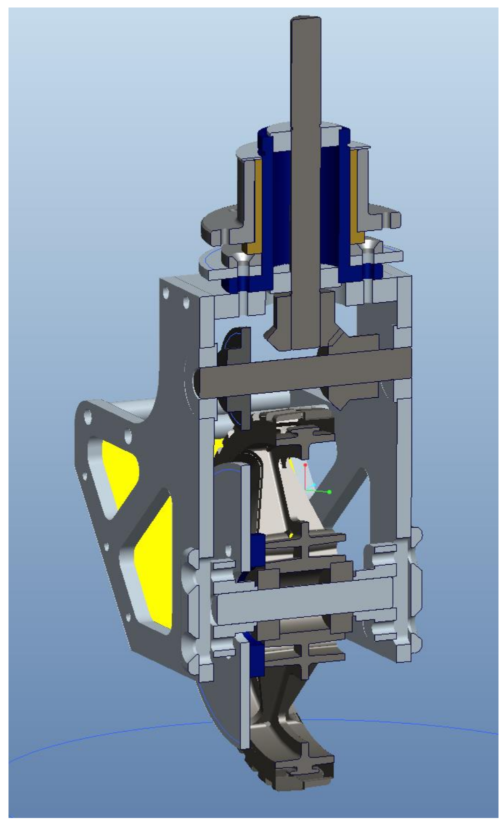
Design Description of Stryke Force "Third Coast" Swerve Drive Units

Introduction and History (up to 2018)

Stryke Force's motivation to convert to Swerve Drive came from watching and being pushed around by another west Michigan team, FRC Team 141 "Wobots" (imitation is the highest form of flattery). We started in the 2011 off season with the commercially available "Revolution Swerve," developed by 221 Robotic Systems. We used it to learn about incorporating Swerve into a robot, and how to drive it. We borrowed freely from the wealth of public information on swerve drive programming and (eventually) field-oriented control available on Chief Delphi. Special thanks are due to the user "Ether," who has provided a wealth of very cogent source information.

We did not compete with the Revolution units due to high BOM cost and a strong desire to incorporate more mechanical learning into our program. Stryke Force developed its first custom swerve drive unit for the 2012 game, Rebound Rumble.



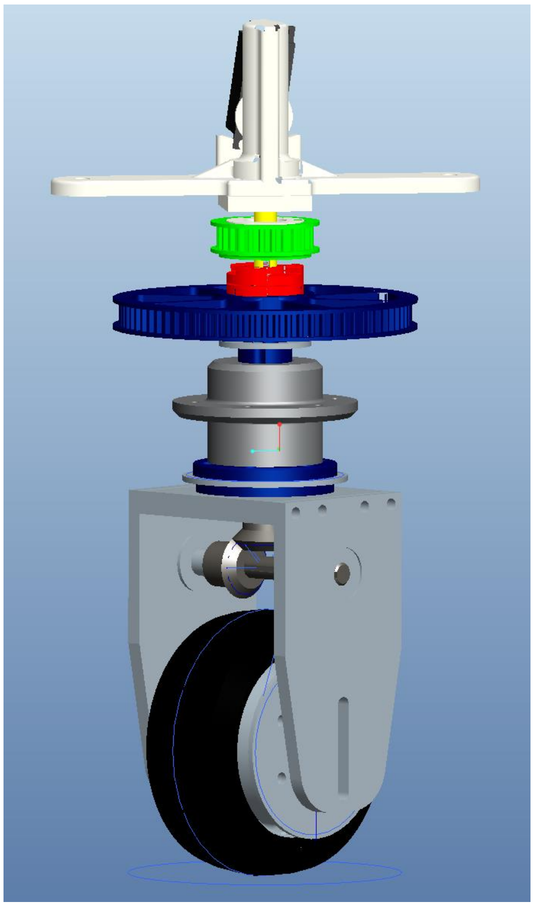


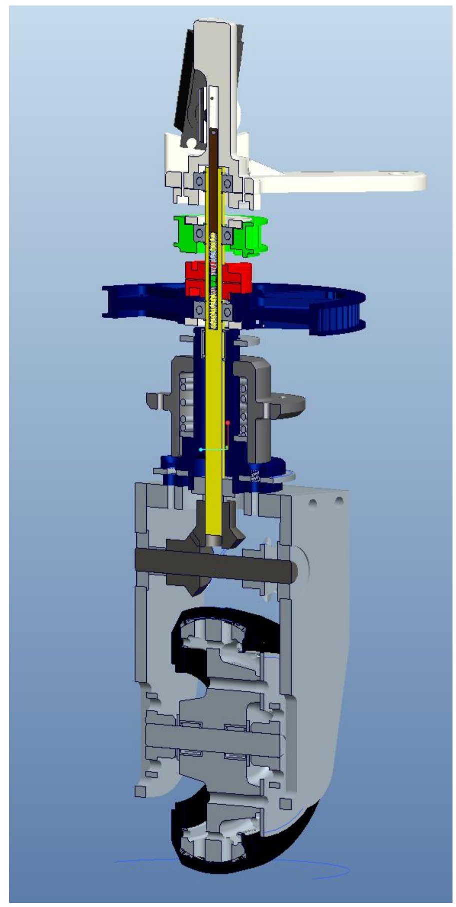
This was essentially a scaled-up version of the Revolution, with "wheel pant" skid plates so that it could skid up on the angled plates and jump over the mid field barrier. It had 6" diameter wheels. Although we had success and were hooked on Swerve, there were several serious shortcomings with this first design:

- Robot center of gravity far too high—causing us to limit acceleration and forcing our driver to be careful to avoid tipping over. This obviated much of the intended advantage of swerve.

- Overall space claim on the robot and weight were too high.
- Too much weight on the perimeter of the robot—limiting rotational acceleration/maneuverability.
- Difficulty driving straight in autonomous and dealing with obstacles.

Our design for Ultimate Ascent in 2013 attempted to address some of these shortfalls by reducing wheel size to 4”, removing discrete bushings for the rotation (employing the housings themselves), adding posi-traction, and adding a servo-actuated, dog clutch two-speed transmission. For the first time, we also 3D printed timing belt pulleys to facilitate the design of the two-speed transmission.



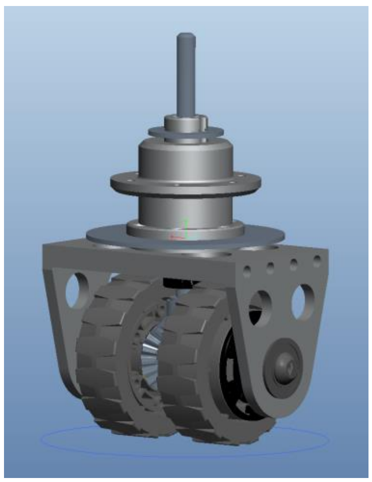
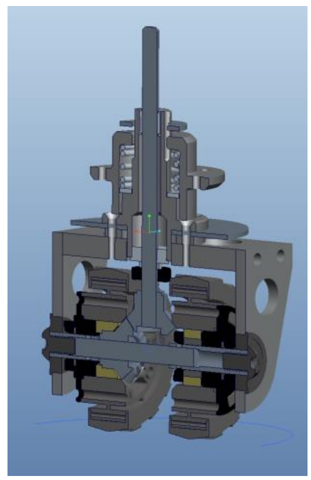


This swerve design was a large improvement. The ¼” throw posi-traction was helpful in improving the control of the robot, but also made it sway during hard maneuvering and the recoil of the Frisbee shooter was visible in the mechanism. There were some other, more significant, shortfalls:

- COG still too high
- Space claim and weight still higher than desired.
- Shifting time limited the utility of transmission.
- High maintenance
  - Custom wheels/tread
  - Multiple chains, which are pinch hazards, potential failure points, and need to be adjusted periodically.

- Multiple light duty belts, which were prone to wear & failure
- Insufficient thickness in mounting plate on robot, leading to bending/alignment issues.
- Motor mounting issues leading to belt walk.

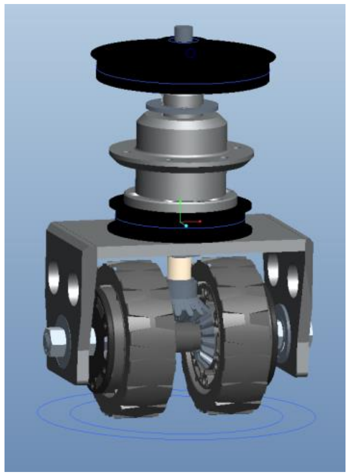
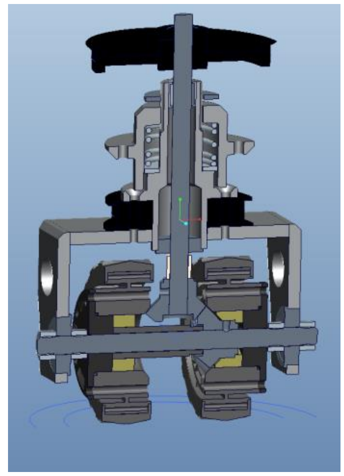
Our next iteration, developed for 2014's Aerial Assist game, began an emphasis on simplification. The most significant and visible change was the elimination of the horizontal drive shaft and its sprockets/chain, and the corresponding move to "dually" wheel sets. Overall height and complexity were reduced relative to previous iterations, reliability was improved, and the maintenance load on the pit crew was dramatically reduced. We also started to notice improved handling. It was visibly unique, and our team started to identify with it. Playing off the "West Coast Drive" name, we've taken to calling our dual wheel posi-traction swerve a "Third Coast Drive," in reference to the Great Lakes region.

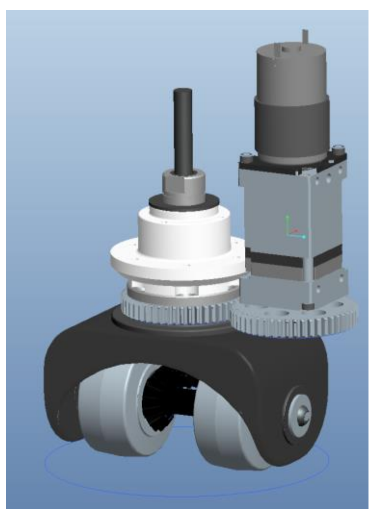
Items targeted for improvement after competing with this first generation Third Coast Drive:

- Weight
- Vertical drive shaft cantilevered off lower bearing too far—led to occasional bent drive shafts. This was in part due to some shafts with improper heat treatment.
- Conversion of azimuth chain to belt
- Method of setting bevel gear mesh

2015's game, Recycle Rush, really didn't emphasize the traditional capabilities of Swerve. However, since we had a lot of comfort and experience with it, we did it simply for the advantages of maneuverability in tight quarters. The main differences between this design and the former were that we changed how the axle was constructed and the bevel gear adjusted, and we converted the azimuth to belt drive. We also eliminated the bolted connection between the side plates and the top plate. In this version, this last change meant that we bolted a retainer for the axle bearings in from the bottom (not easily seen below). At the time, we thought this was necessary for maintenace on the wheels. One item to note is that the design required secondary machining ops on the wheel with the bevel gear. The whole axle assembly also had quite a few spacers.

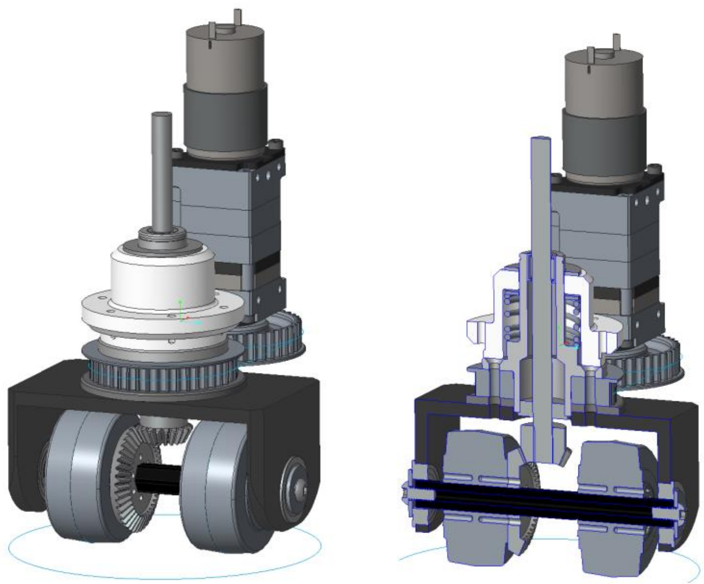
In the off season between 2015 and 2016, we created a Third Coast Drive T-Shirt Cannon Robot. In this design, we hoped to get rid of the hassles and time penalties of azimuth zeroing by shifting to absolute encoders. We developed an in-house method of mounting an optical encoder on a Vex Planetary Gearbox output—only to find out that Vex simultaneously released a similar product with a more robust magnetic-based encoder!!! We happily adapted to using theirs. Other refinements included using a composite saddle, exploring using a gear set rather than pulleys and belts for azimuth control, moving to Colson wheels to improve wear, elimination of several axle spacers, smaller wheel size to reduce the overall gear reduction needed for a target speed, elimination of secondary machining on the wheels, and the axle bearing retainers. Overall, this module, which never saw FIRST competition, was very light and a nice upgrade but the fabrication of the composite saddles was time intensive and we didn't have faith in them or the azimuth gear set given the posi-traction axial motion.



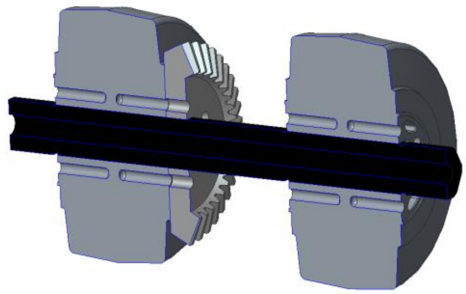
In our initial estimation, 2016's game, FIRST Stronghold, did not lend itself to Swerve Drive. The amount of physical abuse we expected the robots to take gave us pause, and the wide variety of orientation in obstacles made us worry about swerve's appropriateness. For example, if the dual wheels were not aligned with an obstacle when they hit it, the impact with the leading wheel would create a torque-shocking the azimuth belt, potentially skipping teeth or breaking it. Thus, we went to an eight wheel tank drive with the outer wheels raised slightly for maneuverability. Each set of four wheels were mounted in suspended “skiis” intended to smooth out impacts going over obstacles. In hind sight, FRC 16 “Bomb Squad’s” robot for that game proved that Swerve could still be used to very good effect. Hat’s off to their team’s insights on how to make that all work out.

With the wide-open field of 2017’s game, FIRST Steamworks, we went back to swerve. This generation of Third Coast Drive started with what we learned from T-Shirt Cannon Robot and put a lot of emphasis on simplicity, ease of manufacturing, and weight reduction. Key design elements were shifting to a Nylon mounting “bonnet” vs. the traditional aluminum (weight savings), and reduction of posi-traction throw to facilitate a stable shooting platform. This design is described in detail below:

2017 Stryke Force Third Coast Drive Detailed Description

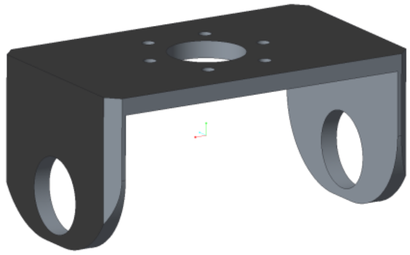


Wheel/Axle Assembly: Use of durable 2.5” Vex Colson wheels with ½” hex bores and Andy Mark’s 2:1 bevel gear set allowed us to keep things simple and the drive pulley ratios reasonable. To use the Andy Mark gears on axles made from Vex ½” Thunderhex, we removed the flange on the large gear’s back side, opened the 3/8” hex to ½” hex (drilling and broaching) and drilled a hole pattern in its face matching the one in the Colson wheels. All torque was transmitted through the hex flats; the screws going through the hole pattern were simply to keep the face of the gear flush against the wheel face, counteracting the moment created by the bevel gear mesh forces. <u>Note that the opening of the 3/8” hex bore to the ½” hex bore must be done very carefully</u>. We used a mill and a dial indicator to set up the job. The concentricity of the bore to the gear tooth pattern is critical to properly setting backlash. Lack of concentricity will force unnecessary backlash. Unnecessary backlash will lead to premature gear wear, noise and poor control. Similarly, care must be used in the broaching operation.

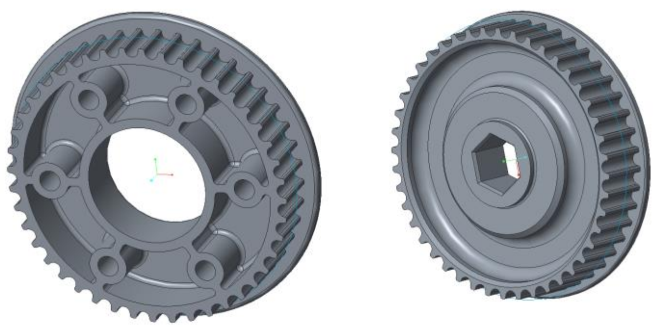


The wheels are axially held in place on the axle with three snap rings (not shown); one for the geared wheel (opposite side from the gear to take the mesh thrust), and one on each side of the non-geared wheel. The location of the snap ring grooves in the axle is determined by the location to hold the geared wheel in the nominal mesh location relative to the mating gear on the vertical drive shaft. The non-geared wheel is located symmetrically about the vertical drive shaft relative to the geared wheel. This is done so that scrubbing torques are equalized and the robot can stay stationary when azimuthing a swerve unit. One way to think about it is that essentially a virtual wheel is created on the vertical axis. The axle length is set carefully so that it can just be rocked in position in the saddle when the bearings are not in place. This elimates the need for a complicated saddle with bearing retainer plates.

Saddle: The incremental design goal for the saddle in 2017 was for it to be one piece and machinable by build team students using basic skills. The saddle started life as a ¼" wall 5"x5" 6061-T6 Aluminum extrusion. The extrusion was cut to length on a horizontal bandsaw and then cut in half using a vertical bandsaw. The width was determined by what is necessary to provide complete support for the azimuth pulley diameter and the height was what is left after cleaning up the bandsaw cuts. The next step was to mill the saw-cut faces in order to square them up. After the faces of the horseshoe were squared up, the axle shaft holes were carefully drilled and reamed to fit 1-1/8" OD Thunderhex flanged bearings. The top hole was then drilled out to intersect the axle shaft axis at right angles. This hole must intersect the axle shaft hole for proper gear mesh. The bolt pattern at the top was also done on the mill at this time and the holes were subsequently tapped. In order to minimize weight and swept diameter, the edges were chamfered and the bottom corners cut off around the axle bearings. Note that in CAD, these corners are radiused, but on the actual robot, they were cut off at 45 degrees—simply easier for fabrication. On our prototypes we didn't even bother with these cuts at all. Note that minimization of swept diameter is important because we set up the wheels so that the swept path is almost tangent to the frame—wheelbase reduces as swept diameter increases, and wheelbase is important for stability/handling.



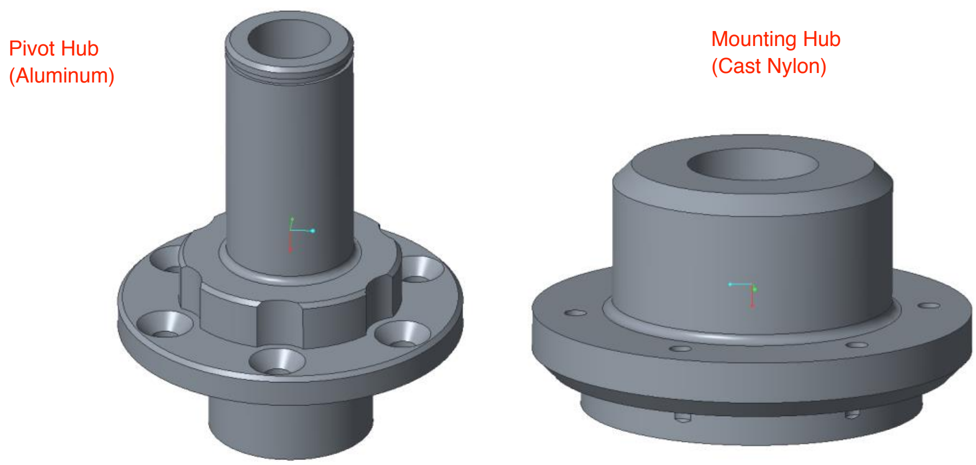
Azimuth Pulleys: The azimuth pulleys were 3D printed by our sponsor in polycarbonate using a commercial FDM type printer (Fortus400MC). A flange for the swerve unit side was also printed (visible in assembly views, but not shown below). We have found that the teeth profiles need to be tweaked a bit (opened ~0.002") to get the timing belt to settle into them fully. This is important because if the teeth don't settle in fully, the belt teeth will jump under load and you'll lose wheel alignment.



Note that to be able to take advantage of the absolute encoder on the output of the azimuth gearbox, these two pulleys must be the same number of teeth. We used 44T in 2017. Also note that we now use HTD, 5mm pitch, 9mm wide belts. To minimize "backlash" due to belt stretch during direction reversals and possible slipping of teeth, these belts need to be fairly tight. Earlier versions used XL type belts which weren't quite as smooth or robust to the loads. The pulleys are a little wider than the belts in order to accommodate the posi-traction motion. One thing we struggled with in this design was durabiltiy of the hex driven azimuth pulley. We prevented outright failure by JB Welding an SAE aluminum washer in around the boss surrounding the hex. This washer took the hoop stress and prevented the cracks we were seeing at the hex vertices. The hex fit can still loosen a bit due to wear over the course of a tournament, leading to some backlash in the system. We inspected for this closely and changed them out as soon as we saw one with some relative motion. The hex shaft-mounted azimuth pulley was retained on its shaft with a washer and button head screw. An off the shelf aluminum ½" hex pulley could be used, but we were looking to save weight and eliminate the backlash associated with the typical clearance fit. Note that in order to keep the overall packaging as tight/low as possible, we cut down the stock versaplanetary hex shafts to custom length and re-drilled/tapped the ends. Off the shelf shafts could be used if the azimuth actuator axis is moved further away from the Swerve Drive. The larger clearance pulley could also likely be an off the shelf pulley with a large bore. The Swerve Pivot Hub would just need slight re-design to accommodate it.

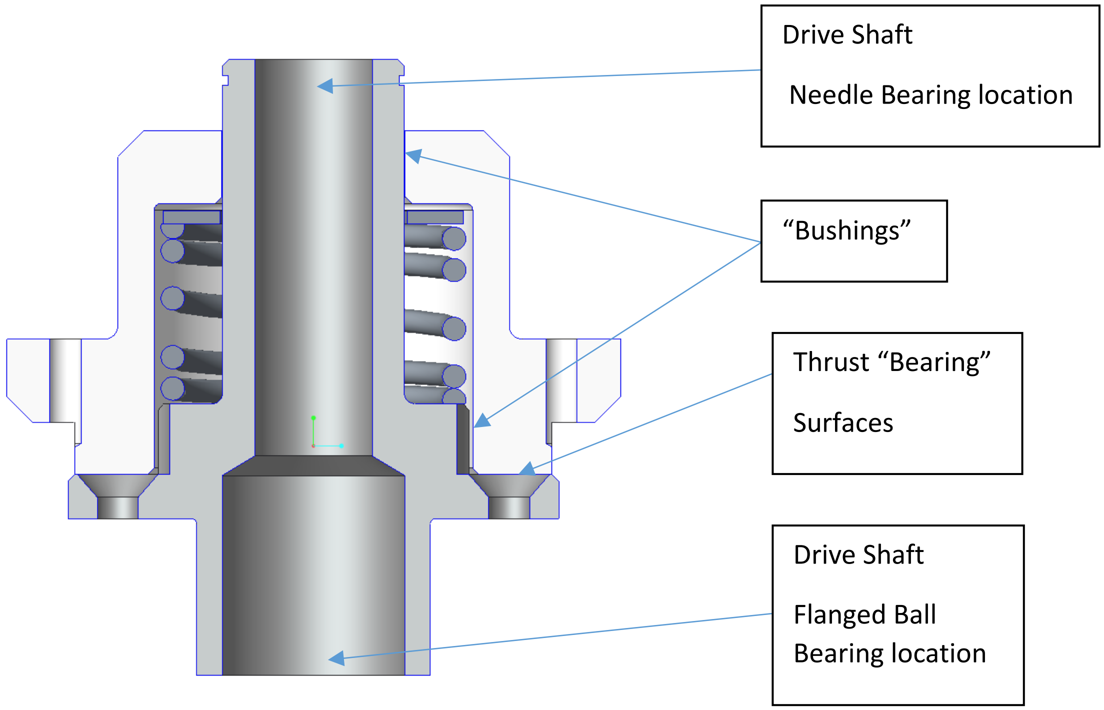
Swerve Pivot Hub and Mounting Hub:

These were the two “complicated” parts in the system which were done on a sponsor’s CNC lathe with secondary ops on a mill.



The Pivot Hub (left) was aluminum and supported an off the shelf 6” long Ø3/8” case hardened steel vertical drive shaft (McMaster-Carr). This support was accomplished with a 7/8” OD flanged bearing (AndyMark) at the bottom, and a 7/16”OD needle bearing at the top (McMaster-Carr), both of which were pressed in. The separation of the two bearings nicely supports the vertical drive shaft. One key to success is to get the lower bearing close to the bevel gear. If this distance gets too long, the 3/8” diameter drive shaft can bend under the combined loading of the bevel gear thrust and wheel side loading. The Pivot Hub was bolted into the top of the saddle using flat head screws. It sandwiched the printed azimuth pulley and a spacer such that those printed plastic parts were vey well supported. The heads of the flat head screws were slightly recessed below the face they go into. This was because that face served as a thrust bearing for the underside of the Mounting Hub. Essentially, ¼ of the robot weight less the posi-traction force (described below) acts on this thrust bearing. The hole pattern was originally determined by our use of off the shelf sprockets for our chain driven azimuth. In this iteration, it was vestigial, and since it drove us to make the milled “scallops” to clear the heads it was redesigned for 2018. The moment was transferred through the assembly to the robot frame by two separated cylindrical faces. The first is the scalloped face and the second is the area immediately below the snap ring groove. The two faces and the thrust face are all carefully deburred and lubricated (we use “Super lube”). The Mounting Hub interfaces with these faces as described next.

The Mounting Hub (right) was made from cast nylon (McMaster Carr), which made a nice bushing material and was still strong. Delrin would also likely work well. The robot frame sat on the flange with the bolt pattern. The holes making up the bolt pattern in the flange were tapped and this is how the Swerve Drive unit attached to the robot.



Positraction Description:

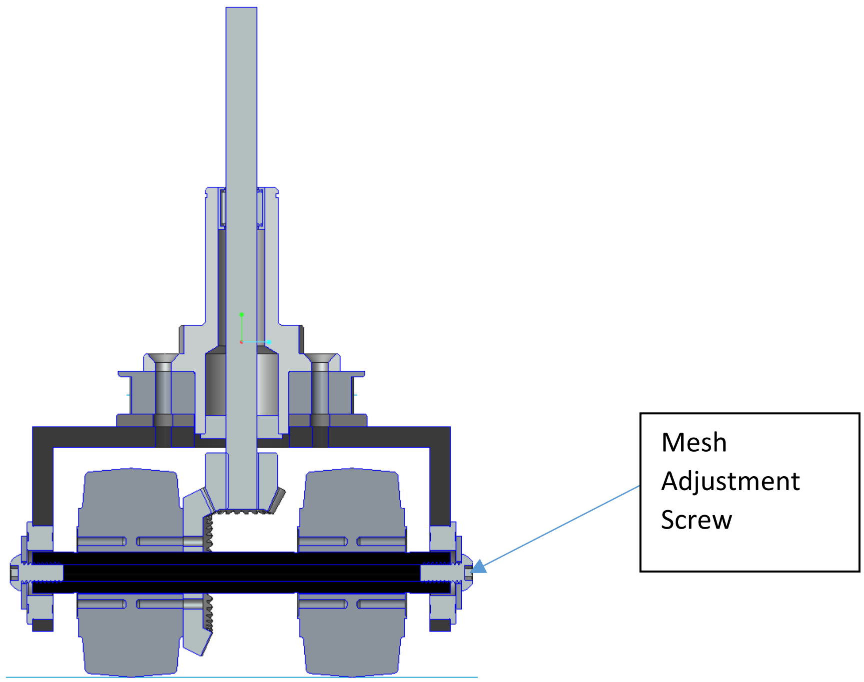
For a robot to efficiently drive straight, the following must be satisfied:

1. All wheels have same surface velocity. Usually:
    a. Same diameter
    b. Same rotational speed
2. Same traction. A result of:
    a. Evenly distributed power.
    b. Evenly distributed traction.
3. All wheels pointed in the same direction (aligned)

Pos-itraction helps with item 2b. Three points define a plane. More points are odd men out—in engineering speak, the plane is "overconstrained." In practical terms, when four rigid swerve units are put on the ground, manufacturing tolerance stackup or post manufacture movement (such as from a damaging collision, or drop) cause one of the points to come off the ground. The robot will then be less stable than it would otherwise be, possibly rocking (depending on frame stiffness), or will at least have less traction on the higher wheel. Even aligned, if the traction isn't similar between wheels, the robot will not drive straight without some other correction. The positraction spring is sized to push the Swerve Pivot Hub and Mounting Hubs apart with a force roughly 20% of the fully weighted robot. Thus, the robot normally rides with its "suspension" bottomed out on the thrust "bearing." However, when one wheel starts to become unweighted or even comes off the carpet, the spring will push back down and keep the wheel in contact with the ground. We know from practical experience that the posi-traction works and will make up for significant frame bending. It also helps control when accellerating hard, driving onto a shallow ramp or over minor obstacles. Unfortunately, the amount of travel must be limited to fairly small amounts, or the robot is not a stable shooting platform. We limited travel to approximately 3/32” for the 2017 robot because of the recoil from the Shooter. The inside surface of the Mounting Hub Nylon was protected from the end of the steel spring by a washer.

Unit Assembly:

The unit, less the Mounting Hub, Washers, and Spring was assembled (as shown below) off the robot.

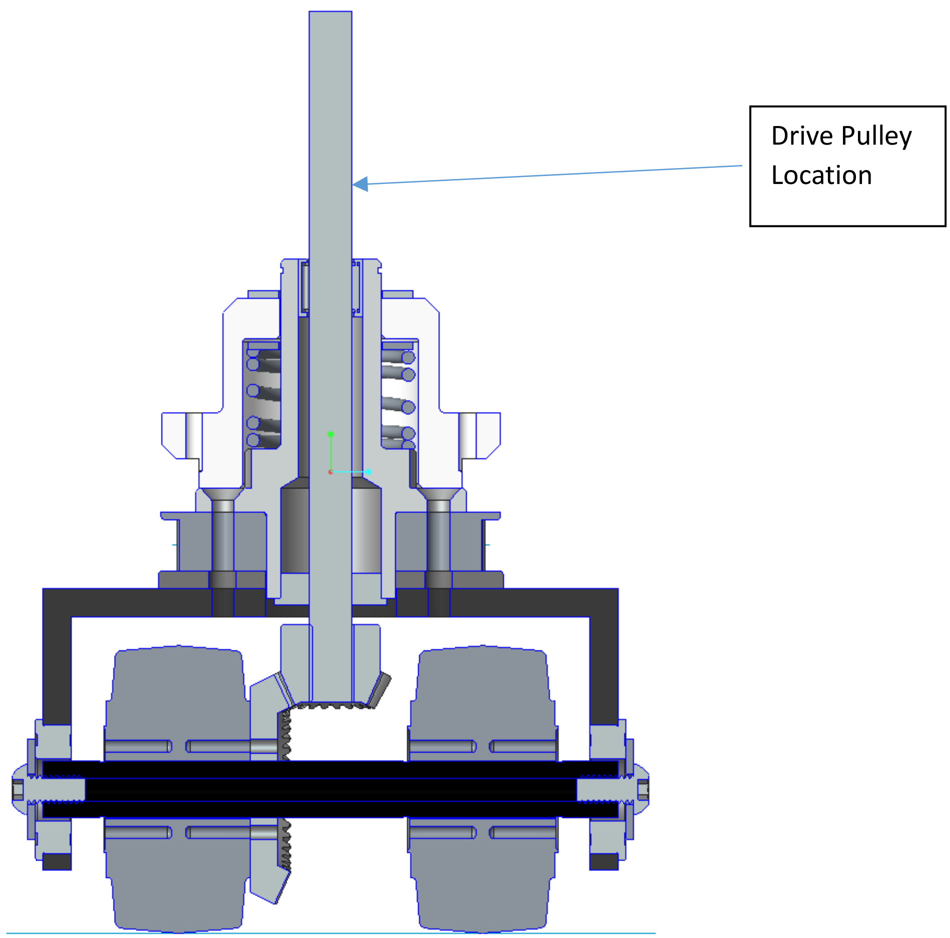


Shimming of the bevel gear set can either be done now or after mounting on the robot and is described next.

Once assembled into the saddles, the horizontal component of the mesh is adjusted by jacking the axle back and forth several thousandths from the nominal location. This jacking is accomplished using the ¼-20 button head screw threaded into the Thunderhex bore (tapped) on the non-geared wheel side. Mesh is adjusted vertically with shims (not shown) between the back of the vertical shaft bevel gear and the support bearing inner race. Mesh is proper when the gears line up as shown (maximizing facewidth engagement), have minimal backlash, and move freely through full rotation. Once set, the opposing ¼-20 button head screw is tightened to lock the shaft in position. Both axle screws are doped with Blue Loctite to prevent loosening. This process may need to be checked again after operation under load. Once re-adjusted after “burn in” we have not had to revisit the mesh during a season.

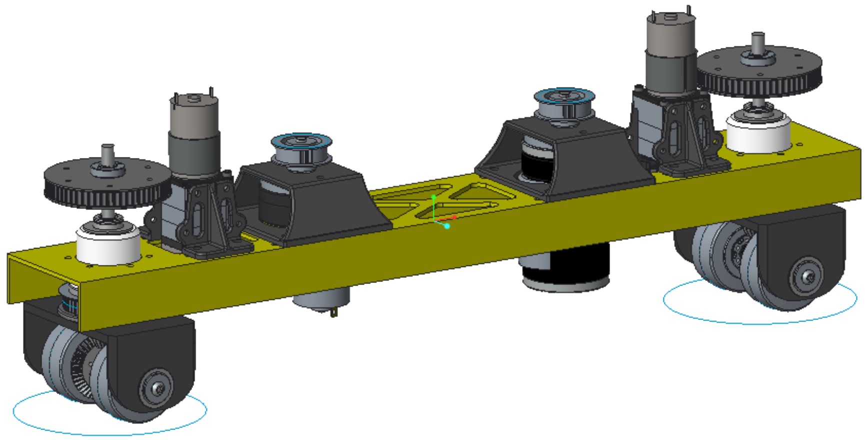
Final Assembly:

The Mounting Hubs are bolted into the robot frame. The posi-traction spring is set on the Pivot Hub with a washer on top and then pushed into the Mounting Hubs from the bottom. The spring is compressed until the snap ring groove at the top of the Pivot Hub comes through the top of the Mounting Hub. A second washer is placed on top of the Mounting Hub and a 7/8” snap ring is put in place to hold the whole thing together. The top washer protects the nylon of the Mounting Hub from the steel snap ring as it rotates with the Pivot Hub. Posi-traction motion can be reduced by adding washers if necessary. Posi-traction force can be adjusted by adding washers inside the Monting Hub or grinding down the spring as needed.



Other Notes:

- In 2017, we opened the bore of the vertical drive shaft bevel gear (it comes 8mm) and welded it to the 3/8” drive shaft. We have also succesfully cross-drilled and pinned them, and used keyed connections in the past.
- It is good practice to try to get the Drive Pulley down close to the needle bearing in order to minimize that cantilever and the resultant moment loads on the shaft. However, we have not had an issue with the upper portion of the shaft bending with the gear ratios we’re using.
- Give careful thought to how motors and gearboxes are mounted. Belt loadings can be significant and if the shafts are not parallel to the swerve drive unit axis, belts will walk and slip off pulleys. Also, note that our azimuth pulleys are significantly larger than the belt widths in order to provide for posi-traction travel.

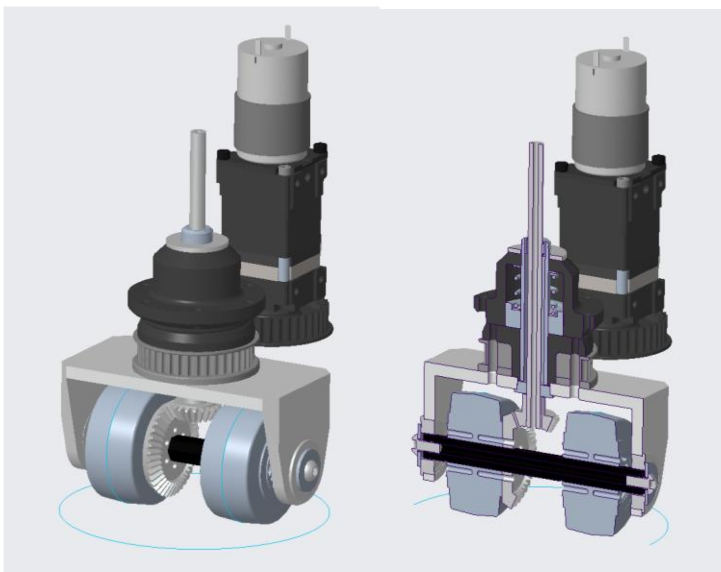


- Make allowances in your design to adjust belt tension for both drive and azimuth belts. We mount the motors/gearboxes/encoders in either sections of tube, or printed structures as shown above and then bolt those down to the structure using slots. The yellow "drive rails" are welded or bolted into the robot frame. Note that this design accommodated either 775Pros with Cimiles or CIMs. The rear unit shows both in this screen shot. Note that we have also mounted swerve units individually rather than in pairs. This was done using sheet metal with edges braked for stiffness. We like the rails because they keep the units planar, which should reduce the need for posi-traction travel.
- We set our azimuth motor pointing down (the belt is under the C-Channel in the above screen shot) and our drive motor pointing up (belt over the C-Channel above). The components nest within the belt paths to minimize overall footprint. One or the other of these could be rotated and the drive motor brought in towards the Swerve Drive if that form factor is advantageous.
- In addition to the azimuth pulleys discussed above, we 3D print our drive pulleys to save weight and cost. We make our hubs out of ¾" aluminum hex to reduce the stress on the plastic. We turn down the ends of the hex to ½" round, slit them and then clamp onto the shaft through the slit round section using heavy duty aluminum clamping collars. When tightened down, they don't slip.
- Closed loop tuning will likely be necessary to get the whole package working nicely. Without it, larger motors, and/or gear ratios may be required. Tuning is discussed briefly below, but a detailed description is another subject…..Stryke Force teaches a course on tuning in the off season. A lot of information we go over is provided in CTRE's Talon SRX user manual/materials.
    - In 2017, we used a BaneBot RS550 for the azimuth motor since it has plenty of power and is very lightweight. At various times we have geared it from 64:1 to 100:1 using Vex planetary gearboxes with ½" hex output shaft and encoder stage. In the past we also successfully used BaneBots's planetary gearboxes. The azimuth pulleys are 1:1, and we use 2.5" Colson wheels set apart approximately 2-5/8." Under position control, with the Talson SRX PID loop properly tuned, that range of ratios easily turns those wheels on carpet and does so very quickly. The tuning is hot enough that the azimuth control loop is marginally stable with the wheels in the air, but good on carpet.
    - In 2017, we used a Vex 775Pro drive motor with a Cimile and Cimcoder. The drive pulley ratio was adjusted to balance acceleration and top speed based on wheel size,

the game and driver preference. In 2017 the drive pulley ratio was approximately 2.4:1. Since the Cimile has a ratio of 29:12 (~2.42:1) and the AndyMark bevel gear set is 2:1, the total ratio used was ~11.6:1 (2.42x2.4x2). Larger wheels would need more gear ratio for similar performance. In the past we've also used mini-CIMS and CIMs. Note that if you use 775Pros, the motors need to be current limited or you will burn them up. The current limit necessary for robustness will depend on how you gear and drive your robot. We also use several driver techniques to help with this issue.

2018 Stryke Force Third Coast Drive Detailed Description

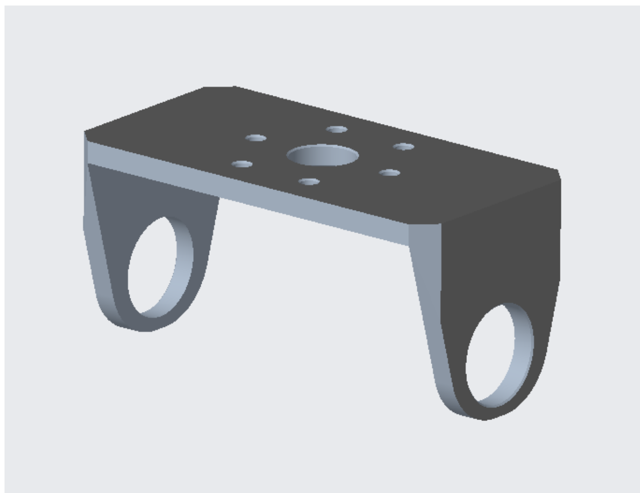
The goals for 2018 were to improve our ablity to manufacture parts using in-house (non-CNC) resources and further reduce weight, if possible.



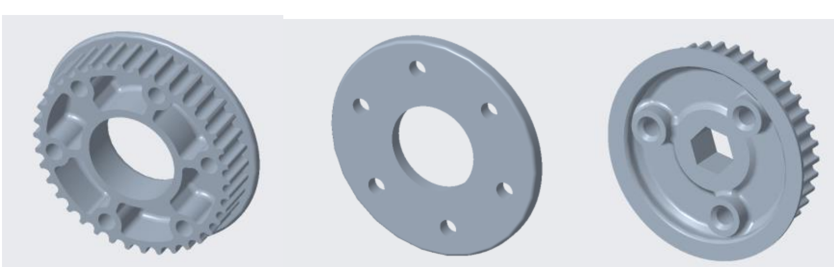
Wheel/Axle Assembly: This was essentially unchanged from 2017 other than a minor chamfer on the ends of the Thunderhex to make putting the axle in the saddles easier. One note: It makes sense to check the straightness of the hex stock before manufacturing the axles. If they are bent, we have seen difficulties in setting the mesh, similar to a non-concentric opening of the bore in the bevel gear.

Vertical Drive Shaft: The 2018 vertical drive shaft was changed from 3/8" to 8mm. The primary reason was to avoid the necessity of re-boring the AndyMark bevel gear. However, once changed, a beneficial cascade resulted. We were able to use smaller bearings which drove smaller housings. These size reductions, along with close attention to detail in all of the other components allowed us to realize a weight savings approximately 20%, or 1 pound per swerve corner—an overall robot weight savings of 4 pounds! We tested key elements of the changes in the offseason and were convinced we didn't loose any significant durability and this was borne out during the season. One other note: We used hollow 8mm shafts in 2018 (SDP/SI "pipe shafts"). This was done not so much for weight savings, but to enable a potential shifting swerve design (ultimately not needed/used). Also new this year, after it was welded to the shaft, we turned down the hub on the bevel gear to save some weight.

Saddle: The incremental design goals for the saddle in 2018 were weight reduction, improved load paths and development of a couple of fixtures to ease manufacturing. The weight reduction was accomplished by reducing width and extending the sidewall tapers. The main fixture developed was a block to ensure the saddle side walls are supported while drilling/reaming the axle bearing openings. This improved our ability to make sure the vertical drive shaft axis and axle axis are perpendicular and in the proper locations. The vertical drive shaft hole was sized to press fit the lower shaft support bearing. This puts shaft thrust and much of the radial load directly into the saddle instead of the Swerve Pivot Hub. We also opened the bolt holes to clearance holes and moved the tapped holes to the Swerve Pivot Hub. This was done primarily to improve the manufacturability of the Swerve Pivot Hub as will be seen below.



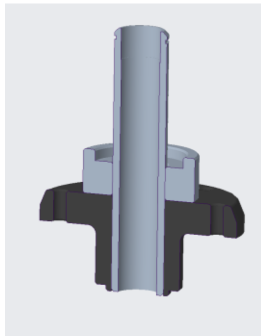
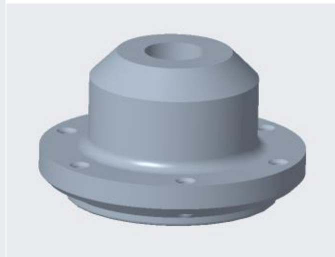
Azimuth Pulleys: The azimuth pulleys were reduced from 44T to 38T to enable the width reduction in the saddles. This potentially could have led to tooth slippage issues, but we upgraded our Azimuth drive mounts so that they are more robust (shorter load path) and convinced ourselves with testing that we were still OK. As in 2017, the pulley was printed without the flange to maximize the tooth profile accuracy. At this point, we believe this is not necessary. The pulley with the hex hole was printed in Nylon with short carbon fiber (Onyx) on a Mark Forged printer with continuous strand carbon fiber around the hex hole to take the hoop stress, avoiding the epoxied SAE washer from last year. The hex interface was a press fit and we thereby eliminated the wear issues we saw in 2017. We printed three ¼-20 holes in this pulley and later tapped them so that we could tie into them if it was every necessary to pull the pulley off the shaft. We printed a “spider” pulley puller to work with them. The puller had a tapped central hole that we could use as a means to jack the pulley up off the shaft by turning a bolt against the ½” hex shaft end. It worked very well, but we never had to use them at a competition.



Spider pulley puller

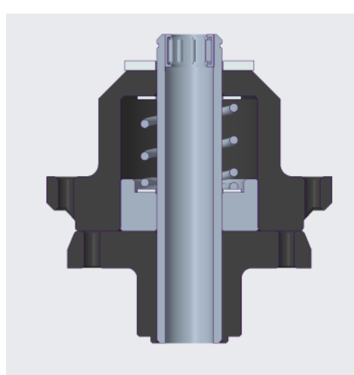
Swerve Pivot Hub and Mounting Hub:

The two “complicated” parts in the system were converted for in-house fabrication.

The Pivot Hub (left) was converted to a three piece hybrid aluminum and printed plastic assembly. The printed plastic was Mark Forged Onyx and had continuous strand Kevlar reinforcement in a few areas. A 5/8” OD 2024 aluminum tube (McMaster-Carr) was pressed into it. This assembly now supports an off the shelf 150mm long Ø8mm case hardened steel vertical drive shaft (SDP/SI). Shaft support is accomplished with a 19mm OD flanged bearing (AndyMark) at the bottom pressed into the saddle, and a 12mmOD needle bearing at the top (McMaster-Carr) which is pressed into the Aluminum tube. One end of the tube was reamed for the 12mm needle bearing and grooved for the snap ring. The Pivot Hub was bolted through the saddle and Azimuth Pulley into tapped holes in the Pivot Hub. This change avoided the conterboring/countersinking operation (and scalloping of the lower bushing) on the 2017 design. We also replaced the lower bushing area with an aluminum tube/sleeve to reduce the likelihood of wear/galling due to plastics of the same type running on each other. This short tube was trepanned at one end to keep the posi-traction spring centered. A thin steel shim washer prevented the spring from digging into the aluminum. All interfacing surfaces were lubricated with Super lube. The step down in diameter at the bottom of the printed part was used to interface with the bearing bore in the Saddle so as to drive concentricity of the assembly. Note that the printed part of this assembly could easily be manually machined from either Aluminum or cast Nylon.

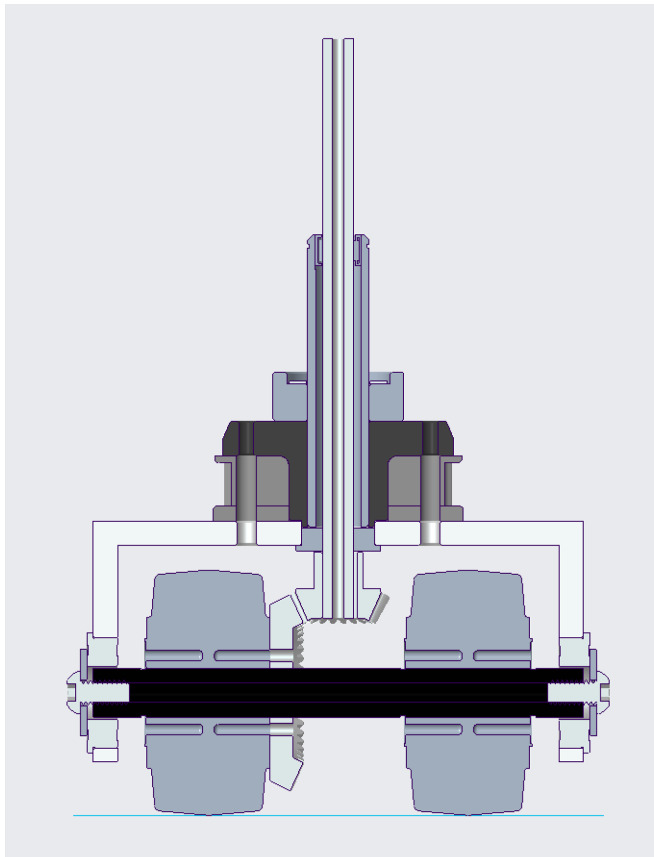
The Mounting Hub (right) was Onyx reinforced with continuous strand Kevlar in select areas. The Mounting hub bushing surfaces (IDs) were printed for slight interference. These surfaces were subsequently cleaned up with a boring bar to ensure a smooth, print artifact free surface finish so as to avoid interference with the positraction axial travel. This part could easily be turned from cast nylon as in 2017.



For 2018 we limited positraction travel to to approximately 1/8”. The printed Nylon was protected from the end of the steel spring by another thin steel shim washer.

Unit Assembly:

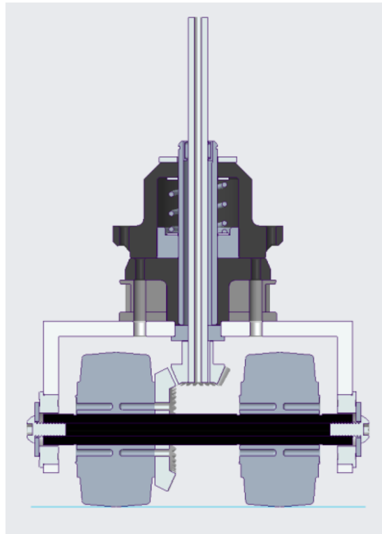
The unit, less the Mounting Hub, Washers, and Spring is assembled (as shown below), off the robot. Socket Head Cap Screws (not shown) come up from the bottom and the heads clear the wheels easily. However, it is easier to do this part of the assembly before the axel and wheels are put in place.



Shimming of the bevel gear set can either be done now or after mounting on the robot, as described for 2017. Mesh is proper when the gears line up as shown (maximizing facewidth engagement), have minimal backlash, and move freely through full rotation.

Final Assembly:

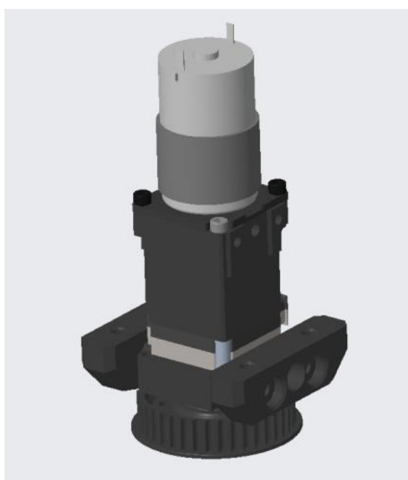
The Mounting Hubs are bolted into the robot frame. Test fit the mating parts, ensuring the bushing surfaces have smooth operation rotationally and axially. Bushing surfaces are then lubed. The posi-traction spring is set on the Pivot Hub with a washer on top and then pushed into the Mounting Hubs from the bottom. The spring is compressed until the snap ring groove at the top of the Pivot Hub comes through the top of the Mounting Hub. A second washer is placed on top of the Mounting Hub and a 5/8” snap ring is put in place to hold the whole thing together. The top washer protects the nylon of the Mounting Hub from the steel snap ring as it rotates. As in 2017, posi-traction motion can be reduced by adding shim washers below the snap ring. Posi-traction force can be adjusted by adding washers inside the Monting Hub and/or grinding down the spring.

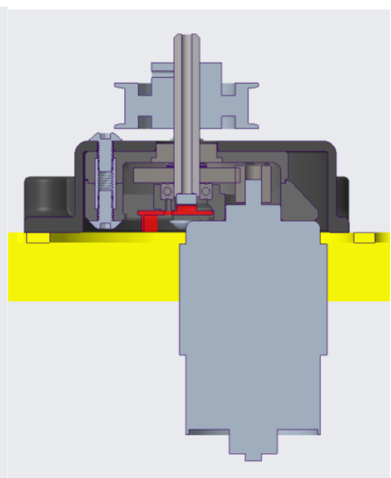


Other Notes:

- Overall weight reduction vs. 2017 was approximately a pound per unit and all manufacturing was done in house, without CNC.
- We improved our azimuth and drive gearbox mounting to add stiffness, reduce weight and ease access for belt tension adjustment.

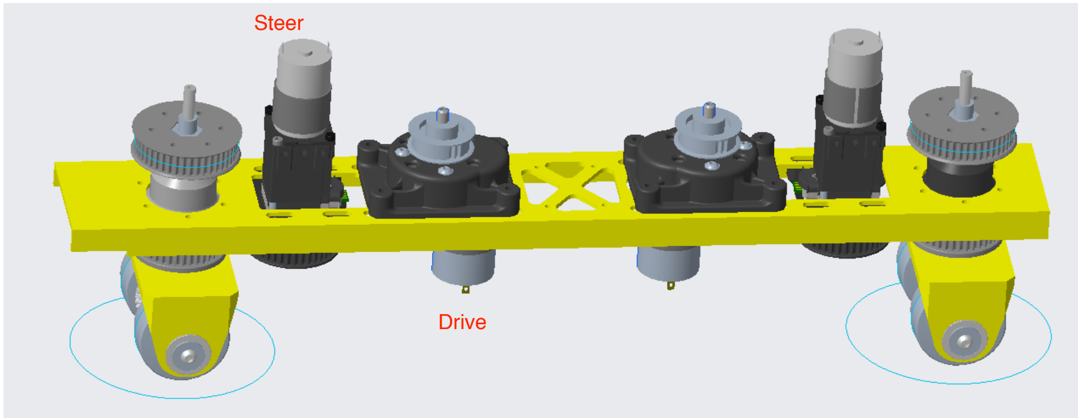
Azimuth Assembly



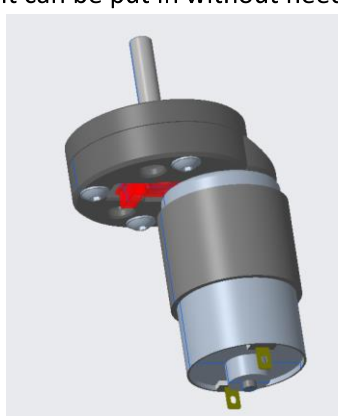


Drive Assembly

- Due to the cascade of size reductions driven by the shift to an 8mm shaft, we were able to use a 3-1/2” channel for mounting instead of the previous 4”, further saving weight and footprint associated with the drive system.



- We used an AndyMark 9015 for the azimuth motor since it has plenty of power and is very lightweight. We geared it 100:1 using Vex planetary gearboxes with ½" hex output shaft and an encoder stage. The pulleys are 1:1, and we use 2.5" Colson wheels set apart approximately 2-5/8." Using CTRE's Motion Magic, with the Talon SRX PID loop properly tuned, that ratio easily turns those wheels on carpet and does so very quickly. The tuning is hot enough that the azimuth control loop is marginally stable with the wheels in the air, but good on carpet.
- This year, we again used a Vex 775Pro drive motor, but with a custom 3D printed (Onyx) gearbox with steel gears and a built in CTRE mag encoder. To save cost, we used stick form gears, cut them to length, bored them, and then case hardened them. The case hardening process was necessary because the stick form gears do not have sufficient carbon for a standard hardening process. The gearbox is shown mounted in the drive assembly picture above and by iteslf below. To change out a motor/gearbox assembly, the belt is rolled off the pulley, the pulley is removed, three screws were removed on the top and the unit drops out from the bottom. In this fashion, a new unit can be put in without need to readjust belt tension.



- This year the drive pulley ratio was approximately 2.29:1. The custom gearbox had a ratio of 40:12 (~3.33:1) and the AndyMark bevel gear set is 2:1, so the total ratio used was ~15.3:1 (2.29x3.33x2). Larger wheels would need more gear ratio for similar performance. Note that <u>if you use 775Pros, the motors need to be current limited or you will burn them up. The current limit necessary for robustness will depend on how you gear and drive your robot. We use 40A</u>. We also use several driver techniques to help manage the issue. We are under closed loop velocity control during Auton and open loop voltage control during Teleop.

- We have helped several teams successfully get started with swerve drives based on the Third Coast design. One of the stumbling blocks is availability of 3D printing for the azimuth pulley. Several teams have done a conversion to (modified?) off the shelf pulleys and that may be worth exploring if robust printing isn't available to you.
- We use the NavX gyro/accellerometer board to provide the field orientation signal.
- We use USB connected flight controllers for the driver. The sticks then function similarly to flying a drone, but without the need to keep track of which way the drone is pointed: The left stick is pushed forward to go down the field, left/right to move cross-wise, and pulled back to come back. The right stick spins the robot clockwise or counter clockwise. This scheme allows drivers to easily drive in a straight line and spin while doing so if they desire. Without field orientation controls, this can be done, but requires difficult mental gymnastics by the driver. Even with this aid, there is no substitute for lots of driving practice on a playing field.
- Chief Delphi has a wealth of information archived on its site. We'd like to thank its site manager and contributors, in particular "Ether" for publicly sharing and clearly communicating the critical analysis and algorythms necessary for Swerve and Field Orientated Controls implementation. An excellent place to start is his paper available on Chief Delphi. Our swerve code is very accuractly described by this document and we would recommend it as a starting point independent of what coding language you are using. We write our code fresh from the CD sources every year—and learn a lot every time. We've now done it sucessfully in Labview, C++ and Java (current). Our current Java implementation can be found at: https://github.com/strykeforce/thirdcoast
- Thank you to everyone who has helped us get where we are. In particular, this swerve drive journey started with inspiration from Wobots which led us to 221's Revolution Swerve Drive. We're grateful that they were there for us.

Final Comments:

Stryke Force didn't arrive at this Third Coast Drive design on its own or overnight. It wasn't dropped out of the sky or bought with bags of money. It was bought by a continuous team effort in a focused evolutionary process combining inspiration, analysis, drive team input/ feedback, and experimentation. We believe it's pretty darn good, but we're not done and probably never will be. One of our chief tenets is "never fall in love with your design"--be open to different ideas and judge them soley on their merits. Not all FRC games have been or will be swerve-appropriate. Further, it's entirely possible that a different and better way of "swerving" will come about and, if so, we'll happily adopt it and work on making it our own. This requirements-driven continuous improvement process is how great things and performances are made possible, and one of the biggest lessons we hope to convey to our students.

Hopefully, this paper and the accompanying links to CAD and code help inspire your own swerve drive development efforts. If they do, it is highly recommended you make it an off-season project which can be wrung out well before kickoff. We believe making the jump to a swerve drive system is worth it (why wouldn't you want to be able to drive sideways while spinning?), but don't forget it comes at a cost and the drive team needs plenty of time to learn how to make the most of it.