SAE Baja

University of Colorado 2020

White Paper

Pictured from left to right:
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Team 15

Contents

Rear isometric view of the 2020 vehicle

Robbie G. TIG welding the chassis

Tristan B. grinding the brake mounts

Nick G. coping the engine mounts

Introduction

SAE Baja is a competition run by the Society of Automotive Engineers (SAE) in which collegiate teams design, build, and race single-seat, off-road vehicles that can withstand the punishment of rough terrain. The CU Baja 2020 team has designed and built fully custom suspension, chassis, drivetrain, and control systems, in addition to implementing its first-ever all-wheel drive system.

The team consists of extremely dedicated engineers who go above and beyond in their passion for automotive engineering. This team is twice the size of a traditional senior design team due to the sheer complexity of the Baja project. In addition to the extent of work required to build a functioning vehicle from scratch, this year's team took on the optional challenge of designing an four-wheel-drive (4WD) system, which has never been done before at CU Boulder.

Chassis

Introduction and Design Process

Figure 1:
Bare Chassis Isometric View

The 2020 chassis was a ground up redesign which facilitated the integration of four wheel drive while focusing on minimizing weight and adhering to all governing rules. A rear braced frame was selected as it gave greater flexibility when designing around the four wheel drive system. The triangulated section behind the main roll hoop houses the critical driveline components. The rigidity gained from this design choice results in less chassis flex, reducing the possibility of rotating components binding under load. Another benefit, though not relating to engineering, is that the rear braced frame is more aesthetically pleasing, with less tubes in the eyesight of the driver.

Figure 2:
Chassis with Raised Seat Structure Highlighted in Blue

The main elements novel to this design all surround the need to run a center driveshaft through the cockpit. The 2020 chassis is larger in both height and length to provide the necessary clearance. The differentials, both front and rear, are mounted in drop cradles to lower the central axis of the driveshaft while still remaining within the confines of the chassis. By routing the driveshaft through the cockpit a smooth skid plate running the length of the chassis is possible.

Manufacturing and Assembly

Figure 3:
Chassis with False Floor and Center Driveshaft

The choice to keep the driveshaft within the confines of the chassis meant that the driver must move vertically in the cockpit to provide clearance for the driveshaft. The advantages gained from this design choice meant that a smooth bottom chassis could be achieved while also maintaining adequate ground clearance. The disadvantages of raising the driver are a higher center of gravity along with a larger frame to accommodate the four wheel drive system. The driver is now placed upon a raised seat structure, allowing the driveshaft to operate safely beneath. There is also a false floor to separate the driver’s compartment from the driveline space below. The raised floor allows for safe operation of the vehicle while strictly adhering to the revised 2020 rules.

Figure 4:
Bare Chassis Top View

The last major improvement to this design was the outsourcing of the bending and notching. By outsourcing, the frame was guaranteed to be within tolerance of the CAD design. This decision saved 40 hours of time spent in the machine shop. It eliminated the time consuming process of perfecting bends on numerous test pieces or the inevitable mistakes that would be made, requiring entire tubes to be remade. By using a professional company full confidence could be taken in the components fitting within the frame, along with expediting the jigging and welding process.

Drivetrain

Introduction and Design Process

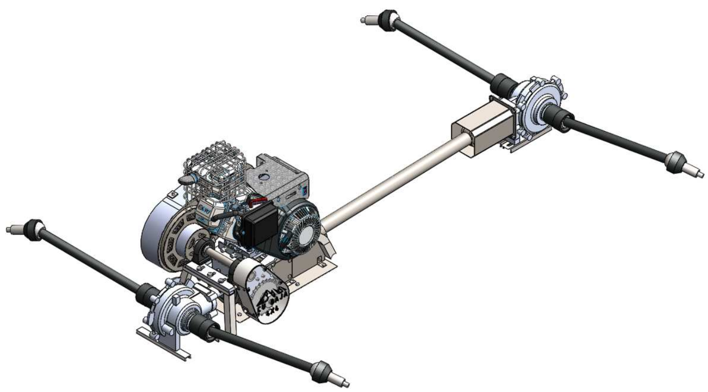


Figure 5:
Drivetrain Assembly Isometric View

With the introduction of 4WD as a design requirement, the drivetrain team has implemented an all-new drivetrain configuration with many elements that have never been seen before in the CU Baja program. The final design is fully configurable and allows the driver to switch between 4WD, rear-wheel-drive (RWD), front-wheel-drive (FWD), and neutral gear by using electronically controlled front and rear differentials. This allows the driver to select the optimal configuration depending on the track. 4WD is used in muddy conditions or areas with many obstacles, where traction is at a premium. RWD may be used when traction conditions are more favorable since it may allow for a higher top speed (due to fewer rotating components and thus fewer efficiency losses).

The big, new challenge of the 4WD design requirement is integrating a driveshaft that runs through the cockpit, while ensuring it is low enough within the cockpit that there is still room for the driver. Additionally, the driveshaft spins along a different axis than the engine's output shaft, and so requires a bevel gearbox or differential to change the orientation of power transmission.

The 4WD design requirement, accompanying differentials, and transfer case significantly increase the overall complexity of the drivetrain design. To keep within the design and manufacturing timelines, the team elected to purchase these complex components and focus on the challenge of integrating them. These parts are intended to fit seamlessly into existing consumer vehicles, so designing custom mounts and couplings to integrate them into the Baja vehicle proved a formidable task.

System Capabilities

Drivetrain Statistics		
Year	**Baja 2020**	**Baja 2019**
Theoretical Max Speed	29 mph	21 mph 36 mph
Overall Reduction	Low Gear: 57:1 High Gear: 8.2:1	Low Gear: 52:1 and 30:1 High Gear: 11.9:1 and 6.8:1

Figure 6:
Key Drivetrain statistics. Note: The 2019 Baja team had an adjustable, dual-speed chain drive, giving the drivetrain two separate overall reductions. This is why each metric for that vehicle has two values. Red denotes the low-speed, high-torque setting, while blue denotes the high-speed, low-torque setting.

The overall reduction is the factor by which the revolutions-per-minute (RPM) is reduced and torque is amplified from the engine to the wheels. A reduction of 57:1 means the engine has to spin 57 times for the wheels to spin once. A higher reduction ratio reduces the top speed but increases the torque and acceleration.

Acceleration statistics are difficult to calculate without testing data, due to the complexities of the transmission. However, the team has reason to expect that the vehicle's acceleration may exceed that of previous years'. 4WD doubles the contact surface with the ground compared to RWD, providing superior grip and allowing the vehicle to be quicker off the line. On the other hand, the additional components necessary for 4WD will drain efficiency and may contribute to slower acceleration. Testing will provide the team with concrete data that can be used to make quantitative comparisons to previous years.

Similarly, different drive modes have different advantages from a maneuverability perspective. 4WD distributes tractive forces to all four wheels for maximum traction, meaning each wheel shares less tractive force, thus allowing the car to turn corners at higher speeds without slipping. Oversteer and its correctability factor (i.e. drifting) make RWD attractive, as the driver can travel tighter corners and regain grip while pulling the car straight again.

Drivetrain

4WD and its Components

The flowchart shown below demonstrates how power is translated through the drivetrain and serves as an introduction to the overall design. The drivetrain has four reductions, one each at the continuously variable transmission (CVT), chain drive, transfer case, and differentials (front and rear).

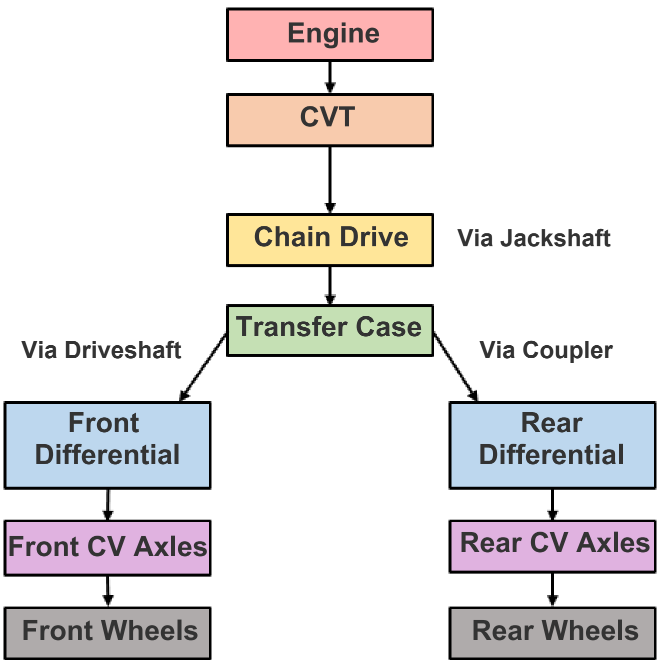


Figure 7:
Power Transmission flowchart

Engine

The engine used is a single-cylinder Briggs and Stratton M19 Vanguard engine, which produces 10 HP and 14 lb-ft of torque. The use of this engine is required by SAE to keep the competition safe and fair. Though the engine is small and limits the top speed of the vehicle, it is the reason why competition is safe enough to have events with dozens of vehicles on the course at once. If the engines were more powerful, those events would likely be too dangerous. (In contrast, Formula SAE competitions are time-trial only because the engines are much more powerful)

Figure 8:
Briggs and Stratton M19 Vanguard Engine

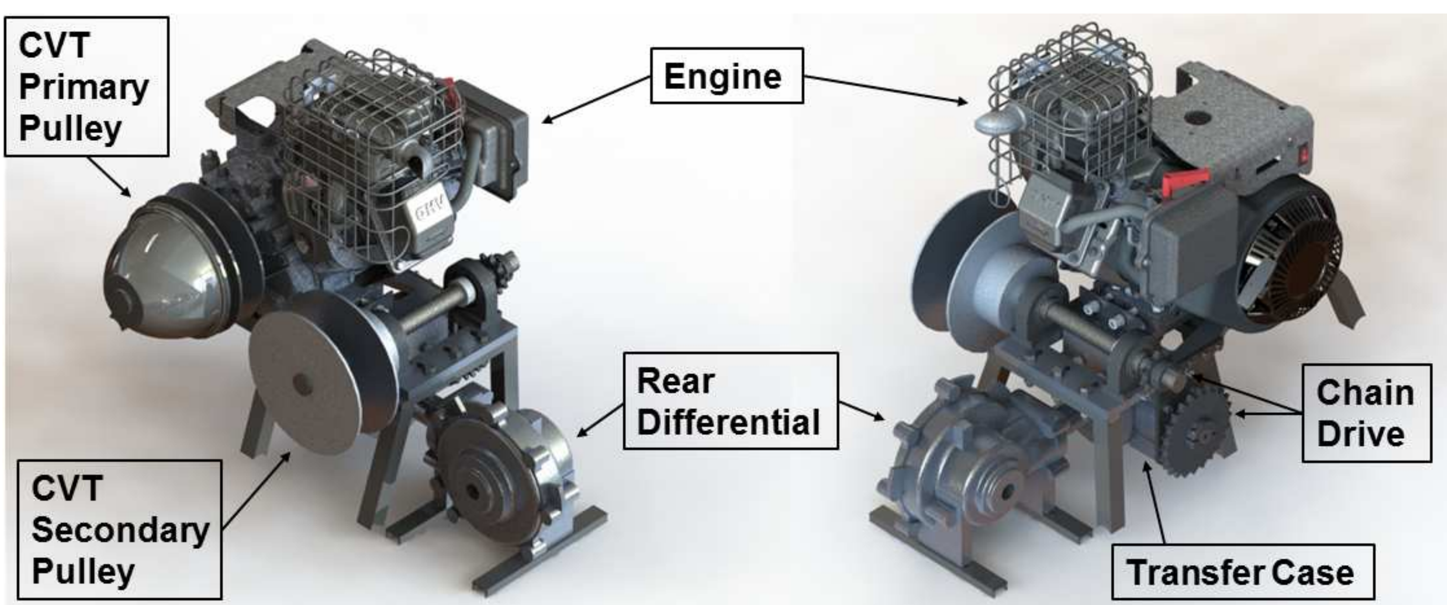


Figure 9:
Major components in the rear section of the drivetrain. Note that the covers and central driveshaft have been hidden, and that the CVT does not have not its belt.

Drivetrain

CVT

A continuously variable transmission is a system of two pulleys connected with a rubber belt. As the engine speed changes, a mechanical system of springs, ramps, and flyweights, engages to change the diameter of the pulleys. This changes the reduction achieved by the CVT, and thus serves to change the overall reduction of the drivetrain during vehicle operation. It serves the same purpose as the gearbox in your car.

Chain Drive

A system of two sprockets connected by a chain couples the CVT to the transfer case. Sprocket sizes can be swapped out during testing to hone in on the optimal overall reduction in the drivetrain.

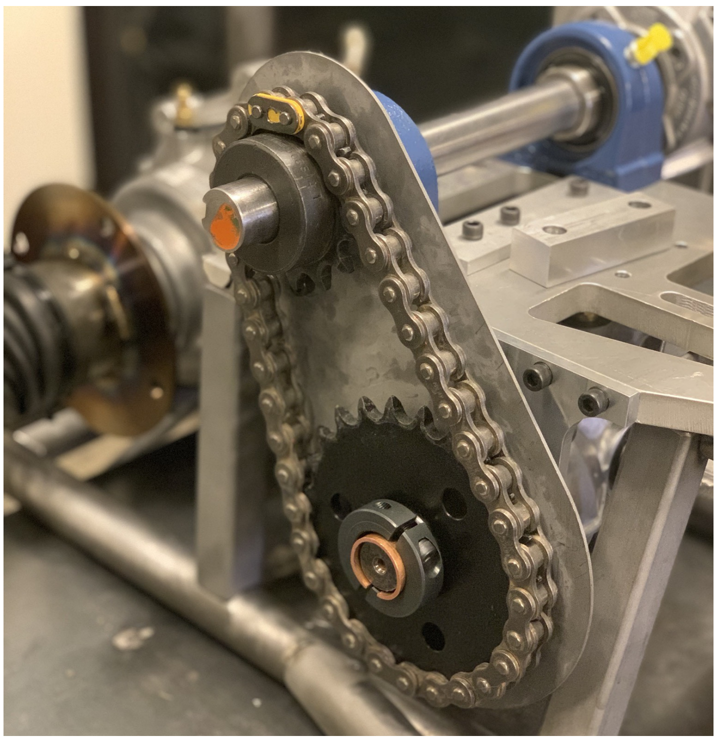


Figure 10:
Chain Drive

Transfer Case

The transfer case is essentially a single-speed bevel gearbox that provides a gear reduction and changes the orientation of power transfer. The transfer case used in our car is a front gearcase from a Polaris Sportsman ATV.

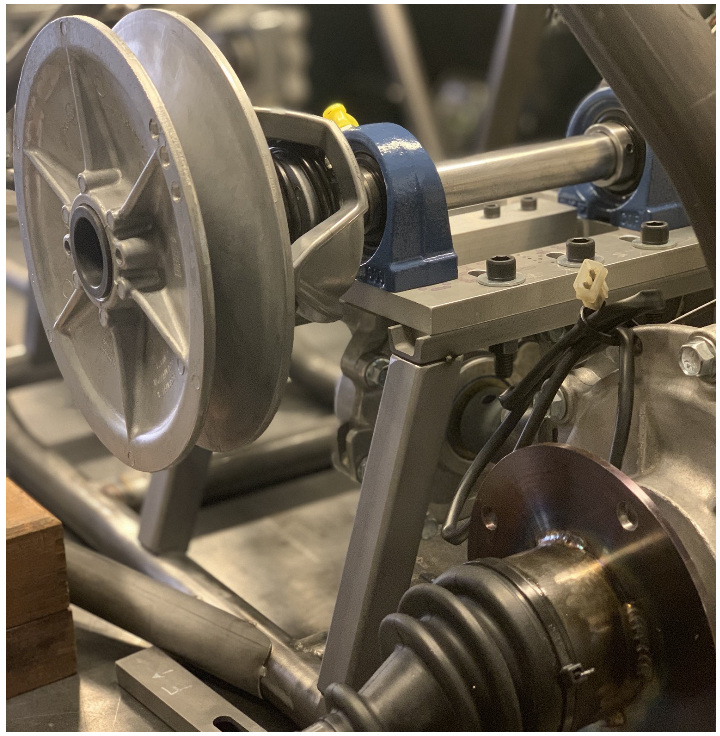


Figure 11:
CVT Secondary Pulley (Shown without belt)

Front and Rear Differentials

The differentials provide the final reduction in the drivetrain as well as another change in power transfer orientation. They transmit power to the constant velocity (CV) axles, which spin the wheels. The differentials used are front gearcases from a Polaris Sportsman. Unlike the transfer case, which is locked at all times, the differentials can lock and unlock by the flick of a switch. When locked, the gears engage and power is transmitted from the input to the outputs. When unlocked, the gears disengage and each gear is free to move on its own. This is valuable because it allows the driver to change the configuration of the drivetrain and thus choose which wheels receive power from the engine.

Rear Suspension

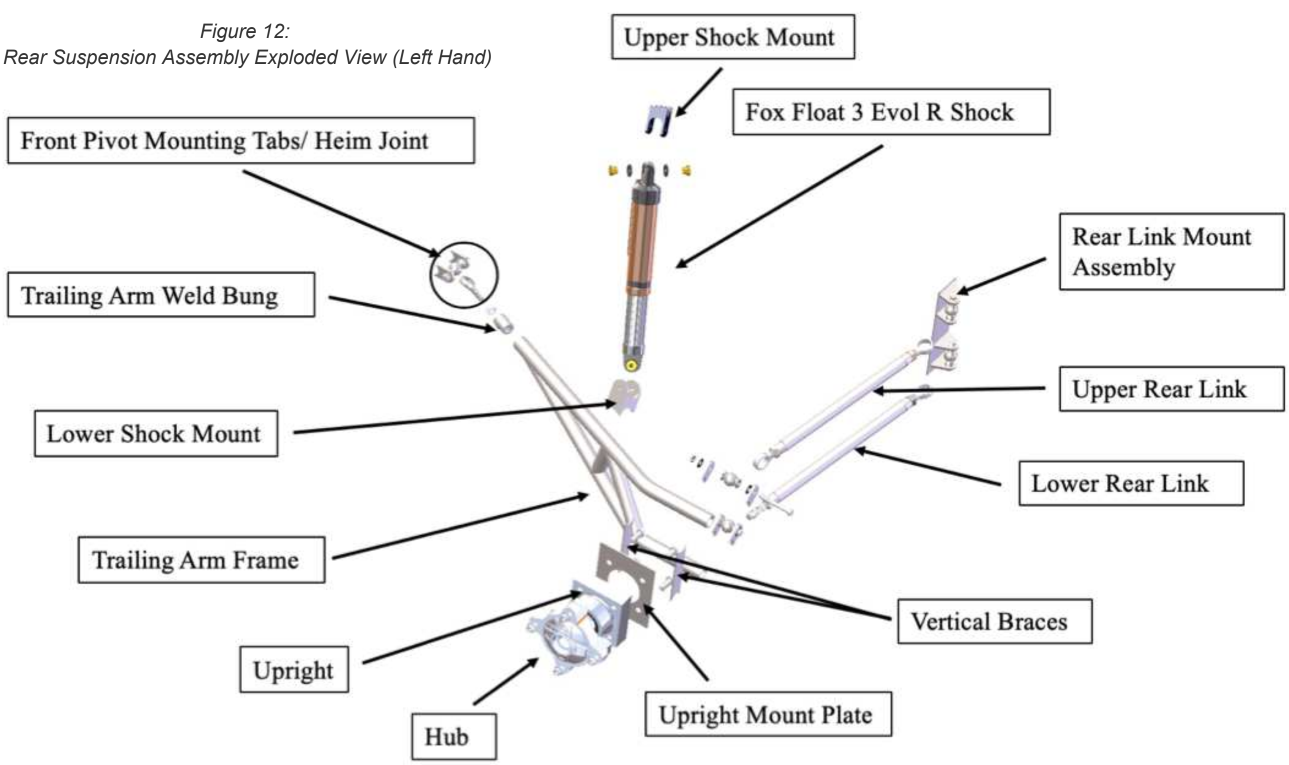
Introduction and Design Process

The rear suspension system on the 2019/2020 vehicle is a linked trailing arm design in which tie rods connecting the trailing arm to the rear of the chassis provide strength under lateral loads and give motion characteristics which are superior to a standard semi-trailing arm. This configuration also provides adjustability to account for manufacturing error and tolerance stack-up as the vehicle is assembled. The system sustains 9.5in of vertical wheel travel, an increase of roughly 2in over the previous year's vehicle, and is more than a pound lighter even though durability was the main focus. We designed for a ground clearance of 4in during full compression. Considering camber change, tire deformation, and potential angle when landing jumps, this decreases the risk of scraping or impact from obstacles. The system uses the same FOX Float 3 Evol R long travel air shocks as the previous year. These shocks are race proven, have a widely tunable progressive spring rate, and simplify the design by serving as the bump and rebound stops in the system.

Suspension Tuning

Dynamic tuning of the suspension was mainly accomplished by manipulating the mounting locations and relative length of the rear links to achieve a desirable balance of motion characteristics. This balance was focused on reducing the amount of plunge in the constant velocity(CV) axles, which is the change in distance between the wheel hub and the differential as the suspension moves. Minimizing plunge allows for increased wheel travel as well as accommodation of manufacturing error. Maintaining usable toe and camber angles throughout the travel was also an emphasis in the design. With the use of the Lotus Shark suspension analysis software, the most practical methods of achieving the desired motion were determined, including adjusting the instant center closer to the inboard CV joints. The final system requires just 0.46in of plunge. Toe angle change was also kept at a minimum for better vehicle stability and decreased rolling resistance. The rear differential was mounted as low as possible to optimize CV axle articulation for wheel travel. The final orientation of the shock mounts was crucial for mitigating out-of-hinge articulation in the shocks. Any amount that could not be eliminated was then spread out between bump and droop scenarios in order to not exceed the limits of the ball joints in the shock ends. Direct angles were prioritized at ride height where much of the higher frequency compression cycles occur during operation.

Figure 12:
Rear Suspension Assembly Exploded View (Left Hand)



Rear Suspension

Trailing Arm and Upright

The trailing arms are made up of a steel tube frame, with the upright mounting plate, support braces, and rear link mount tabs welded to it. The upright mounting plate and braces, which were used to jig the trailing arms as well as increase strength of the hub interface, were cut from 1/8in plate via water jet to reduce manufacturing time. Finite element analysis (FEA) was used to find possible stress concentrations within the trailing arm. Acquiring good FEA results requires a well developed study with constraints that replicate those of real system operation. Results are usually reported as images in which warmer coloration denotes higher internal stresses. The final FEA study employed for the trailing arm accounted for the lateral as well as vertical loads, and informed the decision to add a second internal support tube to distribute the shock force. The 0.095in wall by 1.25in diameter tubing in the trailing arm frame was used in light of the aforementioned focus on durability, giving the trailing arm a factor of safety (FOS) of 2.4 based on 2000lb shock loads. The 6061 Aluminum uprights were designed for simplicity and strength. The square bolt pattern makes manufacturing and installation simpler and reduces the size of the upright allowing the trailing arm frame to be smaller.

Figure 13:
Top: FEA results from preliminary study using an early trailing arm design.
Bottom: FEA results from a study on the final trailing arm design

Manufacturing

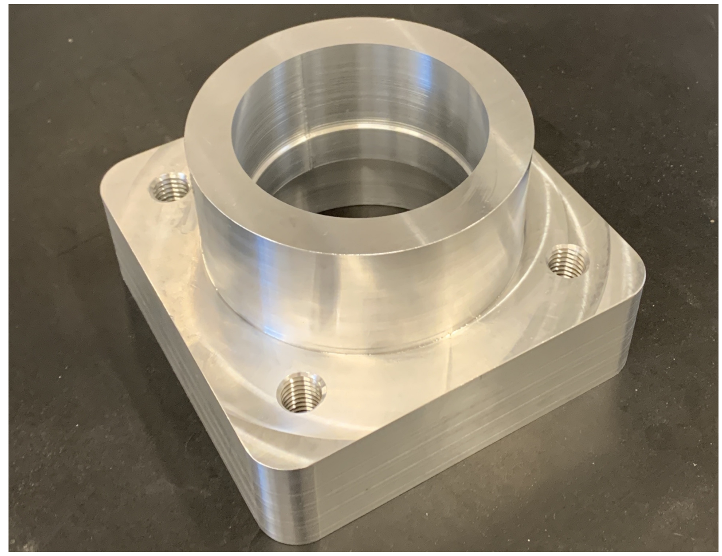


Figure 14:
A fully machined rear upright

The primary challenges in the manufacturing process were in construction of the tubular trailing arm frames. The steep angle notch joining the upper and lower frame tubes required significant by-hand adjustment, since any small error in the bend angle of the frame tubes caused noticeable dimensional deviation at opposite ends of the arm. Additionally, welding along steep notches and around tube joints requires more precision than other welding in the assembly. Each frame tube was therefore bent, cut, and notched in parallel with the opposite hand part, resulting in nearly identical trailing arms despite slight deviation from designed geometry. Any opportunity for parallel manufacturing was taken. The link mounting plates welded to the rear of the chassis were welded prior to installation on the chassis, streamlining fitment of the whole assembly while dynamic tests were being performed. Modularity such as this is nearly always beneficial in the manufacturing stage.

Rear Suspension

Adjustability

Figure 15:
Left hand suspension assembly as manufactured

Every aspect of adjustability in the system was useful in the assembly stage, since the chassis and the placement of the rear differential always exhibit some asymmetry. The minimized plunge allowed both sides to be mounted in a mirrored fashion even though the differential was not perfectly centered. Placement of the shock mounts was done in an iterative fashion, consulting the design drawings for initial placement and performing adjustments until out-of-hinge articulation in the shocks was balanced through travel. The shock mounts were made primarily on a mill, which although extremely labor intensive, made installation easier because of their tight fitment to the chassis tubes. Final motion tests required that the actual shocks be depressurized and installed, whereas laser cut templates representing the compressed and extended shock lengths were used for initial fitment of the shock mounts. Jigs were also designed and laser cut out of plastic to set the angles on the link mount tabs to the trailing arm, with actual fasteners and shims setting the spacing for firm heim joint fitment.

Many aspects of the design represented good design for manufacturability (DFM), but were also contingent on the presence of a skilled welder, given the quantity of welded parts in the design. The uprights were designed to require a minimum of just 3 fixturings, although in practice more were used, with the bearing bores representing the primary difficulty, especially since bore gauges result in tolerances that often exceed those of the bore diameter itself. The use of just four course-thread 0.5in bolts made hole tapping (the process of cutting threads into the bolt holes) less prone to failure from misalignment or thread defects. The deep engagement of the bolts also eliminated the need for steel thread inserts.

Figure 16:
Rear suspension during fitment and welding process

Front Suspension

Introduction and Design Process

With the choice of an 4WD vehicle, the primary design goal for the front suspension sub team was to incorporate driveshafts into the design. In order to accomplish this, the team decided to continue with a double A-arm, double wishbone, design, similar to previous years. This design consists of 5 major components: Upper Control Arm, Shock, Lower Control Arm, Upright, and

Tie-Rod. The system allows for 10 in of overall travel and 3.4 in of ground clearance on the front end in full compression. With the potential of scraping or impacting obstacles, having these travel values minimizes the risk of this. Just like the rear suspension sub team, front suspension is using the same FOX Float 3 Evol R long travel air shocks. The tunable progressive spring rate allows for a large range of adjustability for the front suspension.

Upper Control Arm

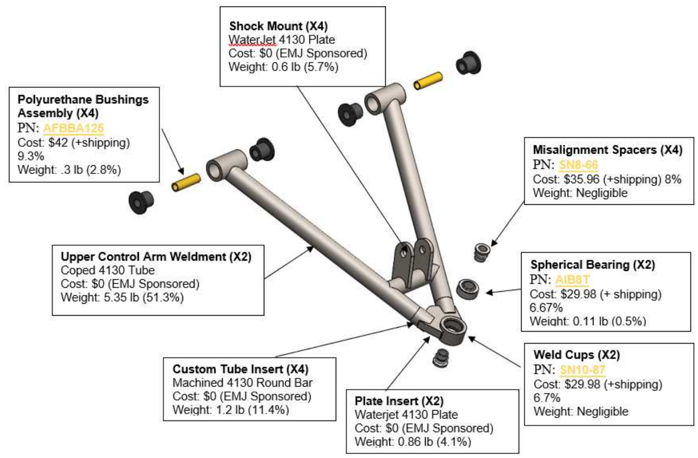


Figure 17:
Exploded view of the upper control arm-assembly

Other design changes to the UCA were made. To avoid using a rod end in a place where bending stress is present, the team incorporated a spherical bearing pressed into a weld cup in place of a heim joint used in previous years. It will be pressed into an off-the-shelf weld cup and retained using a snap ring. The bearing will not need to be staked in place, leading to an easier assembly process. In order to fix the weld cup to the UCA, the design incorporates a coped welded plate and in-house tube inserts. This allowed the team to adapt the weld cup to the tubes without compromising on strength and achieve the desired geometry in the UCA.

Figure 18:
All front suspension components

Front Suspension

Upright Design

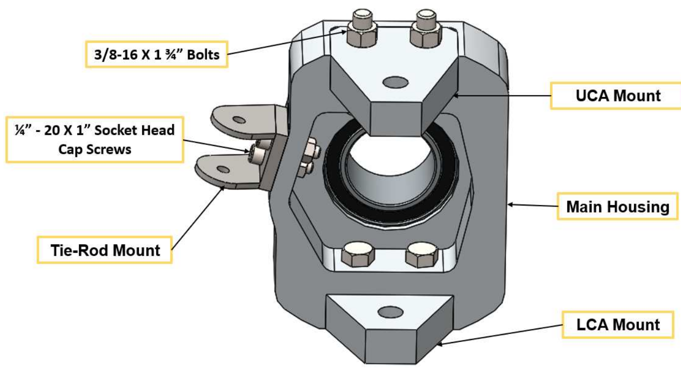


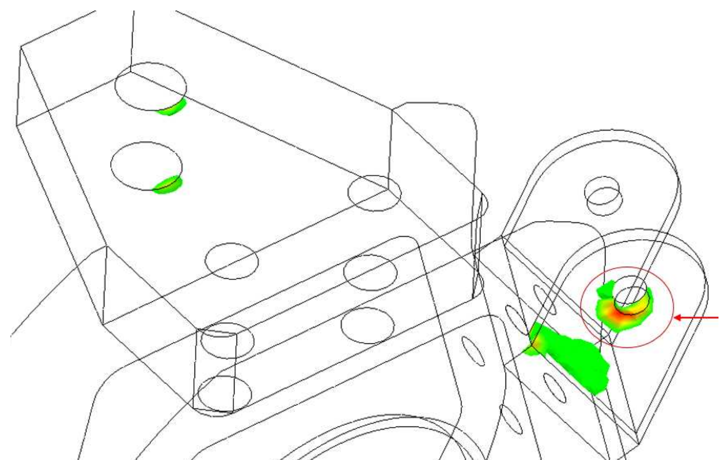
Figure 19:
Upright sub-assembly

Unlike previous years, our upright has to have the capability of integrating a CV axle. The upright main body is made out of 6061 aluminum. For the upright configuration our team focused on simplicity and durability. For example, the UCA and LCA arm mounts are flat pieces. By being flat, they are less complicated to machine. Each mount is bolted into pockets of the main body to help connect each control arms to the upright, which can be seen in the image below. They are designed to be thick pieces with the hope of minimizing the stress seen in the assembly. To keep the bearing press fit in the housing, a snap ring groove was designed inside the main body. The wheel hubs are off of a Polaris RZR 800S EFI. These were specked by the drivetrain sub team to have the correct spline to interface with the CV Axles.

Figure 20:
Upright mount assembly

Upright Analysis

Previous iterations of the upright design had it fabricated from a single block of aluminum. However, due to complexity and predicted problems with machining, the multi-piece design was selected. Multiple loading scenarios were used when performing Finite Element Analysis on the part. This was to make sure the piece would withstand any type of impact scenario. Furthermore, we were able to make design changes from the results. An example of this is the increase of thickness of the control arm mounts. Another thing discovered during the FEA analysis was what piece of the upright assembly will ail first. Our sub-team was able to design the system to fail at the tie-rod mount first. This is ideal because the easiest piece of the assembly to re-fabricate is the tie-rod mount. It was confirmed after seeing the maximum stress concentration at the mount during different loading scenarios. The lowest factor of safety discovered was 1.2 with a very small stress concentration.



Boundary Conditions:	• 1,700 Bearing loads on main upright body • Fixed hinge constraint on UCA and LCA mounting holes • No penetration contact set for the UCA, LCA, tie-rod mount, and upright housing. • Connector sets used from SolidWorks Toolbox with default pre-loading scenarios. • Fixed geometry on Tie-Rod holes

Figure 21:
FEA analysis shown on the tie-rod mount including boundary conditions

Front Suspension

Manufacturing

Figure 22:
Front upright assembly

The manufacturing process for the front suspension components consisted many different processes. The most challenging part was the upright main body. This consisted of the use of a Hurco 3 Axis CNC Mill to remove material for the pockets, clearance holes, and outside features of the piece. Following this a 2-axis CNC Mill was used to bore out the holes for the bearing press fit and the snap ring groove. The UCA and LCA mounts were also fabricated in the 2-axis mill with a custom program. Due to our upright design and wheel clearance, the team plans to face off about a ½" off of the rear face of the hub. After many processes, the upright assembly came together.

Figure 23:
CV axle assembly with the upright

Assembly

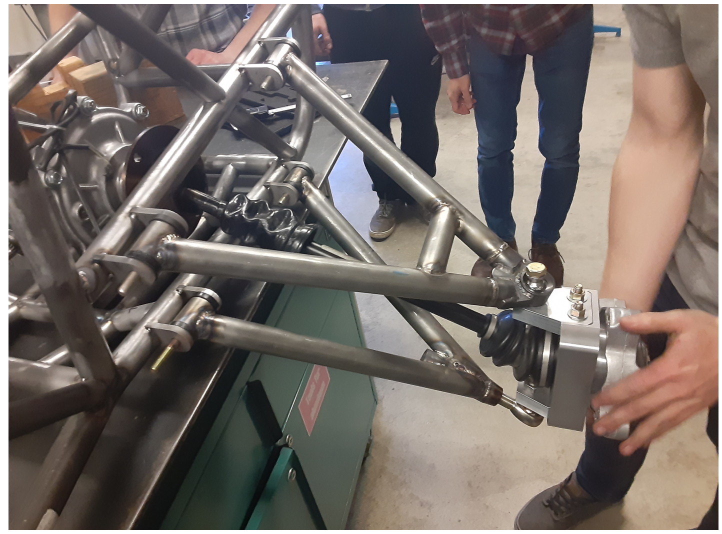


Figure 24:
Full front suspension assembly

In order to fix the control arms in the correct geometric configuration during the welding process all suspension components were located via in house fixtures and jigs. After completion, the entire suspension was able to articulate its full range. Unfortunately, due to the COVID-19 outbreak, the front suspension team has yet to finalize the tie-rod length for the vehicle. A quick redesign and fabrication of the tie-rods will be required before the vehicle is ready to test.

Figure 25:
Front suspension on the rolling chassis

Controls

Introduction and Design Process

The controls system consists of the vehicle's pedals, braking, and steering assemblies, as well as the electrical system. On the 2020 vehicle, these were designed to prioritize reliability and durability over weight and cost in contrast to previous teams.

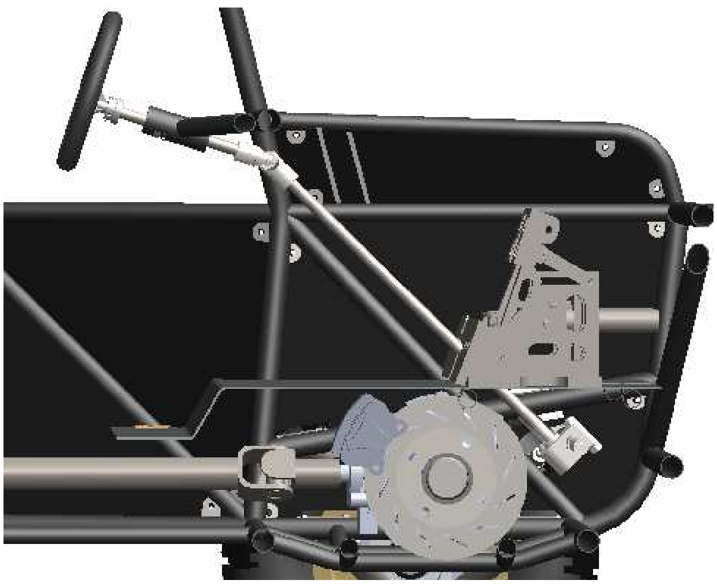


Figure 26: Section view of the vehicle toe-box complete with front brakes, pedal assembly and steering system

Electrical System

With the switch to selectable 4WD, the electrical system in the 2020 vehicle was designed with a battery that could maintain power to two differentials for a minimum of 6 hours, a factor of safety of 1.5 for a 4 hour endurance race. To increase the factor of safety, the system also includes a 1.5A alternator which is capable of sustaining power indefinitely to the vehicle. This heavy redundancy is driven by the fact that the vehicle's differentials will unlock when unpowered, making power to the differentials a system wide failure point. The electrical system allows the driver to independently control the locking and unlocking of the forward and rear differentials, allowing full neutral, front wheel, rear wheel, and four wheel drive options. An OLED high visibility screen, tied into an Arduino with a micro SD storage was included in order to display and record relevant driver information such as speed and remaining battery life. This system is designed to allow for future team development to expand onboard sensor packages, enabling more advanced vehicle testing to inform design decision making.

Pedals

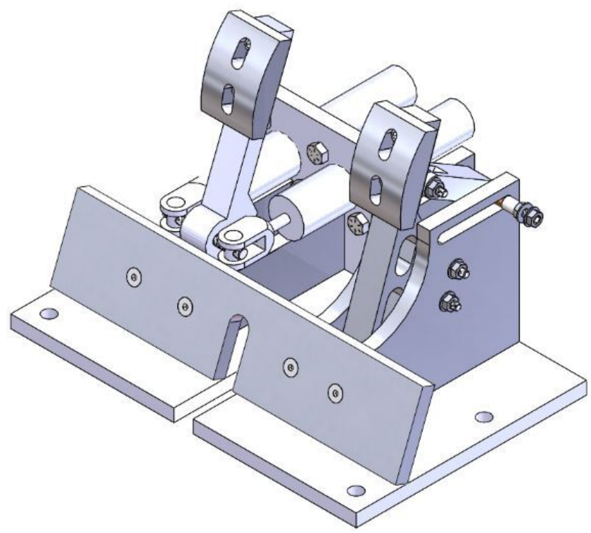


Figure 27:
Isometric view of the pedal assembly

The pedals are designed using a floor up approach as it was prohibitively difficult to gain a sufficient pedal ratio with the traditional hanging pedal design and our toe-box constraints. This choice was selected instead of simply making the chassis bigger, as making the toe box tall enough to achieve similar pedal ratios with a hanging design would have begun to obstruct the drivers view. The pedals were created with a modular design for ease of access to other components in the toe box that would by necessity be underneath the drivers feet. The pedals were designed out of a 0.5" aluminum plate stock to reduce the risk of material yielding while minimizing additional cost. This choice to improve pedal strength came as a result of the buckling of a thin wall tubing at the bearing interface of the brake pedal in the previous year's design. Considering the high possible loads in the system, the master cylinders are mounted to the pedal assembly through a 0.5" thick aluminum bracket behind the brake pedal. This ensures that yielding failure will occur first in the cylinder material itself, making the assembly as robust as possible. While most of the brake system was plumbed with hard line, flexible brake lines were used in the front portion of the brake assembly to interface with the master cylinders and front brake calipers, as well as short segments to both rear brake calipers. This allowed for removal of the pedal assembly for maintenance, while keeping the pedals connected to the plumbing. This also allowed the calipers to be individually raised and bled while remaining attached to the plumbing, greatly reducing the difficulty of bleeding the brake system.

Controls

Brakes

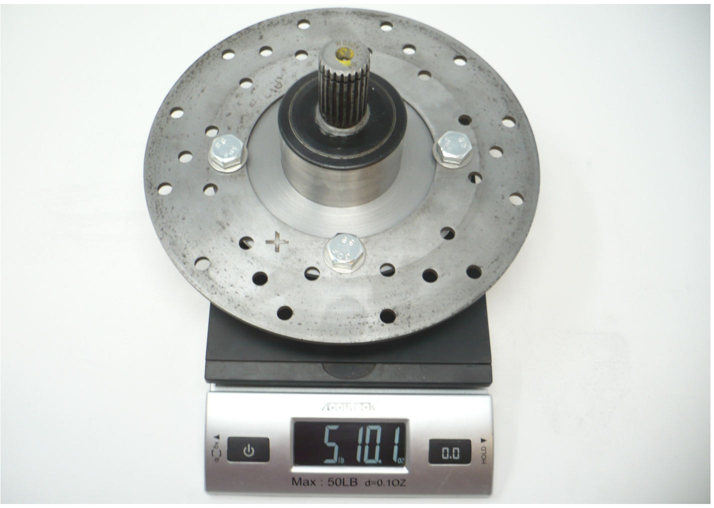


Figure 28:
Full inboard brake assembly with rotor, flange, and CV housing

For the braking system, many off-the-shelf parts were chosen to minimize costs and manufacturing time. Separate circuits for the front and rear braking assemblies are actuated by two Wilwood master cylinders. These circuits are connected to independent proportioning valves, which allow the vehicle to have an adjustable brake bias that conforms to driver specification. A master cylinder bore of 0.75 coupled with 8.625” rotors and a total of 4 calipers enable the driver to lock the wheels with only 49.5lbs of force at the pedal. Each bias valve is capable of reducing the braking force at the caliper to 57% of maximum force. Assuming the driver applies a force of 50lbs at the pedal, with the valves fully closed, the maximum force experienced at the calipers would be 711lbs. This allows for the driver to increase the force needed to lock the wheels in the event that the brakes feel too sensitive. Four Wilwood PS-1 calipers clamp to a pair of inboard 8.6” Polaris rotors in both the front and rear. All four rotors are attached to flanges that have been welded on machined Polaris CV plunge housings. This solution was chosen because outboarding the brakes would require larger wheels and tires and would be significantly more expensive. Inboarding the brakes allowed us to maintain use of our team’s legacy wheel size without exposing the brakes to potential damage, as the traditional outboard brake setup was not compatible with our CV axles without increasing the clearance of the wheel around the upright. Increased wheel size would have raised the ride height of the vehicle, lowering stability. It would also have increased the parasitic rotational mass of the vehicle, decreasing performance.

Steering

The steering system employs a 12:1 steering rack with two external aluminum hard stops to prevent the driver from over-articulating and accidentally damaging the outboard CV joints. Due to the location of the differential, the rack had to be located above and in front of the differential away from existing chassis members. This was accomplished by mounting the steering rack to a thin-walled heavily boxed rack mount to save weight, which was then welded to a front chassis member. By further outboarding the clevis mounts on the rack we were able to reduce bump steer and maintain a slightly pro Ackermann steering system. The steering wheel rotates 120° from top dead center in both directions netting a 40° steering angle at the wheels both left and right. From the steering wheel, the upper and lower steering columns are connected together via a universal joint at an angle of 28°. The columns are D-shafted and secured using set screws in the u-joint. The set screws are secured using nylock nuts as to prevent the column from loosening and disconnecting and eliminate the need for welding so that components may be exchanged easily. By adjusting which detents on the column are held by the set screw, the driver can move the steering wheel +/-2” closer or away to maximize comfort. The steering geometry and CV articulation limits enable the car to have a turning radius of 11.8’ from curb-to-curb and has a maximum of +/- 3° of toe change throughout front suspension travel. This is compared to the previous years’ non 4WD system achieving a turning radius of 7.8’ and +5° of toe in at full bump and -1° at full droop.

Figure 29:
Full steering system assembly with the thin-walled rack mount

Controls

Manufacturing and Assembly

Figure 30:
Before and after comparison of the brake rotor flange.
Left: Waterjet piece of stock
Right: Final finished piece

The braking system required several custom machining operations to mount the brake rotors to the CV axles, as the inboard brake configuration required precise placement of the rotors to avoid interference with other components. The brake calipers were held on with custom machined brackets welded to the frame. The pedal assembly was entirely custom, and was primarily waterjet cut and then post-machined on a 2-axis manual mill. Brake caliper mounts are the only component welded to the chassis directly. The space surrounding the differentials are very densely packed and require a specific order of operations to attach the CV axles, mount the rotors, and align the calipers. All four calipers can be adjusted 1/8" transversely in both directions. All 8 brakes pads were sanded from 0.3" to 0.25" in order to prevent rub on the rotor. The electrical system utilizes a LiFePO battery and arduino control board, with all the wiring being secured within two streamline water-proof harnesses to withstand driving conditions and make it easier to diagnose electrical issues. One circuit and harness contain the essential differential power, alternator, and brake light circuits, while the other contains the accessory circuit.

Figure 31:
Engine kill-switch wiring harness

Figure 32:
Partial pedal assembly with brake pedal shown

Figure 33:
Top: Upper steering column with bearings and retention collars
Bottom: Lower steering column with U-joint

Conclusion

Currently, the 2020 CU Baja vehicle is undergoing the final stages of assembly. With almost all of the manufacturing completed, the next step is to finalize all our documentation for the next team.

The 2020 team took a great risk in pursuing 4WD, but the hard work paid off. We dedicated countless hours machining, balancing a budget, and finding creative ways around obstacles that haven't been faced by previous years' teams. Unfortunately, due to concerns over COVID-19, we had to stop working collaboratively in person, but we continue to work on assembling individual components from home. Our current plans are to resume the final stages of assembly in June 2020 and hopefully have a functioning vehicle in the summer.

The team has learned a great deal about what it means to be an engineer in the real world. Many learned how to operate machinery they've never been exposed to, and others got to refine their skills through a more demanding project. Most importantly, we learned how to work together within a group of 13 people to create something none of us could do alone.

Top Row: Ben H. inside the rolling chassis | Kelton C., Alex T., and Robbie G. holding practice welds | Caio G. turning down the brake rotor flanges

Middle Row: Kelton C. TIG welding the chassis | Kelton C., Tristan B., and Alex S. with the rolling chassis | Kelton C. and Ryan W. checking seat height

Bottom Row: Jacob H. and Ryan W. jigging the upper control arm | Nick G. grinding engine mounts | A rear view of the chassis and rear suspension