The University of Texas at Austin

Comprehensive Design Report

Andrew Frewer, Kenz Love, Aidan Moyers, Austin Vojta, Joseph Voss

Dr. Ben Black

M E 338 - 17915

05 May 2017

Andrew Frewer, Kenz Love, Aidan Moyers, Austin Vojta, Joseph Voss

Dr. Ben Black

M E 338 - 17915

05 May 2017

Comprehensive Design Report

Introduction

Our goal for this project was to design an RC car that would be able to quickly navigate an over race track on a linoleum surface. This paper will go over the design considerations made throughout the process of building our car.

Chassis

For our first pass at designing the chassis, we used a start-simple-and-build-up strategy in order to get an idea out quickly and thus maximize our time for refinement. However, we are aware that a design can be simple to the point of prohibiting the inclusion of more complicated mechanisms, forcing us to consider what major components we would include and their general arrangement. While some components, such as the drivetrain and steering assembly, are clearly required to complete the challenge, some elements are more of a luxury. We decided that it is important to include a differential on the rear wheels because almost half the track consists of a low-radius 180 degree turn. We plan to include a bumper to protect our car both during development and on the track. However, in our first pass we do not believe that a suspension would significantly improve our handling or performance on the flat track.

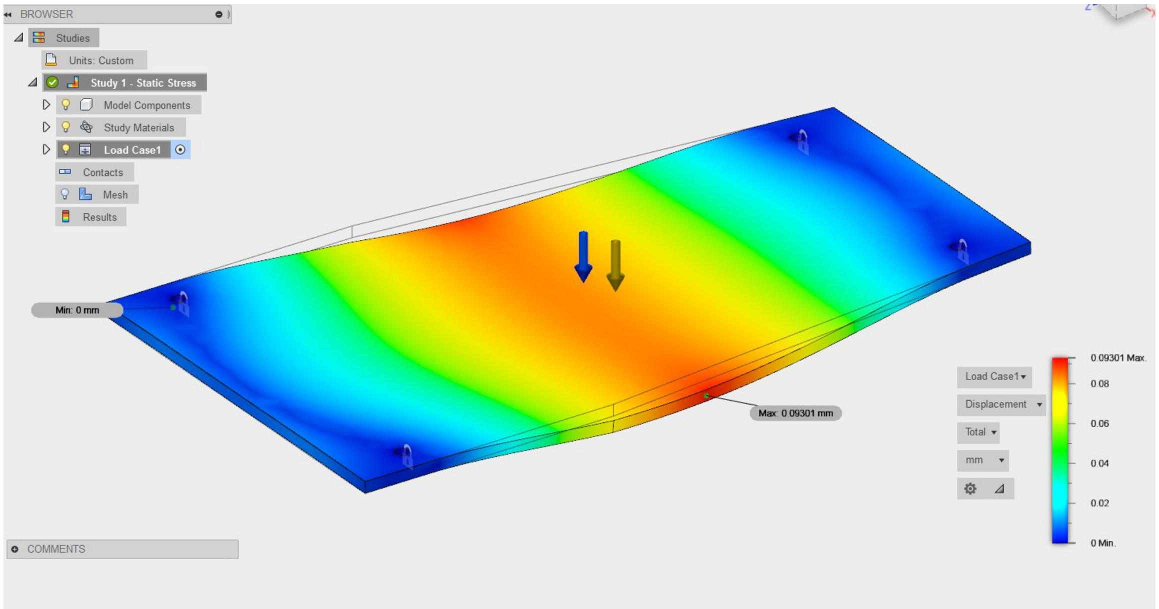
Based on the size and approximate weight of the electrical components, we sketched out a basic design consisting of a single acrylic sheet. To this we would attach the drive, steering, and electrical components via several mounts drilled directly into the base-plate. This design excels in terms of simplicity, modularity, ease of manufacture, and ruggedness. In our opinion a large 3D printed base would be hard to make in a single print, without regard to complexity of supports and the structural support of the material. Additionally, a 3D printed base is much more subject to fracture when the mountings are attached. We are planning on designing custom mounts and 3D printing them to be screwed directly into the chassis, which would not be possible with an extruded base because the screws are likely to split the individual fibers leading to a system-wide failure. Our FEA analysis, outlined below, indicates that an ⅛" sheet of acrylic is more than sturdy enough to act as a chassis, and if the holes we drill in the plate for mounting points we have not yet defined weaken the structure to the point of failure we could easily move to a ¼" plate or include and an additional ⅛" sheet as reinforcement. Furthermore, using a laser cut acrylic for the chassis minimizes manufacturing time and affords us a very fast design cycle, so we will be quick and flexible in our response to issues with our existing design.

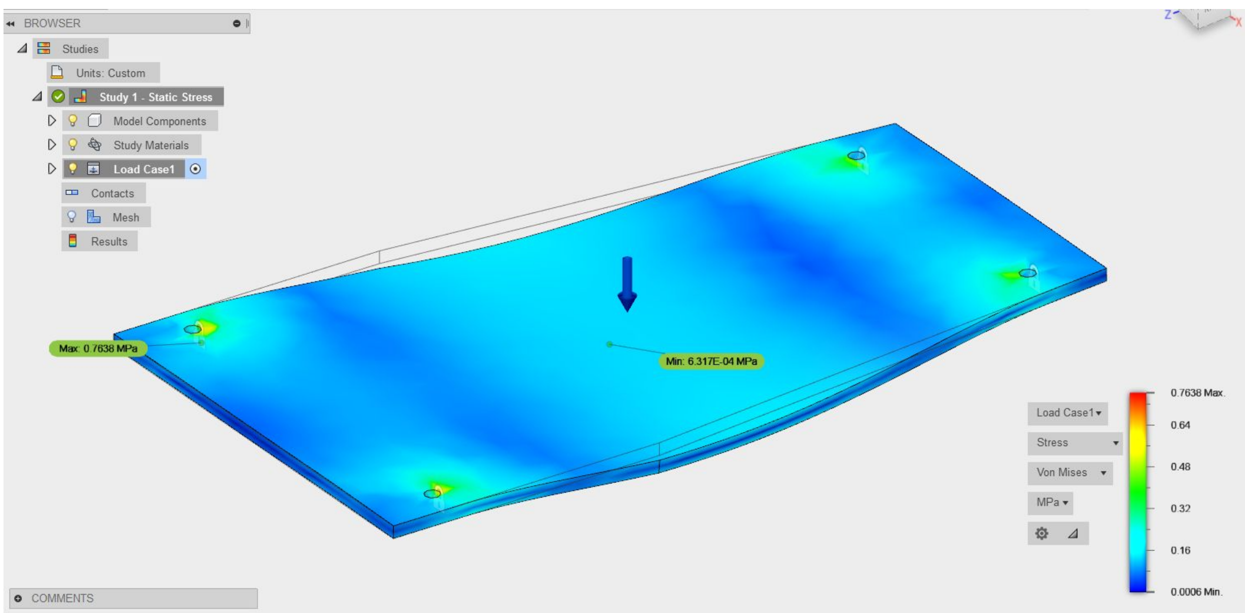
While the full design of the steering mechanism is not a concern in its own right at this point in the project, it is important to ensure that the structure will be able to successfully accommodate a mount and linkage to the wheels. Our preliminary research into the steering mechanisms of RC cars available on the market essentially informed us that any orientation of servo can effectively transmit motion to the wheels with a few creative ball-and-socket joints. This allows us to safely set aside a few inches on the front of the chassis for steering and promise to resolve the issue at a later date.

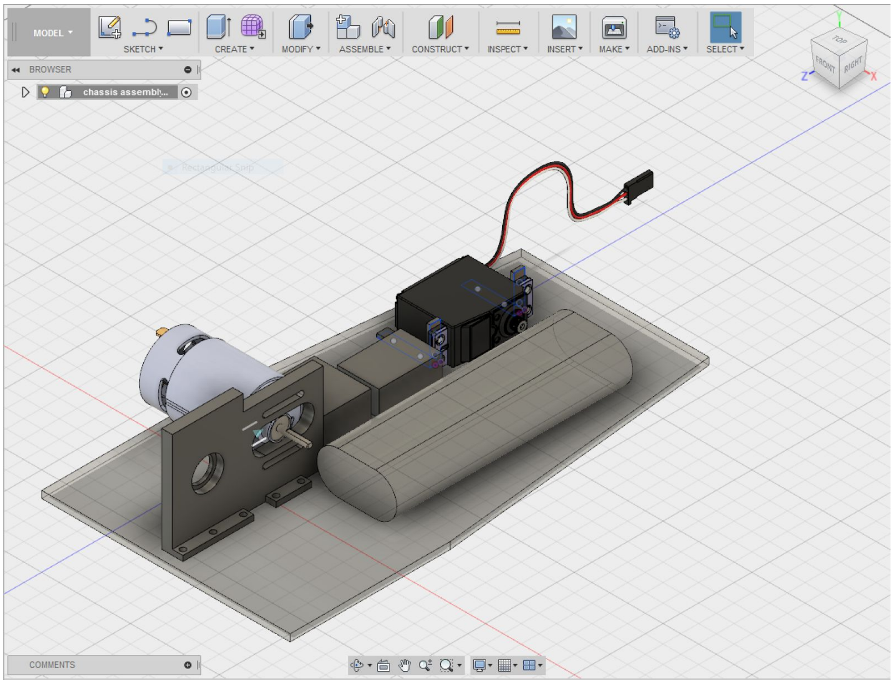
We solved the static free body analysis for the chassis. At first we wanted to lay out the chassis with the essential elements (battery, motor, etc) and wanted to solve for the normal forces on the wheels, but this is statically indeterminate. From there we wanted to state some general assumptions to give a starting point for the analysis. We assumed that the forces on the wheels are symmetric on the left and right, but not between the front and back. This produced values of back wheel normal forces= 1.95N and front wheel normal forces= 1.67N. This rear wheel weight bias is beneficial because it improves the traction on our drive wheels, in turn improving our ideal acceleration value. These results are because we placed the battery and motor (the heaviest elements) closer to the back axle than the front. The elements are in a fixed position on the y axis (front to back). Their position on the x axis (left to right) is being solved for. From here we did forces in the z direction, moment around the x axis, and moments around the y axis. This produced results that let us determine the location of the elements. Because there were not enough equations for how many variable elements we have, the location of most of the elements is variable (element positions for ‘d’ and ‘e’ are based on the location of ‘c’) while some of the elements are fixed (‘a’: battery and ‘b’: servo position were fixed). This is the static analysis and incorporating the thrust based on the motor will change the numbers for the normal forces on the wheels and the distribution of the parts on the car. From here we will need to determine how to calculate the thrust value from the motor, the coefficient of friction between the wheels and the floor, and build a dynamic analysis to account for the accelerating car.

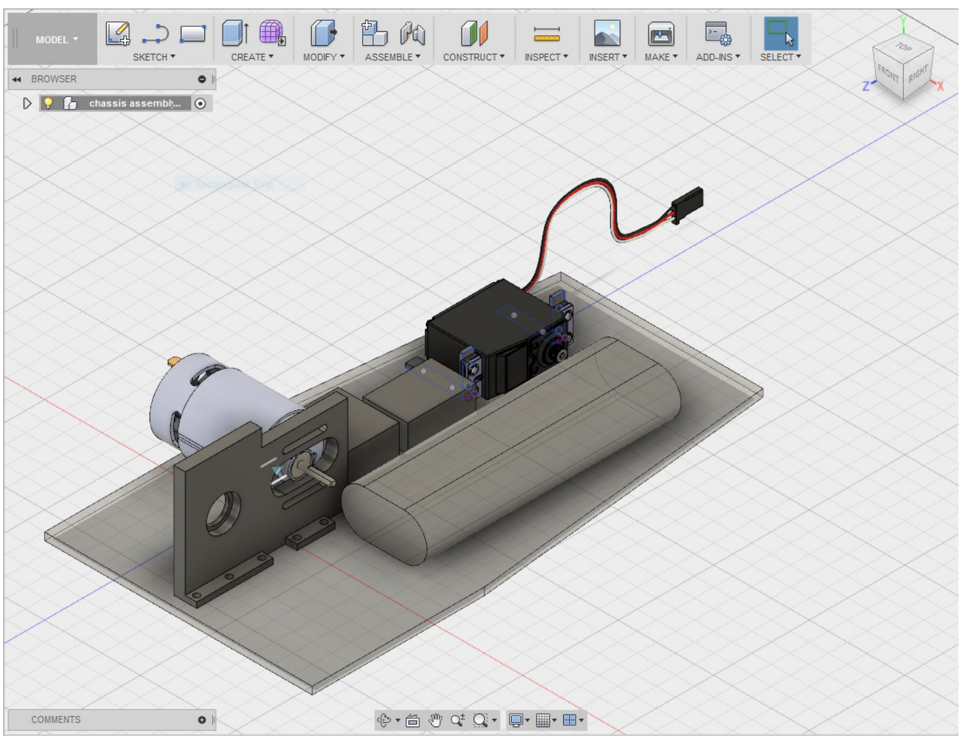
To analyze the stresses, we used a 3D model of the chassis in Fusion 360. We used a scale to measure the mass of each component, then applied a distributed load consisting of the weight of the acrylic plate and each part. This assumes a nearly ideal center of gravity and good load distribution, but seeing as these are both design objectives it should not prove unduly inaccurate. The chassis' mass was calculated using our preliminary dimensions and the density of acrylic, from which we plan to laser cut the chassis.

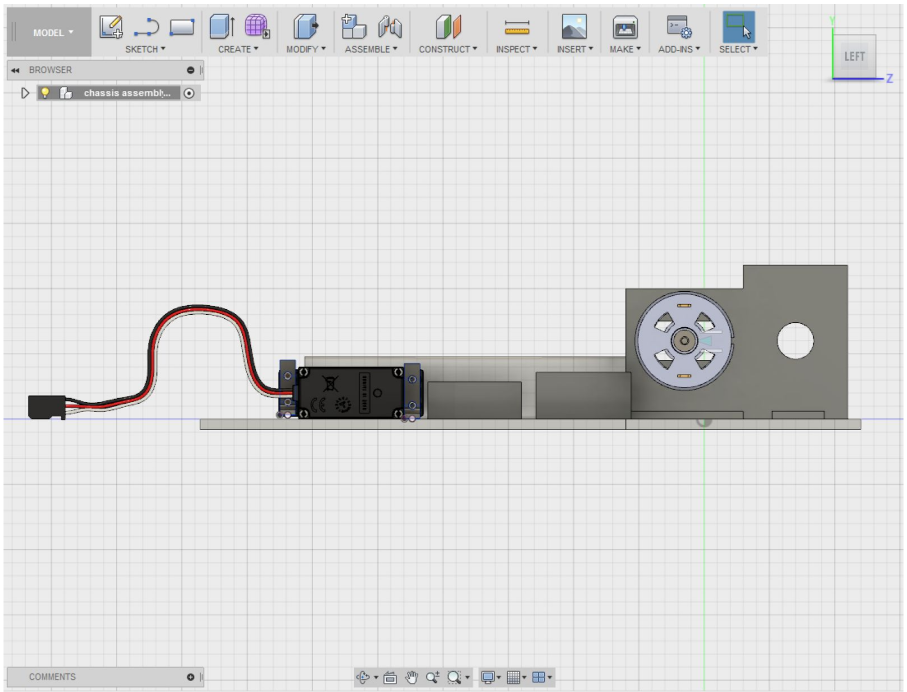
From our preliminary results, we are hopeful that a simple baseplate of laser cut acrylic will prove to be a robust and highly modular platform to serve us through the rest of the project. The simplicity of the base pushes the majority of our design work to creating the mounting structures that join our components and mechanisms to the chassis. These parts will be highly specialized in order to securely mount each component, so while they are an integral portion of our design strategy they will not be readily deliverable until after a prototype has been completed.

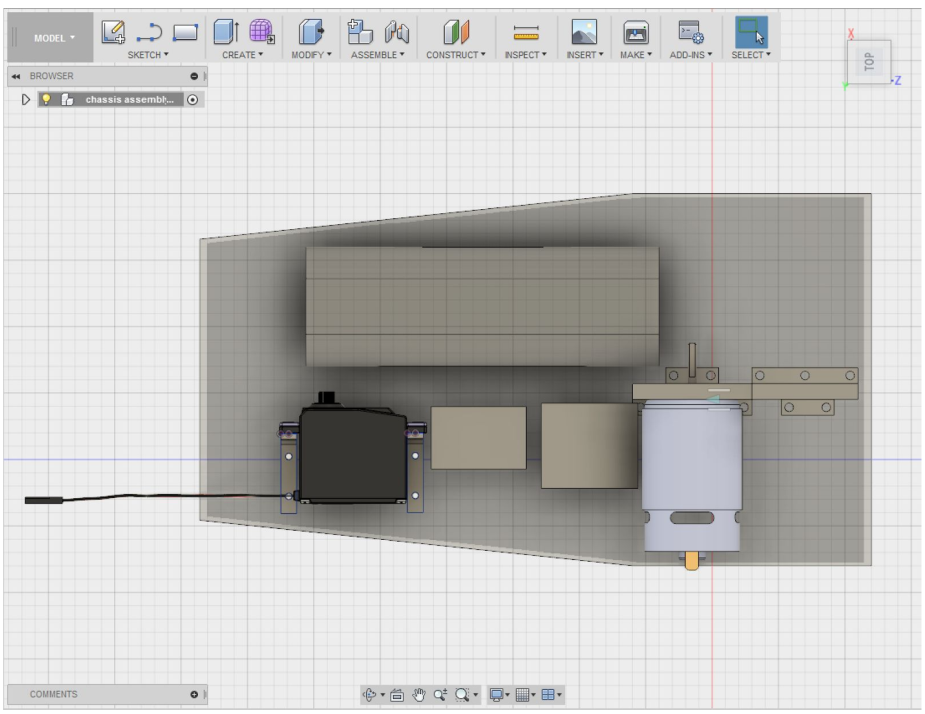

BROWSER
Studies
Units: Custom
Study 1 - Static Stress
Model Components
Study Materials
Load Case1
Contacts
Mesh
Results
Min: 0 mm
Max: 0.09301 mm
Load Case1
Displacement
Total
mm
0.09301 Max.
0.08
0.06
0.04
0.02
0 Min.
COMMENTS


BROWSER
Studies
Units: Custom
Study 1 - Static Stress
Model Components
Study Materials
Load Case1
Contacts
Mesh
Results
Max: 0.7638 MPa
Min: 6.317E-04 MPa
Load Case1
Stress
Von Mises
MPa
0.7638 Max.
0.64
0.48
0.32
0.16
0.0006 Min.
COMMENTS


MODEL
SKETCH
CREATE
MODIFY
ASSEMBLE
CONSTRUCT
INSPECT
INSERT
MAKE
ADD-INS
SELECT
BROWSER
chassis assembl...
COMMENTS


MODEL
SKETCH
CREATE
MODIFY
ASSEMBLE
CONSTRUCT
INSPECT
INSERT
MAKE
ADD-INS
SELECT
BROWSER
chassis assembl...
COMMENTS


MODEL
SKETCH
CREATE
MODIFY
ASSEMBLE
CONSTRUCT
INSPECT
INSERT
MAKE
ADD-INS
SELECT
BROWSER
chassis assembl...
LEFT
COMMENTS


MODEL
SKETCH
CREATE
MODIFY
ASSEMBLE
CONSTRUCT
INSPECT
INSERT
MAKE
ADD-INS
SELECT
BROWSER
chassis assembl...
TOP
COMMENTS

Drivetrain

For our first run at the drive train design, we started by trying to settle upon what gear ratio we wanted to use. We looked at the stall torque and max torque, found where the max efficiency would be, and chose a value that would give us results near it. The rated maximum efficiency from the motor spec sheet was 16130 rpm, producing 47.8 mN m of torque. The estimated operating range was from a motor efficiency of 70% to 20%, producing a torque range of 47.8 to 150 mN m. By setting the thrust force equal to the friction force, we can find the find the desired operating speed without slippage. Assuming a frictional coefficient of 0.9 and using a factor of safety of 2, and dividing the thrust force across two wheels, we can solve for the wheel torque. Additionally, we know the torque at the wheel is equal to the gear ratio times the motor torque. Therefore, the gear ratio can be solved through the following equation:

$$F_{normal} * \mu = \frac{1}{2} * \frac{1}{2} * F_{thrust} = \frac{1}{4} \frac{T_{wheel}}{r_{wheel}} = \frac{1}{4 * r_{wheel}} * x * T_{motor}$$

Using the torque operating range specified above, the gear ratio needs to be in the range 3-7. Because we ideally want the motor to be working at maximum efficiency, we chose a gear ratio of 4.18, achieved through an 11 tooth pinion mating with a 46 tooth differential gear.

Another large component of our work over the past week has been getting mounts made for the chassis so that we could meet the requirement of having “something that rolls” to present and build off of going forward. Being as our chassis design was 2D, we needed to design mounts both for the axes and for each component that will be situated on or under the chassis, including the motor, servo motor, speed controller, and receiver.

For the front axle mounts, we needed to design pieces that allowed clearance when the wheel turns, and could hold either side of the steering knuckle, allowing it to pivot. We chose to make a two-piece mount, using two bolts to connect the top and bottom sections, then 4 bolts to situate it on the chassis. It took a few iterations to get correct tolerances but we eventually settled on a good design that we were comfortable moving forward with. That said, since we designed it to be completely detachable from the chassis, we are always free to tweak and redesign with the same bolt hole constraints if we need to. The rear axle mounts were a similar process. For these, we needed to fit the bearings snugly on either side of the mount piece, in addition to fixing the axle shaft to the wheel and providing adequate spacing between the wheel and the chassis.

Another piece we needed to figure out for the drivetrain was an adaptor to connect our differential to either rear axle. The issue we ran into was different standards used for the female dogbone adapter hole on the two components. To compensate, we had to design an adapter. It took three iterations of messing around with tolerances to get something that fit snugly on to the differential yet gave the dogbone knob enough clearance to rotate and turn freely. The resulting part is bulky, but was designed to have a more-than-safe factor of safety, since it will be handling a lot of torque.

For the failure analysis we decided to analyze the dogbone shaft. We figured that of all of the parts in the drivetrain this plastic shaft would fail before the metal gears on the pinion and diff (This analysis was made before the idler gear discussion was started). To do the simulation we used a torque based on the max efficiency of the motor and the gear ratio. One end of the dogbone was held fixed and the torque was applied around the central shaft. Because the material is ABS, if one side of the dogbone is held static the torque applied bent the shaft more than we would like. However this situation should not occur because the wheels should not lock under any normal circumstances. For the Von Mises stresses the majority of the stress will occur at the base of the sphere/shaft joint. Overall the dogbone should hold up to the stresses because the wheels shouldn't lock during a normal race.

Steering

After testing the initial design of our motor mount, it was determined that our drive gear was not big enough in diameter to mesh properly with the differential gear. To solve this issue, we decided to include an idler gear in between the two. Though it extends the length of our chassis, it ensures good power conversion between the motor and differential, and does not affect our gear ratio. We redesigned the motor mount to include a spot for the idler gear axle, and then used slots through our chassis to align the mount properly and fit all the gears into place with good mesh.

With the new chassis laser cut to include proper mounting holes, the back axle holders were good to be put on firmly in place. We had tested these on the previous chassis by just marking and drilling holes. Because it was just a test we were not very accurate but it did tell us that the general idea was good to go. We discovered that the chassis was 1-2mm too wide and that if we shortened it just a bit the dogbones would have no problems reaching the wheels and the diff. We had considered lengthening the dogbone/diff adapters but consider making the car as small as possible a priority. The downward angle the dogbones make from the diff was concerning to me but after testing them through rotating them a decent amount we feel comfortable with them. It was also pointed out that this is the point of the design of the dogbones; to be able to rotate at an angle.

When designing our steering system, we used a rough simplification of the Ackermann steering formula, which dictated the angle at which the knuckles needed to be mounted. The basic idea is that the knuckles both point in a direction such that if extended, they would meet at the center of the rear axle.

For the design of our steering bars, we needed to choose between a 1-bar and 2-bar design. The bars connect the servo motor and steering knuckles to translate the motor's rotation into lateral movement, which pushes or pulls the bottom side of the wheels and changes their direction. Using just one bar is simpler, but would not work as well in our case considering the movement of the servo motor. Not only will the point of attachment be moving left and right, but it will also move medially forward and backward a bit along the length of the car. Having two bars means that, as long as they are pinned at both ends, their angle with respect to the rear axle is free to change. We 3D printed the bars and found the overall steering concept appeared to work very well after just our first go at it.

The front wheel mounts have been discussed previously in this report, but they required some modification fueled by our steering design. The problem was minimal clearance for the front end of the car, which definitely could have given us issues. We redesigned them slightly to lower the height of the wheel axle, and now have sufficient clearance along the car's entire body.

The steering knuckle adaptors were made to change the height of the steering knuckle up to that of the servo arm so they could be rotated. We considered adding them to the steering bars but had decided on laser cutting the bars, preventing us from adding a more non-uniform 3D element to them. Eventually we 3D printed the arms out of convenience, but it all worked out. These steering knuckles took three iterations to come to the point at which they are now. The first iteration saw the screw holes not lined up with the knuckle screw holes. The second iteration was too wide; the walls were thick for support but interfered with the wheels as we rolled/steered. We have had no issues with the third iteration thus far.

Initially we planned to mount the servo motor behind the front wheels, but after playing with space on the chassis, found it fit better if we flipped it 180 degrees and placed it directly underneath our steering bars. This gave us a lot extra space to work with on the rest of the car. Currently, the servo is not mounted with anything special. We used the holes in its flanges and holes that we cut into the chassis with long bolts. This seems to work ok, but we were worried about longevity of the servo’s flanges until we added nuts on either side of them. If we were to do another iteration of our car the chassis should feature a specialized mount to situate the servo upon.

With the servo oriented to the top of the car, and after modifying initial plans for battery orientation and component mount spots, we are left with a large gap between the battery and the steering linkage. This space was also achieved by mounting the rc receiver and motor controller on top of the battery. This raised concerns with temperature but we figure we will be okay for the short drives that we are going to be doing. We are planning to make a new chassis that cuts this area out to make the car shorter in general. This provides several advantages: a shorter chassis will lead to a smaller turning radius and a stronger chassis; less susceptible to bending and flexing.

Final Revisions

Our last steps included finalizing the size of the chassis and settling on a final iteration. We discussed some under-chassis or over-chassis supports to make it stronger. We also considered designing a servo mount in order to more securely attach it to our final chassis. We found a stronger Gorilla tape to firmly attach the components to the vehicle so that they do not come loose upon collision. Wiring management was handled through the use of zip ties to prevent wires from slipping into the open drive gears. We practiced driving, tuned our controls and wheel alignment, and made sure the car is durable enough to last in the races.

Conclusions

In all, we were very satisfied with how our RC car's build process went. We did not hit any significant hangups, and were able to work through every one of the smaller issues that came our way. Our group worked together well and met often to make sure we were prepared for each of the project's deadlines and checkpoints along the way.

If we were to do this project over again, some things we would consider changing would include using a metal chassis, designing a servo mount, further shortening the chassis length to improve turn radius, adding a bumper, and more eloquently managing the wires. However, we do not anticipate any of these considerations to manifest themselves as shortcomings on race day.