MECH ENG 2C04

Final Report

Group 20

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Problem Framing

We were given the challenge of designing an autonomous vehicle that could tow a load over a given distance, and fit within a $30 \times 30 \times 30\,\mathrm{cm}$ box. The device had to be fast and light, and couldn't be propelled by powered wheels. We were given two arduino motors, a microcontroller, and sensors. In addition, we were given a budget of laser cut and 3D printed material to construct our vehicle.

Strategy

Although the challenge did not imply a specific way of accomplishing the task, we believed our final design should resemble a bed that holds the electronics, situated on top of support wheels, with a central paddle propulsion system. The strategy was to create a vehicle with average speed and torque, while not compromising its structural integrity, and keeping the weight at a minimum. Therefore, we selected which materials to use for the respective components first, and shaped our design process around them. This way, we optimized our design for the chosen materials and reduced the amount of iterations required later into the process.

Chassis Material Decision

The chassis made up a large portion of the device's weight, with the exception of the batteries. We had to use a material that was very light, while not compromising the structural integrity of the vehicle. It was also ideal for the chassis to be one single piece. The fewer pieces we had, the more rigid our vehicle would be. We were given the following options:

- Wood or acrylic - two $30 \times 30\,\mathrm{cm}$ sheets with thickness of 3mm or 6mm
- 3D printed filament - 3 cubic inches

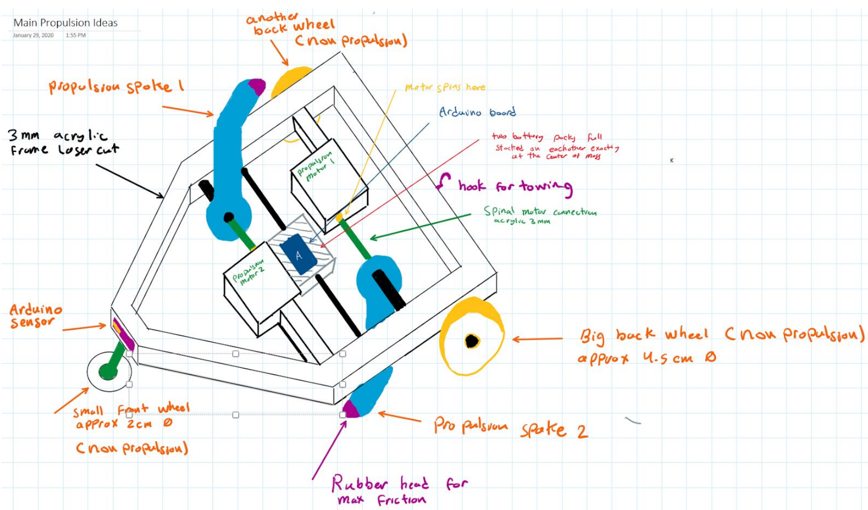
Since the 3D printed filament budget was very small, our options were limited to wood or acrylic plates. We performed rough bend tests at the Thode Makerspace with all of the available thicknesses in order to get a general idea of their rigidity. For both wood and acrylic, 3mm sheets flexed too easily and could be used. Our final choice was between 6mm wood or acrylic, and they were very similar in strength. Ultimately, we decided to go with acrylic for visual purposes. In the end, we had a single piece of acrylic for the chassis, then attached 3D printed mounts and holders onto it.

Propulsion System: Material Decision

A large amount of stress was placed on the propulsion components, as they had to push the weight of the device in addition to the load. Since we did not know the shape of the components at this stage, the material had to be rigid and easily formed into different shapes. In this case, we chose to 3D print the propulsion components, which allowed for more design options.

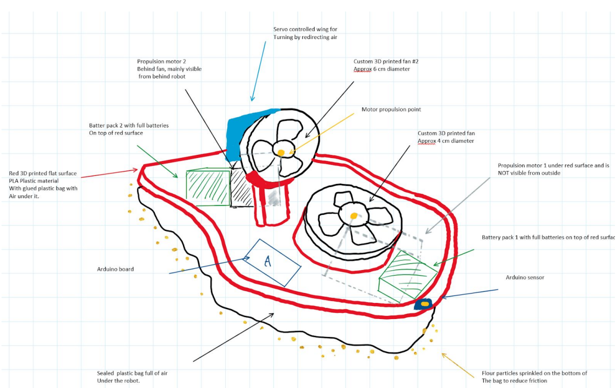
Concept Selection

Idea 1:



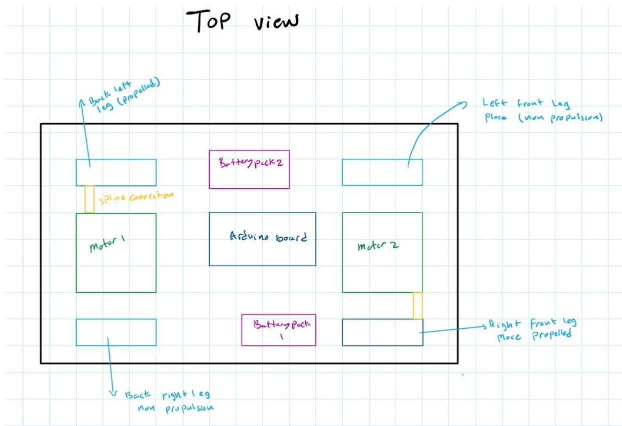
Description: As the two spokes alternate rotation and touch the ground with maximum friction, it propels the robot forward by making the wheels spin faster with every rotation. The spokes have a rubber tip for maximum friction in dragging the robot like a kayak boat does.

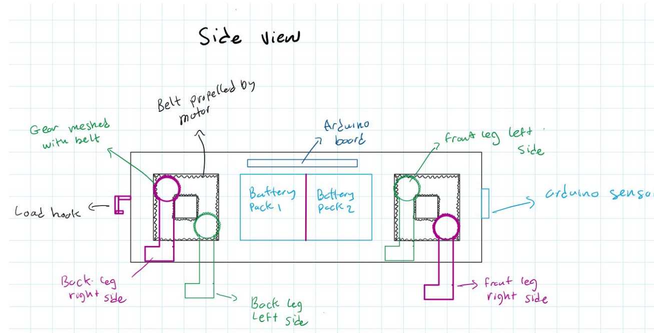
Idea 2:



Description: This idea uses one motor as a fan to blow the robot forward. The other motor fills the bottom of the robot with air. The plastic bag with air on the bottom simulates a hovercraft (reduces friction), propelling the robot forward.

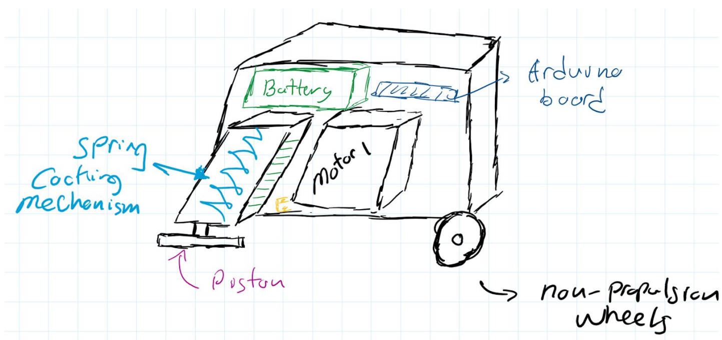
Idea 3:





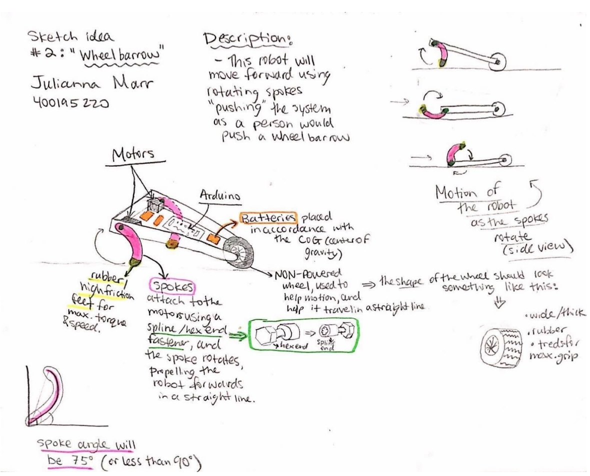
Description: This idea simulatest the galloping of a horse, as each two diagonal legs come in contact with the ground and propel forwards while the other two legs rewind in a circle. The legs are driven by a gear that is connected to a motor.

Idea 4:



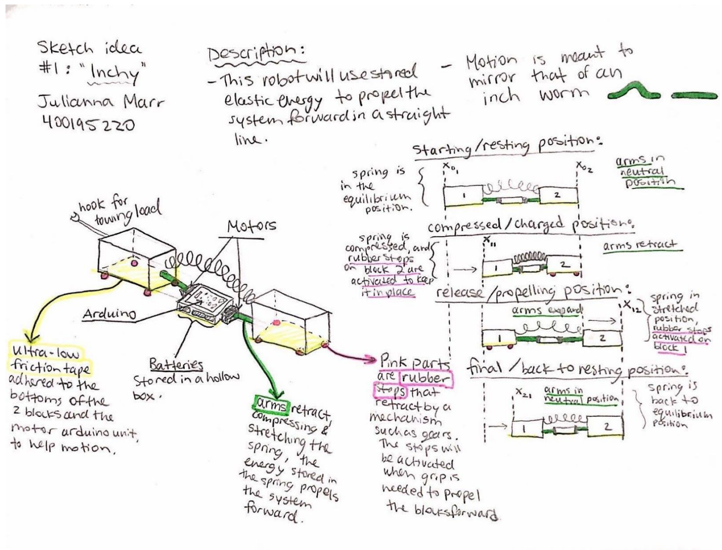
Description: This idea involves a spring mechanism that is cocked by a motor gear that spins on a vertical rack. Everytime the spring is fully cocked, it shoots the robot forwards like a kangaroo.

Idea 5:



Description: This robot will move forward using rotating rubber-head spokes that propel the system forward as a person would push a wheelbarrow.

Idea 6:



Description: This robot will use the stored elastic energy in the spring to propel the system forward in a straight line.

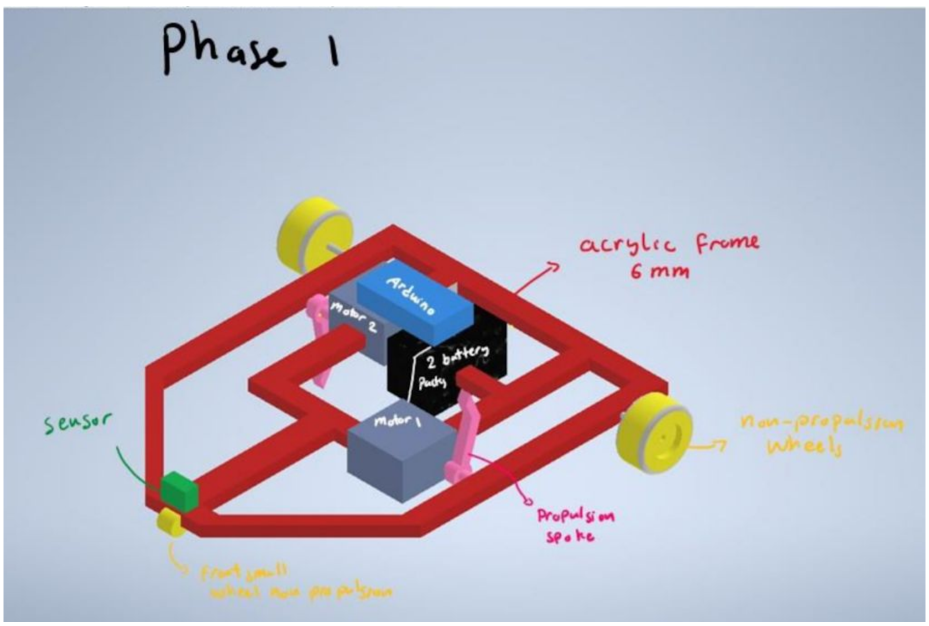
Decision Matrix:

Ideas	Weight (6)	Cost (1)	Speed (5)	Creativity (2)	Towing capacity (4)	Build quality (3)	Total
1	7	8	7	5	9	10	161
2	9	8	10	8	0	3	137
3	5	4	2	5	6	6	96
4	5	4	1	8	4	3	97
5	8	9	5	6	8	8	150
6	4	1	3	8	5	4	88

We used this decision matrix to assess our ideas and give them numerical ratings based on closer inspection of each mechanism. For example, idea 2 used a plastic bag to simulate a hovercraft. We looked at several videos on youtube to see how they work, their speed, weight, and potential towing capacity. Our research provided us with adequate information to estimate a rating for each idea in each category. Each category had a specific weight based on the amount of marks its worth in the final assessment. As shown, the most heavily weighted categories were weight and speed, worth 6 and 5 points respectively on our matrix. Once we rated each idea, we added the total points it earned in each category relative to the weight of the category. Using this method, we eventually came to the conclusion that Idea 1 was the best with 161 points.

Each member in our group was provided with a decision matrix and the 6 main potential ideas. We each rated the ideas based on our knowledge then looked at the results collectively. This allowed us to distinguish the best idea relative to each person in the group, providing a second stage iteration method. After reviewing the results, the first idea was the highest amongst all of us with an average of 149.6 points. Thus we decided to further develop Idea 1 into the final product we were going to build.

Initial Design



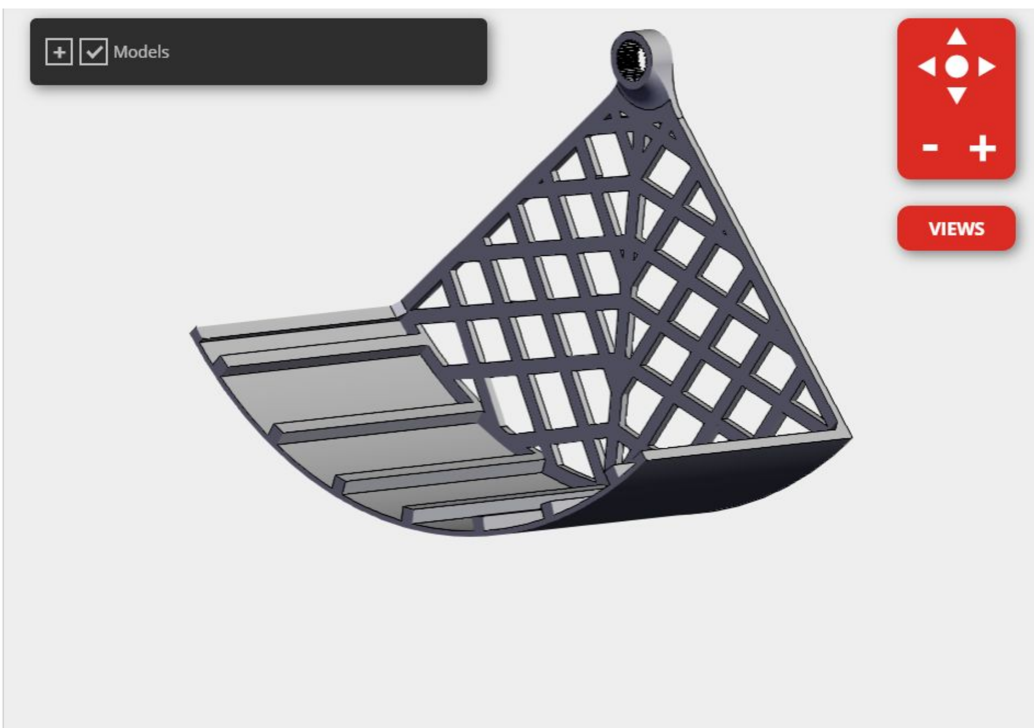
The above rendering depicts our initial design. There are many iterations we made in order to meet the deliverables. First, we changed the shape of the spokes. The shape of the new spokes we designed has a larger surface area which provides more friction with the floor and eventually provides more propulsion. We also changed the distance between the spokes. Our new spokes are placed on top of each other and alternate when turning, so they both contact the floor at the same point. The spokes in our initial design would only make the robot go in circles and that is not what we want to deliver. Another thing is altering the shape of the frame and making it smaller to reduce the weight as we focused mostly on low weight in the final design. The last thing we changed was the position of the battery holders. We were initially going to stack them up as shown above, but then we decided to place them beside each other so we can easily put the batteries on and take them off when needed.

Summary of the things we changed:

- Shape of the spokes
- Shape of the frame
- Position of the battery holders
- Position of the motors, spokes

Troubleshooting

The acrylic is strong enough to hold everything together, from physical observation. The wheel axles are store-bought wooden rods, stronger than necessary for our purposes.The main issue with our design was our spoke. At first, our spoke is shaped as shown:



Since it is really thin, we suspect that the spoke would not be strong enough to push the weight of the whole device, since it weighs about 925g in total. We are not able to print a physical prototype and test it. Therefore, we will use Inventor's FEA features to analyze the stress distribution and see if it would yield.

<u>First analysis</u>

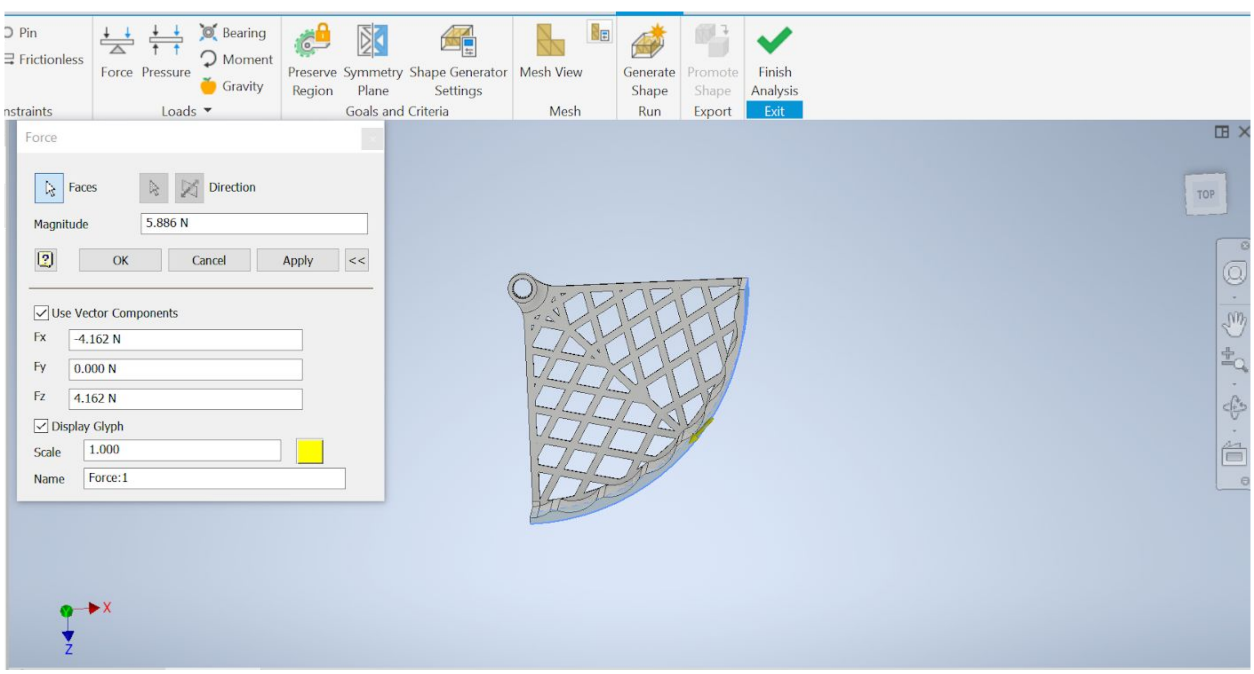
From an article by Sarah Saunders on 3Dprint.com, we see that PLA has a yield strength of roughly 26 MPA, depending on the orientation and infill percentage. Our goal is for the stress to be at most ¾ of the yield strength to ensure the spoke does not break.

Before starting the static simulation, we assume that the weight of the device is 1kg, a little higher than the measured weight to simulate the worst case scenario. Assuming the static friction coefficient is 0.6, we can calculate the force applied to the spoke where it contacts the ground:

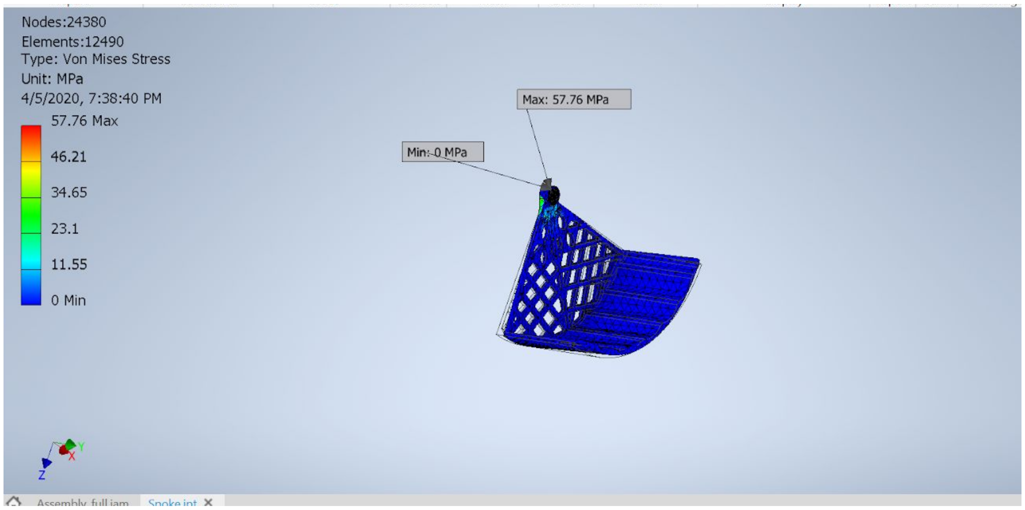
$$f = 0.6 \times 1kg \times \frac{9.81N}{kg}$$

$$f = 5.886\ N$$

Below, we apply a fixed constraint to the circular surface that attaches to the motor's axle, then apply the force of 5.886 N to the surface touching the ground. Here, we input the components of the force so that the equivalent force is tangent to the surface, as frictional forces act tangent to the surface.



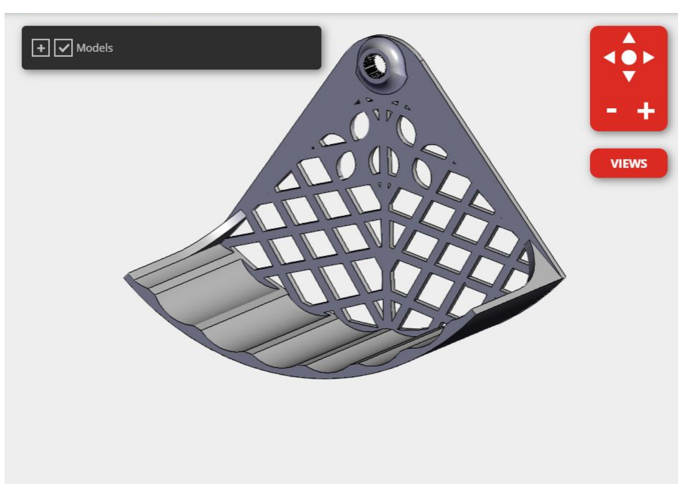
When the force and constraints are finalized, we run the simulation:



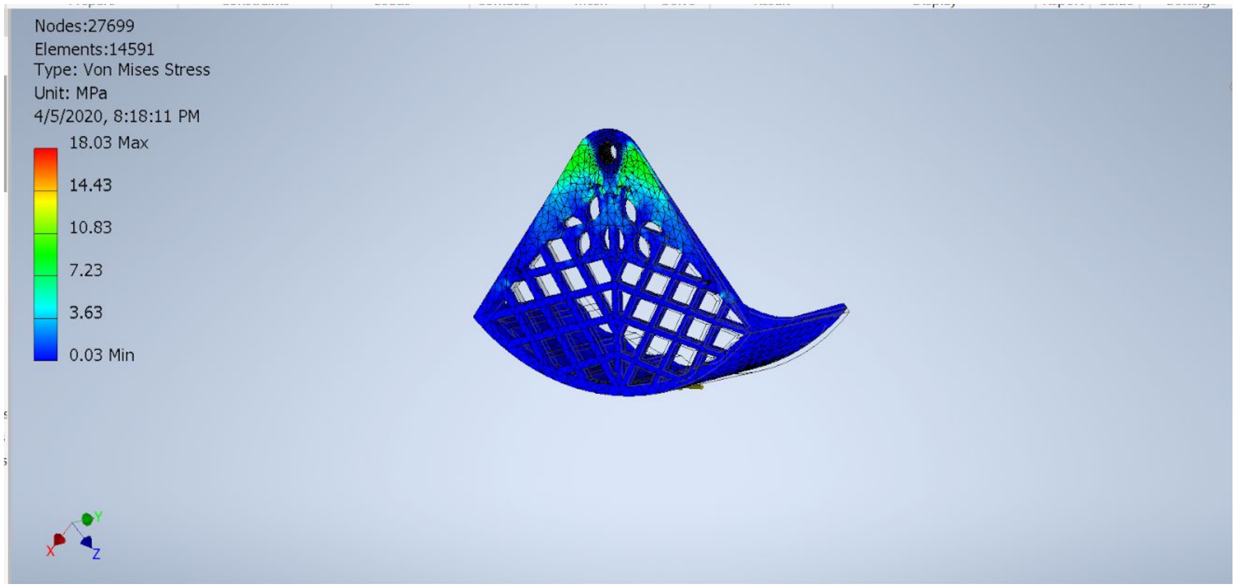
From the figure above, the maximum stress experienced by the spoke is 57.76 MPa. This is almost twice the yield strength. Most of the stress is centered around the small area around the spline connected to the motor axle. The other parts of the spoke experience minimal stress, so ideally we could make them thinner to reduce weight. However, we have to account for imperfections in our final assembly, where the spoke would have to take additional force.

<u>Second Analysis</u>

Knowing where the design would fail, we add material to the failure area:



In the new design, we extrude a large surface around the area of failure to dissipate the stress. We also add fillets in the frame structure of the spoke as we know that sharp corners tend to be points of failure.

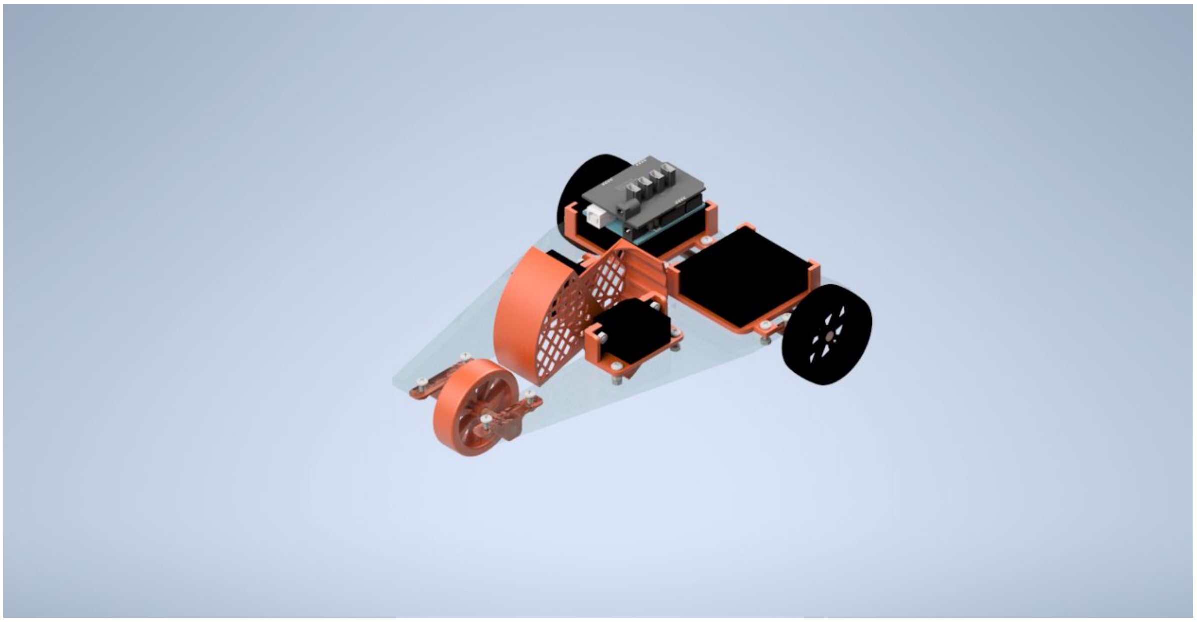


The maximum stress experienced by the spoke is now 18.03 MPa. This stress satisfies our requirements, since it is less than ¾ of the yield strength. The stress is still centered around the axle-spoke connection, but it has spread out more, becoming significantly lower.

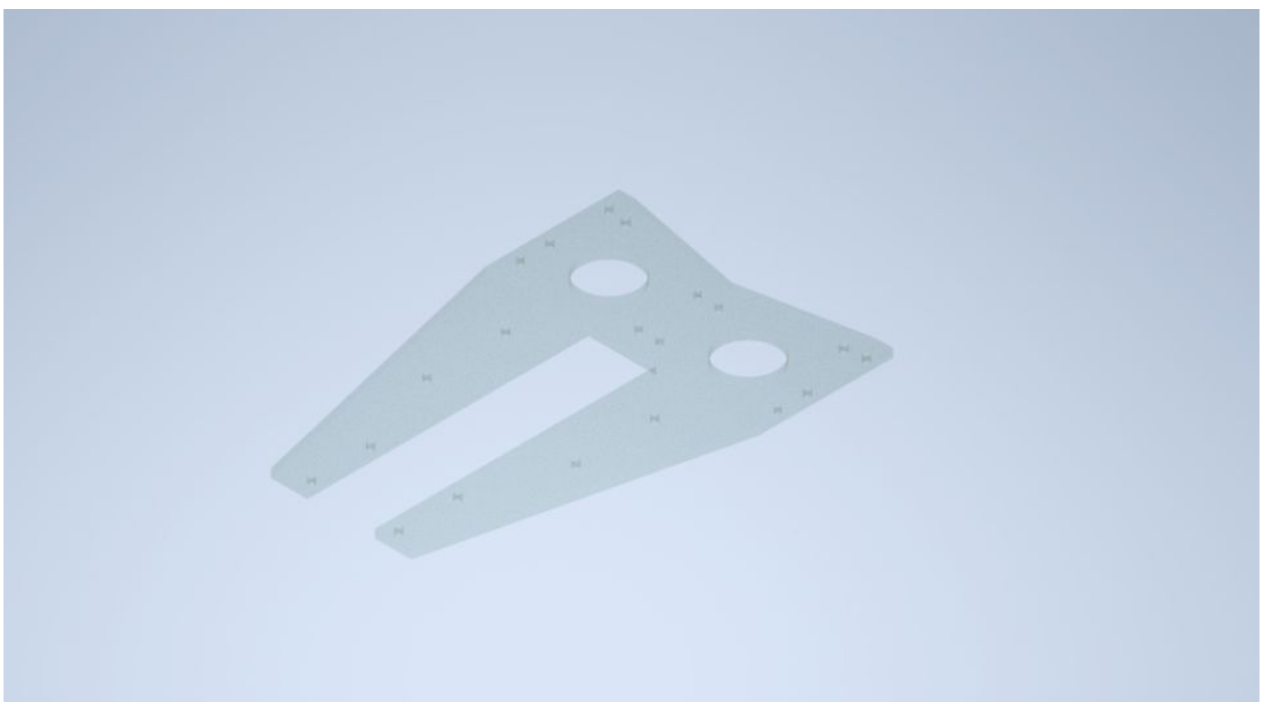
Final Design

Although we were not able to manufacture all of our device, our final design is still fully documented. Included below are some views of the assembled device and its main components, as well as an exploded view and bill of materials.

Full Assembly

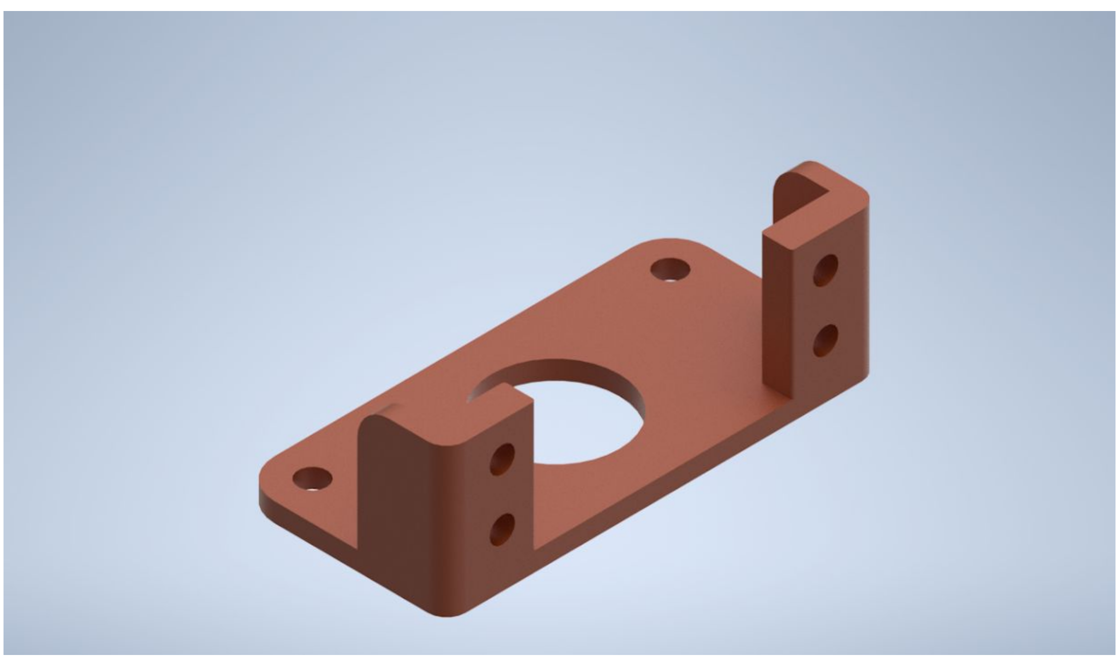


Frame

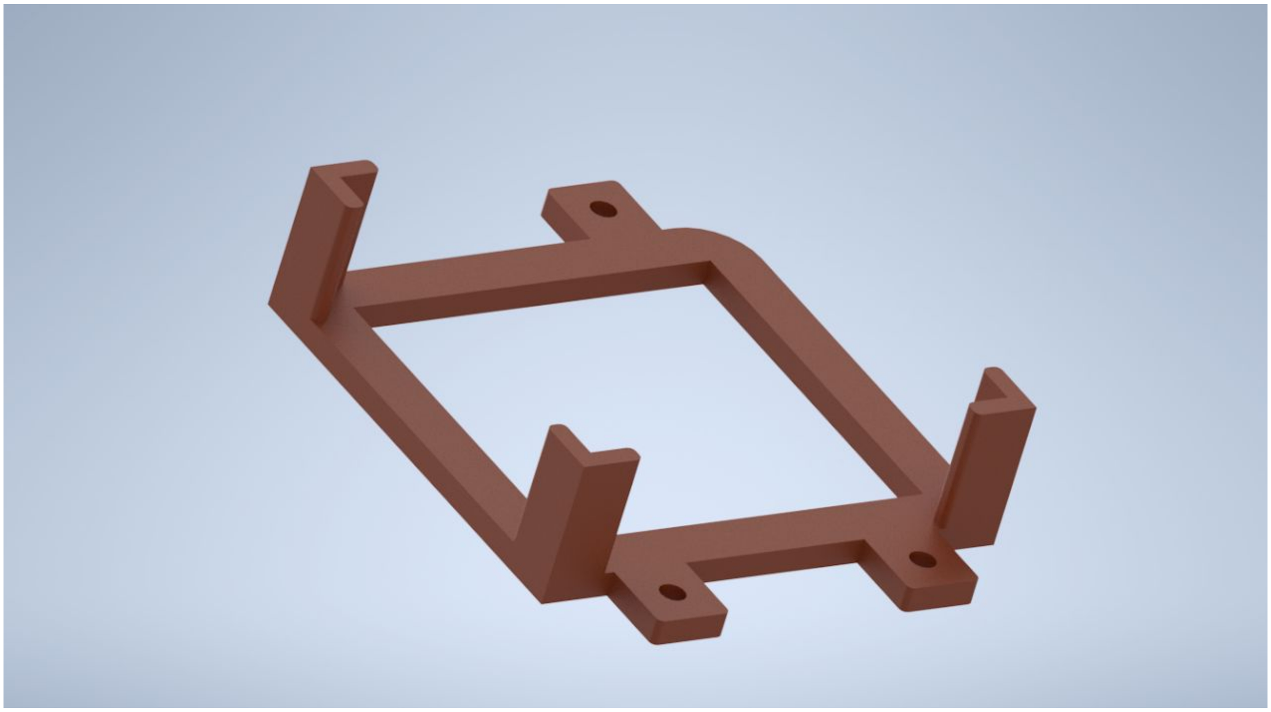


Propulsion Mechanism

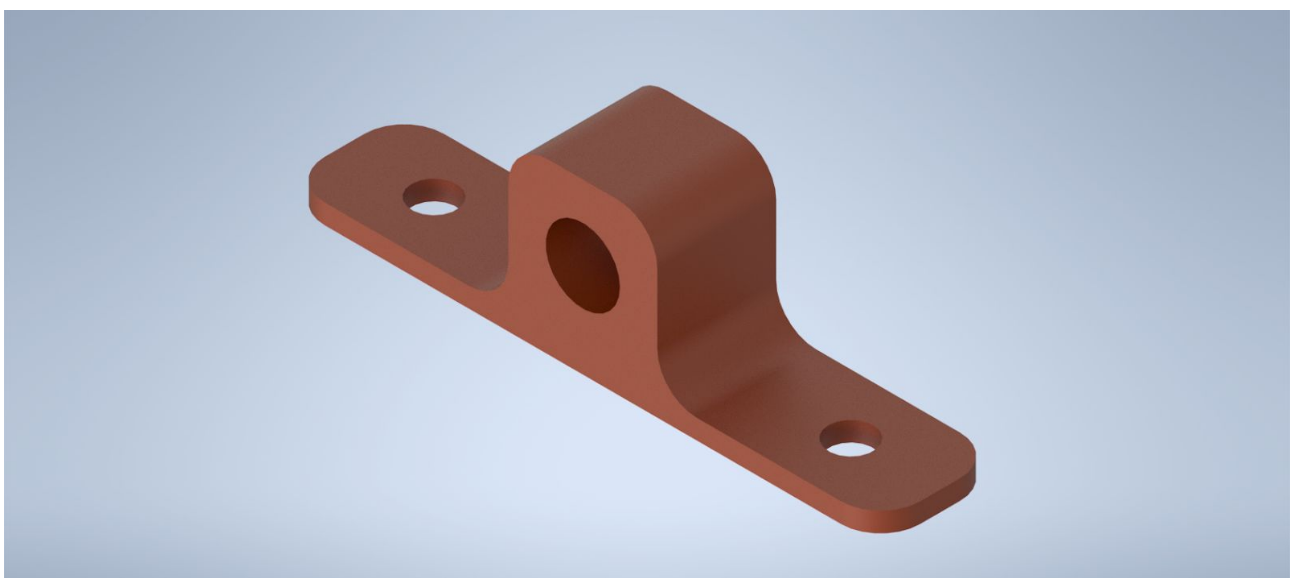
Motor Mount



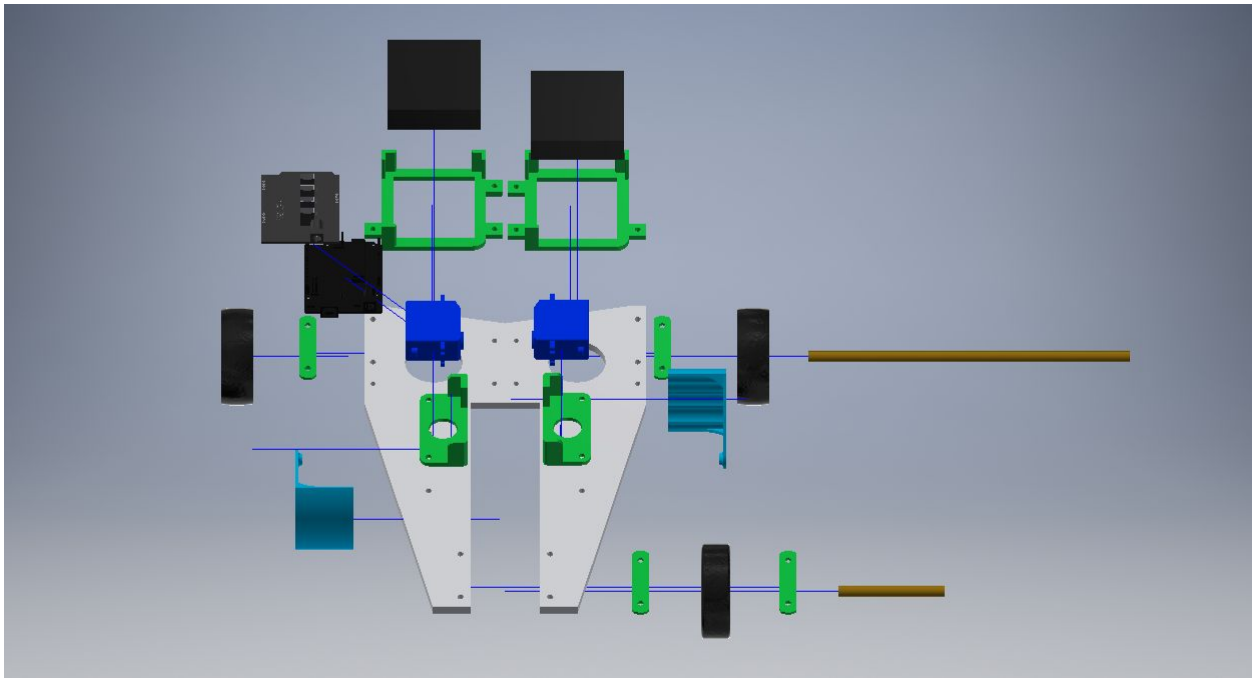
Battery Mount

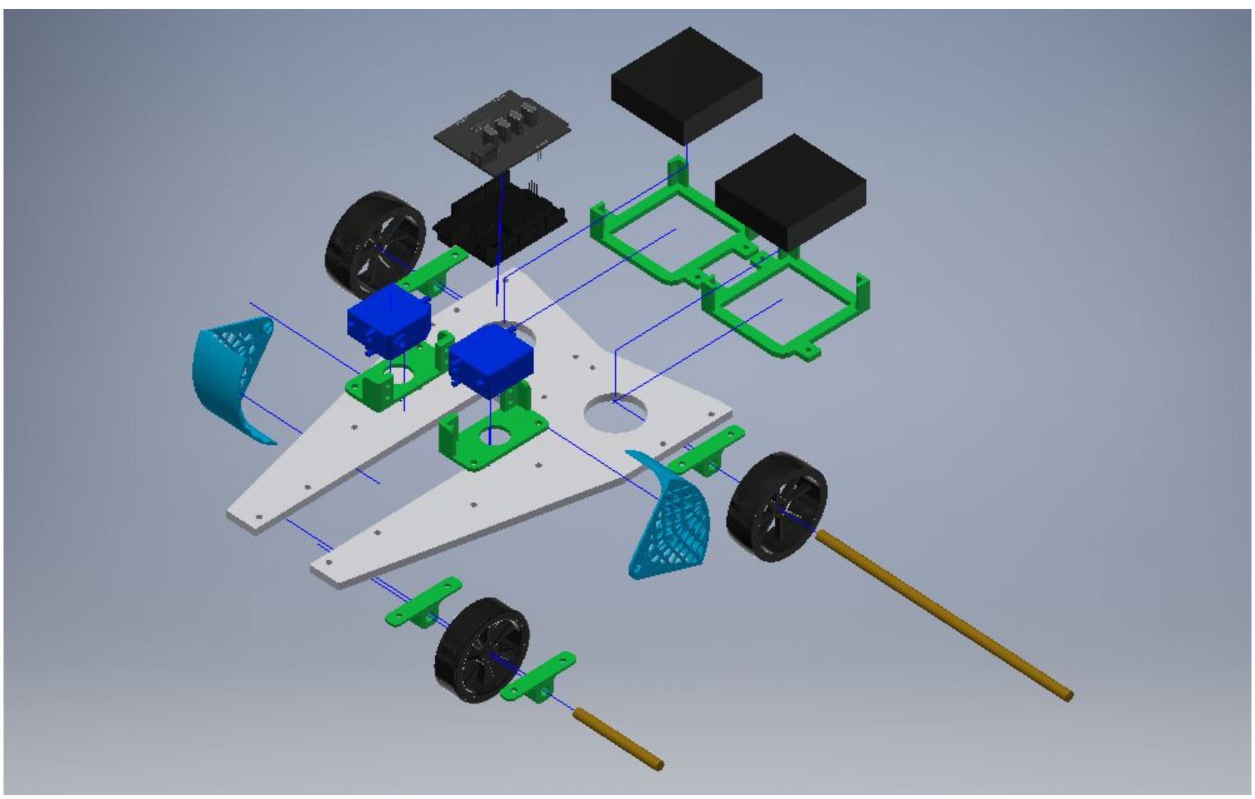


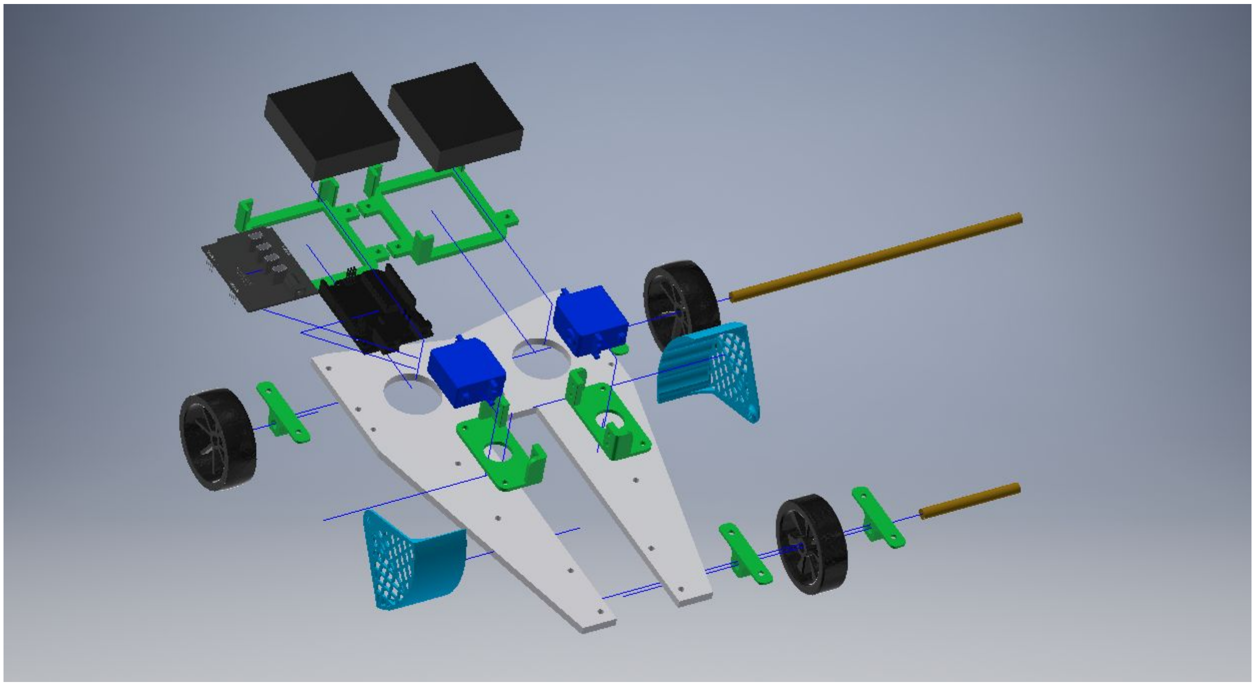
Wheel Mounts



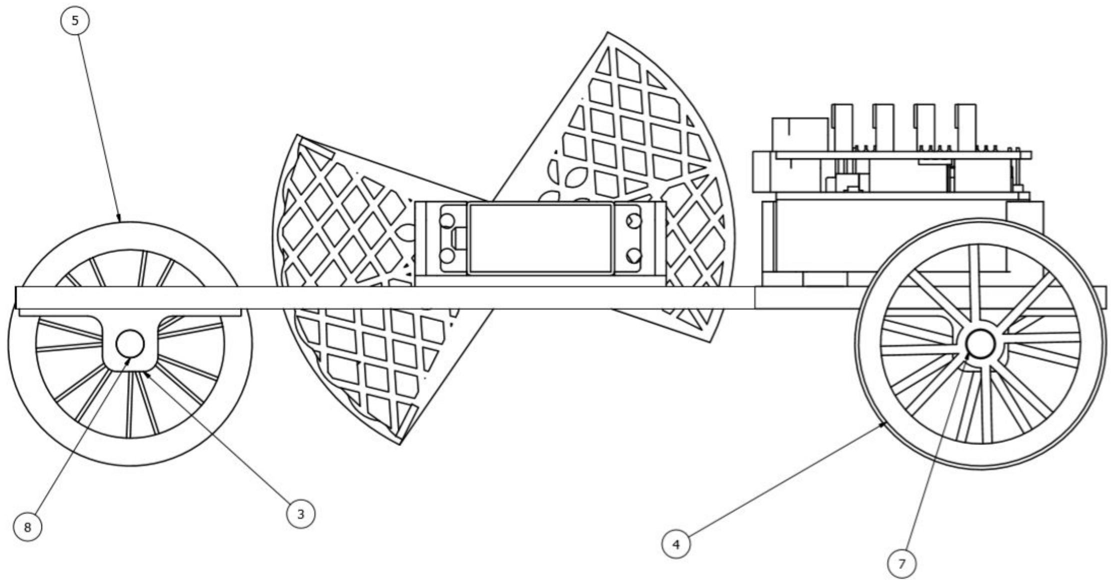
Exploded Views and B.O.M.



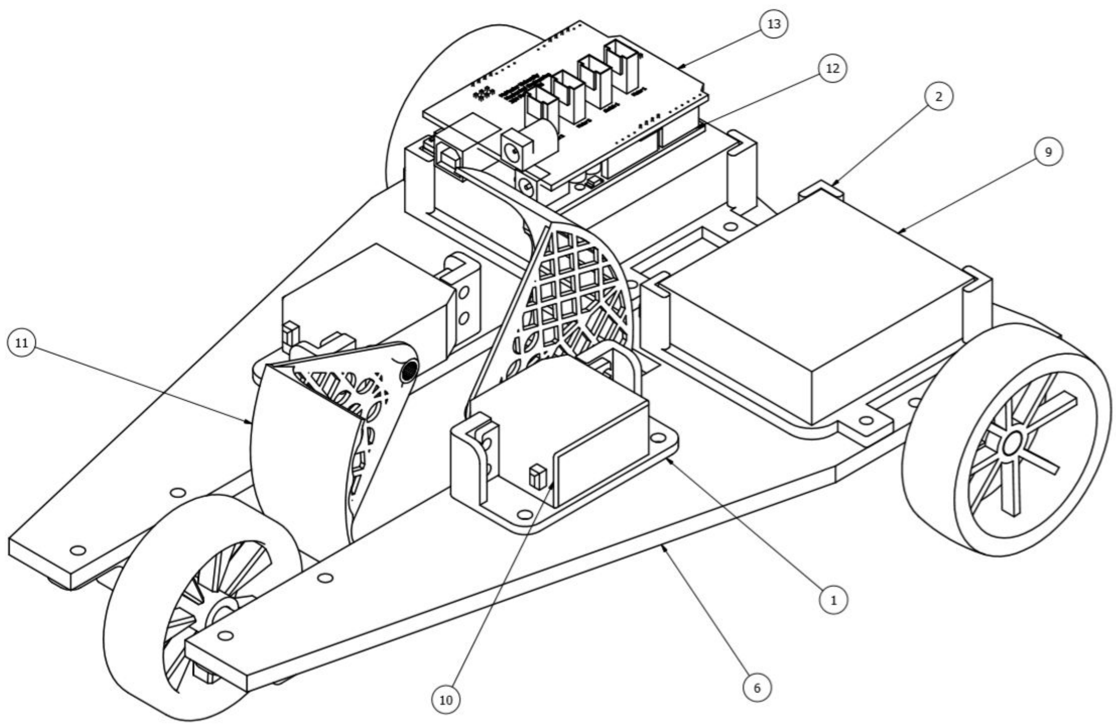




Part Name	Quantity
Frame	1
Motor Mount	2
Battery Pack Mount	2
Motor	2
Battery Pack	2
Front Wheel	1
Back Wheel	2
Front Axle	1
Rear Axle	1
Axle Mounts	4
Spoke	2
Arduino	1
Arduino Shield	1



Above: Side view of underside components
Below: Top view of upper components



Part Name	*Numerical ID*
Motor Mount	1
Battery Mount	2
Axle Mount	3
Back Wheel	4
Front Wheel	5
Frame	6
Rear Axle	7
Front Axle	8
Battery Pack	9
Motor	10
Spoke	11
Arduino	12
Arduino Shield	13

Proposed Design Improvements *(What We Would Do Differently Next Time)*

Firstly, we would probably purchase 3 uniform wheels, rather than 3D printing one of them. This is because light 3d printed wheels are complex to design, and “off the shelf” wheels are much more effective and cheaper. Also, it would be beneficial to refine the wheel mounts so that they are smaller and lighter, but still effective and sturdy. From a creative perspective, our design could’ve involved a more unique and “out of the box” strategy. Part of our grading is based on the creativity of the method we use to solve the problem, and the method we chose was very effective, but also very simple. Additionally, from a DFMA standpoint, our design could do with reducing the number of fasteners we employ. Our main way of connecting components to the frame is by using nuts and bolts which increase cost, weight and complexity. Instead, we could have designed our components with built in attachment ability, for example a snap fit or slotting mechanism.

Summary of Improvements:

- Purchase 3 wheels instead of printing one of them
- Design the wheel mounts more effectively
- Pursue a more creative solution
- Reduce our reliance on fasteners like screws

Final Budget

The factors that most heavily affect the cost of our robot are the materials, the amount of chosen materials, as well as the total time it takes to manufacture and assemble the parts. When deciding which material to use for each component of our robot, we kept these factors in mind.

Frame

In our final design, the frame is laser cut 6 mm acrylic. Initially, however, we considered 3D printing the frame. We then realized that it would take considerably more time and money to only end up with a much heavier frame, if we were to 3D print. By choosing to laser cut the frame rather than 3D print, we saved $200! This shows just how expensive 3D printing can be when printing a larger part.

Wheels

One of our fellow group members, Nick, was kind enough to provide us with the two back wheels that he already had in his possession, so there was no cost there. However, the design of our robot required a 3rd “front” wheel that had all the same qualities as the back two wheels, in order to maintain the robot’s structural integrity and performance. So we decided to 3D print a replica of the wheels that Nick provided and use that as the front wheel. The cost of 3D printing the front wheel alone is $31. Even though we got the two back wheels at no cost, we still could have found 3 uniform, ready-made wheels for less than $30. In any case, by 3D printing the front wheel, we had control over the design, which is something we wouldn’t have had if we bought one off the shelf.

By following the provided spreadsheet template, we came up with our final budget, as shown in the spreadsheet below.