Final Report

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Executive Summary

Our sponsor, Mr. Jason Cummins, utilizes a wheelchair in his daily life, and, as a result, has difficulty participating in certain activities and overcoming difficult terrains. Activities he would like to do include traversing various terrains including sandy beaches, hiking trails, and snow in Northern Michigan alongside his dog. He currently uses a manual wheelchair, and though he has tried various solutions such as different tires, he finds these too laborious to use in these terrains.

There are existing products that could meet Jason's needs, but they are generally too expensive, large, heavy, and/or don't meet all of his requirements. These needs have been translated into engineering specifications to quantify our solution. In order find the best solution to meet these specifications, every team member generated 20 individual design concepts; we then collectively went over each member's design, giving their maker a chance to explain it further and other team members a chance to build on the concept or expand on it. From this point we created a short list of the best concepts and generalized these favorite designs into major concept categories.

The five main concept categories were tank treads, wheels, sleds, mechanical legs, and tread/wheel hybrid. We determined a pugh chart scoring system based upon many metrics, including general, terrain, engineering, and coolness categories. After scoring, the wheels and mechanical legs designs scored highest. The treads scored lowest, but we continued to pursue the design because Jason had made it clear that a tracked wheelchair is his preferred design. Thus, we generated low-level CAD models of the tracks, wheels, and mechanical legs designs. We scheduled a meeting with Jason where we explained the results of our scoring system and showed him the CAD models, so that he could give his input on our final concept.

We chose the final vehicle architecture based on our pugh chart results and our meeting with Jason. We decided to go with a simple but capable 4 wheeled design that includes 5 main components: frame, chair, powertrain, drivetrain, and controller. The frame will be a metal tube chassis, the seat a modified version of Jason's current wheelchair seat. The powertrain will be 2 capable DC electric motors and an appropriately sized battery. The drivetrain will be a 4 wheeled front-steer layout and finally, the controller will include a microprocessor and a joystick as well as any other electronics we deem necessary.

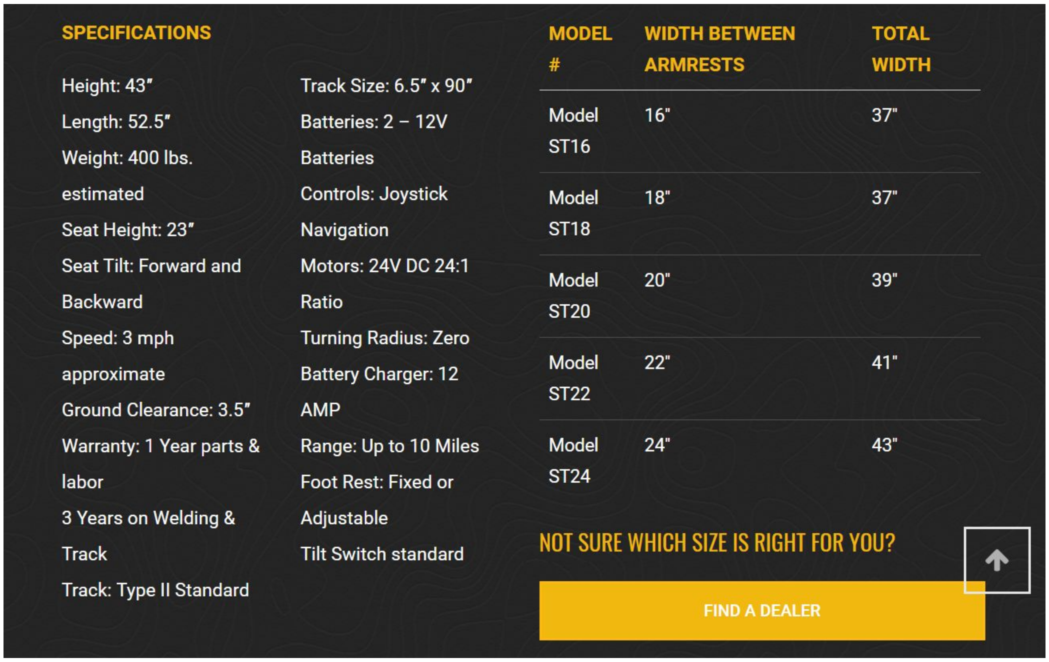
There are several key design drivers that must be met in order to satisfy the needs set forth by Jason. These drivers include a motor powered drive, a compact size, the ability to overcome soft terrain, the ability to maneuver in tight spaces, and maintaining Jason's vision and approval. We have specified the ways that we will achieve these drivers and how they connect to our user needs and engineering requirements.

Problem Description and Background

Our sponsor, Mr. Jason Cummins utilizes a wheelchair as his primary method of transportation. He enjoys being active and walking his dog outside, however his current wheelchair limits him to only sidewalks and roadways. According to the department of veteran affairs publication “choosing a wheelchair system”, mobility is a fundamental part of living [1]. “Being able to move about, to explore, under one's volitional control is a keystone of independence. The degree of mobility individuals have is directly related to their level of independence; restricted mobility significantly affects the ability to live a productive life.” Jason wants to be able to go to the beach, travel through woods, and move through the snow with his dog. His current chair does not allow him to traverse these terrains as they require low ground pressure or contain many physical obstacles. According to the CDC (Centers for Disease Control and Prevention) this is a common issue [2]. The seven most common types of barriers experienced by wheelchair users are listed in the CDC website article “Common Barriers to Participation Experienced by People with Disabilities”. Physical barriers is listed as one of the seven and is defined as “structural obstacles in natural or manmade environments that prevent or block mobility (moving around in the environment) or access” [2]. This is the type of barrier our sponsor experiences every day.

Jason sought to remedy this issue by purchasing a commercially available all-terrain wheelchair through his insurance. Such devices are readily available on the market, but have such high cost that it would put unreasonable financial strain on Jason if he were to fund it himself. Medicare part B insurance covers the cost of power-related scooters and manual wheelchairs as durable medical equipment (DME) to be prescribed by doctors for use in the home [3]. However, power wheelchairs are only covered when “medically necessary”, which is described by medicare.gov as “health care services or supplies needed to make diagnose an illness, injury, condition, disease, or its symptoms and that meet the accepted standards of medicine”. [3] Some coverage may be provided when deemed by a doctor as a “quality of life enhancement”. However, Jason spoke with his insurance provider and was unable to obtain funding for an all-terrain wheelchair through his coverage. Thus, he looked into alternative options.

There are many devices currently on the market that would meet his need, but they are too expensive, heavy, wide, loud, have too many unnecessary features, and/or don’t meet enough requirements. Some currently available all-terrain power chairs are the Trackchair (Action trackchair and Ripchair), Trac-Fab, Zoom All-Terrain Vehicle, and the Blumil Seated Segway. We investigated these and other powered devices that all pertain to assisting those who rely on wheelchairs for mobility. The first device investigated was the Trackchair whose specs are shown in figure 1 below.



SPECIFICATIONS

Height: 43″
Length: 52.5″
Weight: 400 lbs. estimated
Seat Height: 23″
Seat Tilt: Forward and Backward
Speed: 3 mph approximate
Ground Clearance: 3.5″
Warranty: 1 Year parts & labor
3 Years on Welding & Track
Track: Type II Standard
Track Size: 6.5″ x 90″
Batteries: 2 – 12V Batteries
Controls: Joystick Navigation
Motors: 24V DC 24:1 Ratio
Turning Radius: Zero
Battery Charger: 12 AMP
Range: Up to 10 Miles
Foot Rest: Fixed or Adjustable
Tilt Switch standard

MODEL #	WIDTH BETWEEN ARMRESTS	TOTAL WIDTH
Model ST16	16"	37"
Model ST18	18"	37"
Model ST20	20"	39"
Model ST22	22"	41"
Model ST24	24"	43"

NOT SURE WHICH SIZE IS RIGHT FOR YOU?

FIND A DEALER

Figure 1: Action Trackchair specs. The specifications for the Action Trackchair are compared to the engineering requirements requested by Jason.[4]

The weight falls within our limit, but the chair is too wide and too long to fit within the limits of Jason's lift (36" x 32"). The top speed of 3 mph does not agree with Jason's requirement for a top speed of 10mph, and the ground clearance of 3.5" is less than our desired 6" of clearance. The most stark discrepancy is the price tag; our budget is $1000, but the base model offered by Action Trackchair totals $11,300. [4]

To better understand the designs currently on the market, we looked at TRAC-FAB's patent work for their all-terrain wheelchair. An image of this chair can be seen in Figure 2. The chair consists of a frame, a seat, two battery packs, two DC electric motors, and two track assemblies. The creator makes the following claims about the chair: "The present invention easily travels through dirt, mud, grass, snow, gravel, rocks, etc" and "the present invention may be about 30 inches wide overall, and may therefore travel through a standard doorway and into a handicap accessible vehicle. [5] On top of the previously mentioned features, additional components include headlights, a touch screen, an adjustable seat and anti-rollback wheels. While these may be nice features to have, cost considerations will be taken into account in our design. The TRAC-FAB chair as described in US patent 2016/0184150 A1 has a starting price of $9,995 and weighs 485 lbs. [5]

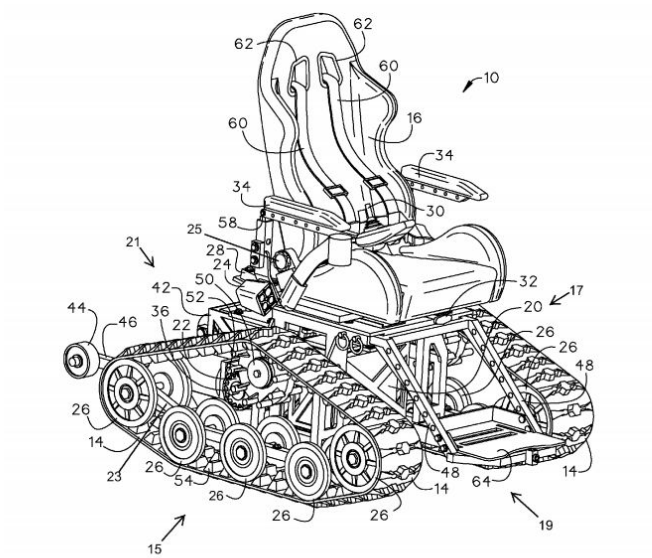


Figure 2: TRAC-FAB chair. The labeled drawing is used to identify components of the chair for the patent. Upon viewing of the patent, we identified no legal limiting factors in the design of a powered wheelchair with treads. [5]

There are also manually powered all-terrain wheelchairs such as the Grit Freedom chair [6]. This chair is similar to a normal wheelchair except it has mountain bike wheels operated by levers [7] and has brakes. The Grit Freedom chair works very well in forests and normal roads but still cannot move quickly in sand or snow. It also requires a large energy expense from the user.

The Zoom all terrain vehicle shown in Figure 3, is another solution we investigated. The electrically powered vehicle is capable of going 12 mph and has a 25 miles range on flat smooth terrain. The vehicle is also said to have a range of 15-19 miles on demanding terrain. It is also 4-wheel drive and is made to have all tires in contact with the ground. Although the Zoom is an ideal solution to our problem, the market solution is too expensive and complex for Jason’s needs. Our solution does not require a full suspension, and the drive system is too complex. The battery also has a feature that allows it to charge in 4 hours from a completely dead state. This is an unnecessary feature that adds to the high sticker price. [8]

Figure 3: Zoomability Zoom. This solution comes closest to meeting Jason's needs as it is relatively small, light, and simple. This design would be cheaper to manufacture than the tracked solutions. [8]

The Ripchair 3.0 is another solution to the problem. This device allows the user to remain in their manual wheelchair while in use. The Ripchair is powered by gasoline and has a starting price of $34,500. It also has a weight of 1,250 lbs and has the dimensions of 70.1" x 60.5" x 75.5". This device has an undesirable powering mechanism and is too expensive, heavy, and large. However it does have the unique feature of allowing the user to remain in their existing wheelchair. [9]

Figure 4: Ripchair 3.0. This track design was evaluated as this device performs very well in all terrains. [10]

The BLUMIL i2 seated segway is an all terrain device that could solve Jason’s problem. The device is a segway that requires the user to lean forward to accelerate and use the handlebars to turn. The i2 is collapsable and folds to 25” x 25” x 28”. The segway also has a top speed of 12 mph with a 20 mile range. This device is a creative solution for Jason’s needs but it introduces some concerns. It has trouble on slick terrains as the wheels slip and in some instances are unable to regain balance. This device harbors the possibility of tipping, harming, and leaving the its user stranded in such situations. [11]

Figure 5: BLUMIL i2 seated segway. The segway is cheaper and less complex than the tracked solutions, but must be designed such that it is stable and versatile in various terrains. [11]

In an effort to minimize the cost of our solution we investigated powered wheelchair assists. One of these devices is Rio Mobility’s Firefly Electric Handcycle. This wheelchair attachment effectively converts an existing manual wheelchair into a power scooter. In the attachment process, the two front caster wheels are lifted off the ground leaving the two rear wheels of the manual chair and the one wheel of the Firefly in contact with the ground, shown in Figure 6. This device is not all-terrain, but does allow for movement on grass, gravel, wood chips, dirt paths, and paved surfaces with ease. This device does enhance the mobility of those wheelchair bound, but does not aid noticeably in sand or over obstacles. [12]

Figure 6: Firefly Electric Handcycle. This attachment can be fitted to an existing wheelchair to increase mobility. [12]

Another assisting device is Max Mobility’s SmartDrive MX2+. The MX2+ attaches to the crossbar structure on the lower rear side of a manual wheelchair. It powers a wheelchair by essentially adding a driving wheel which provides assistance on smooth terrains, grass, and traversing uphill slopes. The wheel design and mounting location are particularly interesting features. The driving wheel is made up of two separate wheels with rollers that allow the user to turn their wheelchair without having the drive wheel skid. [13]

Figure 7: SmartDrive MX2+. This device does not provide the all-terrain capabilities desired, but its compact and waterproof design are worth investigation. [13]

The high price is the biggest drawback shared among all current solutions. We seek to design less on the luxury side and more on the functional aspects of the device to minimize cost. Jason is very engaged in this project and has done some research himself. He has big aspirations but does not have a grasp on some of the project constraints such as budget and timeline. This disconnect is something our team is actively preparing to remedy.

User Requirements & Engineering Specs

Our team was given many direct engineering specifications from our technically minded end user, Jason Cummins. As such we've taken his specifications and turned them into user needs in order to broaden our design options and allow our engineering requirements to be end goals, not the solution. We've rated these user needs / engineering requirements in three categories: high, medium, and low priority. These priorities do not perfectly fall in line with our end user's because we must limit our scope to realistically attainable goals. [14]

High Priority:

Obstacles:

Jason needs to be able to overcome larger obstacles such as branches, rocks, and hills that he will encounter in his desired terrains. We've translated this user need into the need for his new chair to climb a 7.1 degree incline, the designated incline for power chairs, while still operating at 90%

speed. We have also determined that the maximum allowable obstacle is 6 inches, and therefore our wheelchair must be able to overcome objects equal to or less than 6 inches in diameter. [15]

Terrains:
Jason would like to overcome difficult terrains such as the forest, in order to be able to walk his dog freely, and the beach, a place he loves but cannot reach in his current wheelchairs. As a result our chair must be able to traverse rough sand, dirt, mud, and grass. The challenge here is spreading the weight to prevent sinking into these soft terrains, as such our chair must apply less than 5 kPa ground pressure. [16]

Safety Harness:
Jason has requested that only a lap belt be utilized to restrain him while riding our all terrain vehicle. He recognizes that safety is a must and would like to prevent future injury. To ensure the highest safety standards, our wheelchair ideally would be "able to withstand a 30-mph collision at 20-g" without harming its rider according to U of M's power chair safety requirements. [17] However, we believe this is an excessive restraint since the device is to be used off-road and away from the danger of traffic collisions. Therefore to still protect Jason from harm, our wheelchair must be able to restrain its user when on a 30 degree incline.

Battery Life:
Jason would like to limit the amount of time required to charge the batteries. He also needs to be able to utilize the wheelchair for a significant amount of time without worrying about the battery dying. To do this we have identified that the the chair must function at half power for 4 hours, assuming our top speed is 10 MPH, twice that of average powered chairs, and cover a range of 10-20 miles. This number comes from the standard for powered wheelchair battery lives and ranges. [18]

Size:
Jason owns a hydraulic lift, which attaches to the rear of his Jeep, that he utilizes for moving heavy objects such as powered wheelchairs. The lift has dimensions of 36" x 32" (W x L). The width of our chair must not exceed 36", and the length of our chair can only exceed 32" long if the center of gravity is within the 32" lift length.

Cost:
The chair that Jason needs is already commercially available, but ranges between $10,000-30,000. Our project has came about to find a cheaper way to create an all terrain wheelchair, with a current budget of $1000. This limits us in achieving many of Jason's user needs, as we must spend less than $1000.

Medium Priority:

Tipping:
Jason would like to traverse tough terrain, likely with very steep inclines, and has specifically expressed his desire to climb mountains. Mountain terrains do not exceed 30 degrees, as this is the angle at which landslides begin to turn slopes into cliffs. In addition, we have added the desire to climb stairs as a stretch goal, the average stairwell has an angle of less than 35 degrees. Therefore our wheelchair must not tip, the center of gravity cannot fall outside of the wheelbase, on angles less than 35 degrees. [19]

Smooth Riding:
Jason comprehends that the terrain he would like to cover does not lend itself to smooth riding, and as such has expressed that he does not need suspension. However, our team has identified the need for suspension not only to keep Jason safe, but to keep the mechanisms of the wheelchair safe. We've defined smooth riding as the absence of motor vibrations being felt on the chair. [17]

Weight:
While we are unsure of the weight capabilities of Jason's lift, we know it can lift his current standing wheelchair, which weighs around 243 lbs. We'd prefer to be under this number to allow for the chair to move faster and more easily through our terrains, as such, our goal is lightweight but our limit is 243 lbs. [20]

Ground Clearance:
We have defined the largest possible obstacle to be 6 inches in diameter, and as such we require that his feet and the bottom of the wheelchair must be higher than 6 inches from the ground.

Comfort:
Jason has not expressed a need for comfort, however some level is implied. Considering the terrains, our wheelchair will not be very smooth riding, and as such we are requiring that we make our seat out of a deformable material, or have some method of shock absorption.

Ability to tilt/recline:
Jason has explained that when going downhill he needs to be able to tip backwards in order to prevent himself from falling forwards. He's expressed this need by explaining a U shaped servos controlled seat that always keeps the seat parallel with the horizon. While we don't expect to attain this standard, we would like to ensure that the seat is reclinable to maintain safety on hills.

Positioning/Height:
Jason has stated he would like to "sit into the device, not on it," and that he would like to feel like he's surrounded by machine. We also recognize that the average height of a chair is 16" and Jason must transfer into our wheelchair from a chair of similar height. Therefore, our wheelchair seat must be 16 $\pm$ 2 inches from the ground and located within the wheelbase.

Low Priority:

Weather resistant:
Jason has difficulty overcoming snow in his current wheelchairs, however is able to get around by expending lots of energy. In addition, Michigan is a fairly unpredictable weather state and our wheelchair has the chance of encountering a rainstorm. It would be ideal if our powered chair was water resistant and able to overcome snow, utilizing a previous requirement again of applying less than 5 kPa ground pressure. [16]

Speed:
Jason has expressed his desire to "make able bodied people jealous" with the look and speed of his new power vehicle. With the many challenges we must overcome to create this wheelchair, obtaining a high speed is not our top priority. Our goal is to obtain a chair that can achieve speeds up to 10 mph, over twice as fast as the average powered chair. However we would like to specify that our chair must have a top speed of equal to or greater than 4 mph to ensure he is as fast or faster than the average power chair user. [21]

Waterproof:
Jason stated that he would like to go to beach and into the lake in his wheelchair. He would want the wheelchair to be waterproofed up to 12 inches from the ground so he can get deep enough into the water to transfer in. This is also not a top priority for our design since waterproofing electronic components is extremely costly and difficult. As such we would like our chair to be water resistant, and if possible completely waterproof up to 12" from the ground.

Turning Radius:
To allow for agility within tight terrains such as the forest, Jason would like to have a thin wheelchair with a tight turning radius. We've identified that turning in place is an achievable goal, and are requiring that our wheelchair can turn in place or has a turning radius of less than one foot.

Concept Generation

The next step in turning these engineering requirements into a physical solution was concept generation.To design a solution for Jason we first generated ideas and made rough sketches of them individually. We then collectively went over these sketches where their creator could go into more detail. This allowed both the maker to convey the entirety of their idea and other members to expand on the concept. We then took our favorites of these designs and for each of them brainstormed possible variations.The concepts generated can be seen in Appendix 1-10. These favorites combined with some of the suggested variations were generalized into our major categories of concepts.

The major categories of concepts generated are vehicle to ground interaction, chassis and suspension, transmission, and human machine interfaces. The vehicle to ground interaction category contains the methods by which our device can move and conquer all terrains. It includes such concepts as tank treads, mountain bike tires, fat bike tires, large ATV-style tires, mechanical linkage legs, skis / skids, and corkscrews. The transmission category contains all mechanical powering ideas and power transfering. It includes a chain-drive concept, a direct-drive transmission double gearbox, belt drive, animal power, human power by hand cycling or big hooks to pull yourself, and animal powered. The human-machine interfaces category includes the subcategories of seating and controls for our device. Seating includes cloth seating, a plastic bucket seat, a car upholstered bucket seat, and restraint devices. Controls include armrests with a joystick control, handle bars, a steering wheel, and a lower back or waist type controller.

Our major design focus was on the vehicle to ground interaction category as this has the most influence of meeting our overarching goal of creating a wheelchair that can move on various terrains. Our top concepts are described further below.

Top Concepts

From the many concepts created, we narrowed our choices down to five main design categories to focus the rest of our efforts on. These concepts can be seen in Figures 8-12 below.

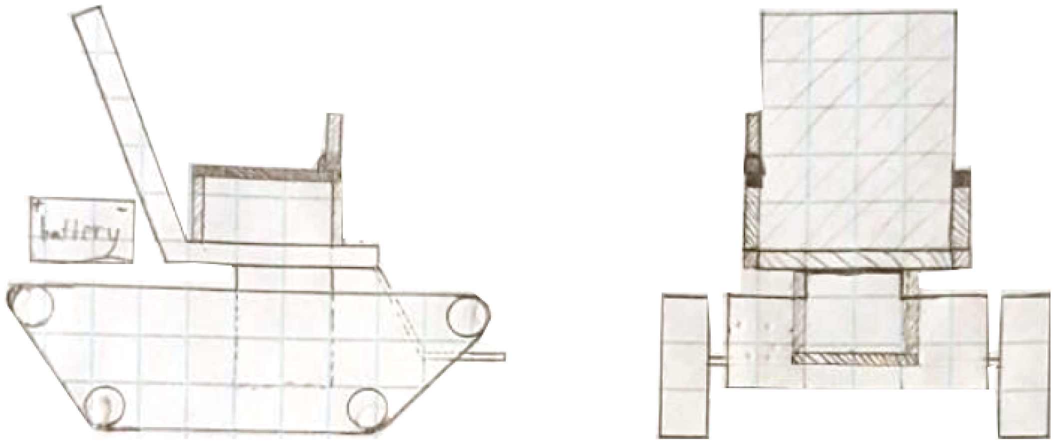


Figure 8. Tank wheelchair with joystick control. This meets our sponsors needs as rubber track belts can conquer all terrains including sand, snow, and brush. It also allows the user to drive on flat pavement fairly comfortably. However, treads are expensive and would be difficult to fabricate ourselves. Independently we generated several designs that implement this tread and differ on such characteristics as the number of treads and their location on the device.

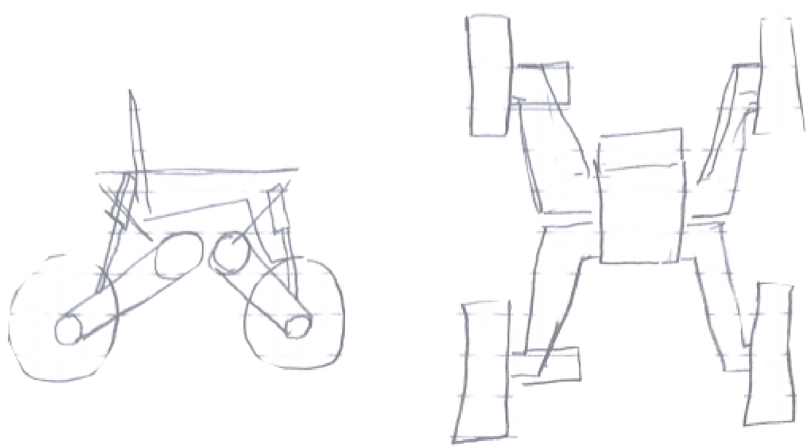


Figure 9. 4 Wheel drive all terrain chair. The wheel design is a simple solution and would be relatively easy and cheap to build. The wheelchair would provide high speed and go over forest terrains with the thick, all-terrain wheels. The downside of this design is that it would still be difficult to traverse sand and snow.

Figure 10. Sled concept sketch. The use of sleds in our design will aid in the traversing of soft or more fluent terrains. This includes sand and snow. The device will not exclusively have sleds and requires driving wheels in the rear. However, sleds offer a cheap way to conquer terrains and effectively replace casters or thin wheelchair wheels which fail in these terrains.

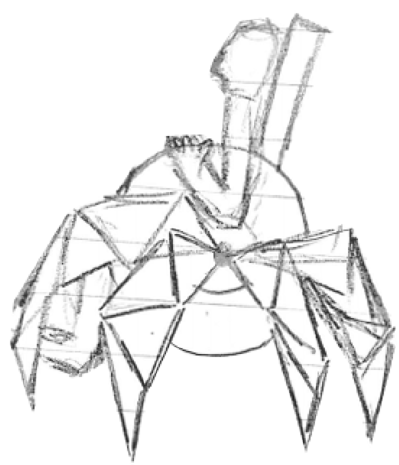


Figure 11. Mechanical legs concept sketch. This design utilizes the Jansen linkage that acts as “legs” of the wheelchair. The user then mechanically walks by the implementation of three sets of linkages mounted on either side of the user allowing them to move through soft terrains and step over obstacles.

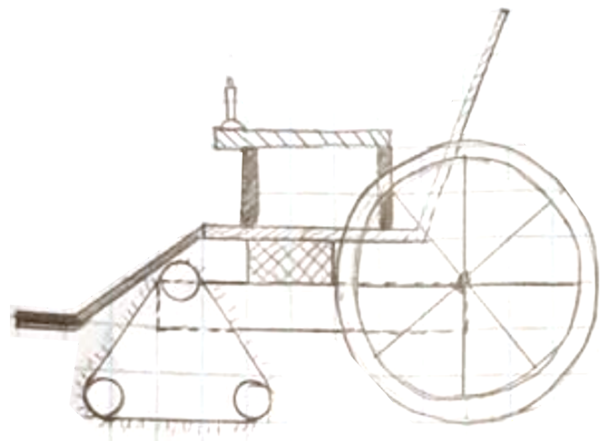


Figure 12. Mix of treads and wheels concept sketch. This design gains maneuverability and speed compared to the purely tank tread design. It also concentrates traction to the driving wheel (if tread is used) and decreases traction on the turning wheels which is useful in a comparison to the purely tank tread design.

Concept Selection

From the five main concept designs we developed a pugh chart to determine which types were most viable. The scoring system was based on general ride quality (see Table 1), terrain capabilities (see Table 2), engineering (See Table 3), and our sponsor (see Table 4).

Table 1. General metrics. The efficiency and stability metrics were weighted highest because they are more important than speed, turn radius, and ride quality. The efficiency affects the battery while the stability is an important safety consideration.

		General				
	Metrics	**Efficiency**	**Ride Quality**	**Speed**	**Turn Radius**	**Stability**
	Weight	*15*	*5*	*10*	*10*	*15*
Wheelchair Types	Tank treads	1	3	2	5	5
	Wheels (2,3,4)	4	4	5	4	4
	Sleds	2	2	3	1	3
	Mechanical Legs	2	2	2	3	4
	Mix-treads & wheels	3	3	3	4	4

Table 2. Terrain metrics. All of the different terrains are weighted equally, but it is important to note that the wheelchair must be able to traverse all of them. This proves a major disadvantage for sleds and mechanical legs, which would be essentially unable to traverse brush.

		Terrain				
	Metrics	**Sand**	**Snow**	**Brush**	**Inclines**	**Hard Ground**
	Weight	*10*	*10*	*10*	*10*	*10*
Wheelchair Types	Tank treads	3	4	5	4	2
	Wheels (2,3,4)	3	4	3	3	5
	Sleds	4	5	1	3	1
	Mechanical Legs	4	3	1	3	5
	Mix-treads & wheels	3	4	3	4	3

Table 3. Engineering metrics. The ease of manufacture is the most weighted metric because we have limited time and experience in the context of ME 450, and want to ensure that we will be able to deliver a well designed and manufactured solution.

		Engineering		
	Metrics	**Ease of Man.**	**Cost**	**Weight**
	Weight	20	15	15
Wheelchair Types	Tank treads	2	1	1
	Wheels (2,3,4)	5	4	4
	Sleds	4	5	5
	Mechanical Legs	3	5	5
	Mix-treads & wheels	3	2	3

Table 4. Jason metrics. Jason has made it clear that he prefers a solution that will look cool. Although this is not as important as other metrics, we still want to consider Jason's preferences for the final design.

		Jason	Total
	Metrics	**Coolness**	
	Weight	5	
Wheelchair Types	Tank treads	5	450
	Wheels (2,3,4)	2	640
	Sleds	1	500
	Mechanical Legs	3	535
	Mix-treads & wheels	4	515

After consideration of the pugh chart, we found that the wheels and mechanical legs scored the highest. However, the tank treads were still heavily considered due to their versatility over various terrains and Jason's explicit preference for a tracked solution. Thus, we generated CAD models for the mechanical legged (see Figure 13), tracked (see Figure 14), and wheeled (see Figure 15) solutions and met with Jason to discuss his preference for the final design based upon the CAD models and pugh chart results.

Figure 13. Mechanical legs. Although complex to design, this solution is easily manufactured with the use of a waterjet. Jason was particularly impressed by the "coolness" of this solution.

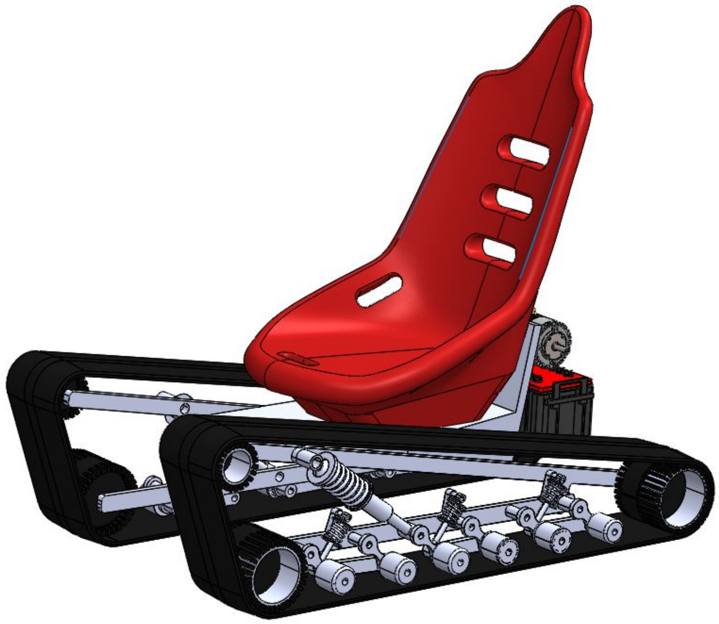


Figure 14. Tracked wheelchair CAD model. This design is also the most favored by Jason.

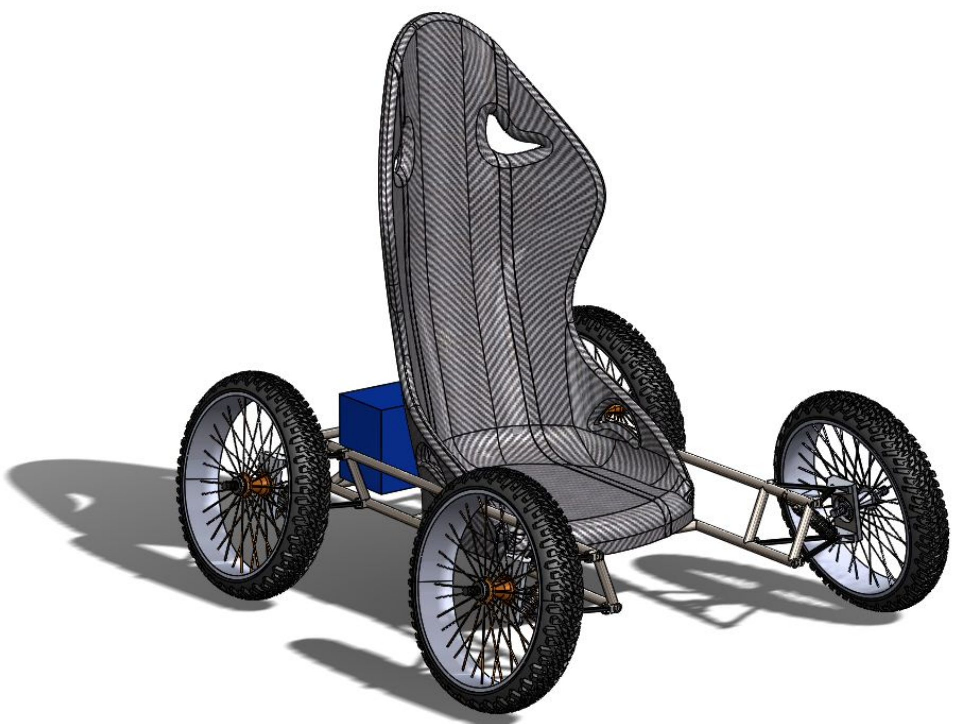


Figure 15. Four-wheeled design. This design fulfills our requirements of an all terrain vehicle as the basic design is highly adaptable in its drivetrain and wheel style or tire choice.

After meeting with Jason, we decided to move forward with a wheeled drivetrain layout. We will decide between tracks and wheels after examining the associated costs with each design (monetary and non-monetary). We have decided on this design for the following reason; while Jason really likes the “coolness factor” of the tracked layout, our team collectively believes that the wheeled solution solves the problem the best. However, we are still researching track options so tracks remain a possibility. We want to give Jason the best product to meet his needs at the end of the day but there will be inevitable tradeoffs due to conflicting requirements mentioned in this report.

Specifically, our design will consist of 5 components/systems. The frame is the primary component to which all others will attach. The seat component will be secured to the frame and will satisfy all respective restraint requirements. There will be a powertrain system consisting of DC electric motors, motor drivers, and a battery. The powertrain system will be selected such that it will provide the required power for the sufficient amount of time, as well as meet the Torque and Speed targets. Next, the control system will consist of a joystick, microprocessor, and various other electrical components, and will be able to accurately command and control the motors. Finally, the drivetrain system will transfer power from the powertrain to the ground and will either be a tracked or wheeled layout.

The benefit of this concept is that it is a simple design from a system integration perspective which will allow us to focus on the subsystems and components themselves without having to worry about system interfaces. The advantage is that team members can focus on perfecting their respective components/systems and then connecting them all together will be a straightforward process.

Key Design Drivers and Challenges

We have identified a few key design drivers in order to satisfy the needs set forth by Jason. First, our device must have be capable of motor powered drive, to achieve this it must be easily rechargeable by Jason and able to move the weight of our device and Jason with ease. A motor powered vehicle with high torque and speed specifications requires a high power motor, and therefore a large battery. We expect that the monetary constraints may be the largest challenge here, along with the coding required to power these motors by use of a joystick. We also must overcome soft terrains and obstacles while maintaining high safety, this means our device must not tip and must be capable of high torques along with having a high forward facing wheelbase to move over obstacles. Here we see the challenge of needing a heavy duty machine that isn’t heavy, or at least has a very large surface area to disperse its weight across. The final machine must be easily maneuverable and compact in order to fit in Jason’s van and be able to fit in tight places like between trees in the forest. This driver requires that our wheelbase and eventually the way we power the wheels/tracks must be done with a tight turn radius in mind and specific spatial constraints. Finally, the wheelchair must satisfy Jason's own vision, if he doesn't like the appearance or feel of this product Jason will not use it, as such this becomes our most important and challenging design driver. To achieve Jason's approval of our end vehicle we've given him a trade study between different designs and allowed him to have a part in deciding which design is our final goal.

To quantify and confirm whether we have achieved these design drivers, we have created design specifications. Our design specifications include the ability to handle inclines, achieve desired speeds, and have a long-lasting battery life. To confirm our solution can handle a certain degree of incline, statics will have to be utilized to confirm the center of gravity is low enough to avoid tipping in specific orientations. Calculations involving speed and torque will be necessary to select the appropriate electric motors for our application. We can then calculate the battery capacity necessary to achieve our mileage and battery life time requirements.

The most challenging part of our design is balancing the engineering requirements derived from Jason's user needs with our budget and time restrictions. Jason desires the capability of quickly traversing rough terrain. Solutions which accomplish this task are both complex and expensive. Thus, we will have to make compromises in the capability of our design to arrive at a solution which is realistic given our restrictions, yet still provides a useful solution.

For example, a solution with tracks, the solution that would bring Jason greatest fulfillment if done successfully, is expensive. Tracks have a greater amount of friction than wheels, which in turn requires more powerful motors, batteries, and money to reach the same speed. Overall, they are also more complex than wheels, requiring a greater amount of time spent manufacturing and troubleshooting the subsystem, which could be spent elsewhere to arrive at a more refined solution. However, if our solution uses wheels, we are not providing a solution inline with Jason's vision, which is important, even if it does satisfy more engineering requirements than a tracked solution. In conclusion, balancing reality and practicality with Jason's desires is what brings difficulty in accomplishing our goals within the constraints of our problem.

Specifically focusing on our chosen solution, a wheeled chair, we expect challenges to include manufacturing, finding large tires with optimal ground pressure, maintaining low weight, and finding motors that can supply enough speed and torque. The cost of each of the subcomponents is worrisome, as such we've defined monetary restrictions on each. This became the deciding factor when our budget only allotted for $350 to the wheels/treads and pulleys subcomponent and we could not find any treads that totalled under a thousand dollars. Even with this simpler system, our budget will restrict us on the capability of the motor we can buy. One of our largest challenges has always been ensuring Jason is content with our final solution, as such we met with him to discuss this option and his greatest concern was feeling like he was in a car and not a wheelchair. To prevent this feeling we've decided that we cannot use a mechanical steering system like a wheel, we cannot put a large frame around Jason, and we need to make it appear open and lightweight.

Concept Description

We chose a 4 wheeled design controlled by a joystick with a fixed chair recline angle. Our device does not utilize mechanical turning, instead, all wheels are driven independently though the use of 4 in-hub motors.

Figure 16. Shows the QS Motor 12 inch 1000W 205 Single Shaft Electric In Wheel Hub Motor.

Without mechanical steering, we must steer our device by spinning the wheels on one side at a different speed or in a different direction than the wheels on the other side.

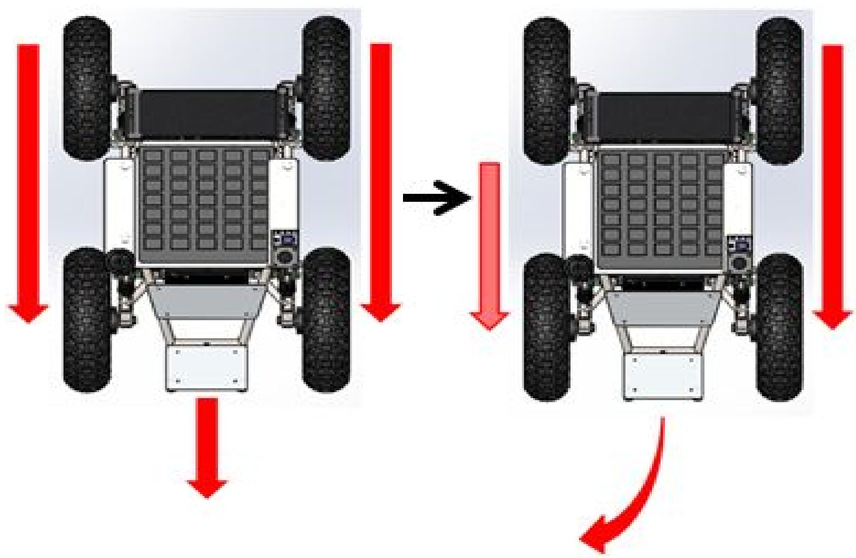


Figure 17. In the left image, the wheelchair moves forward by running all wheels at the same speed. In the second image when the passenger right wheels move slower than those on the passenger left so the chair turns to the right.

While not moving, the wheelchair will have a near zero degree turn radius as the set of wheels on one side will spin in the opposite direction as the other set.

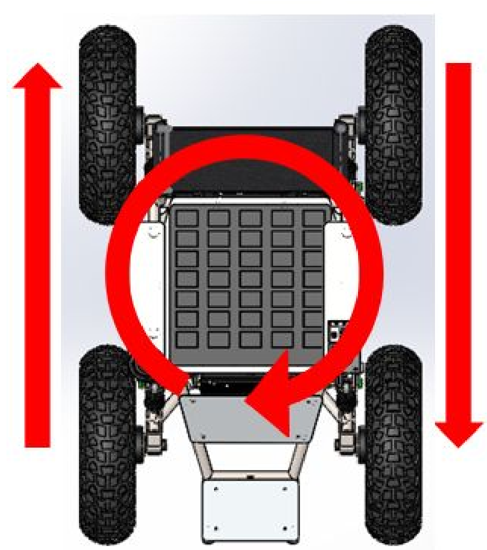


Figure 18. By rotating the tires in opposite directions we can perform a near 0 degree turn on our device. This will not be perfectly 0 degrees due to friction of the dragging tires.

The in hub motors eliminate the need for an exposed chain that links the wheels on a side to a singular motor, and gives us the capability of torque vectoring. The motors are attached to the wheelchair with a keyway, allowing for reliable torque transfer. The chassis consists of a welded 1.00” OD 0.049” wall thickness steel tubing cage to maximize strength and minimize weight.

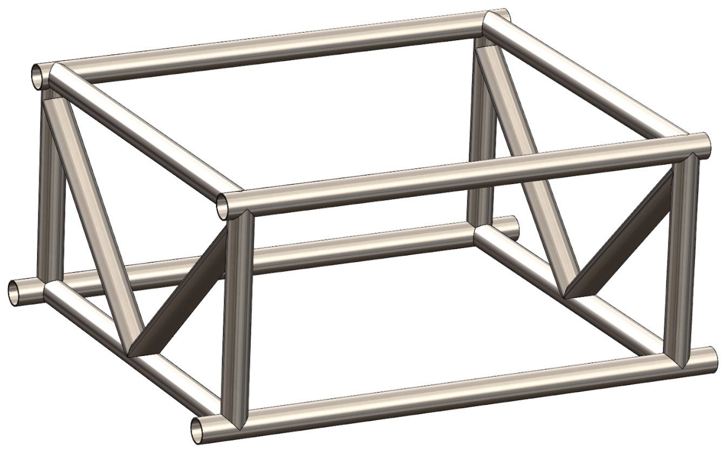


Figure 19. The CAD for the chassis is depicted above. Diagonal members provide torsional support. The chassis was made with space inside and holds up a rigid bottom plate to provide a place for the batteries and control components to remain protected yet close to the ground.

Our concept also has independent suspension on all 4 wheels providing a comfortable ride while protecting our batteries and controls. The suspension consists of a spring damper that attaches to the chassis and control arm where the hub motors are attached and secured using a lock nut. The tabs that connect the spring damper to the chassis and suspension have multiple mounting locations to adjust ride height if needed.

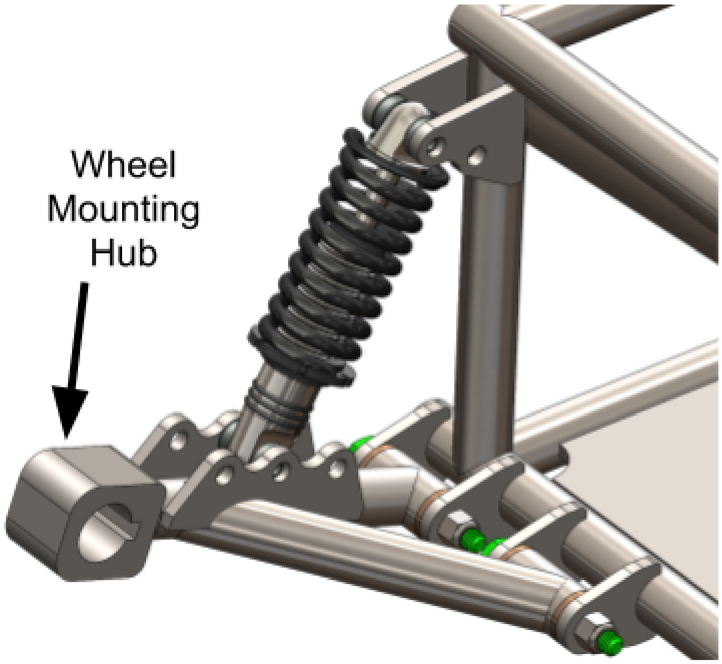


Figure 20. The suspension consists of a bike spring and damper, an A frame, and a wheel mounting bracket. The connection for the bike spring and damper is variable to allow for change in spring force as necessary once the device is constructed.

The seat frame consists of a welded 1 inch OD steel tubing frame. The seat back is an off the shelf wheelchair back while the seat bottom is a metal plate which holds a cushion provided by Jason.

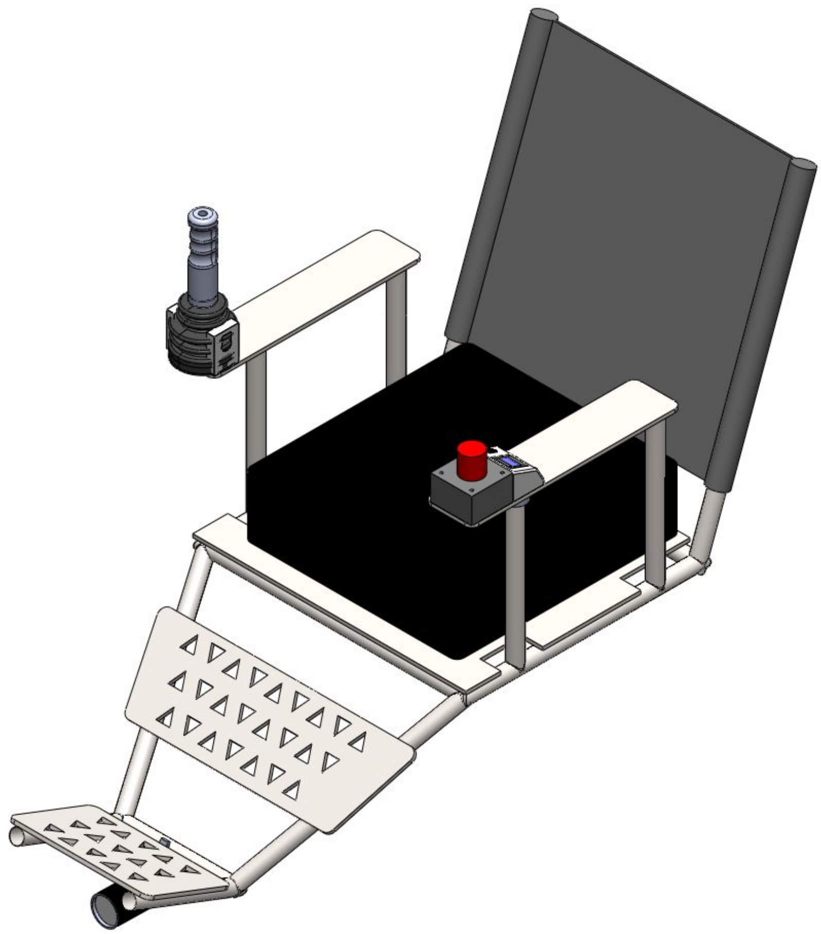


Figure 21. The chair consists of many welded steel tubes and ¼” steel plate in order to provide a strong structure. Dimensions are anatomically driven and based off common wheelchair dimensions.

The control interface consists of a joystick to control direction and speed, a “kill switch” to turn off all electrical systems, a switch to turn on/off the controls, and an LCD screen to provide information and instructions to the user. The joystick utilizes 3 potentiometers, one pot will measure the twisting to control turning, while two pots, for redundancy, will measure linear motion and control forward and reverse speed of the chair. The forms of the joystick and the LCD/switch holder will be 3D printed to ensure best fit, and to minimize weight and complexity.

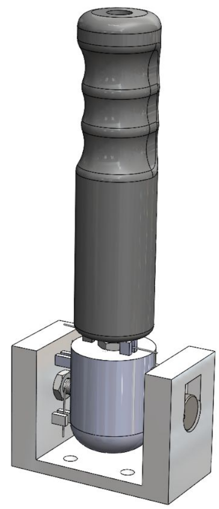


Figure 22. The CAD for the joystick is shown above. The structural components will be 3D Printed while the string pots and torsional springs will provide positioning and positioning knowledge.

The controls system for the wheelchair is centered around on ATMega2560 microcontroller. This was chosen due to its high number of analog output pins, needed to send data to the motor controllers, and the hardware interrupt pins needed to read the hall effect sensor data from each motor. The Arduino takes in user input from the joystick, processes the signals to find the desired speed/angle, and outputs PWM signals to each individual motor controller. These PWM signals are converted to analog signals via a low pass filter and the motor controllers drive the motors at the corresponding speed. All of the components are powered off of one 48V battery. The system diagram is shown in Figure 23 below.

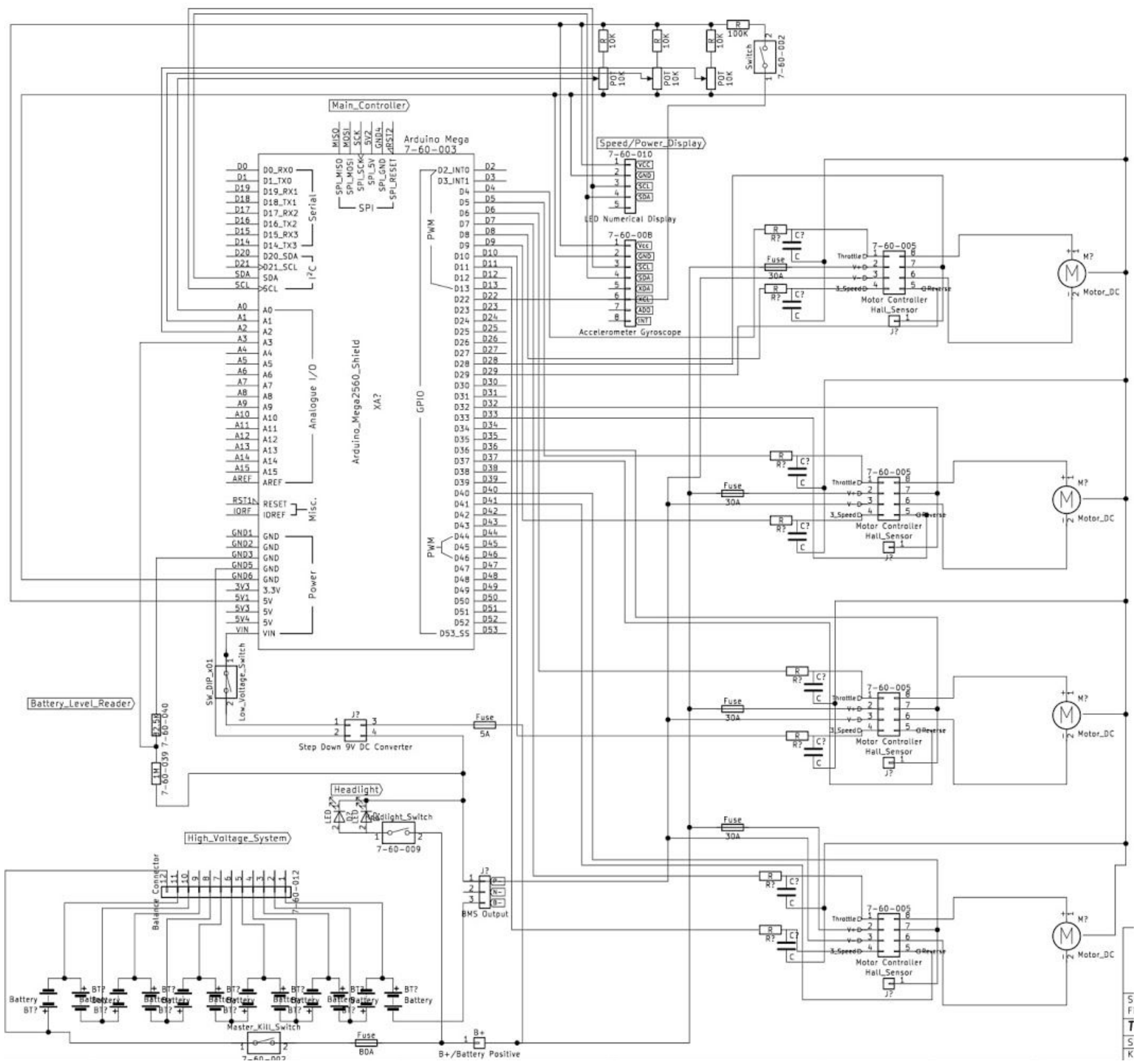


Figure 23. System diagram for all the low voltage and high voltage electronic systems.

Each motor is driven by a 48V 800W brushless electric bike motor controller. These were chosen due to their low cost; traditional motor controllers that handle the amperage requirements of the system cannot be had for less than $200 so these controllers are the best option for our budget. These controllers are intended to be used in an electric bike and take in user inputs via a manual throttle to adjust speed. Since we are sending commands to the controllers from an arduino rather than a physical potentiometer, we have to send analog signals rather than PWM ones which is accomplished using a low pass filter.

The low voltage controls are packaged in a laser cut acrylic box. This includes the Arduino, 48V-9V DC converter used to power the controls, and the accelerometer/gyroscope used to measure the incline being traveled. They are in an acrylic box to protect them from the environment and provide some water proofing. The controls box includes a 5V DC fan needed to cool the DC-DC converter. To prevent water from coming in via the fan, there is a stainless steel mesh screen across the fan. This screen has openings 0.003" inches in diameter which is below the size needed for water to pass through passively; it needs to have additional pressure to pass through. As such, it will be sufficient to meet out waterproofing requirements. This control box can be seen in Figure 24 below.

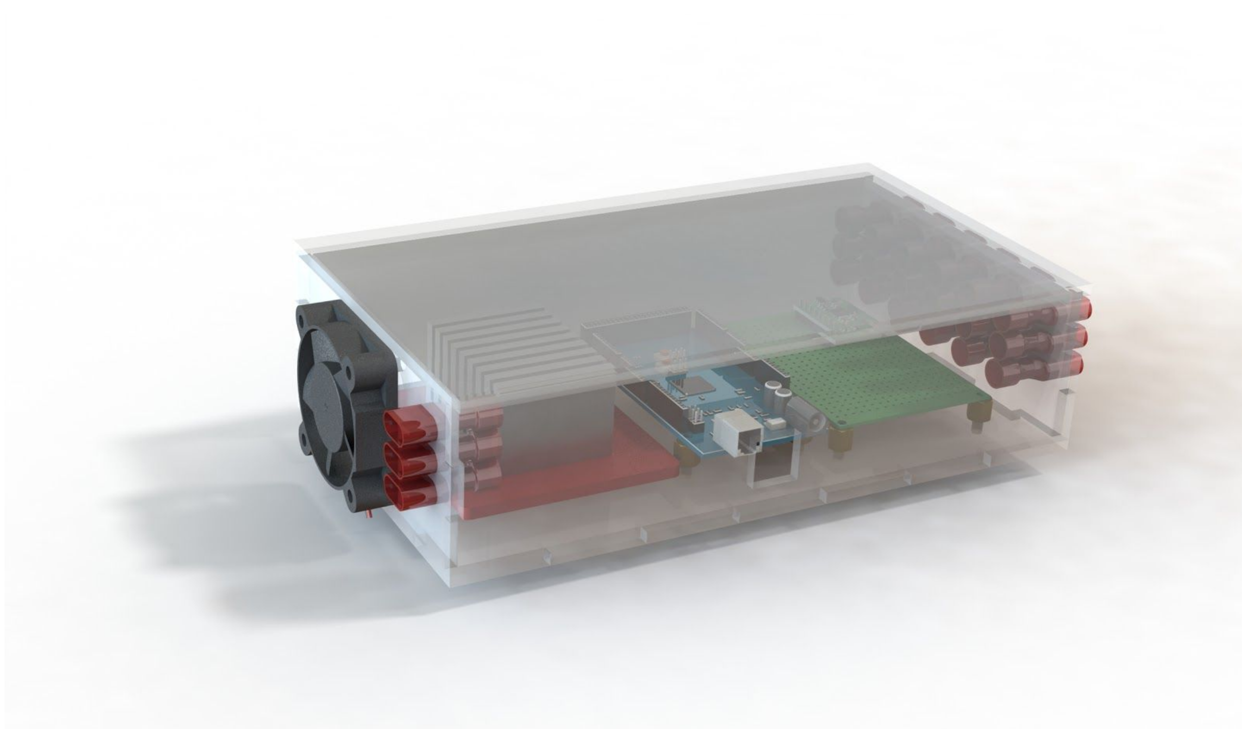


Figure 24. Low voltage controls box. Each wall has nylon spare terminals to connect wires to the Arduino microcontroller.

The high voltage circuit is powered by a 48V accumulator. The batteries used are 3.2V LiFePO4 which come as a generous donation from the Michigan Electric Racing team. Each cell is 3.2V so to reach 48V, the accumulator is running 16 of these batteries in series. Each cell has 20 amp-hours of charge. The accumulator has 2 sets of these 16 series cells for a total of 32 cells and 40 amp-hours of power. Based on the discharge curve for each individual battery, the expected nominal voltage is 51.2V, the max voltage is 59.2V, and the low voltage is 40V. Each of these 16 series battery packs is managed by a 16s 60A battery management system which balances the cells and protects from over-voltage and over-discharge.

It is vital that the user knows exactly how much battery life is left so that they do not get stranded without a working wheelchair. Based on the discharge curve of each individual battery, the voltage of each cell changes as it discharges. By monitoring the voltage across the accumulator, you can determine the charge remaining based on this discharge curve. The Arduino measures the voltage using an analog input. Since the analog input can only read between 0-5V, the 48V accumulator has to be stepped down to 5V to measure it. This is accomplished via a resistor divider. This resistor divider can be seen in Figure 25 below.

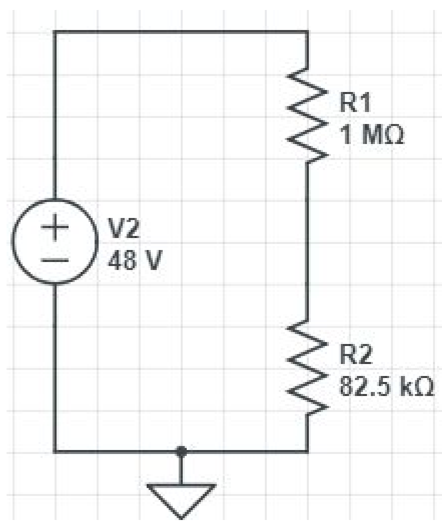


Figure 25. Resistor divider that lowers the accumulator voltage to a point measureable by the Arduino. The microcontroller measures voltage across R2 and based on the expected maximum and minimal voltage in the accumulator, the analog voltage should be between 4.51 and 3.90 volts. The downside of this system is that the accumulator is connected to the ground which results in a passive leakage current of 0.000044 A.

The accumulator is packaged in a large plywood box placed directly below the driver. Since the batteries are one of the heaviest components in the car, this results in a low center of gravity. The plywood box insulates them from the rest of the car and offers protection from the surroundings. This box can be seen in Figure 26 below.

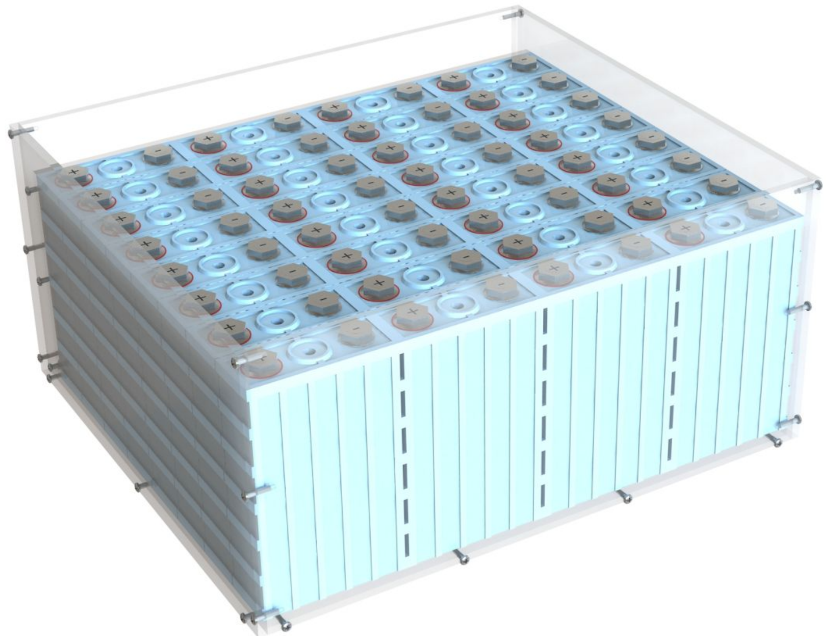


Figure 26. Accumulator placed directly below the driver. There are a total of 32 batteries with 2 parallel sets of 16 series cells.

Since the maximum expected power needed by the wheelchair is 2400W, the system will be limited to prevent it from ever exceeding this wattage. This results in a maximum current draw of 60A. The wires in the battery have to withstand this current so they will be 4AWG which are rated to 70A. The wires connected to each battery therefore have to handle 15A each so they will be 12AWG. Every other component in the wire paths will also be rated to this load and there are fuses that are 10A above the maximum expected voltage in the case of a power surge. The accumulator output also goes directly through the kill switch on the control panel which shuts off all the systems immediately.

The accumulator will be secured on the bottom plate of the chassis. The 4 motor controllers and controller box will be attached on metal plates in the front and back of the chassis.

Engineering Analysis

Our current design includes five design drivers. Our device must be capable of motor powered drive, be able to overcome soft terrains and obstacles while maintaining high safety, be torsionally rigid, be easily maneuverable and compact, and must satisfy Jason's own vision. The drivers were analyzed using theoretical and computer modeling, empirical testing, and CAD mockup construction to evaluate, refine, and optimize our design.

Motor Powered Drive

To achieve motor powered drive, our device must be easily rechargeable by Jason and able to move the weight of our device and Jason with ease. A motor powered vehicle with high torque and speed specifications requires a high power motor, and therefore a battery with a lot of charge. We conducted theoretical modeling analysis to ensure that the motor can supply sufficient torque and power. A free body diagram of one wheel on an incline was generated, where **θ** is the incline of the slope, w is the weight acting on the wheel (lb), r is the radius of the wheel (ft), and F is the force acting on the wheel down the slope (lb). The weight of the system W was estimated to be 400 lb and the radius of the wheel was our selected radius of 9.6 in.

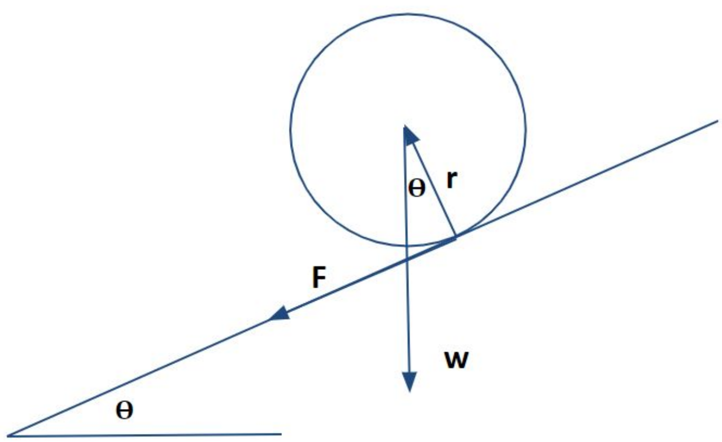


Figure 27. Free Body Diagram of one wheel. The weight is acting at the center of the wheel and is one fourth the total weight of the system.

The torque and power were then calculated for two cases, which were determined based upon our engineering requirements. The wheelchair must be able to climb the slope of a wheelchair ramp at 90% speed, and must be able to climb our maximum slope as fast as a power wheelchair. Thus, the first case uses a velocity of 9 mph at a 7.1 degree incline and the second case uses a velocity of 4 mph at a 30 degree incline. The torque and power were then calculated and shown in table 5 below.

$$T = Fr = Wrsin(\theta) \qquad \text{(Eq. 1)}$$

$$P = Fv = Wvsin(\theta) \qquad \text{(Eq. 2)}$$

Table 5.: Maximum Required Torque and Power for cases 1 & 2. Case 2 gives the maximum required power of 2.1 hp.

	θ	V (mpg)	T (lb-ft)	P (hp)
Case 1	7.1	9	40	1.187
Case 2	30	4	160	2.133

Applying a safety factor of 1.5 on the required power of 2.133 hp, the maximum required power was found to be 2.4kW, which is 600W per motor. We then performed an analysis on our batteries to ensure that this power is allowable.

We have selected 32 LiFePO4 3.2V batteries in series to power our system. These batteries have 40 Ah of charge and a max total current draw of 60A. To determine the maximum allowable power drawn by the motors, we determined the "worst-case scenario" cell voltage and multiplied it by the max allowable current. This minimum voltage was determined by the discharge curve seen in Figure 29 below:

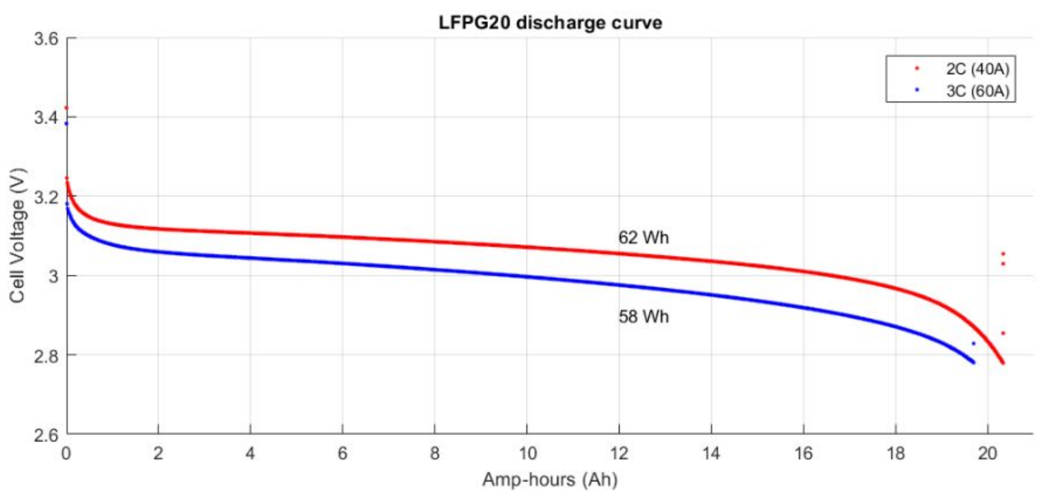


Figure 29. Discharge curve for the batteries used. The minimum cell voltage of 2.8V occurs when the battery is almost fully discharged. This voltage was multiplied by the amount of 32 cells to determine the total voltage of 90V.

Thus, the maximum allowable power (W) drawn by the system was found to be 5376W, or 1344W per motor using Equation 3, where P is the power, I is the current, and V is the voltage.

$$P = IV \quad \text{(Eq. 3)}$$

This total power of 5376W limited by the battery is greater than the value of 2400W required by our safety factor. Thus, we decided that four 1kW in-hub motors (limited to 600W by our control system) will provide sufficient power for our motor powered drive.

It is important to note that these calculations are taken at an assumed efficiency of 100% between the tires and the ground. Realistically, this will not be the case, as the wheelchair will be traveling over various rough terrains. The power provided to the ground by the wheel will decrease proportional to the coefficient of friction between the tire and the ground. The coefficient of friction between rubber and sand was found to be 0.6 [24]. Thus, the power provided by the wheels will be scaled down by a factor of 0.6 when traversing sand. These factors should be considered by Jason as he traverses various terrains with differing coefficients of friction.

Overcome Terrains

Another design driver is the ability to overcome soft terrains and obstacles while maintaining high safety. This means our device must not tip and must not sink in soft terrains. Thus, we performed a theoretical modeling analysis to determine the minimum size of the wheel base to prevent tipping, and to determine the wheel size to prevent sinking in soft terrains. A free-body diagram was constructed to model the wheelchair on an incline, where Θ is the incline (degrees), d is the wheelbase (inches), h is the height of the center of mass (inches), r is the wheel radius (inches), W is the weight of the system (lb), and x is the distance from the line of the center of mass to the center of the back wheel (inches).

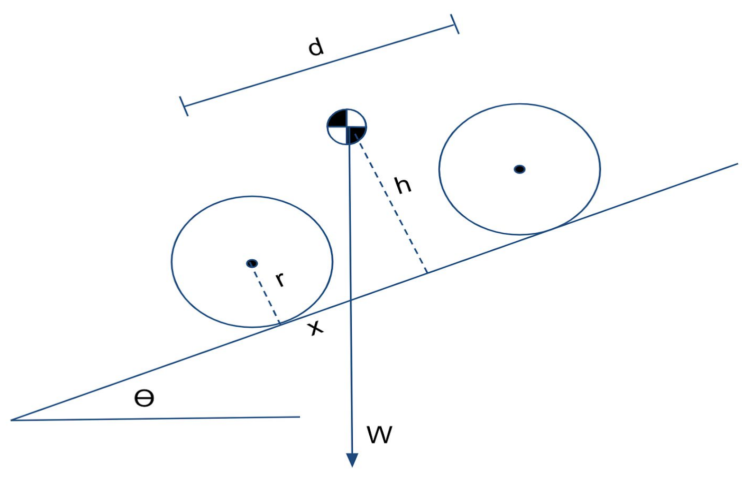


Figure 30. Free-Body diagram for wheelchair on an incline. The higher the angle of the incline, the smaller the distance x to the wheelbase and the more likely tipping is to occur.

Tipping occurs when the line of the center of mass crosses the center of the wheel, and this is defined as when the value "x" is equal to zero. This is more likely to occur when the angle of the incline increases, and when the wheelbase "d" is decreased. The maximum slope our chair can climb is 30 degrees, so we solved for the size of the wheelbase in that case to determine the minimum allowable wheelbase length. Thus, we analyzed the case which the line of the center of mass is directly above the center of the rear wheel.

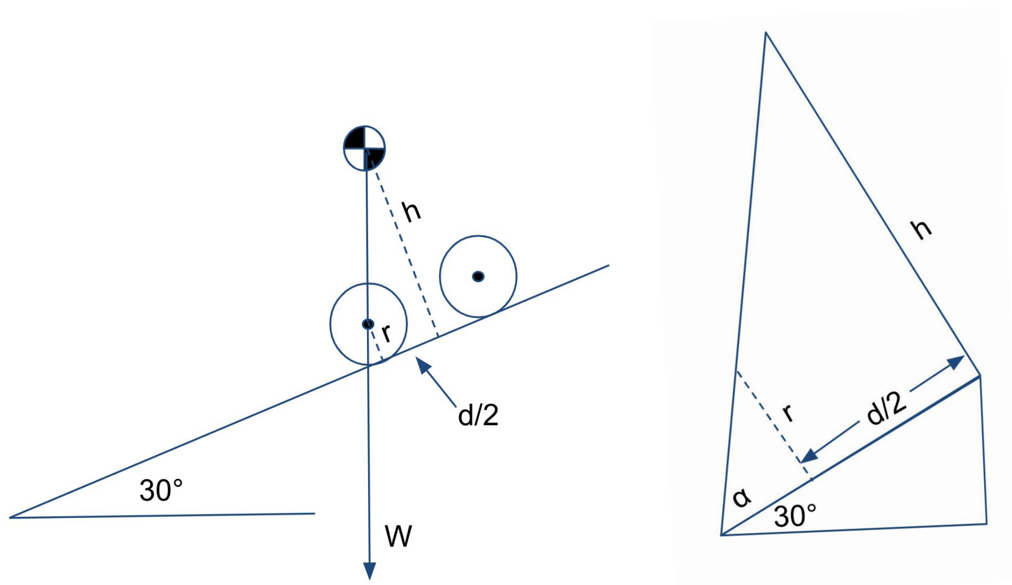


Figure 31. Free-Body diagram for wheelchair on max incline with min wheelbase. Analysis of this model gives us the minimum allowable wheelbase to prevent tipping.

When the Center of Mass (CM) lies directly above the rear wheel, the moment where tipping occurs, the angle α between the hill and the weight of the wheelchair is 60 degrees. In order to find the minimum wheelbase d for the maximized "worst case scenario", we assume the height of the CM is the height of our seat at 16 inches and that the radius of the wheel is 0. Thus, the wheelbase can be solved trigonometrically.

$$d = 2[\,h/tan(\alpha) - r/tan(\alpha)] \qquad \text{(Eq. 4)}$$

The minimum wheelbase d was calculated to be 18.47 inches. We applied the analysis seen in Figure 30 to solve for the distance x between the line of the center of mass and our back wheel. Using a wheelbase d of 32 inches, the selection of which is discussed in the following section Maneuverable and Compact, height h of 16 inches, and angle ϴ of 30 degrees, the distance x was found to be 7.58 inches, which is about half the distance between the center of the wheelchair and the back wheel. Thus, our chosen wheelbase of 32 inches is sufficient to prevent tipping, because at the maximum incline the center of mass is far away from the edge of the wheel base.

The same analysis was performed, but this time when the wheelchair was driving sideways on an incline. Since the width of the chair is fixed at 32 inches, we solved for the maximum incline theta that can be driven on before tipping occurs. A similar free body diagram using h = 16 inches and w = 32 inches gave the following equation for the theta that causes tipping.

$$\Theta = tan^{-1}(2w/h) \quad \text{(Eq. 5)}$$

This gives Θ = 45 degrees, which is much higher than our maximum allowable incline of 30 degrees. Thus, we concluded that the chair would also be safe while traveling on an incline.

We then performed an analysis to determine whether the wheelchair could perform in soft terrains without sinking. We found the recommended maximum ground pressure for soft terrains such as marshes and sand to be 2 psi. [23] A theoretical modeling analysis was performed in order to determine the maximum ground pressure exerted by the tires. A free-body diagram was constructed to represent the wheel traveling on a soft terrain, where W is the weight exerted on the wheel (lb) and Ac is the contact area of the wheel on the ground (in^2), with w and L being the width and length of the contact area (in).

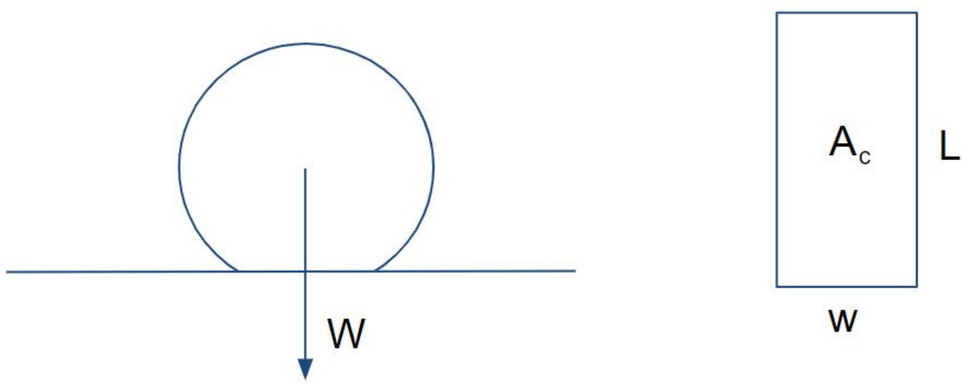


Figure 32. Contact area of the tire and the ground. The weight of the vehicle will cause the tire to flatten slightly on the ground, which forms the contact area Ac. This contact area is dependent on the wheel's dimensions and the pressure inside the tire.

Our chosen tire has a width of 5 inches and a diameter of 19.2 inches. Thus, we approximated w to be 2 inches and L to be 5 inches, giving Ac = 10 in^2. The ground pressure P exerted by the tire on the ground (psi) was calculated, where F is the weight exerted on the wheel of 100 lb.

$$P = \frac{F}{Ac} \quad \text{(Eq. 6)}$$

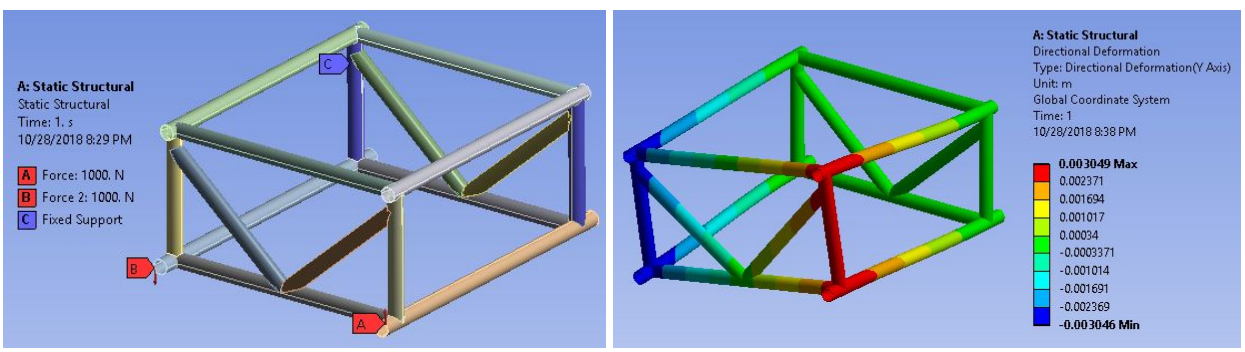
The calculated pressure of 10 psi is greater than the recommended pressure of 2 psi. However, we believe our design is still reasonable because 10 psi is similar to the pressure exerted by a human while standing, which is between 9-11 psi. [23] Although the wheels may sink slightly in a soft terrain, the torque applied by our in-hub motors will be sufficient to overcome this.

Torsional Rigidity

The wheelchair will be subject to impact loading from traveling over rough terrain. In order for the vehicle to resist deflection under these impacts, it must be torsionally rigid. Having a rigid chassis will prevent deflections large enough to cause high stresses and potential fatigue on components attached to the chassis as well as the chassis itself. Torsional rigidity can be defined as the torque applied to the chassis about the longitudinal axis divided by the change in rotation about the same axis. This equation to calculate torsional stiffness is Equation 7 where T is the torsional stiffness, F is the force applied, l is the distance away from the centerline the force is applied, and θ is the angle the chassis rotates.

$$T = \frac{Fl}{\theta} \qquad \text{(Eq. 7)}$$

In order to find the deformation angle, we set up an Ansys model. We fixed the rear pillars and loaded the front ends of the tubes with 1000N per side in opposite direction. This setup can be seen in Figure 33a. The *y*-displacement of the tube ends were found to be 3.04mm and -3.04mm respectively as seen in Figure 33b.



(a) **(b)**

Figure 33. (a) Ansys model constraints setup. (b) Ansys model *y* displacement results.

The displacement y is converted into an angle θ using Equation 8 where y is the maximum displacement and w is the width of the chassis.

$$\theta = sin^{-1}(2y/w) \qquad \text{(Eq. 8)}$$

From the results of Equations 6 and 7, this chassis has a torsional rigidity of 2500 Nm/deg. This is just above what is typical for a racecar and since this frame is under much less for than an actual car, this stiffness is sufficient for the wheelchair.

Maneuverable and Compact

The final machine must be readily maneuverable within tight places like forest trails and compact in order to fit on the wheelchair lift Jason will use to transport the device. To achieve a high level a maneuverability we steered away from conventional mechanical turning methods, like a car with a steering wheel, and opted to maneuver by varying the power of the wheels on either side of the vehicle. Though steering performance at higher speeds is sacrificed when compared to other method of steering, the turning radius is effectively zero.

The compact constraint is introduced by the need to transport the device with Jason's 32 inch by 36 inch wheelchair lift on the rear of his vehicle. The lift is orientated such that, to load the wheelchair, one drives onto the lift in the opposite orientation of the vehicle the lift is mounted on, illustrated in Figure 33. We selected a wheelbase of 32 inches and a width of, corresponding to the lift dimension of 36 inches and a width of 32 inches corresponding to the lift dimension of 32 inches, so the wheelchair can be loaded for transportation quickly. The reasoning behind this is the user will not have to worry about centering the wheelchair perfectly on the lift. The contact patch of the tires will be contained within the dimensions of the lift to prevent the wheelchair slipping off the lift during transportation, though it will be secured with straps.

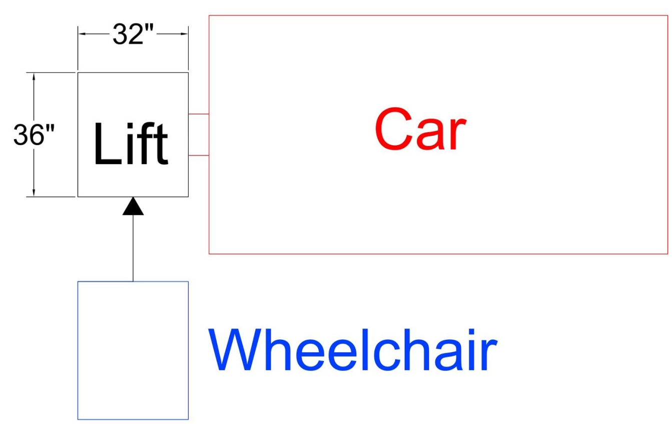


Figure 34. Top view of Jason's car and lift. Jason's current 36 inch by 32 inch wheelchair lift mounts to a tow hitch and lowers flush to the ground. The wheelchair remains on the lift, outside of the vehicle, for the duration of the transportation time.

The dimensions of the lift limited the dimensions of the wheelchair to a maximum width of 32 inches and a maximum wheelbase of 32 inches. These limitations drove many design decisions, and especially affected the construction of the chassis and placement of the suspension. A CAD mock-up model was the best way to depict our design and ensure that the design supported the wheelchair's ability to fit on the lift.

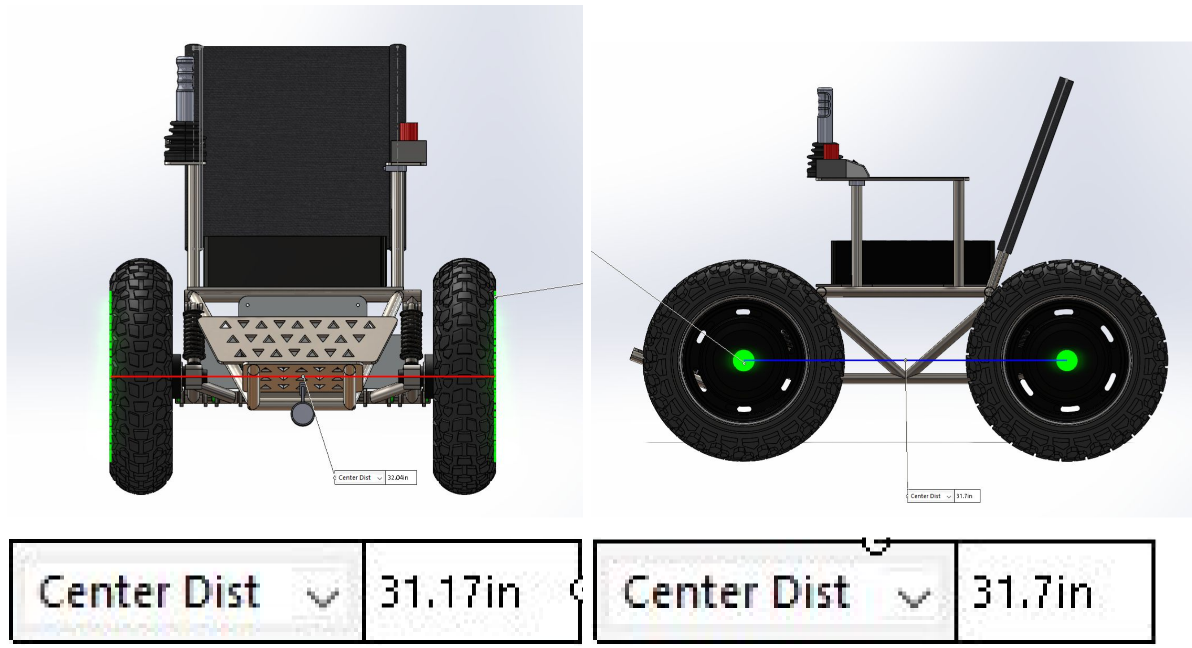


Figure 35. Front and Side view of wheelchair dimensions from CAD mockup. The finalized dimensions of the wheelchair with our chosen wheels will fit on Jason's lift, as they both fall within our desired range.

The side view depicts the measurement of the wheelbase only. This distance is about 32 inches, which allows for about two inches of contact beyond the wheelbase for each wheel on the 36 inch long lift. Thus, we are confident that the maneuverable and compact design driver is fulfilled by our design.

Satisfy Jason's Vision

Finally, the wheelchair must satisfy Jason's own vision. If he does not like the appearance or feel of this product, Jason will not use it. To achieve Jason's approval of our end vehicle we gave him a trade study between different designs and allowed him to have a part in deciding which design is our final goal. The trade study included pugh chart scoring results for tracked and wheeled solutions and preliminary CAD mockups of those models. This process is discussed in more detail in the "concept selection" section on page 18. Jason confirmed that we had his approval to move forward with either design as long as it was able to meet the engineering requirements.

Beyond the engineering requirements, Jason noted a few design preferences that he wished for us to take into account. As part of his "vision" for the project, Jason repeatedly mentioned that he "did not want the device to be a vehicle. It must look like a wheelchair and feel like a wheelchair". As part of this vision, he did not want a steering wheel or levers to control the device, but simply wanted one joystick. In order to "feel like a wheelchair", Jason wanted to be able to sit up straight in the device and be seated "in" the device, rather than "on top of it". He also mentioned that he has a seat cushion that he already enjoys using and wishes to continue using it. This cushion is the roho quadtro select high profile cushion. These requests were reflected by our design.

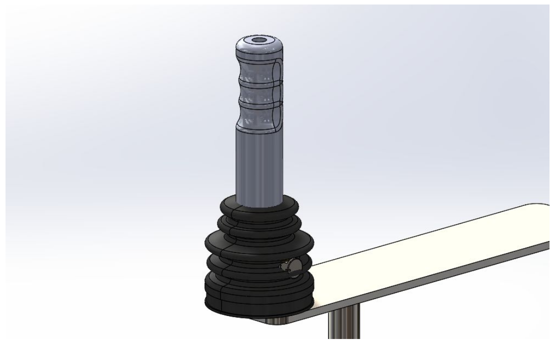


Figure 35. Joystick. We honored Jason's request to use a joystick to control the system, which is equipped with potentiometers to support forward, backward, and rotational movement.

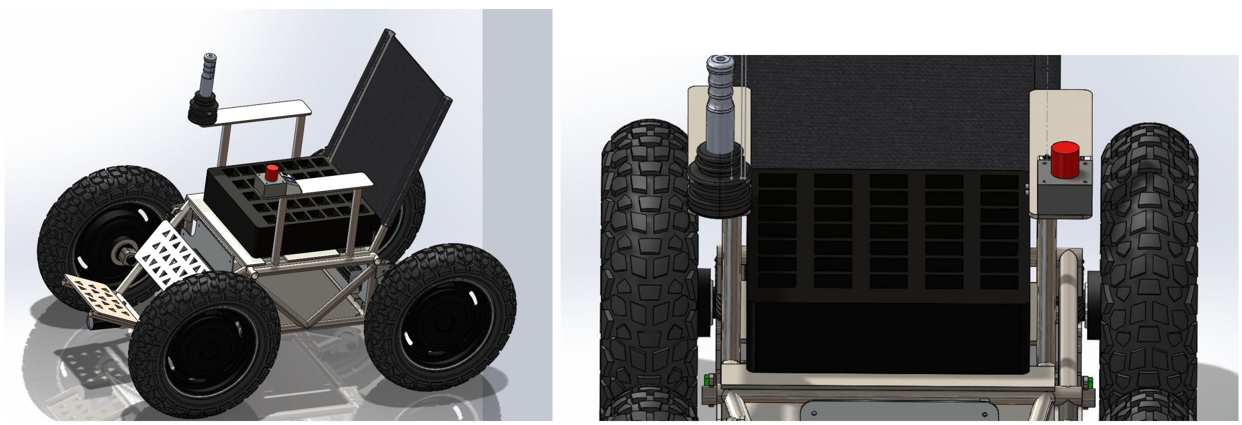


Figure 36. Wheelchair footrest and cushion. The seat cushion was inserted using the CAD provided online for the roho quadtro cushion.

The human machine interfaces were designed such that Jason's vision for the project would be fulfilled. A foot rest was inserted so that Jason could be comfortable, and because it helped the system to "look and feel" more like a wheelchair. The seat was designed so that the measurements matched the dimensions of the provided seat cushion. The entire system was designed so that the chair was seated high enough to avoid obstacles, but low enough so that it did not look as if Jason was sitting "on top" of it. These considerations give us confidence that our design meets Jason's vision for the project.

Failure Mode Effects Analysis (FMEA)/Risk Analysis

Item	Function	Potential Failure Mode	Potential Effects of Failure	Severity of Effect	Potential Causes / Mechanisms of failure	Occur within year	Current Design Controls	Detection	RPN	Recommended Action
Hub motors	Regenetive Braking	Does not brake	Colisions and user injury	9	Motor overheating or water damage	3	Comes within motor	3	81	
	Drive	Does not move chair	Stranding user or not functioning	7	Motor overheating or water damage	3	Comes within motor	3	63	
Controls	Controlling Motor	Fails to control motor power	Chair does not move, user stranded	7	Motor controller overheating	1	Code	5	35	
	Controlling Braking	Fails to control braking	Colisions, and user injury	9	Code failure with braking	2	Code	2	36	
	Steer	Does not steer	function	6	broken joystick	2	Code	2	24	
Suspension	Reducing impact	Does not reduce impact / function	Injury to patient or broken controls/frame	9	Sheared bolt or broken tab	5	Ensuring stability through frame geometry	3	135	
Joystick	Controlling Steer	Does not steer accurately	Collisions or does not function	6	Broken potentiometer	5	potentiometers for acceleration to ensure that at	2	60	
Battery	Provide power to the motors and controls	Overheats	Fire underneath the driver	10	Failure in the battery management system	5	Ensure battery has surrounding air to cool	5	250	
Chassis	Provides a rigid structure that all components are mounted to.	Rusts in two/ welds break	Device is immobilized or causes injury to user	9	Rusting due to worn off enamel/a sudden abrupt force (device being dropped directly on chassis)	3	provide nonstructural guards around the chasssis locations that are at the greatest risk for being scraped (underside of chassis)	5	135	

Risk Analysis

Hazard	Hazardous Situations	Likelihood	Impact	Level	Technical Performance	Schedule	Cost	Action to Minimize Hazard
Dead Battery	When using the device for extended periods of time, the battery can die and shut down the device. This can cause the patient to be stranded in the chair.	High	Serious	5	The wheelchair cannot perform without a functional battery, therefore there must be a mechanical backup.	Minimal impact	Low	Add a mechanical backup to the system, either wheels that can be turned manually or a hook on for a foldable wheelchair.
Crash	When using the device, the user may fail to stop in time to avoid an object, causing the device to impact another object.	Medium	Serious	4	The wheelchair must be able to survive impacts.	Able to meet key dates	Medium	Ensure high strenth components and good structure/restraints surrounding user.
Electric Shock	When using the device, the circuit could accidentally short or connect to the chassis and shock the user	Low/Medium	Serious	4	The HV system must be insulated	Able to meet key dates	Low	Waterproof electrical components and insulate all high voltage components
Mechanical Failure	When using the device, the user may go over uneven surfaces which causes vibration to the frame. Over a long period of time, it may cause failure in the chassis or transmission	Medium	Serious	4	The frame and subsystems attaching to it must be strong	Already accounted for	Medium	Have a mechanical back up and ensure high strength components and good structure/restraints surrounding user.
Controls Failure	Driver is unable to electronically control the vehicle and accelerates out of control	Medium	Medium	3	There must be manual overrides to the controls	Able to meet key dates	Low	Have mechanical brakes and a circuit shut down switch to shut off the system in the event of an emergency.
Terrain Integrity	User drives over terrain that is unstable and may drop from underneith them (soft soil on a hillside)	Low/Medium	Serious	5	The wheelchair must not harm or eject the user if overturned.	Able to meet key dates	Low	There must be a roll bar and seat belt device to restrain the user in the veicle without the vehicle crushing them if overturned.

After analyzing the failure mode for our design, we have determined that the aspect with the highest risk in our design is the battery system. The battery provides power to our motor and control systems which is essential to the wheelchair.

Electrically, the battery could fail when the input voltage is too high or too low which causes excess or insufficient current. This is relevant to our control design because of how complex the system is and the amount of current required to drive the motors. Since the battery is running non stop when the user is using the wheelchair. The batteries has the risk of overheating which could cause catastrophic failure. The electrical and thermal risks of the battery design are alleviate by the battery management system (BMS), careful design/analysis of the wiring, and the use of the lithium iron phosphate (LFP) batteries. The BMS balances the cells and prevents overcharging. LFP batteries has very constant discharge voltage and has more thermal and chemical stabilities compare to other lithium-ion batteries.

In addition to the electrical and thermal risk, the battery could suffer from mechanical deformation when traversing through rough terrains and could cause failure when the chassis undergoes severe vibration or crash. There will be a wooden enclosure that guards our battery while insulating it and it will be attached rigidly to our chassis.

The battery life is also a great concern for us as the current battery gives us 40 minutes of runtime at full load. This could be a problem when the user is traversing terrains that requires a long time. We will implement LCD screens that shows the battery life to alert the user when the batteries are running low and are designing space for more batteries to extend the battery life.

Current Challenges

In the process of completing our design and manufacturing plans, we have identified several areas where potential challenges may arise. The most complex part of our manufacturing will be the welding that is required. The chassis and suspension will be assembled by welding together 1” diameter steel tubes. In the suspension, there are several welds that need to be completed in a very tight space. If this is not completed correctly, the parts will need to be remade. We will address this issue by taking extreme care with the welding and creating small fixtures to complete them with considerable accuracy.

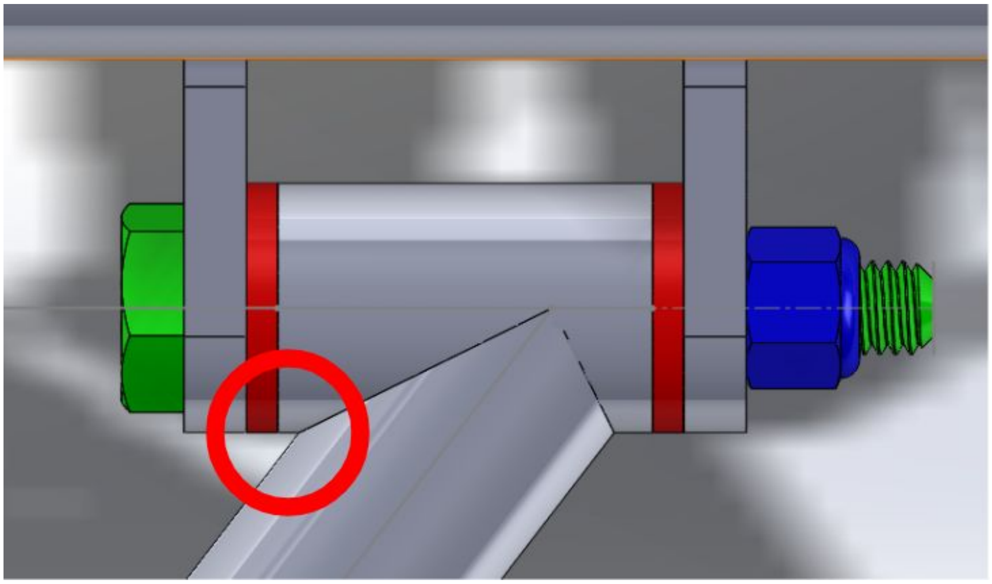


Figure 36. The angled bar of the suspension control arm leaves little room for error while welding.

The control systems will require a significant amount of expertise. The system must be wired correctly to ensure it will be safe for use. The arduino code will require a lot of work, as it performs many functions. It must command the in-hub motors to provide sufficient torque and speed to each wheel, which must be able to operate independently from the others. The wheels must be able to turn forward and in reverse, and operate in sync based upon the joystick control. The wheels must also be able to brake on command and shut off when a kill switch is flipped. We must be able to complete the code in time to be able to troubleshoot. If the coding isn't completed correctly, the wheelchair will not be functionable. We have addressed this issue by seeking advice from Toby in the mechatronics lab, and will continue to utilize his help for the remainder of the project.

Initial Manufacturing Plan

Our wheelchair design is a full vehicle consisting of many subsystems. As a result, it will require several manufacturing processes.

The frame will be a welded steel tube assembly. We will use a bed plate in the Wilson Student Team Project Center to weld the chassis. The 1" x 0.049" steel tubes will first be cut to length. We will then tig weld the tubing together after having ground and shaped the connection points with an angle grinder for optimal contact. We will start by tac welding the square upper and lower sections of the chassis. Then we will tac the vertical bars to one of these square sections.

Finally, we will tac the remaining square section and crossmembers. We will then measure our completed chassis to ensure we are within error. We will then weld on to the chassis the brackets made using the waterjet.

To make the A-arms we first need to machine the hinges where the bushings are pressed in and the axle hub that the wheel shaft is mounted. We will machine the hinge on the lathe using 1 inch diameter solid rod stock. The hole will be drilled and reamed at this time. We will then weld this part onto the A-arm using a jig for positioning. After the part is welded the bushings will be pressed into the hinge part. The axle hub will be machined first on the lathe to make the round profile that is welded into the A-arm tube. The part will them be milled to create the motor shaft hole and the keyway. This part will then be welded onto the A-arm to complete the assembly.

The chair will require multiple manufacturing processes. The armrests, chair backing frame, and footrest will be welded to the chassis. The seat backing will be a standard canvas piece that is slid over the chair backing frame bars. The seat plate will be mounted to the chassis through the use of brackets to allow for easy battery access during testing and may be welded on at a later date.

The boxes containing the electronic systems are laser cut and then screwed together. Low voltage wires will either be soldered together or crimped and high voltage wires will be crimped with ring terminals and screwed together.

Detailed manufacturing plans for individual parts are shown in Appendix D.

Design Updates 11-16-18

The design remains relatively unchanged when compared to our previous design review because it was necessary for us to start manufacturing early in order to complete the project. Nonetheless, there have been some changes.

Chassis

The only major change within the chassis is the elimination of waterjet motor controller mounting panels. Instead, the motor controllers will be mounted directly to the battery box. This results in a cleaner design aesthetically as well as being lighter and easier to manufacture.

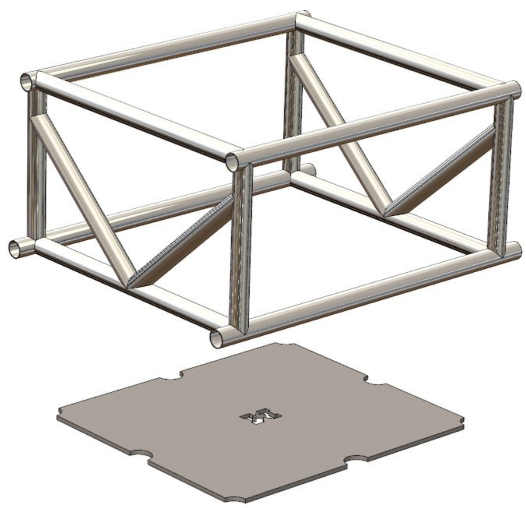


Figure 37. Final chassis structure with base plate which is welded within the bottom frame rails.

Controls

The previous HV accumulator was constructed of ¼" acrylic and screws. The most recent iteration is constructed of ⅛" HDPE. This change was brought on by budget limitations. The controls box remains unchanged.

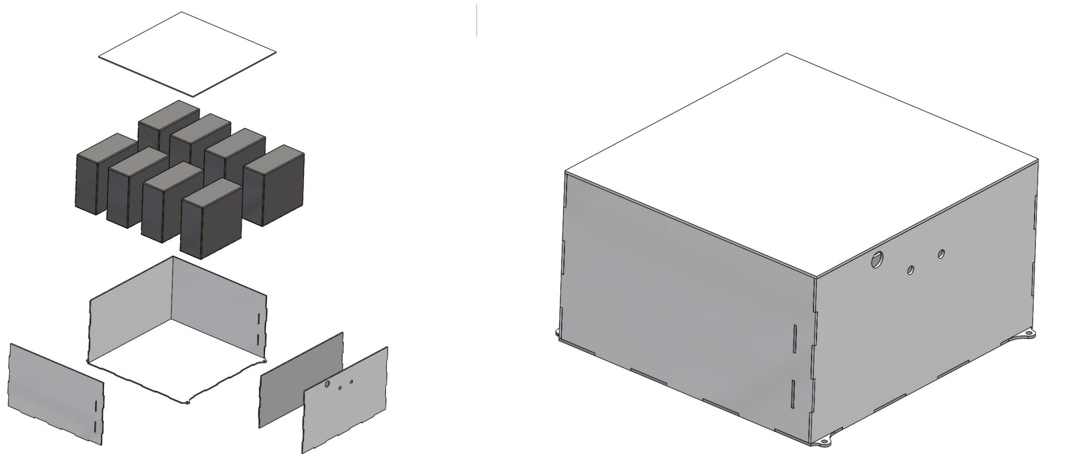


Figure 38. Final 48V high voltage accumulator box constructed of ⅛” HDPE.

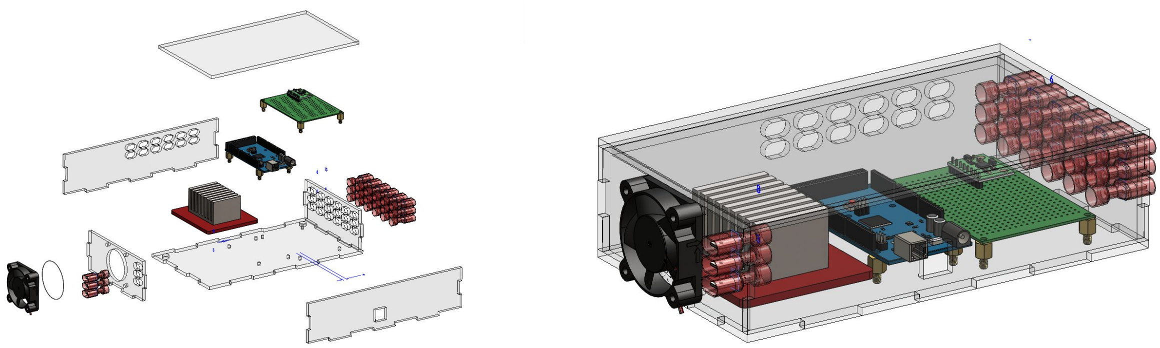


Figure 39. Final controls box constructed of ⅛” HDPE

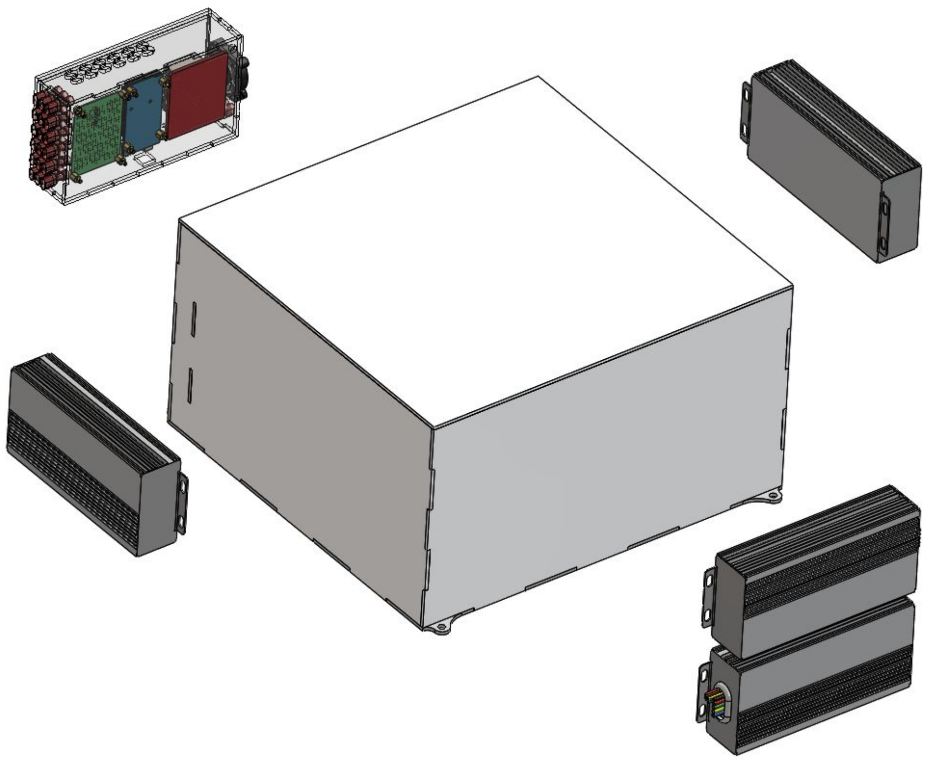


Figure 40. Final integration of all controls components. The motor controllers and controls box will be attached to the HV accumulator with velcro or two sided adhesive.

Human Machine Interfaces

The most changes, when compared to design review three, are present within HMI. The joystick remains fundamentally unchanged although the size of the handle has been decreased to be more ergonomic as well as aesthetically pleasing. The leg rest plate has been eliminated is exchange for a soft velcro strap provided by jason to increase comfort and decrease weight.

The largest change is the addition of a roll bar. This was added because the increase in weight was minimal when compared to the added safety. It is important that the user, Jason, is not trapped under the device in the event of a rollover. The rollbar also serves as a headrest.

The last changes were the addition of structural support members. First, between the armrests and backrest and second, between the chassis and footrest. Originally, the backrest consisted of two long tubes welded to the chassis in one spot. This produced a long lever which is prone to fatigue and failure. The addition of support, tieing in the backrest with the armrest, prevents failure from regular use and also provides support to the rollbar in the event of a rollover. The leg rest support serves the same purpose of reducing fatigue and failure from regular use including the user transitioning to the chair. These revisions can be seen in Figure 41.

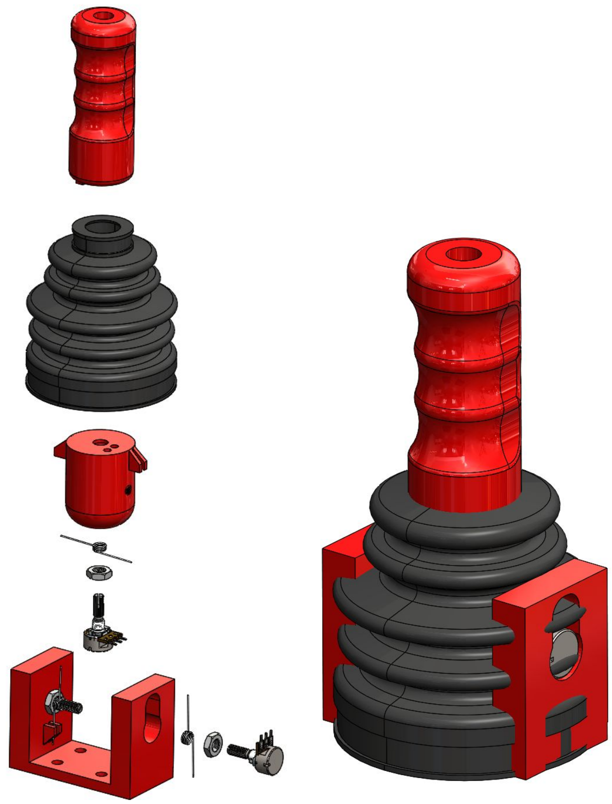


Figure 41. Final joystick design. 3D printed components are depicted in red for the sake of clarity (black in real life).

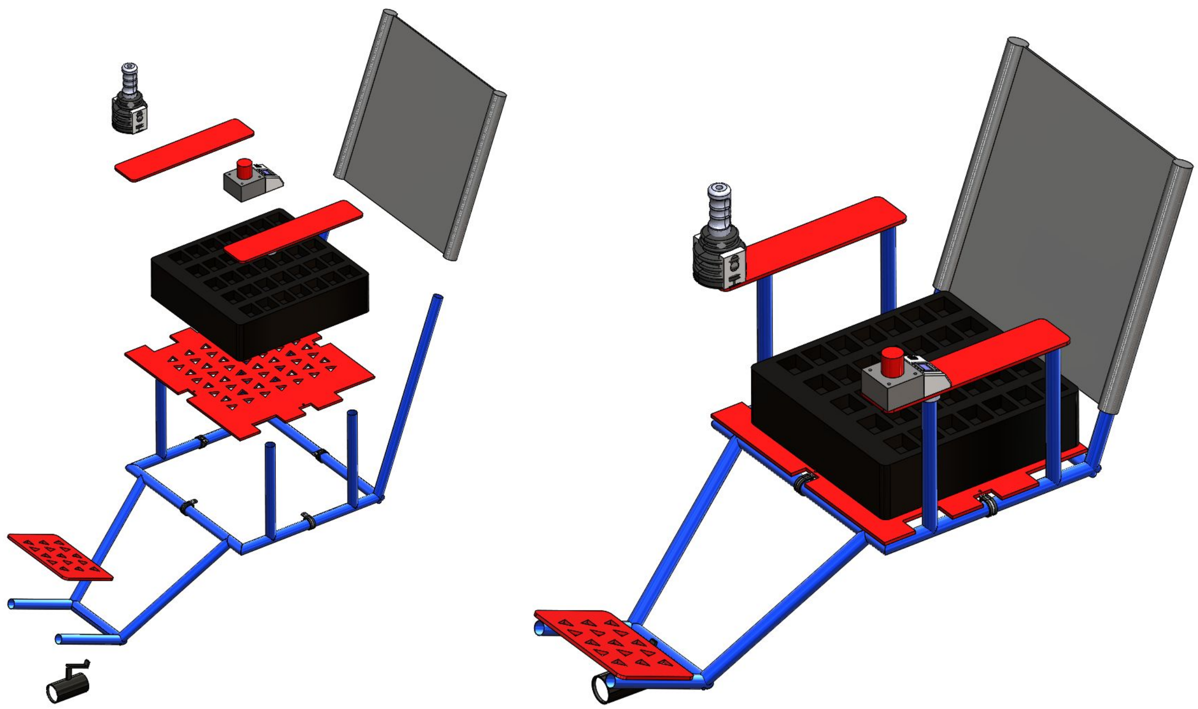


Figure 42. Final human machine interface design. Steel plate is depicted in red and 1” OD steel tubing is depicted in blue for clarity.

Figure 43. Human machine interfaces changes included the addition of a roll bar, backrest structural support, and leg rest structural support.

Powertrain

Changes in powertrain included reducing the motor size from 1000W 12 inch in hub motors to 800W 10 inch in hub motors to be within budget. All engineering requirements are still met. Another change included the revision of the axle hub part so it could be manufactured within budget while still utilizing a key for torque transfer.

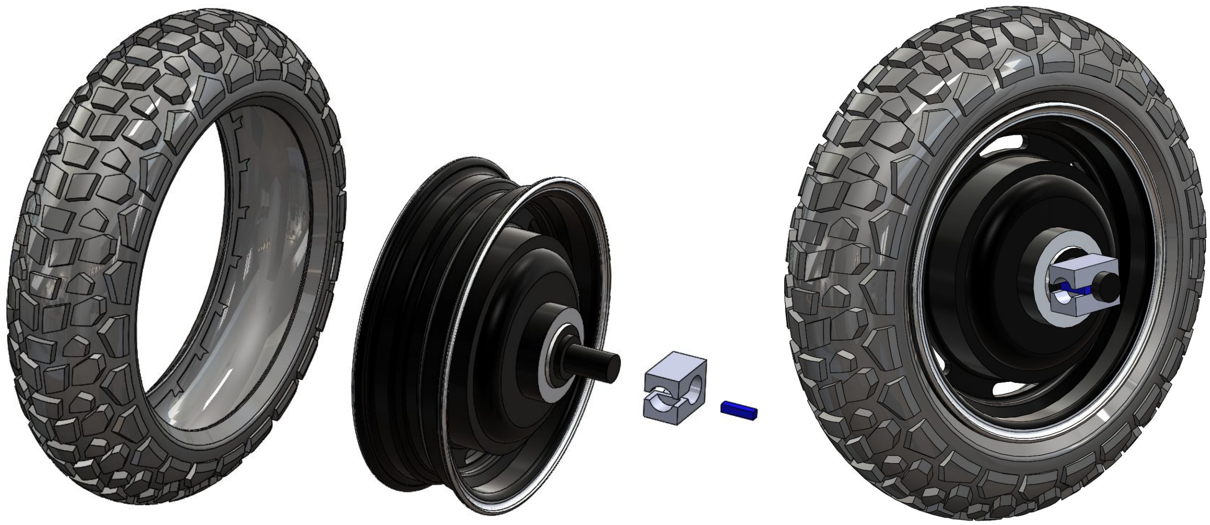


Figure 44. Final powertrain design with 800W 10” in hub motors and 19.5” diameter tires.

Suspension

The suspension remained the same following design review three.

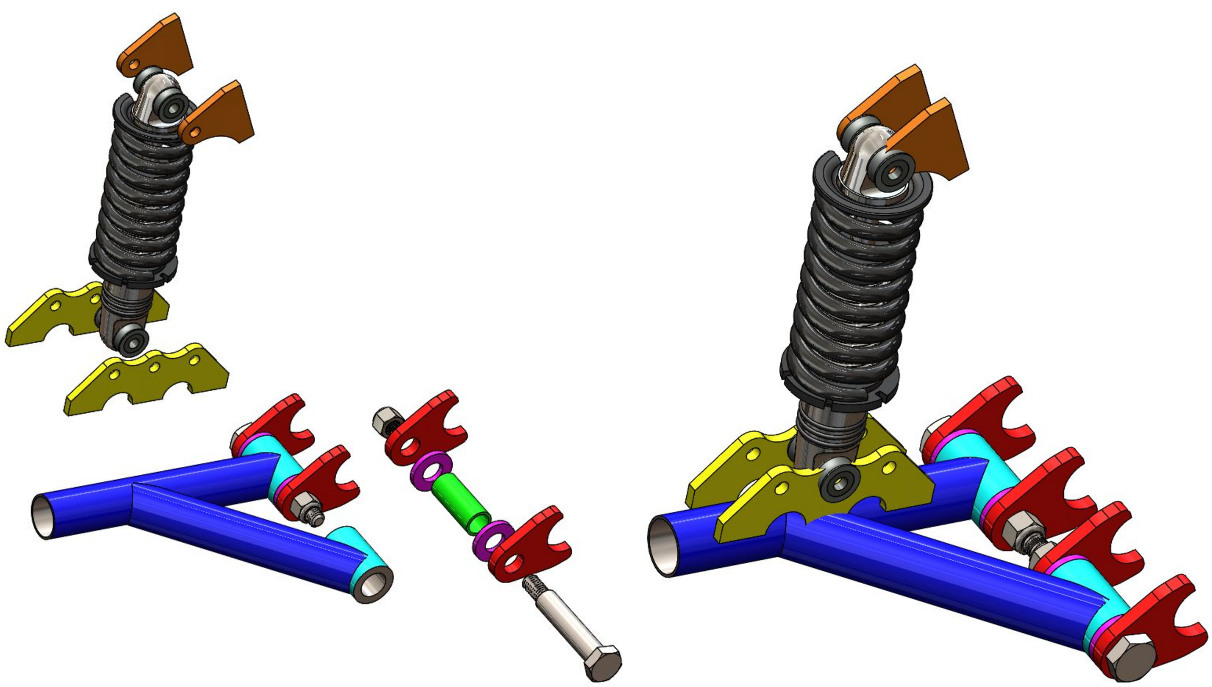
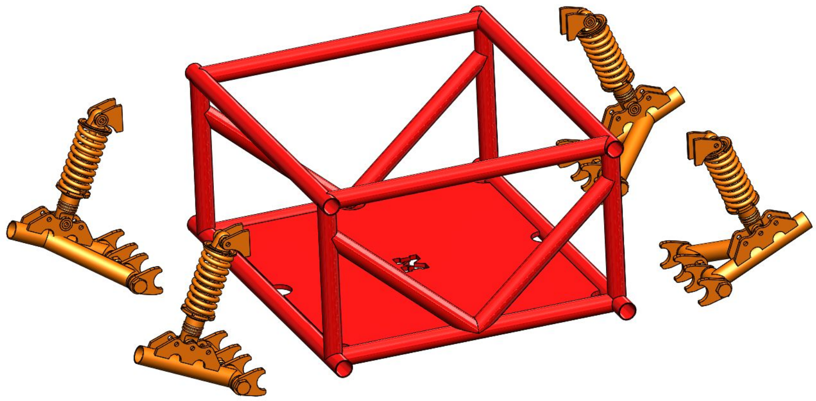


Figure 45. Final design of suspension. The control arm (1” OD steel tubing) is depicted in blue, bushing housing (1” steel rod) in cyan, control arm tabs (3/16” steel plate) in red, lower spring (3/16” steel plate) tabs in yellow, and upper spring tabs (3/16” steel plate) in orange for clarity.

System Integration

The integration of systems and subassemblies is largely unchanged. Following chassis assembly, suspension is attached. Then the human machine interfaces, powertrain, and controls can be assembled and attached.



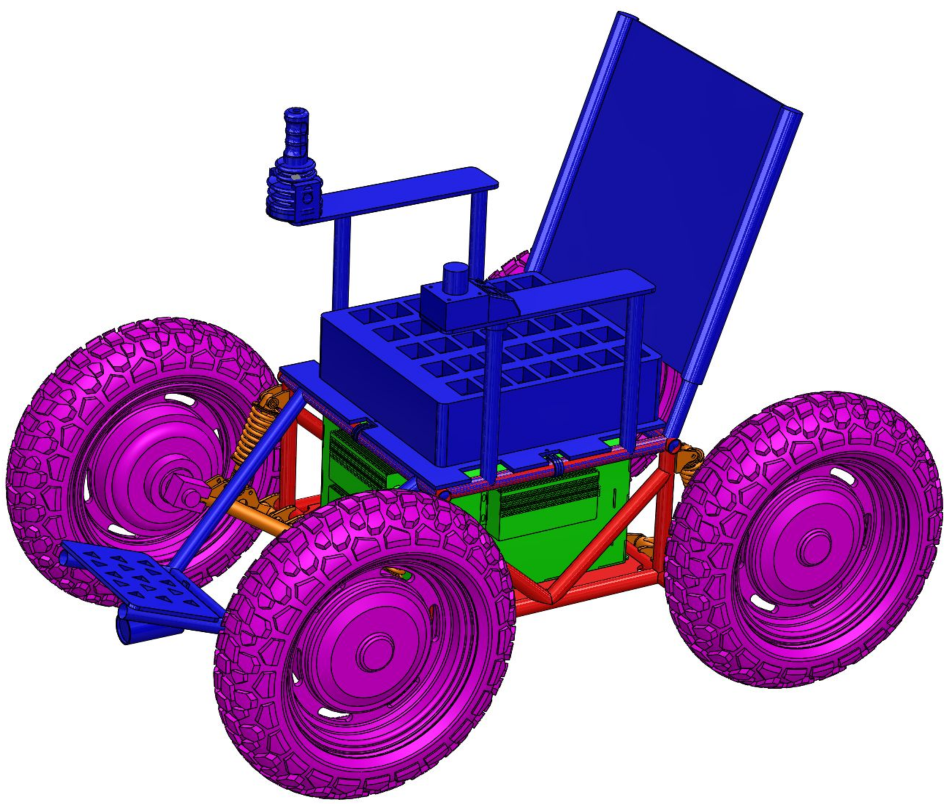


Figure 46. Final system integration is depicted above with chassis in red, suspension in orange, powertrain in pink, human machine interface in blue, and controls in green.

Design Updates 12-11-18

The electrical system saw major changes after the 11-16-18 updates due to an increased knowledge of the motor controllers. The official documentation on the motor controller was lacking and we did not know how to operate most of it until after testing. The official wiring diagram for the motor controllers can be seen in Figure 47 below.

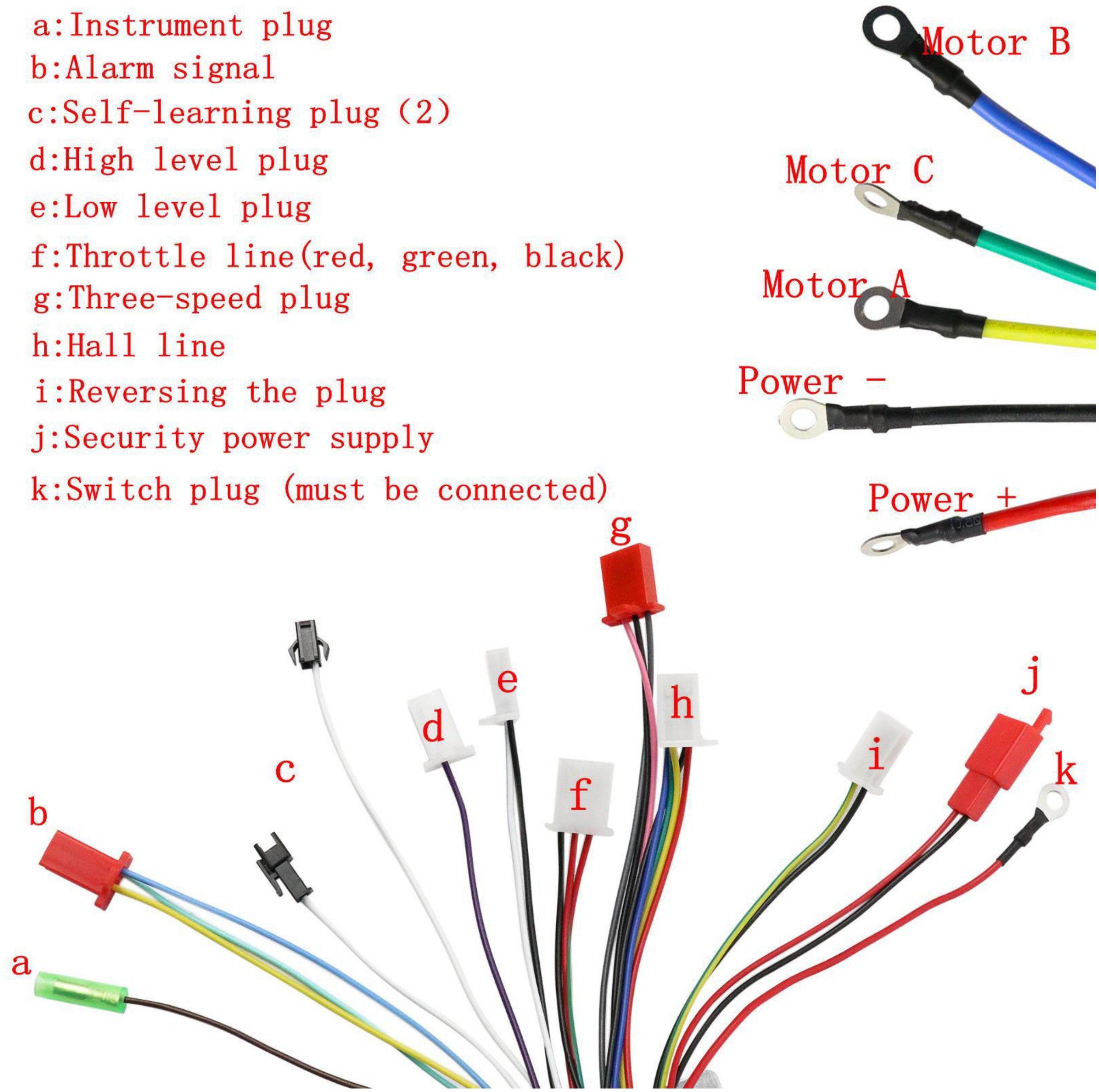


Figure 47. Official wiring diagram for the 48V 800W e-bike BLDC motor controller

An explanation for what most of these connectors do came from a forum post by "Philif" (https://endless-sphere.com/forums/viewtopic.php?t=96736). An explanation of what each connector can be seen in Table 6 below.

Table 6. Explanation of what each of the connectors on the motor controller does

Plug Name	Use	Signals sent/received
Instrument Plug	Informs an instrument panel how fast the motor is moving	Sends voltage corresponding to speed from 0-48V
Alarm signal	Powers and controls an alarm	Unknown
Self-learning plug	Flips the direction the motor spins permanently	Unknown
High level plug	Activates dynamic braking	Accepts 12V
Low Level plug	Activates dynamic braking	+5V/ground
Throttle line (red, green, black)	Controls how fast the motor spins	+5V/analog input/ground
Three-speed plug	Changes the range of speeds for the motor	+5V/ground/+5V
Hall line	Tells the motor controller how fast the wheel moves	+5V/ground/digital inputs
Reversing the plug	Reverses the motor direction temporarily	+5V/ground
Security power supply	Powers security components	+48V/-48V
Switch plug	Sends low voltage power to the controller	Accepts +48V

It was initially believed that sending a high signal to connectors such as the low level plug or reversing the plug would activate them. However, it was found that they are actually triggered by sending the +5V signal attached to each of these wires to ground. The new design has NP2222 transistors which connect these signals to a common ground and are triggered by digital signal from the arduino controller. Figure 48 below shows how each motor controller is wired.

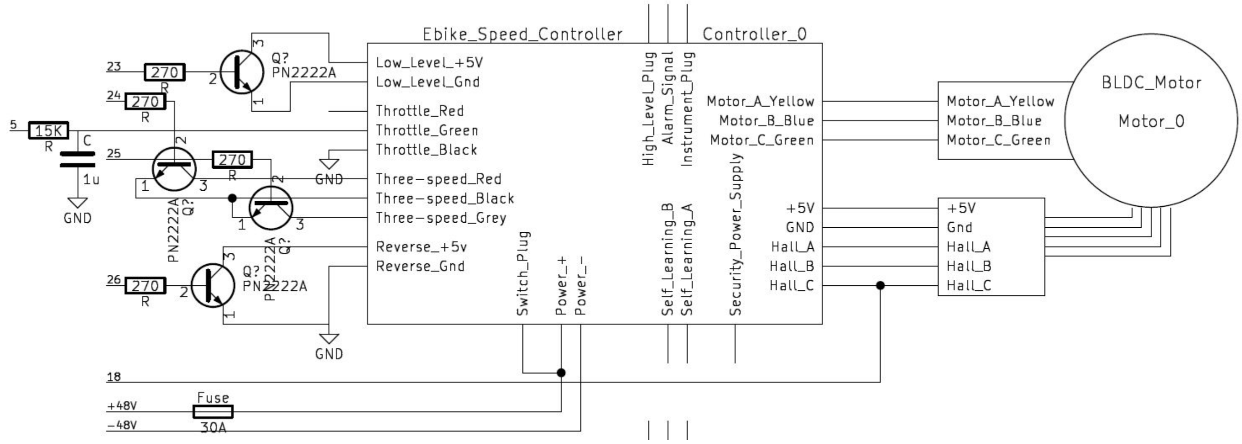


Figure 48. Wiring diagram for a motor controller. The low level, three speed, and reverse plugs are operated with transistors and the throttle is controlled by a PWM signal converted into an analog one by a low-pass filter.

The user interface was modified to not only include a toggle switch in addition to the LCD display and gyroscope. This toggle switch sends a digital signal to the arduino to tell it when it is flipped and the Arduino will not cause the motors to move unless it is flipped. The wiring for this system can be seen in Figure 49 below.

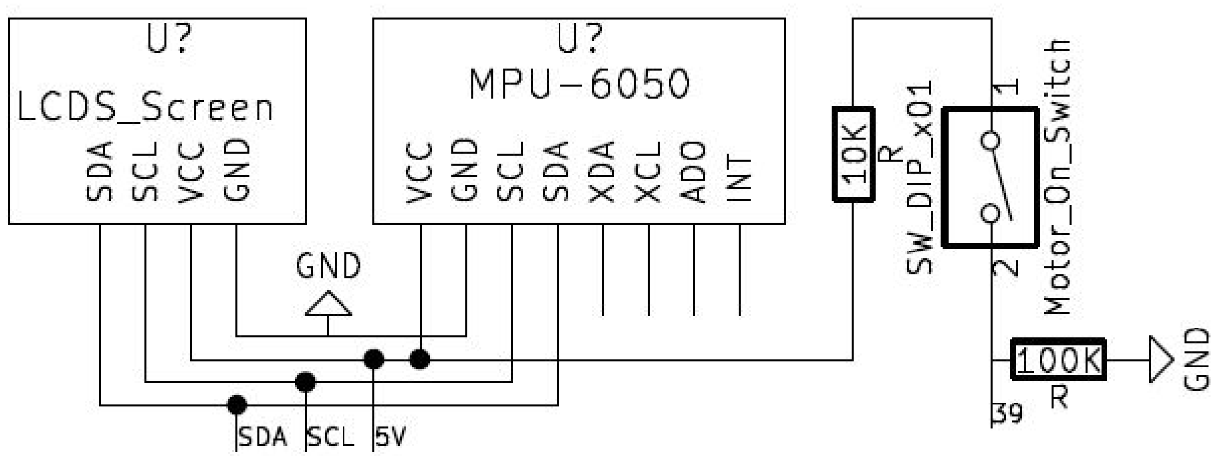


Figure 49. Wiring for the user electronics panel. The switch has a 5V signal with a 10K resistor connected to a digital pin on the Arduino. This digital pin is also connected to ground with a 100K resistor to prevent the voltage from floating. The specific resistor values are not important, all that matters is the pull down network is significantly stronger than the pull-up network.

The high voltage accumulator was updated to a 16S 2P configuration. There are two 16 series 3.7 V lithium-phosphate cell packs connected in parallel to create 48V with a 40 AH capacity. Each of these packs is monitored by a 16S battery management system rated to 45 A. Figure 50 shows how this accumulator is wired,

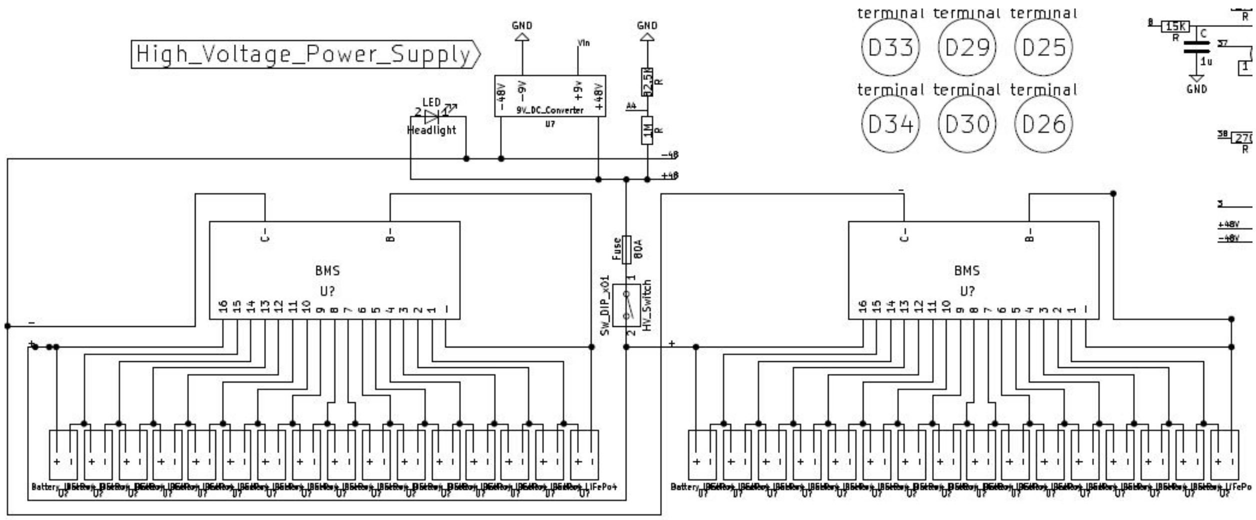


Figure 50. Wiring diagram from the high voltage accumulator.

The entire wiring schematic for the entire wheelchair can be seen in Figure 51 below.

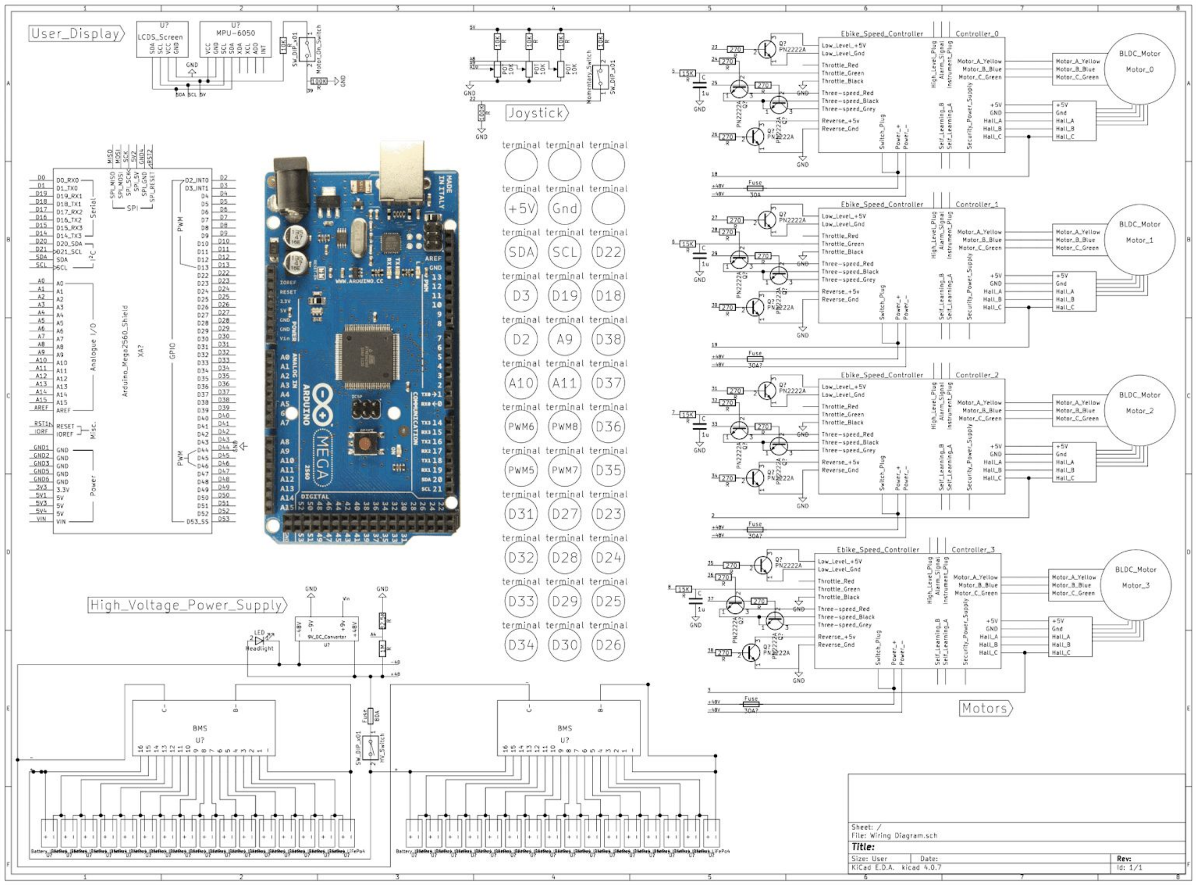


Figure 51. Wiring diagram for the low and high voltage electrical components. The circles in the middle correspond to the quick disconnects on the low voltage controls box and show which wire goes to each connector.

In human machine interface, a few changes were made per the request of Jason and due to purchased parts. Armrest and headrest cushions were added after testing the chair for fit and finding that it was not comfortable. To do this, we used pieces of wood covered in high density foam, secured by fasteners to the arm rests and roll bar, and stapled fabric over it. This provided a good finish, specific sizing for our chair, and increased comfort. We also added mud shields on the sides of the seat, made from HDPE and secured with fasteners, at Jason's request to protect him from splash off of the tires. Finally, upon receiving our seatbelts we were able to determine the locations and sizes necessary for seat belt tabs and guides and welded them onto the frame in order to ensure Jason's safety.

The steel tubes were painted with black rustoleum, and navy blue fabric covered the armrests and headrest. The control boxes were modified because the HDPE plastic was not able to be cut using the waterjet and was too big to fit in the laser cutter. Thus, they were cut using the shearer. We found that we were unable to fasten the box together using adhesive, due to the slippery nature of HDPE. We were able to construct the boxes by using a heated metal stick to melt and fuse the plastic together. The boxes were then painted to match the rest of the wheelchair. The dampers were taken apart and analyzed in order to ensure that they would sufficiently perform under load. They were cleaned, sand blasted, filed, and impregnated with new oil. They were then painted to match the color scheme of the rest of the wheelchair.

Approach and Methodology

The project sponsor, Mr. Jason Cummins, has a very clear idea of what he wants as a solution to his problem; he wants a wheelchair that will allow him to traverse any terrain. He stated this at the first sponsor meeting and showed pictures of a tracked wheelchair which is already on the market. At the end of the semester, he wants a fully working wheelchair that he can use to traverse sand, snow, and forest terrains.

Our current budget is $2000 and our goal is to have a complete and tested wheelchair finished by the end of the semester.In order to realize the team's goals, a Gantt chart has been created to break down tasks and ensure every project is properly assigned (see Table 7-10). The tasks will be broken down such that each can be completed within 2 hours to keep them to a manageable size. Major tasks will be assigned to one or two people to ensure accountability. Pugh charts will also be used to weigh options when major design decisions have to be made.

The non technical aspects of the project are broken down into seven categories each of which is distributed to one member of the team. This breakdown is shown in Figure 52. Below.

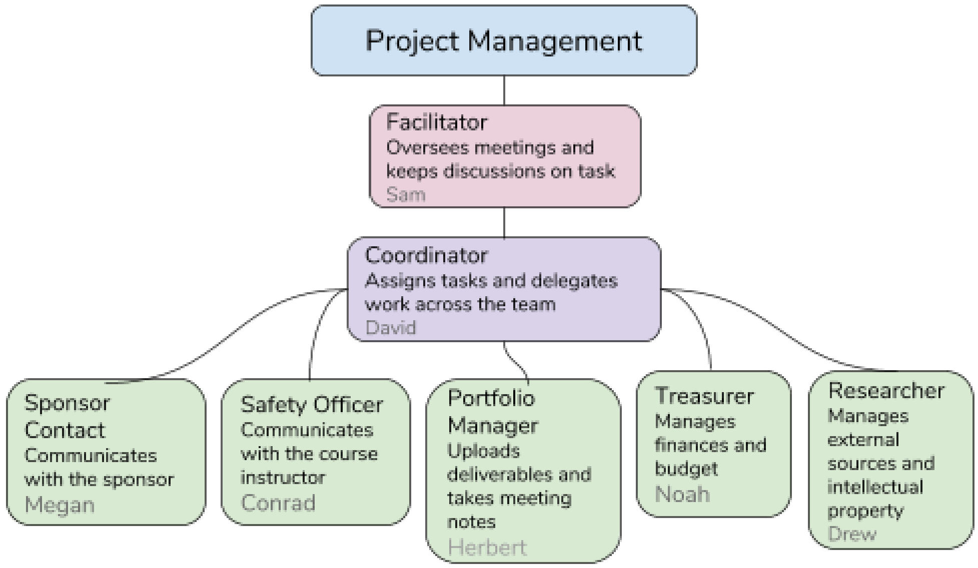


Figure 52. Project Management. This chart shows the distribution of non-technical project management tasks among the team. The facilitator oversees all of the tasks while ensuring everything runs smoothly and the coordinator assigns tasks to each member of the team.

During the design process, the design will be broken down into 6 major subsystems: wheels, suspension, chassis, power transmission, human machine interfaces, and controls. Each member of the team will be assigned to and lead one subsystem with the last person being in charge of integrating the systems together. Each subsystem lead will also be in charge of the manufacturing of their components. While each subsystem has a direct team member responsible, they are not expected to complete the task on their own and should ask other team members for assistance with designing their system when needed. The distribution of technical tasks is shown in Figure 53. [22]

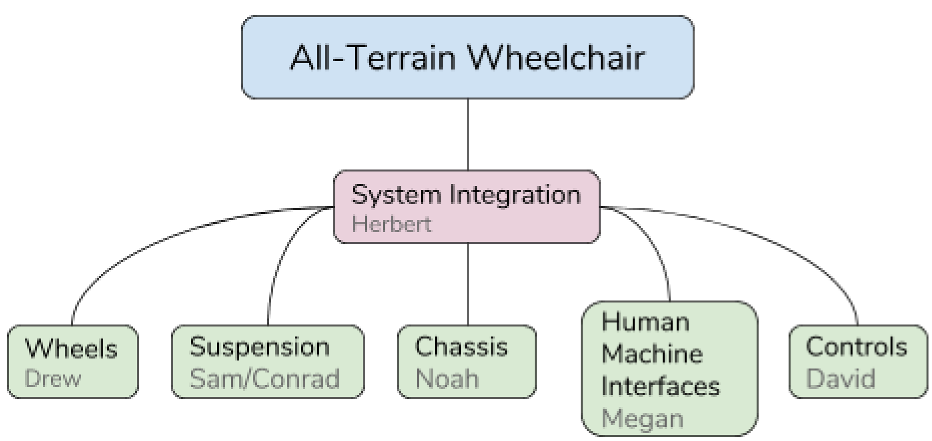


Figure 53. Distribution of subsystems for the all-terrain wheelchair. Each subsystem is assigned to one person who is responsible for designing and manufacturing it and they are expected to get help from other team members when needed. One team member is in charge of system integration and it is their job to ensure each subsystem connects properly.

Table 7. Gantt chart of all the tasks that need to be completed between design review 1 and 2. During this phase of the project, concepts are generated and a final concept for the project is selected.

							Design Review 2													
							9/24 - 9/30							10/1-10/7						
#	Task Title	Task Owner	Start Date	Due Date	Time	% Done	M	T	W	Th	F	Sa	Su	M	T	W	Th	F	Sa	Su
1	Basic Deliverables																			
1.1	Read Modeleing and Simulation	All	9/24/18	9/25/18	1	0%														
1.2	Read Materials Selection	All	9/30/18	10/2/18	2	0%														
1.3	Safety check 1	Conrad	9/30/18	10/2/18	2	0%														
2	Concept Generation																			
2.1	Deliverable: Functional Decomposition	All	9/21/18	9/25/18	4	0%														
2.2	Deliverable: Concept generation	All	9/21/18	9/25/18	4	0%														
2.3	Finalize list of absolutely necessary user requirements	Megan	9/25/18	9/27/18	2	0%														
2.4	Deliverable: Learning plan	All	9/25/18	9/27/18	2	0%														
2.5	Compile all concepts and narrow to 5	Drew	9/27/18	9/29/18	2	0%														
2.6	Pugh chart of basic concepts	Sam	9/30/18	10/2/18	2	0%														
2.61	Budget each concept	David	9/30/18	10/2/18	2	0%														
2.7	Concept Selection	All	10/2/18	10/2/18	0	0%														
3	Concept Building																			
3.1	Detailed conception of specific components	All	10/2/18	10/3/18	1	0%														
3.11	Vehicle to ground connection	Drew	10/2/18	10/3/18	1	0%														
3.12	Suspension	Noah	10/2/18	10/3/18	1	0%														
3.33	Chassis	Sam	10/2/18	10/3/18	1	0%														
3.34	Power transmission	Herbert	10/2/18	10/3/18	1	0%														
3.35	Human machine interfaces	Megan	10/2/18	10/3/18	1	0%														
3.36	Controls	David	10/2/18	10/3/18	1	0%														
3.4	Final system drawing	Conrad	10/2/18	10/3/18	1	0%														
3.5	Creation of physical mockup	All	10/3/18	10/4/18	1	0%														
4	Design Review 2																			
4.1	Oral Presentation presentation	All	9/30/18	10/4/18	4	0%														
4.2	Concept generation written report	Drew Herbert	10/2/18	10/5/18	3	0%														
4.3	Concept selection written report	Sam Noah	10/2/18	10/5/18	3	0%														
4.4	Key design drivers and challenges written report	Megan Conrad	9/27/18	10/5/18	8	0%														
2.5	Project plan	David	9/23/18	10/5/18	12	0%														

Table 8. Gantt chart of tasks between design review 2 and 3. During this phase, we will conduct engineering analysis, design the wheelchair, and create manufacturing plans for all the parts.

#	Task Title	Task Owner	Start Date	Due Date	Time	% Done
5	Basic Deliverables					
5.1	Conflict Styles Inventory	All	10/9/18	10/11/18	2	0%
5.2	Safety Check 2	Conrad	10/9/18	10/23/18	14	0%
5.3	Design Expo Registration	Conrad	10/23/18	10/25/18	2	0%
6	Engineering Analysis					
6.1	Develop and calculate important math behind each major subsystem	Drew	10/8/18	10/12/18	4	0%
6.11	Vehicle to ground connection	Drew	10/8/18	10/10/18	2	0%
6.12	Suspension	Noah	10/8/18	10/10/18	2	0%
6.13	Chassis	Sam	10/10/18	10/12/18	2	0%
6.14	Power Transmission	Herbert	10/8/18	10/10/18	2	0%
6.15	Human machine interfaces	Megan	10/10/18	10/12/18	2	0%
6.16	Controls	David	10/8/18	10/12/18	4	0%
6.2	Set size contrainsts on all parts	Conrad	10/12/18	10/14/18	2	0%
6.21	Determine track width	Drew	10/12/18	10/13/18	1	0%
6.22	Set wheelbase	Drew	10/13/18	10/14/18	1	0%
6.23	Set seat size	Megan	10/11/18	10/14/18	3	0%
6.3	Set design requirements for each subsystem	Conrad	10/11/18	10/14/18	3	0%
6.31	Vehicle to ground connection requirements	Drew	10/11/18	10/14/18	3	0%
6.32	Suspension requirements	Noah	10/11/18	10/14/18	3	0%
6.33	Chassis requirements	Sam	10/11/18	10/14/18	3	0%
6.34	Powertrain requirements	Herbert	10/11/18	10/14/18	3	0%
6.35	Human machine interface requirements	Megan	10/11/18	10/14/18	3	0%
6.36	Controls Requirements	David	10/11/18	10/14/18	3	0%

#	Task Title	Task Owner	Start Date	Due Date	Time	% Done
7	CAD Design					
7.1	Perliminary CAD design of each subsystem	All	10/15/18	10/19/18	4	0%
7.11	Vehicle to ground connection design	Drew	10/15/18	10/17/18	2	0%
7.12	Suspension design	Noah	10/15/18	10/17/18	2	0%
7.13	Chassis design	Sam	10/17/18	10/19/18	2	0%
7.14	Powertrain design	Herbert	10/15/18	10/19/18	4	0%
7.15	Human machine interface design	Megan	10/15/18	10/19/18	4	0%
7.16	Controls design	David	10/15/18	10/19/18	4	0%
7.2	Refine design	Conrad	10/19/18	10/21/18	2	0%
7.21	Vehicle to ground connection refinement	Drew	10/19/18	10/21/18	2	0%
7.22	Suspension refinement	Noah	10/19/18	10/21/18	2	0%
7.23	Chassis refinement	Sam	10/19/18	10/21/18	2	0%
7.24	Powertrain refinement	Herbert	10/19/18	10/21/18	2	0%
7.25	Human machine interface refinement	Megan	10/19/18	10/21/18	2	0%
7.26	Controls refinement	David	10/19/18	10/21/18	2	0%
8	System Integration					
8.1	Combine all subsystems into one assembly	Conrad	10/21/18	10/22/18	1	0%
8.2	Identify all interference issues with subsystems	Conrad	10/22/18	10/24/18	2	0%

							10/8-10/14							10/15-10/21							10/22-10/28						
#	Task Title	Task Owner	Start Date	Due Date	Time	% Done	M	T	W	Th	F	Sa	Su	M	T	W	Th	F	Sa	Su	M	T	W	Th	F	Sa	Su
9	Failure Mode Effects Analysis																										
9.1	Deleiverable: VVT	All	10/8/18	10/11/18	3	0%																					
9.11	Develop validation plan to verify specifications	Drew	10/8/18	10/10/18	2	0%																					
9.12	Proof-of-concept validation, create schmatic for test setup for your validation plan	Sam	10/8/18	10/10/18	2	0%																					
9.2	Deliverable: Risk Assement	Conrad	10/14/18	10/18/18	4	0%																					
9.3	Deliverable: FMEA	Megan	10/14/18	10/18/18	4	0%																					
10	Manufacturing Plan																										
10.1	Create BOM for each subsystem	All	10/18/18	10/21/18	3	0%																					
10.11	Vehicle to ground connection BOM	Drew	10/20/18	10/21/18	1	0%																					
10.12	Suspension BOM	Noah	10/20/18	10/21/18	1	0%																					
10.13	Chassis BOM	Sam	10/20/18	10/21/18	1	0%																					
10.14	Powertrain BOM	Herbert	10/20/18	10/21/18	1	0%																					
10.15	Human machine interface BOM	Megan	10/20/18	10/21/18	1	0%																					
10.16	Controls design BOM	David	10/20/18	10/21/18	1	0%																					
10.2	Combine all BOM into one major BOM spreadsheet	Conrad	10/21/18	10/22/18	1	0%																					
10.3	Create list of purchased parts and manufactured parts	Conrad	10/23/18	10/24/18	1	0%																					
10.4	Make drawings and manufacturing plans for all manufactured parts	All	10/22/18	10/24/18	2	0%																					
10.41	Vehicle to ground connection drawings and plans	Drew	10/22/18	10/24/18	2	0%																					
10.42	Suspension drawings and plans	Noah	10/22/18	10/24/18	2	0%																					
10.43	Chassis drawings and plans	Sam	10/22/18	10/24/18	2	0%																					
10.44	Powertrain drawings and plans	Herbert	10/22/18	10/24/18	2	0%																					
10.45	Human machine interface drawings and plans	Megan	10/22/18	10/24/18	2	0%																					
10.46	Controls drawings and plans	David	10/22/18	10/24/18	2	0%																					

							10/8-10/14							10/15-10/21							10/22-10/28						
#	Task Title	Task Owner	Start Date	Due Date	Time	% Done	M	T	W	Th	F	Sa	Su	M	T	W	Th	F	Sa	Su	M	T	W	Th	F	Sa	Su
11	Design Review 3																										
11.1	Executive Summary	All	10/24/18	10/26/18	2	0%																					
11.2	Concept Description	Drew Herbert	10/15/18	10/26/18	11	0%																					
11.3	Engineering Analsysis	Sam Noah	10/15/18	10/26/18	11	0%																					
11.4	Theroretical Modeling	Megan Conrad	10/18/18	10/26/18	8	0%																					
11.5	Empirical Testing	Sam Noah	10/22/18	10/26/18	4	0%																					
11.6	Mockup Construction	Megan	10/24/18	10/26/18	2	0%																					
11.7	FMEA/Risk Analysis	Conrad	10/19/18	10/26/18	7	0%																					
11.8	Current Challenges	Noad	10/22/18	10/26/18	4	0%																					
11.9	Initial Manufacturing Plan	All	10/24/18	10/26/18	2	0%																					
11.1	Oral Presentation	All	10/22/18	10/26/18	4	0%																					
11.11	Project plan	David	10/22/18	10/26/18	4	0%																					

Table 9. Gantt chart covering the tasks to be completed between design review 3 and design review 4. This phase is where we start manufacturing the actual wheelchair.

#	Task Title	Task Owner	Start Date	Due Date	Time	% Done
12	Deliveranbles					
12.1	Intercultural Awareness	Herbert	11/5/18	11/8/18	3	0%
13	Prototype Construction					
13.1	Place all orders	Noah	10/29/18	10/30/18	1	0%
13.2	Sumbit all manufacturing plans	Herbet	10/30/18	10/31/18	0	0%
13.3	Build Chassis	Noah	1/31/18	11/6/18	276	0%
13.31	Cut Tubes	Noah	10/31/18	11/1/18	1	0%
13.32	Notch	Noah	11/2/18	11/3/18	1	0%
13.33	Weld	Noah	11/4/18	11/6/18	2	0%
13.4	Build Suspension	Sam	10/31/18	11/6/18	6	0%
13.41	Turn tubes	Conrad	10/31/18	11/2/18	2	0%
13.42	Press Inserts	Sam	11/3/18	11/4/18	1	0%
13.43	Notch Tubes	Conrad	11/1/18	11/3/18	2	0%
13.44	Weld	Sam	11/4/18	11/6/18	2	0%
13.45	Connect suspension to chassis	Conrad	11/7/18	11/9/18	2	0%
13.5	Build Joystick	Megan	10/31/18	11/8/18	8	0%
13.51	3D print body	Megan	10/31/18	11/4/18	4	0%
13.52	Insert potentionmeters and test	Megan	11/5/18	11/8/18	3	0%
13.6	Weld chair to chassis	David	11/8/18	11/11/18	3	0%
13.61	Make seat back	Megan	11/5/18	11/8/18	3	0%
13.7	Build high voltage accumulator	David	10/31/18	11/8/18	8	0%
13.71	Laser cut body	David	10/31/18	11/2/18	2	0%
13.72	Drill holes and screw together	David	11/3/18	11/6/18	3	0%
13.73	Connect batteries	David	11/7/18	11/8/18	1	0%
13.8	Build low voltage control box	David	10/31/18	11/8/18	8	0%
13.81	Laser cut body	David	10/31/18	11/2/18	2	0%
13.82	Glue together and add auxillary components	David	11/5/18	11/8/18	3	0%
14	Design Review 4					
14.1	Update report	All	11/12/18	11/16/18	4	0%
14.2	Create presentation	All	11/11/18	11/13	2	0%
14.3	Update gantt chart	David	11/12/18	11/16/18	4	0%

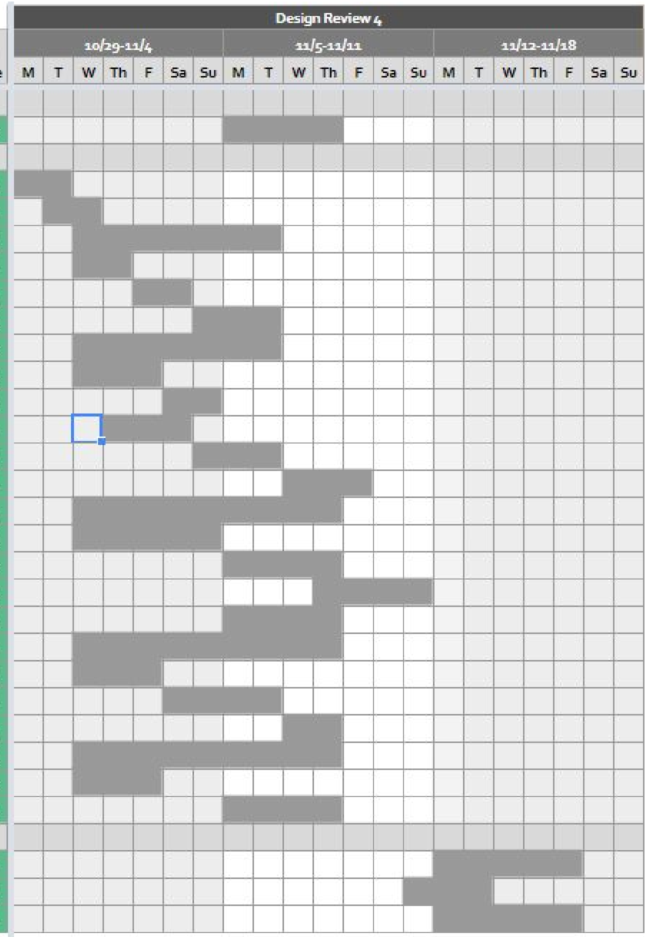


Table 10. Gantt chart covering the tasks to be completed between design review 4 and design review 5. This phase is where we put the finishing touches on manufacturing and start testing

#	Task Title	Task Owner	Start Date	Due Date	Time	% Done
15	Manufacturing					
15.1	Finish welding tabs	Noah	11/14/18	11/16/18	2	0%
15.2	Paint chassis	Drew	11/17/18	11/18	1	0%
15.3	Attach seatback	Megan	11/19/18	11/20/18	1	0%
15.4	Attach seatbelt	Megan	11/19/18	11/20/18	1	0%
16	Component Testing					
16.1	Test potentiometer and fix code	Megan	11/21/18	11/23/18	2	0%
16.2	Test safety loop	David	11/23/18	11/25	2	0%
16.3	Test battery discharge curve	Sam	11/26/18	11/27/18	1	0%
16.4	Test battery charging	David	11/26/18	11/27/18	1	0%
16.5	Test LCD display	Drew	11/24/18	11/25/18	1	0%
16.6	Test gyroscope	Herbert	11/24/18	11/25	1	0%
16.7	Test motor control	David	11/21/18	11/29/18	8	0%
17	System Testing					
17.1	Short distance	All	11/30/18	12/2/18	2	0%
17.2	Long distance	All	11/30/18	12/2/18	2	0%
17.3	Rough terrain	All	11/30/18	12/2/18	2	0%
17.4	Sand	All	11/30/18	12/2/18	2	0%
17.5	Rain	All	11/30/18	12/2/18	2	0%
17.6	Stairs	All	11/30/18	12/2/18	2	0%
18	Design Review 5					
18.1	Update report	All	11/26/18	11/29/18	3	0%
18.2	Create presentation	All	11/26/18	11/29	3	0%
18.3	Update gantt chart	David	11/26/18	11/16/18	-10	0%

	Design Review 5	
11/12-11/18	11/19-11/25	11/26-12/2
M T W Th F Sa Su	M T W Th F Sa Su	M T W Th F Sa Su

Engineering Ethics

Our top priority of creating an all terrain wheelchair for Jason is safety. We maintain this by having high safety factors and constantly thinking of risk analysis. One major area of worry is battery life and mechanical function, as we need to ensure that no matter where Jason goes he can always make it back to his car. Ethically, we must have a mechanical failsafe to provide full certainty that Jason will always make it home. To do this, we've purchased high fidelity in hub motors that when off will allow Jason to push the wheels himself.

As there are many components on our design and therefore many possibilities for failure, we've done an engineering analysis for every failure. Whether that's designing for safety through things like building with strong materials or calculating things like the tipping analysis done in the engineering analysis section, we care about maintaining Jason's safety. In many cases, our specific end user has also been considered, such as our battery calculations. We know Jason would like to go as fast as possible at all times, because of this we're limiting the wheelchair speed to 4 mph in order to have a longer lasting battery and have included a boost mode for when he needs to move faster.

Discussion/Recommendations- noah

Our major concern, a limited testing and verification phase, was the result of some ordering and shipping confusion with our in hub motors. We decided to source our in-hub motors from a Chinese vendor due to the low cost and wider range of options. The turnaround time for the motors was about 4 weeks from production to shipping. By selecting and ordering the motors at an earlier time, we could save on shipping costs, to spend elsewhere. We would also have time to test the wheelchairs capability on different terrains. We could also test battery life to get realistic use times based on different power draw conditions.

Given our limited testing time we are unsure of our current method of braking. Currently our device relies on dynamic braking which may or may not be sufficient to stop the wheelchair. With more time we would be able to test this factor. If more stopping power is required we would attach disk brakes to our in hub motors, both of which are provided by our in hub motor supplier.

Another concern is with our joystick. The joystick we designed and built functions on sound principles but there is room for improvement. Currently the joystick does not have hardstops to limit motion so the springs which return the joystick back to center can be easily damaged. This is a problem because the position of the joystick directly affects the speed of the wheelchair through potentiometers. For finer control of these sensors, we would create a more robust joystick or source one that could be modified for use in our application so the user can confidently and precisely control the wheelchair. If all else fails the wheelchair can be controlled directly through the potentiometers with no interface.

A potential problem exists with the robustness of our electronics. Our budget did not support the use of strong, expensive, or water resistant connections. Given this is an all-terrain wheelchair, meaning it will be knocked and jarred around in unfriendly environments, it is possible for electrical connections to fail. This failure mode could be mechanically, by becoming undone or by snagged on an obstacle, or through other methods like corrosion.

Environmental Impact- drew

To examine the environmental impacts of the wheelchair, we looked at the entire lifecycle of the vehicle. This includes the manufacturing process through the disposal/recycling process. The environmental impacts are small due to the fact that this is a single unit production effort. However, we wanted to fully understand how environmentally friendly this wheelchair is. The wheelchair is mostly constructed out of 1018 mild carbon steel, HDPE plastic, open cell foam, canvas, and rubber. Most of these materials can be reused and/or recycled when they chair is disposed of. The most environmentally harmful component in our wheelchair is the $LiFePO_4$

battery. It contains plastic as well as the following chemicals: carbon, lithium, iron, and phosphate. While these chemicals are not considered dangerously harmful to dispose of in a landfill, the plastic must be recycled. For this reason we will advise Jason to recycle the battery at a recycling center so that the components can be separated and reused or recycled. Because the wheelchair is all electric, there are no direct vehicle greenhouse gas emissions.

If the wheelchair were to be mass produced, the biggest change that would need to be made to the manufacturing process would be to convert the plastic parts to more environmentally friendly stainless steel stamped components. This would provide increased structural rigidity as well as produce less the harmful environmental waste.

Standards - conrad

We held our chassis at the torsional rigidity standard for a race car as it is required to carry more load and be subjected to greater stresses while moving under that load. If our chassis can meet the torsional rigidity of a race car then it will definitely handle the loads and stresses placed on it for its intended use as an all-terrain wheelchair. Since our wheelchair surpassed this standard, the chassis, which holds all of the components to the device together, will not fail under its intended use.

There are existing standards for wheelchairs which list the required static/dynamic stability, braking efficiency, energy consumption, overall dimensions, maximum speed/acceleration, and seating dimensions for electric wheelchairs such as ours. We did not apply these standards in our design process. These standards are meant to make wheelchairs that work in public areas that meet ADA guidelines and fit a majority of consumers. However, our wheelchair will exclusively be used in outdoor beaches and forests so these guidelines are not important to our design. The size restrictions, to ensure the wheelchair can go through doors, also do not matter since the wheelchair will not be used inside. This chair is also meant for exactly one user so instead of sizing it to fit a standard user, it is sized to perfectly fit our one user.

Conclusion

Over the course of the semester, our team has spent numerous hours focused on creating a well functioning, fast, and durable wheelchair for Jason Cummins, who requires increased mobility on terrains such as sand, snow, and forests. We’ve met many challenges along the way, and have succeeded in manufacturing a chair for Jason that we believe meets all of his needs. We prioritised overcoming obstacles shorter than 6 inches tall and terrains such as beaches, forests, and snow. To accomplish these, we’ve incorporated five inch wide tires and powerful in hub motors to provide the necessary ground pressure and torque. We also prioritized safety, this included ensuring we have a long battery life with user feedback to ensure Jason does not get stranded in the woods along with a comfortable and strong 4-point restraint. Finally, we prioritized the size, in order for it to fit on Jason's lift, and the cost, to ensure we did not go over the University's budget. We have succeeded in accomplishing these engineering requirements along with many more, to ensure Jason's happiness, safety, and increased mobility.

In designing a vehicle that would accomplish all of Jason's needs and wants, we went through many iterations and considerations. We began with the goal of creating an attachment to Jason's current wheelchair that would allow him to enter the desired terrains. Upon meeting Jason for the first time we discovered he wanted a fully new wheelchair with treads instead of wheels. After much consideration and deliberation among the team, we eventually decided on a four wheel drive solution with fully independent suspension and a complex controls system.

To ensure that our proposed wheelchair design would meet all of the engineering requirements we laid out, we did engineering analysis on all of our key design drivers: the motor powered drive, ability to overcome terrains, torsional rigidity, maneuverability and size, and satisfying Jason's vision. In these we determined what specifications we needed on our motors, what wheelbase size we required, where additional supports were needed in our seat and chassis, and we showed our models to Jason to ensure his approval. Once Jason and the team were finally content with the results of these analyses, we began to draft engineering drawings and manufacturing plans to begin construction.

To manufacture the wheelchair we utilized the resources in the Mechanical Engineering machine shop and the Wilson Center. We used the ME shop to waterjet our sheet metal for the chassis and chair, 3D print the joystick and user interface, and to mill and lathe components such as the control arm suspension. In the Wilson center we sandblasted all of our metals to provide clean surfaces, and spent numerous hours fixturing and welding to ensure that all components were within tolerance. Our manufacturing was extremely successful, and resulted in a properly assembled and dimensioned chair, chassis, and suspension.

Once our chair was manufactured we began to wire and code the controls system. This required extensive testing of our joystick, LCD, kill switch, e-bike motor controllers, and in-hub motors. With time, all of these systems now operate as intended, allowing Jason to have the full desired function and optimal control over his wheelchair.

In the end, our largest challenges proved to be time constraints. We were constrained in how much work we could put into our controls system once everything was assembled. The late arrival of our in hub motors also made it more difficult to test our full system function and ensure that our e-bike controllers functioned as desired.

In one semester, our team was able to design, build, code, and test a fully functional all-terrain wheelchair for Jason Cummins. We're extremely proud of our final product, and the mobility it will provide Jason to enjoy the outdoors and his increased freedom. Our team is extremely grateful for the opportunity to demonstrate all of the skills we have learned in our time as Mechanical Engineering undergrads at the University of Michigan, and we thank Jason Cummins and Amy Hortop for bringing this project to us.

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Appendix

A: Distinct Designs

Vehicle to ground interaction

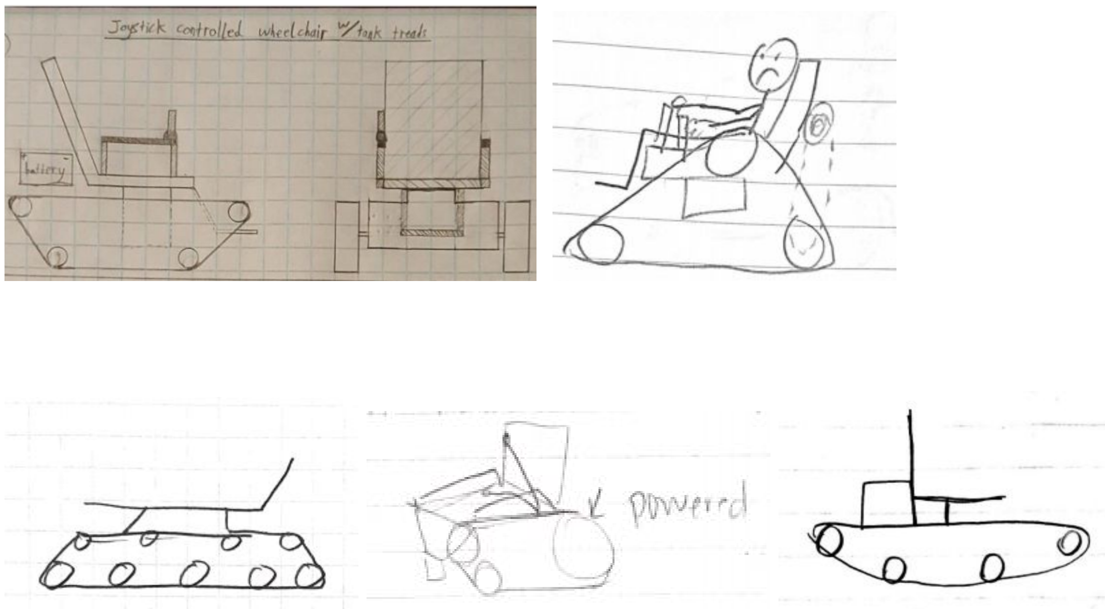


Figure 1. The tank tread joystick controlled wheelchair was a repeatedly generated idea that spawned from currently available products and Jason’s request. This design places the user within it, not on top, with a seat equipped with an armrest where the joystick controller is mounted. It also wields two sets of tank treads of varying design (pulley layout) as seen in our sketches.

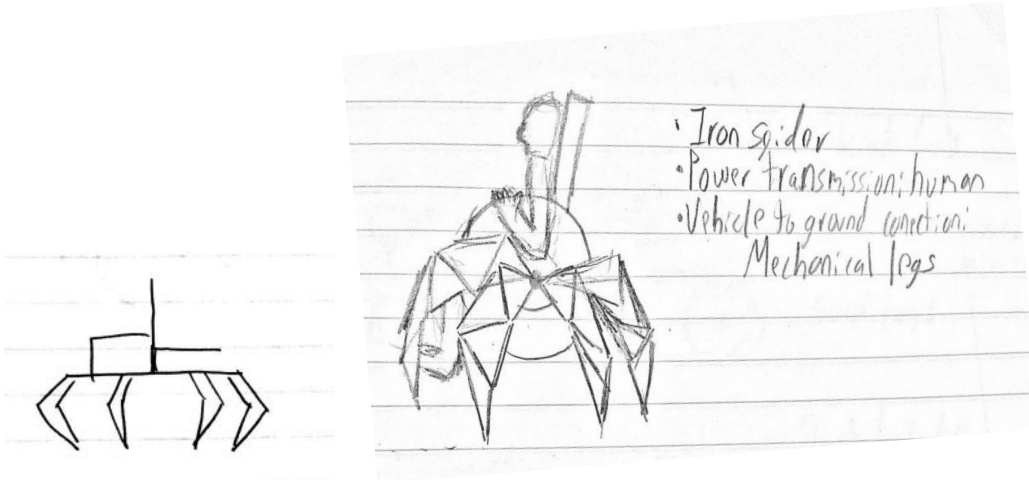


Figure 2: The "iron spider" is a unique design as it employs the use of mechanical linkages for legs that walk the user. In this design a set of legs are attached to each side of the chair the user sits in. There are two sets of mechanical legs on each side that are independently controlled to allow the user to turn. The legs can walk in sand and step over obstacles making it effective for beach and forest terrains.

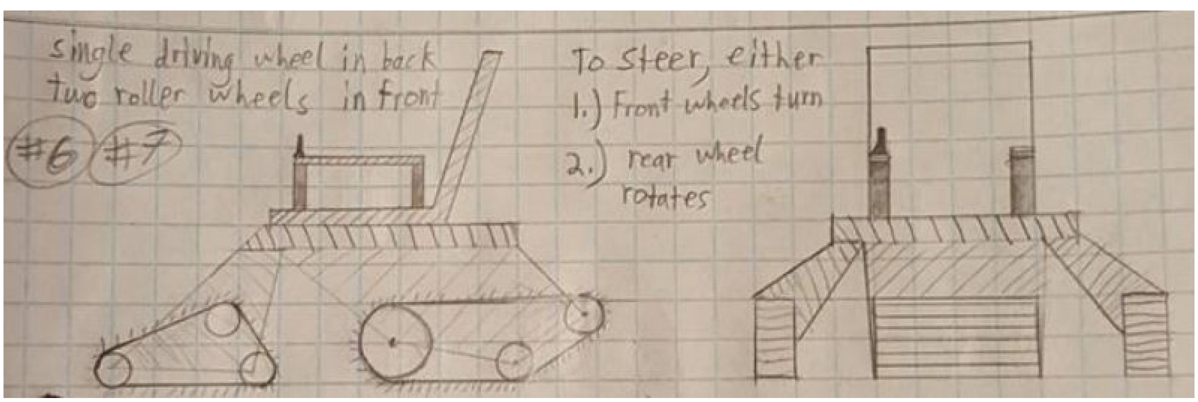


Figure 3: A three wheeled tank design is another reasonable concept investigated. This design has the potential to require only one tank tread to be powered. Similar to a snowmobile in layout, the rear tread sits to the back of where the user sits while two smaller wheels or treads are in front. These two front wheels steer the device and can fold underneath the seat to transport.

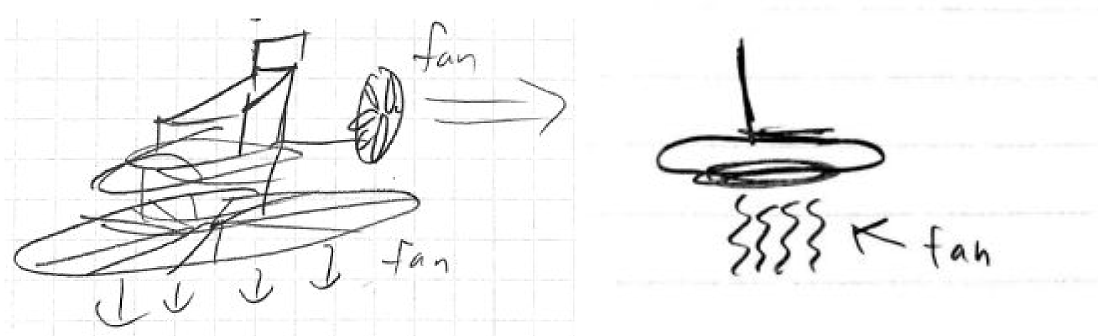


Figure 4: The hovercraft design is more of a imaginative concept than a practical one. In this design, a large propeller fan in the bottom of the structure to elevate the the wheelchair and another turnable propeller fan in the back of the structure to move the wheelchair in the desired direction.

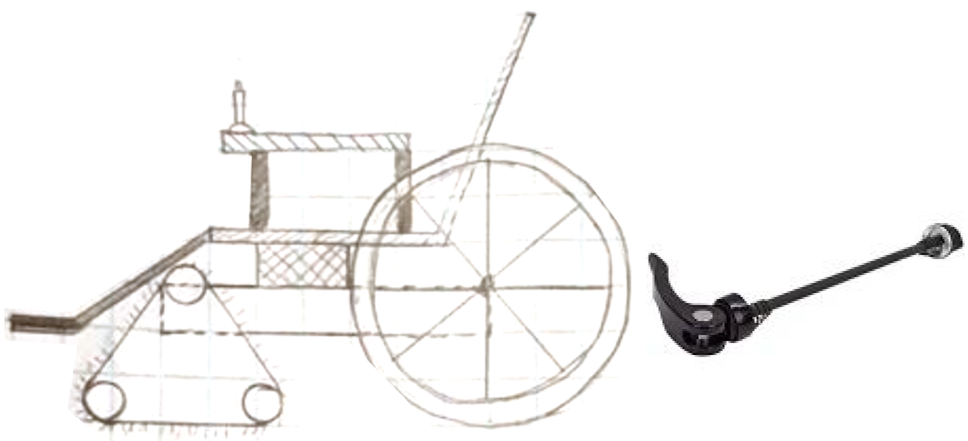
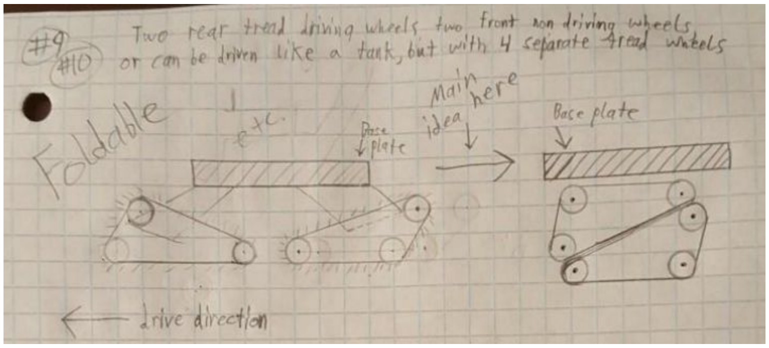


Figure 5: A 2 wheel and 2 tread vehicle where the two front wheels are driven. This is a hybrid vehicle we believe minimizes the turning radius associated with a 4 wheeled vehicle. It is joystick controlled and the large rear tires make the user feel they are sitting in the device not on top of it. For transport, the rear wheels are removable through a quick release mechanism like a current road or mountain bike.



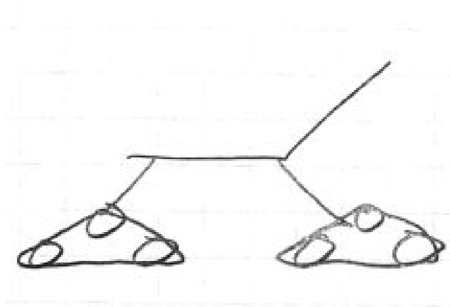


Figure 6: The Collapsible 4-tread quad is a design concept that is similar to the 4-tread quad design. In the design however, the treads fold in on one another which allows it to be stored in a more constrained space. It also offers greater stability with reduced drag in turning compared to a full tread.

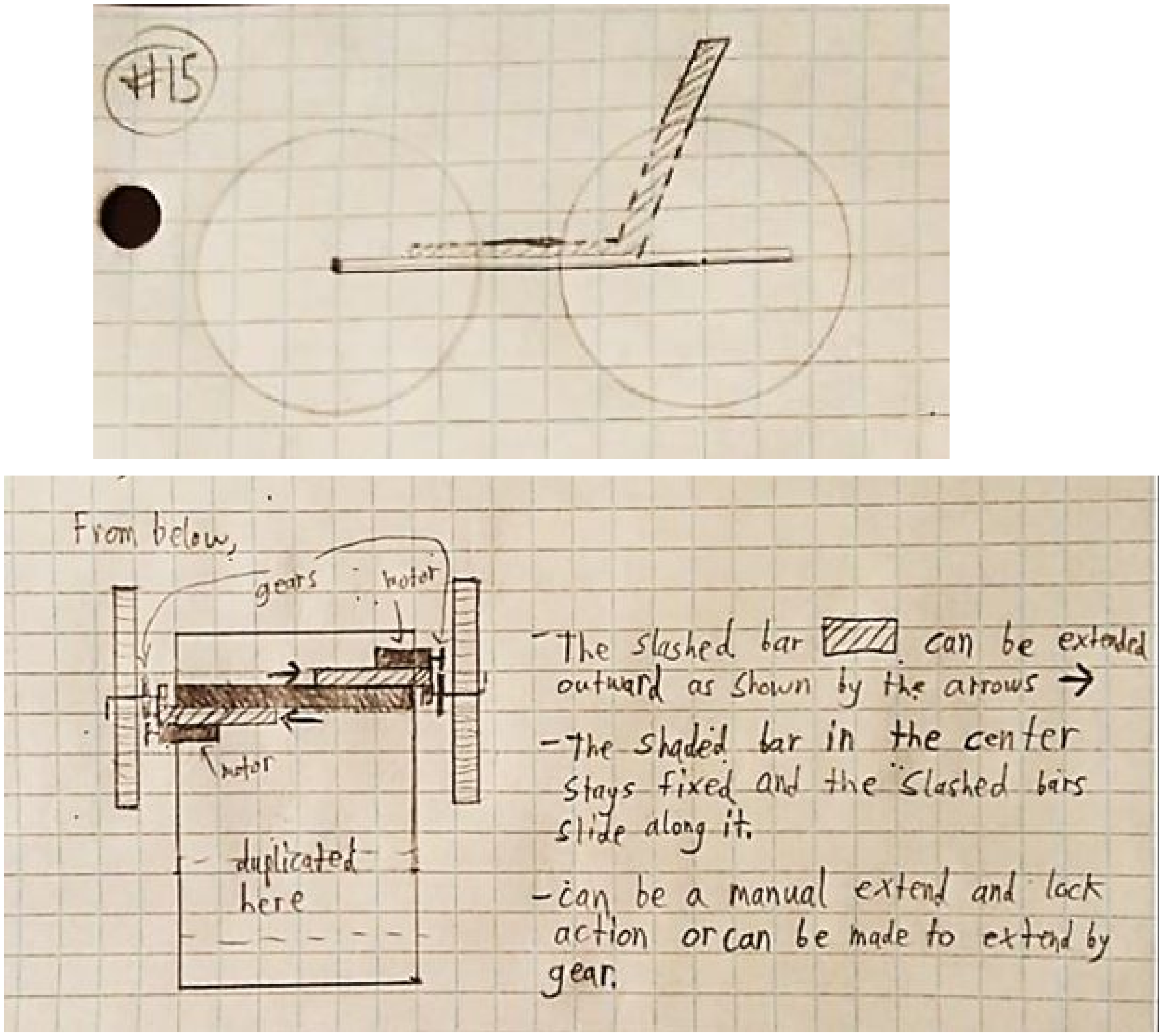


Figure 7: The Collapsible 4 wheeled vehicle design concepts play off of the standard 4 wheel design. The basic structure is similar to a normal 4 wheeled vehicle but with the ability to collapse or fold in to save space. The design allows our end user to store the wheelchair in a smaller space.

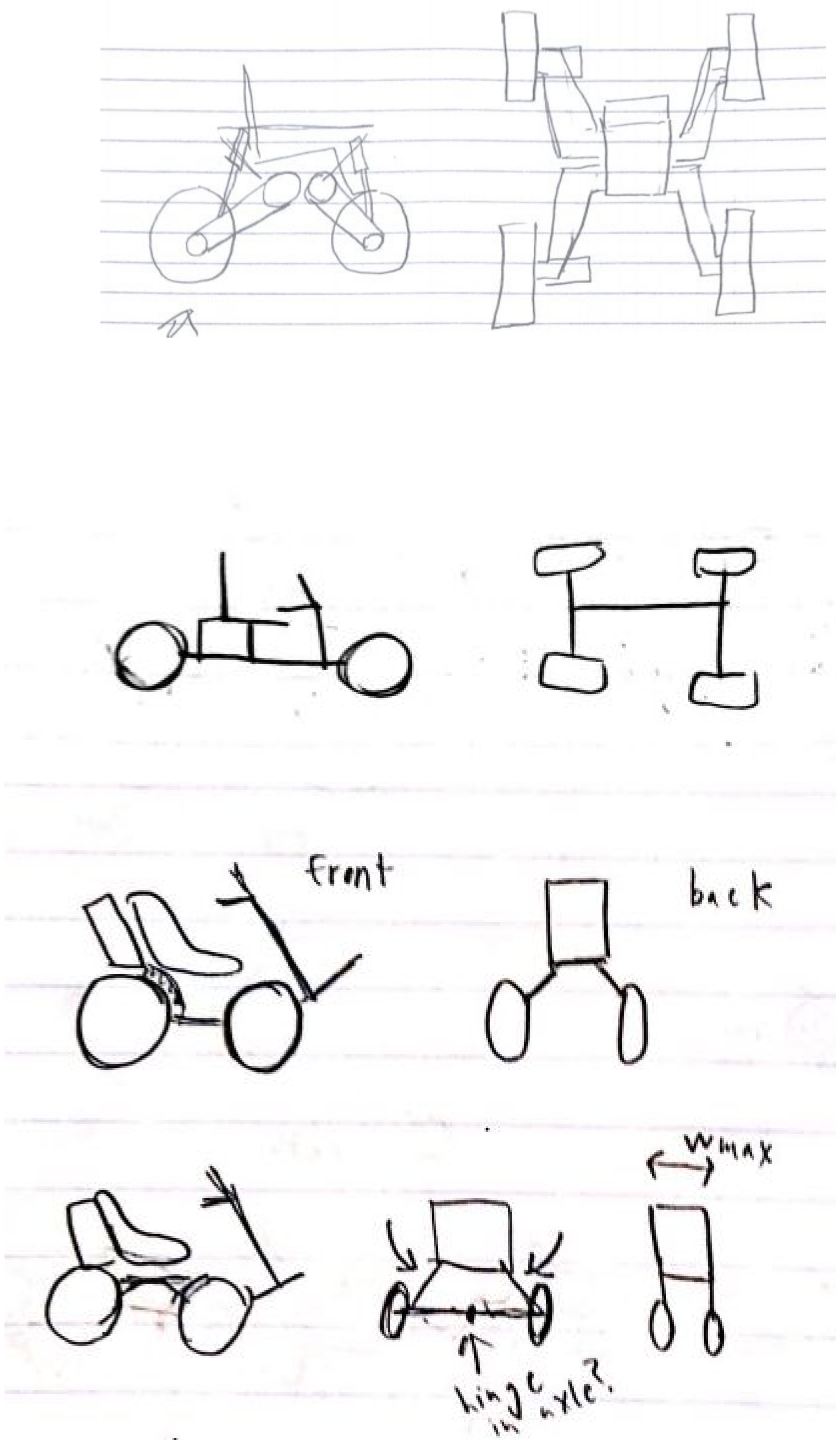


Figure 8: These are other 4 wheeled design concepts that were redundant to show in the main report as they all show similar aspects and the possibility of being collapsible.

Chassis and Suspension

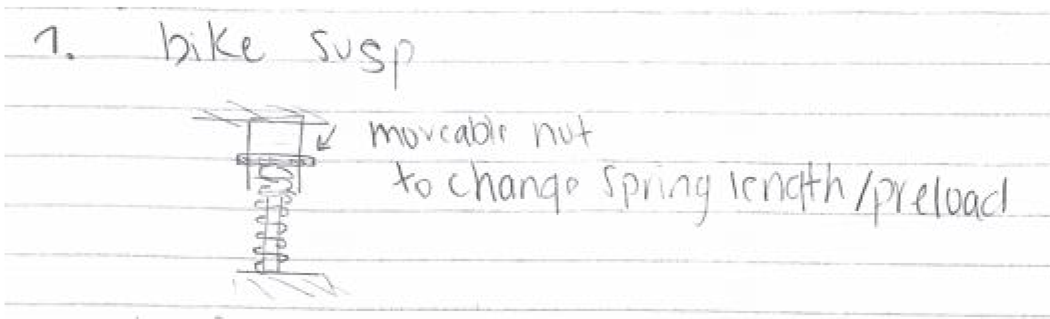


Figure 9: This is a standard mountain bike frame suspension that we can adapt to our purposes

Figure 10: These are a cheap and effective way to damp our device when on rough terrains

B: Bill of Materials

HUMAN MACHINE INTERFACE

							Contributors		
Name	Part Title	Material	Supplier	Quantity	Price	Notes	Design/CAD	Drawing/Plan	Machining
7-50-001	Chair Frame	1.5" steel tube	Us	1	$0.00		Meg	Meg	Mill/Weld
7-50-002	Seat Sheet	1/8" aluminum pl	Us	1	$0.00		Meg	Meg	Waterjet / Weld
7-50-003	Leg Rest	.25" steel plate	us	1	$0.00		Meg	Meg	Waterjet / Weld
7-50-004	Foot Rest	.25" steel plate	Us	1	$0.00		Meg	Meg	Waterjet / Weld
7-50-005	Arm Rest	.25" steel plate	Us	1	$0.00		Meg	Meg	Waterjet / Weld
7-50-006	Joystick Top	PLA	Us	1	$0.00		Meg	NA	3D Print
7-50-007	Joystick Bottom	PLA	Us	1	$0.00		Meg	NA	3D Print
7-50-008	Joystick Base	PLA	Us	1	$0.00		Meg	NA	3D Print
7-50-009	Joystick Nut	NA	Mcmaster 90326A105	1	$4.80	Can prob find in X50	NA	NA	NA
7-50-010	Joystick Spring	NA	Mcmaster 9271K604	1	$5.09	pack of 6	NA	NA	NA
7-50-011	Boot/Fondue Fou	Rubber	MER	1	$0.00		NA	NA	NA
7-50-012	User Interface	PLA	Us	1	$0.00		Meg	NA	3D Print
7-50-013	Chair Backrest	Fabric	Joann	1	$5.00	http://enableyourlife.com/ny	vd	NA	NA
7-50-015	Seatbelt	NA	Ebay	1	$19.99	https://www.ebay.com/i/142	NA	NA	NA

POWERTRAIN

							Contributors		
Name	Part Title	Material	Supplier	Quantity	Price	Notes	Design/CAD	Drawing/Plan	Machining
7-02-001	48V 800W Motor		QS	4	$111.00		Andrew		
7-02-002	130/90-10 Tire		Ebay	4	$40.00		Andrew		

CHASSIS

							Contributors		
Name	Part Title	Material	Supplier	Quantity	Price	Notes	Design/CAD	Drawing/Plan	Machining
7-30-001	Chassis	1" OD tube .049" wall thi	MER	1	$0.00		Noah	Noah	Saw / Grind / weld
7-30-002	Skid Plate	1/4" steel plate	MER	1	$0.00		Noah	Noah	Waterjet / Weld
7-30-004	bracket	1/4" steel plate	alro	16	-		Noah	Noah	Waterjet / Weld
7-30-005	A-arm	1" OD tube .049" wall thi	MER	4	$0.00		Noah	Noah	Saw / Grind / Weld
7-30-006	A-arm bushing housing	1" steel rod	alro	8	-		Noah	Noah	Saw / Lathe / Weld
7-30-007	A-arm bracket	1/4" steel plate	alro	16	-		Noah	Noah	Waterjet / Weld
7-30-009	Lower Spring Bracket	1/4" steel plate	alro	8	-		Noah	Noah	Waterjet / Weld
7-30-011	Axle Hub	1.75" steel billet	alro	4			Noah	Noah	Lathe / Mill / Key/ Weld
7-30-012	Motor Controller Panel	1/8" aluminum	alro	2			Noah	Noah	Waterjet
7-30-013	Upper Spring Bracket	1/4" steel plate	alro	8			Noah	Noah	Waterjet / Weld
7-30-020	3/8 shoulder bolt	NA	Mcmaster 94496	8	$6.52	A arm	Conrad	Conrad	-
7-30-021	3/8 5/16-18 Nylon Lock Nu	NA	Mcmaster 97135	1	4.18	pack of 20	Conrad	Conrad	-
7-30-022	Sleeve Bearing	NA	Mcmaster 6391K	8	$1.53	A arm	Conrad	Conrad	-
7-30-023	Washer	NA	Mcmaster 5906K	16	1.12	A arm	Conrad	Conrad	-
7-30-024	Axle key	NA	Mcmaster 92288	1	6.48	12"	Noah	Noah	Mill
7-30-025	1/4 - 20 Motor controller B	NA	X50	8	0		Noah	Noah	-

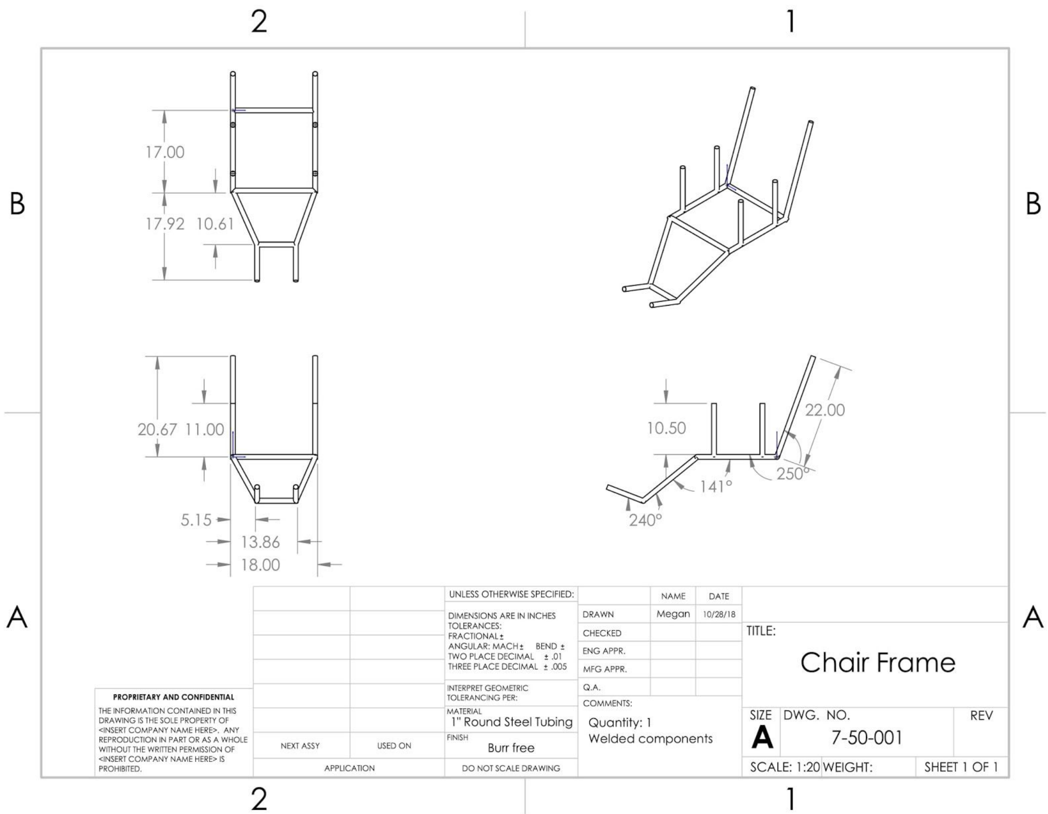
SUSPENSION

							Contributors		
Name	Part Title	Material	Supplier	Quantity	Price	Notes	Design/CAD	Drawing/Plan	Machining
7-40-001	dampers	-	MER	4	$0.00		Conrad	Conrad	Conrad
7-40-002	coils	-	MER	4	$0.00		Conrad	Conrad	Conrad

CONTROLS									
							Contributors		
Name	Part Title	Material	Supplier	Quantity	Price	Notes	Design/CAD	Drawing/Plan	Machining
7-60-001	10K Potentiometer		https://www.amazo	1	$7.20		David		
7-60-002	Momentary Push Button Switch		https://www.amazo	1	$6.89	Mounting Hole 1:	David		
7-60-003	Arduino Mega		https://smile.amaz	1	$14.99	https://www.ebay	David		
7-60-004	Main Switch		https://smile.amaz	1	$17.97	48V-275A	David		
7-60-005	Motor Controller		https://www.ebay	4	$26.59	48V 800W	David		
7-60-006	Rocker Switch		https://www.ama:	1	$6.50	10A/125V	David		
7-60-007	Motor Relay						David		
7-60-008	Accelerometer/Gyroscope		https://smile.ama	1	$5.49	https://www.ebay	David		
7-60-009	Lights/horn		https://smile.ama	1	$13.99	48V/12W	David		
7-60-010	Digital LCD Display		https://www.ama:	1	$8.99	https://www.ebay	David		
7-60-011	DC-DC 48V-9V Converter		https://smile.ama	1	$11.99	48V-9V 3W	David		
7-60-012	BMS		http://www.batter	2	$43.00	48V/60A	David		
7-60-013	Charger		http://www.batter	1	$51.00	5A	David		
7-60-014	PCB Board		David	1			David		
7-60-015	3mm Hex Standoff		https://www.ama:	1	$5.39		David		
7-60-016	Controls Box Bottom	0.125" Acrylic	McMaster Carr	1	$10.99	https://www.mcm	David	David	Laser Cut
7-60-017	Controls Box Long Wall	0.125" Acrylic	McMaster Carr	1			David	David	Laser Cut
7-60-018	Controls Box Short Wall with Terminals	0.125" Acrylic	McMaster Carr	1			David	David	Laser Cut
7-60-019	Controls Box Controller Bottom	0.125' Acrylic	McMaster Carr	1			David	David	Laser Cut
7-60-020	Controls Box Long Wall with Hole	0.125" Acrylic	McMaster Carr	1			David	David	Laser Cut
7-60-021	Controls Box Short Wall	0.125" Acrylic	McMaster Carr	1			David	David	Laser Cut
7-60-022	Nylon Spade Terminal		https://www.ama:	1	$9.95		David		
7-60-023	Controls Box Lid	0.125" Acrylic	McMaster Carr	1			David	David	Laser Cut
7-60-024	LiFePO4 3.2V 20AH Battery		MER	32			David		
7-60-025	HV Box Bottom	11/32 Plywood	Home Depot	1	$14.13	https://www.hom	David	David	Laser Cut
7-60-026	HV Box Side Long	11/32 Plywood	Home Depot	1			David	David	Laser Cut
7-60-027	HV Box Side Short	11/32 Plywood	Home Depot	1			David	David	Laser Cut
7-60-028	HV Box Inside	11/32 Plywood	Home Depot	1			David	David	Laser Cut
7-60-029	6-32 Screw 0.625" Long	Steel	McMcaster Carr	30					
7-60-030	HV Box Lid	11/32 Plywood	Home Depot	1			David	David	Laser Cut
7-60-031	HV box Lid Bottom	11/32 Plywood	Home Depot	1			David	David	Laser Cut
7-60-033	Motor Fuse Holder		https://www.ama:	1	$7.96		David		
7-60-034	30A Motor Fuses		https://www.ama:	1	$5.45		David		
7-60-035	80 A High Voltage Fuses		https://www.ama:	1	$5.99		David		
7-60-036	HV Fuse Holder		https://www.ama:	1	$9.02		David		
7-60-037	Brushless Fan		https://www.ama:	1	$4.94		David		
7-60-038	Controls Box Lid Underside	0.125" Acrylic	McMaster Carr	1			David	David	Laser Cut
7-60-039	Big resistor	Ceramic	https://www.mou:	2	$0.69	1M	David		
7-60-040	Little Resistor	Ceramic	https://www.mou:	2	$0.71	82.5K	David		
7-60-041	Control Box Mesh	Stainless Steel	David	1	$0.00	https://www.mcm	David		

C: Engineering Drawings

HUMAN MACHINE INTERFACES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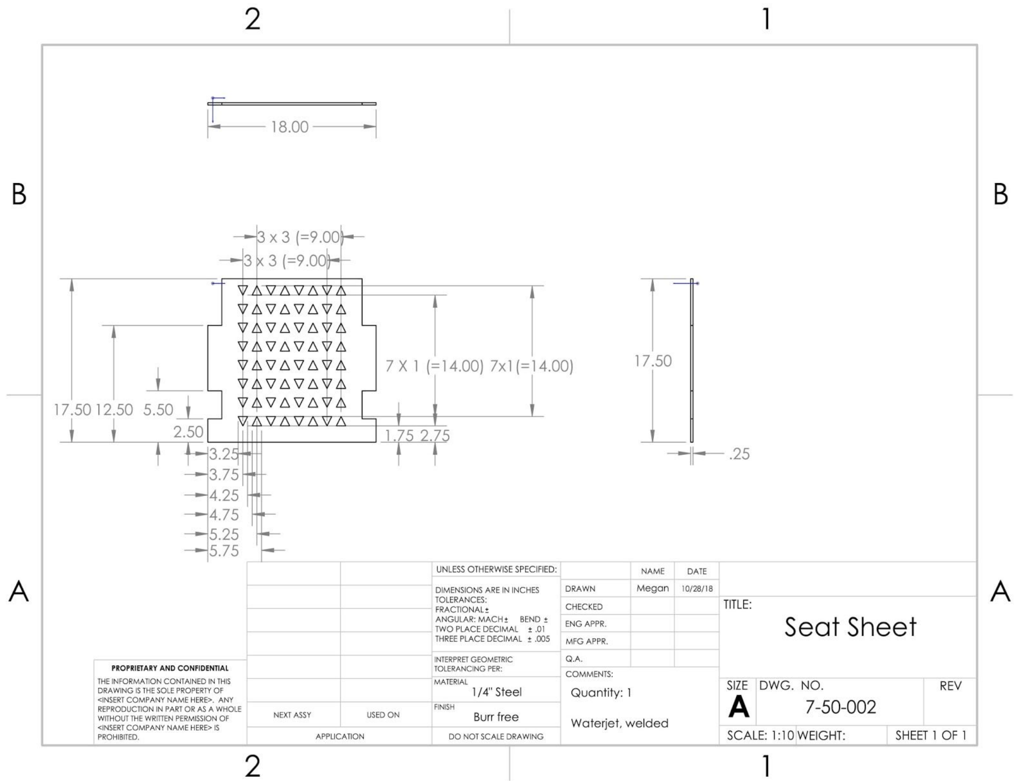
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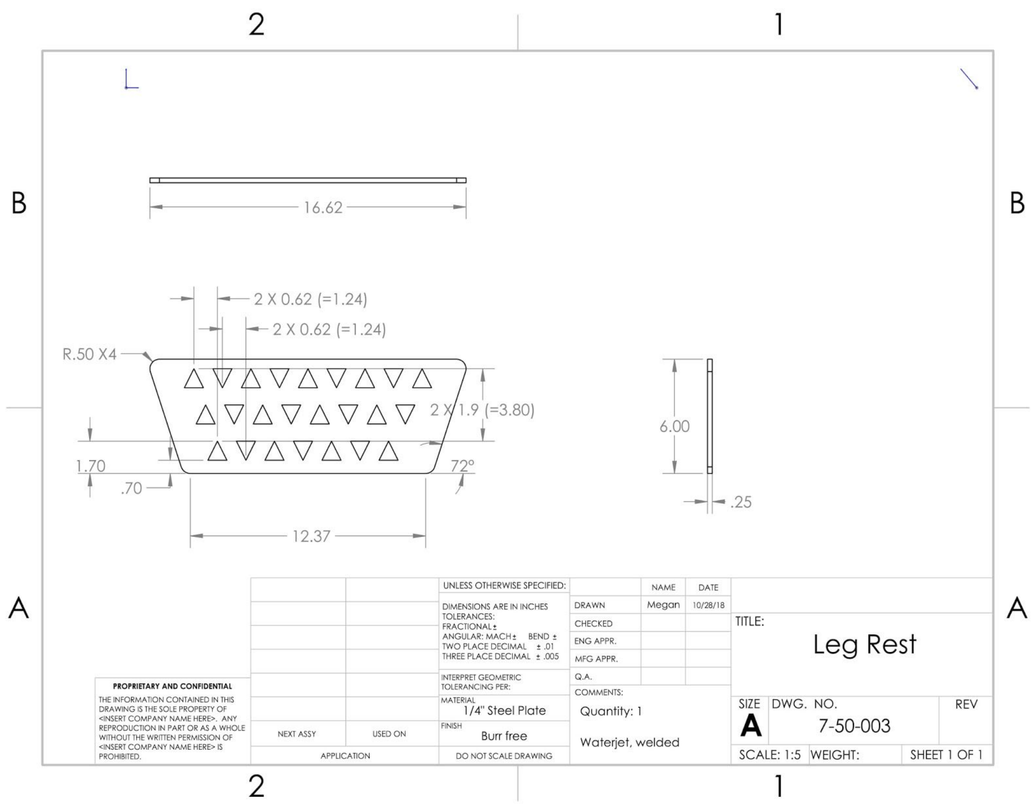
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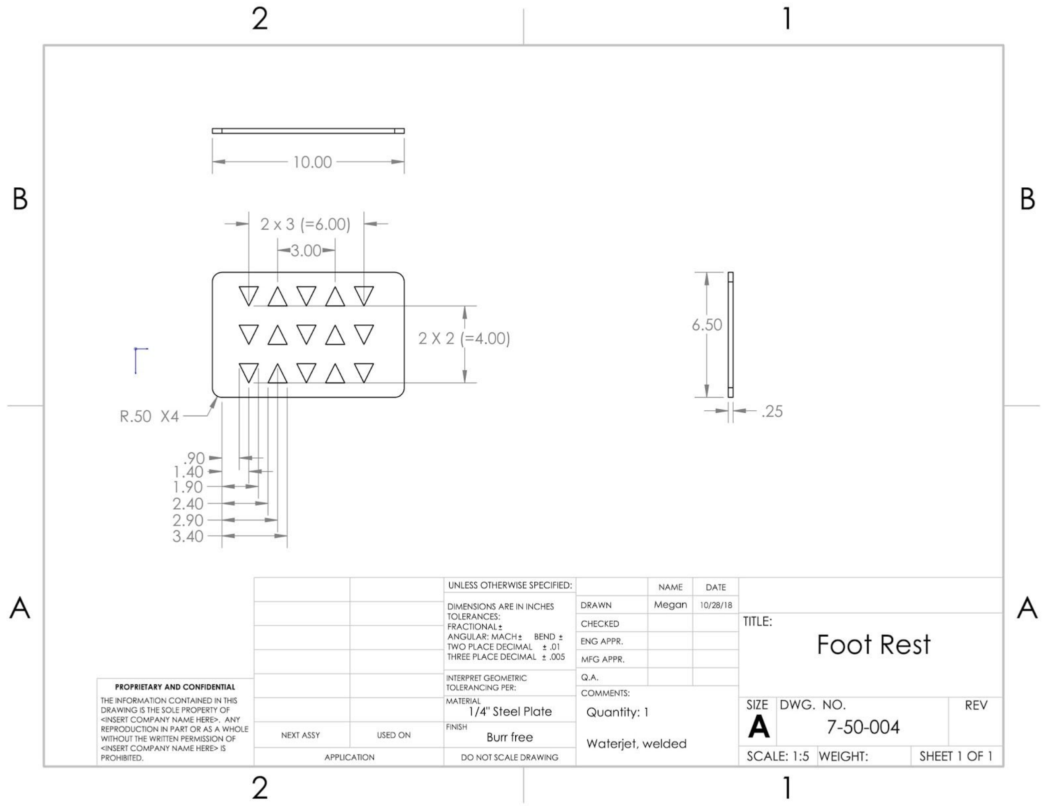

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MFG APPR.
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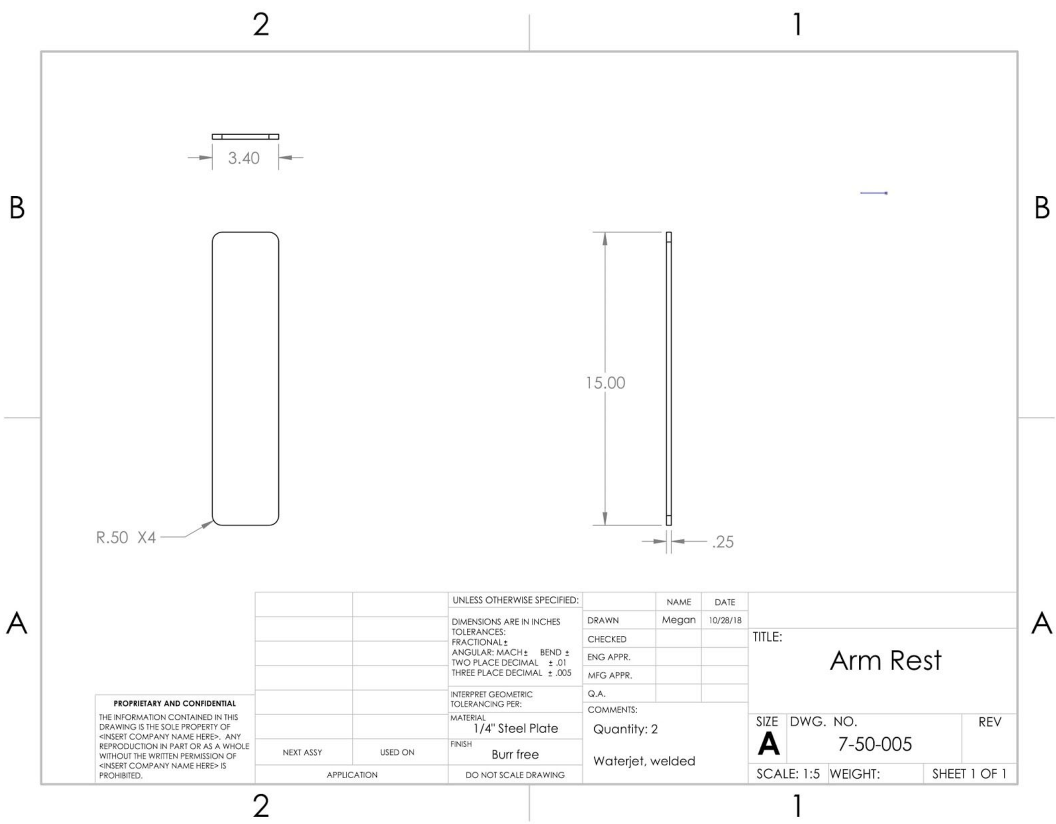

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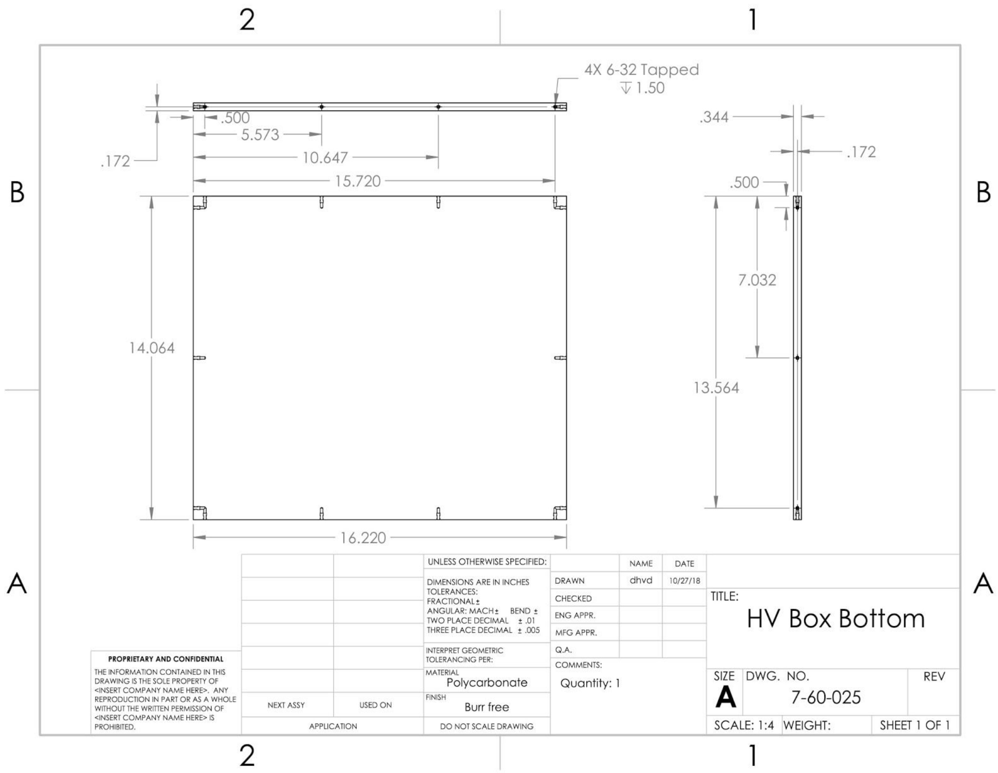
CONTROLS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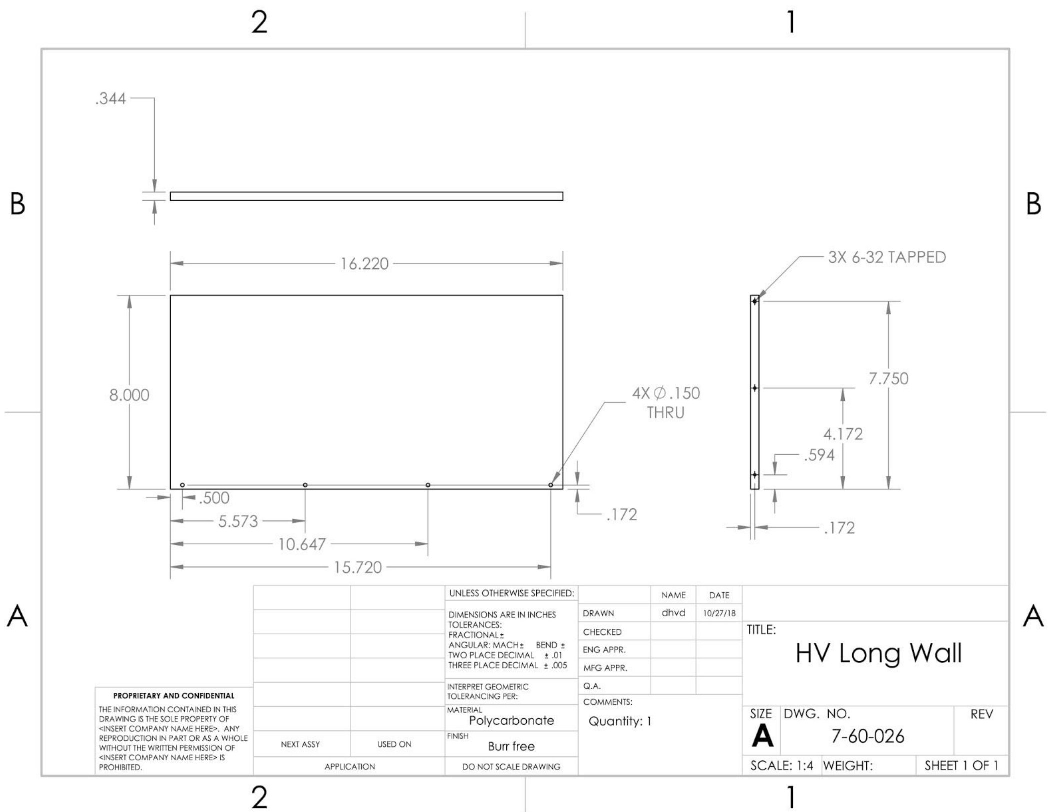
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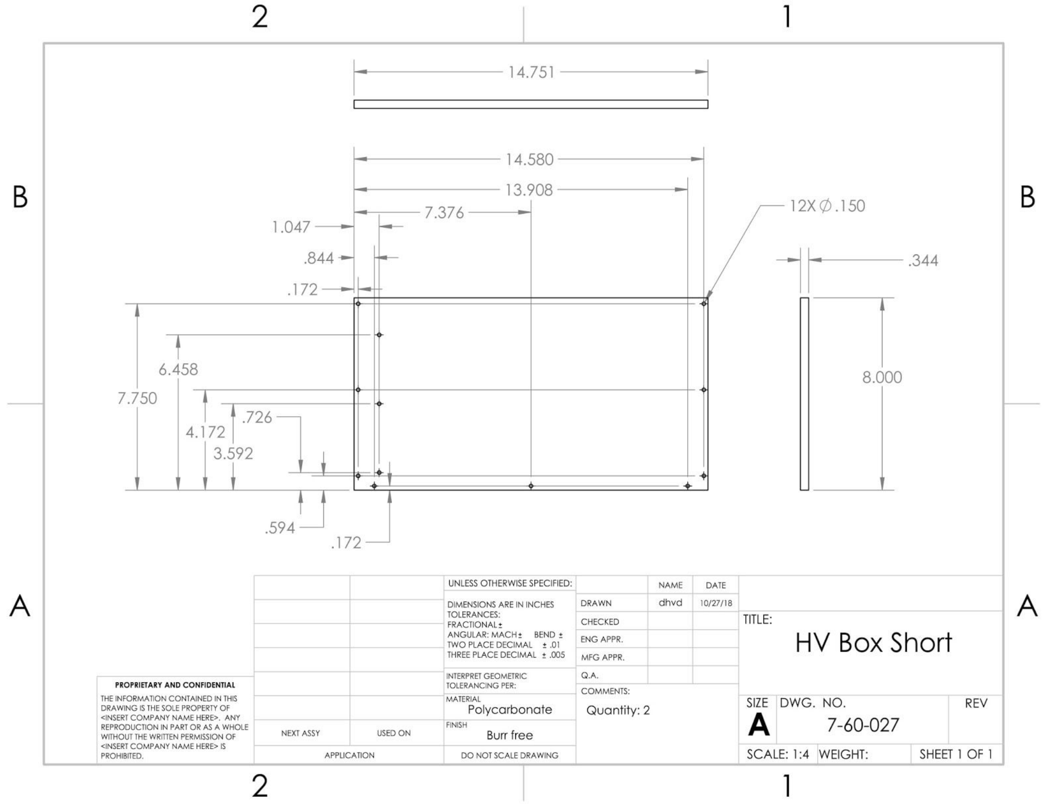
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DO NOT SCALE DRAWING
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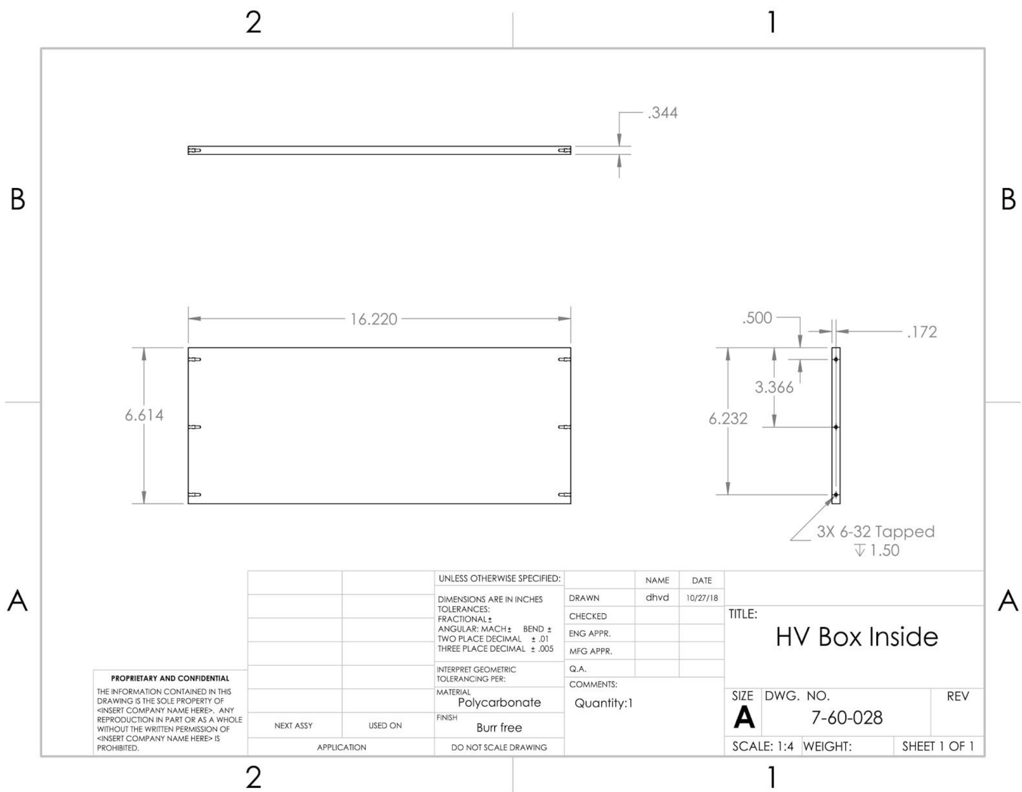
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MFG APPR.
Q.A.
COMMENTS:
Quantity:1
TITLE:
HV Box Inside
SIZE A
DWG. NO. 7-60-028
REV
SCALE: 1:4 WEIGHT: SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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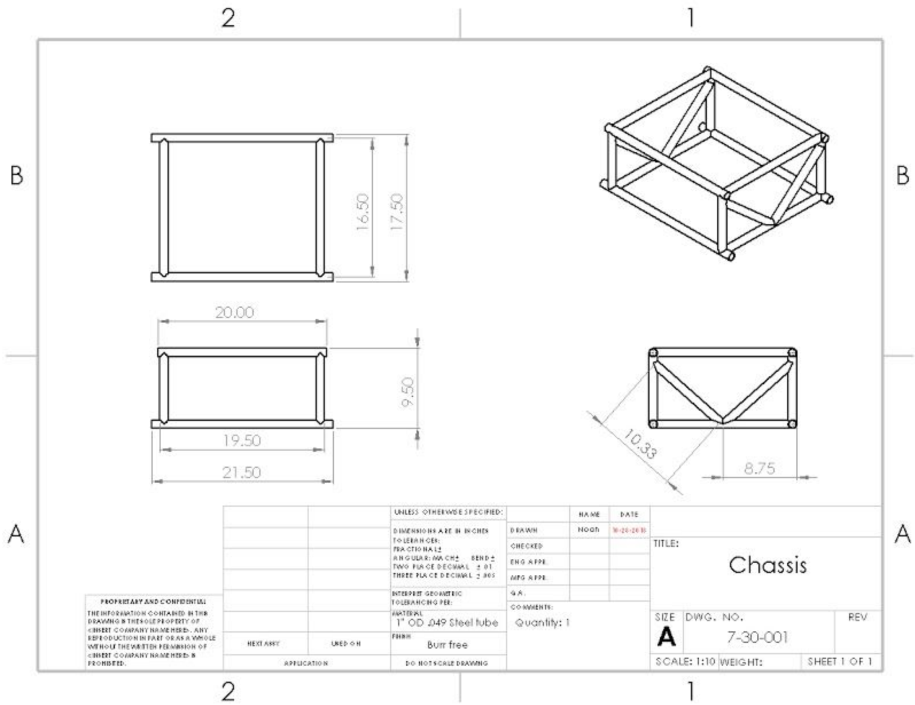
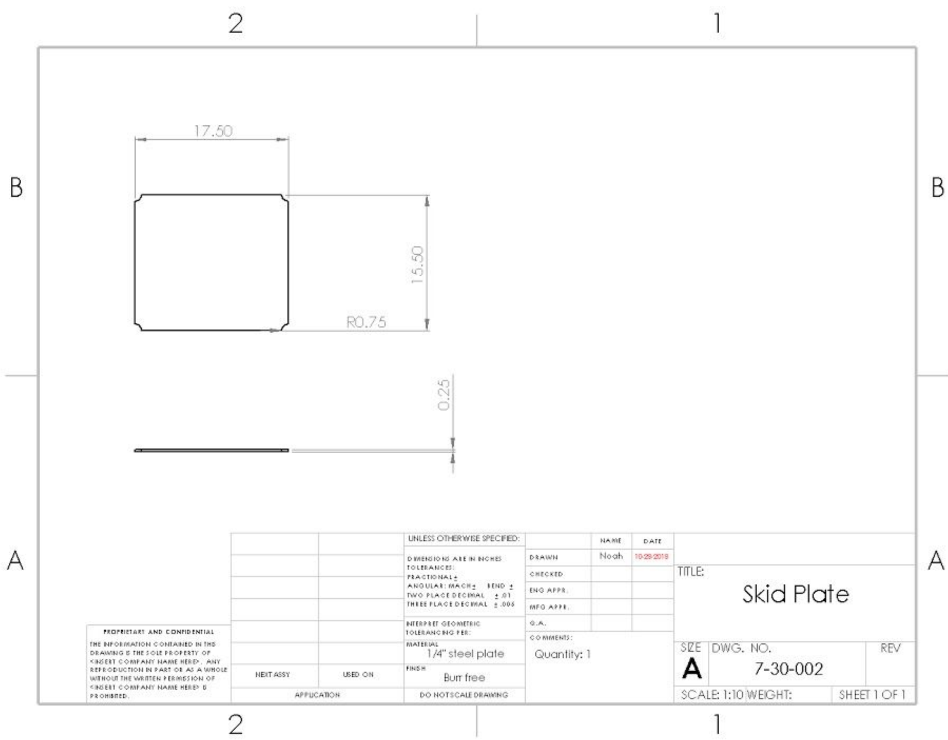
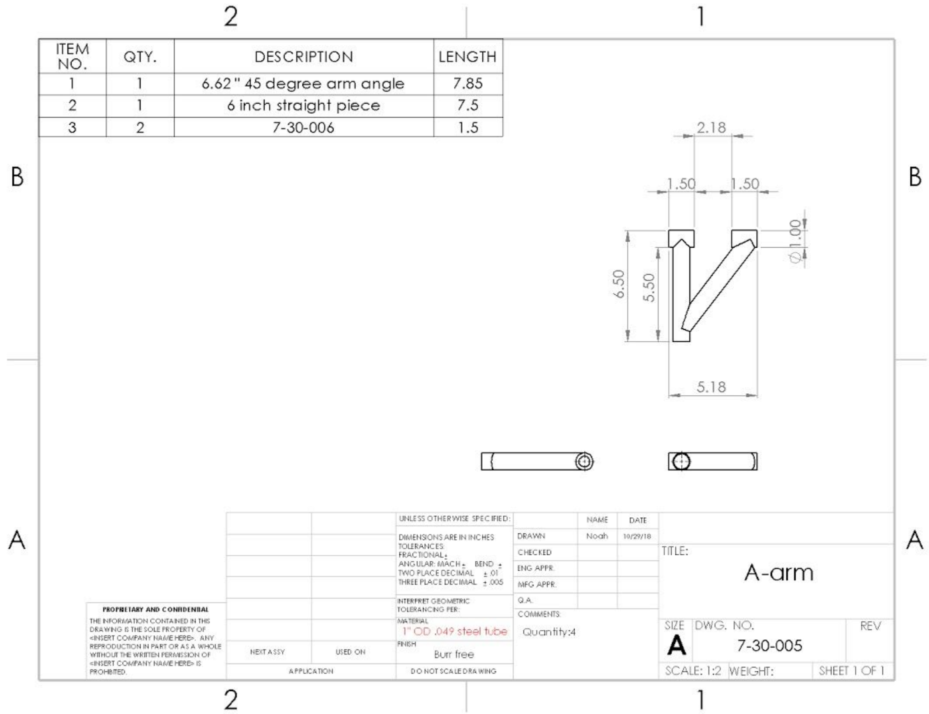
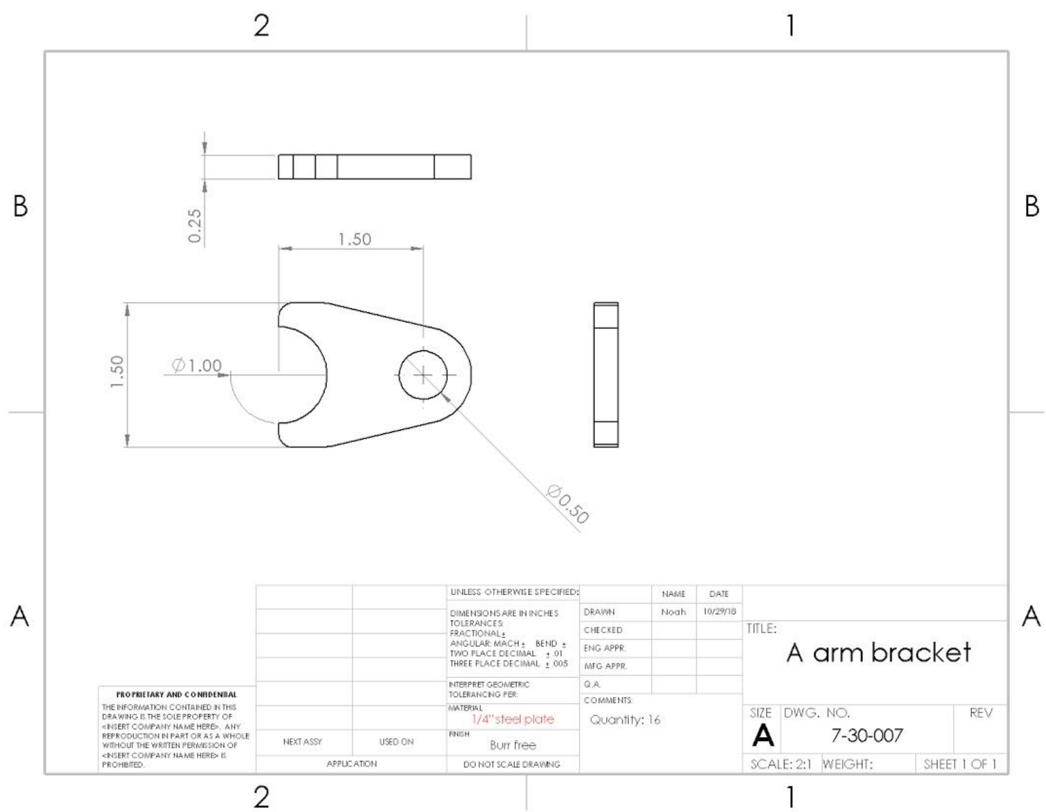
CHASSIS

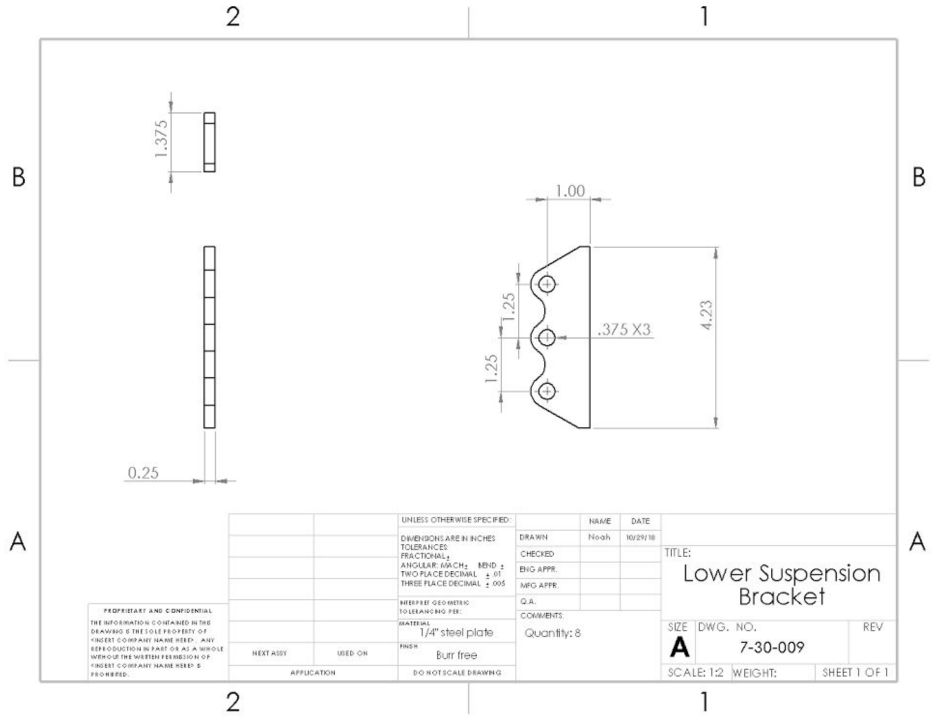

16.50
17.50
20.00
9.50
19.50
21.50
10.33
8.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1" OD .049 Steel tube
FINISH
Burr free
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
NAME
DATE
DRAWN
Noah
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Quantity: 1
TITLE:
Chassis
SIZE
A
DWG. NO.
7-30-001
REV
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1

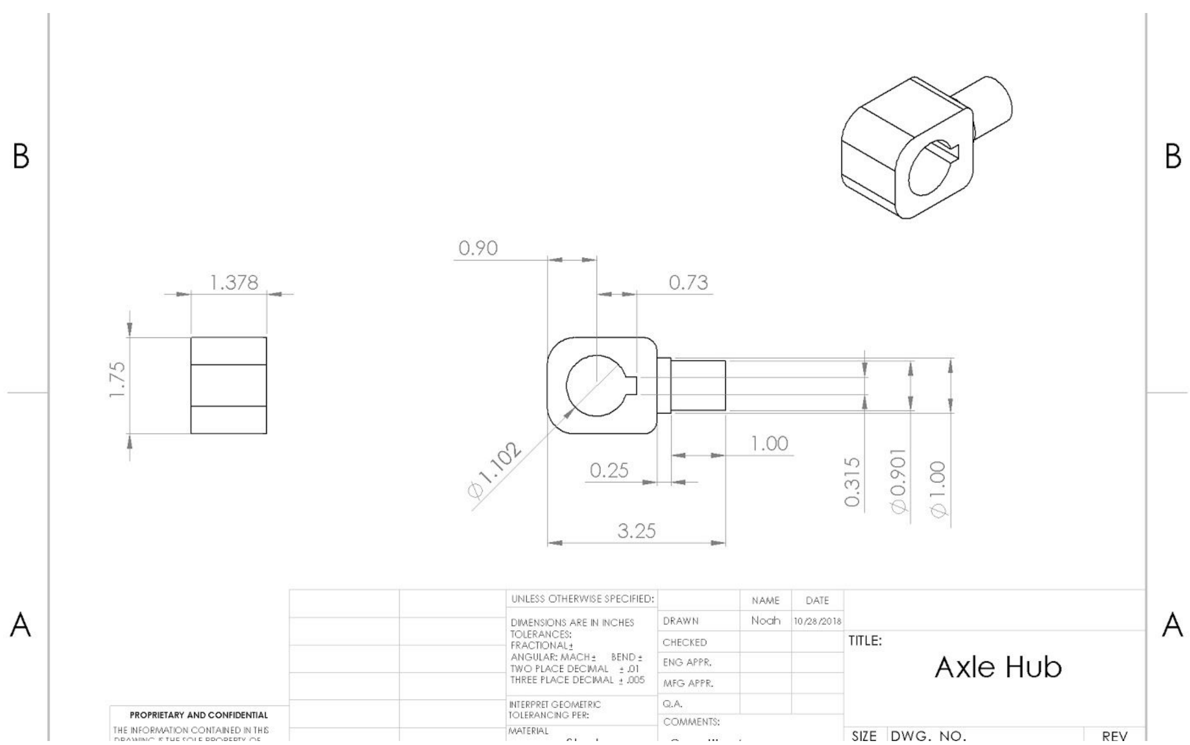

17.50
15.50
R0.75
0.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1/4" steel plate
FINISH
Burr free
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
NAME
DATE
DRAWN
Noah
10-29-2018
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Quantity: 1
TITLE:
Skid Plate
SIZE
A
DWG. NO.
7-30-002
REV
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1

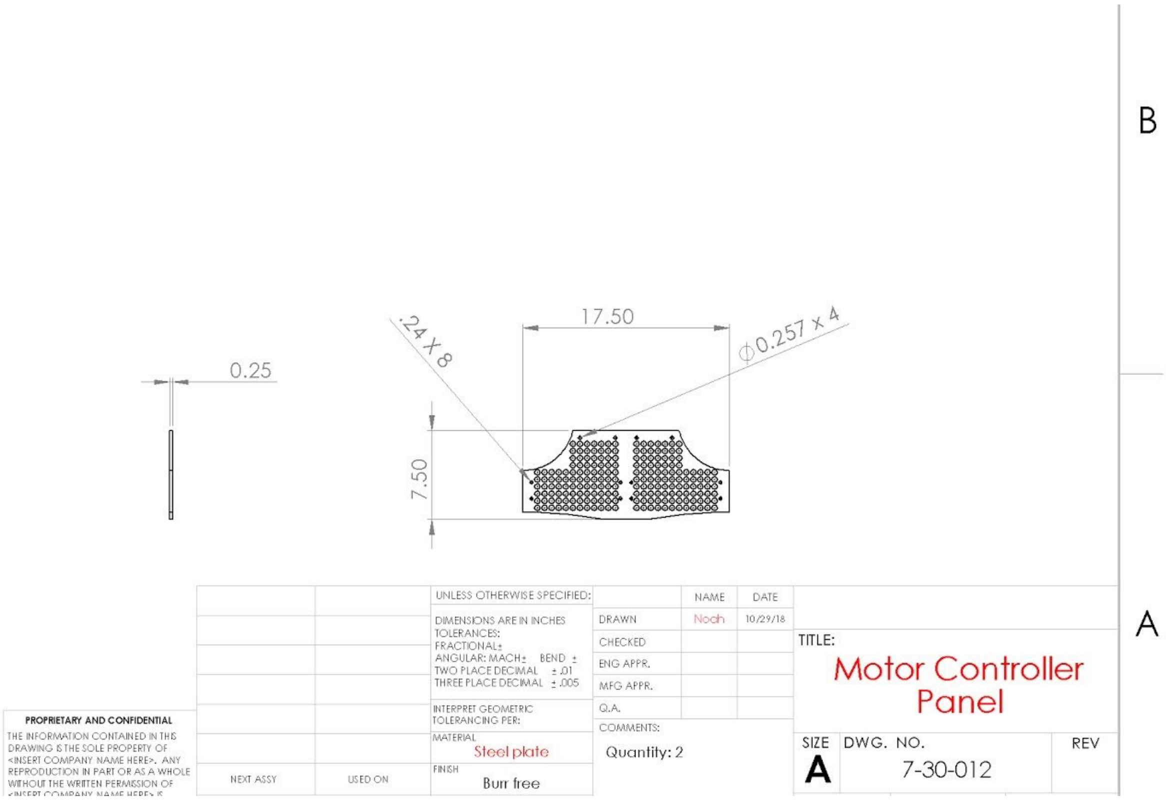


ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	1	6.62 " 45 degree arm angle	7.85
2	1	6 inch straight piece	7.5
3	2	7-30-006	1.5




1.375
1.00
1.25
.375 X3
4.23
1.25
0.25
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
Noah
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Quantity: 8
TITLE:
Lower Suspension Bracket
1/4" steel plate
Burr free
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SIZE
A
DWG. NO.
7-30-009
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


0.90
0.73
1.378
1.75
1.00
0.25
Ø1.102
3.25
0.315
Ø0.901
Ø1.00
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
DRAWN
Noah
10/28/2018
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
TITLE:
Axle Hub
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS
SIZE
DWG. NO.
REV


B
A
0.25
17.50
.24 X 8
⌀0.257 x 4
7.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel plate
FINISH
Burr free
NEXT ASSY
USED ON
NAME
DATE
DRAWN
Noah
10/29/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Quantity: 2
TITLE:
Motor Controller Panel
SIZE
A
DWG. NO.
7-30-012
REV
PROPRIETARY AND CONFIDENTIAL
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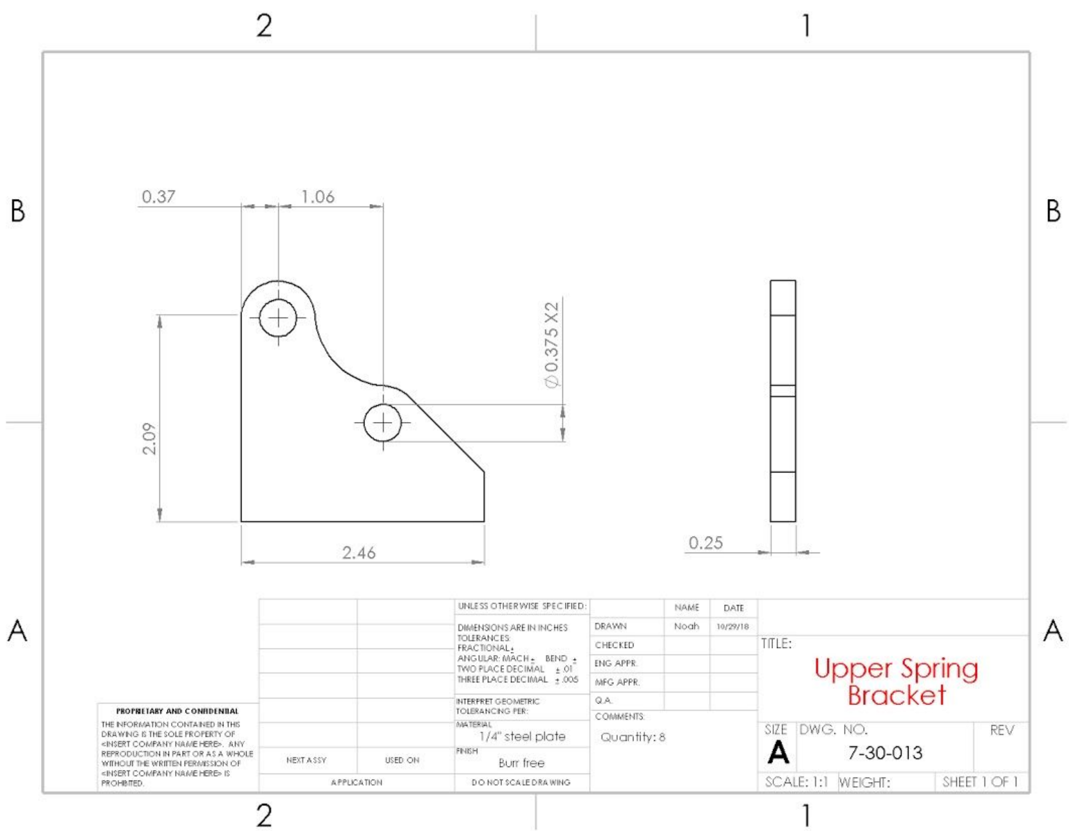
2
1
B
A
0.37
1.06
⌀0.375 X2
2.09
2.46
0.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1/4" steel plate
FINISH
Burr free
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Noah
10/29/18
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Quantity: 8
TITLE:
Upper Spring Bracket
SIZE
A
DWG. NO.
7-30-013
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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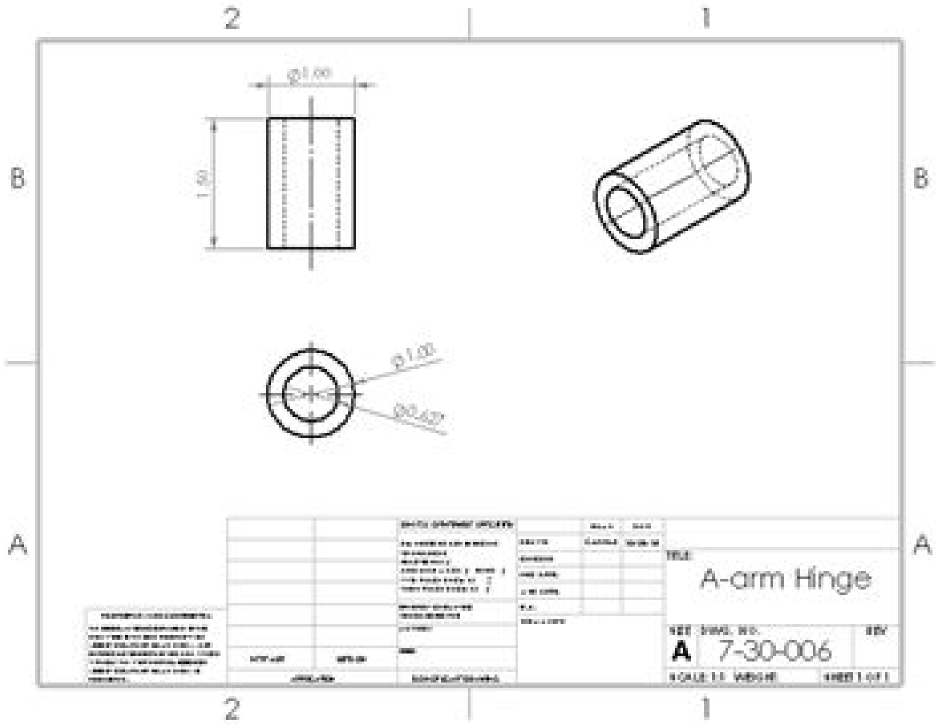
SUSPENSION



D: Manufacturing Plans

CHASSIS

Manufacturing Plan					
Part Number:	7-30-011				
Part Title:	Axle Hub				
Team Name:	7				
Raw Material Stock:	1.75" steel bar				
Step #	***Process Description***	***Machine***	***Fixture(s)***	***Tool(s)***	***Speed (RPM)***
1	cut to near final length	bandsaw	bandsaw vise	File	
2	face to final length	lathe	lathe	calipers	150
3	bore axle hole to 1.103" ~28mm	lathe	vise	bore	350
4	deburr	lathe	lathe	file	
5	key slot	lathe	lathe	file	
6	turn 1" inch profile	lathe	lathe		150
7	turn insert profile .901"	lathe	lathe		150
8	deburr	lathe	lathe	file	

SUSPENSION

Manufacturing Plan

Part Number:	7-30-006				
Part Title:	A-arm hinge				
Team Name:	7				
Raw Material Stock:	1" OD solid rod				
Step #	**Process Description**	**Machine**	**Fixture(s)**	**Tool(s)**	**Speed (RPM)**
1	Cut tube to overall length	Horizontal Bandsaw	bandsaw vise	File	
2	turn to 1.5" length	lathe		1" collet, file	
3	drill a center hole	lathe	lathe drill chuck attachment	center drill	600
4	drill hole for bushing	lathe	lathe drill chuck attachment	19/32 drill bit	600
4	ream a 5/8 hole	lathe	lathe drill chuck attachment	0.6245" reamer	100
5	weld to A-arm	welder	jig		
6	press bushing in reamed hole				

E: Important Questions and Answers

Why isn't the master kill switch a push button instead of a turn switch?

The master kill switch is a turning switch as it sits under the users hand and will be submitted to pressure from the user, therefore it cannot be a push button. This switch is also a cheaper and easier to utilize in our control system. We do not believe this is a safety hazard, as it will be easily within reach and quick to turn.

Why one inch steel round tubing instead of rectangular aluminum tube stock?

We have had a generous donation of steel round stock from the Michigan Electric Racing Team and therefore will be utilizing this material to help maintain a low budget.

Why one joystick not two, and why not mechanical turning? Will this be tested for Jason?

This is a direct wish from our end user, Jason. He wants this to look and feel like a wheelchair, and a big part of that is no mechanical steering and only one joystick. We will suggest using two joysticks in our next meeting with Jason, however the added complexity of one is not above what our team can handle. We will make a prototype of the joystick to test with Jason at our next meeting.

Will water access the controls and electronics through the cooling fan?

This was a valid concern, and as such we have added a mesh over the fan with 0.003" openings. Water cannot pass through this mesh without an external force aiding due to surface tension of the water droplets.

Is there a zero degree turning radius?

We're unsure exactly how close to zero degrees our turning radius will be. We estimate it will be close, however not zero due to the friction of dragging tires.

Is there any concern with overheating on the In Hub Motors?

We have spoken to the supplier and determined these motors have no problems with overheating.

Is Jason OK with wheels?

We met with Jason before DR2 and gave him final choice over our three best options; tank treads, wheels, and mechanical legs. He was very open to all of the concepts and did accept the possibility of using wheels over treads.

F: Revisions from DR2

There have been numerous revisions between DR2 and 3 due to the nature of DR2 being vague on details. Some major changes include the doubling of our batteries to allow for additional power for a longer period of time. We have also changed the inhub motor form 12 inches to a 10 inch design to save on cost, but have maintained the same supplier and all motor specs. We are no longer doing independent double wishbone suspension but a single a-arm suspension. The formerly swinging self balancing chair has been replaced by a fixed chair in order to prevent the center of gravity from swinging outside the wheelbase. Our budget increased from $1000 to $2000.

G. Code for the Arduino Controller

```
//ME450 Team 7 - All Terrain Wheelchair
//Created by team "Better Butt"
```

```
//November 2018
//This file contains all the code for the wheelchair and is flashed to the Arduino MEGA
#include <Arduino.h>
#include <U8g2lib.h>
#include <SPI.h>
#include <Wire.h>
#include "I2Cdev.h"
#include "MPU6050.h"
//Declare global variables
//Desired speed
double top_speed = 4; //MPH

//Speed of left and right wheels
double wheelspeed_right = 0;
double wheelspeed_left = 0;

//Angle of wheelchair/gyro
MPU6050 accelgyro;
int16_t ax, ay, az;
int16_t gx, gy, gz;
double angle_x;
double angle_y;
double angle_z;

//Individual speed of each wheel
double wheelspeed[] = {0, 0, 0, 0};

//Battery level
double battery_level;

//Emergency message
char message = "";

//Set pin locations
//Joystick
//TImer 1
const int joystick_pot_1 = A8;
const int joystick_pot_2 = A9;
const int joystick_pot_3 = A10;
const int joystick_switch = 22;

double j_1 ;
double j_2 ;
double j_3 ;
double resting_1;
```

```
double resting_2;
double resting_3;
//Hardware adresses of LCD display and gyroscope
//Find address of display and make it a global variable here
U8G2_SH1106_128X64_NONAME_1_HW_I2C u8g2(U8G2_R0, /* reset=*/
U8X8_PIN_NONE);

//Battery level reader
const int battery_level_input = A3;

//Output to each motor
//0=FL, 1=FR, 2=RL, 3=RR
//Throttle controller by Timer 3 and 4
const int throttle[] = {5, 6, 7, 8};
//Triggers reverse
const int reverse[] = {26, 30, 34, 38};
//Hall sensors
const int hall[] = {18, 19, 2, 3};
//Triggers dynamic braking for each wheel
const int brake[] = {23, 27, 31, 35};
//Triggers high speed region for each wheel
const int highSpeed[] = {24, 28, 32, 36};
//Triggers low speed region for each wheel
const int lowSpeed[] = {25, 29, 33, 37};

//Controls settings
float KP = 0.2; //Proportional gain
float KI = 0.02; //Integral gain
float KD = 0.001; //Derivative gain
double positionError[] = {0, 0, 0, 0};
double integralError[] = {0, 0, 0, 0};
double derivativeError[] = {0, 0, 0, 0};

//Motor times, used to calculate speed of each wheel
float t_prev[] = {0, 0, 0, 0};
float t_curr[4];

//Overall times, used for the PID control
float time_current = 0;
float time_previous = 0;

//Vehicle Parameters
double wheel_dia = 19.2; //inches

//Switch to activate the motors
```

```
const int motorOn = 39;

void setup() {
  //Initilize variables
  Serial.begin(115200);

  //Initialize joystick readings by averaging the initial values over 2 seconds
  for(int i = 0; i < 20; i++){
    j_1=analogRead(joystick_pot_1) ;
    j_2=analogRead(joystick_pot_2) ;
    j_3=analogRead(joystick_pot_3) ;
    resting_1=resting_1 + j_1*5.0/1024.0;
    resting_2=resting_2 + j_2*5.0/1024.0;
    resting_3=resting_3 + j_3*5.0/1024.0;
    delay(100);
  }
  resting_1 = resting_1/20;
  resting_2 = resting_2/20;
  resting_3 = resting_3/20;
  Serial.println("Pot 1 Initial Location: " + (String)resting_1);
  Serial.println("Pot 2 Initial Location: " + (String)resting_2);
  Serial.println("Pot 3 Initial Location: " + (String)resting_3);
  delay(1000);

  //Initilize pin types, only called for digitial I/O and PWM output
  pinMode(joystick_switch, INPUT);
  pinMode(throttle[0], OUTPUT);
  pinMode(throttle[1], OUTPUT);
  pinMode(throttle[2], OUTPUT);
  pinMode(throttle[3], OUTPUT);
  pinMode(reverse[0], OUTPUT);
  pinMode(reverse[1], OUTPUT);
  pinMode(reverse[2], OUTPUT);
  pinMode(reverse[3], OUTPUT);
  pinMode(hall[0], INPUT);
  pinMode(hall[1], INPUT);
  pinMode(hall[2], INPUT);
  pinMode(hall[3], INPUT);
  pinMode(brake[0], OUTPUT);
  pinMode(brake[1], OUTPUT);
  pinMode(brake[2], OUTPUT);
  pinMode(brake[3], OUTPUT);
  pinMode(highSpeed[0], OUTPUT);
  pinMode(highSpeed[1], OUTPUT);
  pinMode(highSpeed[2], OUTPUT);
```

```
  pinMode(highSpeed[3], OUTPUT);
  pinMode(lowSpeed[0], OUTPUT);
  pinMode(lowSpeed[1], OUTPUT);
  pinMode(lowSpeed[2], OUTPUT);
  pinMode(lowSpeed[3], OUTPUT);
  pinMode(motorOn, INPUT);

  //start LCD
  u8g2.begin();
  //Set initial battery level
  updateBatteryLevel();

  //Initilize wheelspeed hardware interrupts
  attachInterrupt(digitalPinToInterrupt(hall[0]), updateWheelSpeed0, RISING);
  attachInterrupt(digitalPinToInterrupt(hall[1]), updateWheelSpeed1, RISING);
  attachInterrupt(digitalPinToInterrupt(hall[2]), updateWheelSpeed2, RISING);
  attachInterrupt(digitalPinToInterrupt(hall[3]), updateWheelSpeed3, RISING);

  //Update frequency of throttle PWM output pins
  //Sets frequency to 3921.16 Hz instead of 490.20 Hz
  //Warning, other parts using Timer 3 and 4 will be running at this faster speed as well
  TCCR3B = TCCR3B & 0b11111000 | 0x02;
  TCCR4B = TCCR4B & 0b11111000 | 0x02;

  //Setup initial speed
    for(int i=1; i<4;i++){
      digitalWrite(lowSpeed[i], HIGH);
      digitalWrite(highSpeed[i], LOW);
    }
  }

void loop() {
  //This loop updates the speed of each motor to match what is desired
  //Set desired top speed
  setTopSpeed();
  //Update all systems
  updateBatteryLevel();
  updateUserSpeed();
  updateDisplay();

  //Move motors
  //Apply a voltage to the motors or brake them depending on the desired speed
  //Update the time
  time_current = micros();
  //Do the below only if the motor on switch is on
```

```
if(digitalRead(motorOn)){
for (int i=0; i<4; i++){
  //find offset, different desired speed for each wheel
  //Determine the desired speed based on if the wheel is left or right
  double wheelspeed_des = 0;
  if (i==0|| i==2){
    wheelspeed_des = wheelspeed_left;
  }
  else{
    wheelspeed_des = wheelspeed_right;
  }

  positionError[i] = wheelspeed_des - wheelspeed[i];
  integralError[i] = integralError[i] + positionError[i]*(time_current - time_previous);
  derivativeError[i] = derivativeError[i] + positionError[i]/(time_current -
time_previous);
  double desiredVoltage = KP*positionError[i] + KI*integralError[i] +
KD*derivativeError[i];
  //Enable brakes and reverse features if necessary
  //Don't use brakes/reverse unless a reverse direction is desired, otherwise let the wheel
coast
  if(wheelspeed_des < 0){
    //Activate braking if you are still moving foreward
    if (wheelspeed[i] > 0.2){
      digitalWrite(brake[i], HIGH);
      digitalWrite(reverse[i], LOW);
      desiredVoltage = 0;
    }
    //Activate reverse if you are already stopped
    else{
      digitalWrite(brake[i], LOW);
      digitalWrite(reverse[i], HIGH);
      desiredVoltage = -desiredVoltage;
    }
  }
  else if(wheelspeed_des > 0 && wheelspeed[i] < -0.2){
    digitalWrite(brake[i], HIGH);
    digitalWrite(reverse[i], LOW);
    desiredVoltage = 0;
  }
  //if the motor is not going backwards, ensure brake and reverse are off
  else{
    digitalWrite(brake[i], LOW);
    digitalWrite(reverse[i], LOW);
  }
```

```
      //Send throttle signals to the motor
      //If the desired voltage is over 5, stop it at 5
      if(desiredVoltage >5) desiredVoltage = 5;
      int pwmOutput = desiredVoltage/5.0*255;
      //writes a pwm signal to the throttle pin which is converted back to an analog signal by
the low pass filter
      analogWrite(throttle[i], pwmOutput);

    }
    }
    else{
      for(int i=0; i <4; ++i){
        analogWrite(throttle[i], 0);
        digitalWrite(brake[i], HIGH);
      }
    }
    time_previous = time_current;
  }

  //Update the current battery life left (0-100)
  void updateBatteryLevel(){
    double arduino_voltage = analogRead(battery_level_input)*5.0/1024.0;
    //Serial.print(arduino_voltage);Serial.print("/");
    double bv = arduino_voltage*(1+1000000/82500)/4;
    //Serial.print(bv);Serial.print("/");

    double cap = 27.857*pow(bv,6) - 1971*pow(bv,5) + 58084*pow(bv,4) -
912508*pow(bv,3) + 8000000*pow(bv,2) - 40000000*bv + 70000000;
    if(bv>12.4)
    {
      cap=0;
    }
    if(bv<11.2)
    {
      cap=20.34054;
    }
    //Serial.print(cap);Serial.print("/");
    battery_level = (1-(cap/20.34054))*100;
    //Serial.print(battery_level);Serial.print("\n");
  }

  //Updates the desired left and right speed based on joystick inputs
  //Modify wheelspeed_left and wheelspeed_right, between [-100, 100]
  void updateUserSpeed() {
      double j_1= analogRead(joystick_pot_1);
```

```
        double j_2= analogRead(joystick_pot_2);
        double j_3= analogRead(joystick_pot_3);
        j_1=j_1*5/1024;
        j_2=j_2*5/1024;
        j_3=j_3*5/1024;
        Serial.println("Pot 1: " + String(j_1) + "  Pot 2: " + String(j_2) + "  Pot 3: " +
String(j_3));
        //Skip all of the below steps if the values are garbage. Wheelspeed will be unchanged
from what it was previous
        if(!(j_1 < 0 || j_1 > 2.5 || j_2 < 0 || j_2 > 2.5 || j_3 < 0 || j_3 > 2.5)){
        //Constant expected voltage increase of 0.40 volts to maximum position
        const double voltInc = 0.30;
       //Get voltage change in pitch and yaw
       double pitchChange = ((j_1-resting_1) + (j_2-resting_2))/2;
       double yawChange= j_3-resting_3;
       double y = pitchChange/voltInc*100;
       if(abs(y)<20){
        y = pow(y,3)/8000;
       }
       double x = yawChange/voltInc*100;
       if(abs(x)<20){
        x = pow(x,3)/8000;
       }
       if (x>100) {
        x=100;
       }
       if (x<-100) {
        x=-100;
       }
       if (y>100) {
        y=100;
       }
       if (y<-100) {
        y=-100;
       }
      //determine wheel speed difference
      //k = constnat value to adjust under and over steer
      double k = 2.0;
      double diff = 0;
      if(x != 0){
        diff = pow((x/(x+y)),k)*2*x ;
      }
      if(diff > 200){
        diff = 200;
      }
```

```
            if(diff < -200){
              diff = -200;
            }
            wheelspeed_right = y + diff/2 ;
            if(wheelspeed_right > 100){
              wheelspeed_right = 100;
            }
            if(wheelspeed_right < -100){
              wheelspeed_right = -100;
            }
            wheelspeed_left = wheelspeed_right - diff;
            if(wheelspeed_left >100){
              wheelspeed_left = 100;
            }
            if(wheelspeed_left < -100){
              wheelspeed_left = -100;
            }

             //Reduce noise by setting to 0 if it is damn low
             if(abs(wheelspeed_left) < 3) wheelspeed_left = 0;
             if(abs(wheelspeed_right) < 3) wheelspeed_right = 0;
             }
            String output = "Left Speed: " + (String)wheelspeed_left + "  Right Speed: " +
(String)wheelspeed_right;
            Serial.println(output);

            //Set wheelspeed to miles per hour
            wheelspeed_left = top_speed*wheelspeed_left/100;
            wheelspeed_right = top_speed*wheelspeed_right/100;
          }
          void updateDisplay() {
            int averageSpeed = (wheelspeed[0] + wheelspeed[1] + wheelspeed[2] +
wheelspeed[3])/4;
            u8g2.firstPage();
            do {
                u8g2.setFont(u8g2_font_logisoso16_tf);
                u8g2.setCursor(0, 24);
                u8g2.print("Battery");
                u8g2.setCursor(70, 24);

                u8g2.print((int)battery_level);u8g2.print("%");
                u8g2.setCursor(0, 56);
                u8g2.print("Speed");
                u8g2.setCursor(60, 56);
                //u8g2.print("10 mph");
```

```
        u8g2.print((int)wheelspeed_left);u8g2.print("L");
u8g2.print((int)wheelspeed_right);u8g2.print("R");
        //u8g2.drawXBMP( 32, 0, logo_width, logo_height, logo_bits);
        //char buf[9];
        //sprintf (buf, "%d", x);
        //u8g2.drawStr(10,54,buf);
        //emergency
        //if(EMERGENCY){
        //  u8g2.setCursor(0, 40);
        //  u8g2.print("DANGER!");
        //}
  } while ( u8g2.nextPage() );
}

//Updates the speed of the wheel, called whenever the hall sensor is trigged
//Passed a wheelNumber so it knows which wheel to modify
//0=FL, 1=FR, 2=RL, 3=RR
void updateWheelSpeed0() {
  int wheelNumber = 0;
  //FInd the new time
  t_curr[wheelNumber] = micros();
  //Uses the change in time and radius of the wheel to get the MPH speed of the wheel
  wheelspeed[wheelNumber] = calcSpeed(t_curr[wheelNumber] - t_prev[wheelNumber]);
  t_prev[wheelNumber] = t_curr[wheelNumber];
}
void updateWheelSpeed1() {
  int wheelNumber = 1;
  //FInd the new time
  t_curr[wheelNumber] = micros();
  //Uses the change in time and radius of the wheel to get the MPH speed of the wheel
  wheelspeed[wheelNumber] = calcSpeed(t_curr[wheelNumber] - t_prev[wheelNumber]);
  t_prev[wheelNumber] = t_curr[wheelNumber];
}
void updateWheelSpeed2() {
  int wheelNumber = 2;
  //FInd the new time
  t_curr[wheelNumber] = micros();
  //Uses the change in time and radius of the wheel to get the MPH speed of the wheel
  wheelspeed[wheelNumber] = calcSpeed(t_curr[wheelNumber] - t_prev[wheelNumber]);
  t_prev[wheelNumber] = t_curr[wheelNumber];
}
void updateWheelSpeed3() {
  int wheelNumber = 3;
  //FInd the new time
  t_curr[wheelNumber] = micros();
```

```
  //Uses the change in time and radius of the wheel to get the MPH speed of the wheel
  wheelspeed[wheelNumber] = calcSpeed(t_curr[wheelNumber] - t_prev[wheelNumber]);
  t_prev[wheelNumber] = t_curr[wheelNumber];
}

//Calculated the speed of a wheel given the change in time over one full rotation
//Returns a double in MPH
double calcSpeed(double timeChange) {
  return 3.14159 * wheel_dia /3 * 60 * 60 / 12 / 5280 / timeChange;
}

//Sets max speed of the wheelchair
void setTopSpeed(){
  //Sets it to 10 if the switch is being depressed, otherwise it defaults to 4
  if (digitalRead(joystick_switch)) {
    top_speed = 10;
    KP = 0.4; //Proportional gain
    KI = 0.02; //Integral gain
    for(int i=1; i<4;i++){
      digitalWrite(lowSpeed[i], LOW);
    }
  }
  else {
    top_speed = 4;
    KP = 0.2; //Proportional gain
    KI = 0.02; //Integral gain
    for(int i=1; i<4;i++){
      digitalWrite(lowSpeed[i], HIGH);
    }
  }
}
```

Authors

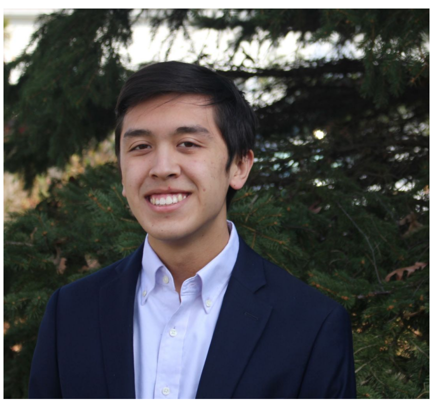
Megan MacKellar is a Senior in Mechanical Engineering, focused on medical technologies such as surgical devices and hospital equipment. In her free time she work as a board member for Camp Kesem, a free camp held for children affected by a parent's cancer. Sge also works as a mechanical designer for Michigan Neuroprosthetics, through which she has created a myoelectrically controlled prosthetic hand for an 8 year old boy. Outside of school and orgs, Megan likes to camp, hike, and play IM sports. After her senior year, Megan will be working as an R&D Engineer for Stryker, a medical device company located in Kalamazoo, Michigan.

Andrew Suchezky is a Senior Mechanical Engineering student at the University of Michigan. His professional interests are in the transportation sector, specifically in future vehicle technology. He has experience working for Williams International as an intern in manufacturing and aerospace engineering. Williams International specializes in turbofan engines for the department of defense as well as the commercial light jet class. Andrew's most recent work has been at Pratt & Miller Engineering, a product development firm in the defense and motorsports industry, as a design engineer working on designing full vehicle systems and subsystems for the military. He has secured a full-time job at Pratt & Miller following graduation. Andrew's non-professional interests include playing and watching team sports. He played competitive baseball growing up and then transitioned to ultimate frisbee, playing for his high school and eventually the University of Michigan. Other interests include mentoring high school students at his local church and attending performance car events.

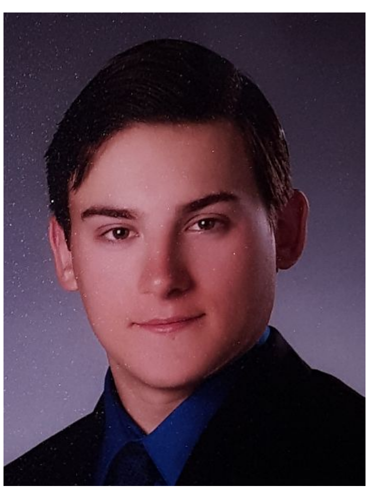
Sam Morris is a mechanical engineering major with an entrepreneurship minor, slated to graduate with the class of 2019. In his time at the university of michigan he has followed this entrepreneurial spirit by continually pursuing new experiences that fulfill his passions. Sam has led small groups for freshmen students in west quad and east quad with new life church and participated in a summer leadership training program on mackinac island. This included teaching history and performing demonstrations as a historic interpreter. Sam has also participated in michigan basketball and marching bands, and participated as a contestant in the college-run youtube series "survivor: michigan". Sam's passion for film led him to create a marketing video for danish startup "squarely" while interning for them during an entrepreneurship study abroad program. This passion is continued while on the production team for survivor: michigan. He has also interned at Humphrey Products, who creates pneumatic valves and switches through engineered solutions. Sam hopes to pursue a career in either the automotive or furniture industry, and hopes to one day start his own company.

Herbert Hsu is a senior studying Mechanical Engineering at the University of Michigan. His interests are in product design and mechatronics. He is currently working at the UM Transportation Research Institute to design canine crash test dummies. Last summer, he interned at a startup to design commercial UV air purifiers. In addition to mechanical engineering, he also enjoys coding. He worked on a web demonstration program that takes in weather data and visualizes it into an animation on a globe for a research project. In his free time, he likes to travel, play basketball, hang out with his friends and take frequent naps.

Noah Diroff, a Senior Mechanical Engineering student at the University of Michigan, is proud to be a Michigan wolverine. In his time at Michigan, he has developed an appreciation for all types of engineering feats, but specifically plans on developing his interest in manufacturing following graduation. He has interned at Plastipak, a major rigid plastic container manufacturer, in the manufacturing services department as well as at Duro-Last Roofing. His most memorable experiences include studying abroad in Berlin, Germany in support of the creation of mobile, solar-powered phone charging stations and studying rocks at Camp Davis in Jackson Hole, Wyoming. Throughout college, he has frequented the all rec centers in the pursuit of lifting heavier weight in the sport of powerlifting. He has also enjoyed his time as a general member of Triangle Fraternity. Go Blue!



David is a senior majoring in mechanical engineering and minoring in electrical engineering at the University of Michigan. He is currently working in the Shih biomedical research lab on campus to create the world's first phantom for rat brains to mimic microwire insertion and is the lead chassis designer on the Michigan Electric Racing team. In previous years he worked as a SolidWorks CAD designer for model train company Tangent models and was the division lead for the vehicle dynamics and chassis division on the Michigan Hybrid Racing team



Conrad Carver is a senior Mechanical Engineering student attending the University of Michigan. His interests include mechanical design, mechatronics, and inventing simple devices. In past summers, he has worked fixing and remodeling a grandparent’s home to raise its market value for resale. He has also hand built a dolly/trailer that can transport and launch an 11’ 9”, 160 lb inflatable boat. He enjoys biking, kayaking, boating, and swimming during his free time.