Regenerative Braking Electric Skateboard

Mid-Project Report

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Senior Design Team Members:

Ryan Hawkins - Electrical Engineering

Fawzi Al Hadrab - Electrical Engineering

Brad George - Mechanical Engineering

Brendan DeJonge - Mechanical Engineering

Department of Electrical and Computer Engineering

Colorado State University

Fort Collins, Colorado 80523

Project Advisor: Ali Pezeshki

Approved by:

Date of Approval

Abstract

There are two major issues with modern day electric skateboards. The first problem stems from the implementation of the regenerative braking system in most electric skateboards. When the battery pack is completely charged, there is nowhere for the excess current to be directed to when using the regenerative braking system, meaning that the user is unable to use the brakes when the batteries are charged. It is also a common issue that the regenerative brakes could produce too much current and could shut the system down completely, also disabling the ability to brake. The other major concern comes from the feature of allowing users to adjust the tightness of the trucks to their liking. The looser the trucks, the more control, which is better for slower speeds. For higher speeds, it is advantageous to have tighter trucks for more stability. Users typically choose a tightness in the middle of the extremes and do not get the benefits of either option at the higher and lower speeds. This is not necessarily a problem in itself, but it would be beneficial to be able to quickly and easily adjust the tightness of the trucks based on the speed the user is actively traveling at.

There are many active communities online within the niche of electric skateboarding. After searching online, it becomes apparent that there are several recurring concerns within the community. Many users are concerned about the loss of ability to brake when the batteries are completely charged. The common consensus is that the user should refrain from charging the battery more than around 90 percent capacity. Another common point of contention appears in discussions surrounding the tightness of the trucks. In particular, new riders are not sure how tight or loose their trucks should be. The most common response is to choose a tightness somewhere in the middle so that you are still able to maintain control over the turning capabilities, but not have them so loose as to cause serious concerns of “speed wobbles”, or loss of control at high speeds.

A thorough search online concludes that there does not appear to be many, if any, solutions to the problems stated before. Some of the solutions, such as refraining from charging the battery past 90 percent capacity so that the user does not lose the ability to brake, is a band-aid solution, and does not correct the problem that is occurring. Instead, the user must be inconvenienced themselves, which is a definite oversight on the ability to safely brake. Other problems, such as being able to adjust the truck tightness without dismounting the board, acquiring the proper sized wrench, then tightening or loosening the trucks manually do not exist. As a result, many users do not bother adjusting the trucks at all, which defeats the purpose of having the adjustable trucks. As the majority of research on regenerative braking has been conducted on large electric motors, a noticeable lack of effort can be seen in the development of regenerative braking between large and small electric motors. The same development in small electric motors does not appear to be profitable enough, either because the cost to develop and implement better systems for these small electric vehicles is not worth the value it would add to the particular company's profit, or because energy efficiency has become less marketable in past years, as suggested in an environmental journal [1]. As the market for electric skateboards and for small electric vehicles continues to grow yearly, so will the demand for new features, better capabilities, and sustainability. The market cap will continue to rise, and with that comes more demand for electric skateboards both at the top of the cost spectrum as well as the bottom.

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Introduction

The electric skateboard has exponentially increased in popularity, quality, and capability in recent years, proving itself valuable to everyone from college commuters to professional racers. While there are many great electric skateboard brands out there, there is still significant room for improvement.

First, most electric boards with regenerative braking do not allow the rider to brake when the battery is full. In certain cases, such as a passenger beginning their ride at the top of a hill with fully charged batteries, could leave the passenger with the inability to brake at any point while traveling down the hill. Another issue occurs when too much current is generated, which also has the ability to disable the braking system. This issue is commonly an issue when the passenger is traveling down a particularly steep hill. The goal of this project is to resolve this issue by designing an electronics system that will redirect the excess current under braking away from the main battery.

The next issue concerns the trucks (which control steering sensitivity) Normally, a rider has to manually adjust the skateboard trucks. If the trucks are loose, the board will be highly maneuverable at low speeds, but will be incredibly unstable at high speeds. Conversely, if the trucks are tight, the board will be stable at high speeds, but hard to maneuver at low speeds.The other primary goal of this project is to resolve this issue by developing a system that will autonomously adjust the trucks while riding according to the speed of the board or input of the rider.

The project is broken down into two separate but equally important parts. Two prototype boards will be built with different focuses on each. One board will primarily focus on the entrepreneurial aspect of the project. Existing parts will be bought where available so that the focus of the board can be on the regenerative braking capabilities as well as the automatic adaptive truck system. Any additional components or improvements will need to be fully implemented with the prebuilt parts utilized on this board. The main focus will be to make this board as competitively viable as possible by putting considerable effort into an easy to install, separate system which will control the truck adjustment, as well as any improvements to the regenerative braking capabilities that can be easily added to the existing market components.

For the second board, a larger, longboard type board will be used instead, and the primary focus will be to build as much from scratch as possible. The plan is to learn as much as possible by building from the ground up. Some components will still be store bought, such as the motors and skateboard decks as it is unfeasibly to build these components based on the scope of the project, Building the remaining components should allow a better understanding of interrelations between the components. This leaves the remaining components to be fully custom made, such as building an open source ESC that suits the needs of the project, as well as designing the controller, custom made enclosures for any of the systems developed, custom motor mounts and drive train systems, and a custom made battery pack. The first board will use a prebuilt ESC, battery pack, and controller so that the focus will remain on the improvements rather than the creation of the market available parts, while the second board will be focused on learning.

Hardware Design

Battery Management System and Battery Pack

To ensure maximum range and performance, custom battery packs will be created using two series of 14 Samsung 40T's lithium ion batteries in parallel. These batteries are rated at 4000mAh and have a nominal discharge of 3.6V each giving us the capability to have a total capacity of 8000mAh and a total output voltage of 52V to power the board.

This battery pack will be paired with a smart BMS with bluetooth connectivity that will utilize balanced charging and enable us to push the batteries to their maximum potential while ensuring the safety of the battery pack by monitoring the health of individual cells in the pack. Moreover, the BMS will be able to ensure the batteries are working in an optimal environment by monitoring heat and humidity inside the enclosure. Over charge protection which ensures the batteries are not being over charged when connected to the charger, over discharge protection which cuts off a series of cells if they have a higher discharge than 3.7V, and current overshoot protection will also be a part of the BMS primary functions. A 3D model of the proposed battery pack is shown in Figure 1.

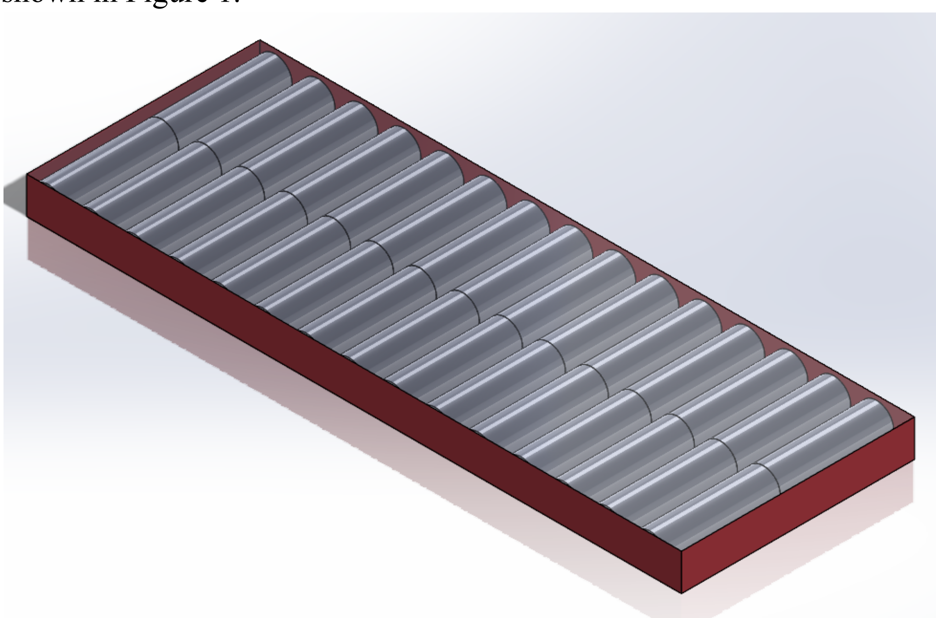

Figure 1: Prototype of Battery Pack

Dynamic Regenerative Braking

To avoid overloading the batteries by regenerative braking and major sudden cut-offs to all electrical features, one of which is braking, the implementation of a 4-quadrant chopper, also known as a Class E chopper, would achieve all the quadrants representing forward motoring, forward braking, reverse motoring, and reverse braking. Class E choppers are preferred over the more popular H-Bridge circuit design as the H-Bridge can only function in 2 quadrants while Class E choppers utilize all 4 quadrants as discussed earlier. Integrating a heat sinkable resistor with a heat sink would help dissipate any excess current that exceeds the threshold of the batteries as measured by the BMS in real time while keeping the enclosure at the correct temperature. Excess current will be directed by the ESC towards the heat sink instead of towards the batteries. This poses the extra challenge of properly dissipating heat while maintaining a water and dirt proof enclosure.

The effectiveness of an electric vehicle's regenerative braking capabilities is determined by several factors. Regenerative brakes convert mechanical energy into electrical energy by using the momentum of the electric vehicle and its passenger to spin a motor, effectively turning the same motor used to propel the vehicle into a generator. The amount of mechanical energy available to convert is in itself the largest variable. Since large electric motors, such as in cars, carry much more weight, the amount of mechanical energy available that they can convert back into electrical energy is much greater. For every multiple of two in the total weight directly doubles the amount of kinetic energy available. According to the formula for kinetic energy, speed has even more of an effect on kinetic energy than weight. For every multiple of two in the speed of a vehicle results in a kinetic energy four times as large. As larger electric vehicles tend to travel at higher speeds, this means that they also tend to carry a much higher kinetic energy total. Larger vehicles tend to be much more efficient at converting wasted energy back into electrical energy, as shown in a journal article discussing regenerative braking in hybrid vehicles, which states that regenerative braking can increase the efficiency of a hybrid vehicle by anywhere from 20-50% [2], increasing with the motor size. Other factors such as temperature of the system, total amount of current returning to the batteries, and SOC of the battery. Overcharging the batteries also has a negative effect on the life of the batteries according to the same journal. For larger hybrid vehicles, the recommendation is that the regenerative braking capabilities be shut off once the SOC of the battery reaches 80%.

To increase the efficiency of regenerative braking capabilities in a small electric vehicle, several small steps can be taken. Proper temperature control of the braking system, smoother torque acceleration as well as smoother braking, proper charging of the battery, and less friction coefficients as well as proper configuration of the motor and drivetrain system will all have a positive influence on the regenerative braking efficiency.

Arduino and RF Transceiver

Communicating with the ESC of each board will be an Arduino Nano alongside a RF Transceiver (HC-05). The purpose of the transceiver is to receive the input from the controller. The Arduino Nano will then relay these instructions and transform them into a format that the ESC can understand, and can then translate into motor controls. The specific selection of the (HC-05) transceiver helps to protect the signal from its transmission from the controller to the Arduino Nano from frequency interferences, whether intentional or not. This system will also control the servo motor that will adjust the trucks via input from the user. The user will also have the ability to modify the Arduino code using preset parameters to customize the board to their liking. An Arduino Nano was chosen as the microcontroller because its computing and connectivity capabilities are more than adequate for the computations and communications that are required, while saving both on space and on budget compared to its larger, more robust counterparts. An additional benefit comes from the abundance of resources available online dealing with Arduino microprocessors. To check the fit of the Arduino Nano microprocessor, and 3D CAD has been created as shown in Figure 2.

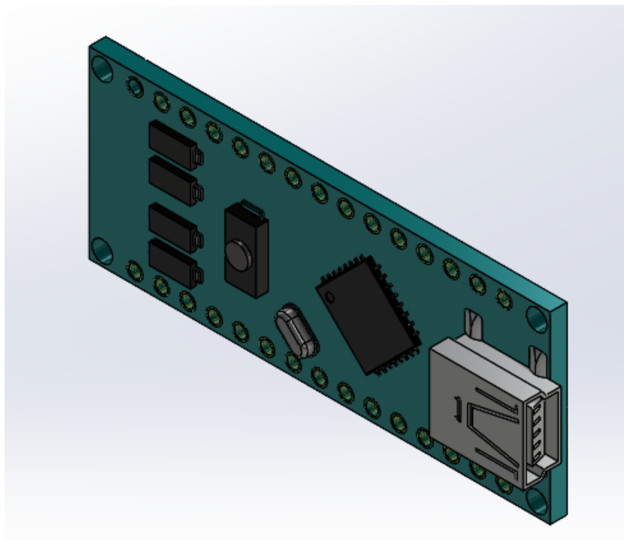

Figure 2: CAD Arduino Nano

Motors and Electronic Speed Controller

Two separate Electric Speed Controllers are going to be utilized. For the longboard type board, a custom made ESC is being developed. If properly functioning, this ESC would allow the complete customization of the code and software utilized by the ESC to communicate with the rest of the components. This would allow the easy integration of the chopper circuit as well as the regenerative braking software needed to recharge the batteries off of the spinning motors. Correct implementation of the custom ESC would also reduce the cost of the ESC system, as the components cost approximately $166 per circuit board, which includes a PCB stencil, compared to $300 equivalent of a prebuilt ESC. The custom ESC is also sizably smaller than the store bought equivalent, at approximately 42% the length and 38% the width, with a similar disparity in weight as well.

The cruiser type board will utilize the Focbox Unity, a prebuilt ESC which specializes in the control of dual motor setups. This ESC will provide a baseline of comparison with the custom made ESC. It should also allow a much quicker setup and installation time, allowing the majority of the improvement design and implementation of the cruiser board to be centered around the regenerative braking improvements as well as the adaptive truck system. This ESC can also be custom programmed and interfaced with through a number of different channels, such as UART, CAN-BUS, analog, and USB-C in order to allow for any necessary coding improvements or changes.

Both ESCs will control the same dual motor setup. The motors being used will be the 6374 motors with a maximum power output of 3500 watts. These motors will be accompanied each with a pulley system connecting them to the wheels, utilizing a steel gear coupled with a customized 3D printed gear. The dual motor setup will provide a large power output, and will supply sufficient torque to propel the skateboard and passenger forward. Proper software implementation of the ESCs will be necessary to smooth our acceleration of the board, both to increase safety and stability as well as energy efficiency.

Adaptive Trucks

As previously alluded to, the adaptive truck system is meant to autonomously adjust the truck sensitivity by adjusting the torque on the truck bushings during riding.

Essentially, the speed controller will read and record the velocity of the skateboard, relay that information to the Arduino, which will then process it and send a signal to two servo motors (one for each truck), which will then rotate a given amount, turning a tapped sprocket in order to adjust the trucks according to the speed.

Due to space limitations and precise geometry alignment needs, this is one of the more difficult systems to implement effectively on the board. In order to accomplish this, a custom mount, shown below in Figure 3, is to be 3D printed in Nylon, which will house, protect, and anchor the servo motor to the deck in alignment with the kingpin of the trucks.

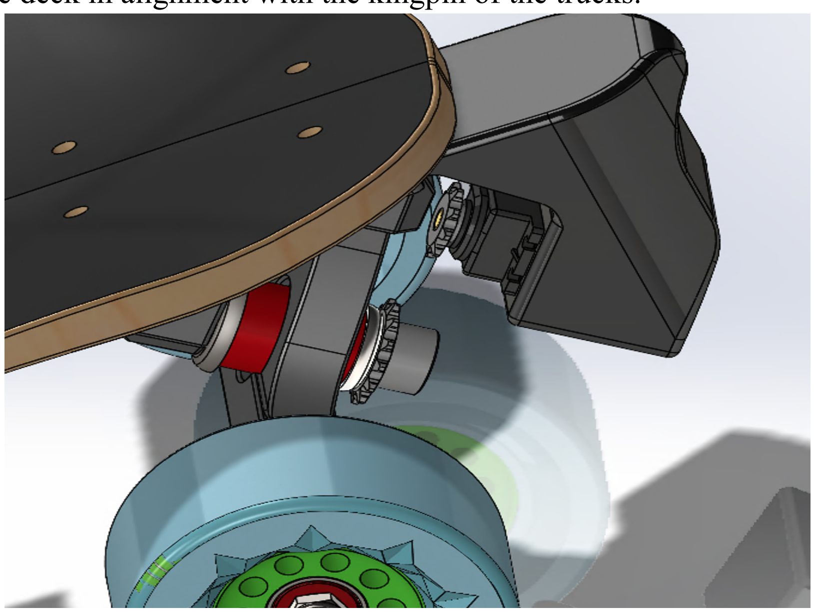

Figure 3: Adaptive truck mount on front of Cruiser Board

In order to enable high rigidity, the mount will be sandwiched between the trucks and deck using the existing mounting holes, and in this way will also serve as riser pads for the board. Initially, ideas of anchoring this mount directly to the trucks were considered, but since the trucks are always pivoting about the hinge, this idea was unacceptable.

The adaptive truck mount is also designed to enable perfect orientation between the kingpin of the truck and the servo motor, to allow either a chain or a belt to transfer power from the servo to the truck most effectively. A tensioning system will likely need to be implemented, as there is no room for adjustment of the servo location on the mount, and research will be done early next semester to determine the best way to do that.

One final concern regarding the adaptive truck system is that by necessity, the mount sticks past the front of the board. Were the rider to accidentally slip off the board and allow it to hit a curb, this could compromise the entire adaptive truck system. To help mitigate this risk, the mount protrudes past the profile of the motor to act as a bumper which would dissipate the energy from such an impact. Actually testing will commence on this once a physical prototype is in hand.'
The design of prototype adaptive truck mount, as well as a cross section of the design, can be seen below in Figures 4 and 5 respectively/

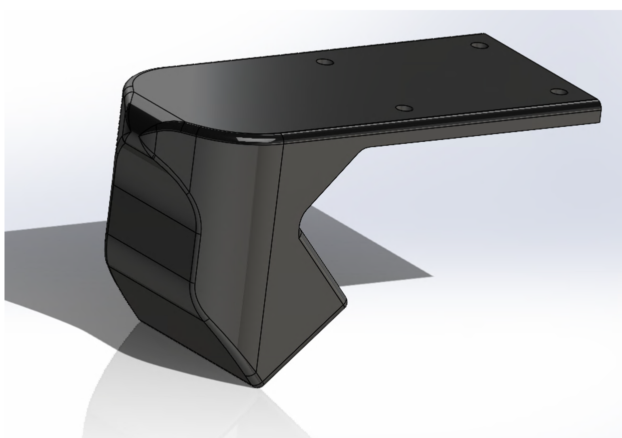

Figure 4: Adaptive Truck Mount Prototype

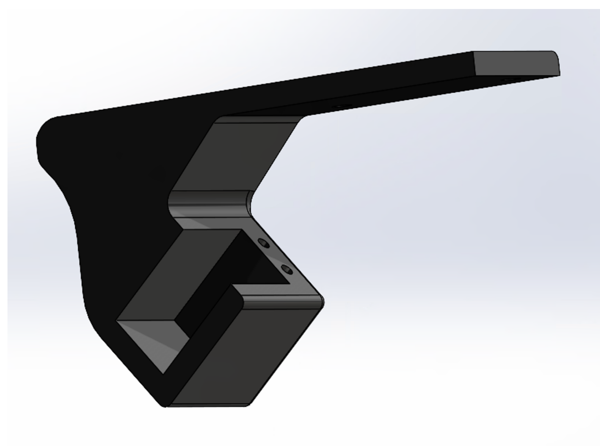

Figure 5:Adaptive Truck Mount Prototype Cross-Section

Motor Mounts

For maximum functionality and reliability of the motors and drivetrain during all modes of operation, it is vital that the motor mounts remain completely fixed. Unpredictable or unfavorable motor mount motion under working conditions could potentially lead to a misalignment or removal of the drivetrain belt from the system. Such a failure would indefinitely compromise the safety of the rider especially at higher speeds by suddenly stopping one or both of the rear wheels. To ensure the reliability of the motor mounts, the rotation and translation about the trucks must be eliminated and can be visualized below in Figure 6. Other design criteria that were considered were proper belt tensioning and material selection.

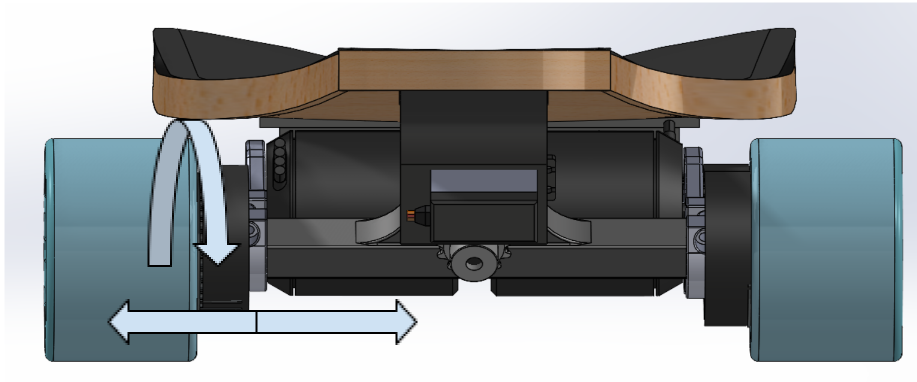

Figure 6: Criteria for a Fixed Motor Mount Visualized

Because the trucks feature a non-circular cross section, designing a mating surface on the mounts that matched that of the trucks can be used to prevent all motor mount rotation. Although an actual mating envelope between the two surfaces could be used to reduce some translational motion, incorporating the principles of a shaft collar to this connection more reliably prevents translational motion of the motor mounts along the trucks and can be seen in Figure 7 below.

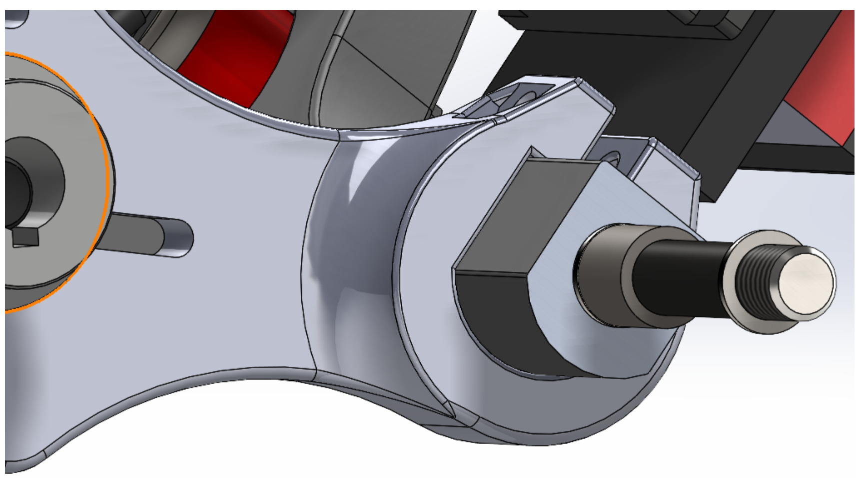

Figure 7: Mating Surface between the Trucks and Motor Mount

As previously stated, the importance of rigidity in electric skateboard motor mounts is to ensure the alignment of the drivetrain during operation. In addition to keeping the motor mounts fixed, the last design criteria that needs to be met for a reliable system is proper belt tensioning. Preliminary designs of the motor mounts did not account for variable belt tension, meaning that a given design would fit only one size belt at only one tension setting. This situation could result in a belt that is too loose with an additional chance of misalignment, or a belt that is too tight that could lead to an increase in stress to the bearings, over amperage of the motor, or eventual motor failure. The final motor mount design for our electric longboards which can be seen below in Figure 8 features mounting slots instead of holes which provide an option for the user to manually adjust the location of the motor and thus altering the belt tension in the process for maximum belt functionality and minimum chance of misalignment.

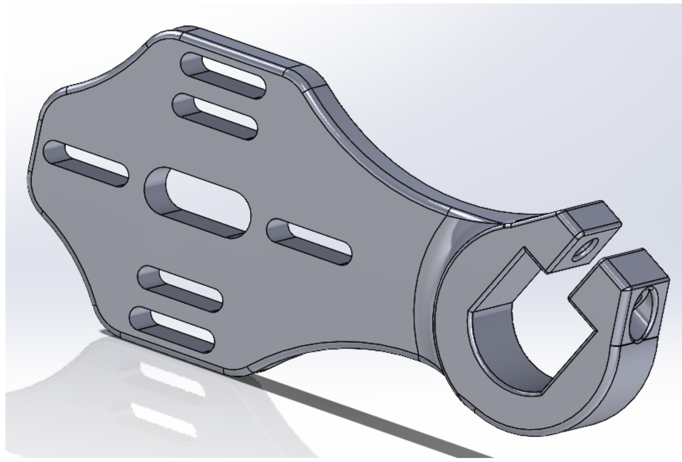

Figure 8: Final Prototype of Rear Motor Mount Design

Electric skateboard motor mounts that are on the market today are traditionally made from aluminum 6061. As this is the most common material that is consistently used, it was an option that was researched to a good extent; however, for the sake of flexible design, quick prototyping, and low cost, 3D printing proved to be the superior option especially considering the team's desire to create a new and proprietary design.

An in-depth analysis of different materials and printing processes was carried out to determine if manufacturing motor mounts could be successful for our final products. By the end of the research phase there were two options that stood out the most: Markforged Onyx chopped carbon fiber and MatterHackers Nylon X. These are two carbon fiber based materials that have the potential to print complex geometries while being comparable to the critical material properties of aluminum 6061. After careful consideration of the motor mount application, it was determined that the MatterHackers Nylon X is the best material that can be used because of its additional impact resistance, larger flexural strength, and a much lower density than aluminum 6061.

In addition to material properties, the price to manufacture each part was also considered. Because Nylon X is priced at $116/kg and the estimated weight for each mount is around 31.1 grams, the price for each motor mount that is produced is approximately $3.61. When compared to the raw price of aluminum, producing these mounts with carbon fiber filament is slightly more expensive, but is still the best option considering the additional benefits to 3D printing rather than traditional manufacturing that were mentioned earlier. Material properties for aluminum 6061 and MatterHackers Nylon X can be seen in Appendix D and E respectively.

Enclosures

The electronics enclosures are a hugely important part of the mechanical system of the electric skateboard, as they house and protect all the vital systems which keep the board running. There are typically four main factors to take into consideration when designing enclosures for electric skateboards: flex in the deck, matching the deck contour, ease of access to electronics, and weatherproofing. A mockup for the enclosure for the cruiser type board can be seen in Figure 9.

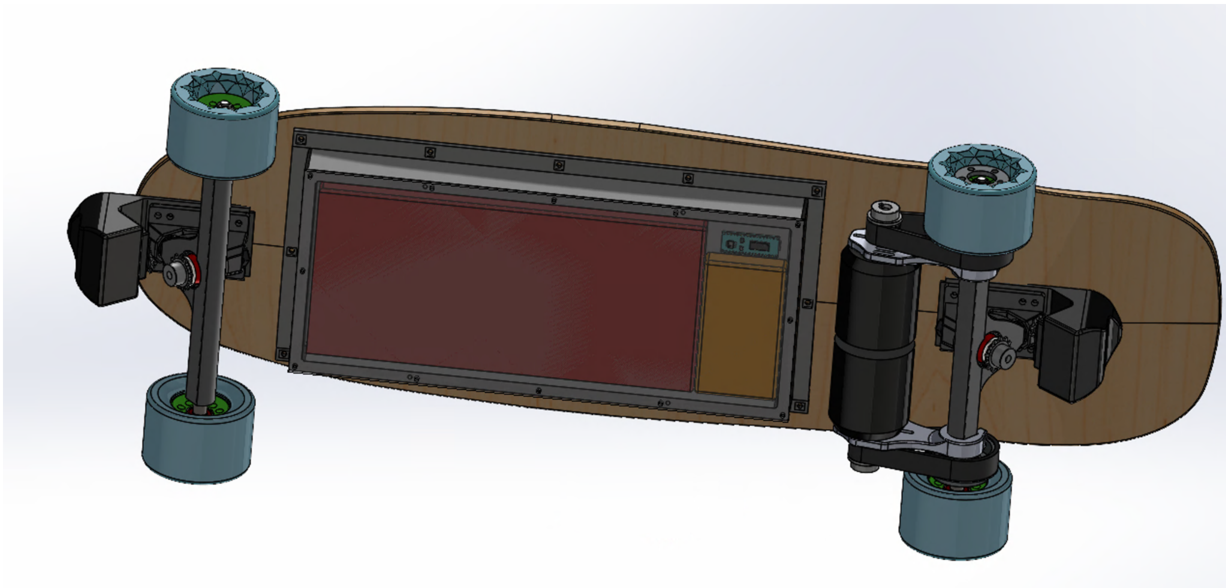

Figure 9:Enclosure Mounted on Cruiser

Firstly, many longboard decks utilize a certain amount of flex to act as suspension when riding, adding comfort to the rider. The problem with highly flexible decks, aside from the fact that they are known to be unstable at high speeds, is that they make it difficult to adequately secure the electronics in a rigid way, as the flex in the deck can bend and destroy the electronics, or damage the enclosure at the very least. Some electric skateboard brands compensate for this by separating the battery and speed controller, but this puts unnecessary limits on the size of the battery, and therefore decreases performance. Other brands, such as Evolve, compensate by developing flexible enclosures and flexible batteries, but this greatly increases the price. Since these options both seemed less than ideal, highly stiff, downhill rated longboard decks were chosen for this project. Not only will this allow more room for bigger batteries on the boards, but it will also increase stability at high speeds, which is critical to the safety of the rider. The team will evaluate through testing next semester whether or not the ride is too harsh with these stiff boards, and if so, bigger, softer wheels will be implemented to act as suspension.

Secondly, it is important to match the deck contours with the enclosure. Since modern longboard decks have varying profiles to add strength and rider grip, mating the enclosure to the deck can be quite difficult. Thanks to the advancement of 3D scanning and 3D printing, this team was able to address this challenge with gusto. In order to determine the exact geometry of the decks used, they were 3D scanned in the I2P lab. From the mesh that the scanner delivered, a profile could be constructed that matched the deck perfectly. This profile was used in the final design of the enclosures used.

In order to provide ease of access to the electronics, the enclosure design features a single panel/cover that can be easily removed with a hex key. The electronics will be mounted to this panel via flat head screws, so the electronics can be easily worked on on a table or workbench, instead of deep within the board itself. Furthermore, the panel will be clear, enabling the rider to visually inspect the electronics without even removing the panel.

Lastly, and most importantly, weatherproofing had to be considered. Since electric skateboards can be subjected to dust, dirt, and water quite frequently, weatherproofing is a serious concern. Water in the enclosure could result in the destruction of all electrical components, and can be dangerous to the rider. In order to mitigate this challenge, only the top cover of the enclosure will be removable, ensuring that no water or dust gets in between the deck and the enclosure. The removable cover will mount onto the rest of the enclosure, sandwiching a neoprene strip, which will form a seal and prevent all moisture and dust from entering. Figures 10 and 11 show the CAD renders of both the designed enclosure base, as well as an enclosure cover respectively.

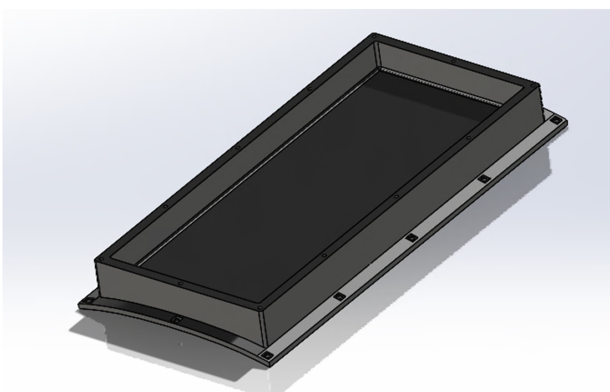

Figure 10: Enclosure Base

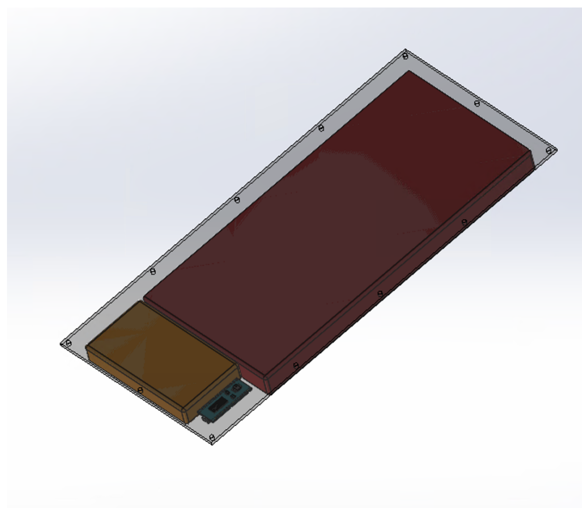

Figure 11: Enclosure Cover w/ Sample Electrical Components

Potential Market, Manufacturability, and Marketability

The electric skateboard market was expected to rise in value by 19% over a 10 year period since 2015. Newer reports have identified a bigger market potential that would surpass the 19% but also show a larger gap between the cost of production of electric skateboards. In recent years, the market has seen an increased production of low cost electric skateboards equipped with preliminary technology. Furthermore, some brands have opted to equip its boards with highly technologically developed equipment that has been in development for years but have lacked to address significant safety concerns and come with a price tag that exponentially exceeds the cost of the equipment equipped. In other words, the average product starts at approximately $2500.00 without addressing any electrical issues that can be prevented with the use of different implementation techniques. Although some companies have addressed riding comfort before by adding shock absorbers, these systems are heavy and don't eliminate speed wobbles but instead makes the board heavier and slower but excels in the off-roading department.

In addition, the use of 3D printed components would cut on production cost while having better properties than most conventional materials used. This also allows for quick and easy manufacturing and a very effective method to continuously develop the prototype with cheap physical testing.

Those prototype regenerative electric skateboards are built to compete with the higher-end of the electric skateboard market with an intention to beat the competition by price, technology and safety. Although the prototypes do utilize some off the shelf components it has been determined that manufacturing those parts in-house would prove to be more costly and would fall behind other electric skateboards on the market currently. Rather than build those components from scratch; taking advantage of what is already available for other electronic devices, modifying and fabricating it for these prototype applications, and further developing the code would make these prototypes a solid competitor in the current market especially with the added features addressed.

Standards

To maintain high standards on all aspects of the board's performance both mechanically and electrically, an objective list containing all the target criteria has been compiled below. To ensure all the electric components meet the specifications, initial testing of all the boards components will be administered. The data gathered in the lab will be compared to factory specifications to achieve a benchmark for the components.

Table 1: BMS Standards

Objective	**Objective Direction**	**Description**	**Metric**	**Target**	**Priority (1-5)**
Over-charge	Protect	Protect the battery pack from over charging	Voltage	4.3	5
Charge current	Protect	Ensure suitable discharge	Ampers	45	5
Balance	Protect	Ensure all battery cells are charged equally	Ampers	50-60m	5
Temperature	Protect	Ensure the temperature in the enclosure is at optimum	Degrees Celsius	80	5

Table 2: Battery Cell Standards

Objective	**Objective Direction**	**Description**	**Metric**	**Target**	**Priority (1-5)**
Nominal Voltage	Protect	Ensure the cells operate at nominal voltage	Voltage	3.6	5
Continuous Discharge	Maximize	Achieve a continuous discharge within the target	Ampers	45	5
Discharge	Cut-off	Ensure all battery cells	Voltage	2.5	5

		discharge meets minimum requirements			
Discharge Capacity	Cut-off	Ensure the discharge capacity doesn't go below threshold	Ah	3900m	5

Table 3: Complete Electric Skateboard Standards

Objective	**Objective Direction**	**Description**	**Metric**	**Target**	**Priority (1-5)**
Maximize Speed	Maximize	Achieve the maximum speed each board can handle	mph	35	5
Maximize Range	Maximize	Achieve the maximum range out of the battery pack	mi	15	5
Maximize Smoothness	Maximize	Achieve a smooth acceleration	Current	smooth	4
Maximize Hill Climb Ability	Maximize	The ability to overcome a steep climb smoothly	degrees	25	3
Minimize Weight	Minimize	Achieve the lowest weight of the board	lbs	25	2

Table 4: Regenerative Braking System Standards

Objective	**Objective Direction**	**Description**	**Metric**	**Target**	**Priority (1-5)**
Maximize Torque	Maximize	Achieve adequate torque to rotate the nut	ft-lb	15	5
Maximize Water/Dust Resistance	Maximize	System should be splash and dust proof to protect the electrical and mechanical internals	IP rating system	67	4
Maximize Reliability of Braking	Maximize	Braking system should work safely at all times	#	1/10000	5

Capabilities		during a ride			
Maximize Efficiency of Regenerative Braking System	Maximize	Regenerative system should effectively re-charge the batteries	%	70	4

Table 5: Adaptive Steering Sensitivity Control Standards

Objective	**Objective Direction**	**Description**	**Metric**	**Target**	**Priority (1-5)**
Maximize torque	Maximize	Has adequate torque to help maneuvering and cornering	Nm	10	4
Maximize Live Speed Data	Maximize	Compile live data on the fly using a hall sensor	ms	1	3

Conclusion

While still a market viable option to increase the efficiency of the regenerative braking electric skateboards, it is clear that regenerative braking in small electric vehicles is not as important as it is in larger electric or hybrid vehicles. The efficiency of regenerative braking scales directly with the size of the vehicle in question. This means that by default, the regenerative braking capabilities of small electric vehicles such as electric skateboards are not as efficient as those found in larger electric vehicles such as cars. This does not completely rule out the viability of regenerative braking systems in electric skateboards however. From a marketing standpoint, increasing the regenerative braking capabilities would offer a substantial competitive advantage over electric skateboards of otherwise similar quality.

The larger benefit of the improvements made to the battery system and regenerative braking system would come in the form of the safety improvements. Creating a system with more reliable braking capabilities would greatly increase the value to potential customers who would place safety as their number one priority when choosing an electric skateboard. While potentially alienating a portion of the market with the increase in price, other customers would be willing to accept the higher price point as a tradeoff to a higher safety standard. The marketing benefit in general would also greatly benefit from a higher degree of safety. Coupled with statistical analysis would be a great selling point when compared to similar skateboards on the market.

The portion of the project that has the highest potential of having market viability stems from the creation of the adaptive truck system, as at the moment, there is not a similar system on the market. This makes market analysis difficult, and predicting the success of such a system in the market is nearly impossible. There could be any number of reasons that such a system does not currently exist on the market. Many undiscovered problems could contribute to this, with the most obvious being the lack of interest from the market. Other problems could arise, from a specific problem with the mass production of the system, to the system becoming a safety hazard, stopping it from reaching the market in the first place. However, another possibility is that such a product simply has not been released to the market. In this case, it is very possible that an adaptive truck system would be widely accepted by the market.

Future Work

The majority of future work involves the manufacturing of designed parts, assembly of both hardware and software, testing, and failure corrections. Due to the COVID-19 pandemic, shipping times are exceptionally longer than normal. This has delayed some aspects of the project, but has given the opportunity to focus on other aspects in the meantime.

The next step for future work involves the assembly of the first board using off the shelf components. For the assembly of the first board, progress is still stunted by the delay in the last few required components. Once the required parts arrive, the team will assemble the board as a baseline for improvement. Design of custom manufactured and 3D printed parts has been completed. Production of some of these parts, such as the enclosure, is contingent on the arrival of the store bought components so that they can be evaluated and changes can be made before committing the costly production step. Production of motor mounts and pulley systems have started already.

Once the base electric skateboard is assembled, tests can be run to establish baseline parameters, such as the efficiency of the regenerative braking. This will also be an important step to measure other parameters such as torque, maximum speed, maximum range, and minimizing the refresh rate for the live data transfer of the speed of the motors. This will give a strong indication of where the skateboard compares to the rest of the market. It will also allow the development of the adaptive truck system, as well as comparing any improvements to the regenerative braking as a percentage compared to the baseline previously established.

Table 6: Future Work Timeline

Task	Assigned for	Due by	Dependencies
ESC Assembly	Ryan Hawkins & Fawzi Al Hadrab	12/15/2021	Design and component ordering
Controller Design and Assembly	Brad George & Brendan DeJonge	12/15/2021	Design and component ordering
Manufacturing and Machining	Brendan DeJonge	12/20/2021	Design (mechanical and electrical)
3D Printing	Brad George	1/3/2022	Design (mechanical and electrical)
Testing individual components	Team	1/10/2022	Ordering components, manufacturing parts and 3D printing

Electrical Assembly	Ryan Hawkins	01/15/2022	Testing individual components
Mechanical Assembly	Brendan DeJonge Brad George	01/15/2022	Testing individual components
Insulating	Fawzi Al Hadrab	01/25/2022	Electrical and mechanical assembly
Programing and Coding	Fawzi Al Hadrab & Ryan Hawkins	01/25/2022	Electrical assembly
Entrepreneurship Improvements	Team	02/20/2022	Programming and Assembly
Physical Testing	Team	02/20/2022	Programming and assembly
Fixing Testing Failures	Team	03/1/2022	Physical testing

References

[1] E. R. Stafford, “Environment: Science and policy for sustainable development 2009 guidelines for contributors,” *Environment: Science and Policy for Sustainable Development*, vol. 51, no. 3, pp. 60–61, 2009.

[2] J. K. Ahn, K. H. Jung, D. H. Kim, H. B. Jin, H. S. Kim, and S. H. Hwang, “Analysis of a regenerative braking system for hybrid electric vehicles using an electro-mechanical brake,” *International Journal of Automotive Technology*, vol. 10, no. 2, pp. 229–234, 2009.

[3] Howard E. Boyer and Timothy L. Gall, Eds., American Society for Metals, Materials Park, OH, 1985.

[4] MatterHackers Nylon X Carbon Fiber Filament. MatterHackers. Lake Forest, CA. 2019.

Appendix A - Abbreviations

Abbreviation	Description
BMS	Battery Management System
DIY	Do It Yourself
ESC	Electronic Speed Controller
PCB	Printed Circuit Board
SOC	State of Charge
VESC	Vedder's Electronic Speed Controller

Appendix B - Budget

Preliminary Approved Budget

Unit 1: Cruiser	
Loaded Omakase Grip N Rip (Complete)	$300.00
Battery Pack	$400.00
Motors	$500.00
VESC ^ MkV-12s	$350.00
Unit 2: Longboard	
Loaded Vanguard Monster Truck (Complete)	$360.00
Battery Pack	$400.00
Motors	$500.00
VESC ^ MkV-12s	$350.00
Other:	
Controller (x2)	$100.00
Arduinos (x3)	$90.00
Miscellaneous	$600.00
Machined Components	$1,200.00
Total Cost:	$5,150.00

Running Total

Board One - Cruiser - Plug and Play							
Part	**Name**	**Quantity**	**Unit Cost**	**Total Cost**	**Date Ordered/Manufa**	**Ordered By**	**Reimbursement R**
Deck/Trucks	Loaded Omakase	1	$290.31	$290.31	9/30/2021	Brendan	10/20/2021
Wheels	Orangatang Kegels 80mm	1	$60.00	$60.00	10/21/2021	Brendan	TBD
Bearings	Bones REDS	1	$27.95	$27.95	10/21/2021	Brendan	
Battery Pack	10s2p 40T	1	$324.99	$324.99	TBD		TBD
ESC	FocBox Unity	1	$299.99	$276.92	TBD	Ryan	11/30/2021
Motors	2x MBoards 6374 180KV	2	$84.99	$169.98	TBD		TBD
Pulleys	Complete 36T Kegel Pulley System	1	$39.99	$39.99	TBD		TBD
Microcontroller	Arduino Nano	1	$20.70	$20.70	TBD		TBD
Trucks	MBoards Extended	1	$54.99	$54.99	TBD		TBD
Nuts	8-32 Steel Hex Nut	100	$0.02	$1.81	12/1/2021	Brad	TBD
Socket Head Screw	8-32 3/4"Lg Socket Head Screw	100	$0.17	$16.71	12/1/2021	Brad	TBD
Remote	VX1 Remote	1	$49.99	$49.99	TBD		TBD
Enclosure	Custom 3D Printed			$0.00			
Motor Mount	Custom 3D Printed			$0.00			
Kingpin Adjustment Mount	Custom 3D Printed			$0.00			

Board Two - Longboard							
Part	**Name**	**Quantity**	**Unit Cost**	**Total Cost**	**Date Ordered/Manufa**	**Ordered By**	**Reimbursement R**
Deck	Sector9 Fault Line Perch	1	$110.00	$96.21	10/1/2021	Ryan	11/11/2021
Wheels	Orangatang Caguama 85mm	1	$68.00	$68.00	10/21/2021	Brendan	
PCB Stencil	OSH Park PCB Stencils	1	$62.17	$62.17	11/7/2021	Ryan	11/30/2021
ESC Microprocessor	DRV8302DCA IC Motor Controller	2	$5.50	$15.08	10/19/2021	Ryan	11/11/2021
Custom PCBs	OSH Park PCB Boards	3	$12.50	$38.80	10/19/2021	Ryan	11/11/2021
ESC Pin Headers	Newark Board Pin Headers			$17.18	10/19/2021	Ryan	
Misc ESC Components	Digi-Key Misc Electronic Components			$24.37	10/19/2021	Ryan	11/11/2021
ESC IRF Components	IRFS7530-7PPbF	5*3	$7.76	$29.37	10/19/2021	Ryan	11/11/2021
ESC CAN Transceiver	SN65HVD232DR	3	$2.66	$8.40	10/19/2021	Ryan	11/11/2021
Misc ESC Components	Mouser Misc Electronic Components			$66.48	10/19/2021	Ryan	11/11/2021
ESC Microprocessor	STM32F405RGT6 Microprocessor	2		$23.65	10/19/2021	Ryan	11/30/2021

Appendix C - Project Timeline Evolution

Initial Timeline

Task	Assigned for	Assigned on	Due by	Dependencies
Design (mechanical)	Brendan DeJonge & Brad George	09/16/2021	10/20/2021	None
Design (electrical)	Fawzi Al Hadrab & Ryan Hawkins	09/16/2021	10/20/2021	None
Select and Order Individual Longboards	Brendan DeJonge	09/16/2021	10/25/2021	Design (mechanical and electrical)
Electrical Components Ordering	Fawzi Al Hadrab	09/16/2021	10/31/2021	Design (mechanical and electrical)
Mechanical Components Ordering	Brad George	09/16/2021	10/31/2021	Design (mechanical and electrical)
Controller Design and Assembly	Brad George & Brendan DeJonge	10/8/2021	11/15/2021	Design and component ordering
Manufacturing and Machining	Brendan DeJonge	09/16/2021	11/20/2021	Design (mechanical and electrical)
Testing individual components	Team	09/16/2021	12/10/2021	Ordering components, manufacturing parts and 3D printing
Electrical Assembly	Ryan Hawkins	09/16/2021	01/15/2022	Testing individual components
Mechanical Assembly	Brendan DeJonge Brad George	09/16/2021	01/15/2022	Testing individual components
Programing and Coding	Fawzi Al Hadrab & Ryan Hawkins	09/16/2021	01/25/2022	Electrical assembly
Entrepreneurship Improvements	Team	10/8/2021		
Physical Testing	Team	09/16/2021	02/20/2022	Programming and assembly
Fixing Testing Failures	Team	09/16/2021	03/1/2022	Physical testing

Current Timeline

Task	Assigned for	Completed	Due by	Dependencies
Design (mechanical)	Brendan DeJonge & Brad George	Yes	10/20/2021	None
Design (electrical)	Fawzi Al Hadrab & Ryan Hawkins	Yes	10/20/2021	None
Select and Order Individual Longboards	Brendan DeJonge	Yes	10/25/2021	Design (mechanical and electrical)
Electrical Components Ordering	Fawzi Al Hadrab	Yes	10/31/2021	Design (mechanical and electrical)
Mechanical Components Ordering	Brad George	Yes	10/31/2021	Design (mechanical and electrical)
ESC Assembly	Ryan Hawkins & Fawzi Al Hadrab	In Progress	1/11/2021	Design and component ordering
Controller Design and Assembly	Brad George & Brendan DeJonge	In Progress	1/20/2021	Design and component ordering
Manufacturing and Machining	Brendan DeJonge	In Progress	1/20/2021	Design (mechanical and electrical)
3D Printing	Brad George	In Progress	1/30/2021	Design (mechanical and electrical)
Testing individual components	Team	No	2/10/2021	Ordering components, manufacturing parts and 3D printing
Electrical Assembly	Ryan Hawkins	No	2/15/2022	Testing individual components
Mechanical Assembly	Brendan DeJonge Brad George	No	2/15/2022	Testing individual components
Insulating	Fawzi Al Hadrab	No	2/25/2022	Electrical and mechanical assembly
Programing and	Fawzi Al Hadrab &		2/25/2022	Electrical assembly

Coding	Ryan Hawkins			
Entrepreneurship Improvements	Team	No		
Physical Testing	Team	No	03/1/2022	Programming and assembly
Fixing Testing Failures	Team	No	03/10/2022	Physical testing

Appendix D - Aluminum 6061 Material Properties

Physical Properties	**Metric**	**English**	**Comments**
Density	2.7 g/cc	0.0975 lb/in^3	AA; Typical
Mechanical Properties			
Hardness, Brinell	95	95	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	120	120	Converted from Brinell Hardness Value
Hardness, Rockwell A	40	40	Converted from Brinell Hardness Value
Hardness, Rockwell B	60	60	Converted from Brinell Hardness Value
Hardness, Vickers	107	107	Converted from Brinell Hardness Value
Ultimate Tensile Strength	310 MPa	45000 psi	AA; Typical
Tensile Yield Strength	276 MPa	40000 psi	AA; Typical
Elongation at Break	12 %	12 %	AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break	17 %	17 %	AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity	68.9 GPa	10000 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Notched Tensile Strength	324 MPa	47000 psi	2.5 cm width x 0.16 cm thick side-notched specimen, K_t = 17.
Ultimate Bearing Strength	607 MPa	88000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	386 MPa	56000 psi	Edge distance/pin diameter = 2.0
Poisson's Ratio	0.33	0.33	Estimated from trends in similar Al alloys.
Fatigue Strength	96.5 MPa	14000 psi	AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen
Fracture Toughness	29 MPa-m½	26.4 ksi-in½	K_{IC}; TL orientation.
Machinability	50 %	50 %	0-100 Scale of Aluminum Alloys
Shear Modulus	26 GPa	3770 ksi	Estimated from similar Al alloys.
Shear Strength	207 MPa	30000 psi	AA; Typical

[3]

Appendix E - MatterHackers NylonX Material Properties

MatterHackers

TECHNICAL DATA SHEET

Commercial name: MatterHackers Nylon X Carbon Fiber Filament

Raw material: Carbon fiber reinforced polyamide

Designation: 3D printing applications

Supplier: MatterHackers, Inc.

Material specifications

Property	Value	Test Method - ISO
Density	1.00 g/cm^3	1183
Melting point	180°C	11357
Tensile Modulus	6000 MPa	527
Tensile Strength	100 MPa	527
Impact strength	60 kJ/m^2	179/2-1eU
Ball indentation hardness	110 MPa	2039-1
Heat deflection temp. HDT/A	155°C	75
Thermal expansion coefficient	0.5 10^{-4}/K	11359
Max usage Temp. long term	90-120°C	2578
Max usage Temp. short term	150°C	2578D
Dielectric strength	-	IEC 60243
Specific volume resistivity	10^3 Ωm	IEC 60243
Flammability	HB	1210
Linear mould shrinkage	0.3	294

Filament specifications

Property	Value and Tolerances
Diameter 1.75mm	1.75 ± 0.05 mm
Diameter 2.85mm	2.85 ± 0.05 mm
Roundness deviation	max 2%
Suggested print temperature (guideline)	240°C
Suggested print speed	40 mm/s
Suggested bed temperature	20°C (not necessary)

[4]

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