University of Southern Indiana
Pott College of Science, Engineering, and Education
Engineering Department
8600 University Boulevard
Evansville, Indiana 47712

Solar Stripes

Solar Powered Push Lawn Mower

Zach Barton
Travis Sides
Reid Steffe

ENGR 491 – Senior Design
Spring 2023

Approved by: ____
Faculty Advisor: Glen Kissel, Ph.D. Date

Approved by: ____
Department Chair: Paul Kuban, Ph.D. Date

ACKNOWLEDGEMENTS

The Solar Powered Lawn Mower team would like to express appreciation for the following. This project would not have been possible without the contributions of these people.

The University of Southern Indiana Engineering Department:

Dr. Glen Kissel

Dr. Paul Kuban

Dr. Todd Nelson

Mr. Justin Amos

Mrs. Jamie Curry

Spencer Industries

Abstract

This senior design report details the stages of a design project in which the team created a prototype of a solar powered push lawn mower. The team provided an economic analysis to justify the success or failure of the design. The goal of this design was to determine if adding electrical components to an existing push lawn mower frame was a cost-effective alternative to purchasing a new lawn mower. To start the design process, the team researched previous design reports which attempted to build a solar powered push lawn mower. After considering the pros and cons of these past projects, three preliminary designs were developed. From these preliminary designs, a final design was chosen. Next, the components needed to complete a prototype were designed and chosen based on calculations and requirements. Once the prototype was constructed, tests were completed to see if the design was successful. The first tests resulted in the conclusion that the motor was undersized. A new motor was sized and selected which resulted in better cutting capabilities. An economic analysis was completed based on a budget and it was decided that this design could be justified financially. Finally, future changes and improvements to the design were discussed.

Table of Contents

List of Figures

List of Tables

Solar Stripes

1.0 Introduction

Designing a solar powered push lawn mower is an engineering challenge which will require continuous research and improvement of the design. This report details the process involved with the research and design of a solar powered push lawn mower.

1.1 Objective

The objective of this project is:

Design a Solar Powered Push Lawn Mower and Construct a Prototype to Validate the Design.

1.2 Deliverables

The deliverables for this project are the following:

- Solar Powered Push Lawn Mower prototype
- Economic Analysis
- Senior design report, Senior design presentation, Informative poster

2.0 Background

2.1 Motivation

Climate Change is perhaps the greatest challenge humans will face in the next 100 years as it could directly impact all life on Earth. While the exact causes of climate change are heavily debated, it is no secret that human activity is speeding up the Earth's natural climate change. Day to day human activity has many contributing factors to climate change. Some factors are far worse than others. The release of greenhouse gas emissions is one of the factors that governments across the world continue to regulate. According to the EPA, 5% of the nation's greenhouse gas emissions are a result of the gas-powered lawn equipment industry **[9].** As a result, the LA Times reports that California plans to ban the sale of gas-powered lawn equipment as early as 2024 **[7].**

The reduction in greenhouse gas emissions was the primary motivation for the design of the solar powered push lawn mower. The current electric push lawn mower options rely on the United States energy grid for recharging. While this solves the problem of greenhouse gas emissions on the consumer end, nevertheless according to the Department of Energy, 61% of the nation's electricity is supplied via the burning of fossil fuels **[9]**. Therefore, electric lawn mowers do not solve the problem of greenhouse gas emissions in its entirety. The solar mowing team realized the need for a solution that would eliminate greenhouse gas emissions.

2.2 Current Lawn Equipment

Solar powered lawn mowers are not yet readily available to the average consumer. There are a few brands (Husqvarna and Mean Green Mowers) that have attempted to produce them, but they are all expensive and inefficient. This leaves the consumer with two standard options for lawn mowers and weed trimmers, gas or electric. Gas powered lawn mowers have large, powerful engines which require gasoline and oil. The gas lawn mower is by far the most popular among consumers due to its reliability and cutting results. However, electric lawn mowers have begun to flood the market. These mowers are lighter and quieter than traditional gas mowers. They require a battery that can be removed after using and charged through any outlet in your home. The same battery can also be used in other lawn equipment such as weed trimmers and leaf blowers. The electric mower requires little to no maintenance after the initial purchase. However, the gas lawn mower is far from being replaced. Electric lawn mowers have shorter run times, higher purchase cost, and high charging cost. A comparison table between four gas and four electric lawn mowers can be found in Appendix I. The solar powered push lawn mower design aims to be an alternative to the gas and electric push lawn mower.

2.3 Lawn Stripes

Lawn stripes are caused by the sun reflecting off grass that has been mowed in different directions. For instance, Figure 1 shows typical stripes found on yards across the country. The arrows indicate the direction the grass was mowed that causes the grass to lie in a certain direction. The sun reflects off the grass differently depending on which way the grass is lying. The average mower can make these stripes; however, the stripes may be hard to see. Many companies sell aftermarket mower add-ons called stripe kits. These kits help lay the grass over to create more defined stripes. The Figure 1 image was taken from a website advertising a stripe kit which gives the stripes additional clarity. Traditional mowers come with a safety guard that acts as a stripe kit. This safety guard is a small flap of rubber attached to the back of the mower deck and lies flat on the ground. The safety flap, generally used as a stripe kit, is shown in Figure 2.

Figure 1 - Lawn Stripes [23]

Figure 2 - Rubber Safety Guard / Stripe Kit

2.4 Similar Projects

The following section details past projects that attempted to create a solar powered lawn mower. Each design has pros and cons that can be taken into consideration.

2.4.1 JNTUA College of Engineering Solar Lawn Mower

The first similar project was completed by JNTUA College of Engineering in India and was published in the *International Journal of Scientific Research in Science and Technology* **[14].** This design is a solar powered push lawn mower as seen in Figure 3. This design is not very durable or effective in cutting grass. With all the electrical components exposed, they may experience damage. Also, the motor bed and structural bars are all grey cast iron, leading to a heavy, hard to maneuver mower. This design is very difficult to replicate and would take someone with extensive experience with metalwork to construct. Another drawback of this design is the lack of safety. The underside of the mower deck is completely open, leaving the cutting blade exposed. This could result in unwanted objects being projected, or the user being struck by the blade. One positive aspect of this design is the integrated circuit. The purpose of this comparator circuit is to constantly monitor the temperature of the motor using a temperature sensor. If the temperature reaches a certain value, the motor is automatically switched off. Overall, this design has many pros and cons that will be considered in the design process.

Figure 3 - JNTUA College of Engineering Solar Lawn Mower ***[14]***

2.4.2 Turkish Journal of Agricultural Engineering Research Solar Lawn Mower

The second design, from the *Turkish Journal of Agricultural Engineering Research* **[17]**, is pictured in Figure 4. This design is much more efficient than the first and much simpler. This report provides step by step calculations on how they sized their motor and battery. This process will be helpful to determine how much torque is required by the motor. In this design, they also performed a cutting efficiency test on different blade geometries. They tested the efficiency when cutting with designs that had two, three, and four blades. They also designed a motor driver which allows the operator to control the speed of the motor. This would allow the user to turn up the speed when cutting thicker grass and decrease the speed for longer run times. This is a feature that would prove useful in this design as run times and grass thickness will vary. However, like the previous project, this design lacks safety guards for the user. The blade is exposed and could encounter the user's feet. It also could launch projectiles out of the bottom of the mower in the case of contact with objects other than grass. In conclusion, this solar mower proved to be a possible replacement for the gasoline powered lawn mowers.

Figure 4 - Turkish Journal of Agricultural Engineering Research Solar Lawn Mower ***[17]***

2.4.3 International Journal of Women in Technical Education and Employment Mower

The third design, shown in Figure 5, is from the *International Journal of Women in Technical Education and Employment* **[1]**. This design is much more efficient and lighter than the first two. The frame is made of mild steel and features a solar panel above the electrical components. One drawback to this design is the use of a single blade instead of a double blade. The report goes into detail about how they sized the motor and battery. Many of the equations used in this report were referenced when sizing our components. This source also provides the shear cutting force required to cut most annual and perennial grasses to be between 9.2 N-11.5 N. They also claim that a motor power of not less than 628.3 W (0.84 HP) having 3,000 rev/min rotational speed and cutting force of 10.5 N is recommended. This design features an 18.8-inch stainless steel blade, 1 HP motor, 12 V 200 Ah battery, and 60 W solar panel. This design claims to require a 30-minute charge time for 70 minutes of mowing time. While this ratio would be ideal, it requires a very large battery and solar panel.

Figure 5 - International Journal of Women in Technical Education and Employment mower ***[1]***

2.4.4 Mean Green Electric Mowers

This final design is one that is currently available to purchase commercially. It is offered by Mean Green Electric Mowers **[10]**. Figure 6 shows the mower with solar electric canopy. This design provides shade for the user and extra electricity for the battery. Mean Green Electric Mowers claim to have an 8-hour battery life, but say the canopy only provides 20 extra minutes of mowing time per day. This size of mower would require much larger solar panels to have any electrical savings. Also, to add this attachment to your Mean Green mower, the price jumps $1,600 extra. This shows that solar powered lawn mower technologies are not ready for the average consumer, but they are beginning to be designed.

Figure 6 - Mean Green Electric Mower ***[10]***

2.5 Applicable Professional Standards

Occupational Safety and Health Administration (OSHA) states that hearing protection should be used in the event of noise levels exceeding 85 decibels **[8].** The solar powered push lawn mower shall produce noise no greater than 85 decibels.

OSHA also requires that once the mower is turned off, the blades stop spinning within 3 seconds **[8].** The solar powered push lawn mower uses weed trimmer line along with a brushed motor that stops spinning in under 3 seconds.

U.S. Consumer Products Safety Commission (CPSC) requires that operator controls for engaging and disengaging the mower must be within 15 inches of the operator handle **[20]**. The solar powered push lawn mower has on/off controls within 15 inches of the operator's handle.

2.6 Factors That Impact Design

Public Health, Safety, and Welfare

During the design of the solar powered push lawn mower public health, safety, and welfare were top considerations. Lawn mowers can be very dangerous to operate. Therefore, the team was keen on designing a mower that was safer than any other product on the market. The team designed the shutoff switch to be easily within reach for the user so that in an emergency the mower can be shut off quickly. The brushed electric motor chosen, when used in conjunction with the weed trimmer line, quickly stops spinning when power is shutoff. The weed trimmer line in and of itself is a much safer feature than a traditional mower blade. The weed trimmer provides enough cutting force to cut grass, but not enough to cut off fingers, toes, etc. An analysis was done in the calculations section to prove the weed trimmer line is safer than a blade. Another area of concern is the noise levels produced by a typical push lawn mower. The noise levels typically produced require hearing protection. The team designed the solar powered push lawn mower to be quiet enough not to require hearing protection during operation per OSHA regulations **[8].**

Environmental and Economic

One of the mains goals of the project was to be environmentally clean. The solar powered push lawn mower was designed to be self-sufficient and rely solely on clean energy from the sun to operate.

By utilizing a renewable resource, the design is environmentally friendly and cheap to operate. The solar powered push lawn mower has a much smaller carbon footprint than a typical push lawn mower.

Economic considerations were very important in the design of the solar powered push lawn mower. The mower needed to be cheap enough to be competitive with other lawn mowers, but also feature well-made components to last years in service, all while providing the user with more features and capabilities than a typical mower. The team designed a mower that is competitive with other mowers on the consumer market and is far less costly to operate.

2.7 Requirements

The solar powered push mower shall…

1. Operate continuously for one hour.
2. Charge itself to 100% capacity via solar charging in 5 hours or less.
3. Have a total weight of less than 80 lbs.
4. Cut Grass.
5. Consist of no mounted components outside the original width of the mower deck.
6. Produce less than 85 decibels.

2.8 Noise Pollution

The lawn mowers on today's market are very loud. One main goal of this design is to reduce noise pollution. Sound is energy that travels in waves. It can be measured in two ways: frequency and amplitude. Amplitude, reported on the decibel (dB) scale, measures sound pressure or forcefulness. The more amplitude a sound has, the louder it is. In daily life, we often think of this as volume. Standard gas lawn mowers produce around 90 decibels (dB) of noise. Appendix G shows a chart of the decibel level of other sounds to compare. As stated in section 2.5, OSHA recommends hearing protection for anything over 85 dB. To test the dB level of current lawn equipment and our prototype, the noise app on an Apple Watch was used. As shown in Figure 7, the gas lawn mower produced 89 dB of sound and the electric weed trimmer produced 75 dB of sound. This data will serve as a baseline for our design as we aim to reduce the noise created while mowing.

Figure 7 - Noise Level Testing on Apple Watch

3.0 Concept Selection

For each of the conceptual designs listed there are a few similarities to point out. Each concept features the same major components. These major components include: the electric motor, the battery, the mounting plate, the solar panel, the charge controller, and the on/off switch. However, the placement of some of these components will differ between each concept. It is important to note that the placement of the electric motor, battery, and mounting plate will not change between each concept.

3.1 Concept 1: Solar Charging on Mower Handle:

Concept 1, shown in Figure 8, was what was originally brainstormed on day one of designing. This concept is unique because it features the solar panel mounted between the rails of the handle on the mower. The charge controller would be mounted next to the battery on the mounting plate shown. This concept would keep the mower more evenly balanced on the back wheels which would make the mower easier to turn for the user. This concept will also enable the mower to charge while mowing which in theory would extend the running time for the mower. However, this concept is very heavy and would make mowing anything other than perfectly flat ground very labor intensive.

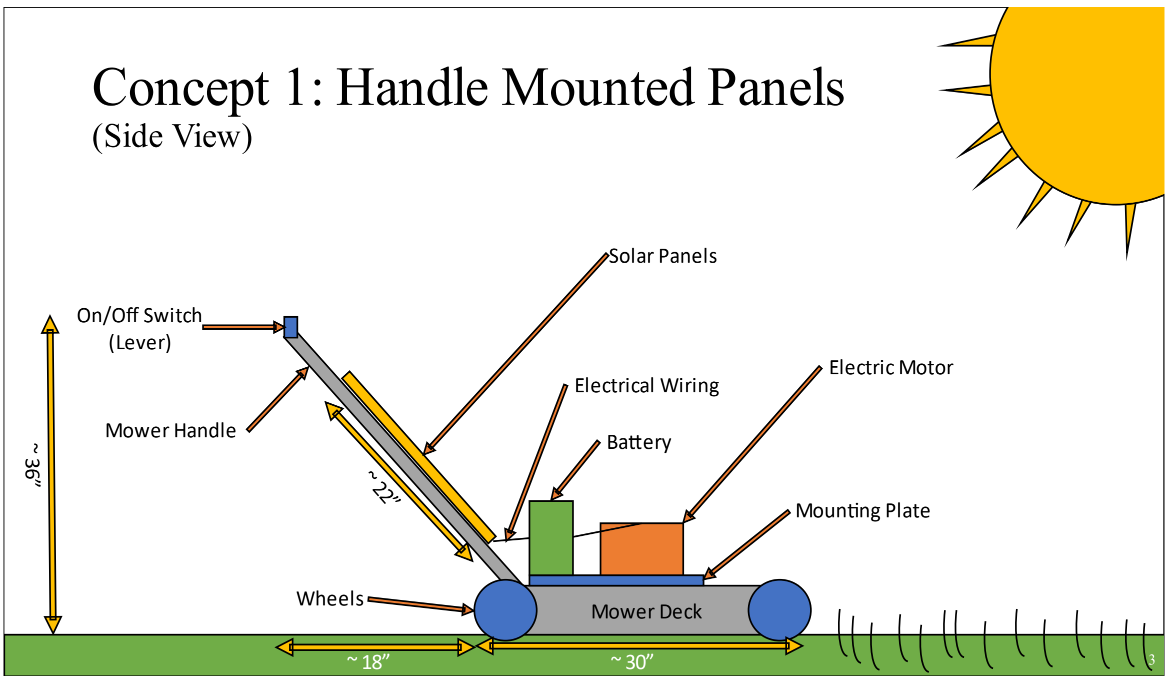

Figure 8 - Concept 1

Pros	Cons
Compact	Heavy
Rear Wheel Center of Gravity	Little adjustability for solar panel
Enables Charging While Mowing	Exposes solar panel to more wear and tear
Less wiring and more user friendly	More stress on mower frame

3.2 Concept 2: Solar Charging on Mower Deck:

The second concept, shown in Figure 9, features the most compact design of the three concepts in this report. In this concept the solar panel is mounted to the mounting plate directly above the motor, battery, and charge controller. The solar charger is again placed next to the battery and motor on the mounting plate. This design features the lowest center of gravity which would make this concept the easiest of the three to operate. This concept also enables the mower to charge while in use. A nice perk to this design is that the solar panel would provide a certain level of weather protection for the battery, motor, and charge controller. However, this design is again very heavy and would be very taxing on the operator to use for any length of time.

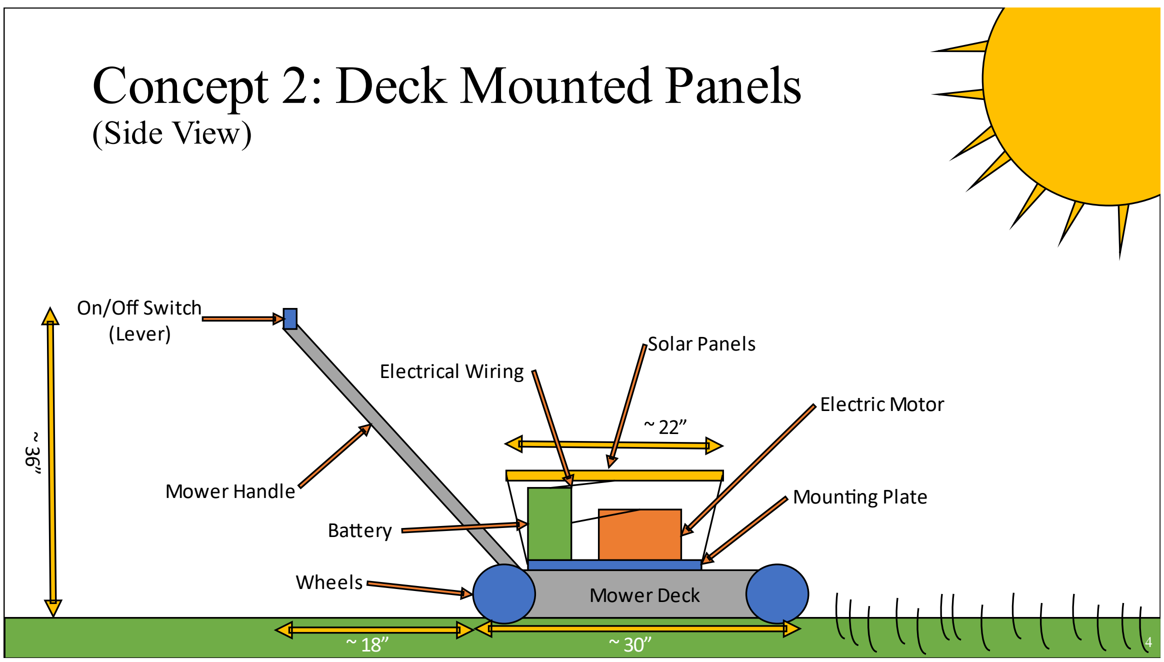

Figure 9 - *Concept 2*

Pros	Cons
Most Compact Design	Heavy
Lowest Center of Gravity	Little adjustability for solar panel
Enables Charging While Mowing	Exposes solar panel to more wear and tear
Less wiring and more user friendly	More stress on mower frame

3.3 Concept 3: Solar Charging Station:

Concept 3, shown in Figure 10, features a separate charging station where the solar panels and solar charge controller will reside. The biggest advantage to this design is the weight savings on the mower from removing the solar panel and charge controller. There is also significantly less wear and tear on the solar panel and charge controller. In order to charge the mower, the user would have to plug the mower into the solar charging station in between uses. The biggest drawback is the additional cost from the solar panel station support structures. The loss of run time from not being able to charge while mowing is small and not significant enough to make a noticeable difference.

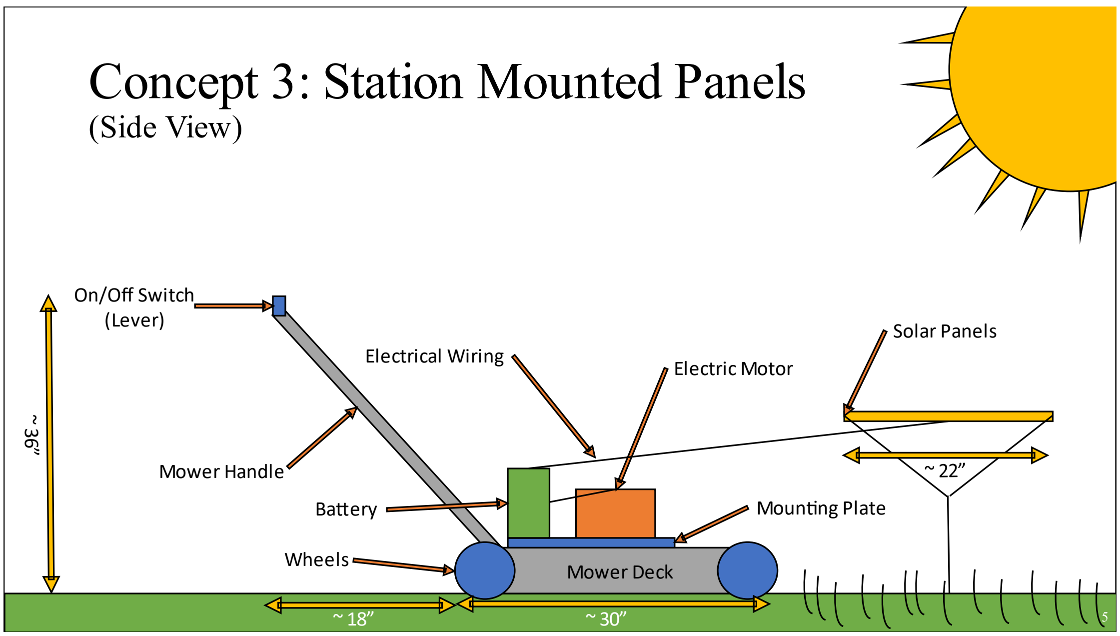

Figure 10 - Concept 3

Pros	Cons
Most solar panel adjustability	No charging during use
Least mower weight	Additional cost in solar charging supports
Least amount of strain on mower frame	Additional wiring needed
Larger Solar Panels can be used	

3.4 Chosen Design

After reviewing the conceptual designs, multiple design decisions were made. Typical electric lawn mowers that use traditional metal blades require a large motor and large battery. These batteries, typically 40 volts, are very heavy. To reduce the overall weight of the mower and decrease the power requirements, an alternative to a traditional mower blade must be found. One alternative, weed trimmer line, is very light weight, and has similar grass cutting capabilities of a standard blade. It is also more affordable and safer to use. While it does have limitations, such as frequent breaking and lower cutting forces, using weed trimmer line is a good alternative to a typical metal cutting blade. Pros and cons of blades and trimmer lines are discussed in Figure 11.

Blades	
Pros	Cons
• High Cutting Force • Cutting Versatility (cuts more than just grass) • Healthy and even cuts	• Heavy • Require large motors • Potentially Dangerous • Expensive

String	
Pros	Cons
• Lightweight (smaller motor) • More affordable • Cuts grass effectively	• Strings break frequently • Less cutting power • Can damage grass

Figure 11 - Blade vs. Trimmer Line Comparison

With this design change, a smaller motor and battery can be chosen for our design. The final solar push lawn mower design can be seen in Figure 12. This design was based off of concept 1 and then a few changes were made.

The team will NOT be designing the mower frame, handles, and wheels shown in red in Figure 12. An electrical power system will be designed made of purchased components. These components include a DC motor, battery, speed controller, solar panel, and solar charge controller. Calculations will be completed in order to make engineering design decisions on what components will best suit our design.

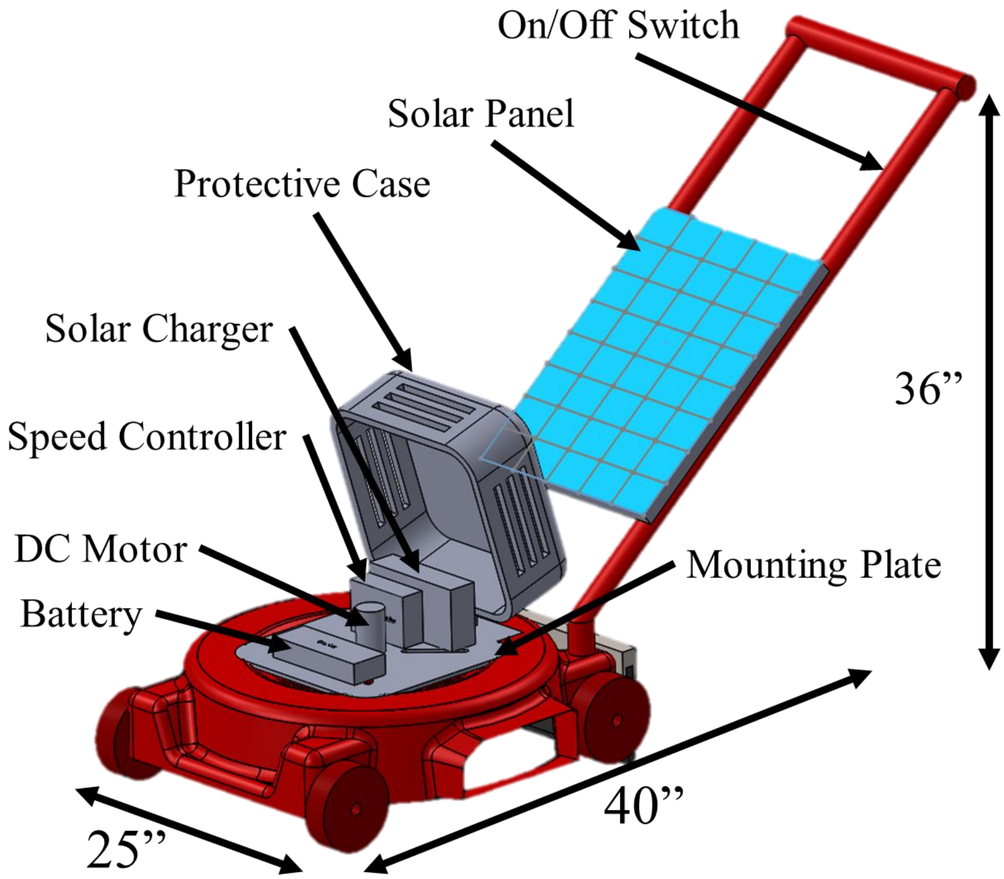

Figure 12 - Final Design Solid Works Model

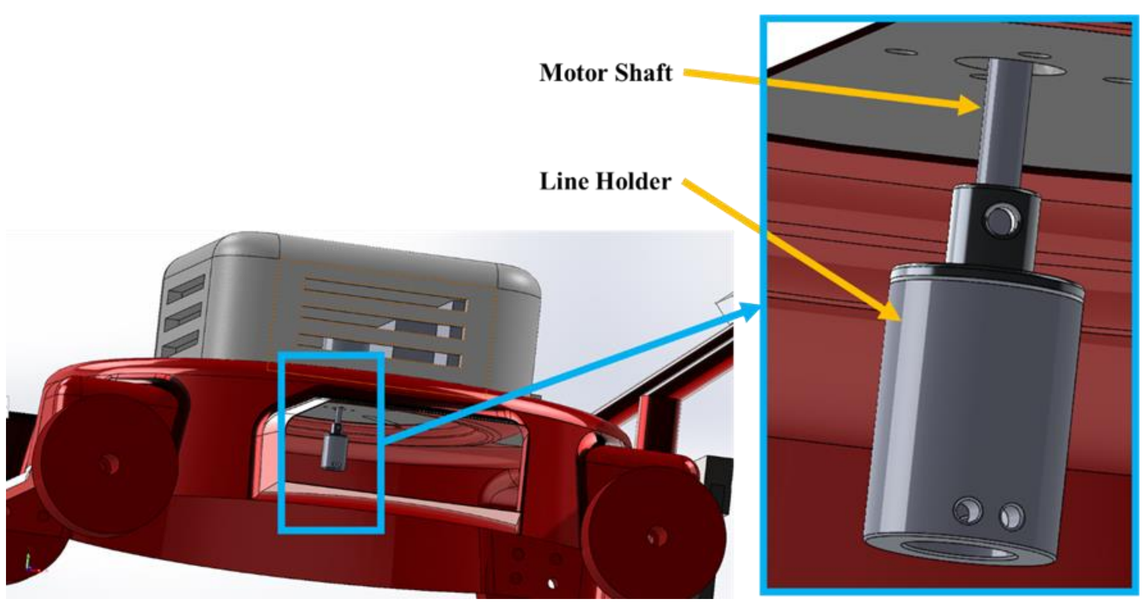

Figure 13 - Final Design Under Deck View Solid Works Model

A mounting plate will fix the electrical components to the existing mower deck. The protective case will cover the electrical components to prevent damage from debris and overheating. A weed trimmer line holder, shown in Figure 13, will be designed to hold the line in place and connect to the motor shaft. Also, solar panel mounting brackets will be designed to fix the panel to the handles. This final design is a product of conceptual designs and lessons learned from past projects. The design and how it will function is detailed in Section 4.

4.0 Final Design and Analysis

4.1 Overview of Operations

The concept chosen has the potential for simple maintenance and operation. The end user can follow a few simple steps for proper operation.

1. Set mower outside to charge. (Approximately 5 hours)
2. Once charged, remove solar panel. (optional)
3. Insert the weed trimmer line.
4. Turn on, mow the yard.
5. Reconnect the Solar Panel if removed.
6. Repeat steps 1-6.

It is recommended that the solar panel be removed during use. This will protect it from dust and possible projectiles. However, the mower is fully functional if the panel is left attached to the handle.

The main source of maintenance for the end user will be replacement of the weed trimmer line. The frequency of line replacement will vary depending on the yard size, thickness of grass, and amount of non-grass objects in the yard (sticks, rocks, mulch, etc.). It is likely that the trimmer line will need to be replaced after every 1-3 mows. To replace the line, the user must first ensure that the motor is turned off. Next, turn the mower onto its side to access underneath the deck. Remove the old string by holding the line holder and pushing the line back through the holes shown in Figure 14 and 15. Cut two, 20-inch sections of weed trimmer line. Then, insert one end of the line through one of the holes and feed the same end back through the adjacent hole. Turn the mower back to its upright position, turn on, and begin mowing.

Figure 14 - Weed Trimmer Line Holder

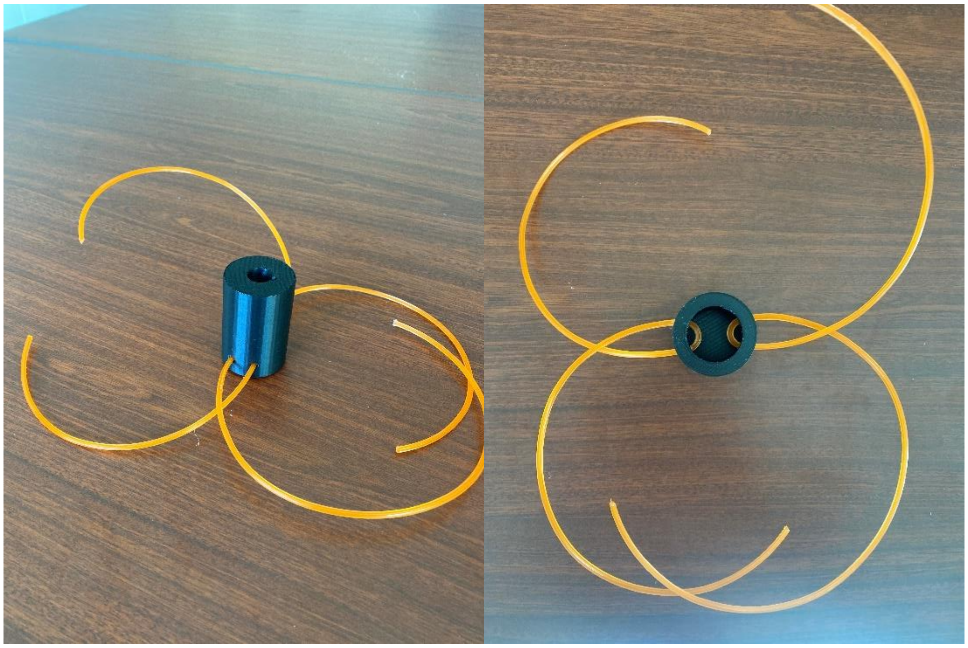

Figure 15 - Weed Trimmer Line Overview of Operation

4.2 System Overview

The design is divided into two main subsystems in accordance with their functions. The two main subsystems are mechanical and electrical. The mechanical block diagram for the solar push lawn mower can be seen in Figure 16. The diagram shows the electrical and mechanical components and how they are connected. A system hierarchy can be found in Appendix A. This chart shows which components fall into each subsystem. To simplify, structural and mechanical subsystems can be combined into one.

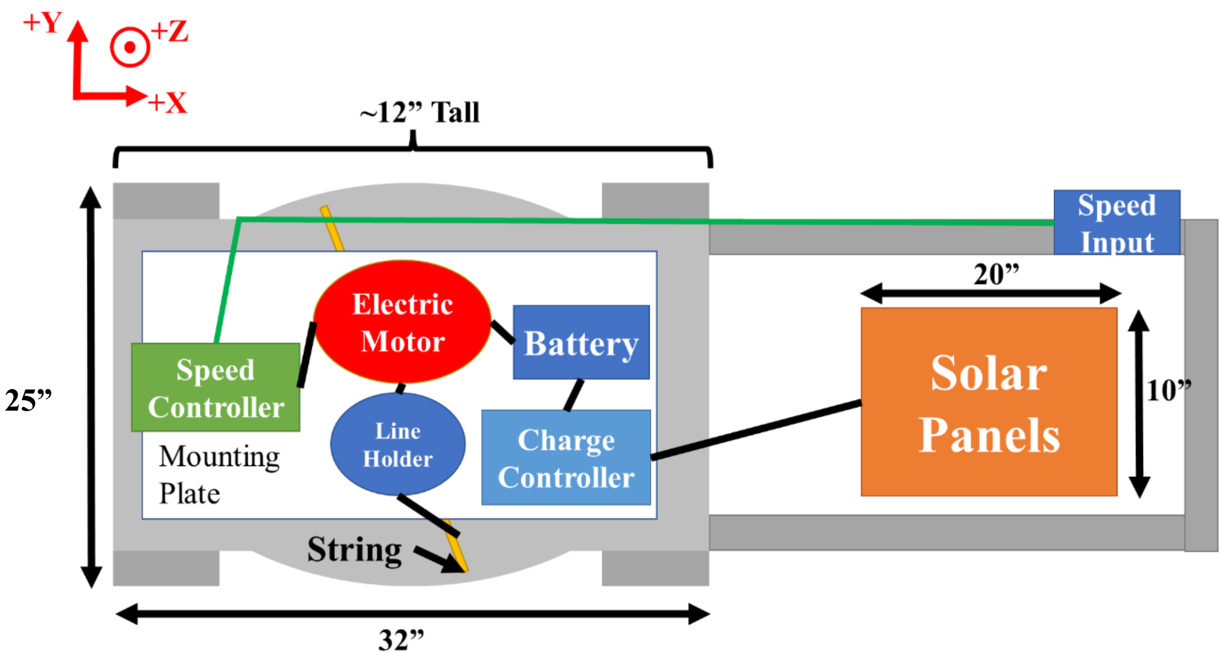

Figure 16 - Mechanical Block Diagram

4.2.1 Subsystem 1 - Electrical Components

The first subsystem is the electrical components system. This subsystem consists of the solar panel, charge controller, battery, speed controller, and DC motor. The components are connected using 16-guage wire in the order listed previously. The solar panel collects radiation from the sun and transfers it to the MPPT (maximum power point tracker, discussed in section 5.4) charge controller. The charge controller provides a measured amount of voltage and current to the LiPo (Lithium Polymer, discussed in section 5.2) battery. LiPo batteries have a suggested charge and discharge rate, which is regulated by the charge controller. Next, a speed controller connects the battery to the DC motor. The DC motor then spins at a rate controlled by the speed controller. The details of each electrical component can be found in Section 5.0.

4.2.2 Subsystem 2 - Mechanical Components

The second subsystem consists of mechanical components. The frame of the mower is from an existing Murray 20-inch lawn mower with a Briggs and Stratton motor shown in Figure 17, so the design already includes the wheels, deck, and handle of the mower. The first mechanical component is the mounting plate. The purpose of the mounting plate is to hold the electrical connections in place on top of the mower deck. Also, not pictured in the mechanical block diagram, a protective case will sit on the mounting plate to cover the electrical components. A 3D printed line holder will connect to the motor shaft and secure the trimmer line.

Figure 17 - Original Mower Frame

5.0 Component Selection and Justification

5.1 DC Motor

During the design process there were several motors looked at ranging from 12 V to 48 V. The team identified strengths and weaknesses of each motor and battery combination. The team opted to select a 12-volt system due to several factors including price of components, availability of components, and number of available combinations of components. The following calculations were originally done to size the motor.

At first, the team calculated the torque needed to spin the trimmer line. This was done by taking the weights and radiuses of paths of the line holder and weed trimmer lines and adding them together.

Mass of String: 5 grams per line, 2 lines needed.

$5\ grams\ \times 2 = 10\ grams$ = .01 kg

Weight of Strings (Force)

$$.01\ kg\ \times\ 9.81\frac{m}{s^2} =\ .0981\ N$$

Radius of String Path

$$10\ inch =\ .254\ m$$

Torque Requirement of Strings

$$.0981\ N\ \times\ .254\ m =\ .0249\ Nm$$

Mass of String Holder

$$15\ grams$$

Weight of Holder (Force)

$$.015\ kg\ \times\ 9.81\frac{m}{s^2} =\ .147\ N$$

Radius of Holder Path

$$.5\ inch =\ .0127\ m$$

Torque Requirement of Holder

$$.147\ N\ \times\ .0127\ m =\ .00187\ Nm$$

Total Torque Requirement from String and Holder

$$.0249\ Nm +\ .00187\ Nm =\ .02677\ Nm$$

The team then calculated the angular velocity based on the desired rpm of 10,000. This rpm was chosen based on Appendix K where the team found that common weed trimmers had rpm ranges between 6000-9000. 10,000 rpm was chosen so that the mower would not have to be run at 100%.

Angular Velocity

$$\frac{2\pi(10000rpm)}{60} = 1047.2\frac{rad}{s}$$

Taking the angular velocity and torque draw of the weed trimmer line and line holder the team was able to determine the power required to turn the components at 10,000 rpm.

Power Required

$$.02677\ Nm\ \times 1047.2\frac{rad}{s} = 28.03\ W$$

28 Watts of power needed at 10,000 rpm

Chosen Motor: 80W, 12 V, 10,000 rpm

During testing, it was discovered that the motor was undersized. The first prototype did cut grass, but it bogged down easily when mowing thick patches of grass to the point that the charge controller turned the motor off as a safety mechanism. During analysis of the team's calculations, it was found that the calculations were inaccurate. The team did not correctly account for the friction caused by the grass. With the team's limited knowledge on friction of grass, the team resorted to literature review 2.4.3 which stated that the minimum power required to cut grass was 628.3 W for a bladed lawn mower. With the team's design calling for a weed trimmer line instead of a blade the team looked for other references. Based on Appendix K, the average weed trimmer operates around 120-150 Watts. With this new knowledge the team chose a 12 V 1125 W motor. This second motor, shown in Figure 19, was more expensive, better built, and more powerful than the first motor.

Figure 18 shows the performance chart of the motor. The new motor will require more current which means the run time will decrease. To determine the exact current and run time, testing would be required to determine what power the motor would have to be run on. The newly selected motor will provide enough power to cut grass, however, the run time may fall short of the 1-hour requirement. The team has estimated 30 minutes of run time if the motor is run at 120 watts based on Appendix K and the performance chart of the motor in Figure 18. The performance chart shows the team the outputs in torque, current draw, and rpm based on the input watts. Testing will verify run times with varying watt inputs. These results are discussed in section 6.1.2.

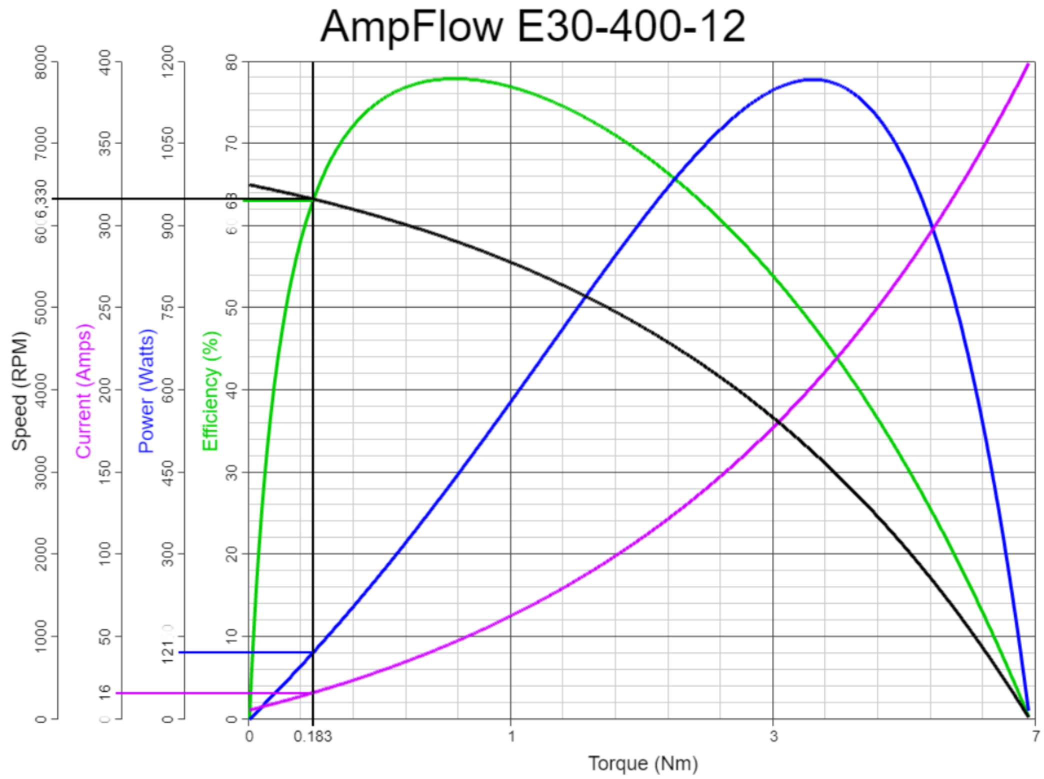

*Figure 18 – Amp Flow Motor Performance Chart **[5]***

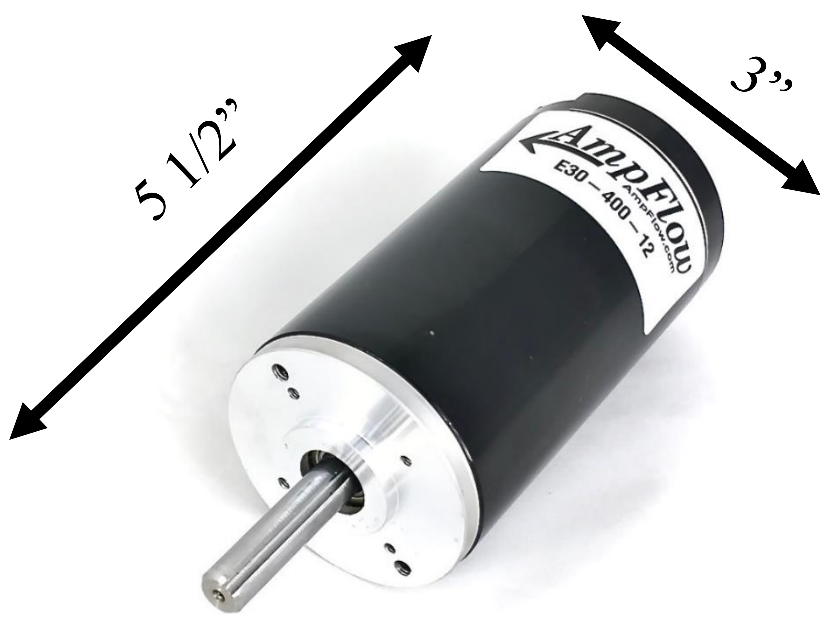

*Figure 19 – Amp Flow E30-400-12 DC Motor **[5]***

5.2 Battery

The battery originally chosen was a lead acid battery, like a car battery. This battery was big and heavy but would provide the capacity to power the mower for the time required. However, this battery was changed out for a Lithium Polymer battery (LIPO). The LIPO battery, although more expensive, is much smaller and weighs less than a lead acid battery. The LIPO battery also does much better during cycling meaning the battery will withstand more charges and more uses without needing to be replaced. The LIPO battery chosen was a 12 V 10 Ah battery that could give the mower 83 minutes of run time at full power based on the first motor chosen.

Following the first round of testing the original motor was found to be too small and the new motor is much bigger which requires more current. The team estimated, using Figure 18, that the new motor will need 16 amps of current which is more than double the original motor. At 16 amps of current the chosen battery will provide 30 minutes of run time as seen in Figure 40. If 16 amps of current does not provide enough power to cut grass then Table 1 shows the run times of using more current to run the motor at higher watts.

Figure 20 – 10Ah LIPO Battery ***[3]***

Table 1: Run Time Comparison

Motor Option		Voltage	RPM	Max Watts	Watts Used	Run Time
First Choice	XD-775	12	10,000	80	80	83 min
Final Choice	E30-400-12	12	6,500	1125	120	30 min
	E30-400-13	12	6,500	1125	240	7.5 min
	E30-400-14	12	6,500	1125	400	4.5 min
	E30-400-14	12	6,500	1125	600	3 min

5.3 Solar Panel

The main design goal of this project was to power a lawn mower by solar power. This was a critical part of the design as the solar panel charges the battery. A solar panel collects radiation from the sun as shown in Figure 21 from SolarPower.guide **[16]**. This graphic gives a detailed explanation as to how solar panels work.

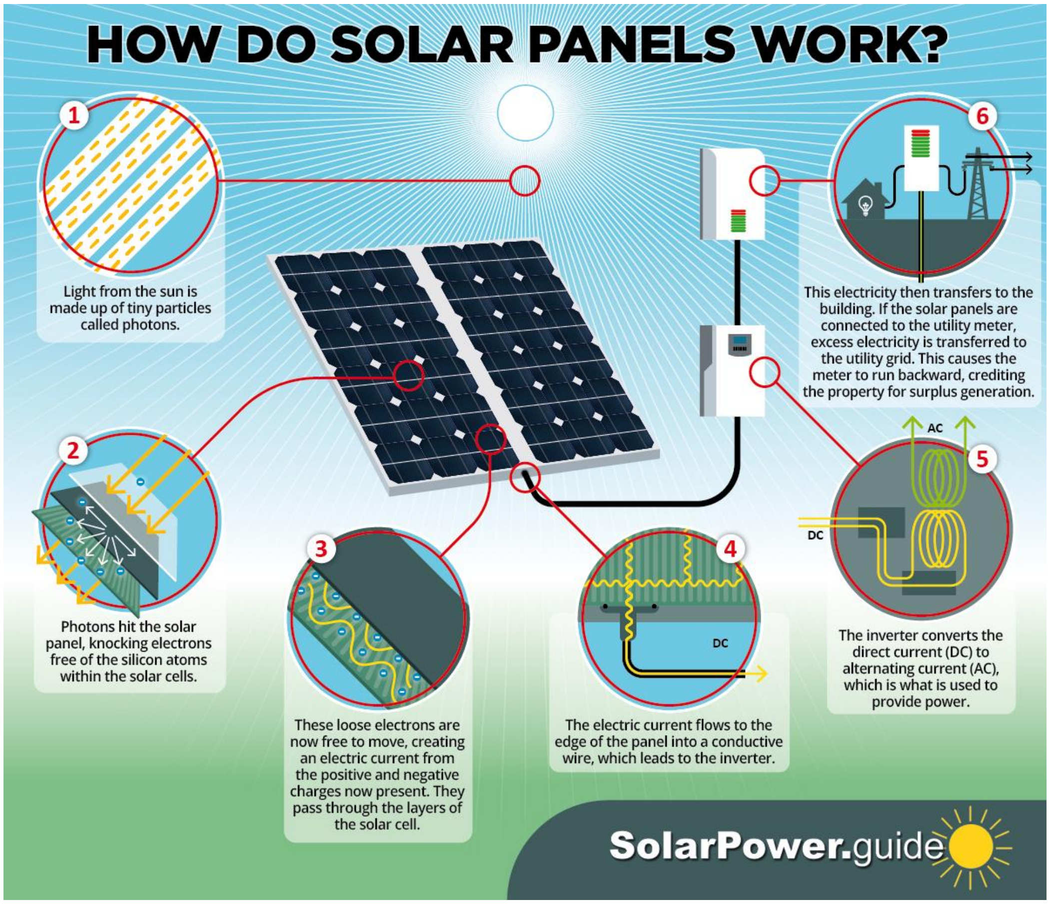

Figure 21 – Solar Panel Operation ***[16]***

When choosing a solar panel, the first step was to calculate the power requirement needed to charge the battery chosen. Using the desired charge time, 5 hours or less, the following equation shows how to calculate the solar panel watts required. Plugging in the battery charge of 10 Ah and voltage of 11.1 V, 22.55 Watts is required to charge the battery at the desired charge rate.

$$\frac{Battery\ Capacity}{\left[\frac{Solar\ Panel\ Power}{Battery\ Voltage}\right]} = 4.92\ hours$$

$$\frac{10\ Ah}{\left[\frac{Solar\ Panel\ Power}{11.1\ V}\right]} = 4.92\ hours$$

Solar Panel Power = 22.56 Watts

Several solar panels were considered, looking at different power, weight, dimensions, and materials. The panel that was selected was a Newpowa 25-watt monocrystalline solar panel **[2]**. This solar panel, shown in Figure 22 with dimensions, weighs 3.78 lbs. The solar panel is designed for outdoor use with a heavy-duty anodized frame to prevent corrosion. It is waterproof and has a 25-year transferable power output warranty. The frame has mounting holes which allow for easy mounting to the lawn mower frame. A clamp was designed, found in Section 5.9, to connect the panel to the mower handles.

Figure 22 – Newpowa 25 W Solar Panel ***[2]***

5.4 Solar Charge Controller

A Maximum Power Point Tracking charger is required to safely charge a LIPO battery with solar panels. The selected MPPT controller maximizes the solar panel to battery relationship by tracking the peak current and voltage to get the most charging watts seen in Figure 23. The selected controller also allows the team to set charge and discharge parameters to protect the battery and has built in safeties to kill power to the motor if it detects a problem within the circuit.

The MPPT charge controller works by converting a higher DC voltage coming from the solar panel to a lower DC voltage needed to charge the LIPO battery. The selected Newpowa solar panel outputs 17.8 volts and 1.43 amps [2]. The MPPT charge controller takes the solar panel output and selects a current at which to pair with that voltage to maximize charge wattage while also staying within the charge parameters of the LIPO battery.

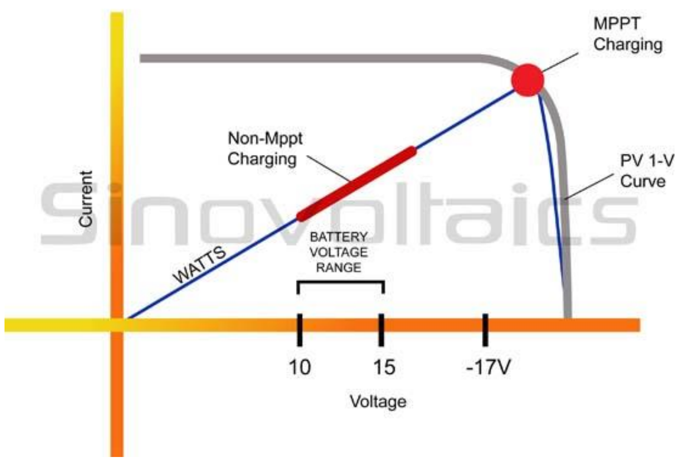

*Figure 23 – MPPT Charge Controller Chart **[21]***

*Figure 24 – MPPT Charge Controller **[21]***

5.5 Speed Controller

The next component needed for this design was a speed controller. The purpose of a speed controller is to monitor and control the speed of the motor. The speed controller is connected between the battery and the motor and controls the amount of power being provided to the motor. There were a variety of options to choose from all with different functions and sizes. After considering the pros and cons of each, the speed controller shown in Figure 25 was chosen. This certain controller is a PWM DC Motor Speed Controller purchased from Amazon. It features an on/off switch which was extended up to the mower handle for the user to easily reach. It also has a speed controlling dial which can be adjusted depending on grass thickness and desired run times. If the user is encountering cutting issues, the speed can be increased. However, this will decrease the operation time as the motor will be drawing more power from the battery. The speed controller also includes a digital monitor which displays a percentage of speed from 0-100%. For example, at 100% the motor is spinning at max rpm and 50% means the motor is spinning at half of its max rpm. The user can adjust the knob and view the monitor to find their desired speed which works best for their yard.

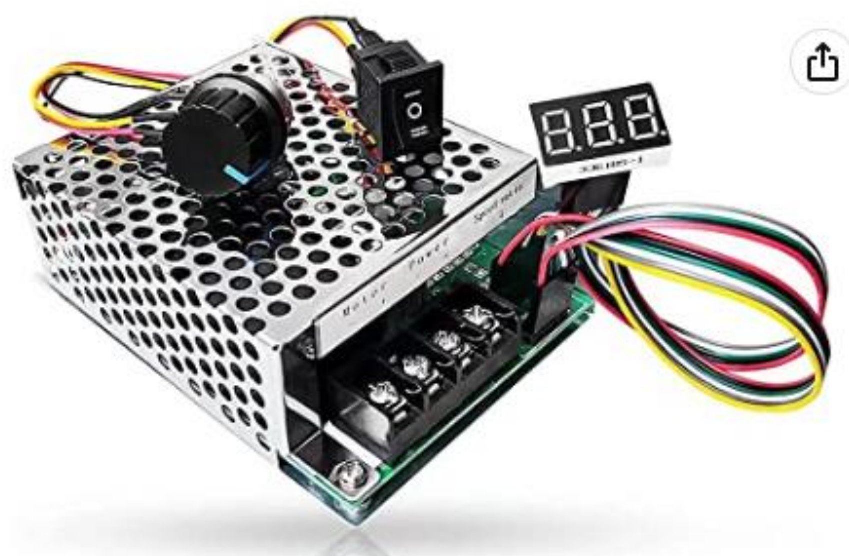

Figure 25 -DC Motor Speed Controller ***[15]***

5.6 Mounting Plate

Once all the electrical components were chosen, the next step was to design a method of mounting them to the existing mower deck. The requirements of this mounting plate were to have space for electrical components, withstand vibrations of the DC motor, and withstand outdoor use and high temperatures. The existing mower deck shown in Figure 26, unaligned bolt holes where the original gas engine was mounted.

Figure 26 – Original Deck

The first design of the mounting plate had four slots cut out for bolts to slide in and out and adjust for various sized mower decks. However, the mower we chose required the plate to have 3 holes in more precise locations, rather than adjustable. The overall dimensions of the plate are 12 x 14 inches at 1/4-inch thickness.

Several materials were considered for the manufacturing such as carbon steel, aluminum, and 3D printed PLA plastic. The metal options all added extra weight and higher cost. The 3D printed material was not durable enough for outdoor applications and would take too long to print at 100% infill. However, a new option was presented thanks to a generous donation from Spencer Industries. The team was given 3, 2x2 feet 1/4-inch-thick ABS plastic sheets that could be easily cut using the water jet. The ABS plastic sheet was coated in a Korad film **[18]** which increases UV protection and is commonly used in agricultural equipment.

The plate was designed using Solid Works, Figure 27, and then cut using the water jet located at the USI AEC. A central hole was cut at ½ inch diameter to allow the motor shaft plenty of room to spin. Four screw holes surround the central hole to allow easy mounting of the DC motor. The bolt holes for mounting to the mower deck are located in precise locations and allow for the use of the 0.5-inch bolts that came with the mower.

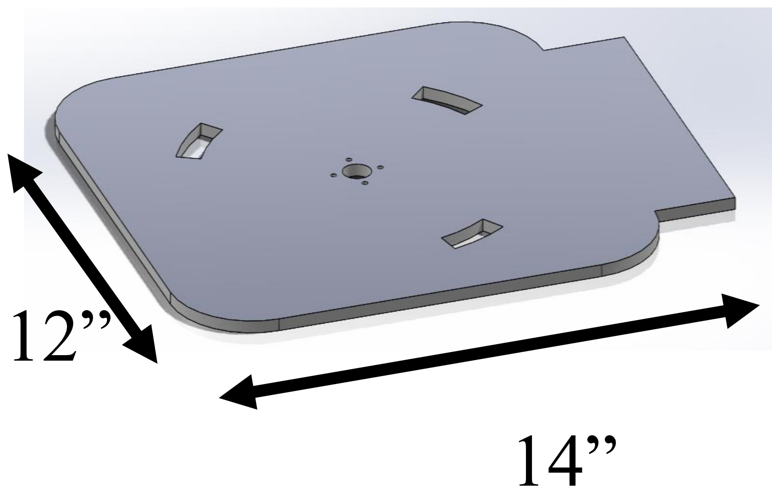

Figure 27 – Solid Works Model of Mounting Plate

5.7 Protective Case

After the design of the mounting plate, the next step was to design a method of protecting the electrical components. Most gas or electric mowers have a protective case to cover the important components. The protective case should protect the encased components from dust and debris, while not causing them to overheat. It also must be easily removable in order to access the electrical parts inside. The proposed design was created using Solid Works and can be seen in Figure 28.

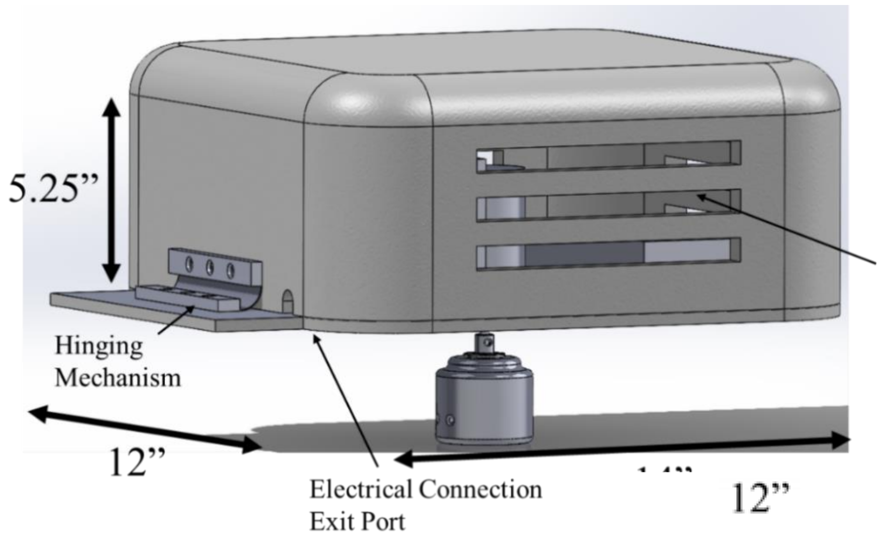

Figure 28 - Protective Case

The dimensions of the design are 12x12 inch to match the mounting plate. The case is also 6 inch tall with ventilation slots cut into the side to prevent overheating of components within. An electrical connection exit port would allow for all wiring to be run to the solar panel and the on/off switch on the handle. A hinging mechanism will be designed to allow for the user to flip the case up and access the electrical components. Also, a Velcro strip, not shown in Figure 28, will hold the case in the closed position.

The team decided to use the same ABS plastic sheet that was used on the mounting plate. Since the plastic is flat, it would need to be thermoformed into shape. Thermoforming is the process of heating up a flat piece of plastic and then forcing it over a mold (often called a tool). ABS is typically formed around 300 degrees Fahrenheit. In order to complete this process, the team must design a pattern that would allow this process to be done using a heat gun. This pattern, shown in Figure 29, was designed using the Solid Works sheet metal program in order to make a 3D model into a flat pattern. The final protective case can be seen in Figure 47.

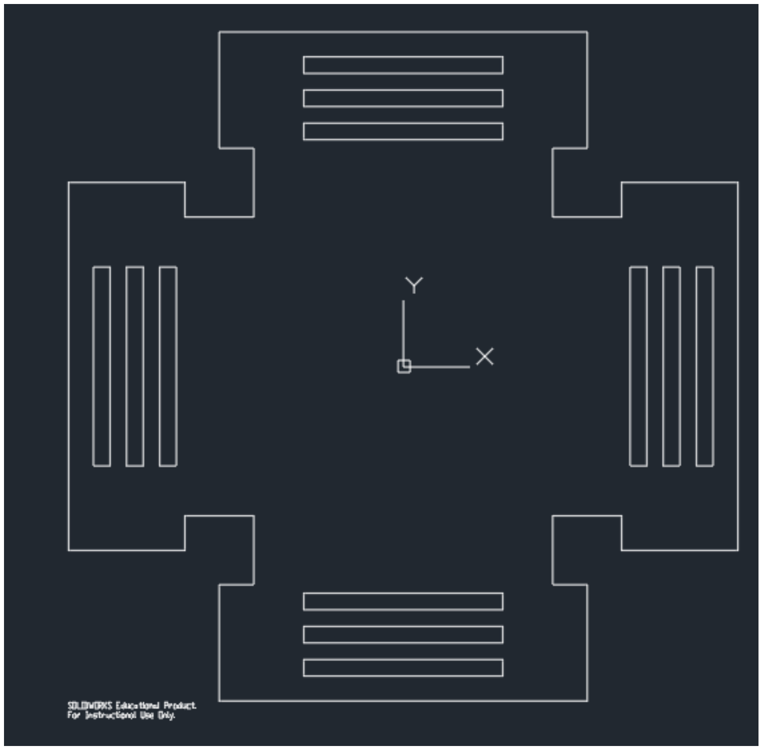

Figure 29 - Protective Case Flat Pattern

5.8 Weed Trimmer Line and Line Holder

The design of the weed trimmer line holder was dependent on the weed trimmer used. The weed trimmer line diameter chosen was .105 inch. This thickness is on the thicker end of the market. The team chose this thickness to increase the life expectancy of the weed trimmer line used and in turn decrease the frequency of changing the line out.

Figure 30-.105-Inch-Thick Weed Trimmer Line ***[4]***

The weed trimmer line will be held in place with a line holder that connects to the motor shaft. The line holder will be connected to the motor using a 1/8 inch motor key.

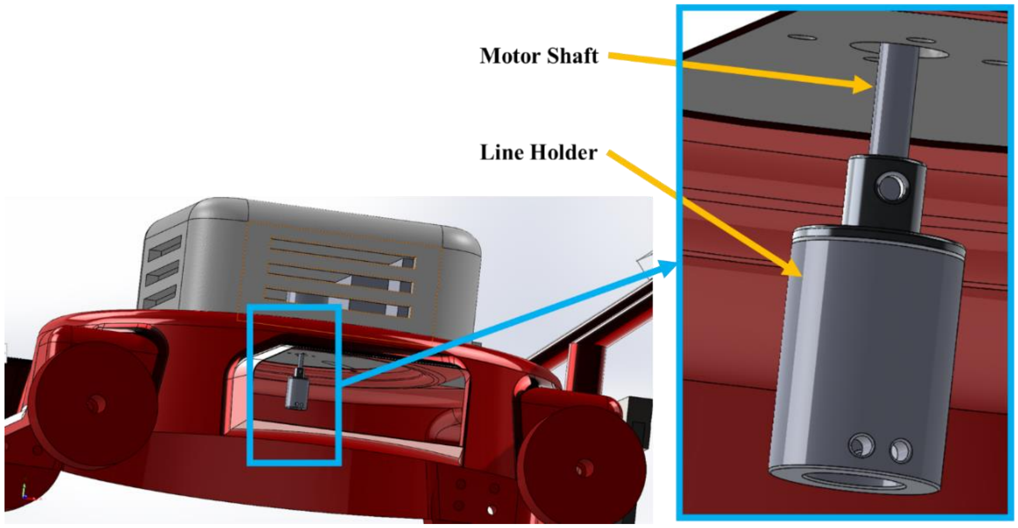

Figure 31 - Trimmer Line Holder Location

The first line holder model can be seen in Figure 32. This was the first 3D printed component of the build so there was a learning curve the team had to overcome. This first design had a couple issues as it was too small for the trimmer line the team selected and it was not long enough to reach the desired cut height under the mower deck.

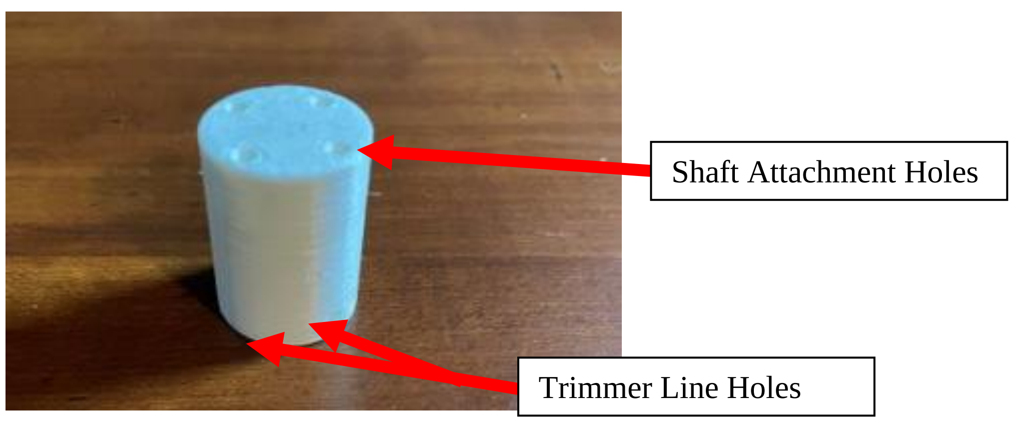

Figure 32 - Line Holder Version 1

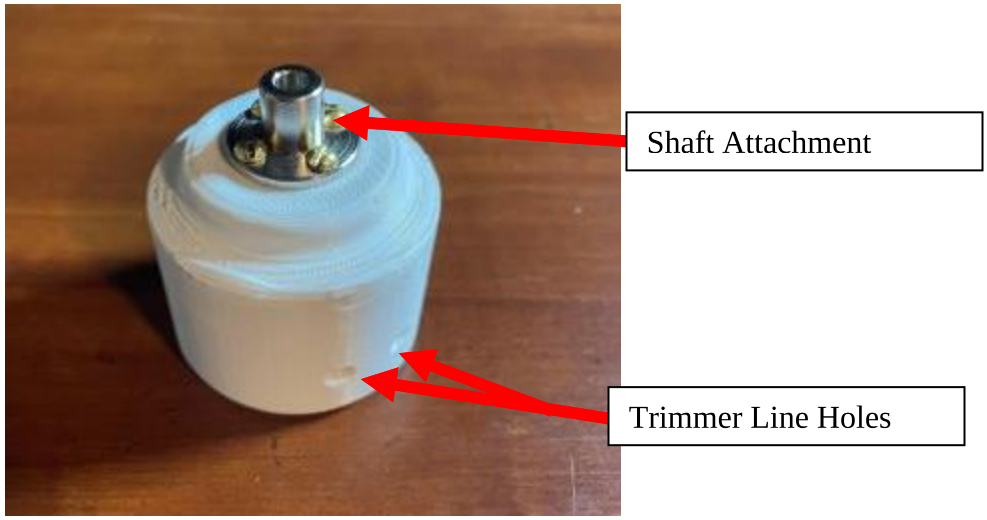

Figure 33 - Line Holder Version 2

For the second version of the line holder these problems were corrected. The second version can be seen in Figure 33. This version made the holes for the weed trimmer line larger and extended the depth of the cutting plane under the mower. This version was carried into the simulations done on Solid Works and testing. During testing, version 2 performed as expected. With the acquisition of a new motor, the line holder had to be modified again to accept the new motor's larger shaft.

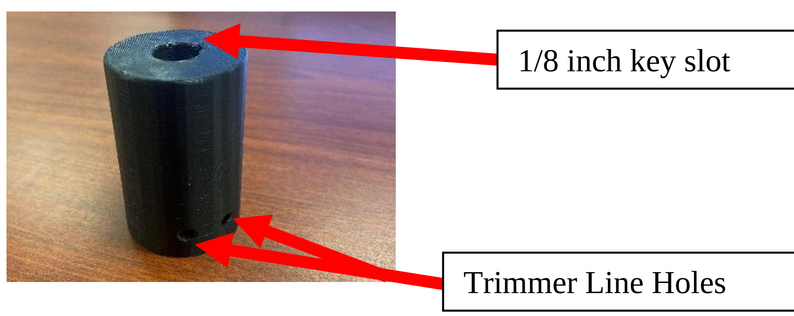

Figure 34 - Line Holder Final Version

The final version shown in Figure 34 was modified to fit the Amp Flow E400-12-30 motor which features a 1/2 inch diameter shaft with a 1/8 inch key. This final version does not require a shaft attachment, but rather an 1/8 inch key that compression fits the line holder to the motor shaft.

5.9 Solar Panel Mounting Bracket

The panel was designed with holes in the frame for bolts to mount to flat surfaces. In order to connect the flat frame to the round bars, the mounting brackets shown in Figure 35 were designed.

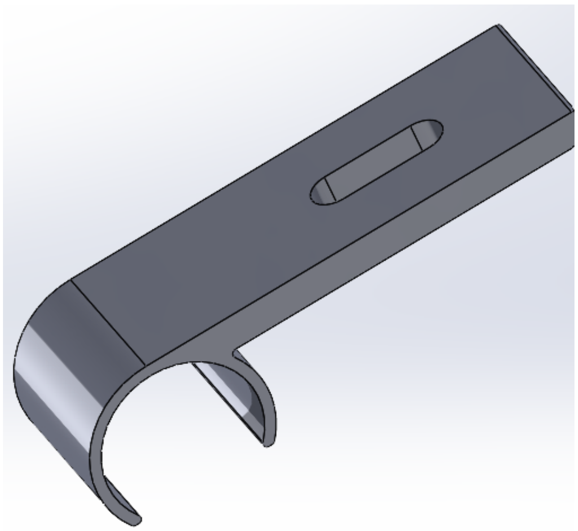

Figure 35 – Solid Works Model Solar Panel Mount

Figure 36 - Solar Panel with Mounts

These brackets have a round clamp that attaches around the round bar. This clamp was designed to have an inside diameter slightly smaller than the diameter of the handles. This creates a tight fit, which holds the bracket in place. Next, the bolt holes were extended out in order to make up for the distance between the handle and the solar panel. The chosen panel is slightly smaller in width than the distance between the mower handles. An image of the mounted solar panel can be seen in Figure 37. In order to prevent the brackets from sliding down the handle, rubber was added to the inside of the clamp.

Figure 37 - Solar Panel Mounted on Mower

5.10 Compliant Hinge

After designing the mounting plate and protective case, a way of connecting the two was required. The case needed to be able to be taken off or flipped up easily to access the interior components. In order to achieve this, a hinging mechanism was designed. The hinge is needed to hold the case in place and allow it to be easily lifted. To achieve this, the team decided to stay away from a standard three piece pinned hinge and design a compliant hinge. A compliant mechanism is a mechanism that gains at least some of its mobility from the deflection of flexible members rather than from movable joints only. Compliant mechanisms are advantageous because they reduce part count, increase production capabilities, and lower price to manufacture. The hinge is made of 3D printed PLA material. A prototype of the hinge and the Solid Works drawing can be found in Figure 38.

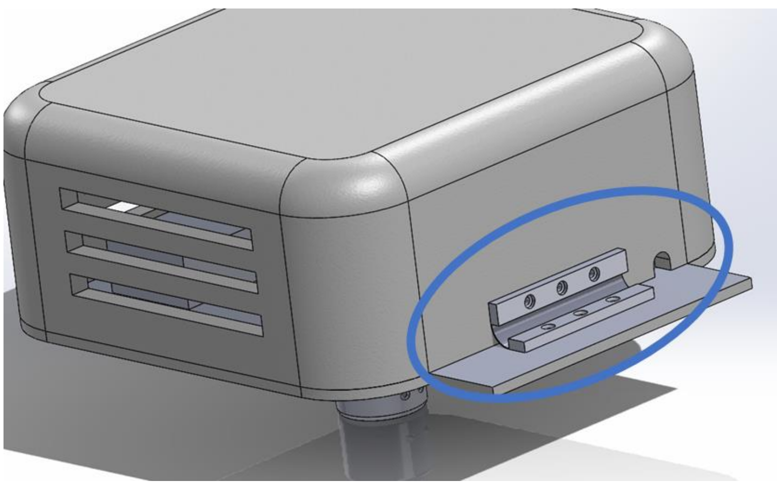
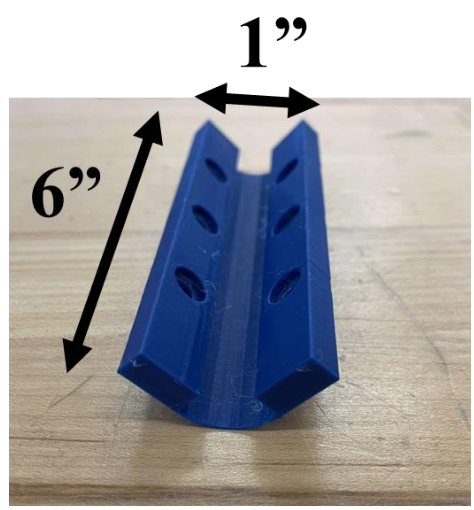

Figure 38 - Compliant Hinge for Protective Case

5.11 Back Up Charging Option

One of the main drawbacks of using solar energy is the risk of low amounts of sunlight. If there are multiple cloudy or rainy days in a row, the user may not be able to charge the solar mower. In this case, a backup charging option is needed. To solve this issue, the adapter shown in Figure 39 can connect the LiPo battery to a standard 120-volt outlet in your home. This method of charging would serve as an emergency case scenario considering this mower can run completely on solar energy.

Figure 39 - Wall Charger for LiPo Battery ***[11]***

6.0 Final Design Validation

6.1 Calculations

6.1.1 Charge Time

In order to calculate the final charge time of the battery, the values from chosen components were inserted into the following steps and equations **[6]**.

1. Multiply battery voltage by battery amp hours to get battery capacity in watt hours.

$$\boldsymbol{Battery\ Capacity = 11.1\ V\ x\ 10\ Ah = 111\ Wh}$$

2. Multiply battery watt hours by battery depth of discharge to estimate how much of the battery's capacity has been discharged.

$$\boldsymbol{Discharged\ Battery\ Capacity = 111\ Wh\ x\ 80\% = 88.8\ Wh}$$

3. Divide discharged battery capacity by the battery's rule-of-thumb charge efficiency factor (lead acid: 85%; lithium: 99%) to get the amount of energy required to fully charge the battery after factoring in losses during charging.

$$\boldsymbol{Energy\ required\ for\ full\ charge = 88.8\ Wh\ \div\ 99\% = 89.7\ Wh}$$

4. Multiply solar panel power by rule-of-thumb charge controller efficiency (PWM: 75%; MPPT: 95%) to estimate solar output.

$$\boldsymbol{Solar\ Output = 25\ W\ \ x\ 95\% = 23.75\ W}$$

5. Multiply solar output by 100% minus a fixed percentage to consider system losses. The National Renewable Energy Laboratory's PVWatts Calculator uses 14.08% as its default value for system losses.

$$\boldsymbol{Adjusted\ Solar\ Output = 23.75\ W\ \ x\ (100\% - 14.08\%) = 20.406\ W}$$

6. Divide the amount of energy required to fully charge the battery (in watt hours) by the adjusted solar output (in watts) to get your estimated charge time.

$$\boldsymbol{Charge\ Time = 89.7\ Wh\ \div 20.406\ W = 4.4\ Hours}$$

- This calculation was not confirmed.

6.1.2 Run Time

The run time for the solar lawn mower will depend on a few variables. The LiPo battery can supply 11.1 V and 10 Ah of charge to the motor. The user can set the speed controller to whatever speed they wish, depending on the thickness of grass. Ideally, the motor would run between 100-200 watts (like electric weed trimmers on the market). Using an online LiPo calculator, used to calculate flying time for a quadcopter, we can estimate that the battery will last around 30 minutes. To maximize run time, the team tested various motor speeds to see which combination resulted in the best performance. The result was that the mower cut grass well at 11 amps of current draw. At this current draw the motor runs at 121 Watts. This is the lowest setting that the mower can still adequately cut grass, therefore, is the best setting to maximize run time. The calculated run time at this power is 55 minutes. This calculation was not tested.

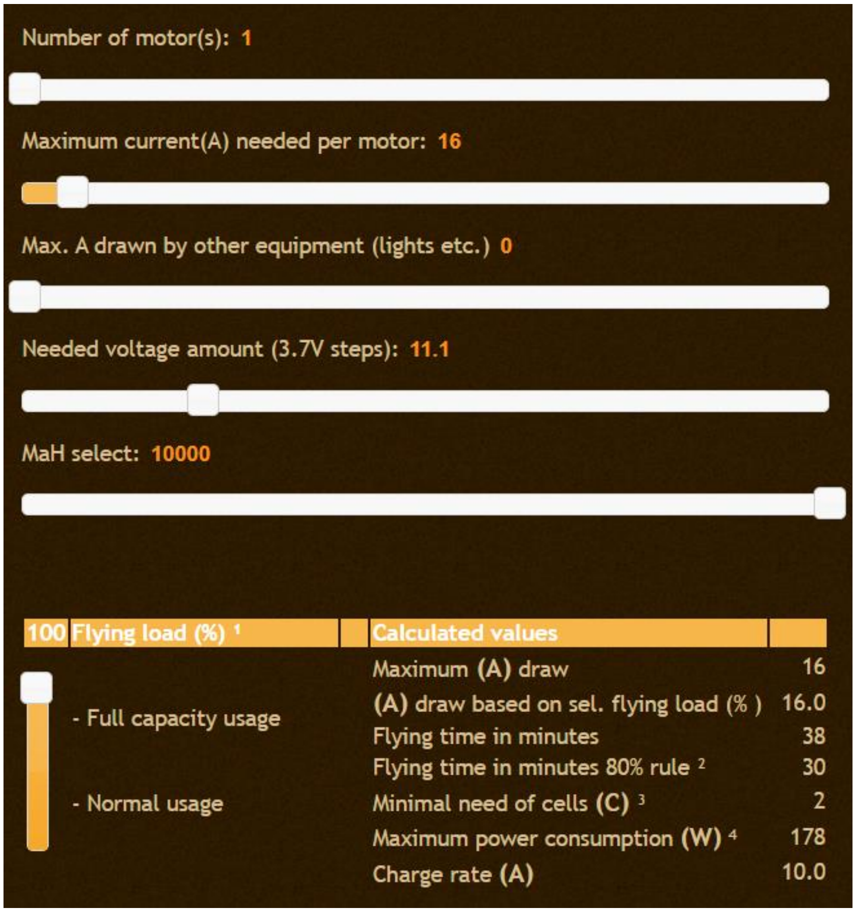

Figure 40 - Run Time Calculator ***[12]***

6.2 Solid Works Simulations

6.2.1 Weed Trimmer Line Holder

The line holder is a crucial part of the solar powered push mower design. During FMEA discussions the weed trimmer line holder was identified as a high-risk design item. The simulation shown in Figure 41 and Figure 42 was done before the line holder was 3D printed in PLA. Appendix L shows the material properties of PLA. The simulation was done by putting the minimum Torque required to cut grass of 10.5 Nm, from Literature review 2.4.3, on the weed trimmer line holes at the bottom of the holder and setting the fixture at the top of the holder. The first simulation in Figure 41 shows the displacement of the line holder. These displacements were minimal and within an acceptable range. The max displacement was less than .01 mm. Figure 42 shows the Von Mises stress result from the simulation. The max Von Mises stress was 77000 N/m^2. This is less than PLA's yield strength according to Appendix L.

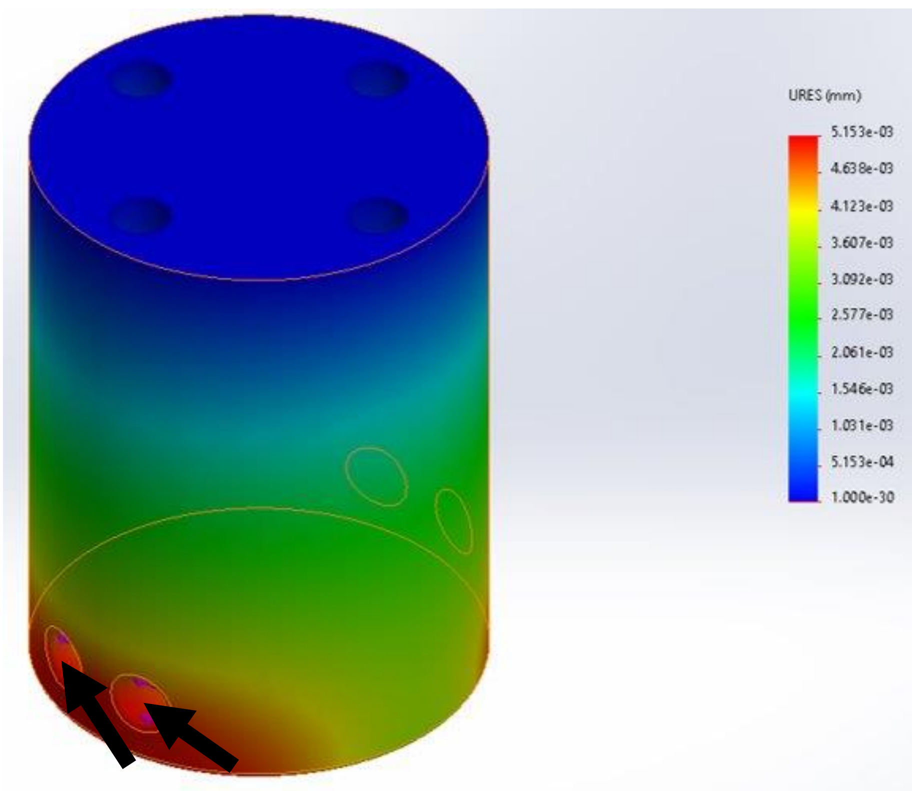

Figure 41 – Line Holder Displacement Simulation

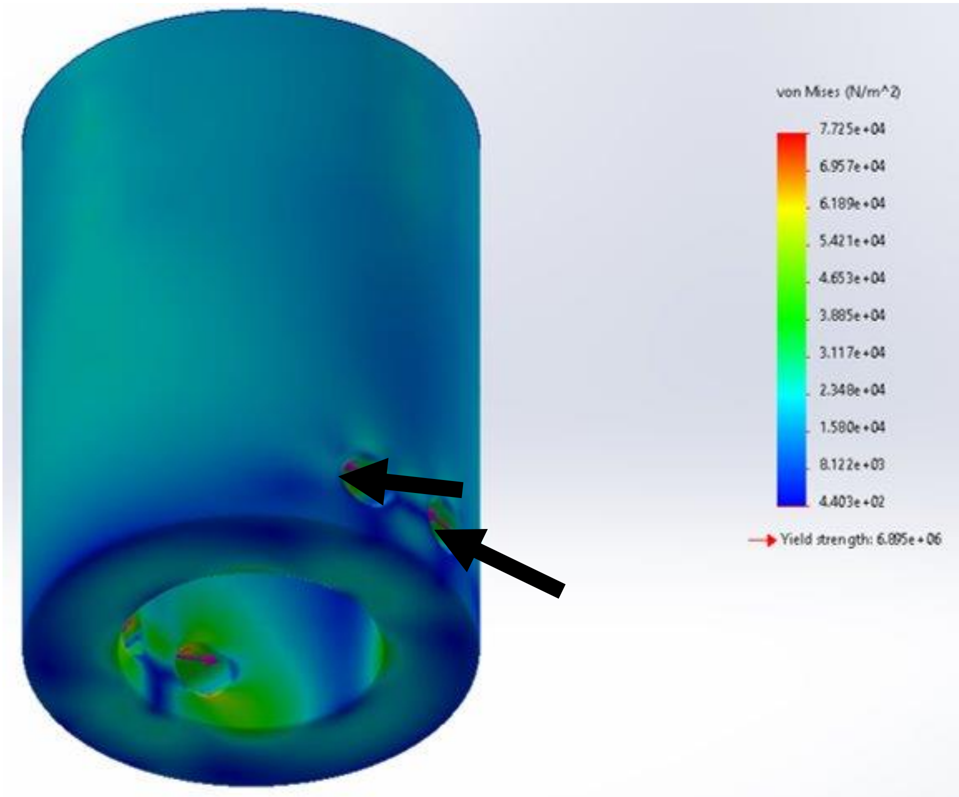

Figure 42 - Line Holder Stress Simulation

The simulation showed minimal displacement of the line holder and resultant stresses well below PLA's max yield strength. This design was carried into the prototype phase and altered slightly as the project progressed. No additional simulations were done for further variations of the line holder.

6.2.2 Heat Analysis

During the design of the protective case and mounting plate the team was concerned with the possibility of heat warping or melting the components. The team elected to utilize Solid Works simulation software. The components were placed together in a Solid Works assembly and a heat analysis was done with a worst-case scenario situation applied. The temperature of the motor and battery were assumed to be 100-degree Fahrenheit. The outside air temperature was assumed to be 110 degrees Fahrenheit. Lastly, the sun's radiation was perpendicular to every exterior surface. These constraints created the most extreme condition the mower could potentially operate in.

The Solid Works simulation, shown in Figure 43, shows this worst-case scenario situation. This simulation was important to make sure the chosen material of ABS would withstand the heat generated by the mower and atmosphere. Figure 43 shows that the maximum temperature reached was 210 degrees Fahrenheit. Appendix I shows the material properties for ABS plastic. This appendix shows that the softening point of ABS plastic is 225 degrees Fahrenheit. This simulation proved the team's design would function as intended. This design was carried into the prototype phase and no further heat analysis was done.

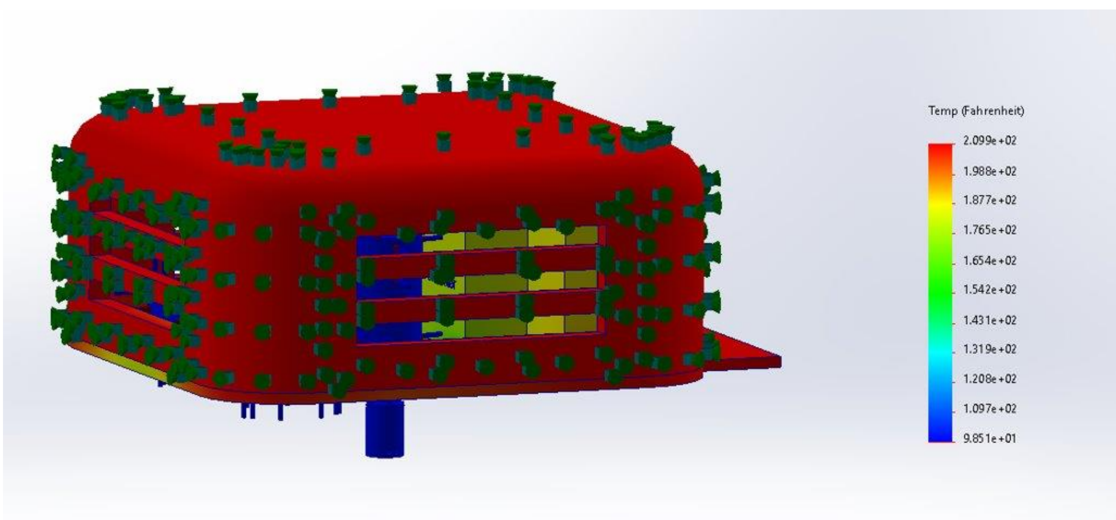

Figure 43 - Assembly Heat Analysis

6.3 Experimentation

6.3.1 Cutting Test 1

After completing the construction of the prototype, several cutting tests were performed with the first motor. In the first test, a few patches of grass were passed over with the speed controller at 75% speed. The motor was struggling to cut the grass, so the speed was turned up to 100%. The motor was still bogging down and being held up by the friction of the grass. The motor was also shut off when it encountered too much resistance. This was caused by a feature within the MPPT charge controller acting like a fuse. In the second cutting test, the MPPT charge controller was disconnected, and the speed was turned all the way up to 100%. This time, the mower cut slightly better but was still bogged down by the resistance of the grass. Without the MPPT to shut off the motor, the motor was overloaded and began to smoke. This led to the conclusion that the motor was most likely undersized.

Figure 44 - Cutting Test

6.3.1 Cutting Test 2

A second cutting test was performed after the mounting of the amp flow motor. In this test, the mower effectively cut grass. The new motor was not struggling to cut like the previous motor, and even handled a few thick patches of clover. However, the MPPT charge controller is still acting as a fuse and shutting the motor off after a few minutes of usage. To fix this issue, more in-depth research is required to learn what causes the controller to shut off. For testing purposes, the MPPT can be removed from the circuit if needed. During the second cutting test, the sound intensity was also measured using an Apple watch. The solar mower was measured at 66 dB. This measures below the 85 dB requirement and is much quieter than standard lawn mowers.

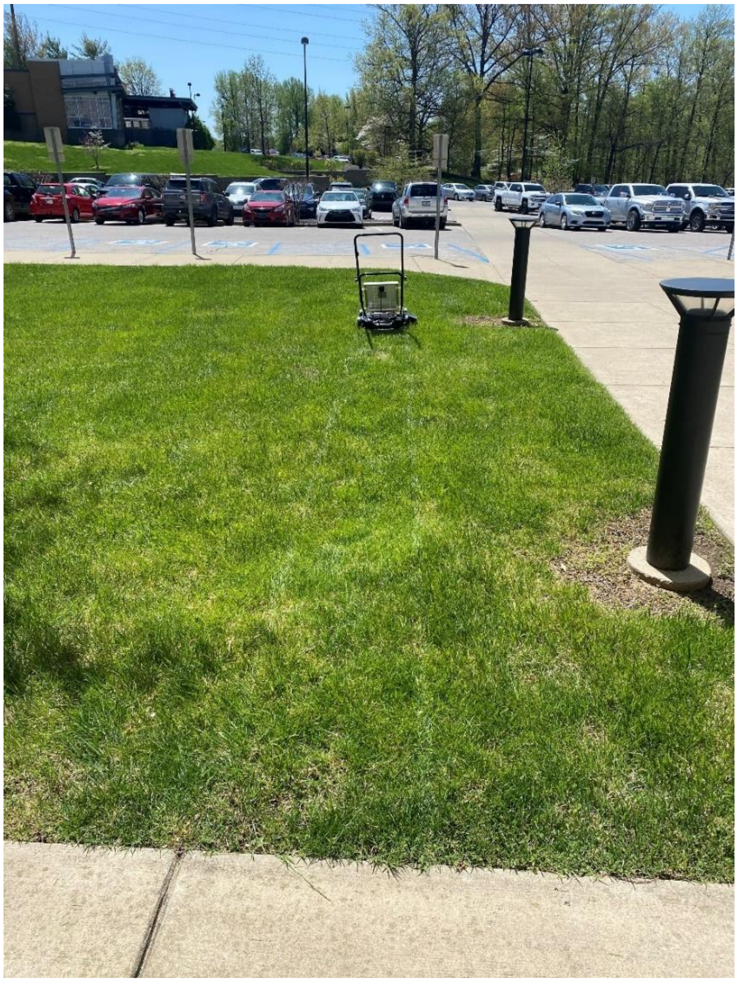

Figure 45 - Cutting Test 2

Figure 46 - Final Noise Test

7.0 Disposal Plan

Once the project has been completed and the Solar Mowing Team has graduated, the Solar Powered Lawn Mower will be donated to the University of Southern Indiana Engineering department. The Product will be taken to Solar Splash events and will be put on display for alternative Solar Powered Products made at USI. If the Product is not wanted anymore or it has reached the end of its useful life, it will be parted out and or sold. These can be seen in Table 2.

Table 2 - Disposal Plan

Component	If in working condition	If obsolete	Recycle as
Electric Motor	Use for at home project	Sell for scrap	N/A
Battery	Use for at home project	Recycle	e-waste
Charge Controller	Use for at home project	Recycle	Metal
Speed Controller	Use for at home project	Recycle	Metal
Deck	Sell for Scrap	Recycle	Metal
Mounting Plate and Case	Use for at home project	Recycle	Plastic
Solar Panel	Use for at home project	Recycle	Glass

8.0 Budget

A budget was set by the University of Southern Indiana Engineering Department at $500 per team. This value could increase if the spending is justified. We initially stated that we wanted it to be around $500 because that is closest to lawnmower similar in range. When adding up all our parts that were necessary, we ended up exceeding our personal budget by around $200. In order to justify our spending, product quality was considered. A full parts list and budget can be seen in Table 3.

Table 3 - Budget

Budget			
Description	Quantity	Unit Cost	Total
Gas Lawn Mower	1	$270	$270
Solar Panel	1	$37	$37
Battery	1	$90	$90
Wire connections kit	1	$15	$15
Digital Voltmeter	1	$13	$13
Electric Motor	1	$109	$109
Mounting Plate and Case	1	$20	$20
Weed Eater String	1	$22	$22
Wire tubing	1	$10	$10
Charge Controller	1	$30	$30
Shaft Attachment	1	$9	$9
Speed Controller	1	$21	$21
Battery Wall Charger	1	$35	$35
Total			$681

9.0 Economic Analysis

To determine the viability of this project, an extensive economic analysis was performed using previous literature reviews. The summary of the economic analysis with a 5-year life for our Solar Powered push Lawnmower is shown in Table 4. The startup cost is $411 but if a new lawnmower is needed, it would be $681 to start. In the economic analysis, the average cost per mow is analyzed by assuming the solar panels are the only charging source needed. If the solar panel is not to be used there is a $0.04 addition to account for the alternative wall charging. The average amount of mows per year is listed as 25. This average comes from the team's own experience mowing an average of 25 mows per year. The average yearly maintenance listed accounts for only the weed trimmer line being replaced because that is the only piece of equipment that requires constant change. If there is anything else that needs to be fixed, there is an additional $25 listed in parenthesis. Finally, a 5-year combination of maintenance and fuel is added together to show the total it would cost. Also in Table 4, the total cost over 5 years can be compared to both gas and battery electric push lawnmowers.

Table 4 - Economic Analysis Summary

	Gas	Battery Electric	Solar
Avg Start up cost +/- $50	$320	$355	$411 ($681 with new lawnmower)
Avg cost per mow	$2	$0.50	$0.00 ($0.04 alt source)
Avg Yearly Maintenance Cost	$20	$10	$4
Avg Yearly fuel Cost (25 mows)	$50	$12.50	$1
5 Year Fuel Cost (125 Mows)	$250	$63	$0.00 ($5.00 alt source)
5 Year Maintenance Cost	$100	$50	$20 (+ or – $5)
Total Cost for 5 years from start	**$670**	**$468**	**$436 ($706)**

When going through the economic analysis listed in appendix H, many factors were brought into consideration. The Economic analysis portion covers average startup costs for a typical Gas, Battery Electric, and Solar Powered Push Lawnmowers. A list of prices can be seen in Table 4. Here we will talk about the in-depth analysis that took place.

When creating a solar powered lawn mower, the engineering team had an end goal of making it quieter, lighter, less maintenance, and safer than both the normal gas and electric lawnmowers. When making the claim, the economic aspect was studied to prove that it is also cheaper in the long run.

An average gas push lawnmower costs the buyer around $320 compared to the average cost of a battery electric push lawnmower which is $355. Although the gas option is cheaper in the beginning, there are still a lot of maintenance tasks that add up in cost. With the average gas prices in the Midwest being around $3.30 per gallon **[22]**, it costs the user around $2 in fuel to mow the average sized yard, ½ acre. After a full year of mowing, 25 mows, that adds up to around $50 which could be a lot to someone who doesn't want to invest a lot into their yard maintenance. When looking at the Battery Electric option, we can see that it costs around $0.50 per charge. After mowing for a full year, that brings the user around $12.50. These numbers may not seem large but when comparing to $0.00 it takes to run our Solar Powered Push Lawnmower it adds up. Even though the Solar option costs around $411, within an average life span of 5 years, we can see that the solar option balances out and becomes the cheapest option of around $436 compared to gas and electric being $670 and $468. The total cost also includes maintenance for each option and solar still comes out on top with around $20 (+ or - $50). These costs include line replacement and a possible battery replacement. When looking at the gas option, we see that the average maintenance cost for 5 years is around $100. This includes the oil change every year, fuel, and a potential new blade. When looking at the Electric option of the 5 years, the maintenance cost is around $50 (+ or - $50). These costs include charging, and a potential new battery.

Once the in-depth economic analysis was completed, our claims of being less maintenance, and cost effective came true. Within 5 years, the average useful life cycle of all types, the solar powered option came out on top. Since the solar option is new to us, these numbers were assumptions based off average life expectancy of the individual parts. The parts that caused the most concern and had the highest chance of failing were the weed trimmer line, battery, and motor. Assuming these parts failed within the 5 years only brought it out to around an additional $100.

10.0 Future Improvements

Like all projects, something can be done in the future to make it better. We learned very quickly what could be done to the Solar Powered Push Lawnmower to make it better. With the amount of time we had, and the budget we set ourselves to, our project could have been done better. The main components that could have been improved are a new motor, double solar panel, and double battery.

The motor first selected for the Solar Powered Push Lawnmower was 80 W and 10,000 rpm. The tests in the lab went well because the motor spun up and spun the weed trimmer line with ease. Once we took the mower outside to run a live test on the grass, the motor started to bog out. When a motor bogs out, it is because there is not enough power and it is being overworked. The conclusion was that the motor was undersized. When running the calculations, section 5.1, the friction of the grass was not considered, and this impacted the motor tremendously. We found that the friction of the grass was not accounted for in the initial calculations. With this being the case, a new motor was researched and purchased. For future improvement, a larger motor needs to be selected in the beginning. Money will be saved, and time will not be wasted trying to figure out what could be the issue. We put blame on everything but the motor because we wanted to make it work.

When designing the mower, we had to find a place for the Solar Panel. We constantly asked ourselves where, but we should have also asked ourselves how many. Once the solar panel and the mounts were placed onto the mower, we realized that we could fit at least one more. Adding an additional solar panel would have cut the charge time in half. When looking at the weight, an additional solar panel would not have added a noticeable amount so overall weight would not have been seriously affected. The mounts that were created were adjustable so only 2 new ones would need to be printed. One solar panel does the job, but an additional one would make it more efficient.

Having a large motor, and two solar panels is amazing, but the battery would be depleted too quickly. Taking 5 hours to charge, depleting in 45 minutes, and not having enough power to cut grass consistently could be improved. Adding another 12 V battery would allow the mower to run more effectively. If an additional battery were to be added in the future, the motor would be allowed to run longer at its full potential. The wiring would not change, only another connection to the charge controller.

As always, once something is built, there will always be room for improvement. That was certainly the case for the Solar Powered Lawn Mower. The three main improvements that would make the mower run more efficiently is the additional battery, solar panel, and larger motor.

11.0 Lessons Learned

Learning and adapting is something that every group needs to be open minded to in order to be successful. When we worked through the project, lessons were taught without us even realizing it. The main lessons learned were from teamwork and design.

We, the solar power lawn mowing team have all worked together in every class project since our second semester freshmen year. When going through the design phase, there were many conversations about which option was the best. As always, there were disagreements, but the team settled on something as one because being closed minded doesn’t allow anything to be completed. The team had to work together in order to meet deadlines and disagreements over a design did not add any benefit to the end goal. The project was never split up because we wanted to make sure everyone was on the same page for each decision. Pride was swallowed and the result was a completed project that all group members agreed on and were proud of.

12.0 Conclusion

Climate Change is perhaps the greatest challenge humans will face in the next 100 years as it could directly impact all life on Earth. While the exact causes of climate change are heavily debated upon, it is no secret that human activity is speeding up the Earth's natural climate change. Day to day human activity has many contributing factors to climate change. In order to help with this situation, a solar powered push lawnmower was designed and built. The Lawn mower has a charge time of 5 hours in direct sunlight with a run time of 30 minutes and costs $411 to complete with an existing lawnmower.

The goal of this project was to design a solar powered push lawnmower and create a prototype to validate. In this process, research of previous projects that were similar was conducted. The past projects helped guide us to make our decisions and improve upon what they had done. All of these designs were considered, and a final design was chosen. The selected option was a solar powered push lawnmower with custom mounts and optimal electrical components. The prototype was designed to determine the economic analysis and validate our claims of being quieter, lighter, less maintenance, safer, ecofriendly, and powered by solar power. Upon completion of this project, the team believes that the solar powered lawn equipment market will begin to expand as technology advances. The prototype designed is a valid replacement to a traditional gas lawn mower, but future improvements will help increase the efficiency and reliability of solar powered lawn mowers.

Table 5 - Final Summary

Type:	Gas	Electric	Solar
Average Weight:	71 lb	56 lb	38 lb
Yearly Cost (est):	$70	$20-30	$10-15
Noise Level	95 dB	75 dB	66 dB
Run Time (min)	58.75	50	55
Purchase Cost (average)	$320	$355	$681 ($411 if using existing mower frame)

Figure 47 - Final Solar Mower

References

[1] Ajetunmobi, D. T., M. M. Odede, and T. Bello. "Development of an Improved Solar Powered Lawnmower." *International Journal of Women in Technical Education and Employment (IJOWITED)* 3.1 (2022): 12-18.

[2] *Amazon.com : Newpowa 25W Monocrystalline Solar Panel 12V 25 Watt Mono ...* https://www.amazon.com/Watts-Monocrystalline-Newpowa-Module-Marine/dp/B01M9B6RQI.

[3] *Amazon.com: HRB 11.1V 3S 10000mAh 25C Xt90 Lipo Battery Compatible with ...* https://www.amazon.com/HRB-10000mah-Battery-Traxxas-Infraction/dp/B07XHFV7VD.

[4] *Amazon.com: String Trimmer Line, Commercial Grade Orange Pentagon Weed ...* https://www.amazon.com/Trimmer-Commercial-Pentagon-Universal-Diameter/dp/B09YT7CWQP.

[5] *Three-Inch High-Performance Motors*, https://www.ampflow.com/motors/highPerformance /threeInch/.

[6] Beale, Alex. "Solar Panel Charge Time Calculator." *Footprint Hero*, 9 Dec. 2022, https://footprinthero.com/solar-panel-charge-time-calculator.

[7] "California Regulators Sign off on Phaseout of New Gas-Powered Lawn Mowers, Leaf Blowers." Los Angeles Times, Los Angeles Times, 9 Dec. 2021, https://www.latimes.com/california/story/2021-12-09/california-regulators-phaseout-new-gas-powered-lawnmowers-and-leaf-blowers.

[8] "Department of Labor Logo United States department of Labor." *Requirements of the Occupational Noise Exposure Standard with Regards to Hearing Protectors. | Occupational Safety and Health Administration*, https://www.osha.gov/laws-regs/standardinterpretations/1996-03-26-1#:~:text=Under%20the%20promulgated%20regulation%20%5B29,shall%20be%20replaced%20as%2 0necessary.

[9] *EPA*, Environmental Protection Agency, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

[10] Generac Power Systems, Inc. (2022, March 23). *Accessories*. MEAN GREEN MOWERS. Retrieved September 27, 2022, from https://meangreenproducts.com/accessories/

[11] *Lipo Charger Lipo Battery Balance Charger RC Charger RC Car Battery ...* https://www.amazon.com/Charger-Battery-Balance-Discharger-Adapter/dp/B07R18YNZQ.

[12] “Multicopter.” Multicopter Build Log, http://multicopter.forestblue.nl/lipo_need_calculator.html.

[13] “Noise.” *City of Albuquerque*, https://www.cabq.gov/environmentalhealth/noise.

[14] Prasanthi, Smt G., and R. Balaiah. "Fabrication of solar powered lawnmower." *International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET)* 3.8 (2017): 477-480.

[15] *PWM DC Motor Speed Controller, DC 10-55V/60A, LED Display Stepless DC ...* https://www.amazon.com/Controller-Stepless-Adjustable-Potentiometer-Forward-Brake-Reverse/dp/B089273KVZ.

[16] Robertson, Joe. *How Do Solar Panels Work? - Solarpower.guide Solar Energy Insights - Infographic*, https://solarpower.guide/solar-energy-insights/how-do-solar-panels-work.

[17] SOYOYE, Babatunde. "Development and Performance Evaluation of a Solar Powered Lawn Mower." *Turkish Journal of Agricultural Engineering Research* 2.2 (2021): 348-362.

[18] Sparks Milling Digital (sparksmilling.com) Marketing Machine Builders in Chesterfield, MO USA. “KORAD®.” *Spartech*, https://www.spartech.com/brand/korad.

[19] “The Online Materials Information Resource.” *MatWeb*, https://www.matweb.com/search/DataSheet.aspx?MatGUID=ab96a4c0655c4018a8785ac4031b9278&ckck=1.

[20] *U.S. Consumer Product Safety Commission*. https://www.cpsc.gov/s3fs-public/pdfs/blk_pdf_Lawnmowerregulatorysummary.pdf.

[21] *Wercht 60A MPPT Solar Charge Controller 12V/24V Current Auto Focus ...* https://www.amazon.com/WERCHTAY-Controller-Tracking-Regulator-Multiple/dp/B09XF1S3W1.

[22] “We Do the Math: Will an Electric Mower Trim Lawn Care Costs?” *Wise Bread*, https://www.wisebread.com/we-do-the-math-will-an-electric-mower-trim-lawn-care-costs.

[23] “Z900 ZTrak Mower Torsion Lawn Striping Kit JDZGSTRIPE.” *ZGlide Suspension*, 12 Jan. 2023, https://zglidesuspension.com/product/z900-ztrak-mower-torsion-lawn-striping-kit-jdzgstripe/.

Appendices

Appendix A: Final Test Results

Figure 48 – Final Test Results

Appendix B: Weight Table

Table 6 - Weight Table

Weight Table			
Description	Quantity	EstimatedWeight (lbs)	Actual Weight (lbs)
Gas Lawn Mower	1	30.00	20.00
Solar Panel	1	5.00	3.78
Battery	1	2.00	1.45
Wire connections kit	1	0.50	0.50
Electric Motor	1	5.90	5.90
Mounting Plate and Case	1	1.00	5.52
Speed Controller	1	0.50	0.51
String holder	1	0.10	0.10
Shaft Attachment	1	0.05	0.05
Charge Controller	1	0.75	0.63
Weed Eater String	1	0.01	0.01
Total		45.81	38.45

Appendix C: Bill of Materials

Table 7 - Bill of Material

ITEM	QTY	DESCRIPTION	SOURCE	Model Number	Cost per unit	Total Price
1	1	Motor Shaft Key	Grainger	#5UE57	$3.00	**$3.00**
2	1	.105" Weed Eater Line (200 ft)	Amazon	#B09YT7CWQP	$20.00	**$20.00**
3	1	Solar Panel	Amazon	#B01M9B6RQI	$37.00	**$37.00**
4	6	1/4-20 x .75" lg. hex bolt	Home Depot	#800424	$1.25	**$7.50**
5	2	1/4 washer (6 pack)	Home Depot	#800341	$1.38	**$2.76**
6	1	1/2" x 4" Velcro straps (4 pack)	Amazon	#B08V8NK5TN	$10.00	**$10.00**
6	2	1/4-20 nut (4 pack)	Home Depot	#800051	$1.38	**$2.76**
7	1	Electrical Wire (24 ft)	Home Depot	#112-1601A	$7.00	**$7.00**
8	1	Pack of Assorted Wire Nuts	Home Depot	#ESA-30	$5.00	**$5.00**
9	1	Black Wire Wrap (25 ft)	Home Depot	#FLX-538C10	$10.00	**$10.00**
10	1	Solar Charge Controller	Amazon	#B09XF1S3W1	$30.00	**$30.00**
11	1	12 V Lipo Battery	Amazon	#B06XNS5NGH	$90.00	**$90.00**
12	1	Speed Controller	Amazon	#B0991XYV4F	$21.00	**$21.00**
13	1	Battery Wall Charger	Amazon	#B07R18YNZQ	$35.00	**$35.00**
14	1	12 V DC Motor	AMP FLOW	#E30-400-12	$109.00	**$109.00**
15	1	Lawn Mower (Traditional Gas)	Home Depot	#MNA152506	$270.00	**$270.00**
16	2	2' x 2' x 1/4" thick ABS Sheet	Spencer Industries	NA	$15.00	**$30.00**
17	3	1/2-13 x 1" lg. Bolt	Home Depot	#810078	$1.25	**$3.75**
18	1	1/2-13 Nut (4 pack)	Home Depot	#811571	$1.38	**$1.38**
19	2	1/2 Washer (6 pack)	Home Depot	#802521	$1.38	**$2.76**

Appendix D: Schedule

Table 8 - Schedule

Date	Task
1/18/2023	First Presentaion for Dr. Kissel
1/20/2023	Finalize Design Layout
1/23/2023	Finalize Component Specifications
1/25/2023	Second Presentation
1/26/2023	Address Concerns from 2nd Presentation
1/27/2023	Begin SW Simulations on 3D parts
1/28/2023	Review Energy Calcs/ Meet with Dr. Deirsing if req.
1/30/2023	Finalize bought components
1/31/2023	Completed Weight Table/ Budget
2/1/2023	Third Presentation
2/1/2023	Address Concerns from 3rd Presentation
2/2/2023	Complete SW Simulations
2/3/2023	Refine 3D printed models as needed/ meet with Dr. Nelson if req.
2/5/2023	Complete Model Rendering
2/7/2023	Last Team meeting before Critical Design Review
2/8/2023	Critical Design Review
2/9/2023	Submit Order Form for Parts
2/10/2023	Begin Design Report (team allocations)
2/13/2023	Order Parts (1-2 weeks for delivery)
2/14/2023	Initial 3D printing (Line Holder)
2/16/2023	Acquire Scrap Sheet Plastic from Spencer Industry
2/20/2023	Dryfit Line Holder to Motor Assembly
2/27/2023	Prepare Lawn mower deck for mounting parts
3/1/2023	In-Depth Calculations Done
3/1/2023	Program Info to Shared Drive
3/1/2023	Names and Emails on invite list to drive
3/3/2023	Check Motor Components and Confirm Function
3/5/2023	Progress Checkup on Design Report before break
3/6-11/2023	First Solar Charge Days (Spring Break)
3/13/2023	Make Rough Base Plate out of spare wood
3/13/2023	Assemble Components w/ wood base plate
3/14/2023	Make Adjustments to baseplate model
3/15/2023	Cut Base Plate out of ABS plastic Sheet
3/15/2023	Assemble components and test initial operation
3/17/2023	Begin Powerpoint Poster
3/13-20/23	Test functions and adjust as needed
3/20/2023	Fabricate Protective Case
3/20/2023	Cut some Grass!
3/20-4/21	Refine/Redesign/Retest
3/22/2023	ME department review
3/22/2023	Review Poster with Dr. Kissel
3/24/2023	Project Poster to Shared Drive
3/24-4/6	Work on Report/Powerpoint/Prototype
4/6/2023	1st Draft Report to Advisor
4/14/2023	2nd Draft Report to Advisor
4/21/2023	Final Presentation day, Powerpoints to drive
4/27/2023	Poster Session
4/27/2023	Complete CATME Survey
4/27/2023	Complete Exit Survey and Interview
4/27/2023	Final Report to advisor and shared drive
4/27/2023	Final repoert submitted to SOAR

Appendix E: FMEA

E.1: Design FMEA

Table 9 - Design FMEA

FMEA: Design (Solar Powered Lawn Mower)						
Item	**Failure Mode**	**Cause**	**Possible Effects**	**Prob.**	**Level**	**Possible Action to Reduce Failure Rate or Effects**
Electric Motor	Insufficent Power	Improper Motor Calcs.	Destruction of Motor	Medium	Critical	Review Calculations before ordering. Review wiring schematic from motor manufacturer and confirm with mower design. Confirm proper wiring before connecting to power.
	Spins in Wrong Direction	Defective Motor	Poor Performance			
	Too heavy for easy op.	low power supply	Safety Hazard			
		Incorrect Wiring				
Solar Panels	Insufficent Power Produced	Manu. Defect	Loss of Power	Low	Critical	Review Calculations, Review Manufacturers specifications; both before ordering. Research necessary subcomponents (Inverter & Charge Controller) and confirm compatibility.
	Fail to Collect any Energy	Incorrect Calculations	Poor Performance			
		Improper Wiring/Setup	Failure to Operate			
Battery	Insufficient Storage Cap.	Incorrect Calculations	Low Run Time	Medium	Critical	Review Reqs., Review Wiring prior to use, Confirm power to motor meets req. before connecting. Confirm Charge controller and inverter compatibilty.
	Incorrect Output Req.	Incorrect Wiring	motor/battery destruction			
	Overcharging	Faulty Battery	Underperforming Motor			
		Improper charge controller	Unable to Charge			
Deck/Frame	Warping	Damaged Frame	Safety Hazard	Medium	Critical	Confirm weights of components are within accepted range, Confirm integrity of frame prior to install. Use Solidworks simulations to verify components can hold up to stresses of mowing.
	Cracking	Components too heavy	Motor Damage			
	Rusting	Improper Installation	Inability to cut grass			
		Improper Use				
Mounting Plate	Warping	Too Much Stress	Motor Damage	Medium	Mid	Perform Stress analysis on motor prior to choosing material and thickness. Use trusted material supplier. Confirm design with SW simulations. Confirm motor mount locations.
	Cracking	Poor Material Choice	Safety Hazard			
	Improper Fitment	Motor alignment incorrect	Vibrations			
			Improper Cutting			

E.2: End User FMEA

Table 10 - End User FMEA

FMEA: Customer (Solar Powered Lawn Mower)						
Item	**Failure Mode**	**Cause**	**Possible Effects**	**Prob.**	**Level**	**Possible Action to Reduce Failure Rate or Effects**
Electric Motor	Lack of Power	Poor Connections	Destruction of Motor	Medium	Critical	Check wires and check for proper installation.
	Failure to Power On	Defective Motor	Poor Performance			
	Spins in Wrong Direction	Faulty Wiring	Safety Hazard			
		Damage during Handling				
Solar Panels	Insufficent Power Produced	Manu. Defect	Loss of Power	Medium	Critical	Ensure good solar panel placement and wiring. Make sure panels are clean and in direct sunlight. Check inverter and charge controller wiring.
	Fail to Collect Energy	Incorrect Placement	Poor Performance			
			Failure to Operate			
Battery	Not Charging properly	Faulty Battery	Premature Loss of Power	Low	Critical	Follow manufacturers guidelines for charging and follow wiring diagrams in provided instructions. Check Solar Panels and Charging Controller.
		Incorrect Wiring	Motor Destruction			
			Underperforming Motor			
Deck/Frame	Warping	Damaged Frame	Safety Hazard	Medium	Critical	Customer needs to confirm integrity of deck and frame prior to install. Confirm proper installation.
	Cracking	Improper Installation	Motor Damage			
	Rusting	Improper Use	Inability to cut grass			
Mounting Plate	Warping	Improper fitment	Motor Damage	Low	Mid	Write good installation instructions with easy to understand directions and pictures. Inspect part for cracks/defects.
	Cracking	Material Defects	Safety Hazard			
			Improper Cutting			

Appendix F: Functional Block Diagram

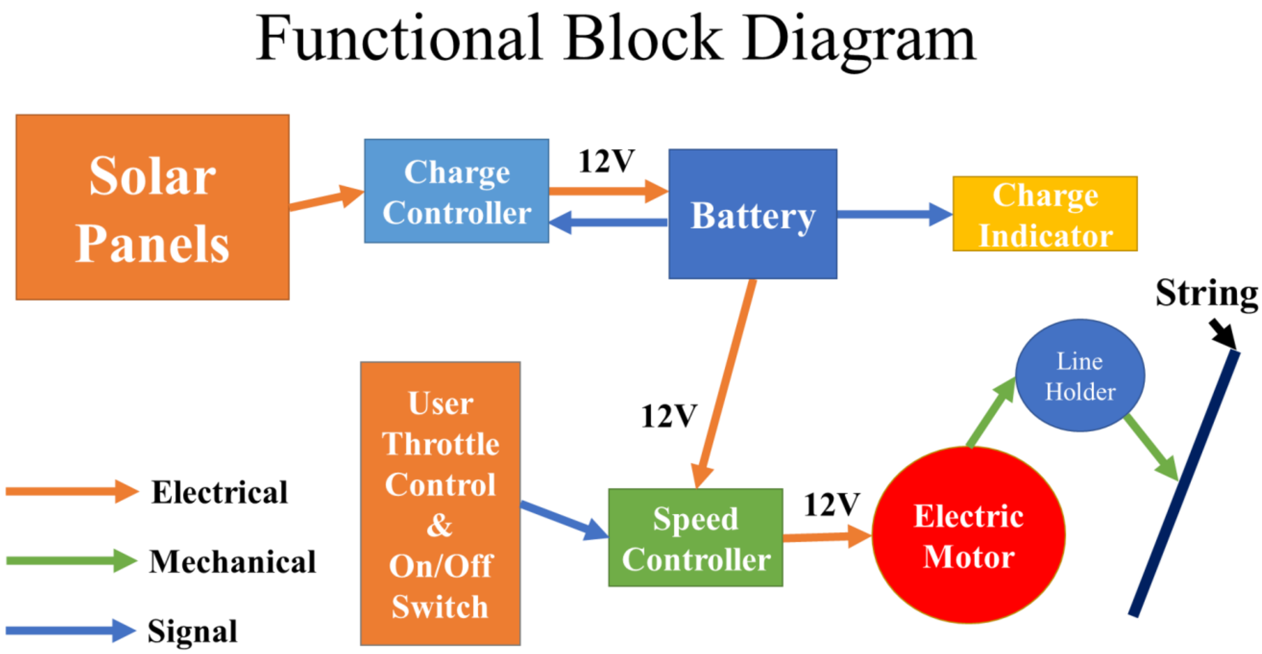

Figure 49 - Functional Block Diagram

Appendix G: Decibel Chart

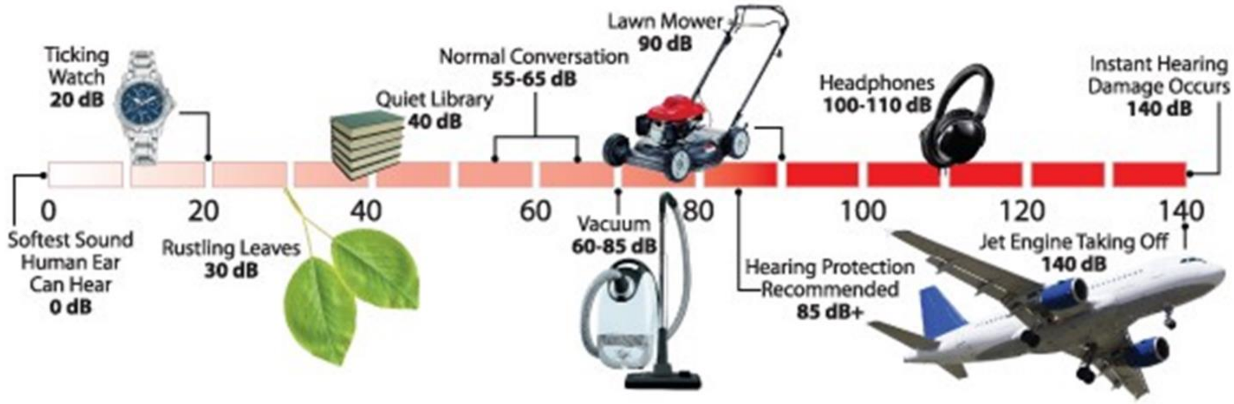

Figure 50- Decibel Chart ***[13]***

Appendix H: ABS Material Properties

Overview of materials for Acrylonitrile Butadiene Styrene (ABS), Sheet

Categories: Polymer; Thermoplastic; ABS Polymer; Acrylonitrile Butadiene Styrene (ABS), Sheet

Material Notes: This property data is a summary of similar materials in the MatWeb database for the category "Acrylonitrile Butadiene Styrene (ABS), Sheet". Each prope
report the average value, and number of data points used to calculate the average. The values are not necessarily typical of any specific grade, especiall

Vendors: **Click here to view all available suppliers for this material.**

Please click here if you are a supplier and would like information on how to add your listing to this material.

Printer friendly version Download as PDF Download to Excel (requires Excel and Windows)
Export data to your CAD/FEA program

Physical Properties	Metric	English
Density	0.775 - 1.28 g/cc	0.0280 - 0.0462 lb/in^3
Linear Mold Shrinkage	0.00400 - 0.00700 cm/cm	0.00400 - 0.00700 in/in
Melt Flow	1.20 - 2.60 g/10 min	1.20 - 2.60 g/10 min

Mechanical Properties	Metric	English
Hardness, Rockwell R	80.0 - 105	80.0 - 105
Tensile Strength, Ultimate	15.9 - 39.9 MPa	2310 - 5790 psi
Tensile Strength, Yield	31.0 - 42.7 MPa	4500 - 6200 psi
Elongation at Break	7.80 - 190 %	7.80 - 190 %
Elongation at Yield	2.60 - 2.90 %	2.60 - 2.90 %
Modulus of Elasticity	1.83 - 2.21 GPa	265 - 320 ksi
Flexural Yield Strength	34.5 - 77.9 MPa	5000 - 11300 psi
Flexural Modulus	1.59 - 2.55 GPa	230 - 370 ksi
Izod Impact, Notched	1.86 - 5.34 J/cm	3.48 - 10.0 ft-lb/in
	0.520 - 2.99 J/cm @Temperature -29.0 - -17.8 °C	0.974 - 5.60 ft-lb/in @Temperature -20.2 - 0.000 °F
Izod Impact, Unnotched	2.67 - 4.27 J/cm	5.00 - 8.00 ft-lb/in
	0.58729 - 2.1356 J/cm @Temperature -40.0 - -40.0 °C	1.1002 - 4.0009 ft-lb/in @Temperature -40.0 - -40.0 °F
Falling Dart Impact	20.3 - 47.5 J	15.0 - 35.0 ft-lb
	4.06746 - 31.1839 J @Temperature -40.0 - -40.0 °C	3.00000 - 23.0000 ft-lb @Temperature -40.0 - -40.0 °F
Instrumented Impact Total Energy	27.1 - 54.0 J	20.0 - 39.8 ft-lb

Thermal Properties	Metric	English
CTE, linear	59.4 - 101 µm/m-°C	33.0 - 56.0 µin/in-°F
CTE, linear, Transverse to Flow	93.6 - 101 µm/m-°C	52.0 - 56.0 µin/in-°F
Deflection Temperature at 0.46 MPa (66 psi)	82.2 - 98.9 °C	180 - 210 °F
Deflection Temperature at 1.8 MPa (264 psi)	77.8 - 106 °C	172 - 222 °F
Vicat Softening Point	107 °C	225 °F
Flammability, UL94	HB - V-0	HB - V-0

Figure 51 - ABS Material Properties ***[19]***

Appendix I: Lawn Mower Comparison Chart

Table 11 - Lawn Mower Comparison Chart

Type of Mower	Blade Size	Weight (lbs)	Engine Power	Run Time (min.)	Purchase Cost	Cost to Fill tank / Charge Battery (cents) ($3/Gallon of Gas & 18 ₵/kWh of Electricity)
Gas: Honda HRX217HZA	Two 21" Blades	106	200 cc (4657.5 W)	100	$1,200	0.75
Gas: Murray	20"	42	125cc (2062.5 W)	50	$200	0.633
Gas: Troy-Bilt TB160	21"	70	160 cc (3000 W)	25	$300	0.75
Gas: Toro Recycler	21"	67	140 cc (2557.5 W)	60	$499	0.72
Electric: Ryobi RY401100	17.5"	40	40 V 9.6 A (384 W)	25	$229	2.88
Electric: EGO Power+ LM2135SP	Two 20" Blades	55	56 V 7.5 A (420 W)	60	$229	7.56
Electric: Green Machine 62 V Brushless	21"	60	62 V 5.33 A (330 W)	45	$450	8.928
Electric: Echo eFORCE	21"	69.56	56 V 7.5 A (420 W)	40	$513	5.04

Appendix J: Weed Trimmer Comparison Chart

Table 12 - Weed Trimmer Comparison Chart

Type of Weed Eater	Cutting Path Diam. (in)	Weight (lbs)	Power	Run Time (min.)	Purchase Cost	Decibels (dB)	RPM
STHL Fs 91R (Gas)	16.5"	10	1.27 bhp (947 W)	60	$350	90	9,500
Husqavarna 525 LST (Gas)	19.3"	10	125cc (1.34 HP) (1000 Watts)	55	$400	98	8,500
Ryobi Expand-It 40V (Electric)	15"	11.3	18 V 4.8 A (86.4 W)	50	$180	75	6,000
Greenworks 40V (Electric)	14"	10	40 V 2.5 A (101 W)	95	$135	70	6,000

Appendix K: PLA Materials Properties

Physical Properties	Metric	English
Density	1.00 - 3.41 g/cc	0.0361 - 0.123 lb/in^3
	1.08 - 1.12 g/cc @Temperature 230 - 230 °C	0.0390 - 0.0405 lb/in^3 @Temperature 446 - 446 °F
Moisture Absorption at Equilibrium	0.0600 - 2.00 %	0.0600 - 2.00 %
	0.550 - 1.30 % @Temperature 70.0 - 70.0 °C	0.550 - 1.30 % @Temperature 158 - 158 °F
	0.550 - 1.30 % @Time 180000 - 1.44e+6 sec	0.550 - 1.30 % @Time 50.0 - 400 hour
Additive Loading	10.0 - 40.0 %	10.0 - 40.0 %
Moisture Vapor Transmission	8.30 - 15.7 cc-mm/m^2-24hr-atm	21.1 - 39.9 cc-mil/100 in^2-24hr-atm
Water Vapor Transmission	3.88 - 170 g/m^2/day	0.250 - 10.9 g/100 in^2/day
Oxygen Transmission	14.0 - 27.6 cc-mm/m^2-24hr-atm	35.6 - 70.1 cc-mil/100 in^2-24hr-atm
Oxygen Transmission Rate	130 - 1450 cc/m^2/day	8.37 - 93.4 cc/100 in^2/day
Nitrogen Transmission	1.65 - 7.29 cc-mm/m^2-24hr-atm	4.18 - 18.5 cc-mil/100 in^2-24hr-atm
Carbon Dioxide Transmission	76.0 - 118 cc-mm/m^2-24hr-atm	193 - 300 cc-mil/100 in^2-24hr-atm
Maximum Moisture Content	0.0200 - 0.0800	0.0200 - 0.0800
Linear Mold Shrinkage	0.000600 - 0.0130 cm/cm	0.000600 - 0.0130 in/in
Linear Mold Shrinkage, Transverse	0.00150 - 0.00650 cm/cm	0.00150 - 0.00650 in/in
Melt Flow	0.200 - 92.8 g/10 min	0.200 - 92.8 g/10 min

Mechanical Properties	Metric	English
Hardness, Rockwell R	104 - 118	104 - 118
Hardness, Shore A	63.0 - 87.0	63.0 - 87.0
Hardness, Shore D	34.0 - 87.0	34.0 - 87.0
Ball Indentation Hardness	105 - 190 MPa	15200 - 27600 psi
Tensile Strength, Ultimate	0.160 - 3000 MPa	23.2 - 435000 psi
	5.00 - 42.0 MPa @Temperature 30.0 - 110 °C	725 - 6090 psi @Temperature 86.0 - 230 °F
Film Tensile Strength at Yield, MD	19.0 - 54.0 MPa	2760 - 7830 psi
Film Tensile Strength at Yield, TD	14.0 - 48.0 MPa	2030 - 6960 psi
Tensile Strength, Yield	8.00 - 103 MPa	1160 - 14900 psi
	46.0 - 49.0 MPa @Temperature 30.0 - 110 °C	6670 - 7110 psi @Temperature 86.0 - 230 °F
Film Elongation at Break, MD	2.00 - 4550 %	2.00 - 4550 %
Film Elongation at Break, TD	2.00 - 3980 %	2.00 - 3980 %
Elongation at Break	0.500 - 1400 %	0.500 - 1400 %
	15.0 - 100 % @Temperature 30.0 - 110 °C	15.0 - 100 % @Temperature 86.0 - 230 °F
Elongation at Yield	1.00 - 400 %	1.00 - 400 %
	2.00 - 2.00 % @Temperature 30.0 - 110 °C	2.00 - 2.00 % @Temperature 86.0 - 230 °F
Modulus of Elasticity	0.0500 - 13.8 GPa	7.25 - 2000 ksi
	2.96 - 3.60 GPa @Temperature 30.0 - 110 °C	429 - 522 ksi @Temperature 86.0 - 230 °F
	6.10 - 8.90 GPa @Temperature 70.0 - 70.0 °C	885 - 1290 ksi @Temperature 158 - 158 °F
	6.10 - 8.90 GPa @Time 0.000 - 1.44e+6 sec	885 - 1290 ksi @Time 0.000 - 400 hour

*Figure 52 - PLA Material Properties **[19]***

Appendix L: ABET Outcome 2, Design Factor Considerations

ABET Outcome 2 states "*An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health safety, and welfare, as well as global, cultural, social, environmental, and economic factors.*"

Table 13 - Design Factor Considerations

Design Factor	Page number, or reason not applicable
Public health safety, and welfare	Section 2.4 - page 6
Global	Section 2.1 - page 1
Cultural	N/A - Lawn mowers have no cultural impacts.
Social	N/A – Mower is a consumer product.
Environmental	Section 2.1 – page 1
Economic	Section 9 – page 39
Ethical & Professional	N/A – no ethical or professional factors in a mower.
Reference for Standards	Reference 8 (OSHA pg 6) ,9 (EPA pg 1) ,18 (CPSC pg 6)