Senior Capstone Design

Fall 2023

Green Ellipsis- Splicing of PET Plastic

Final Design Proposal

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Acknowledgments

We'd like to thank our sponsors at Green Ellipsis, Brian Alano and Jane Kang. We greatly appreciate their guidance and knowledge which have helped make this project what is. We recognize and appreciate the trust they have put in us to see this project through.

We'd also like to express our deepest gratitude to our professors Dr. Aceros and Dr. Stagon, whose mentorship and expertise have been instrumental in guiding us through the engineering process. We appreciate how they always made time in their schedules for us and answered any question no matter how small. Without them, we wouldn't be able to push our ideas into reality and strive to bring about the best work imaginable.

Team Value Statement

As members of the Green Ellipsis team, we pledge to work hard, to be respectful to each other, and open to all ideas. We will keep each member of the team accountable to themselves as well as the group. Disagreements between group members won't be taken personally and will be resolved quickly so the work can continue without suffering. We are committed to making sure that we each do our fair share and that no singular member is overburdened. When a team member has hardships outside of the group, the other members will compensate as much as possible to help lessen their load. Above all, our goal is to work as a cohesive team to complete the project and produce a viable solution.

As requested by our sponsor, all design components will use the metric system of measurements. When possible, open-source software and platforms will be used for easy adoption by the community. Our working motto will be to test early and test often to find problems early before they propagate into the design.

We also pledge to follow the credo of the company we are working with, Green Ellipsis. We will put health and safety concerns above all else. We hope to work in a way that supports the environment and community. All processes we use in the design and production of our project will consider environmental impacts and attempt to have a positive impact.

Allison Wolfson	
RYAN HUNTER	
Christopher Zervos	
Jacob Davis	
Printed name	Signature

Executive Summary

Green Ellipsis is a small innovative company working to create a complete process of upcycling PET plastic soda bottles into 3D printer filament that can be adopted and recreated by small community organizations. Currently a fully manual process that creates a viable product has been created and is being used, however this current process is unsustainable due to the minimal amount of filament that is produced from such a labor-intensive undertaking. The goal of this project was to optimize the ratio between the cost of production and the overall value of the end product. For the product to be viable, the filament must have a diameter of 1.75mm and withstand the stress of spooling and 3D printing. The raw material that makes up the filament should continue to be from plastic bottles, without any major additives, and the process should be environmentally friendly. Since the goal is for the process to be recreated by others, it should be reliable, safe, cheap, and simple to reproduce. The budget for this project was $1,000.

The ratio of production cost to selling value could be decreased by either increasing the revenue of the filament produced or by decreasing the cost of labor that goes into production. Initially, ideas were pitched to decrease the labor costs by automating one of the subprocesses of the already created machine. Ideas were developed to automate the cleaning, pultrusion, or spooling process. It was then decided that it would be more useful to focus on increasing the value of the filament through splicing multiple pieces together to form a single 1kg spool. Since the team discovered that splicing was a major problem that has yet to have a solution, it was deemed to be the most beneficial way to increase the cost/value ratio of production.

Eight potential splicing techniques were brainstormed, fleshed out, and designed to attempt to join the end of one filament strand to the next. Methods will be tested on both the ribbon strips and the filament itself in hopes of finding a reliable process. Each method will be performed as many times as is necessary to evaluate the reliability, quality, and commercial viability of the splicing technique.

The next steps of this project are to fully create each designed technique and begin vigorously testing them. Parts and materials have been ordered and experimentation can commence immediately once received. Once the most promising technique has been identified, it will be optimized to make the highest quality splice joint with the smallest amount of effort or time in order to maximize the cost/value ratio of the process.

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Division of Labor

Figure 1 breaks down the division of responsibilities within the Green Ellipsis team. Brian Alano and Jane Kang act as primary industry points of contact for all project related needs. Brian orchestrates progress update meetings and steers the team towards accomplishing the laid out objectives. Meanwhile, Jane plays a pivotal role in procurement, sourcing parts and tools, while also facilitating the transformation of ideas into tangible designs.

Ryan Hunter serves as the team lead, orchestrating meetings within the senior design group and organizing weekly work agendas. Jacob Davis utilizes Autodesk Inventor and Siemens' NX to craft high-quality CAD drawings. Allison Wolfson conducts thorough research and translates conceptual ideas into practical implementations. Christopher Zervos takes the helm in overseeing test builds, spearheading the testing protocols across various scenarios. These roles collectively contribute to the team's cohesive functioning.

Table 1, presented below, outlines the billable hours logged by each team member over the course of the semester, reflecting their individual contributions and engagement. These hours represent only time spent working on the project and do not reflect class sessions or meetings.

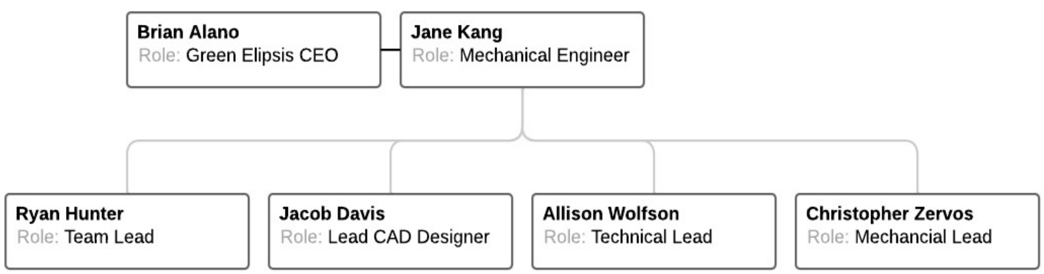

Figure 1: Company Tree

Table 1: Billable hours by person

Week/Person	1	2	3	4	5	6	7	8	9	10	11	12	Total
Ryan Hunter	0	2	4	5	6	3	7	6	26	3	2	10	74
Jacob Davis	0	2	3	5	5	2	3	3	17	3	2	7	52
Allison Wolfson	0	2	4	5	5	3	7	8	23	3	2	9	71
Christopher Zervos	0	2	3	4	5	1	5	5	17	3	2	5	52
Total Hours	0	8	14	19	21	9	22	22	83	12	8	31	249

Background

Green Ellipsis is a company with a dedicated focus on fostering a more sustainable future for all. To advance this mission, they have chosen to concentrate their efforts on recycling two-liter plastic bottles, primarily Pepsi brand, into filament that can be used by a 3D printer for a multitude of projects and can be infinitely recycled. Single use plastics are a growing problem, not just in the US but worldwide. Almost 400 million tons of plastic is produced worldwide each year with more than two thirds of that thrown away into dumps or the ocean [1]. Although plastic recycling is not free, the cost of returning the materials back into the production cycle can in many cases be an economical and environmentally friendly alternative to the cost of disposal [2].

Going from two-liter bottles to usable filament requires multiple sub processes as can be seen in action below in Figure 2. The sub processes required are as follows:

1. Bottle preparation: Before the bottles can be processed, they must first be prepared in several ways. The labels need to be removed, the label adhesive needs to be removed, the plastic needs to be cleaned, and the bottles must be dried.
2. Cutting: After the bottles have been cleaned and prepared, they are cut into 8mm wide strips. A previous UNF senior design team automated this process.
3. Threading/Pultrusion: After being cut into thin strips, one end needs to be fished through an extruder nozzle. This is currently done by hand and can be difficult to do. Once fished through, the strip is heated to reform into the desired shape of a 1.75 mm strand. This strand is pulled through the hot nozzle in a process called pultrusion. The strand is attached to a spool and continues to be pulled until the entire strip obtained from the bottle is formed into the desired filament.
4. Winding/Packaging: The filament is finally unwound from the spool on the machine and packaged in a way that it can be stored before use/sale. This is currently done by hand and must be done for each individual bottle which can bottleneck the process.

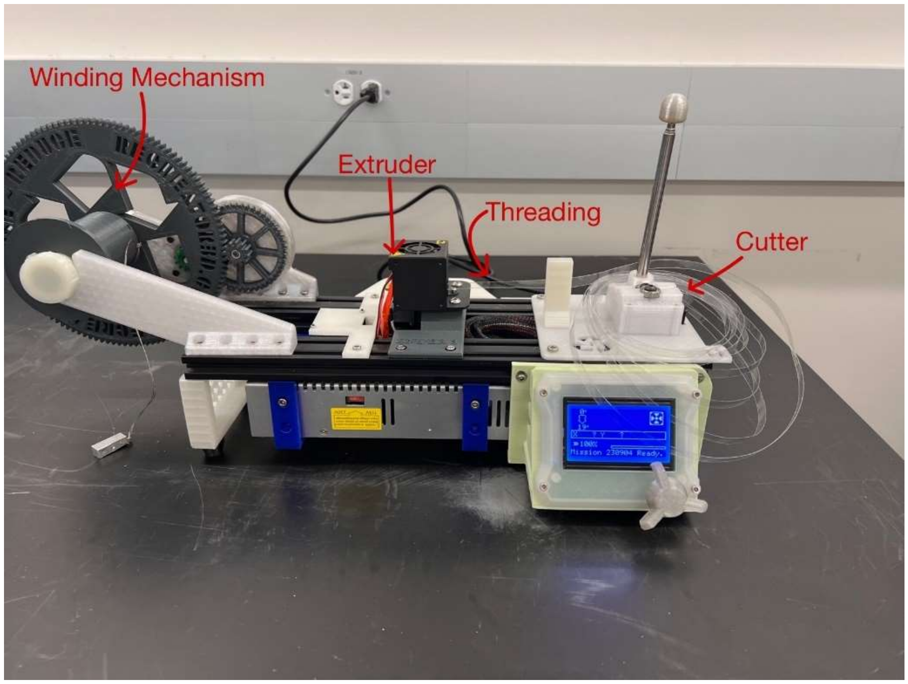

Figure 2: Pultrusion machine taking already cleaned bottles, cuts them and forms them into filament.

Green Ellipsis focuses on utilizing bottles made from polyethylene terephthalate, commonly referred to as PET. PET is a thermoplastic polymer, one of the most common plastics found in various everyday products, from bottles to clothing fibers, and is extensively employed in manufacturing processes. Due to its widespread use, PET production has surpassed a staggering 75 million tons annually [3]. PET two-liter bottles are the primary source of material that Green Ellipsis uses due to their relatively large size and ideal thickness for reforming into filament. Pepsi brand bottles are preferred due to their uniform cylindrical shape when compared to other soda brands. This uniform shape allows for a more consistent filament to be created. These bottles are made from amorphous PET which allows them to be strong and durable yet still pliable. These same properties are desired in a 3D printer filament to provide the highest quality prints. PET plastic does provide some difficulties that make it hard to work with. PET has a glass transition temperature of 70° C and a melting point of 245° C [4]. The glass transition temperature represents the point above which the material can be easily reformed but is not a liquid like if melted. If during the process the material is not thermally quenched quickly enough, about two seconds, the amorphous material will begin to crystallize [4]. The semi-crystalline

PET is much less pliable than the original amorphous form. If the plastic is allowed to crystalize too much, it will become brittle and not survive the spooling or printing process.

Using the recycled PET filament is quite straightforward and may be used on most home 3D printers. The quality of the printed object is directly related to the quality of the filament produced. According to Green Ellipsis, filament that was made from a very uniformly stripped bottle with a consistent pull speed produces a very high-quality product similar to commercially available PET filament. As the quality of the upcycling procedure falls, so does the quality of the produced filament. Although generally easy to use, the upcycled filament does have some requirements for printing that must be followed. The first requirement is that the print must be executed at relatively high extrusion temperature, ideally at 265° C. This temperature often requires an all-metal hot end for the printer which is not included for every model. According to Green Ellipsis, a lower temperature may be used but the printing quality is generally worse. Additionally, an enclosure is preferred so that the material does not cool too quickly during the printing process.

3D printer filament is generally sold in 1kg spools, and this is typically more than enough for a single print. If a switch must be made mid print, however, either because the end of a spool was used or color needs to be swapped out, it can damage or cause inconsistencies in the print. Additionally, if filament swaps occur multiple times during a print, the user must be much more involved with the process which is often inconvenient. In cases where filament swaps would otherwise be needed, one potential solution is filament splicing. Splicing is the joining of two ends of different continuous pieces of filament, commonly through heat-based methods. Most splicing methods that have been developed are for the more common types of printer filament, mainly PLA. There are numerous methods that have been experimented with and used by different hobbyists [5]. Due to the nature of PETs chemical structure these methods aren't as consistently viable as they are with PLA mainly due to the risk of recrystallization.

Project Problem Statement and Description

Polyethylene terephthalate (PET) plastic waste is a major contributor to pollution of the environment [6]. Because of this, many people and companies have been working to create ways to manage this waste by reusing and recycling. Green Ellipsis processes two-liter PET plastic bottles and upcycles them into usable filament for 3D printing. The company currently has a manual process that creates a viable end product but is not economically feasible due to the labor-intensive nature of the operation and the minimal amount of filament that is produced from each bottle. The goal that Green Ellipsis has for the future of this endeavor is to reduce the cost of producing the filament (primarily labor) so that the filament can be sold for a profit or at least cover the cost of producing it as much as possible. After optimizing the process, Green Ellipsis plans to either sell kits with the required components for individuals to replicate it or offer free plans to achieve the same goal. The hope is that the process developed will be used by community level groups that have interest in environmental work, 3D printing, or both. Because the raw material (two-liter bottles) will generally be acquired at no cost through donation and recycling collection, the only cost to these groups would be buying/building the process and whatever running costs it takes to make the filament.

The problem faced by Green Ellipsis is that the current cost of producing the filament compared to what it can sell for is too high. It is expected of this group to find solutions to improve that cost/value ratio to make the process economically feasible. Currently, the filament is produced one bottle at a time which produces discrete, 10m long, 20g strands of filament as seen in Figure 3. Generally, it is desirable to have a single longer strand of filament for ease of use while 3D printing. Due to the short length of the filament currently produced, the sale value of the product is low. Green Ellipsis has indicated that one of the best ways to increase the value is by splicing multiple strands of filament together into 1kg or half kg spools.

Figure 3: Current produced end product, from bottle to strips to filament

There is currently no known process for reliably splicing strands of PET filament in a way that maintains the desired mechanical properties for 3D printing. Creating such a process would increase the value of the filament and increase the viability of selling the product. The main hurdle that must be overcome when splicing PET filament is avoiding the brittleness that comes from recrystallization. If the material is brought above the glass transition temperature, as is common in many traditional splicing methods, it must be quickly cooled in order to maintain its amorphous form. The filament also needs to stay a consistent diameter of 1.75 mm so as not to cause any inconsistencies when running through the 3D printer. Attempts by others to find methods to splice this filament have had mixed results. Some solutions have been found but have been unreliable and difficult to repeat with any level of accuracy. The objective of splicing would be to explore and identify a simple, repeatable method for connecting plastic from one bottle to the next, aiming to create a continuous spool of filament that can be effectively utilized by a 3D printer. This would involve chemical, thermal, and mechanical experimentation as part of the efforts to seek a solution to the problem.

Requirements and constraints:

Each of the following design requirements and constraints were imposed by Green Ellipsis and are needed for the final process to be viable. The constraints are strict limitations to be followed to create a final product. The goal of this project is to produce an open-source solution and implement it into community-based buildings. Because of this, it needs to be safe and usable by an average person with minimal or no training. Safety is the number one constraint; whatever process is created should not pose any harm to the user. Because the goal is to make a widely appealing product, the filament produced must work in an average 3D printer. The standard filament size of 1.75 mm is most used and is the target size for production by this process. The filament must consistently hold up against the stress of being wrapped around a spool and being used in a 3D printer. A break or jam of the filament will prevent the printer from functioning correctly and consistent problems like these are a sign of a poor product. Finally, any power requirements the design needs must come from a standard U.S. outlet, being 120V AC.

Design Requirements:

- Process should use all portions of the plastic bottle with minimal waste or byproducts.
- The filament should be cheaper to produce than the cost it can sell for, the current cost to produce is $109 including labor.
- The filament should be continuous up to 1kg spools.
- The raw materials should be sourced from used plastic bottles.
- The filament should not consistently clog or outgas the 3D printer. Should at least get through five prints without clogging or outgassing.
- All design components should use the metric system of measurements.
- Any changes to the process should be low cost to build so the average consumer can afford to repeat it, ideally less than $100.
- Any changes to the process should improve the cost/revenue ratio of the filament.
- The process should be environmentally friendly with a net positive impact.
- The project budget should stay under $1000.

Design Constraints:

- The process must be safe and usable by an average person.
- The filament must be of desirable properties to use on any standard 3D printer: 1.75mm diameter +/- 0.1mm.
- The Filament must withstand the stress of spooling and 3D printing. Bending stress is the greatest risk. Must withstand 45° bend with radius of 5mm.
- The filament must not break or become jammed during the pultrusion process 90% of the time.
- Any power requirements must be available from a standard outlet: 120V.

Design Alternatives and Decision-Making Process:

Many potential opportunities for improvement were identified to solve the problem laid out by Green Ellipsis. The final concepts considered to increase the cost/revenue ratio were as followed:

- Automation of the cleaning process
- Automation of the pultrusion process
- Automation of the winding and packaging process
- Creation and automation of a coloring method
- Creation of a reliable splicing method

Each of these concepts were discussed and explored. Potential ideas and solutions were created for each. A down selection process in the form of a Pugh chart was used to determine which process was best suited for the goals of this project. The following section provides detailed descriptions of process improvement ideas and their components.

Automation of the Cleaning Process

The concept that received the most consideration from the sponsor, Green Ellipsis, was the automation of the cleaning process due to its significant time consumption and operational challenges. The heat shrunk labels of the bottles must be removed, then the leftover glue and remaining pieces of the label must be gently scraped or scrubbed off. This is currently done by a dull blade and an abrasive sponge dipped in D-limonene. D-limonene is a natural cleaner derived from citrus fruits and acts as a solvent for the glue. The inside of the bottles must also be cleaned to ensure there are no contaminants in the filament once formed.

Illustrated below in Figure 4 is a potential design for automating the cleaning process. This proposed design drew inspiration from the principles of a car wash. In this envisioned setup, warm water was introduced into a lower reservoir located beneath a spinning contraption upon which the bottle was secured. The table the bottle sat on was spun by a slowly revolving motor. D-limonene was added and mixed into the warm water. This mixture was delivered through a nozzle equipped with an abrasive cloth that moved vertically, meticulously cleaning the spinning bottle.

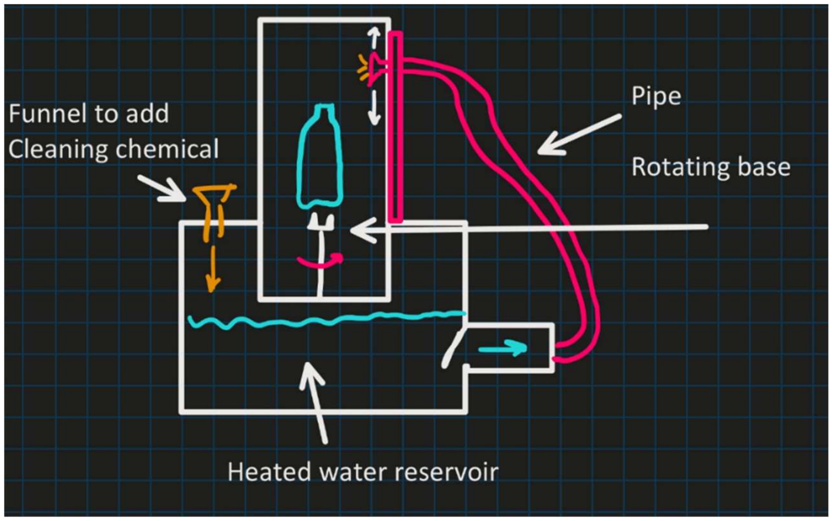

Figure 4: Potential design sketch for automation of the cleaning process

Automation of the Pultrusion Process:

The pultrusion process can be difficult to get started. The user must fish a thin piece of the ribbon into the hot nozzle using pliers before pultrusion can begin. The current process, which is done by hand, is prone to unreliability and often requires multiple attempts to achieve proper alignment. A proposed concept that the sponsor presented was to cut the hot end nozzle in half and have it close around the initial strip cut from the bottle. Once the hot end was closed around the strip, an automatic locking mechanism would activate and the pultrusion process would begin. There is already a program implemented in the machine to track the temperature, so once the temperature reached steady state, rollers would be used to propel the strip forward through the nozzle. A sketch of this proposed process can be seen below in Figure 5.

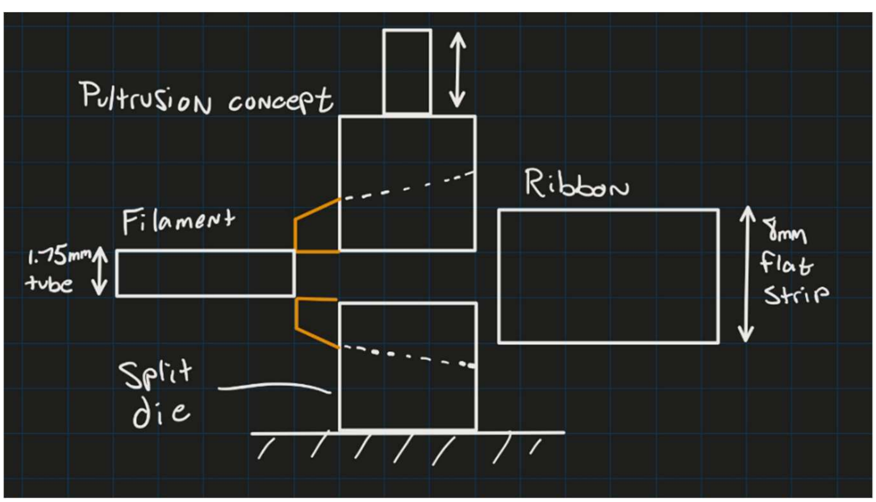

Figure 5: Potential design sketch for automation of the pultrusion process

Automation of the Winding and Packaging Process:

In the current process, the filament is wound onto a spool at the end of the upcycle machine. This spool is powered by a stepper motor controlled by the same interface as the pultrusion hot end. The filament is tightly wound during the process of its creation but must be undone and cleared off by hand after each bottle is processed. Automating this procedure would save time and allow more bottles to be processed consecutively with less down time. Figure 6 below shows a sketch of a proposed concept for the automation of this process. This concept involves double-sided spools that automatically flip using a sensor-controlled motor once a bottle has been fully processed into filament, enabling a seamless transition to the next round of filament production.

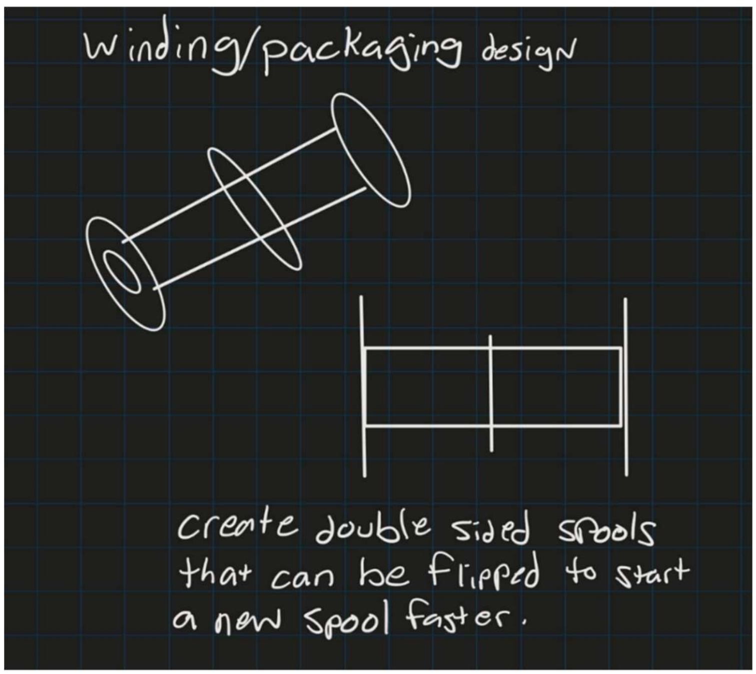

Figure 6: Potential design sketch for automation of the winding/packaging process

Creation and Automation of a Coloring Method:

Single use PET bottles are typically clear; this means any filament made from the upcycling of the bottles will also be clear. Clear filament means a semitransparent, colorless result out of the 3D printer which is not always desired. One way to increase the sale price of the produced filament would be to diversify the product by adding color to it. This proposal would be an additional process that could be implemented and automated with the existing machine. The initial design concept was to implement a device consisting of two piston-like ink reservoirs immediately after the pultrusion hot end. These pistons would continuously stamp down on both sides of the filament, dyeing it with a selected color just as it is created. A sketch of this proposed idea can be seen below in Figure 7.

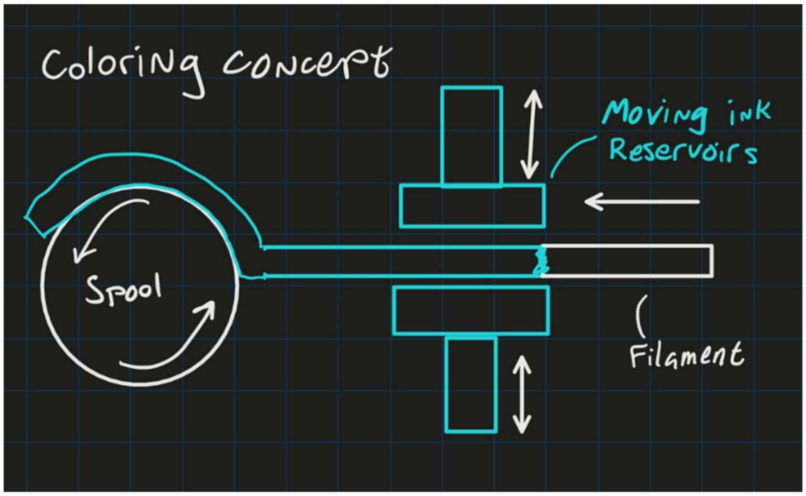

Figure 7: Potential design sketch for automation of the coloring process

Creation of a Reliable Splicing Method:

Each standard two-liter PET bottle creates approximately 20 grams of usable filament. Typically, 3D printer filament is sold in either 1kg or half kg spools. It is difficult to sell or use such a small amount of product because a single print may require multiple 20g strands. The sponsor suggested that a great way to improve the marketability of the filament would be finding a way to splice multiple strands of filament into a single continuous 1kg spool. PET filament is notoriously difficult to splice together. Currently, the only agreed upon method by hobbyists is to use a $700 machine known as the Palette 2 Pro [7] which can be seen below in Figure 8. Even this professional method of filament splicing can be unreliable for PET due to the plastics tendency to crystalize. If splicing was to be the selected method for improving the overall process, multiple methods would need to be explored and tested experimentally to find a viable solution. If a reliable method of splicing was found, optimizing it and ideally automating it would be the stretch goal.

Figure 8: Palette 2 Pro [7]

Down Selection of Process Alternatives:

A Pugh chart was created to determine which design alternative would yield the greatest benefit for the main process. Eight criteria were selected and weighted on a scale from one to five, with one indicating the least importance and five indicating the most importance. This Pugh chart can be seen below in Table 2.

Table 2: Pugh Matrix and results for process down selection

Pugh Matrix							
Critical Quality	*Weight 1-5*	Cleaning/ Prep	Pultrusion	Winding/ Packaging	Coloring	Splicing	
Difficulty	1	1	-1	0	1	-1	
Team Knowledge	2	0	1	1	-1	-1	
Time Saved	3	1	0	1	0	0	
Sponsor Preference	4	1	0	-1	-1	1	
Benefit	5	0	-1	0	0	1	
Maintenance	2	-1	1	0	-1	1	
Cost to Reproduce	2	0	-1	0	1	0	
Safety	3	0	1	1	1	0	

Summary Table						
Total "1s"	3	3	3	3	3	
Total "0s"	4	2	4	2	3	
Total "-1s"	1	3	1	3	2	
Total Weighted Score	6	-1	4	-2	8	

The difficulty criterion was based on how difficult the team perceived it would be to move forward with a given concept. This matched with the next criterion of the team's prior knowledge on the individual topic. These were both given lower rankings since the team could conduct research and learn about each topic, minimizing the impact these criteria have on the final product. The time saved criteria are a measure for how much time the proposed idea would reduce the filament creation process by. This criterion was given a moderate weight since the main goal of the project is to lower cost/revenue ratio and time saved is labor saved. The sponsor's preference received a high ranking because the group aimed to enhance what the sponsor had identified as the most important. The benefit criterion was given the highest weight. This criterion measures the positive impact a given concept would provide the process based on the group's experience and research. Both maintenance and cost to reproduce were given equal weight, as it's moderately important for the chosen process to be replicable by hobbyists and communities. Finally, safety was included as a measure of how safe it would be both for the team to expand upon and for someone else to be able to use.

Final Concept Selection

The down selection process yielded that the creation of a reliable splicing method for the filament would be the most beneficial concept to move forward on. For this process, a single concept could not be picked since it would be based on experimentation and the testing of different methods to find something consistent and viable. The following pages of this review will discuss the different methods the team will attempt and how these methods will be tested.

Design Calculations and Testing Criteria

Multiple of the splicing methods described below, in the proposed solutions portion of the report, use heat as a method of splicing the two ends together. Because it is common to many of the methods, it is useful to calculate the energy required for the splice to occur. For this calculation, it was assumed that the PET was a cylinder 10mm long and 1.75mm of constant density. The total heat energy transfer required was calculated using equation 1 below.

$$\text{Total Energy Transfer} = m*c*\Delta T \tag{1}$$

Where:

m is mass

c is the specific heat of the material

ΔT is the temperature differential.

The temperature change used for this equation was the glass transition temperature of PET. This varied between different samples of PET, so two calculations were performed to get the most conservative and least conservative heat transfer values [8][9]. Running through these calculations yielded a maximum value of 16.524J and a minimum value of 6.14J. The hand calculations made supporting this value can be seen in the Appendix A.

Before presenting the proposed splicing methods to examine, it is important to discuss how the various solutions will be evaluated against each other. Each proposed method will be performed until either 15 successful joints have been created or until 30 attempts have been made. The number of successful joints will be compared to the number of total attempts to determine how reliable that method of joinery is. If success in joining the filament is achieved, then each of the 15 joints will be evaluated for strength, flexibility, shape, and printability. A 99% success rate is required for commercial success but since time is a major limiting factor, these testing criteria will be evaluated to achieve a 90% success rate instead. This will mitigate both type I and II errors, considering the potential for human error [10]. Since the production material, PET bottles, are so cheap to acquire, the only constraint for testing the methods is time.

Tensile Testing

The first criteria that will be evaluated is the tensile strength of the filament joint. Whether it was joined before or after reforming, the joint must withstand the tension requirements of 30N, according to internal testing done by the sponsor. A testing apparatus has been designed and can be seen below in Figure 9, with the full drawing placed in appendix C. This apparatus holds one side of the filament joint fixed while the other is connected to a small bucket that hangs free. The bucket has weights added incrementally until the joint snaps. The bucket is then weighed to determine the force it took to snap the joint due to tension. The more force the joint can withstand, the more likely it is to survive the requirements of the 3D printer and not break before it can be used.

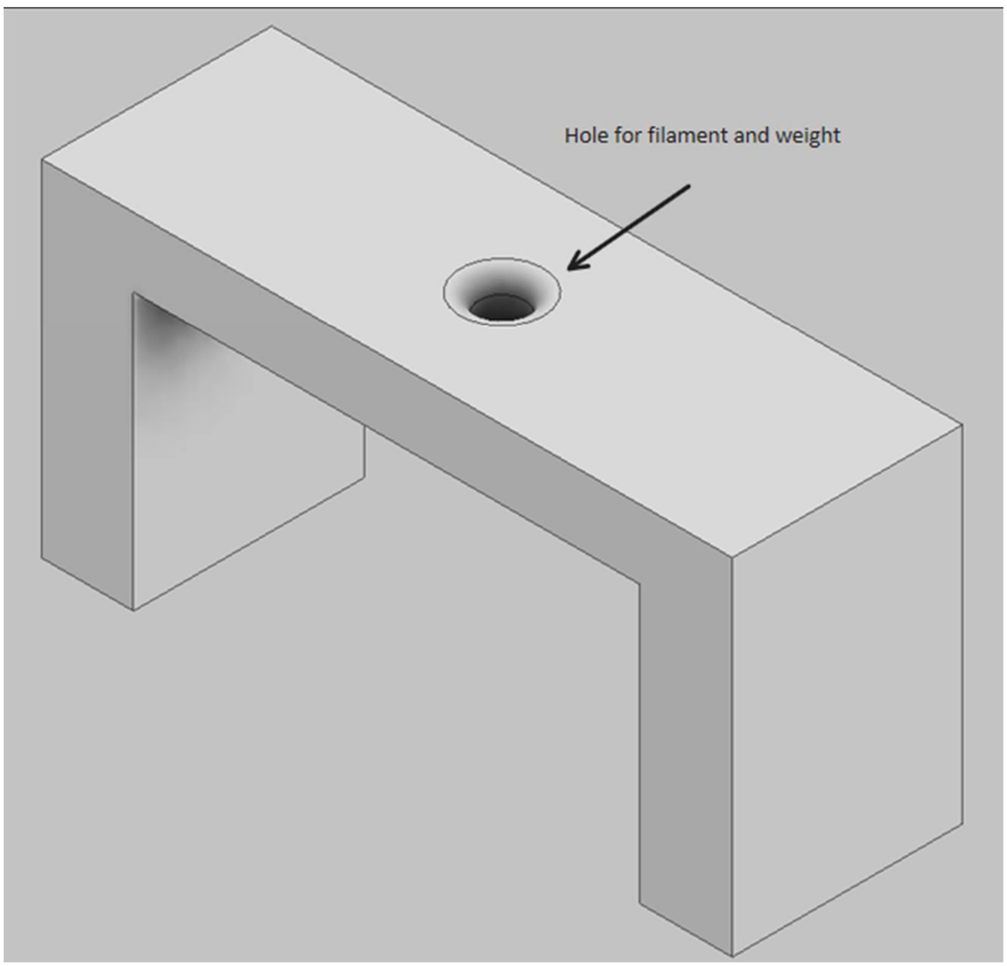

Figure 9: Filament tensile test jig

Angle Testing

The second criterion that the filament will be graded on is the flexibility of the joint. Because the methods that heat the plastic could turn the joint brittle, it is important to test the joint's bending strength so that it does not snap while spooled or while going through the 3D printer. The proposed design for a bend testing jig can be seen below in Figure 10. This test is designed to bend the filament to a 45º angle at a radius of three times its diameter. The diameter of the filament is 1.75 mm, so the radius of the bend is 5.25 mm. This angle and radius combination is a common requirement for filament to withstand the spooling and 3D printing process according to the project sponsor. The filament joint will be graded by the number of these bends it can withstand before failing.

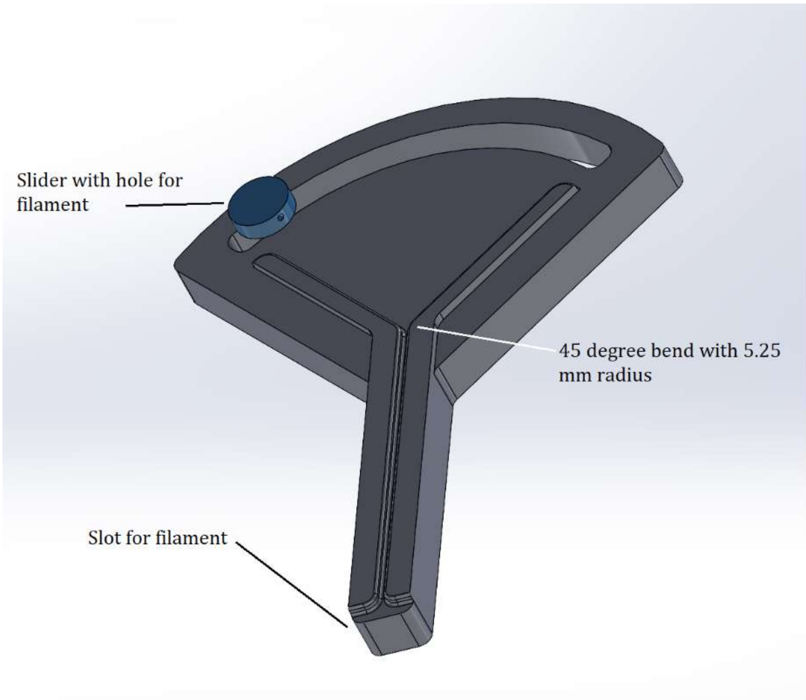

Figure 10: Filament bending test jig

The filament joint must be of a constant diameter identical to the rest of the filament. An increase or decrease in diameter can cause the 3D print to be inconsistent or worse, the printer could clog. The diameter of the filament joint will be measured with calipers and error will be calculated from the actual diameter and the ideal diameter as seen in Equation 2. The lower this error value, the better the joint will be graded on its shape.

$$\text{Percent Diametral Error} = \frac{|D_{actual} - D_{ideal}|}{D_{ideal}} = \frac{|D_{actual} - 1.75mm|}{1.75mm}$$

(2)

Another shape factor that needs to be addressed is the angle of the joint. A perfect joint will have 180º between the two sides. If a joint is spliced at an angle, it is more likely to break and could fail to fit through the extruder or bowden tube on a 3D printer. The angle for each joint will be measured and the error percentage will be calculated using Equation 3 below.

$$\text{Percent Angle Error} = \frac{|\theta_{actual} - \theta_{ideal}|}{\theta_{ideal}} = \frac{|\theta_{actual} - 180º|}{180º}$$

(3)

The two error values described above will be combined to grade the overall shape of the splice joint. This overall shape grade will be used to compare the shapes of each produced joint to that of the ideal seamless joint.

Printing/Clog Testing

The final test of the filament joints is to evaluate the quality of the 3D prints of those connections. It needs to be verified that the splice will run through the printer without breaking or clogging the hot end. To test this ability, a sample print guide was created and can be viewed below in figure 11. The sample print consumes 20cm of filament which is equivalent to 1g. To test specifically how the joints print, the 20cm of filament consumed will have four splices along it, much more than the standard one joint every 10 meters. A higher frequency of splice joints facilitates quicker testing of the joints and simplifies the detection of any printing flaws. The test print will be completed five times for each splicing method to ensure the splice does not break or clog while printing.

The sample print design contains two objects that will print successively. The first object is a series of lines one layer thick that surrounds the other component. This is commonly called a "skirt" and is often used to prime the filament through the hot end nozzle to prepare for the print itself. In addition to priming the nozzle with filament, here it is used as a control to make sure the unspliced filament prints evenly and adheres to the print bed. The second object to print is a hollow cylinder 20mm in diameter and 30mm tall. After completion the cylinder will be inspected for defects such as poor bed adherence, over/under extrusion, or other visual imperfections that could result from a poorly spliced section of filament.

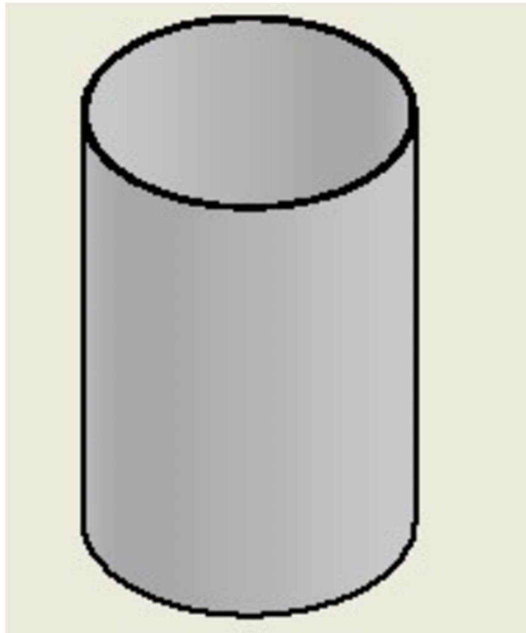

Figure 11: Test print model for 20mm diameter cylinder

After all proposed solutions have been completed and assessed, a new decision matrix will be created using the experimental data found during these evaluations. This decision matrix will guide the project towards the most viable solution which will then be optimized. Once this solution path is apparent, the method will be refined and ideally an automated or semi-automated process based on this solution will be created.

Proposed Solutions

Multiple attempts by others have been made to solve this splicing problem with no reliable answer found [11]. The aim of this project is to first find a reliable method to splice the PET filament together then to optimize that process either through partial or complete automation. As many possible solutions may exist, the decision was made to design and complete a series of experiments to test the effectiveness of many methods. The attempted solutions can be broadly categorized into two groups: ribbon methods and filament methods. The primary distinction between these categories is that the former aims to join the strands before reforming them into filament, whereas the latter does the joining after the reforming process.

Ribbon Connection Methods

The first group of solutions is a series of attempts to connect the ends of two PET ribbons together. A simple diagram of this can be seen below in Figure 12. In the current process, these ribbons are created during the middle stages of production. The bottles would still need to be prepped and cut into ribbon before this connection could occur. The connection could take many forms, but they would all be connected before going through the hot end to be reformed into filament. These methods rely on the fact that before reforming, there will be very little stress on the joint, so only a minimal connection is required to keep them together. The ribbon itself is never under much tension during the process. After going through the hot end, the filament must continue to pull the ribbon through the hot end which can require upwards of 30 Newtons of force according to Green Ellipsis. The idea is that after going through the hot end, whichever joint method that held the ribbons together will be strengthened and will withstand the stresses of spooling and printing that are required. If a method of joining ribbons together proves successful, large spools of connected ribbon could be set up and turned into a continuous filament all in one go with limited human interaction.

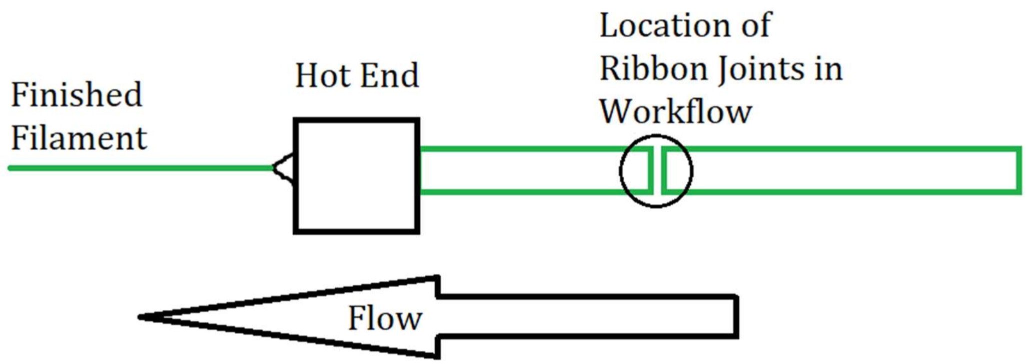

Figure 12: Diagram of a generic ribbon joint before going through the hot end

Zip Tie Method

One proposed ribbon connection has been nicknamed the 'zip tie' approach. This method cuts a specific geometry into the end of one ribbon and the start of the next so that they fit together. This mechanical connection can take many shapes, but the leading design can be seen below in Figure 13. This design weaves the arrow portion of the second ribbon through the slits cut into the first. The tip of the arrow will rest in the foremost slit and provide mechanical strength so that the two pieces do not slip apart. The “tail” of the first ribbon is also tapered to tuck into the slits cut in the second ribbon.

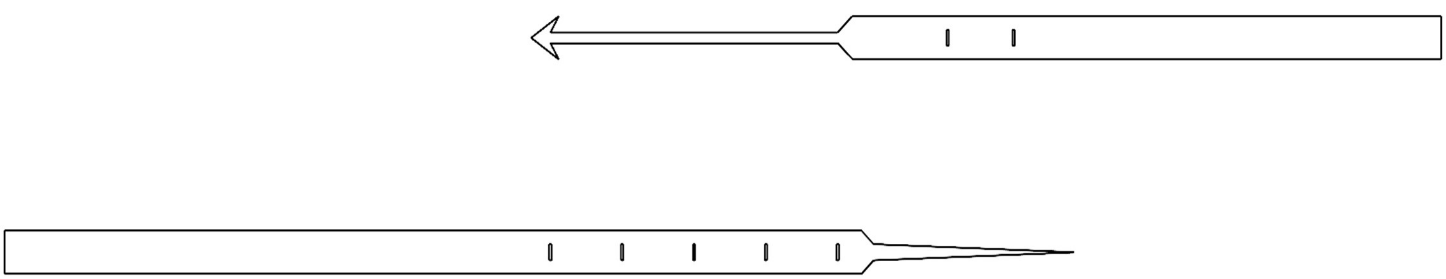

Figure 13: Zip tie method cut example

This method of joinery between the two ribbons holds a lot of promise. The long, thin portion of the second ribbon should provide a large amount of contact area on the first once sent through the hot end. This contact area, once formed, should hold the two newly formed pieces of filament together.

The zip tie method does have several drawbacks. Both pieces of ribbon have several important, precise cuts required to work together to form the connection. Cutting these shapes by hand would be tedious at best and possibly dangerous. The goal with this joinery method would be to test its effectiveness and if it works, create a device to make these cuts automatically.

Perforation Method

A second proposed method of connecting two ribbons together is to perforate them into each other. This method overlaps two ends of ribbon and punctures uniform holes through both ribbons. The punches through the plastic ribbons will temporarily hold them together until it can be sent through the hot end. Different shapes of perforations will be tested but a device like that seen in Figure 14 below is to be used to create the perforations. A close up of one of the potential wheels to be used can be seen below in figure 15. The tool shown in this figure is not equipped for it, but a heated version of the perforation method is also to be tested using a metal wheel that has been heated up above PET's glass transition temperature.

Figure 14: Example of perforation tool

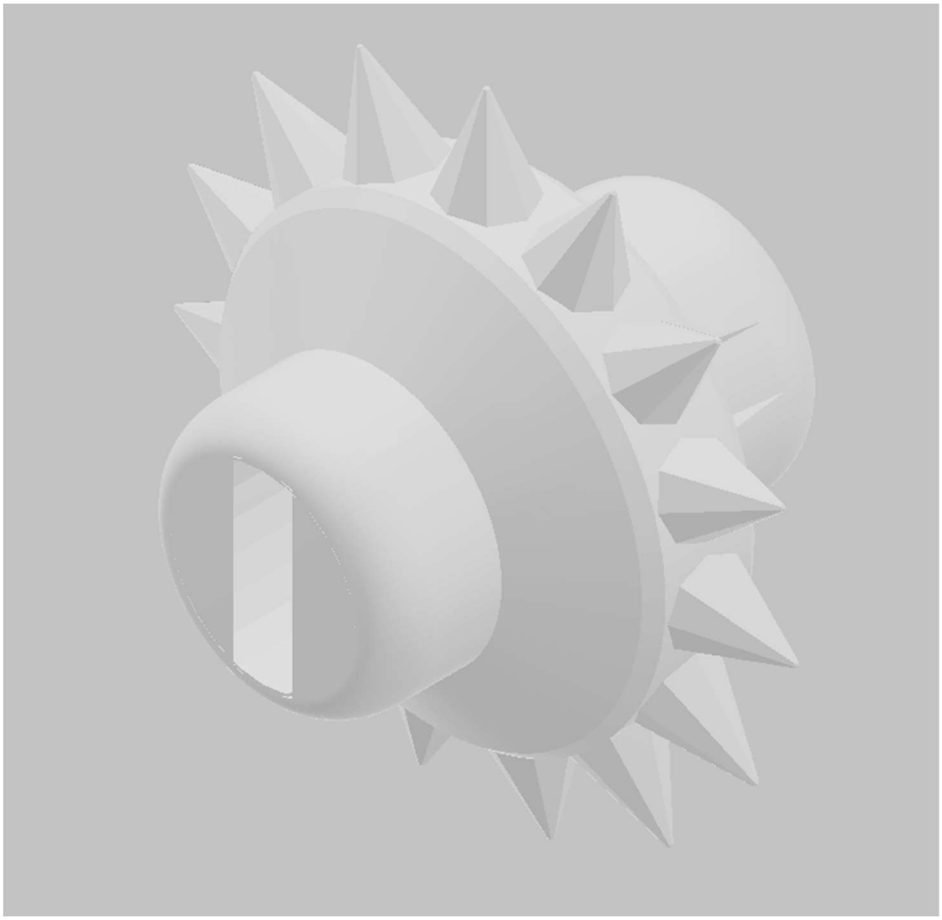

Figure 15: Spiked Wheel of the Perforation Tool zoomed in [12]

The advantage of this connection type is that it is very easy to create and requires a minimal amount of time to use. This type of tool can be very versatile because the perforating wheel is easy to replace with either a new sharper wheel or one of a different shape. Different shaped wheels create different shaped perforations, and each can be tested for strength and effectiveness.

The disadvantage to this type of connection is that it may be weak or fragile. Preliminary tests have proven that the connection is possible but does not hold up to very much stress on the joint. Luckily, as previously stated, the ribbon methods of connection are never under much tension during the reforming process. Once the two overlapping ribbons go through the hot end and are turned into filament, the strength of the joint should increase.

Filament Connection Methods

The second group of possible solutions attempts to join two ends of already formed filaments together. This could happen in a multitude of ways, but all would follow the same workflow in terms of the filament creation process. The bottles would be processed into filament exactly as the process currently does but would be attached end to end after reforming. Many other types of 3D printer filament such as PLA or ABS are spliced this way but as discussed above, the high melting point and risk of crystallization prevents these methods from working well on PET. Some preliminary success has been seen by others attempting these types of connections with PET, but none so far have proved to be a repeatable or reliable method.

Nichrome Filament Welder

The first filament connection method to be tested uses nichrome wire to weld the filament. The proposed welder will be created using a 3D printed outer shell, a battery box, nichrome wire, a limit switch, a clothespin, and aluminum foil. The 3D printed outer shell is designed to facilitate sliding, allowing the current to flow through the nichrome wire when in position. The nichrome wire conducts electricity, heating the material to a stable high temperature. The activation of the nichrome wire is controlled by the limit switch, which detects the connection of the screw to the nichrome for current conduction. Moving the block outward disengages the heating element, and a clothespin with a 1.75 mm hole, wrapped in aluminum foil, is used to rapidly cool the filaments.

As illustrated in Figure 16, the filament welding test involves two different filament color combinations: one with clear and green filaments, and another with clear filaments. These color differences will help determine what the splice looks like after joining. Once the filament is joined, it will go through the process again to assure the splice was created. Once this is complete, the material will be cut to have a smooth outer surface and a diameter of 1.75 mm. The joined filament that was created from the process being the green-to-clear mixture and the clear-to-clear mixture will be tested to see if the different colored materials influence the strength or brittleness of the joint.

This method has several advantages, including the ability to quickly splice the materials together and have them ready to use for printing. This method also uses relatively inexpensive materials that are readily available to order and use, which is one of Green Ellipsis' goals of open sourcing its products. This method does have some disadvantages, the battery box is separate from the main unit so it could easily become detached, and the wires would have to be attached again. Additionally, nichrome wire can become rapidly hot and burn someone who is not paying close enough attention.

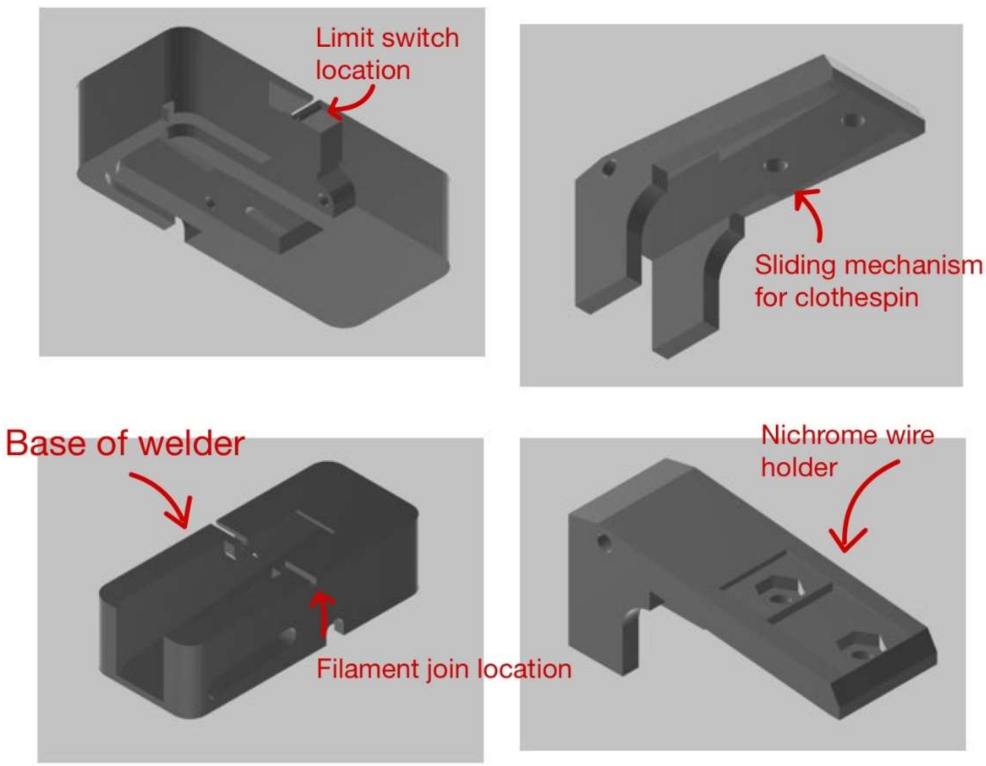

Figure 16: Nichrome Filament Welder [13]

For this heating method a PID temperature controller, along with a steady state relay and PLC controller could be used to better monitor and limit the heat transferring to the filament. A PLC could be easily programmed with on/off ladder logic to keep the heat at a consistent temperature. Figure 17 shows a sample wiring diagram that would be used for this setup and Figure 18 shows the ladder logic code for the PLC.

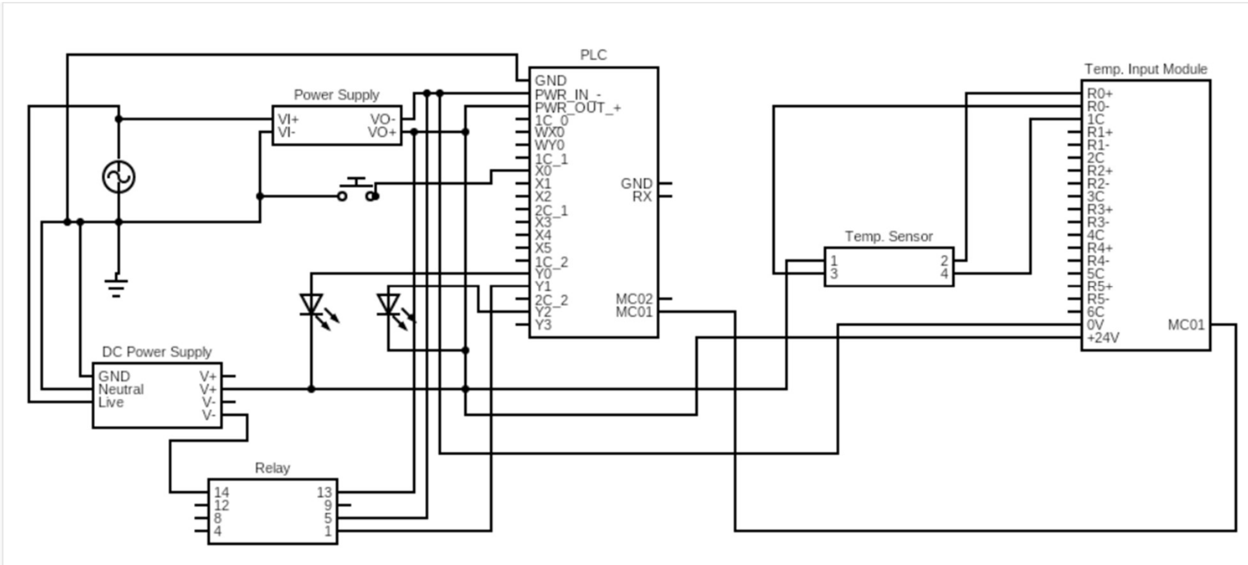

Figure 17: Wiring diagram for temperature controlling.

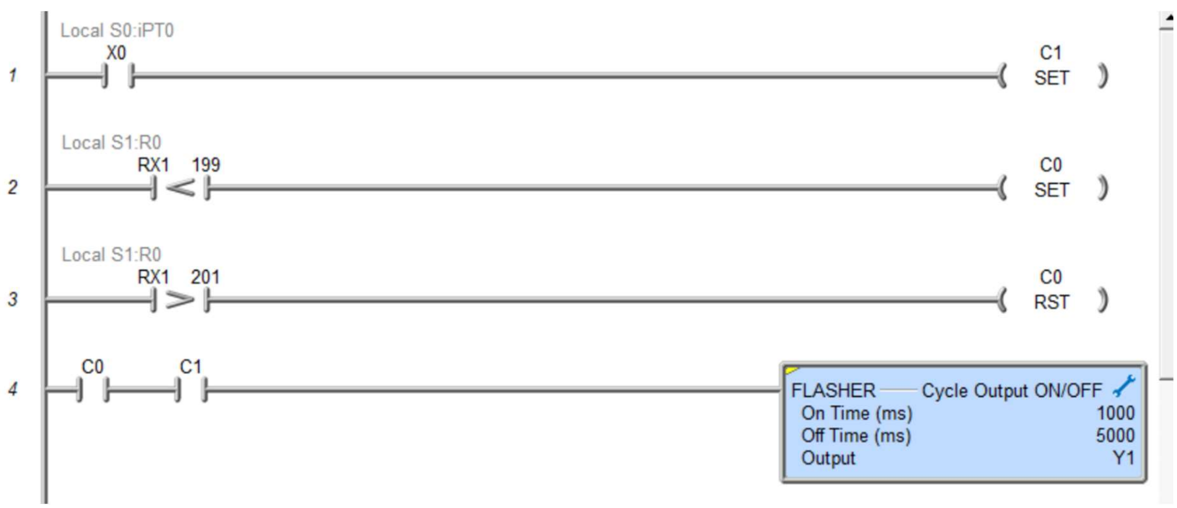

Figure 18: Sample Ladder logic code for the PLC

Soldering Iron

The Soldering Iron test will include two main parts, the soldering iron and the 3D printed block in Figure 19. The 3D printed block allows for the 1.75 mm filament to smoothly enter and exit the block. The block contains a notch to allow for the soldering iron to be placed in between to allow for the two to be melted together. Once the two filaments are together, they are pushed to the left side of the block and pushed back and forth to smooth and join the two together. The material is then removed from the 3D block and smoothed using cutting tools to have a smooth finish.

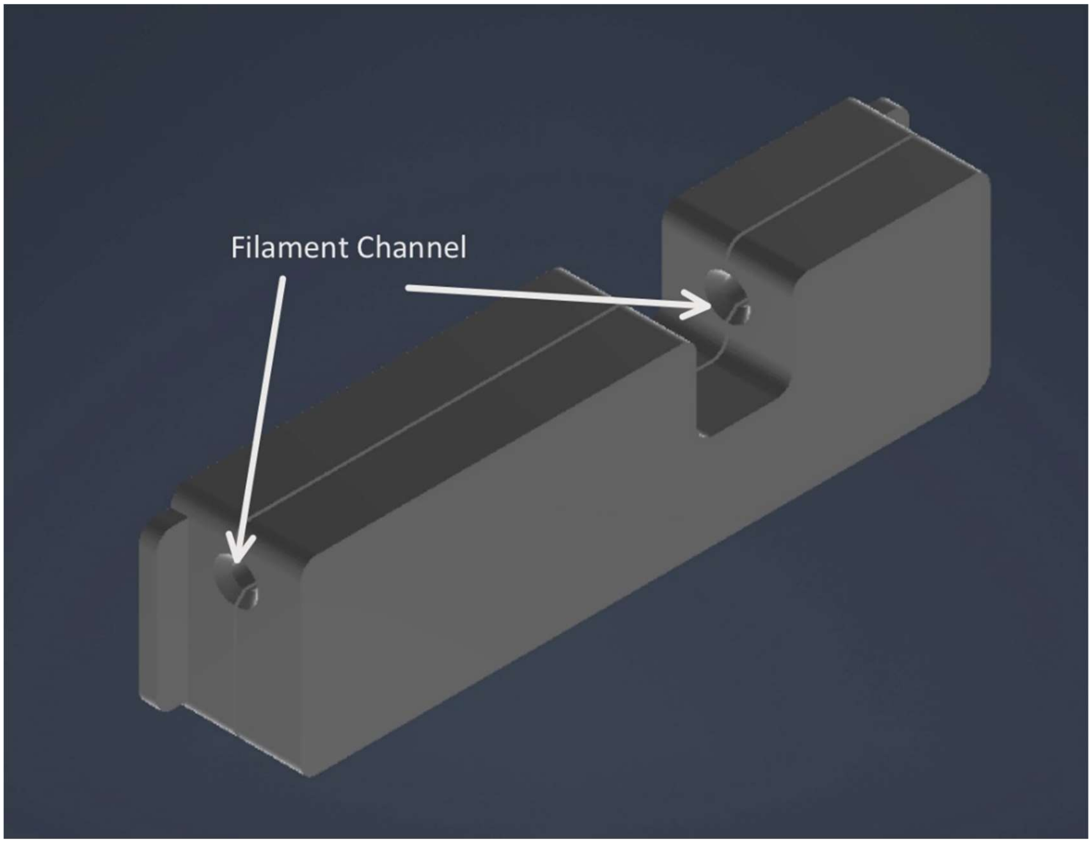

Figure 19: Soldering Jig to Hold Filament in Place

To better improve the described soldering method, some hobbyist forums suggest using food grade silicone tubing as a heat sink and guide for the filament to heat up in [14]. As seen in Figure 19 the two pieces of filament slide snuggly into the tubing and are further held by a small aluminum band to better distribute heat. Silicone can withstand higher temperatures than PET and, even when reaching an elevated temperature, only degrades instead of melting, this makes it an excellent joiner for the filament. As the soldering iron is pushed against the aluminum piece its heat is distributed through the silicone tubing, which then evenly distributes the heat across the filaments' points of contact. This melts the filament together just enough without causing burning. After removing the soldering iron, the splice point will be quickly cooled by either a rag wetted with cool water or a high-powered fan. The silicone tubing can then be cut off or slid off and the filament should be joined together. Silicone tubing is very easy and cheap to acquire. Since the material is food grade, there should be no safety concerns in exposing it to heat. Due to the even distribution of heat and the rapid cooling, the PET should remain relatively strong and not recrystallize.

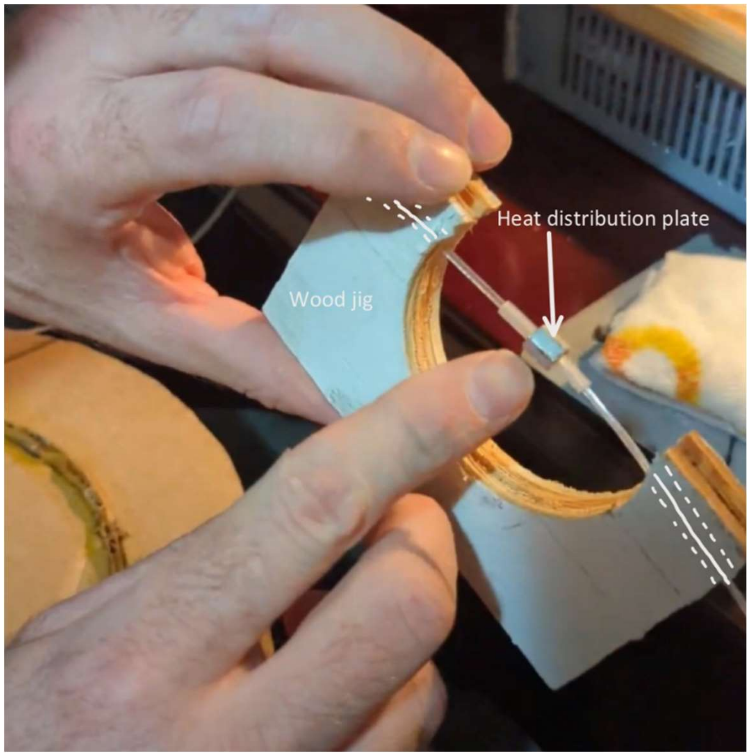

Figure 20: Set up for silicone soldering.

Friction Welding 1

A different filament joining method under examination involves friction welding. In this approach, one end of a small piece of filament is rapidly spun against the stationary ends of two strands held end to end by a jig. As illustrated in Figure 21, a rotary tool will have a small segment of pre-made filament placed inside the chuck which will then be spun at a high speed, upward of 5000 rpm. The two ends of filament will then be clamped into place within a jig to keep them square to one another. The spinning filament will then be pushed into the seam of the two filaments to be joined and the friction will generate heat and mechanically mix the material together. This process must be done multiple times as the filament needs to be rotated and clamped back in to reach other areas.

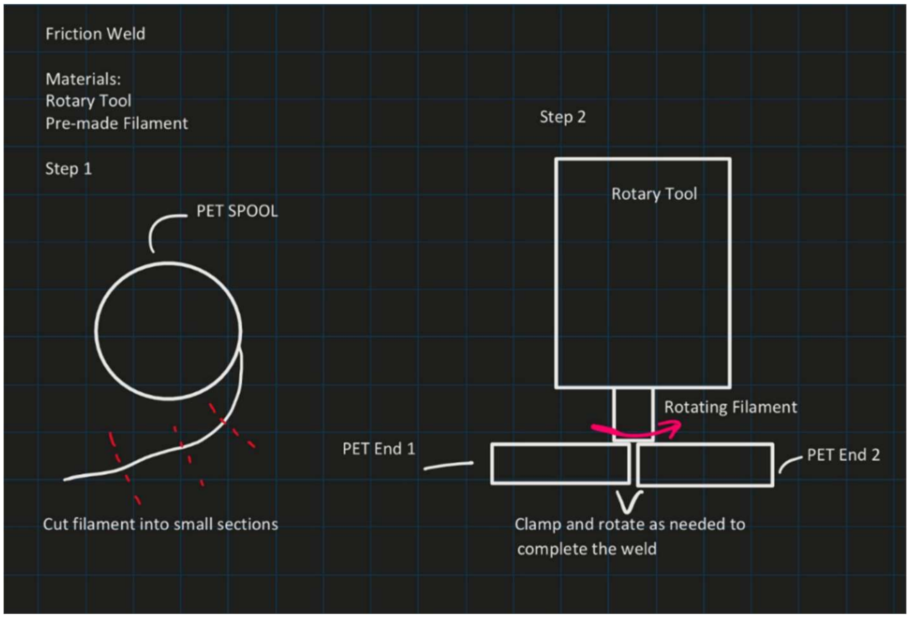

Figure 21: Friction Weld Clamp Method

This method for joining the filament could be advantageous because it has no need for external heating sources. Additionally, the only material needed besides the jig is a rotary tool which is very common and relatively inexpensive.

The main disadvantage of this method is needing to cut small, straight pieces of filament to fit into the chuck and getting consistent diameter. This can be cut or sanded down to mitigate the inconsistent diameter and the strength of the joint may make up for this downfall.

Filament Welding 2

In addition to the friction welding method described above, a second type of friction welding will be used in an attempt to fuse two ends of filament together. This method of friction welding will also spin one side of a filament strand very quickly (around 5000rpm) while in the chuck of a rotary tool. The other end of that piece of filament will be inserted into a bowden tube. This tube is made of heat resistant thermoplastic called PTFE that has very low friction. The tip of the rotating filament will be pressed against the stationary end of a second filament piece that is also clamped inside the bowden tube. The friction of the two pieces of filament as they rub together generates heat and promotes the joining of the two ends. The primary distinction between the two friction welding methods lies in their approach. In method one, two strands of filament remain stationary while a small third piece is used to weld them together. In method two, one side of the splice joint rotates rapidly in relation to the other, and it's this relative motion that generates the friction, facilitating the joint. The bowden tube has very tight tolerances and should prevent the joint from bulging or bending out of shape. If necessary, the joint can be cleaned up with a razor blade to the desired diameter.

This method has recently shown a lot of promise and has reportedly produced good results by both hobbyists and members of Green Ellipsis. An image of this method in use can be seen below in Figure 22. In this image, the white bowden tube can be seen sticking out of the piece of wood. The rotating filament is sticking out the top of the bowden tube and into the rotary tool. The second piece of filament is fixed out of view at the bottom of the bowden tube inside the piece of wood.

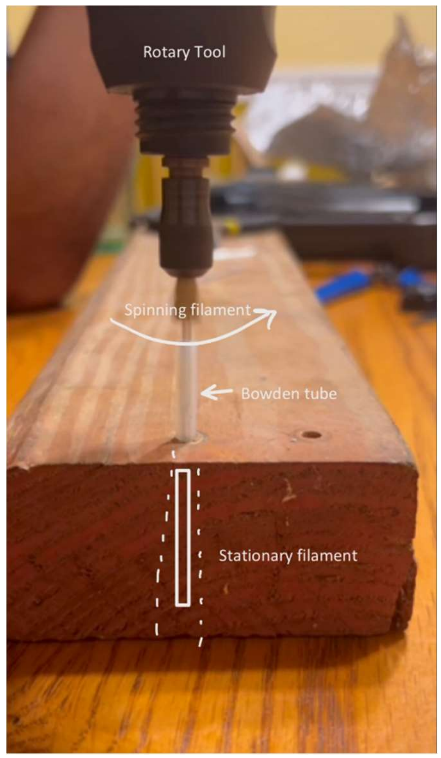

Figure 22: Stationary Friction Weld 2 Method.

The advantages of this method of joinery are that it is a quick and relatively safe method of splicing. There has been a recent surge of promising results that have shown successful splices with nice size and shape tolerance due to the bowden tube. This method is also relatively easy to recreate as the only required materials are a rotary tool, piece of bowden tube, and something to hold the parts in place.

The disadvantages of this method are that the current setup can only weld together short pieces of filament. The goal is to join 10m strands end to end which would not be compatible with sticking a piece in the chuck of the rotary tool. A separate method or device would need to be created to adapt it to working with full length strands.

Ultrasonic Welding

Another method of welding the filament is to use an ultrasonic welder. Ultrasonic welders use high-frequency acoustic vibrations ranging from 30kHz to 75 kHz to produce low amplitude mechanical vibrations that generate heat at the splice points of the parts being welded [15]. This method will require the welding tool itself, a metal plate to conduct the welding on top of, and the 3D printed block from the soldering iron test. As shown in Figure 23, the filament ends will be clasped in the case and placed on top of the metal plate. The ultrasonic welder will then be placed on the metal plate to conduct a safe weld of the PET plastic.

The greatest advantage of this method is that it is the fastest known welding technique. This method also allows for the PET to cool much more quickly than the previously mentioned tests. The finished welded material should be the most consistent when evaluated in the durability section due to the process it undergoes. The material is not affected as much as the others and should have few errors when it is printed. The main disadvantage of this method is how expensive the welding tool is and that ultrasonic welders are not commonly owned by hobby level enthusiasts.

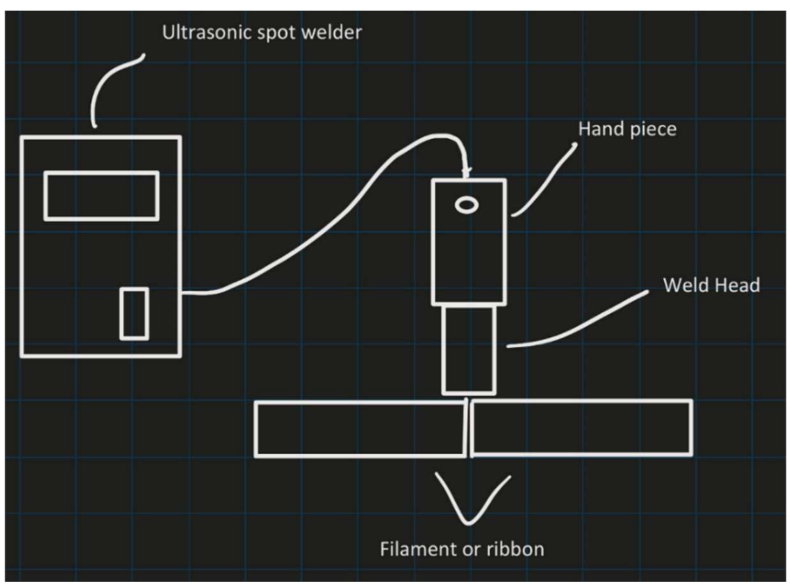

Figure 23: Ultrasonic Spot Welder Diagram

Scope of Work / Work Breakdown Structure

The scope of work remaining for this project includes three main areas. Experiment production includes making the individual test setups and should be completed by the end of the calendar year. Experiment and data gathering includes testing and evaluating all the aforementioned splicing methods and should be complete by February 2024. Finally, Process optimization includes taking the most viable splicing method identified and attempting to optimize that method for quality and reliability. This optimization process will use all remaining time in the semester. The official timeline for these tasks and their subtasks can be seen below in Figure 24.

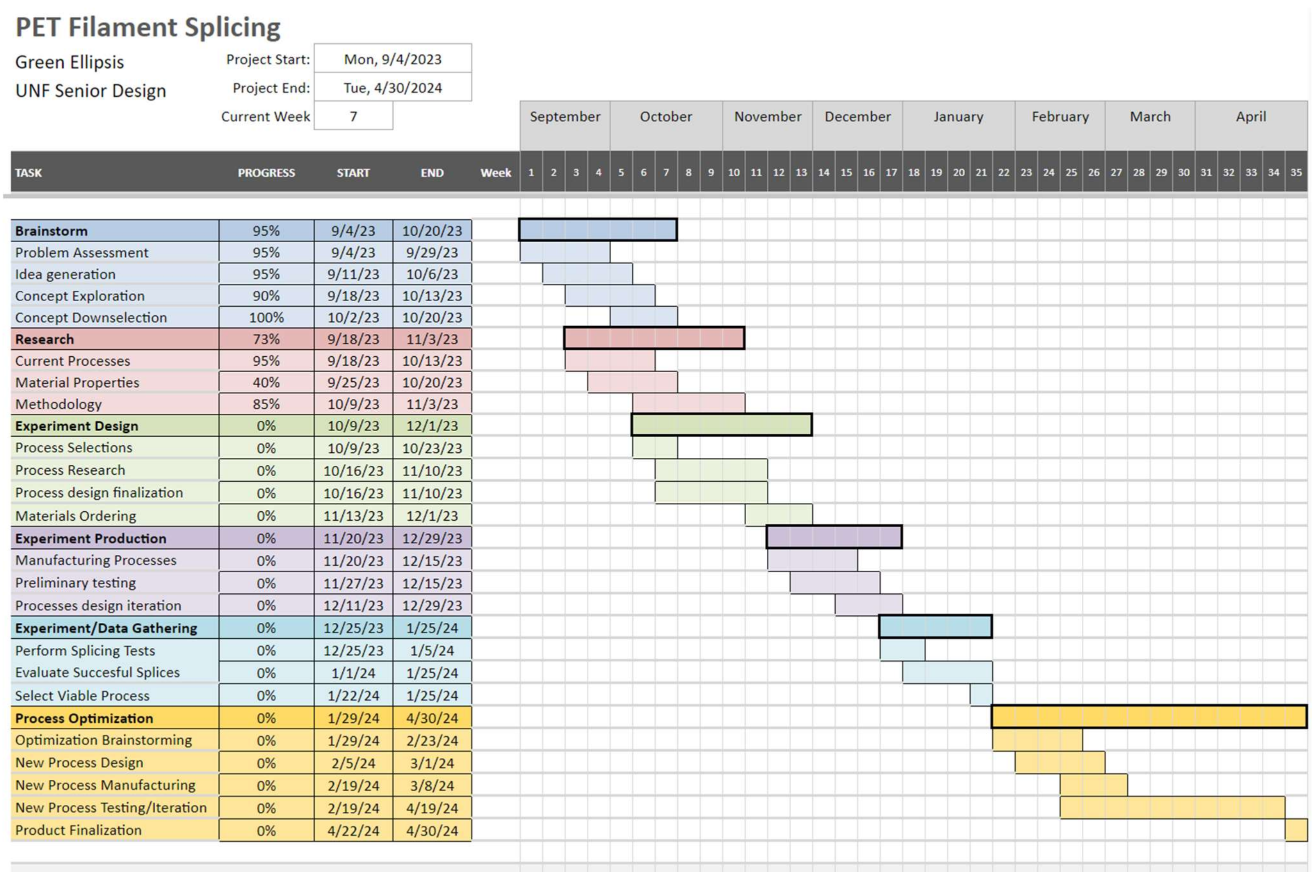

Figure 24: Gantt chart for the work remaining of the project

Experiment Production

Once the materials needed for the splice testing have been ordered, the various jigs and devices required for each splice method must be manufactured and tested. This will require 3D printing, some machining, and a lot of assembly. In addition to those devices, the two testing apparatuses (one for tensile strength and one for bending strength) will need to be made.

Once manufactured, all these need to be inspected for quality and used to run a series of preliminary tests. These preliminary tests are not to evaluate the individual process but rather to ensure that each possible splice joint attempt is done uniformly and to the best ability of the user. Any device or jig that does not perform correctly will need to be iterated upon until it does.

Experiment/ Data Gathering

Once the required tools have been created, experimentation on each splicing method will be performed. Each method will be attempted upwards of 30 times and will be evaluated on the testing criteria as described above in the calculations section. The data created by running these experiments will be used to make a decision matrix for each method. Using this decision matrix, the most viable splicing solution will be selected for further testing and optimization.

Process Optimization

Once the most viable solution has been selected. All remaining time will be spent attempting to optimize the process. The device or jig previously used for testing will be redesigned based on experience using it. The minimum goal for optimization is to create a jig or device that with human assistance can repeat the processes relatively quickly and very reliably. This portion of the remaining work will include iterating design of the new device, manufacturing, and process testing until some level of optimization is achieved.

Proposed Budget and Bill of Materials:

The overall budget constraint on the design project for Green Ellipsis is $1000. This will cover initial and final testing along with any new ideas that occur while performing the experiments. Currently it is projected that $682.08 of the budget will be used, this includes shipping and tax. Once materials are ordered there should be no issue with wait times since almost all components are readily available on Amazon. This will allow production and testing to begin as soon as parts arrive, which puts the project on time for the spring semester. The bill of materials can be seen below in table 3. The sponsor, Green Ellipsis, aims to provide whatever they already have on hand, as is indicated in the table. The largest portion of the budget is taken up by the ultrasonic welder, but it is a very promising splicing method and should be explored. There is a possibility that an ultrasonic welding machine will be provided by UNF, adding a lot more leeway for the budget in case any more parts need to be ordered.

Table 3: Bill of Materials

	Item	**Vendor**	**Quantity**	**Price**	**Total Cost**
1	Nichrome wire	Amazon	1	$8.49	$9.09
2	Clothespin (pack of 50)	Amazon	1	$5.99	$6.41
3	Aluminum foil	Amazon	1	$2.99	$3.20
4	Battery box (pack of 3)	Amazon	1	$5.99	$6.41
5	Omron SW (pack of 4)	Amazon	1	$6.91	$7.40
6	3D Printer Filament	Provided	1	$0.00	$0.00
7	Soldering Iron	Amazon	1	$35.99	$38.51
8	Ultra sonic welder	Grainger	1	$548.53	$548.53
9	Silicone Tubing	Amazon	2	$12.99	$27.80
10	Pepsi Brand Bottles	Donations	25	$0.00	$0.00
11	PID Temperature Controller Kit	Amazon	1	$25.99	$27.81
12	M3 X10 mm screws	Accu	6	$0.21	$1.35
13	15 mm screws	Screwerk	4	$1.3	$5.57
14	Washers	Donated	10	$0.00	$0.00
15	Rotary Tool	Provided	1	$0.00	$0.00

Conclusions and Recommendations

Taking waste two-liter bottles and upcycling them into 3D printer filament is a noble task that shows promise but in its current state still has several challenges to make it fully viable. Eventually, the hope of Green Ellipsis is to streamline the process as much as possible so that the product may be sold for more than the cost of creating it. Although the process has other opportunities for growth and improvement, splicing was identified as the current primary problem that holds the process back. Finding a method of reliably splicing the PET filament would greatly increase the value and make the upcycling process more worthwhile, bringing it closer to the goal of economic viability.

As no reliable method of splicing currently exists, the recommendation for moving forward on this project is to experiment with the different methods proposed above to identify the best path forward. Splicing methods both before and after the reforming process occurs are to be tested. In total, eight methods have been proposed and include techniques using mechanical connections, heat, friction welding, and ultrasonic welding. Each method will be explored first for its ability to make a connection and adjusted until it either creates a joint or is clear it is a non-viable solution. Every method that produces a joint will be then evaluated for reliability as well as quality of the joint. Quality testing will include tensile strength, bending strength, diametral size error, and print quality.

Once the most promising splicing technique has been identified, optimization of the method will be done to try and maximize the reliability and quality of the joint while minimizing the time it takes to create. This process could include creating an automated or semi-automated device that assists the user with repeating the process in a precise, safe, and easy way. Creating such a device would certainly improve the current cost/sale ratio of creating and selling the filament. Although automation is the long-term goal of the splicing process, the primary goal of this project is to identify the most viable method for splicing through experimentation and testing.

Each of the proposed solutions described above are so far theoretical in nature and have been untested. As experimentation begins and each process is performed, they will likely need to be adjusted or tweaked in order to be fully explored as a possible solution. The given descriptions of proposed methods is not exhaustive but rather a starting point to searching for the best splicing solution. It is likely that new methods may be uncovered during this exploration and those must be tested as well to ensure that the best possible solution is chosen to move forward with.

The next step that must be taken to accomplish the goal of finding a solution is to begin building all the devices, jigs, and testing apparatuses described above. Each method has a variety of tools and holders that must be purchased or made before testing can begin. The focus for the rest of the fall semester is to prepare each method for testing by preparing all the required items. Many of the jigs and tools have been designed and modeled but must be 3D printed and assembled before use. Preliminary testing of each device must also be done so that an accurate assessment of the splicing method may be taken. As soon as all methods have been set up and preliminary testing is complete, the official method experimentation and testing will begin.

The best-case scenario is that a worthy method is found quickly so that most of the spring semester can be spent optimizing and automating that process. However, it is possible that none of the proposed solutions will prove fully viable. In this worst case where none of the explored methods meet the testing standards set out, the research provided will still be valuable to Green Ellipsis and the community as a whole. Narrowing down the field of possibilities with vigorous testing will provide guidance for future endeavors to find a better solution.

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Appendices

Appendix A: Heat Transfer Calculations

Maximum energy transfer allowed:

All references from Matweb Source

Most conservative case:

$T_{glass} = 70°C \quad T_i = T_\infty = 23°$

$C_{cons} = 1 \, J/g\,K$

$\rho_{avg} = 1.36 \, g/mL$

length $\approx$ 1cm - Assumed

radius : 1.75mm = 0.175 cm

$A_{circle} = 0.096 \, cm^2$

$\forall = 0.096 \, cm^3$

$M = \rho_{Avg} \forall = 0.13056 \, g$

$Q = mc\Delta T = 0.13056\cancel{g} \cdot 1 \frac{J}{\cancel{g \cdot K}} (70° \cancel{C} - 23° \cancel{C}) = 6.13632 J$

Least conservative case

$T_{glass} = 78°C \quad T_i = 23°C$

$m = 0.13056$

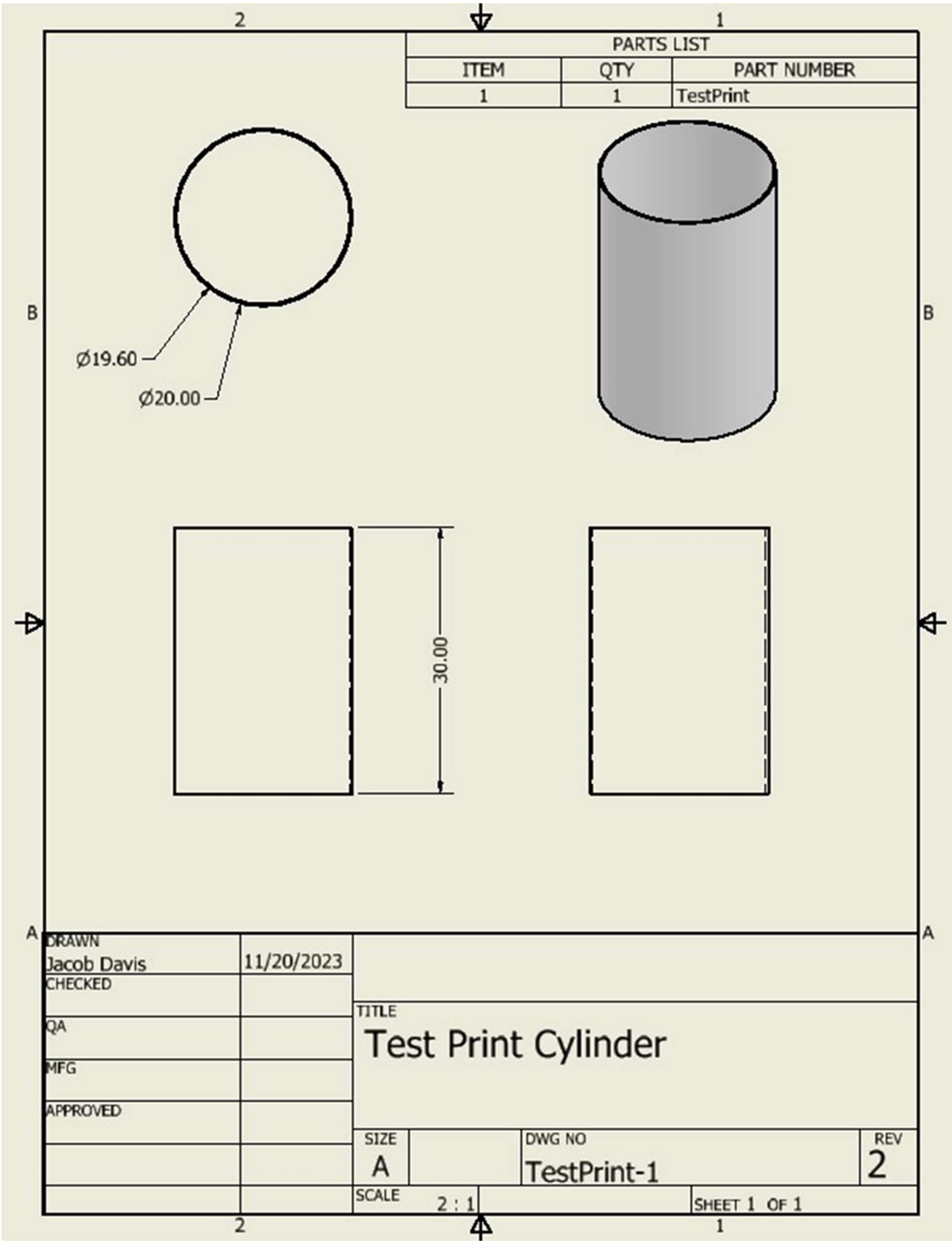
$c = 2.30$

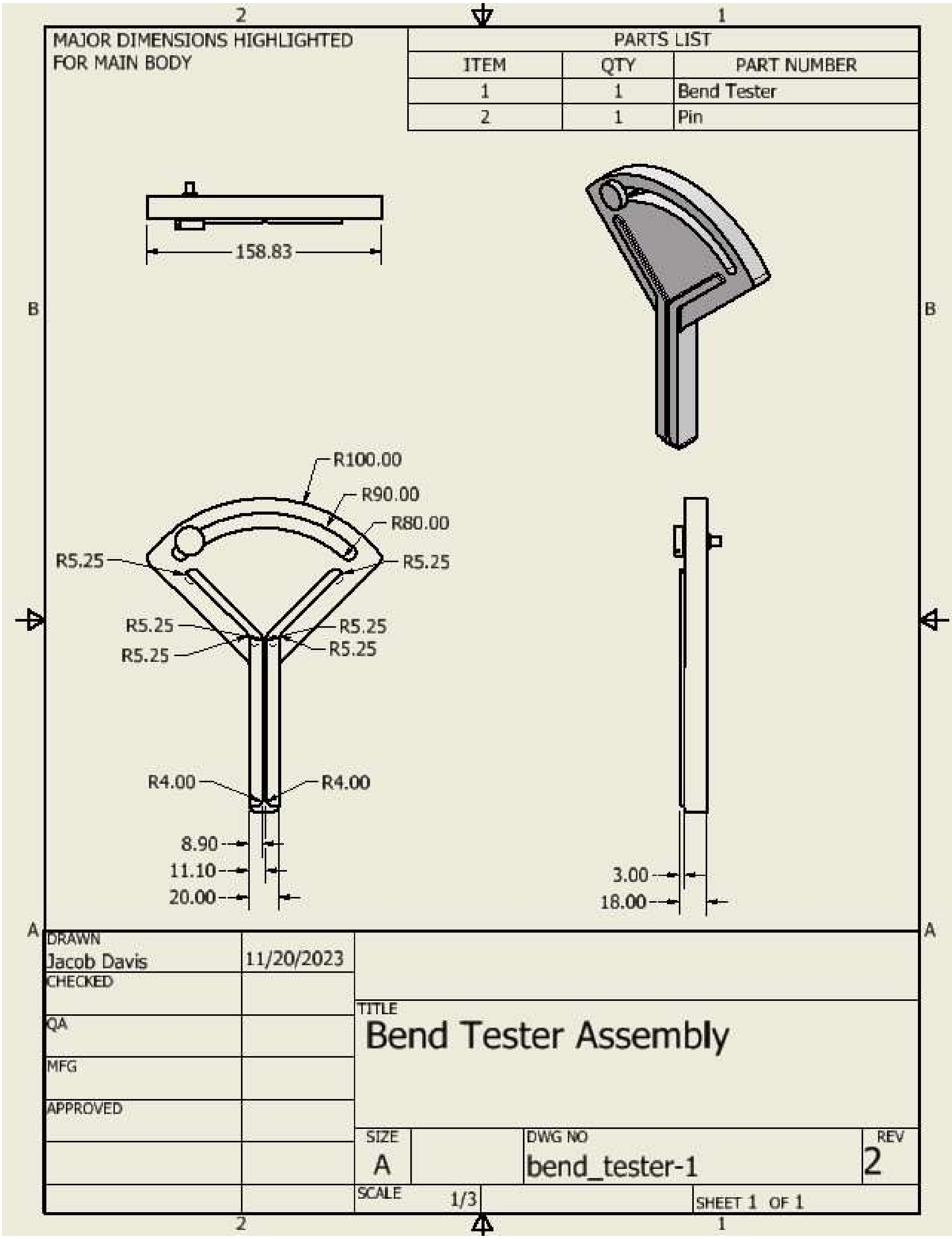
$Q = mc\Delta T = 0.13056\cancel{g} \cdot 2.30 \frac{J}{\cancel{g \cdot K}} \cdot (78 - 23)° \cancel{C} = 16.51584$

Appendix B: Bill Of Material Links:

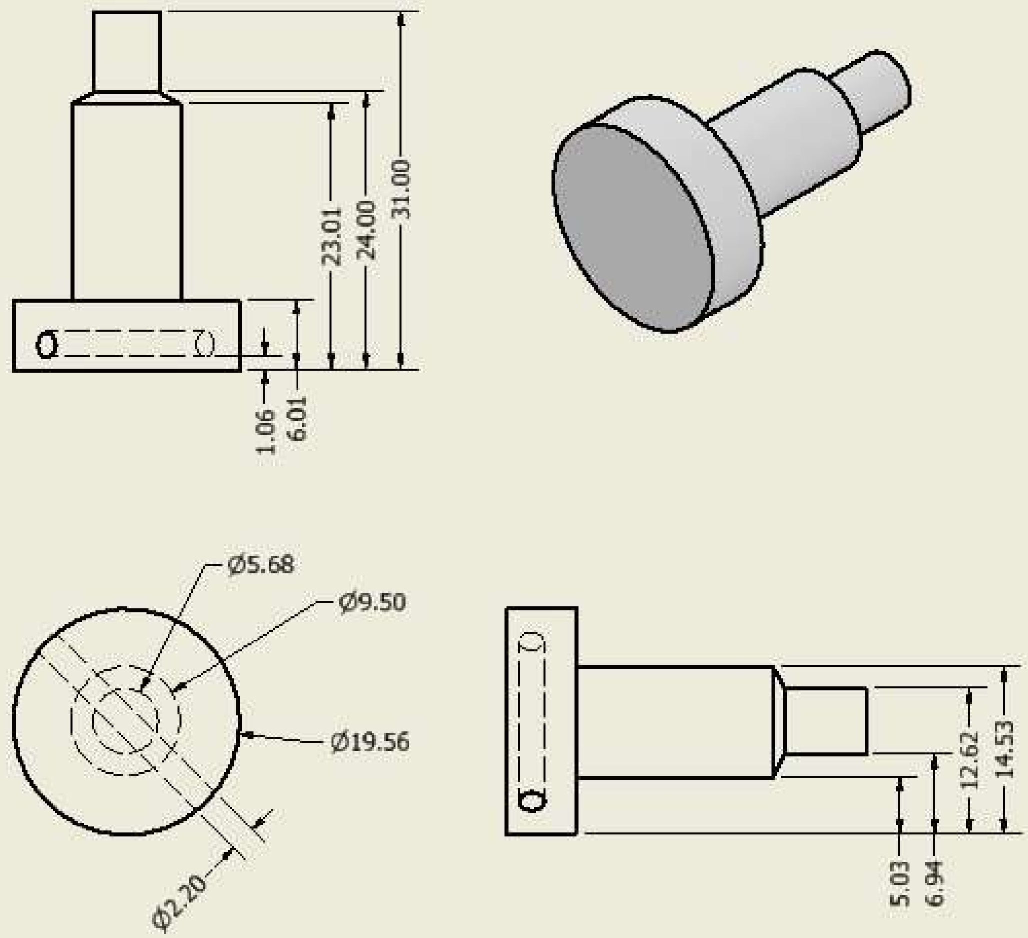
Nichrome Wire	www.amazon.com/dp/B01FHX7R3M
Clothespin	www.amazon.com/dp/B092LBVPPP
Aluminum foil	www.amazon.com/dp/B005GPJCHQ
Battery Holder	www.amazon.com/dp/B07TB4HDYH
Omron Switches	www.amazon.com/dp/B01K0ZLMYM
Soldering Iron	www.amazon.com/dp/B0C36VB783
Thermoplastic welder	www.grainger.com/product/4UZR6
Silicone Tubing	www.amazon.com/dp/B093F6F2L4
Thermocouple	www.amazon.com/dp/B08ZYHFBYW
10mm screws	www.accu-components.com/us/cap-head-screws/3819-SSCF-M3-10-A2
15 mm screws	www.us.screwerk.com/en/shop/detail/stp/STP420300150S.html

Appendix C: CAD Drawings

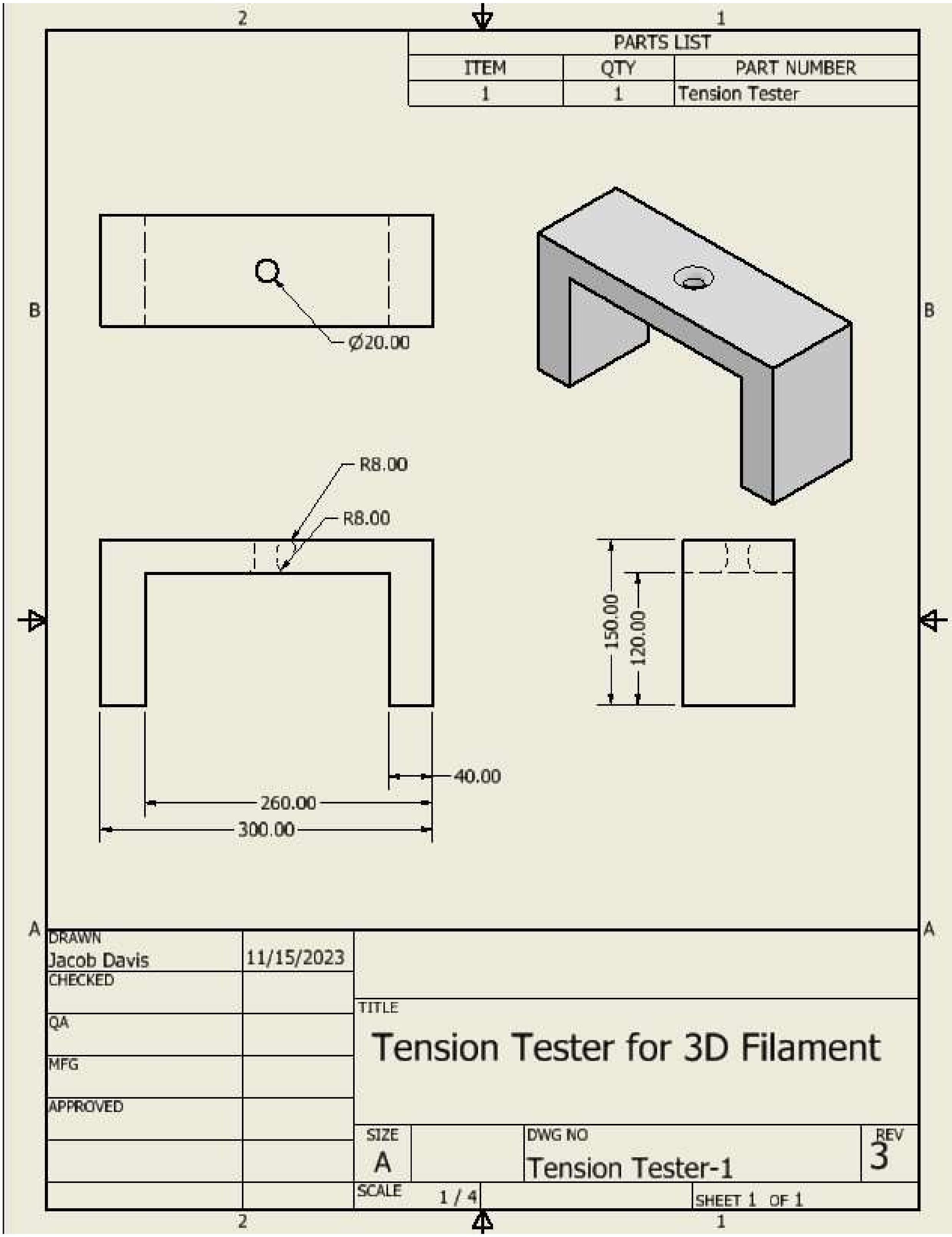


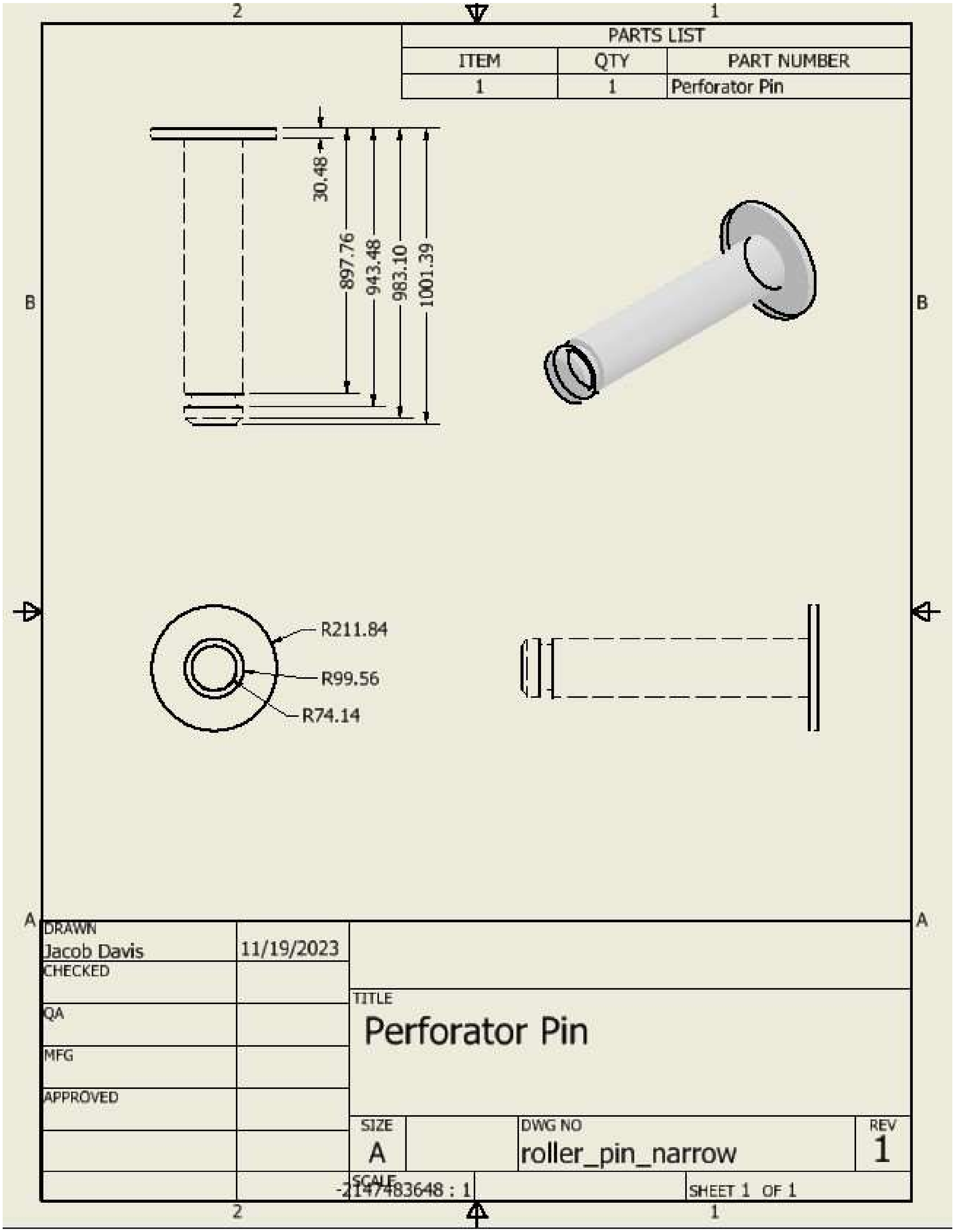

MAJOR DIMENSIONS HIGHLIGHTED
FOR MAIN BODY
PARTS LIST
ITEM
QTY
PART NUMBER
1
1
Bend Tester
2
1
Pin
158.83
R100.00
R90.00
R80.00
R5.25
R5.25
R5.25
R5.25
R5.25
R5.25
R4.00
R4.00
8.90
11.10
20.00
3.00
18.00
DRAWN
Jacob Davis
11/20/2023
CHECKED
QA
MFG
APPROVED
TITLE
Bend Tester Assembly
SIZE
A
DWG NO
bend_tester-1
REV
2
SCALE
1/3
SHEET 1 OF 1

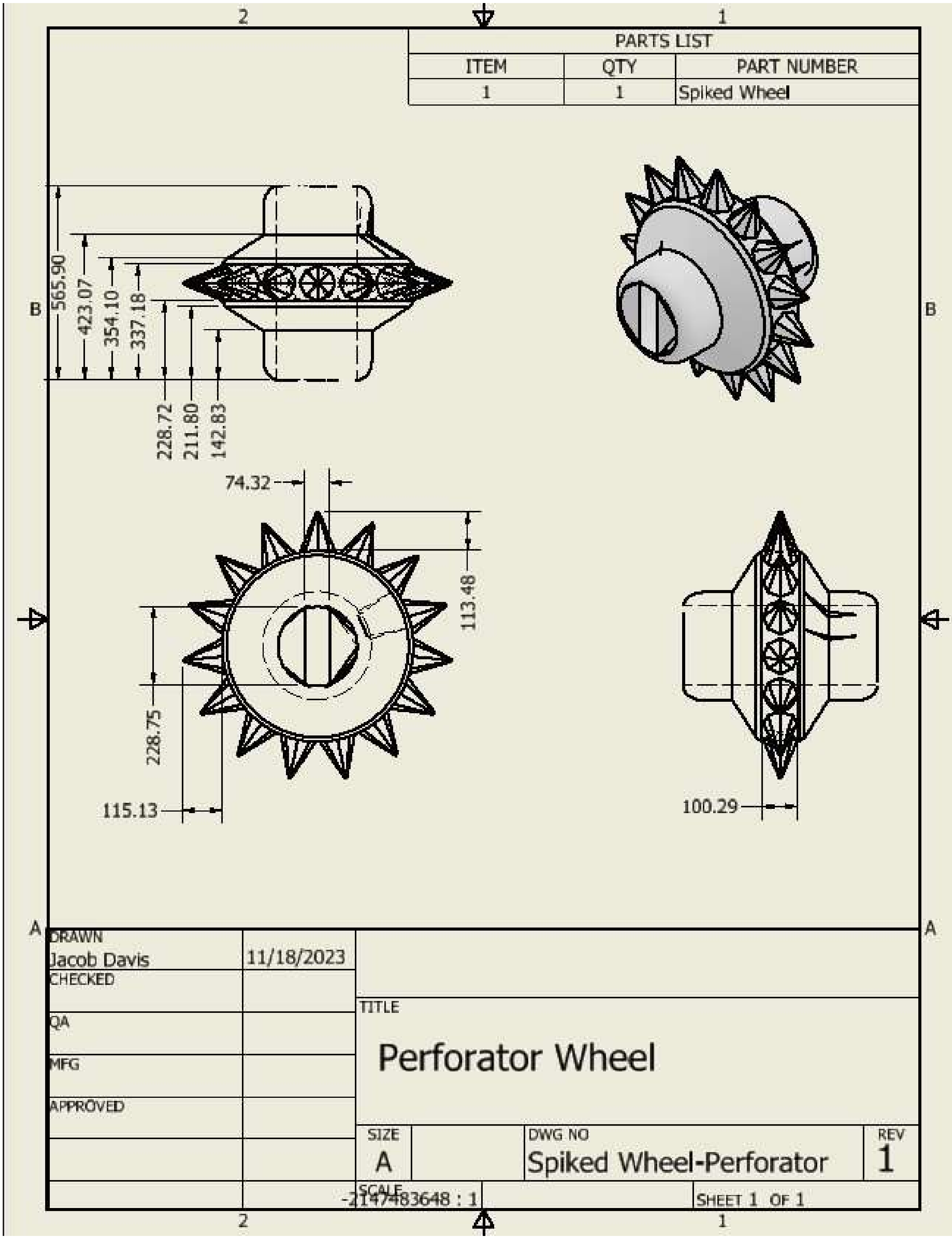
PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Pin



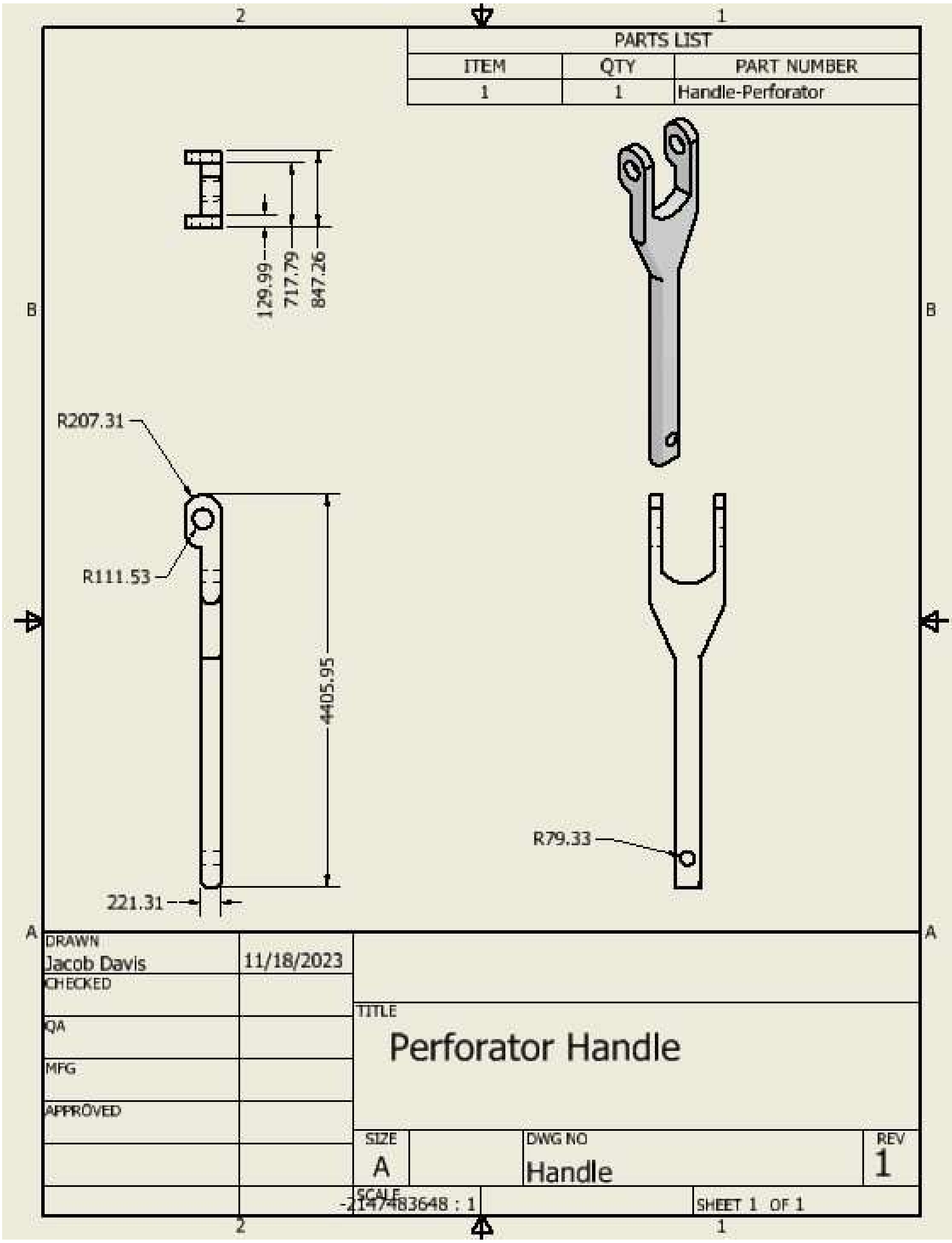
DRAWN Jacob Davis	11/20/2023	
CHECKED		TITLE Bend Tester Pin
QA		
MFG		
APPROVED		SIZE A · DWG NO Bend Tester Pin · REV 2
		SCALE 2 : 1 · SHEET 1 OF 1


PARTS LIST
ITEM
QTY
PART NUMBER
1
1
Tension Tester
Ø20.00
R8.00
R8.00
150.00
120.00
40.00
260.00
300.00
DRAWN
Jacob Davis
11/15/2023
CHECKED
QA
MFG
APPROVED
TITLE
Tension Tester for 3D Filament
SIZE
A
DWG NO
Tension Tester-1
REV
3
SCALE
1 / 4
SHEET 1 OF 1

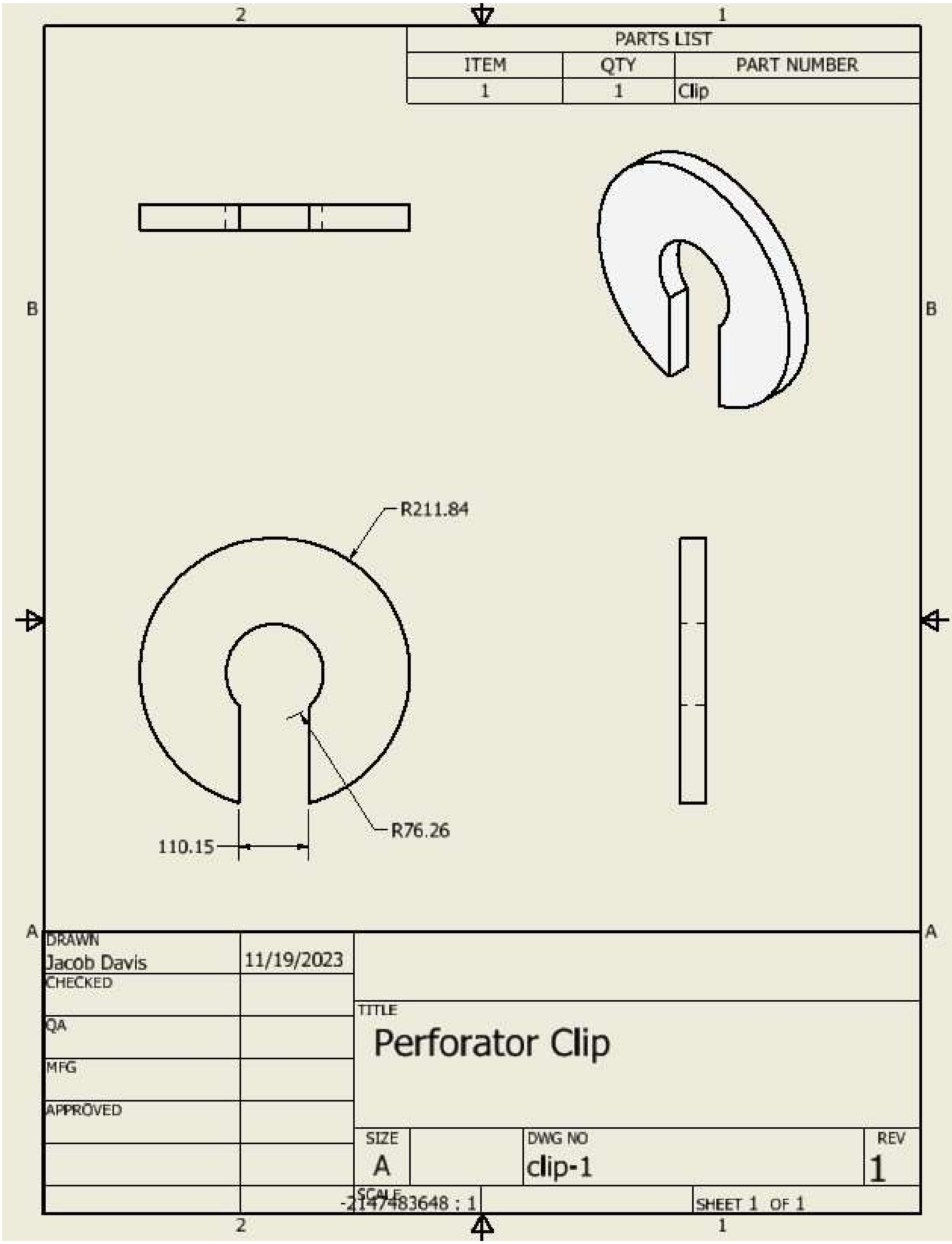

PARTS LIST
ITEM
QTY
PART NUMBER
1
1
Perforator Pin
30.48
897.76
943.48
983.10
1001.39
R211.84
R99.56
R74.14
DRAWN
Jacob Davis
11/19/2023
CHECKED
QA
MFG
APPROVED
TITLE
Perforator Pin
SIZE
A
DWG NO
roller_pin_narrow
REV
1
SCALE
-2147483648 : 1
SHEET 1 OF 1

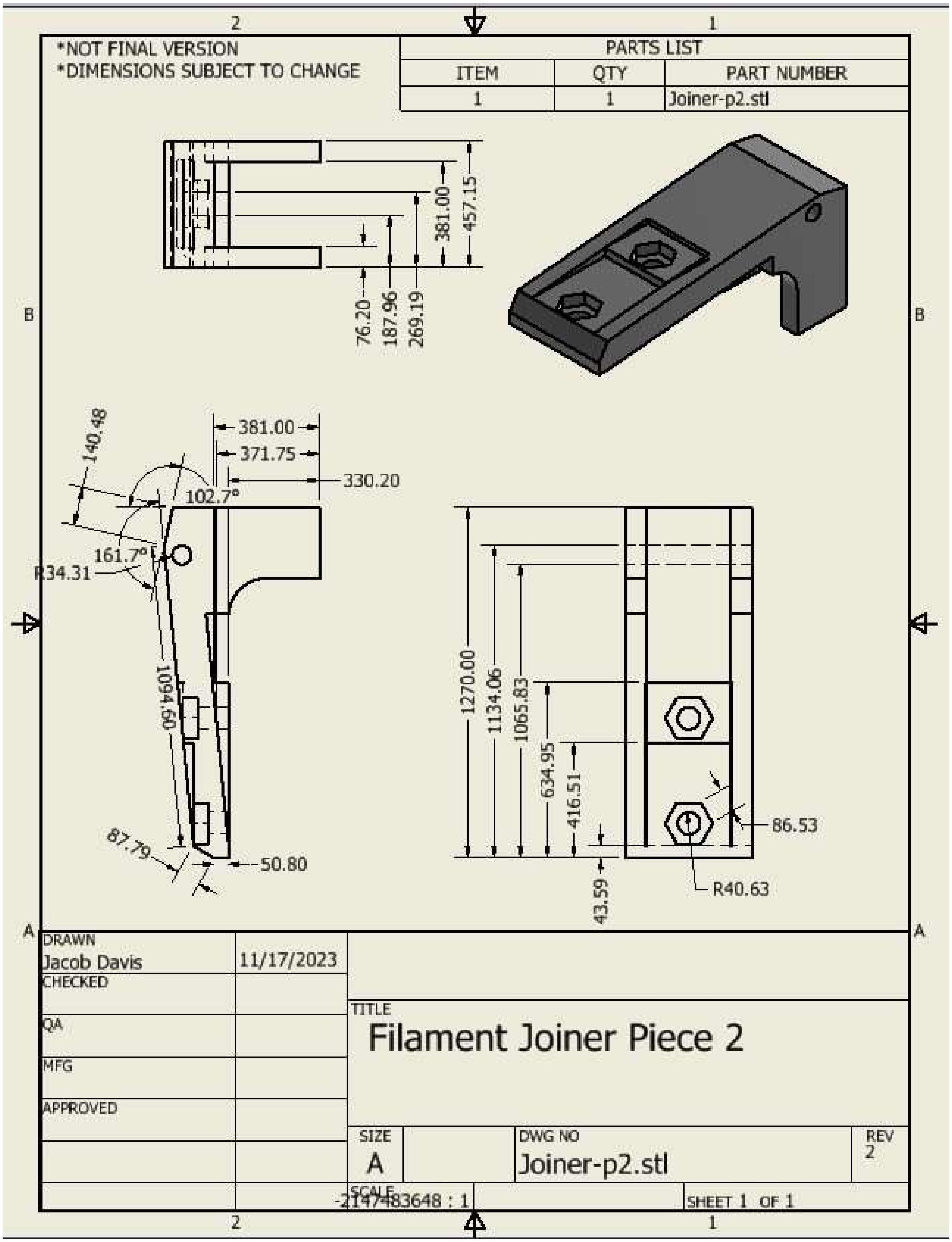


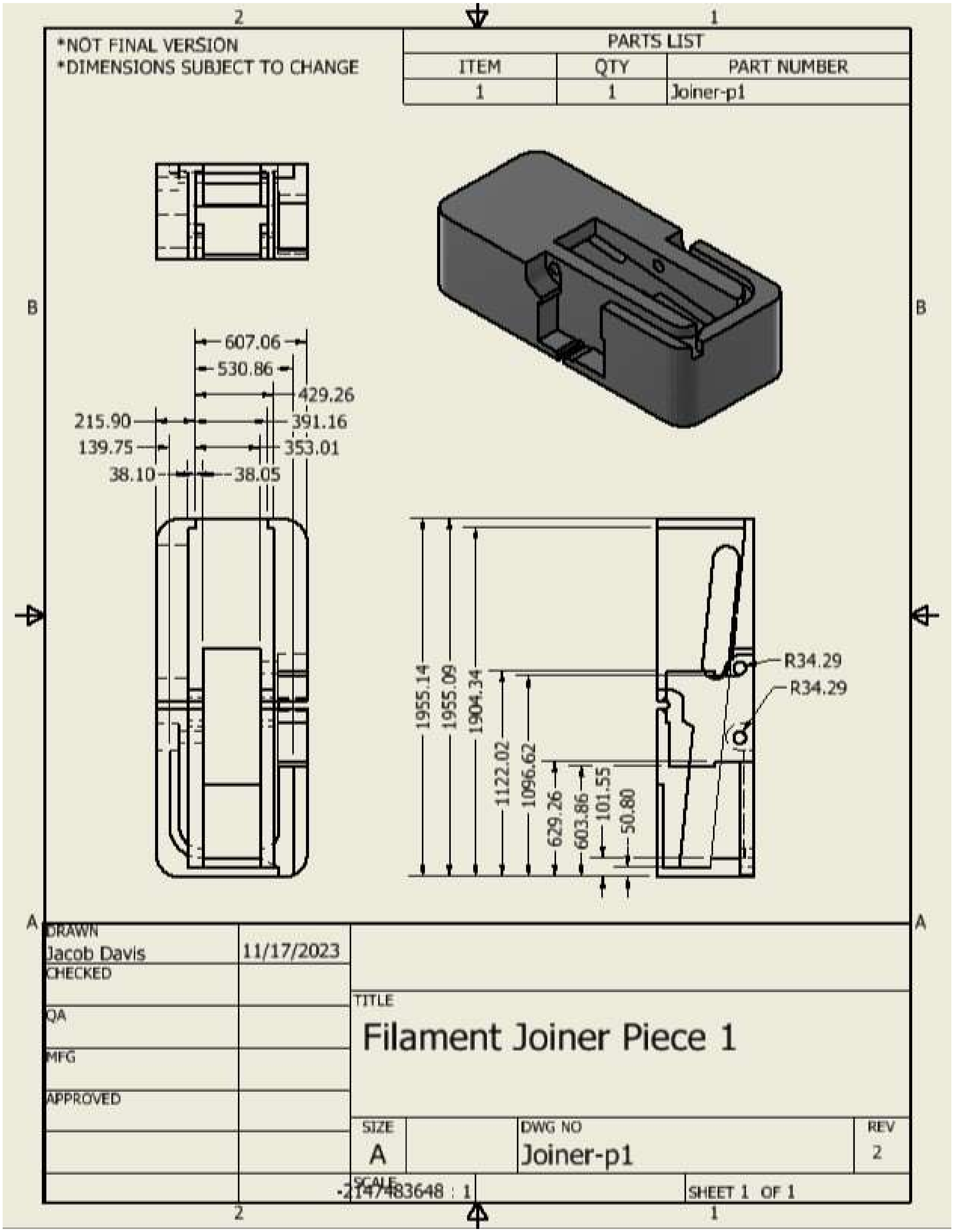
PARTS LIST
ITEM | QTY | PART NUMBER
1 | 1 | Spiked Wheel
565.90
423.07
354.10
337.18
228.72
211.80
142.83
74.32
113.48
228.75
115.13
100.29
DRAWN
Jacob Davis
11/18/2023
CHECKED
QA
MFG
APPROVED
TITLE
Perforator Wheel
SIZE
A
DWG NO
Spiked Wheel-Perforator
REV
1
SCALE
-2147483648 : 1
SHEET 1 OF 1



PARTS LIST
ITEM
QTY
PART NUMBER
1
1
Handle-Perforator
129.99
717.79
847.26
R207.31
R111.53
4405.95
221.31
R79.33
DRAWN
Jacob Davis
11/18/2023
CHECKED
QA
MFG
APPROVED
TITLE
Perforator Handle
SIZE
A
DWG NO
Handle
REV
1
SCALE
-2147483648 : 1
SHEET 1 OF 1


PARTS LIST
ITEM
QTY
PART NUMBER
1
1
Clip
R211.84
R76.26
110.15
DRAWN
Jacob Davis
11/19/2023
CHECKED
QA
MFG
APPROVED
TITLE
Perforator Clip
SIZE
A
DWG NO
clip-1
REV
1
SCALE
-2147483648 : 1
SHEET 1 OF 1
2
1
B
A


*NOT FINAL VERSION
*DIMENSIONS SUBJECT TO CHANGE
PARTS LIST
ITEM
QTY
PART NUMBER
1
1
Joiner-p2.stl
457.15
381.00
76.20
187.96
269.19
140.48
381.00
371.75
330.20
102.7°
161.7°
R34.31
1094.60
87.79
50.80
1270.00
1134.06
1065.83
634.95
416.51
43.59
86.53
R40.63
DRAWN
Jacob Davis
11/17/2023
CHECKED
QA
MFG
APPROVED
TITLE
Filament Joiner Piece 2
SIZE
A
DWG NO
Joiner-p2.stl
REV
2
SCALE
-2147483648 : 1
SHEET 1 OF 1



*NOT FINAL VERSION
*DIMENSIONS SUBJECT TO CHANGE
PARTS LIST
ITEM
QTY
PART NUMBER
1
1
Joiner-p1
607.06
530.86
429.26
215.90
391.16
139.75
353.01
38.10
38.05
1955.14
1955.09
1904.34
1122.02
1096.62
629.26
603.86
101.55
50.80
R34.29
R34.29
DRAWN
Jacob Davis
11/17/2023
CHECKED
QA
MFG
APPROVED
TITLE
Filament Joiner Piece 1
SIZE
A
DWG NO
Joiner-p1
REV
2
SCALE
-2147483648 : 1
SHEET 1 OF 1