3D Filament Recycler

Final Report
May 4, 2018

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2017-2018

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EXECUTIVE SUMMARY

The 3D Filament Recycler Team, is comprised of four team members: Abdulaziz Abdulghafour, Marc Hsu, Nicole Tabac, and Micki Yasuda. All team members are mechanical engineering students at Northern Arizona University (NAU) who researched and designed a machine that can recycle waste material created from Fused Deposition Modeling (FDM) 3D Printers. FDM 3D printers were chosen for their popularity in research labs, universities/schools, and homes of hobbyists. The filament materials chosen are polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) at a 1.75 mm diameter and a tolerance of +/-0.05 mm. Benefits of having a machine that is capable of recycling filament include lowering the cost of prototyping/production and decreasing the carbon footprint that is created by using FDM 3D Printers.

The team’s key focus in developing the filament recycler consists of three main functions: filament extruder, shredder for plastics, and a filament spooler. Each system serves a different purpose that will make recycling 3D filament waste possible. Research on different topics of the filament recycler was distributed evenly between team members; which allowed the team to move forward quickly with research. To assure the quality of the machine, each subassembly was tested separately to allow each component to function independently, while allowing customization for different components for future development. Once all subassemblies are fully functional, the final system will be a representation of the cumulative knowledge of the team's research.

ACKNOWLEDGEMENTS

The capstone team would like to recognize all the people and organizations who took the time to assist with this project. First, the team would like to thank W.L. Gore for their gracious donation, which provided funding for this project. The team would like to express gratitude to Chuck Vallance, the team's technical advisor, who volunteered his time to support the team with insightful, industry-level thinking practices and planning strategies. The team strongly believes that Chuck's experience, patience, and guidance led the team to success. The class professor, Dr. Sarah Oman, provided the team with beneficial and constructive criticism that guided the team throughout the year. She also donated an abundance of 3D scraps that was especially helpful during the testing process. Lastly, the team would also like to acknowledge the machine shop managers for always happily assisting the team, especially Tom Cothrun and Marco Sliva. Tom Cothrun provided valuable technical advice with manufacturing and Marco Sliva cut the beautiful shredder teeth on the CNC. The majority of manufacturing and testing was conducted in the NAU's manufacturing building, 98C.

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1 BACKGROUND

The background includes the introduction, project description, and the information about the original system in relating to this project.

The efforts of the NAU 3D Filament Recycling Team cover the review of existing 3D filament winders, and the various analyses and discussions of the team in its efforts to create a more comprehensive architecture and machine to cover all aspects of the problem statement.

1.1 Introduction

Fused deposition modeling (FDM) 3D Printing is a manufacturing process that has grown in popularity with hobbyists and industries. 3D printers' have the ability to create virtually any geometry, it has become a widely used process in rapid manufacturing. Two popular materials used in 3D printing are polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). While other materials can be printed, these two materials are very desirable for they are thermoplastics. Thermoplastics are capable of heating, shaping, and cooling repeatedly without losing their chemical structure, making them easily recyclable.

A lot of material is wasted in printing, as support of the part or as defects. Usually, plastic is disposed or recycled, but never reused. Waste that are produced from these 3D printers consist of rafts, brims, supports, and failed prints. Brims are produced when the printer starts the print with the purpose of ensuring the filament is flowing out of the extruder to make the initial adhesion onto the print bed. Rafts are similar to brims except their main purpose is to create a removable base for the main part to print on. Supports are usually made when there are large overhangs in the part. Failed prints are also expected depending on the 3D printer and the types of geometry that are desired by the user. This project entailed creating a machine to recycle the wasted material into reusable filament for printing. The project objectives include designing and manufacturing a 3D filament recycling machine to create quality filament for prototyping. The team designed the machine to be easy to use for industrialists and hobbyists alike, saving money in materials for the team's customers.

1.2 Project Description

The team have designed and manufactured a 3D filament recycler with the capability to recycle PLA. The machine has three main functions: shredding, extruding, and spooling. The original project description was provided as the following:

"The project is proposing a 3D Filament Recycler that takes wasted materials like structural supports, rafted plates, or even failed 3D prints and turning it back into usable 3D filament. Understanding that reheating and reforming the recycled filament will cause some form of structural material change, so making a mixture between old and new plastic polymer plastics will most likely be needed in the recycling process. Key features of this recycler machine would involve:

- A shredder that can break down failed 3D prints of various sizes to plastic pellets that may be needed to be mixture.
- A heater and extruder for melting plastics into filament that can adjust temperatures on demand depending on the plastics being used.
- A unit that can spool the filament coming out of the extruder.
- A device able to check the thickness of the extruding filament for quality control." [1]

1.3 *Original System*

While there are many 3D recycling systems, homemade and industrially manufactured, Filabot was the first and only company who has put industrial-grade products on the market. Filabot sells five machines separately: an extruder, spooler, reclaimer, airpath, and pellet dryer. With prices ranging from $649-$6,200 for each component, Filabot has provided a reliable and functioning product, but for a very steep price [2].

1.3.1 **Original System Structure**

A typical 3D filament recycling system consists of a shredder (reclaimer), extruder, and spooler. Filabot also provides an airpath and pellet dryer. Filabot's reclaimer in Figure 1 is a 24" x 24" x 51" machine to grind the material into pellet-sized plastics to easily melt the material upon entering the extruder [2].

Figure 1: Filabot Industrial Reclaimer, $6,200 [2]

Figure 2: Filabot Original Filament Extruder, $1,399 [2]

The extruder in Figure 2 is the main component, standing at 18" x 17" x 9". This machine feeds plastic pellets ground from the reclaimer into a heating chamber, where molten plastic is formed and is injection molded into the material into usable filament [2].

The spooler in Figure 3 takes the cooled, usable filament and neatly winds it onto a spool to easily store and organize the filament in spools of up to 8.5" x 3" in size [2].

Figure 3: Filabot Spooler, $1,200 [2]

Figure 4: Filabot Airpath, $649 [2]

The airpath seen in Figure 4, is a machine used to cool filament using forced convection on the filament being extruded, ensuring the machine is producing filament within tolerance [2].

The pellet dryer in Figure 5 is used to remove moisture from the material that is to be recycled. PLA tends to absorb moisture easily, which makes the material brittle, so it is imperative to use a dehumidifying mechanism to ensure quality filament upon extruding [3].

Figure 5: Filabot Pellet Dryer, $6,139 [2]

1.3.2 **Original System Operation**

The system operates with three main components: the shredder, extruder, and spooler. The shredder's purpose is to pulverize the plastics into small pellets to easily feed the plastic into the hopper. After being fed through a hopper into the heating chamber, the molten material is pushed by an auger through a nozzle as filament. The extruded filament then passes through the filament spooler to neatly reel the material to prevent tangling. A control board ensures the filament in the system is within tolerance [2].

1.3.3 **Original System Performance**

Filabot's reclaimer provides a tool-free and simple design for maintenance and cleaning. With its 13.5" x 6.3" feed opening size, the reclaimer can grind almost any part at 170 pounds of plastic per hour. After grinding, the pellet dryer is to be used before inputting the ground plastic into the extruder. The extruder works reliably if set up and executed as directed by the manufacturer's instructions. On average, Filabot's extruder can produce filament at a rate of 40 inches per minute and stays within a tolerance of ±0.05mm. The spooler has variable controls for speed and includes a mechanism to evenly distribute the filament throughout the spool. The airpath has variable controls to ensure a consistent cooling temperature for different materials [2].

1.3.4 **Original System Deficiencies**

According to customer reviews, failure to properly abide by the manufacturer's requirements can result in complications during set up. The extruder can have difficulty keeping within tolerance if the extruder is set too fast or too slow. Because each of the components are sold separately, it can be difficult to produce the best product if all components are being used. For example, if PLA cannot have its moisture removed before extruding the extruder will skip or clumping at the nozzle, producing inconsistent and brittle filament with air pockets in them [3]. If the air dryer is not cooling the material properly, the filament can lose its shape or tolerance as it is fed out of the extruder. Lastly, without a spooler, the filament can get tangled or break depending on the relationship between the feed speed and spool speed [2].

2 REQUIREMENTS

Customer requirements were chosen from comparing the advantages and disadvantages off competing products (shown in Section 3). The team interviewed hobbyists regarding what functions and features were desired from a 3D filament recycler and created customer requirements, in addition to those of the original statement of work, accordingly. After choosing the customer requirements, the team derived engineering requirements from each customer need.

2.1 Customer Requirements (CRs)

The team designed for 3D printing labs and home hobbyists. The complete system needed to be easy to use and affordable. Consumers wanted a compact, durable machine with little to no maintenance required. Overall the machine needed to produce quality filament (in PLA and ABS) that the consumer deems reliable to print with. Keeping all of these requirements in mind, the machine that is aesthetically appealing will allow the consumer to proudly display the machine in their home or workplace. See Table 1 for the chosen customer requirements, listed 1-8, 1 being most important.

Table 1: 3D Filament Recycler Customer Requirements

Customer Requirement	Weight	Justification
Safety	1	Any moving mechanisms are enclosed/concealed to avoid user injury (ie. moving gears, shredder blades, hot parts of the machine)
Material extrudes 1.75mm diameter filament	2	Producing reusable filament for printers that use 1.75mm diameter filament (most common filament size)
Reliability	3	Machine can run without need maintenance (ie. having to respool filament that does not get on the spool)
Durability	4	Machine needs to be sturdy, can withstand impacts (ie. falling off a tabletop)
Affordable	5	Have the machine cost less than $2000, which is less than a competitor's price allowing recycling to be more accessible
Performs three functions (shred, extrude, spool)	6	Machine will compose of three simple machines: shredder, extruder, spooler
Size/Compact	7	Machine is small enough to sit on top of a table, can be easily transported by the user
Aesthetically Pleasing	8	Sleek look, can match any house/office interior

2.2 Engineering Requirements (ERs)

The team derived the engineering requirements (see Table 2) from their customer needs, allowing them to decide on the type of engineering constraints the project will have. The overall safety of the machine is necessary, since the team is liable if the customer is injured using the machine. The team has decided on set requirements and features to assure the machine is simple and intuitive to operate. By creating control units for the spooler speed, temperatures, and auger speed, being able to plug into any household outlet is a basic necessity to allow use anywhere, and choosing the materials are vital to producing a high-functioning, quality product. Additionally, the team wants to make the 3D filament recycler as affordable as possible, so a key design effort is to be able to incorporate premade parts.

Table 2: 3D Filament Recycler Engineering Requirements

Engineering Requirement	Unit	Target	Anticipated Tolerance
Voltage	Volts	120	Maximum
Amperage	Amps	15	Maximum
Melt Temperature	°C	164°C (PLA) 221°C (ABS)	±7°C (PLA) ±17°C (ABS)
Budget	$	$1,500	±$500
Control Speed	rev/min	Variable	Variable
Extrudes within tolerance	mm	1.75	±.05

The engineering requirement for the voltage and amperage are for powering any and all of the electronics on the recycler. The recycler should be compatible with any U.S. household outlet.

The recycler needs to be capable of reaching the melting temperature range of 160°C to 225°C for melting different types of filaments (ABS and PLA). This requirement made the team consider ways to control the melting temperatures manually to help with the machine testing.

The team also came up with a requirement to keep the machine under $1,500 to give the team extra funding for testing or extra parts, if necessary. This also keeps a lower price of the recycler than its competitors on the market.

The control speed requirement had the team design for a manually controlled system. The controllable speed for spooling allows the team to test which speed would be best to produce a filament with 1.75mm diameter. This requirement helps with the last requirement which is have a machine that produces filament with a 1.75mm diameter.

2.3 Testing Procedures

Once each subsystem is built and assembled, an analysis for quality control and functionality will be performed. This is done to assure each component is functioning properly and the machine is performing as designed. The testing procedures (TP’s) are described below:

1. A teammate will place different size thicknesses of failed prints/scraps in the shredder to test what thickness of prints can be shredded.
2. Prints with different infills/resolutions will be placed into the shredder to test what the maximum infill/resolution that can be shredded.
3. Different sized shredded prints will be put into the auger to test what the motor can push through the extruder.
4. A teammate will use a timer to measure how long it takes for the heating band to reach the desired temperature for PLA (164°C).
5. A caliper will be used to measure the diameter of the filament that is being produced to see if it extruded at the right size.
6. Different motor speeds of the spooler will be tested to see what is the ideal spool speed as the filament is being extruded.

2.4 House of Quality (HoQ)

A 3D Filament Recycler consumer would be someone who uses FDM 3D printers, mainly found within hobbyists and research labs. Customer needs were developed by interviewing existing FDM 3D printer users. These potential customers asked to have a machine that was affordable with small form factor, reliable enough to produce filament consistently, and does not require a lot of maintenance. The recycler would also need to be more cost efficient than its competitors, while keeping its functional integrity. The idea of having all three functions in one machine was strongly desired, becoming a customer requirement. Users of FDM 3D printers primarily use filament made of PLA and ABS, which determined the types of plastics the team aimed to extrude. Consumers also showed interest in an aesthetically pleasing model to proudly display in their home or lab. By using the House of Quality shown in Table 3 (also see Appendix A, Table A-1), the team was able to determine eight customer requirements. The requirements by the customers were weighed based on the importance of the features desired.

From the engineering requirements, the team chose to ensure the machine is capable of functioning in any household. Thus, designing a machine that draw no more than 120V and 15 amps to fit a standard U.S. outlet was necessary. This means all the motors, heating coils, and other electrical components must be chosen to fit these restrictions. The extruder needed to reach and adjust to the correct melting temperatures for ABS and PLA since they melt at different temperatures. The recycler needed a controller system that was capable of adjusting the extrusion speed of the filament and the spindle speed of the spooler. By having these two adjustments, the extruder would not produce filament too fast, and the spooler would not tug on the filament as it being made. The team also determined the requirements needed to fit within their budget of $2,000.

Table 3: Excerpt of HoQ (Table A-1)

Customer Requirement	**Weight**	**Engineering Requirement**	Voltage (V)	Amperage (amps)	Melt Temperature (°C)	Parts Budget (<$2000)	Control Speed (rev/min)	Extrudes within tolerance (mm)
1. Safe to use	1		9	9	3	1	1	1
2. Reliability	3		9	9	3	9	9	9
3. Durability	4		1	1	9	9	3	3
4. Includes 3 functions (shred, extrude, spool)	6		9	9	9	3	9	9
5. Affordable	5		1	1	3	9	3	1
6. Material able to extrude @ 1.75mm	2		1	1	9	3	1	9
7. Size/Compatability	7		1	1	3	1	3	1
8. Aesthetically pleasing	8		1	1	1	1	1	1

3 EXISTING DESIGNS

There is a very small market for industry-level 3D filament recyclers. Most 3D filament recyclers were found on crowd funding or do-it-yourself (DIY) websites. Thus, much of the research done was on existing designs such as homemade devices with little information on industry level competitors. Most of the existing designs did not include all three main functions that the team desired in one machine. The existing designs mainly had extruders with spoolers or grinders as an “add-on” item or not available at all.

3.1 Design Research

The scope of this project focuses on having three main functions within the product: a grinder, extruder, and spooler that can recycle PLA and ABS. The team conducted research on existing devices that performed these functions, each in extensive detail to understand the functionality of each mechanism. A small list of existing 3D filament recyclers can be seen with what is included below in Table 4 and Table 5. The designs the team researched were Filabot, Protocycler, and Filament Extruder by Russ.

Table 4: Competitors on the Market [4]

	ProtoCycler	Filastruder	Filabot	ExtrusionBot 2	Strooder	Noztek Pro
Price	$799	$300	$650-$950	$725	$400**	$1250**
Recycles	Included	Not Available	$440 Extra	$475 Extra	Not Available	Not Available
Safety Certified	Yes!	No	No	No	No	No
Easy to Use	Yes!	No	No	Yes	Yes	No
Tolerance	+/- 0.02 mm	Not Reported	Not Reported	Not Reported	+/- 0.10 mm	+/- 0.04
Energy Effeciency*	10x	1x	1x	3x	2x	1.5x
Extrusion Speed	10 ft/min	2 ft/min	2 ft/min	6 ft/min	4.9 ft/min	3 ft/min
Assembled	Yes!	No	No-Yes	Yes	Yes	Yes
Spooling	Included	$160 Extra	Not Available	$195 Extra	$110 extra	$930 Extra (!)

*Energy effeciency computed per foot of filament extruded, therefore speed and power usage both factor in!
**Converted from British pounds into USD on December 7th 2014 for comparison purposes.

Table 5: Additional information on the selected existing designs

Existing Design:	**Filabot [2]**	**ProtoCycler [3]**	**Homemade Recycler [4]**
Price	~$10,000	~$1,300	~$250
Safety certified	Yes	Yes	No
Includes 3 main functions	No	Yes	Yes
Plastic used	PLA, ABS, PC, HIPS, PP, PS, ULTMEM	PLA, ABS	PLA

3.2 System Level

The existing designs chosen for further background research were Filabot, ProtoCycler, and Filament Extruder by Russ. Each of these existing designs were chosen for further research because the system includes all three functions and are in three separate stages of availability and marketing. Current designs of each system needed to be reviewed to see what was currently available as potential competitors. The systems reviewed can be seen below.

3.2.1 **Existing Design #1: Filabot**

Filabot is a research and development (R&D) company that is impacting the 3D market [2]. Filabot has four individually sold machines on the market: Filabot EX2 Filament Extruder, Filabot Spooler, Filabot Industrial Reclaimer, and Filabot Airpath [2]. These machines have the capability of processing plastics such as Polyethylene Terephthalate (PET), ABS, and PLA. The recycling process starts off with failed 3D prints or plastic pellets. The failed prints can be processed in the Filabot Industrial Reclaimer, which grinds the unwanted prints into pellets. These pellets can be purchased on the website or can be from failed 3D prints of the user. The pellets are then added to the hopper, which feeds the pellets into the auger which pushes them through the heating chamber to be melted and extruded through the nozzle. The Filabot hopper can be seen in Figure 6. The user chooses the temperature preference and diameter size. The temperature is dependent on what type of plastic is used and the diameter is dependent on the 3D printer. Once the plastics are heated it will begin to extrude. The extruded filament is then cooled on the Filabot Airpath, seen in Figure 6, which uses forced convection to cool the filament. The user would need to pull the filament and attach it to the Filabot Spooler which would need to be synchronized with the Filabot Extruder and Airpath. The Filabot Spooler will then maintain a steady spooling speed as the filament is being extruded. Once the process is done, the filament can be used to print.

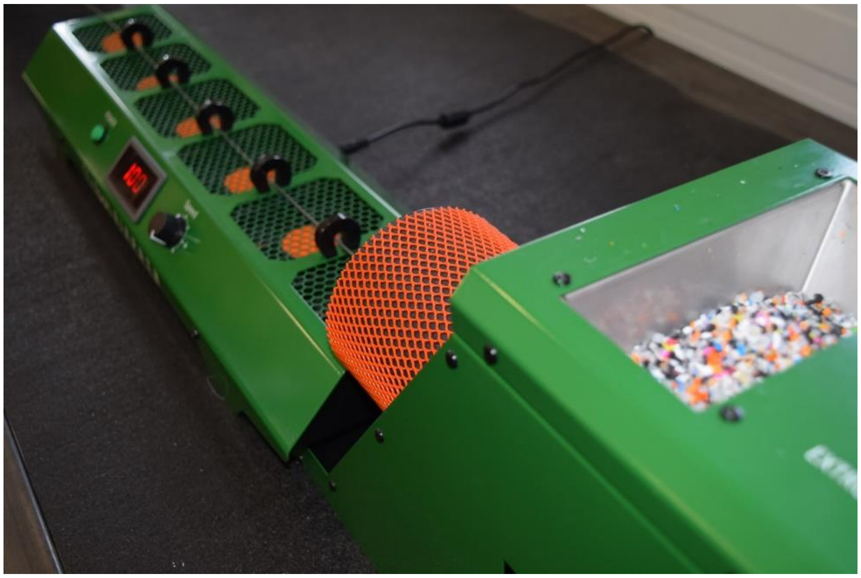

Figure 6: Extruded filament on Filabot Airpath and hopper [2]

The Filabot EX2 Filament Extruder is $2,499 and the Filabot Spooler is $1,200 which totals to over $3,500 for just two machines [2]. The Filabot Industrial Reclaimer is $6,200 and the Filabot Airpath is $649 which would be an extra $7,000. In all, the entire system would cost over $10,000.

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3.2.2 **Existing Design #2: Protocylcer**

ReDeTec is a 3D printing startup with many products in the market including the Protocycler, seen in Figure 7. The Protocycler is a new product that allows you to recycle waste plastic into valuable 3D printer filament. The user can make their filament hassle-free as it contains a built-in grinder, intelligent computer control and real-time diameter feedback. It converts the recycled waste or raw pellets into filament with just pusha of a button. ProtoCycler automatically creates filament at up to 10 feet per minute, at industry leading tolerances, in any color. This filament can be used with any desktop 3D printer [4].

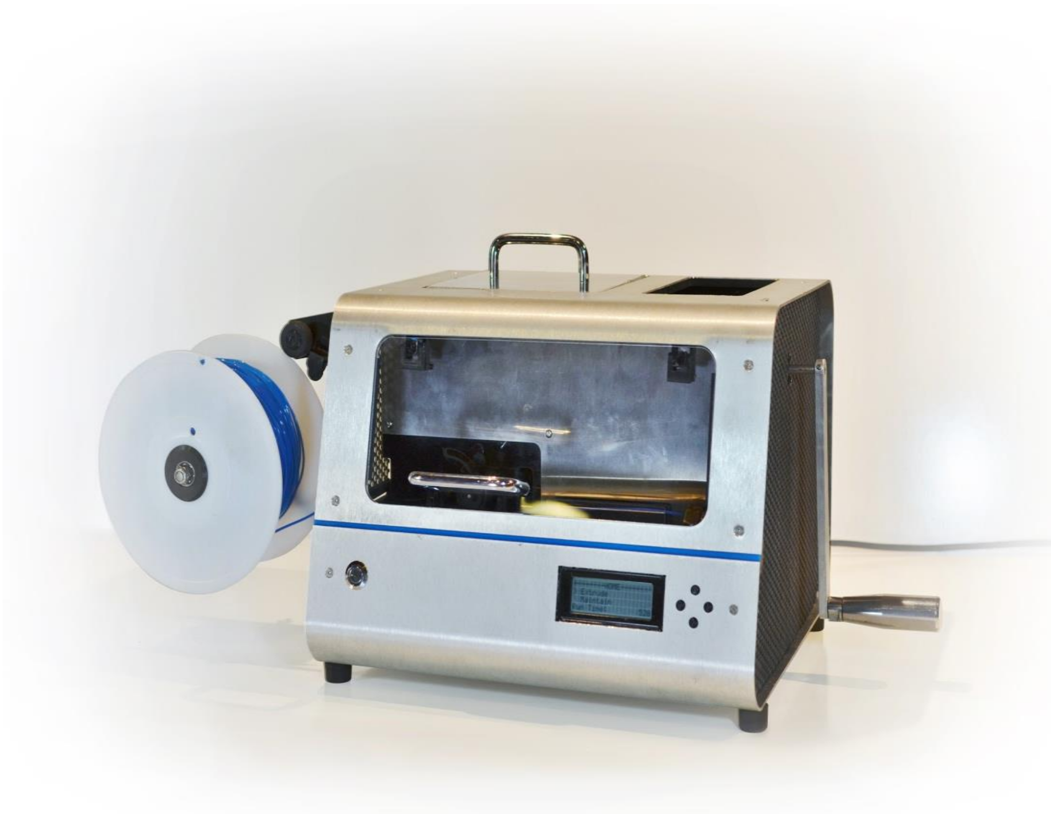


Figure 7: Protocycler Unit [4]

3.2.3 **Existing Design #3: Russ's Homemade Design**

Russ Gries is a researcher and designer with various devices in his own garage. He created his own filament extruder, by using a recycled material for most of his design parts, buying only a wood auger bit and used hair dryers [5]. Russ showcases his designs online through Youtube videos. He also reviews different solutions he came up with for the extruder and spooler. For instance, he tested a torsion spring on his spooler, testing a tight spring and loose spring. Concluding that the looser spring was better for the spool as filament was collected. He used his own recycled filament to create 3D parts in the redesign phase of his project (seen in Figure 8 and Figure 9). The biggest disadvantage to making a DIY extruder is that the product is very difficult to get safety-certified [5]

Figure 8: Russ's Homemade 3D Filament Recycler [5]

Figure 9: Russ’s Extruder Unit [5]

3.3 Functional Decomposition

This section illustrates the functions of the 3D filament recycler machine. It includes a Black Box model and a work process diagram.

3.3.1 **Black Box Model**

Figure 10 depicts the Black Box model of the 3D filament recycler system. It shows the inputs into the system, what makes it function, what materials are inputted into the recycler, and what signals will make the whole system run. The Black Box model also shows the outputs of the system which is the processed plastic, the energy, and the signals.

Figure 10: 3D Filament Recycler Black Box Model

The Black Box model inputs all the unwanted plastic, electricity to power the recycler, full hopper, and an empty spool. As the recycler shreds the unwanted plastic, electricity would be used to power the shredder, extruder and spooler. The full hopper refers to the shredder filament that is fed into the extruder where it would be heated and extruded. The recycled filament would then be collected on an empty spool.

The Black Box model shows the output of the recycler as spooled filament, an empty hopper, and a full spool. The extruder would feed the spooler with recycled filament and as a result, the filament would be collected on the spool. The hopper would be empty indicating that the system processed all the unwanted plastic into filament.

3.3.2 **Work-Process Diagram**

Figure 11 illustrates a work-progress diagram of the 3D filament recycler, broken into its sub-functions explaining their materials, energy types, and signals. The functional decomposition chart is important to this project because it shows the inputs during different stages of the system and breaks down the energy inputs and outputs. This is essential for knowing what will be anticipated for the system as designing progresses.

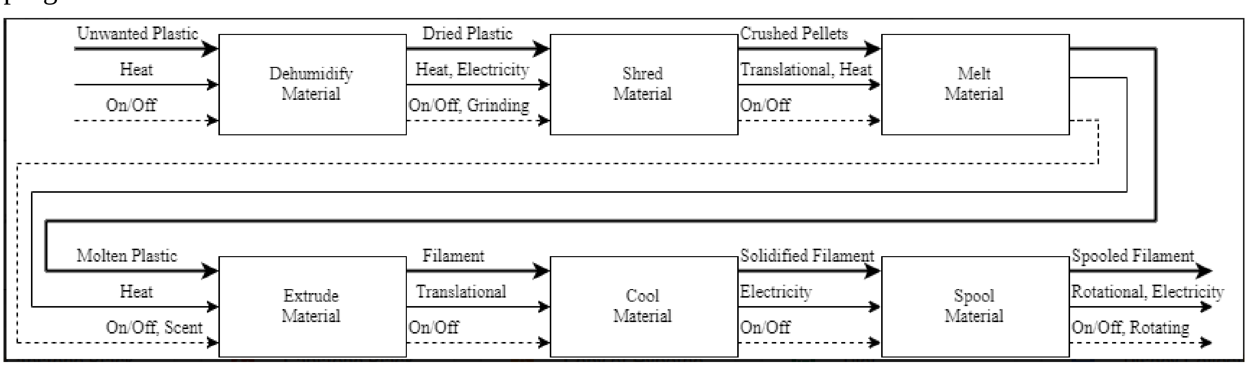


Figure 11: 3D Filament Recycler Work-Process Diagram

The Work-Process diagram was divided up into the individual subsystems with some additional steps to create quality filament. The first function dehumidifies the 3D scraps to eliminate any traces of H2O in the material. Inputting heat and unwanted plastic, and heating it to evaporate any unwanted H2O particles that remain on the product. H2O can ruin PLA and ABS and change its material properties. This function outputs dried plastic that is ready to be recycled. Next, the dried plastic is shredded in the first subsystem of the recycler. This entails breaking down the dried plastic into smaller pieces to feed into the next subsystem. The extruder subsystem includes the following functions: melting material, extruding material and cooling filament. The melting material function inputs the crushed pellets from the previous function and electricity to heat the plastic. This function outputs molten or melted plastic and heat. The molten plastic is then inputted into the extruding function and filament is outputted. The filament is then inputted into the cooling function and outputs solidified filament. The spooler subsystem describes the last function in the Work-Process diagram. Solidified filament is collected on a spool and spooled filament is outputted.

3.4 Subsystem Level

There are three subsystems within a typical 3D filament recycler: shredder, extruder, and spooler. The team researched three different types of these subsystems to further understand the functions and processes the units provide.

3.4.1 **Subsystem #1: Shredder**

Shredders are responsible for crushing waste plastic or raw material. The raw material enters the grinder and is crushed into small pieces or pellets. The grinder uses shear and compression forces to crush the raw material depending on the type of mechanism used in the shredder. The shredder is a vital component in the extruder as it sizes the material to fit into the extruder for further processing [6].

3.4.1.1 ***Existing Design #1: Filabot Reclaimer***

The Filabot Reclaimer (see Figure 12), is one of Filabot's products to compliment the extruder system. The shredder is a commercial-quality plastic processing unit that granulates plastics down to a particle size where the Filabot can extrude. It is powerful enough to effortlessly recycle failed 3D prints at 100% infill as well as other plastic material allowing the user to recover these resources for conversion into 3D filament. The unit processes material at a rate of up to 170 pounds per hour and operates at low RPM, preventing thermal degradation of the regrind. The Filabot Reclaimer has a universal 230V AC 3 phase power input [2].

Figure 12: Filabot Reclaimer [2]

3.4.1.2 ***Existing Design #2: Protocycler Shredder***

Unlike the Filabot Reclaimer, the ProtoCycler's shredder is built-in with the extruder. All the three main components are included in the device which benefits in smooth flow of the process. The device does not use a motor to power the shredder, but instead a hand crank (for safety reasons) as it has been engineered to provide the fastest, easiest shredding possible. Cranking ensures the safest experience possible and helps keep costs low. The grinder feed is 5" x 5" and contains blades which are placed in two shafts that are driven by two gears. The ProtoCycler grinder can be seen in Figure 13 below [4].

Figure 13: Protocycler Shredder [4]

3.4.1.3 ***Existing Design #3: Russ's Homemade Shredder***

Russ's shredder performs with an auger bit that sits in a steel casing. As raw material passes through the auger bit (see Figure 14), it crushes the raw material into pieces and is forwarded to be heated. The grinding element is built-in. To save time on manufacturing, the auger bit was store-bought. One disadvantage may be that limited force at the auger may not be capable of grinding the raw material at a substantial rate, making large parts difficult to shred [5].

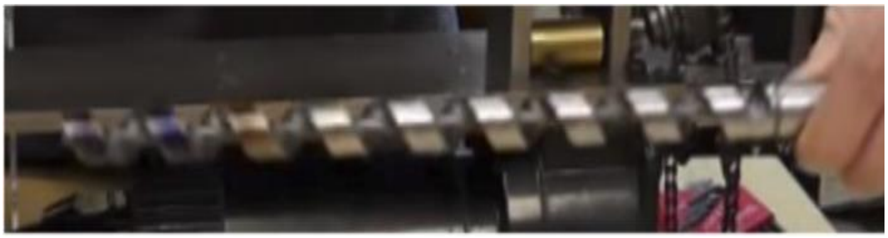


Figure 14: Russ's Shredder Auger Bit [5]

3.4.2 Subsystem #2: Extruder

An extruder is the main body of a filament recycler. The hopper, auger, and heating chamber are three main components located on the extruder, and together they turn the shredder plastic pellets into filament. The control boards are commonly inside of the extruder housing for compact form. The control board has to control the motor for the auger, which in turn sets the production speed of filament coming out of the extruder [7].

3.4.2.1 *Existing Design #1: Filabot Extruder*

The extruder is designed to produce 1.75mm and 2.85mm filament within a tolerance of ±0.05 mm, extruding at a rate of 251 ipm (inches per minute) with adjustable controls. The temperature can be set to a maximum of 450°C. The plastics it can extrude are ABS, PLA, PC, High Impact Polystyrene (HIPS), Polypropylene (PP), Polystyrene (PS), and ULTEM. The power system used can be bought to run on 110VAC or 220VAC with a draw of 500 watts depending on region locations. The extruder can take powder or pellets up to ⅛ inch [2].

3.4.2.2 *Existing Design #2: Protocycler Extruder*

The recycler's extruder works with PLA and ABS and produces diameters of extruder with a tolerance of ±0.05mm. The maximum temperature is 260°C with a control unit that regulates temperature along with other feeding speeds, and the power consumption is about 90 watts for the unit. The extrusion speed can reach up to 10 feet per minute. The unit also allows for manual overrides for customization of the extruder machine [4].

3.4.2.3 *Existing Design #3: Russ's Homemade Extruder*

This homemade extruder has features similar to the previous two designs. It has easy adjustment of temperature and speed control. It is also easy to see the current temperature and speed on the control unit. However, unlike the other products he crafted the machine out of "scraps" and common household materials [5].

3.4.3 Subsystem #3: Spooler

The spooler mechanism for the 3D filament recycler plays a huge role in filament recycling. The spooler is used to collect the extruded filament onto a spool. If a mechanical spooler is not present, the user is left to spool the filament by hand. Different methods of spooling were researched on existing designs such as an attachment for the extruder, or an all in one recycler. Filabot sells the spooler individually and is a completely separate unit that can stand alone. This means the placement of the spooler can be almost anywhere, but this increase the amount of space required [6].

3.4.3.1 ***Existing Design #1: Filabot Spooler***

The Filabot spooler (seen in Figure 3) is one of Filabot's products to compliment the extruder system. The spooler allows the user to adjust the speed of the puller wheel so the spooler pulls filament from the extruder at speed will not that allow the filament to get tangled or fractured. Users can customize the holder for spools sizes of up to 8.5" x 3" [2]. The spooler unit winds the filament consistently to prevent tangles in the spool. It also assures the spool is as compactly wound as possible. The control knobs are labeled physically on the machine, so adjustments are more difficult than having a digital screen. The Filabot spooler has a universal power input for 110VAC and 220VAC [2].

Although the spooler is an important component for a 3D filament recycler, it is not included with the Filabot Extruder, costing an extra $1,200. Because Filabot sells the spooler individually and is a completely separate unit that can stand alone, a disadvantage with Filabot is the extra cost.

3.4.3.2 ***Existing Design #2: Protocycler Spooler***

Unlike the Filabot spooler, the ProtoCycler spooler is attached to the recycler as seen in Figure 15. The benefit of having all three main components in one machine is that processing is normally smoother where it distributed spooling produces evenly distributed filament on the spool with little to no chance of tangled filament [4].

The ProtoCycler spooler is attached at the end of the recycler. The distance between the spooler and the extruder is kept to a minimum since the device is an all in one machine. The spooler is mounted to the Protocycler on the left side. It is attached by an arm that comes out from the main body of the machine. The distribution module is guided by a servo which is a small device that has an output shaft, and it moves back and forth to organize a distributed amount of filament on the spool. The filament is then collected using a clutch system. The clutch system uses a motor on one shaft with the spool on another shaft and it's connected with a timing belts. The clutch system slips, pulling the filament with enough force to pick up the slack [4].

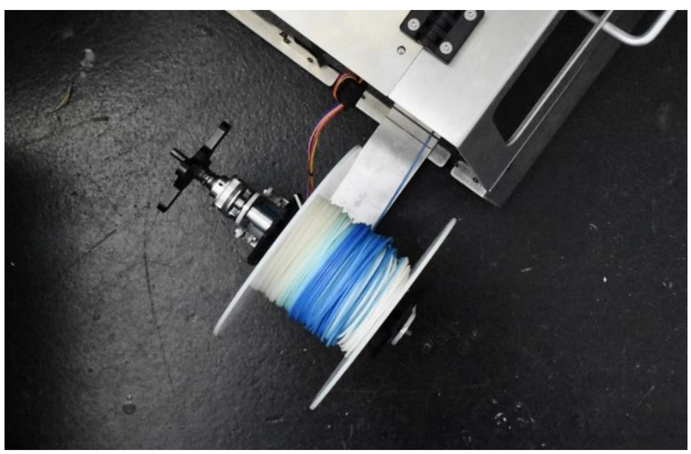


Figure 15: Protocycler Spooler [4]

3.4.3.3 ***Existing Design #3: Russ's Homemade Spooler***

Russ's Filament Spooling Oscillator as seen in Figure 16, is one of the three main components of his filament recycler. The spooler is mounted alone on a pegboard separately from the extruder and shredder units. This style allows the unit to be mounted anywhere on the pegboard. He uses magnets to adjust the distance between the spooler and the extruder. The rotating shaft holds the spool is attached to a belt that is connected to a gearbox. The gearbox creates a reduction to the oscillator which allows the filament to move back and forth on the spool while it is winding. This is similar to the other existing spooling machines researched. Russ's Filament Spooling Oscillator is still going through testing. His testing involved re-spooling filament onto an empty spool with the device. He observed that he needed a wider spool to collect the filament because of the size of his oscillating mechanism [5].

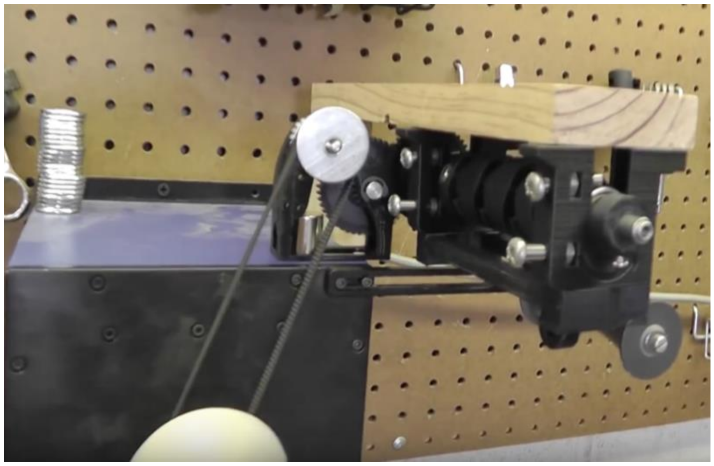


Figure 16: Filament Spooling Oscillator [5]

4 DESIGNS CONSIDERED

The functions were divided into by the three different subsystems for the recycler. There were seven different designs for the shredder, six designs for the extruder, and four designs for the spooler. The team mixed and matched the different subsystems to create different designs. Appendix B explains how each design works along with the pros and cons on four different full-system designs. The following sections explain the team's top three designs per function.

4.1 Design #1: Shredder Designs

While designing different functions of the recycler, household items which similar functions to shredding that could be used to shred or break apart materials were considered. Table 6 weighs the pros and cons of each design considered.

Design 1 for the shredders is based off of a blender. Having this in mind, the team developed the idea of a blender-type shredder. Design 1 has multiple layers of blades on a shaft that are attached to a motor. The shaft sits vertically upright in a container that has a cover. The failed prints or filament that is placed into the container would be shredded with the blades as it rotates.

Design 2 is inspired by the idea of a paper shredder or wood chipper. A paper shredder has a horizontal set of shredding blades that rotates on two shafts. This is similar to Design 1 except that there will be two shafts with counter rotating blades positioned at a certain distance from each other. The shafts will be rotating inward grabbing the failed prints, shredding them and releasing the pieces to the bottom of the shredder.

Design 4 is based off an immersion blender. This kitchen gadget has a rotating blade at the end of the tool allowing the user to move the blades around to where it needs to be specifically. Similarly, design 4 except the blade would only be able to move vertically in an enclosed container.

Table 6: Pros and Cons of Shredder Designs

Design	Pros	Cons
1	Filters through shredded pieces through the bottom	Chance of getting plastic stuck in the blades
2	Little to no chance of getting plastic stuck in blades	Dangerous due to the exposed blades of the design
4	Blades move according to size of the failed prints	Chance of the blades hitting the bottom of the container

4.2 Design #2: Extruder Designs

The extruder consists of a hopper, auger, heating coils, and a nozzle. Filabot, Protocycler, and Russ's homemade design they all use an auger-type extruder system, which influenced some the designs made. Another source of inspiration came from plastic injection molding and how pressure is used to force plastic into molds. The piston designs came from the same idea of trying to create a pressure force that would push plastic through the extruder. The team decided to use the auger-type system due to the concerns of accuracy and control in the other designs. Table 7 shows the pros and cons for each of the extruder designs considered.

Design A is a representation of the auger-type system placed in a horizontal position. This is a common design among current commercial and homemade designs. The hopper would be placed on top where the plastic pellets are inputted and funneled by the auger down the heating chambers. In the heating chamber the pellets will be melted so they can be extruded out of a precision sized nozzle.

Design B is the auger system set up in a vertical position. This design looks similar to an upside-down bottle to combine the hopper and auger placement. Benefits of having it vertical would be the help of gravity pushing down on the plastic pellets as it melts into the heating chamber and out of the nozzle. There would also be no issue of the filament sticking to the nozzle as its extruded.

Design E is the auger system in a tilted angle of about 105°. This system would implement similar positives as Design B since gravity would still help push the plastic pellets through the extruder. It would look similar to Design A also, but would have a smaller base. By putting it in the angle, there is the possibility of placing more components around the extruder.

Table 7: Pros and Cons of the Extruder Designs

Design	Pros	Cons
A	Easy feeding from the hopper with shredded plastic	Filament might be susceptible to sticking to bottom of nozzle
B	Uses gravity rather than pressure to move melted filament downward	Upright position makes it easier for the machine to topple over
E	Uses gravity to push the melted filament through extruder	This design would have a relatively smaller base

4.3 Design #3: Spooler Designs

The spooler designs were inspired by objects in daily applications, like a towel holder, sewing machine spooler, and a tire changing machine. Table 8 lists the pros and cons of the considered spooler designs.

Design I is similar to an electric paper towel dispenser. The spool slides onto a horizontal rod. The motor is also separated from the spool rod and is driven by a belt system, which would allow for mechanical advantages but adds more parts.

Design II uses a motor that is directly attached to the spool rods. Having the motor and rod directly attached simplifies the design with less parts and a smaller form factor.

Design IV is spool-incorporating a gear, driven by a motor that also has a gear attached. This design allows for different mechanical advantages by allowing more gears to be added. Similar to a transmission the gears allow for torque and speed advantages, and by being able to change the layout the motor, it can be set to one constant speed.

Table 8: Pros and Cons of the Spooler Designs

Design	Pros	Cons
I	Mechanical advantages of having the spooler on separate shaft than motor	Amount of space required in between the spooler and motor
II	Having the spooler directly attached to the motor, easy assembly	Limits the ability to mount spool since it is the same as the motor
IV	Speed and torque advantages due to the gear train	Extra material and more expenses towards parts

4.4 Design #4: Full System Designs

Below are a few full system designs that were a combination of a shredder, extruder, and spooler design. The names of each design was based on the type of shredder, extruder, and spooler. Shredders were categorized as 1 through 7, extruders A through F, and spoolers I through IV.

4.4.1 **Design #1: 2EII**

This design is the combination "2EII". The shredder was inspired by a paper shredder with two horizontal blades that rotate inward. The extruder is positioned on an incline of 105º, this allows gravity to help the extruded filament exit the nozzle with gravity assistance. The spooler has a motor that will sit upright, having the spooler on top of the shaft. The design can be seen in Figure 17.

The Pugh chart in Table 9 shows, this as one of the highest-ranking designs. The pros of this design is that it is easy to use and the gravitational force will allow the device to be more reliable. A con to this design is that the spooler is sitting vertically which can make the filament unevenly distributed across the spool, causing the filament to be tangled and uneven.

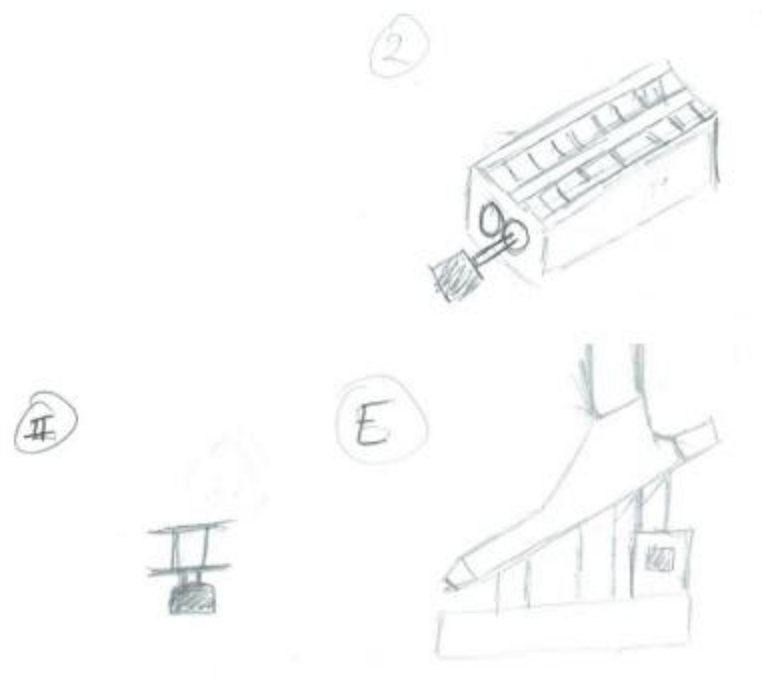


Figure 17: Design 2EII

4.4.2 **Design #2: 1AI**

Between the different sketches of extruders, shredders, and spoolers from Appendix B, design "1AI" was conceived. The shredder shown in Figure 18, represented by the number "1", is a design similar to a blender, except the shredder would consist of more blades to better break down the plastic pieces into pellets. It also has the possibility of sitting on top of the hopper and feeding straight into the extruder. The extruder, represented as "A", is mounted horizontally on a base that will house the speed and temperature controllers. The extruder uses an auger type system where plastic pellets are fed through a hopper and then pushed by a rotating spiraled shaft in a pipe. As the pellets move down the pipe they are heated to the melting point and extrude out the nozzle at the end of the pipe to become filament. The filament extruded is then wound by the spooler, represented by "I". The spooler is mounted similarly to a paper towel dispenser, attached to a motor that is controlled by the speed controller.

The team reviewed this system in the Pugh chart (see Table 9) and found it to be one of the higher ranked systems. However, the team felt that the "1AI" didn't have any originality to it, as the system is very similar to current products on the market. An advantage to the system is that it would be easy to design and manufacture. A possible negative effect would be the shredder not being able to consistently make small pellets.

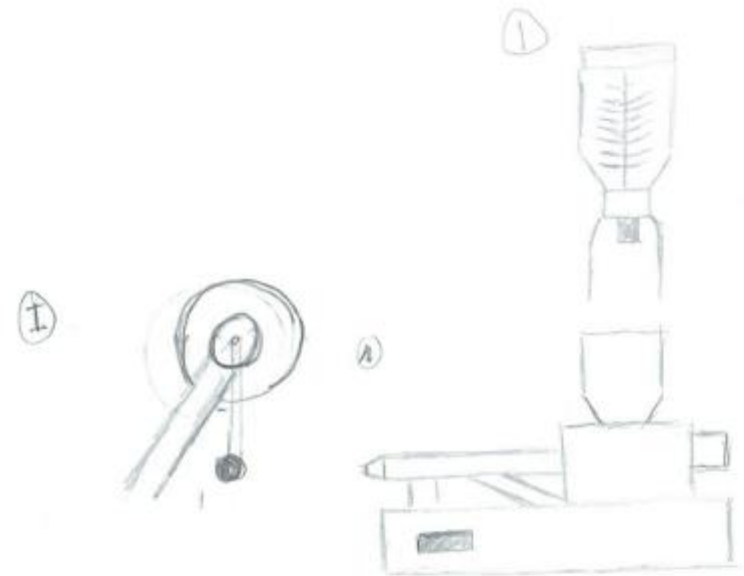


Figure 18: Design 1AI

4.4.3 **Design #3: 3BI**

For design "3BI", the shredder shown in Figure 19, uses blades similar to a blender. With two layers of blades that would help refine the plastic into smaller pellets, the horizontal position will help compact the size. The extruder, is in the vertical position allowing the pellets to be placed collinear to the auger. The spooler is the same design used in "1AI".

A benefit to this design is that gravity help pushes down on the melting plastic as it comes out of the extruder and how it takes more space vertically than horizontally, which would allow for more Table space. This design ranked in the top four designs in the Pugh chart, but the team concluded that using a blender type shredder is too unreliable. There was also a concern that the final system could be too tall and perceptible to falling over.

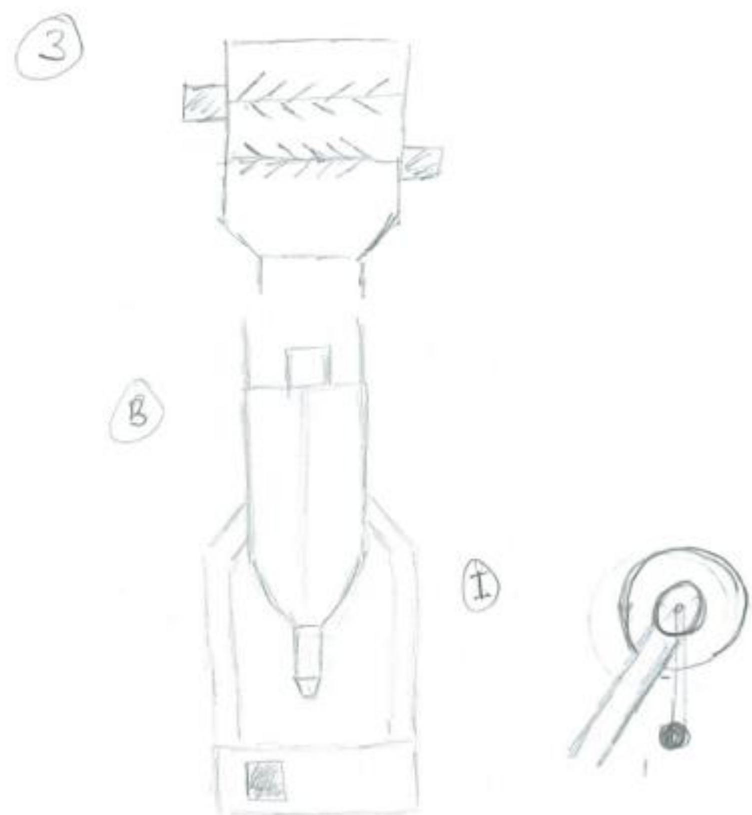


Figure 19: Design 3BI

4.4.4 **Design #4: 2BIV**

The "2BIV" design (see Figure 20) includes a shredder-like a wood chipper or paper shredder. It has two shafts and blades connected by motorized gears. The extruder is placed perpendicular to the base where crushed plastic, fed from top, gets pushed down by an auger. The spooler is attached by a gear in the center and driven by a motorized gear that attached underneath it.

According to the Pugh chart, the team found that it is one of the highly recommended designs by rank. The advantage to this design that it has more durability, reliability, safer, and easy to use. The disadvantages of this design that it is not affordable and very difficult to connect the filament to the spooler.

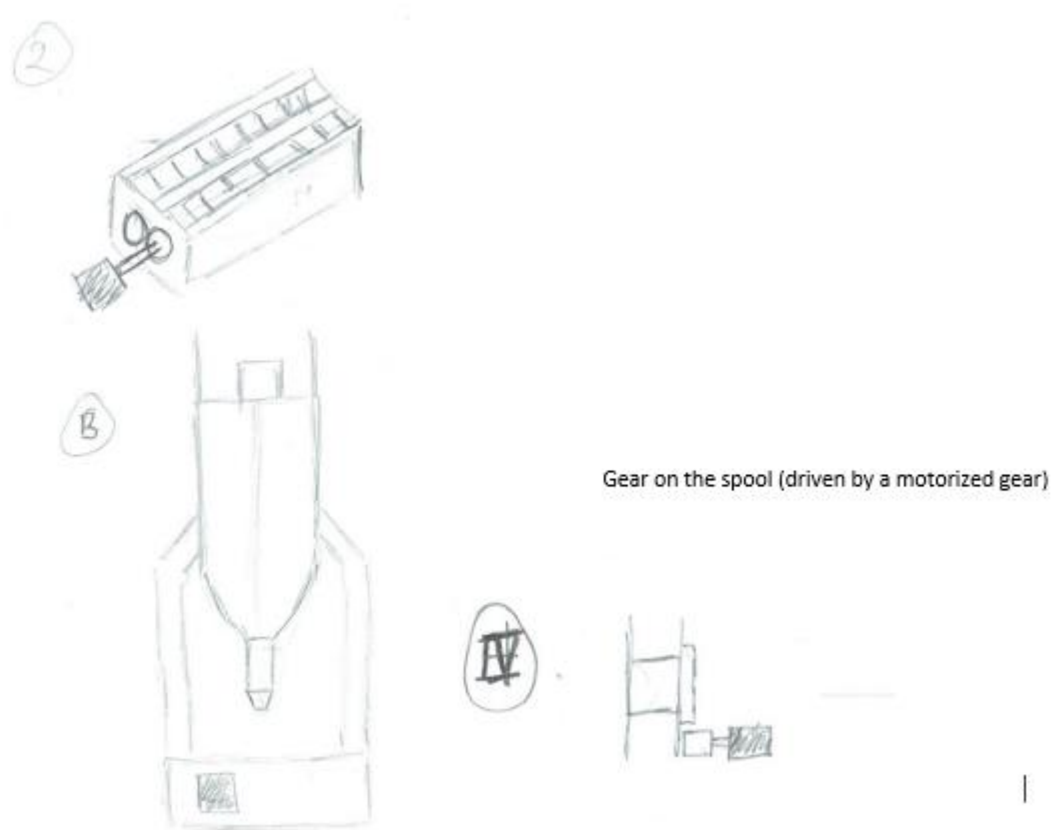


Figure 20: Design 2BIV

5 DESIGN SELECTED – First Semester

The design "2EII", was selected by the team to move forward in the design process. The team chose this design by using a Pugh chart and decision matrix. This section also explains how the design will work as well as how the design will look with engineering drawings and pictures of prototypes.

5.1 Rationale for Design Selection

The team narrowed down ten designs with a Pugh chart seen in Table 5. The designs were ranked based on criteria from the customer needs. Carefully looking at the designs, the team decided whether the design would receive a + or - based on the datum. The team chose the Protocycler as the datum because it is an existing recycler that includes all three functions in one machine, recycles the same plastics (PLA and ABS), and was one of the only machines researched that is currently on the market to successfully achieve similar customer needs as the team.

Table 9: Designs Pugh Chart

CRITERIA	DESIGNS										
	Protocycler	2EII	1AI	3BI	4FIV	5EII	6DIII	7FII	4CIII	3CI	2BIV
Safe to use	D	-	+	+	+	-	+	-	+	+	+
Reliability		+	-	-	-	-	-	-	+	-	+
Durability	A	+	-	+	-	+	-	-	-	-	+
Includes 3 functions (shred, extrude, spool)		+	+	+	+	+	+	+	+	+	+
Affordable	T	-	+	-	-	-	+	+	-	-	-
Filament Accuracy		+	+	+	-	+	+	-	+	+	-
Size/Compatibility	U	-	-	-	-	-	-	-	-	-	-
Easy to use		+	+	+	-	-	-	+	-	+	+
	M										
SUMS											
+		5	5	5	2	3	4	3	4	4	5
-		3	3	3	5	5	4	5	4	4	3
TOTAL		2	2	2	-3	-2	0	-2	0	0	2

The designs 2EII, 1AI, 3BI, and 2BIV were the highest ranked in the Pugh chart. The Pugh chart was a good method to use to narrow down ten designs to four.

These four designs were put into a decision matrix where the team ranked each design based on the customer needs on a scale from one to five. One being that the machine could not satisfy the customer need and five being that it could completely satisfy the customer needs. The decision matrix allowed the team to rate each design with greater fidelity based on the design's functionality versus customer needs. The highest score was for design 2EII. The results from the design matrix can be seen below in Table 10.

Table 10: Designs Decision Matrix

Designs Considered									
Criteria	**Weight**	**2EII**		**1AI**		**3BI**		**2BIV**	
		Rank	Weighted	Rank	Weighted	Rank	Weighted	Rank	Weighted
Safe to use	5	3	15	4	20	3	15	3	15
Reliability	3	4	12	3	9	2	6	3	9
Durability	2	4	8	2	4	2	4	3	6
Has 3 functions	3	5	15	5	15	5	15	5	15
Affordable	1	3	3	3	3	3	3	3	3
Filament Accuracy	2	3	6	2	4	3	6	3	6
Size	2	4	8	2	4	3	6	3	6
Easy to use	2	5	10	4	8	4	8	5	10
Total	20		77		67		63		70

5.2 Design Description

The design 2EII, was selected for the design the team wanted to pursue. See Appendix C for the full CAD drawing package of the current design. The CAD drawings have built-in tolerances in the dimensions. For general length dimensions, the tolerance is ±0.03 inches and hole placements or for critical dimensions, the tolerance ±0.010 inches.

Despite the cons of this design, there were modifications that could be done to the design to make the design more efficient. Solving this disadvantage was easy to do. There needed to be a small mechanism that moves back and forth, or up and down that allows distributed spooling. Compared to the other designs, the shredder in the design seemed more efficient than a spinning blade that was in other designs. The shredder can be safer than other designs because an enclosure could be made to protect the user from the rotating blades.

Since the design is gravity assisted, the reliability is better because there is less need for a mechanism for pushing melted filament through the extruder. The fully upright designs for the extruder may provide too much gravitation force that may clog up the machine or extrude the filament faster than desired. This design helps with the filament accuracy and it makes it easier to control the feed speed.

The fully automated design of 2EII would make the device easy to use. Once the filament is put into the device the filament would be shredded, extruded and be fed to the spooler. It allowed very little user interaction with the machine which leads too little to no chance of injury and repeatable results.

In addition to the above-mentioned design advantages, the affordability of this design is the most ideal. The parts that are required for this design can be 3D printed or bought, allowing the team to keep the cost of the entire machine under $2,000.

5.2.1 **Shredder**

The original design for the shredder can be seen in Appendix B indicated with the number 2. The shredder has two inwardly-rotating shafts to grip onto the filament to feed to the hopper. The shredder (seen in Figure 21) would be powered by one motor having gears to transmit power through both shafts. The torque the shredder needed to exceed is about 15 ft-lb. The shredder needed to be able to overcome the tensile strength of the PLA and ABS filament.

The team decided to redesign the overall shape of the shredder since the original shape was a unique which can be difficult to manufacture. The shredder is also independent of the extruder and spooler, allowing the machines to fit in smaller spaces. The pellets will now be hand-fed into the extruder after shredding. An advantage to this design also allows the user to shred as much plastic as they want without overflowing the extruder. The blades for the shredder will all be the same size rather than alternating the two different sized blades on the shaft. The team decided on the larger blades and alternating the orientation of the blades on the rotary shaft.

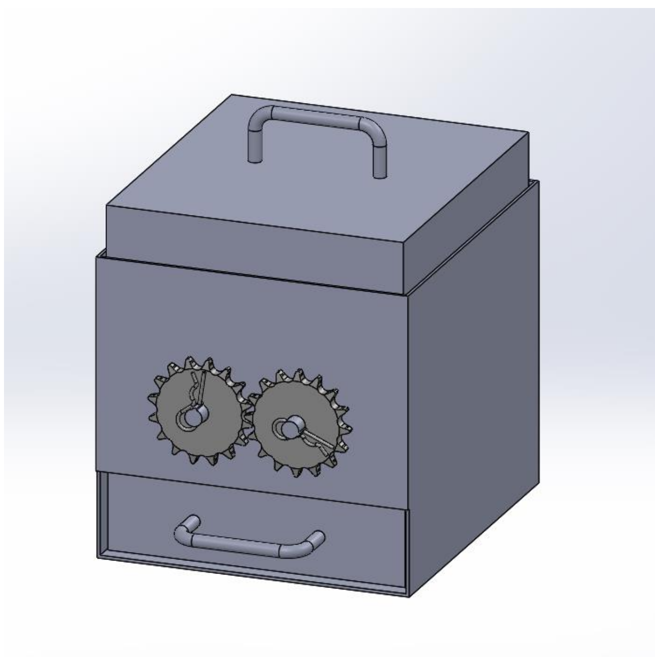


Figure 21: Shredder CAD Model

5.2.2 **Extruder**

The extruder and spooler will be combined on one base (see Figure 22) to keep a fixed location between the extruder nozzle and spooler. The extruder and spooler are bolted into pallet wood. The CAD model is seen below.

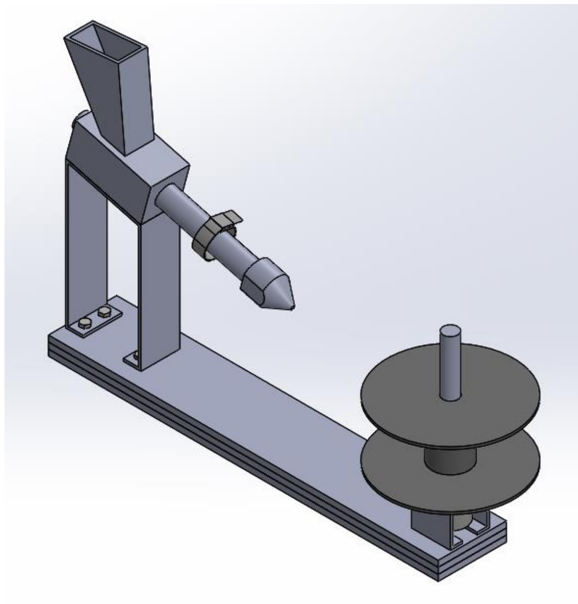


Figure 22: Extruder and Spooler with Base

The heating elements of the extruder (seen in Figure 23) will be heating bands that will be placed around an aluminum tube. The heating bands will be controlled with an Arduino to ensure the correct melting temperature for the filament. The extruder can be seen in Appendix B, indicated with the letter E.

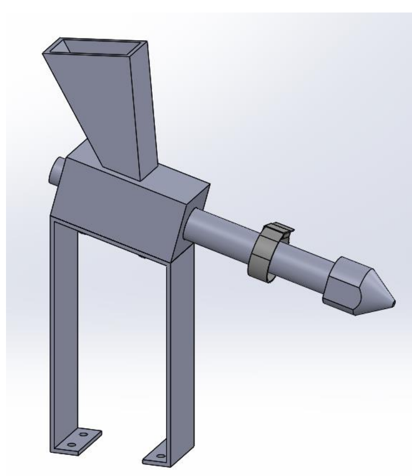


Figure 23: Extruder Assembly

5.2.3 **Spooler**

The spooler is power on one motor, attached with four cap screws at the motor mounts. The use of a soft torsion spring will be used in efforts to help adjust the spool speed when necessary. This will allow different size of spools on the spooler without having to change the spool speed. The spooler can be seen in Appendix B, indicated with the letters II. The CAD model can be seen in Figure 24.

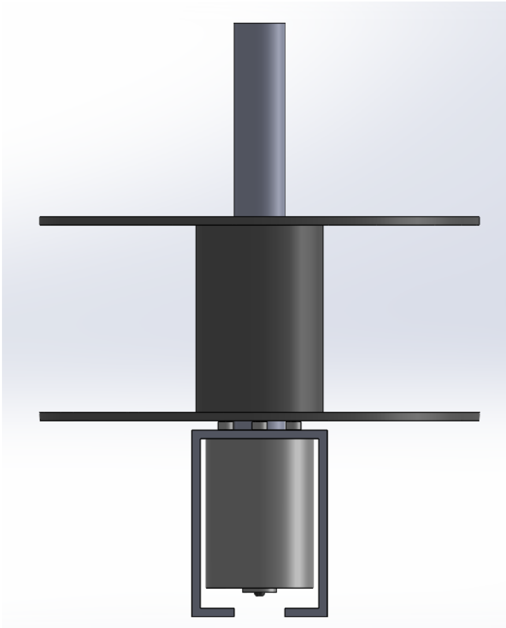


Figure 24: Spooler Assembly

6 PROPOSED DESIGN

The implementation of the proposed design, will be conducted during Spring Semester. The schedule, prototype, Bill of materials, and budget will be discussed in this section.

6.1 *Phase 1*

January 15th - February 9th, 2018

The breakdown of Phase 1 can be seen below in Figure 25. This phase will entail manufacturing the main parts of the shredder and extruder, assembling the recycler, programming the control board, and testing the plastics compatible with the recycler.

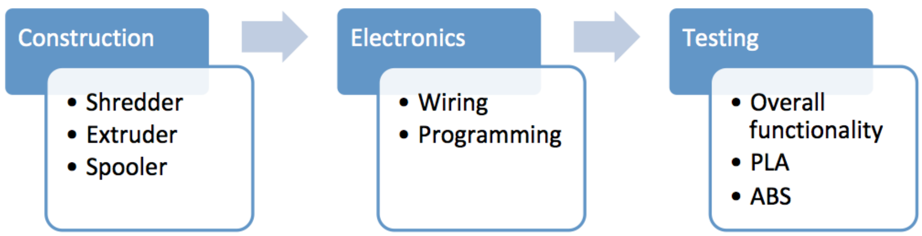


Figure 25: Phase 1

6.1.1 **Construction**

During the beginning of the spring semester, (January 2018) the three main components will be constructed. The parts and material selection were made by performing analytical analyses to determine the optimal performances for each function. The entire 3D filament recycler will be assembled throughout this phase. The construction process will be from January 16th - February 2nd, 2018 and take place in the 98C Engineering Fabrication Shop. The first two weeks will be dedicated to manufacturing the parts designed by the team. For the shredder, the blades and the shredder housing will be manufactured. The hopper, extruder housing, and the nozzle will be manufactured for the extruder. The last week will be for assembling the entire recycler, January 29th - February 2nd, 2018.

6.1.2 **Electronics**

Electronics will be done during the last week of this phase, February 5th - February 9th, 2018. An Arduino will be used as the control board and programming will be done to ensure the amount of power to the motors are sufficient. Wiring will also be done to connect each mechanism (shredder, extruder, and spooler) to the control board.

6.1.3 **Testing**

Testing will be done simultaneously with the electronics on February 5th - February 9th, 2018. Testing needs to be implemented on both PLA and ABS filament to ensure that the recycler can process both materials. Testing will also include adjusting the procedure for cleaning out the recycler so that the plastics do not get combined when the user wants to recycle PLA after ABS and vice versa.

6.2 *Phase 2*

February 12th - April 23th, 2018
Phase 2 will be a five-week timespan and will encompass machine modifications, the Midpoint Report, and Annual Undergraduate Symposium (UGRADS). The outline of Phase 2 can be seen below in Figure 26.

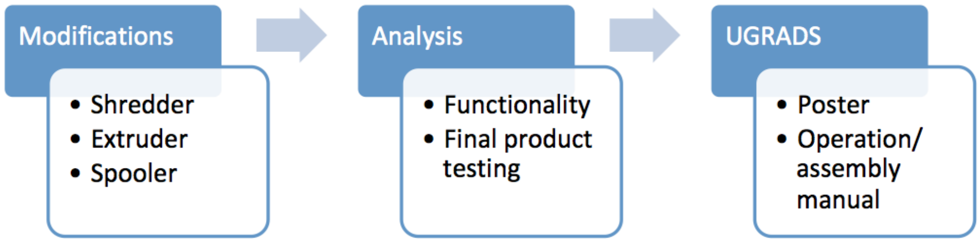


Figure 26: Phase 2

6.2.1 **Modifications**

The changes that need to be implemented will be done during this phase. Modifications to the three main components (shredder, extruder, spooler) will done here as well. This involves creating a housing for the entire machine so that it is safe and aesthetic. Modifications are inclined to be done with by the first week of March so the new changes can be presented at the second Hardware Review on March 6th, 2018.

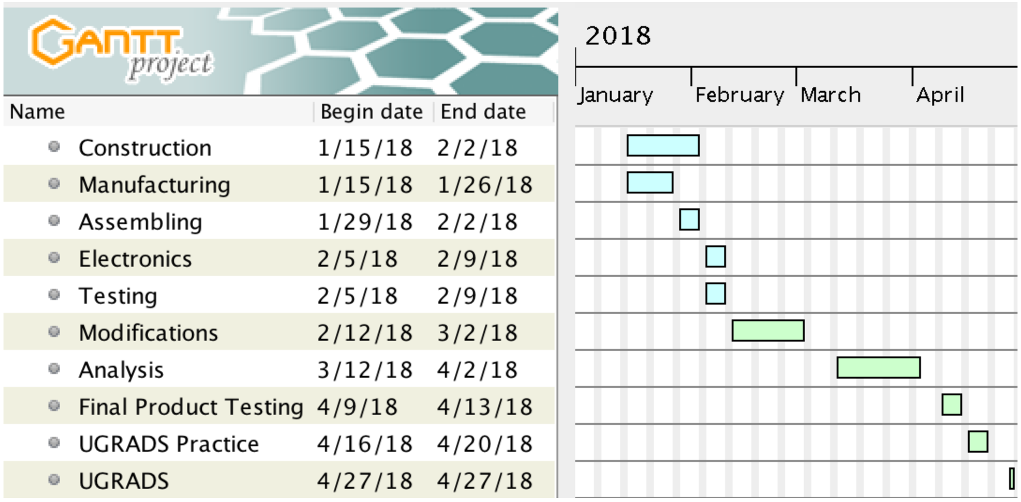
6.2.2 **Analysis**

The machine's functionality needs to be analyzed after modifications are done. There will be a testing phase from March 12th - April 2nd, 2018. The three main functions will be assessed as well as testing the filament produced in a FDM printer. Final product testing will be conducted two weeks prior to UGRADS, April 9th - April 13th, 2018. This will entail ensuring that the shredder can break down failed prints at the maximum size (12"x12"x12"), the extruder produces filament that is 1.75mm (0.06889in) in diameter, and the spooler does not break the filament as it is being collected.

6.2.3 **UGRADS**

UGRADS will take place on Friday, April 27th, 2018 at the J. Lawrence Walkup Skydome. The poster for the symposium will be worked on during this phase. The draft of the UGRADS poster and operation/assembly manual will be due on Tuesday, April 3rd, 2018. Practice for the symposium will be conducted during the mid-April, April 16th - April 20th, 2018. The final poster and operation/assembly manual will be due the week before the UGRADS symposium.

The overall schedule can be seen in the Gantt Chart in Figure 27. The light blue represents Phase 1 and the mint green represents Phase 2.



Name	Begin date	End date
Construction	1/15/18	2/2/18
Manufacturing	1/15/18	1/26/18
Assembling	1/29/18	2/2/18
Electronics	2/5/18	2/9/18
Testing	2/5/18	2/9/18
Modifications	2/12/18	3/2/18
Analysis	3/12/18	4/2/18
Final Product Testing	4/9/18	4/13/18
UGRADS Practice	4/16/18	4/20/18
UGRADS	4/27/18	4/27/18

Figure 27: Gantt Chart for Second Semester

6.3 Prototype

The team constructed a downscaled version of the shredder, extruder, and spooler. For clarity, the housing for the entire machine was not constructed so that the internal components would be visual. The prototype can be seen in Figure 28. The 3D printed shredder and extruder are made out of PLA, which will later be recycled by completed machine.

Figure 28: Prototype I

6.4 *Bill of Materials (BOM)*

Appendix D shows the BOM of all the material used in the 3D recycler. The list includes the part numbers and costs of all the purchases materials. The materials are divided into five sections for materials and expenses: shredder, extruder, spooler, external, and testing. It shows the raw materials for the different components for the recycler. Please note that hardware used in the recycler is deemed free due to class fees and the availability of these parts at the machine shop but they are listed in the BOM. The main sources for the materials are Metal Supermarkets, Amazon, Home Depot, HomeCo., and Southwest Steel Sales, LLC [9] [10] [11] [12] [13]. A lot of the material was purchased in store to reduce shipping costs and time].

The material choices for all the mechanisms changed due to limited material selection at metal distributors. The shredder teeth are still going to made out of A36 steel and the material for the first iteration of the shredder housing was made out of 5052 aluminum sheet metal. The final iteration of the shredder housing was made out of 5/8-inch-thick particle board.

6.5 *Budget*

The team is currently under-budget. The team has saved over $1,000 with in-store purchases. Table 11 shows the budget break down for the anticipated costs and the actual costs. The totals include tax and shipping and handling. The information shown in Table 11 is a shortened version of the BOM shown in Appendix D.

Table 11: Budget Breakdown

Components	**Estimated Costs**	**Actual Costs**
Shredder	$351.32	$219.79
Extruder	$284.90	$102.88
Spooler	$16.83	$15.99
External	$285.92	$78.97
Hardware	$0.00	$0.00
Testing	$400.00	$14.99
Total	$1,858.00	$476.85

In all, the team is doing well with the budget. The team is well under-budget with a lot of remaining money for replacement parts and testing.

7 IMPLEMENTATION

Spring semester commenced the manufacturing of the 3D filament recycler. The team spent numerous weekends in the machine shop manufacturing parts for the recycler. The following section discusses the work the team has done with manufacturing and the design changes made.

7.1 Manufacturing

The manufacturing that was done was divided into three different parts. Shredder manufacturing, extruder manufacturing, and spooler manufacturing. This section goes in depth on what the team did and the calculations that was done to ensure that the material that was used for manufacturing was sufficient.

7.1.1 **Shredder Construction**

To ensure that A36 steel shredder teeth would not chip or break while crushing filament, an analytical analysis was conducted to make sure that the teeth would withstand the loads that would applied onto them. The assumptions made for this analysis is that the filament that the shredder teeth will try to break are 100% infill PLA. PLA was used in this analysis since PLA has a higher tensile strength than ABS. For safe measures, the analysis was done for a factor of safety of 2. Finite element analysis was done on SolidWorks. The results show that the teeth will withstand the stress it will undergo in the shredder.

The new design for the gears were analyzed to see how much stress and pressure the gears would undergo if the motor ran at maximum capacity. The gears that were analyzed are at a 1:1 gear ratio. The assumptions that were made during this analysis is that the gears are made of 100% infill of PLA, the torque the gears will undergo is 1225 Nm, and move at a constant speed of 30 rpm. The analysis concluded that the gears would exceed the allowable stresses and loads that PLA can handle at 100% infill. Since this is the theoretical stresses that the gears will undergo, the team decided to go with PLA gears anyways to see how it would actually withstand the stresses caused by the shredder. If the teeth on the gears break, other options the team discussed is annealing the gears (putting the gears in boiling water to increase the tensile stress) or having the gears at a different gear ratio.

The following is the outline of the shredder construction:

I. Shredder housing/drawer/guard
   a. Cut aluminum sheet metal
   b. Bend sheet metal
   c. Rivet corners of housing/drawer/guard
II. Shaft for teeth/blades
   a. Lathe down the surface of the shafts
   b. Create keyway for blades and gears
   c. Cut PVC for spacers
III. CNC shredder teeth from 10 x 24 x 0.5 inch A36 sheet metal
IV. 3D print gears

As manufacturing continued, the team cut a 4 x 5 foot 5052 aluminum sheet metal into cut outs of boxes. The overall shape of the shredder housing that was cut out of the aluminum sheet can be seen below in Figure 29. In theory, the corners of the shredder box would be bent at the solid lines. This was done with the shredder guard and the shredder drawer. Flaps were created in order to rivet the sides together. The rivets were done at the edges of the side panels with half an inch away from the edge. The cut section on the right panel of the shredder housing is for the shredder drawer.

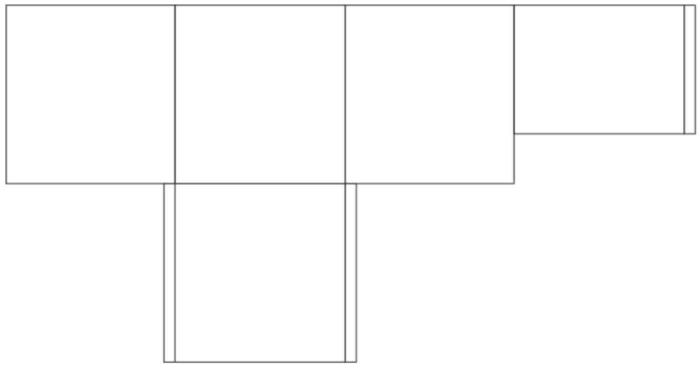


Figure 29 Shredder housing, unbent

The shredder shafts were keyed using a mill. The width of the keyway is 3/16 of an inch and the depth of the keyway is 0.09 inches. Twenty passes were done to each shaft to make the keyway. The depth of cut with each pass was 0.005 inches at 660 rotations per minutes. The keyways were done at a low speed and had a small depth of cut because steel is a very strong material. The slower speed and smaller depth of cut ensured that the bit would not break upon impact.

The work order for the shredder teeth are currently being processed and the teeth will hopefully be done by the end of Spring break. The gears for the shredder are being 3D-printed and will be done by the end of Spring break.

7.1.2 Extruder Construction

The extruder contains several components to melt the plastic. The housing of the extruder connects everything together. A 2 x 3 x 7 inches block of 6061 aluminum was manufactured on the mill to a size of 2 x 2 x 6 inches with a center hole of ⅞ inch made on the 2 x 2-inch side. A ¾"-14 National Pipe Threading (NPT) tap was used on one side of the ⅞ inch hole made to allow the heating chamber to be attached. On the top side a ½ inch hole was drilled using a drill press until it breached into the ⅞ inch hole previous made. This ½ inch hole is where the funnel attaches to the housing and allows plastic pellets to be fed into the extruder.

Manufacturing the heating chamber a ¾ x 5 inches cold rolled steel pipe was taken bored to an ID of ⅞ inch on the lathe. The OD of the pipe was then lathe down to 1 inch and both sides were threaded on the lathe. The threads were redone with a ¾ inch - 14 NPT die to get the threaded taper, which helps to seal and secure the heating chamber snuggly to the extruder housing. This process also helps to attached the store-bought cap to fit properly onto the pipe. The cap is modified by sanding a flat the end of the cap and drilling a hole in the center with a 1/16-inch drill bit to act as the extruder nozzle. The 1/16 inch is equal to 1.58 mm which is slightly smaller than the 1.75 mm filament diameter to help account for extrusion expansion.

The main component in the extruder that drives the plastic through the system is the auger. The auger was modified by cutting 1.5 inches off the drill bit using a cut off wheel. To ensure that the motor chosen has enough torque to drive and push plastic out, analysis was done. The full analysis can be found in Appendix E3. Since the auger acts similarly to a drill, equations intended for a drill bit removing material was used. This idea meant that instead of material being removed from the drill bit, it was delivering material. Since the motor has already been purchased, the output speed is 30 RPM and the maximum torque it can apply is about 900 ft/lb. From the analysis, the auger needs about 311 ft/lbs of torque, so in conclusion the motor power is sufficient. An extra analysis to check for back pressure was done to see if it would be an issue, but the pressure was small enough to be neglected. The auger is attached to the motor using a drill chuck.

To verify that the extruder mount can hold the load of the assembled extruder, calculations were done to figure out the stresses on the mount. The extruder mount is at a 45-degree angle which reduces the load from the extruder. In conclusions, the 6062 T6 aluminum material used for the mount is strong enough to hold up the extruder.

The following is the outline of the extruder construction:

- I. Extruder heating chamber manufacturing
  - a. Bore out inside of heating chamber to create ID of 0.875”
  - b. Thread outside of the heating chamber for nozzle
- II. Extruder nozzle manufacturing
  - a. Sand down the top face of the pipe cap
  - b. Drill 0.158-inch hole using a 1/16 drill bit
- III. Extruder auger
  - a. Cut off tip of drill bit
  - b. Cut 1 and ½” from the auger to fit in extruder housing
- IV. Extruder housing

7.1.3 **Spooler Construction**

The spooler mechanism was completely 3D printed. The motor housing was made from the dimensions of the motor. The spooler shaft was printed as well and went through a couple iterations. The first iteration of the spooler shaft was a cone shaped shaft to accommodate any type or size of spool. The second iteration is a nut and bolt type of shaft. This includes two pieces, one is a threaded shaft, and one piece is a screw-on that goes on the shaft to hold in any size of spool.

The following is the construction done for the spooler:

- I. 3D print motor housing
  - a. Mount motor into motor housing
- II. 3D print spooler shaft
- III. Solder extension wires to motor

7.2 Design Changes

Design changes were made it became too difficult to manufacture or acquire parts. Other design changes occurred to reduce cost or production time since they were readily in stores. In this section, it discusses the design changes made to the shredder, extruder, and spooler.

7.2.1 **Shredder**

As manufacturing progressed, the team ran into problems with having the correct equipment. The team decided to resize the shredder. The new dimensions of the shredder are 11 x 11 x 12 inches.

The shafts for the shredder were also resized to fit the availability of the metal supplier. The new shafts are 5/8 inches in diameter. All of the components that sit on the shafts; the shredder teeth, spacers, bearings, lock nuts, and gears were resized to fit the new diameter of the shafts.

The gears were redesigned to fit the dimensions of the shredder. The distance between the center of the shafts is 4 inches. The new teeth were redesigned to make it fit in between the distance between the shafts' centers. The number of teeth on new gears were reduced to 36 teeth. The new gears are 0.5 inches thick. The original design of the gears was an altered version of a set of McMaster Carr gears that had 64 teeth but did not mesh correctly. The new gears can be seen below in Figure 30.

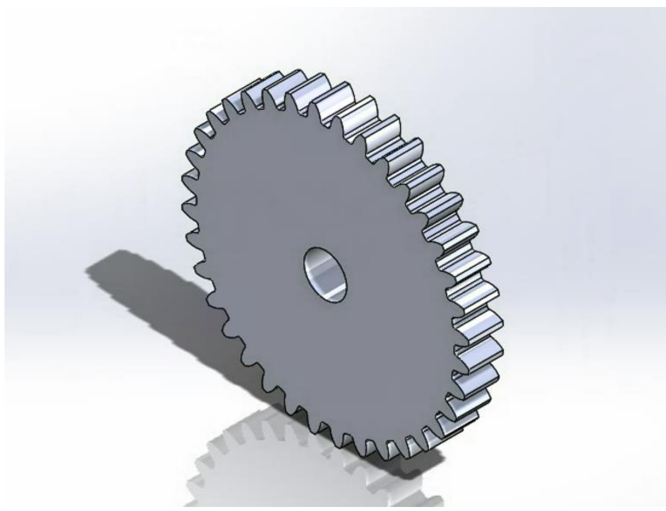


Figure 30: New Gear

7.2.2 **Extruder**

The extruder hopper the team originally had would have been manufactured but remained a problem for manufacturing. The new "hopper" is a plastic funnel that sits on top of the heating chamber allowing the broken bits of 3D filament to fall into the extruder housing. The plastic funnel is a store-bought, all-purpose funnel. This design change reduced manufacturing time by simplifying the hole that needed to be cut on the extruder housing. A simple drill hole of was made on the top side of the housing using a ½ inch drill bit, instead of a rectangular cut that would have required more time on the mills or CNC.

The nozzle of the extruder also changed to a simple pipe cap. This allowed the team to do less manufacturing on this part of the extruder and reduce the cost of having to buy extra raw material. The new extruder "nozzle" was sanded flat so the top of the cap was even and a hole was drilled into the center of the cap. The hole is a little smaller than 1.75mm to compensate for expansion of the filament. The manufactured extruder can be seen below in Figure 31.

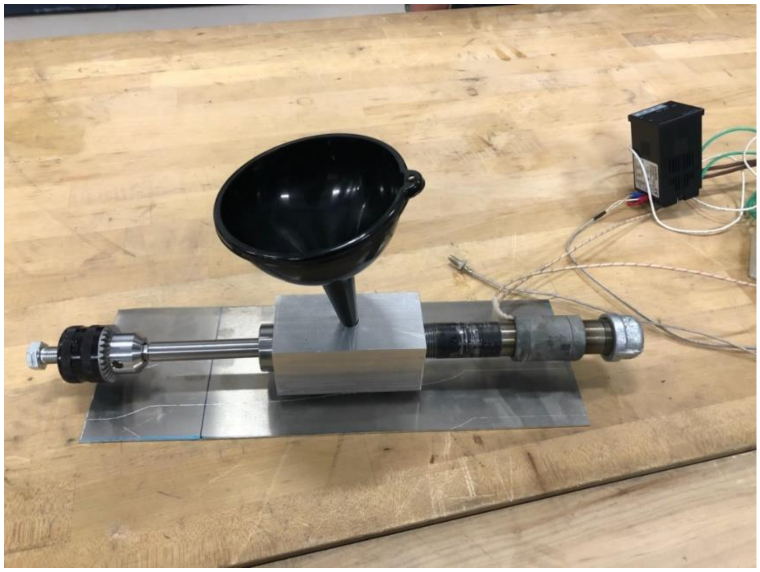


Figure 31: Extruder

7.2.3 Spooler

The spooler was completely redesigned. The motor housing was 3D printed using PLA filament. Allowing the motor to be screwed into it, and having the housing screwed to its own platform.

The shaft for the spooler was redesigned like a nut and bolt. The new spooler was 3D printed as well with PLA filament. The spooler shaft sits on top of the motor shaft and has another component that screws itself on top of the shaft to secure and accommodate any type of spool used to collect the recycled filament. The completed configuration of the spooler can be seen below in Figure 32.

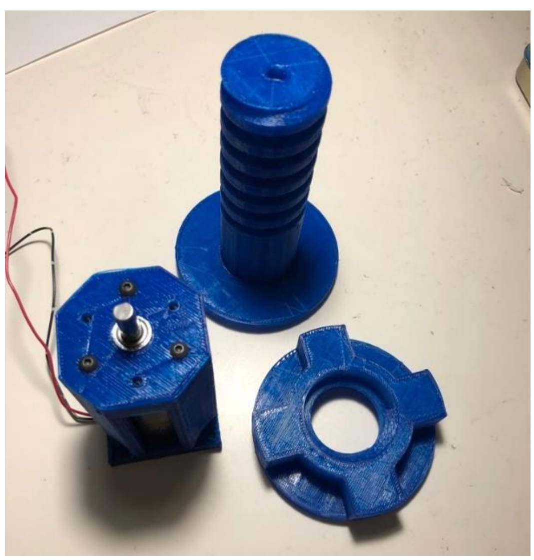


Figure 32: Completed Spooler

8 TESTING

Once manufacturing the shredder, extruder, and spooler each component was tested to makes sure it met the engineering requirements derived by the team. During these tests the safety requirements were also taken into account be sure each subsystem would not harm the user.

8.1 Shredder

The following tests were done to ensure that the shredder was functional:

1. Test the amount of torque needed for shredder
2. Test the different types of infill that can be shredded
3. Test the different plastic thicknesses that can be shredded

By visual inspection, the team could tell that the purchased motor would not provide enough torque to shred the unwanted plastic. So a design change to make the shredder manually operated was done to make the shredder functional. While testing the shredder the aluminum housing showed deflection, which caused alignment issues with the gears and teeth. So the aluminum housing was changed to particle board to provide increase rigidity.

Next, the team tested the different types of infills that could be shredded. Table 12 shows the results of the infill test. The shredder was able to shred anything that had a 25% infill or less. The compressive and tensile strengths of 100% infill PLA are significantly higher than standard infill PLA. The amount of torque needed to break 100% infill prints exceeds what the hand-crank can produce for the shredder.

The team also tested the thickness of the prints that it can shred. The maximum thickness the shredder can break down is ½ inch. This is due to the spacing of the shredder teeth, the size of the shredder teeth, and the space inbetween the shredder shafts. The results from the shredder testing can be seen below in Table XX. While testing the shredding it was observed that the shredder could only break down plastics to a ¼ inch size, which did not meet the team's desired ⅛ inch requirement. The team ended up using a normal household blender to break down the shredded pieces more.

Table 12: Shredder Testing Results

Infill (%)	Result (Y/N)	Size (in)	Result (Y/N)
10	Y	< 0.25	Y
25 (Standard)	N	0.5	Y
100	N	1	N

8.2 Extruder

The initial testing procedure was changed from testing how long it took for the heating band to preheat before testing different temperatures and extruder speeds. An addition test was added to find the best location for the thermocouple. Several tests were performed on the extruder to assure the filament being produced was up standard and could be compared to the filaments on the market.

1. Test different types of temperatures and extruder speeds
2. Test location of thermocouple on heating chamber
3. Measure diameter of the extruded filament
4. Visual inspection of the extruded filament after cooling

One test was performed to determine the correct temperature that the plastics melt at. The results of the test determined that the extruder operates at around 190-220°C, and the best operating temperature was 210°C. The team noticed that to reach the desired temperature in the heating chamber, a 30 minute preheating time at 245°C was required before setting the correct temperature. The extruder's motor was also tested to see what motor speeds were required at those temperature ranges. The results from these two tests are seen below in Table 13.

Another test conducted was making sure temperatures stayed accurate was finding the correct place to put the thermocouple that regulated the extruder temperature. This test was done by placing the thermocouple at numerous places and reading the temperature on the PID. The best position for the thermocouple was next to the extruder nozzle since the exiting temperature is most important.

Table 13: Temperature Test Results

Extruder Temperatures (°C)	Extruder Speed (RPM)	Result/Observations
190	9	Filament produced okay, but the spooler could not spool slow enough to match the extrusion rate
210	15	Filament made was fine and the spooler could match the extrusion rate
220	30	Filament made was fine, but took longer to cool and sometimes clot/bunch up as it extruded

After filament was extruded, the filament diameter was measured using a digital caliper to ensure the quality of the filament. The results from this test can be seen below in Table 14. The first three sample of filament was slightly under the requirement of have a 1.75mm diameter. The initial hole for the extruder was drilled smaller to compensate for expansion during extruding. The team later drilled the hole to a diameter of 1.75mm. The last three samples are from the last iteration of extruder hole. The first two sample had a larger diameter than what was required. This was due to a lack of tension as it was being extruded. The last sample of filament had a diameter of 1.75mm which matched the required diameter perfectly.

Table 14: Filament Diameter Test

Sample	Result (mm)	Difference (mm)	Observation
1	1.55	0.20	Brittle, blackish/brown (Temperature too high)
2	1.65	0.10	Brittle, blackish/brown (Temperature too high)
3	1.70	0.05	Brittle, blackish/brown (Temperature too high)
4	1.80	0.05	Flexible filament, held color and shine
5	1.77	0.02	Flexible filament, held color and shine
6	1.75	0.00	Flexible filament, held color and shine

The team did a visual inspection after the measuring the filament diameter. The first three sample were brittle and a very dark brown color. The filament broke easily when bent and the color was different than the initial plastic. The temperature the first three samples were extruded at were too high and changed the material properties of the plastic. The last three samples were flexible when bent and still held the color they were initially.

8.3 Spooler

The following test was done to determine the correct spooler speed:

The team tested a few different motor speeds to see what the best spool speed was. Initially the test was conducted with visual inspection. The test ranged from 10 to 12 percent of the motor speed which was 3 to 3.6 RPM. The team put the motor at 3.6 RPM initially but it was too fast. The spooler pulled on the filament and stretched it out. As it continued to spool the elongated filament, the spooler speed finally broke the filament. The spooler was then tested at 3 RPM which proved to be a good spooling speed for the filament because it continuously spools while keeping the filament intact filament. The team learning during this test that the potentiometer could not control the motor at less than 10% of the motor speed, the motor did not move. Table 15 shows the results from the spooler tests. No redesigns were needed for the spooler.

Table 15: Spooler Test Results

Spooler Speed (%RPM)	Spool Speed (RPM)	Result/Observations
< 10	≤ 2.7	Potentiometer cannot control the motor at %RPM less than 10%
10	3	Good, spools filament constantly. User needs to keep an eye on the filament to make sure it is being spooled properly.
12	3.6	Too fast, pulls filament quickly. Not enough time for filament to cool, breaks easily.

9 CONCLUSIONS

The following section reflects on the team dynamic and the work done during throughout the year. It highlights the positive and negative aspects of the team and the work they did.

9.1 Contributors to Project Success

The team was successful in creating a 3D filament recycler. From the start, the team wanted to make the three subassemblies. The ambition of the team sustained throughout the year, especially during manufacturing, which was done to the best of the team's ability.

Halfway through the year, the team revised the Ground Rules and Coping Strategies in the team charter. New rules needed to be enforced to stress the importance of Capstone. Capstone needed to be set as one of the highest priorities amongst the team. However, the team was understanding when it came to other priorities. If someone needed time to study for another exam or do another assignment, the workload would be divided among the team to help each other. Team deadlines were heavily enforced so work was not done last minute. Throughout the year, the bond between people on the team became stronger and coping strategies were not needed.

The team efficiently managed time and made sure all available free time would be spent in the machine shop to finish the manufacturing as quickly as possible. This meant giving up almost every Friday and Saturday of the spring semester. The team also meet at other times during the week when necessary to ensure tasks were being completed on time. In the machine shop, the team sought to manufacture parts as close to the specified design as possible, while solving unexpected issues along the way. Some issues were large enough to cause redesigns, which lead to slight setbacks. Issues in designs were usually solved within one to two days to prevent time lost for manufacturing. The team gained a considerable amount manufacturing experience along with quick-thinking, problem solving skills. The final product was the most rewarding for the team, who a functional 3D filament recycler despite all of the adversity and setbacks they needed to overcome.

9.2 Opportunities/Areas for Improvement

The biggest struggle the team faced was the manufacturing in the shop since only two team members were advanced certified. This means that vital machines, like the mill and lathe, could be used by these specific team members. Because these individuals were familiar with these machines and understood its and their capabilities, this made manufacturing parts slower. If one of the two people could not come to the shop in time, manufacturing processes were delayed.

Redistributing the workload amongst three team members was done to complete team assignments. Capstone did not remain a high priority amongst some team members and started to become an issue with the amount of effort put into assignments. This was not ideal since the work would more often than not need to be edited or redone by another team member, which became time consuming. With most team members spending their time in the machine shop to finish manufacturing the device, it was taxing to then go home and finish written assignments on their own as well.

The team ran into problems at the machine shop when it came to manufacturing. One of the biggest issues finding the best tools for the materials the team had. With large or thick pieces of material, it was difficult to manufacture due to the lack of resources. This put the team behind on manufacturing and assembly time. The team also ran into problems internally. With stress in the machine shop and uneven work distribution, tensions rose between team members when the load became nearly unbearable. Some team members took on more tasks than they could handle which then ultimately decreased the quality of the team's work.

The most important lesson that the team learned was to buy premade parts to reduce manufacturing time, which also increases precision of parts for assembly. This also means spending more money for higher quality parts. While manufacturing time became scarce, the team had the machine shop manufacture the shredder teeth. This reduced the workload for the team and ensured parts were being completed on time. With the money saved from manufacturing most parts, the team was able to comfortably afford the work orders requested. From allowing the shop to manufacture the teeth, a double check in CAD drawings were necessary since the first six teeth were manufactured incorrectly to the team's design. The team also learned to overestimate the manufacturing time more than a magnitude of three. These lessons will help the team run with future projects and scheduling in the future.

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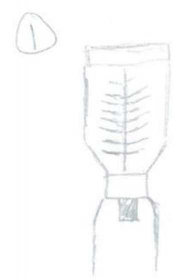
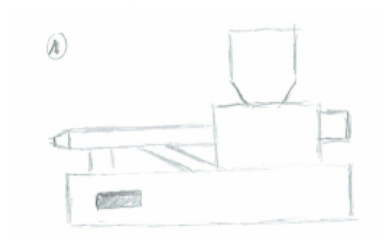
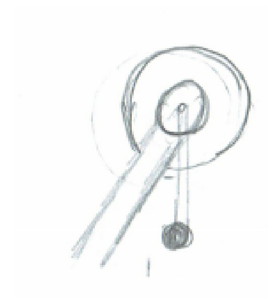
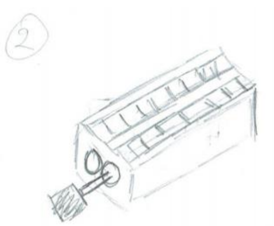
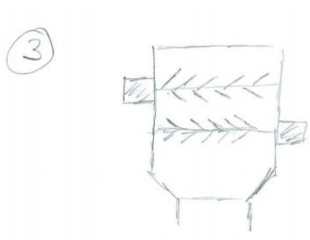
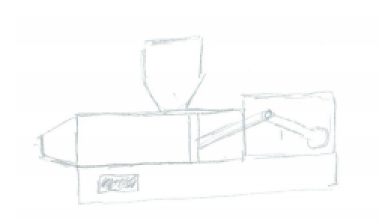
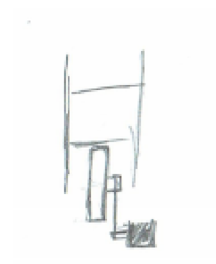
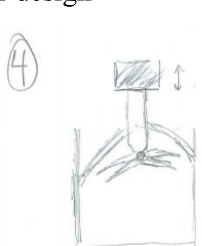
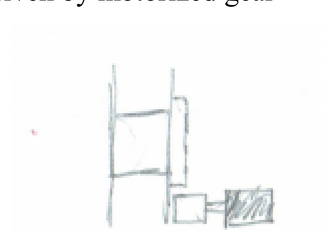
APPENDIX A: House of Quality

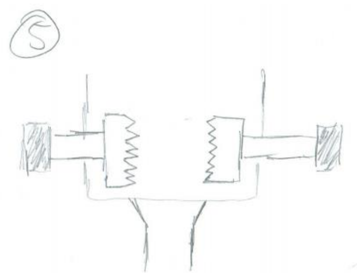
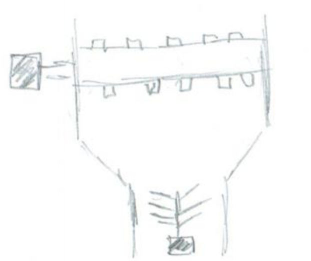
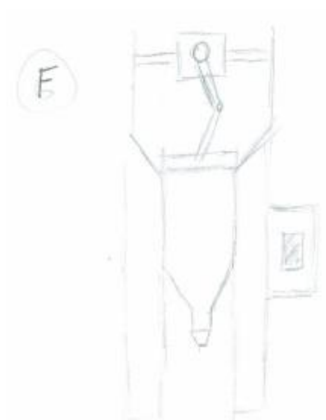
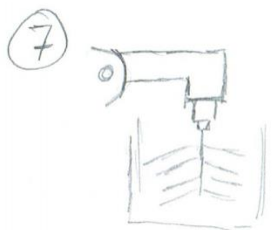
Table A- 1: House of Quality

Customer Requirement	Weight	Engineering Requirement	Voltage (V)	Amperage (amps)	Melt Temperature (°C)	Parts Budget (<$2000)	Control Speed (rev/min)	Extrudes within tolerance (mm)
1. Safe to use	1		9	9	3	1	1	1
2. Reliability	3		9	9	3	9	9	9
3. Durability	4		1	1	9	9	3	3
4. Includes 3 functions (shred, extrude, spool)	6		9	9	9	3	9	9
5. Affordable	5		1	1	3	9	3	1
6. Material able to extrude @ 1.75mm	2		1	1	9	3	1	9
7. Size/Compatability	7		1	1	3	1	3	1
8. Aesthetically pleasing	8		1	1	1	1	1	1
Absolute Technical Importance (ATI)			116	116	164	148	140	132
Relative Technical Importance (RTI)			5	5	1	2	3	4
Target ER values			120	15	164C (PLA) 221C (ABS)	$1,500	Variable	1.75
Tolerances of ERs			max	max	±7C (PLA) ±17C (ABS)	±$500	Variable	±0.5
Testing Procedure (TP#)								

APPENDIX B: Designs

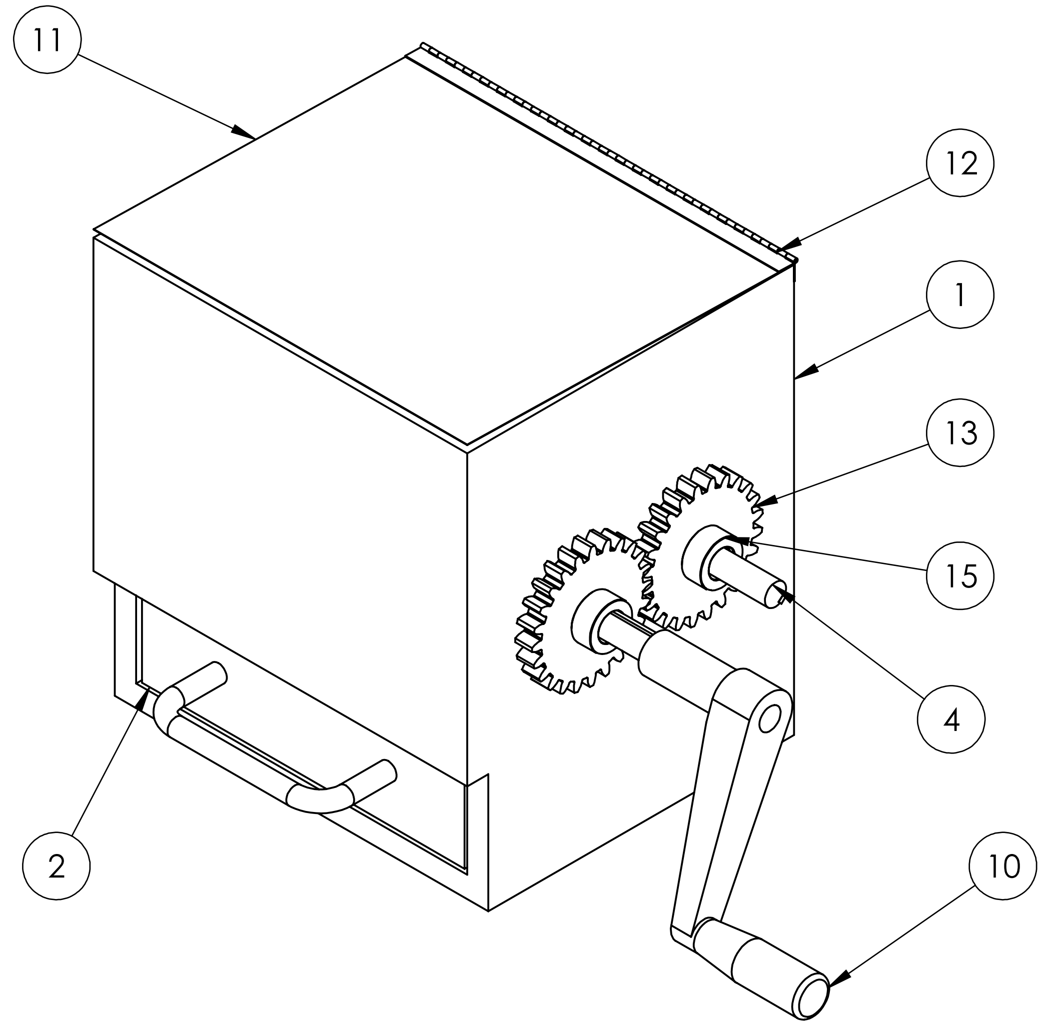
Table B- 1: Mix-and-Match Designs Table

Shredder	Extruder	Spooler
1. Load from top with cap, blender type * 	A. Fed from hopper on top and end, injection molding system * 	I. “Princess Leia” clamps on spooler, cable-driven motor * 
2. Load from top, wood chipper/paper shredder design (popular with other shredders) * Issue: Exposed teeth 	B. Fed from top, auger pushes down * 	II. Mount spool on motor, motor facing up, “record player” design * 
3. Load from top, two sequences of blender teeth (horizontally set) 	C. Pump arm instead of auger, “rowing machine” design 	III. Tension wheel on spool, winding like a sewing machine 
4. Load into barrel, immersion blender design 	D. Pump instead of compressed air, “balloon idea” 	IV. Gear attached to spool, driven by motorized gear * 

5. Load into compartment, “chomping dinosaur mouth” 	E. A at an angle, gravity assistance * 	
6. Combination of 1 & 2, 2 layers of grinding * 	F. Vertical pump arm bouncing with ner filament, “vertical shake weight design” 	
7. Mixer style with multiple layers of blades 		

*Indicates team’s top three choices from each category

APPENDIX C: CAD Drawing Package



ISOMETRIC VIEW

ITEM NO.	DESCRIPTION	QTY.
1	HOUSING, SHREDDER	1
2	FILAMENT DRAWER, SHREDDER	1
3	TOOTH, BIG, SHREDDER	15
4	SPACER, SHREDDER	23
5	BEARING, FLANGE, 5/8 ID	2
4	ROD, 3/8 DIA, 16 LONG, A36 STEEL	2
7	STOCK, KEYWAY, SHREDDER	2
8	BEARING, PRESISION BALL, 1 IN DIA	2
9	HANDLE, SHREDDER	1
10	HANDLE, CRANK	1
11	PLASTIC GUARD, CLEAR, SHREDDER	1
12	HINGE, PIANO, 11IN, 1/2 THK	2
13	SHAFT GEAR, SHREDDER	2
14	SHAFT COLLAR, SET SCREW, 5/8 ID	2
15	SHAFT COLLAR, SET SCREW, 3/4 ID	2
16	WASHER, 1/4 ID, SST 18-8, NARROW	2
17	SCREW, 1/4-20, PAN HD, PHILLIPS, SST 18-8	2

NEXT ASSY	USED ON
3D FILAMENT RECYCLER	3D FILAMENT RECYCLER

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: 1°
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.010

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: SEE BOM

FINISH: N/A

DO NOT SCALE DRAWING

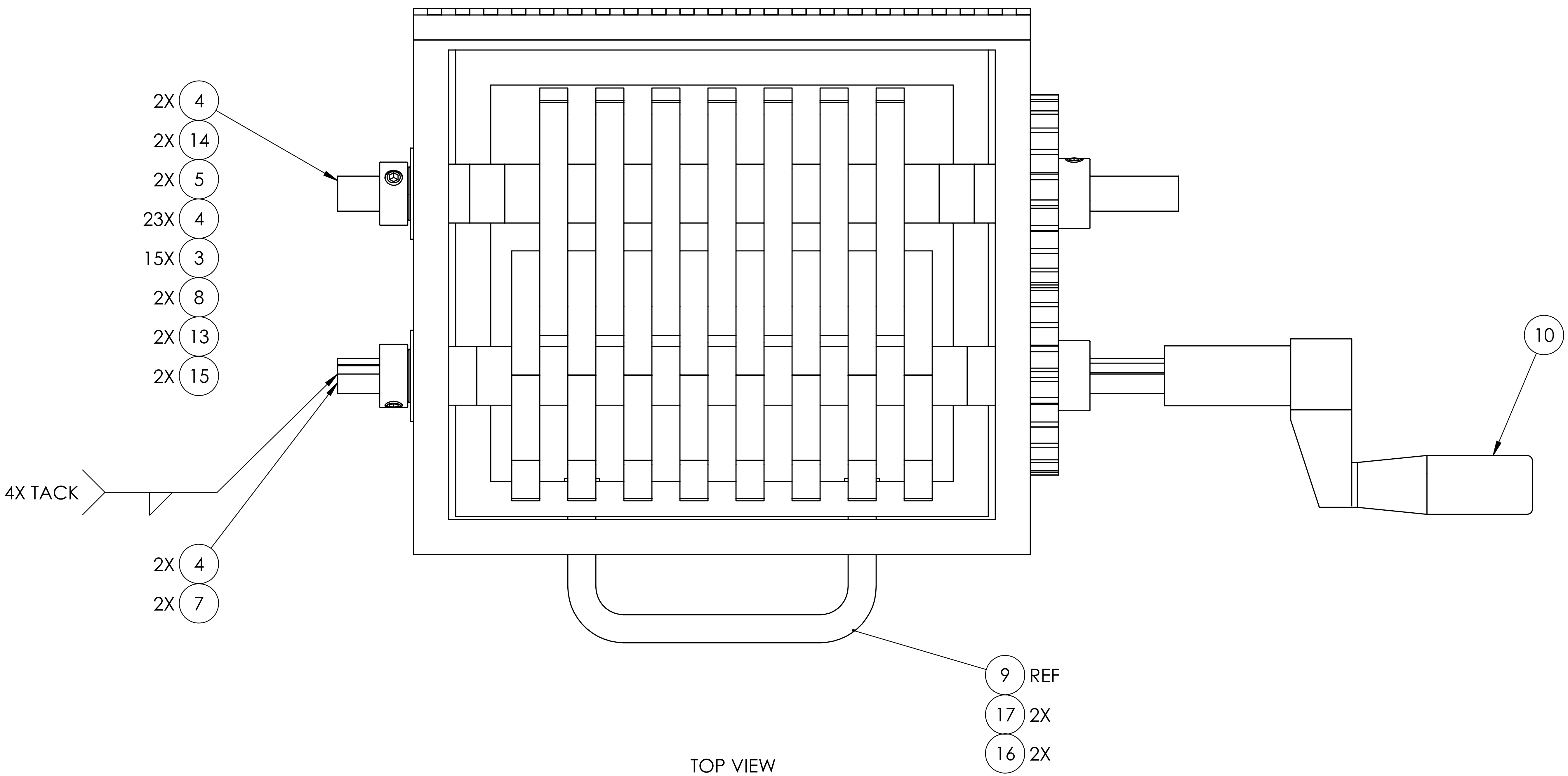
	NAME	DATE
DRAWN	MMY	11-10-17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: SHREDDER ASSEMBLY

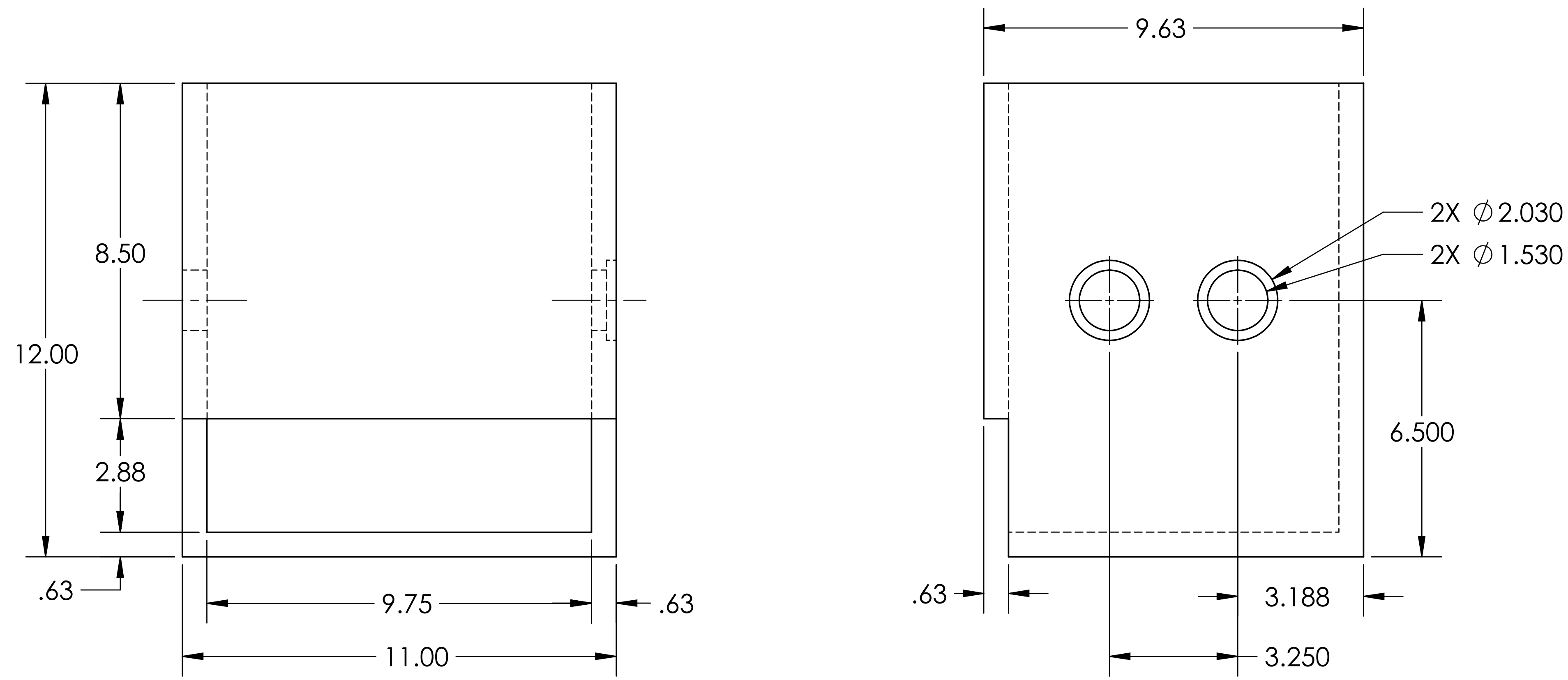
SIZE	DWG. NO.	REV
B	SHREDDER ASSY	1

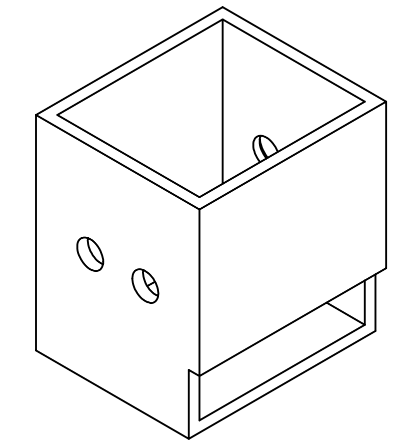
SCALE: 1:4 WEIGHT: SHEET 1 OF 2



TOP VIEW
SCALE 1:2
ITEM 17 HIDDEN FOR CLARITY

SIZE	DWG. NO.	REV
B	SHREDDER ASSY	1
SCALE: 1:4	WEIGHT:	SHEET 2 OF 2





ISOMETRIC VIEW
SCALE 1:8

SHREDDER ASSEMBLY	SHREDDER ASSEMBLY	
NEXT ASSY	USED ON	
APPLICATION		

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
SHEET METAL, 1/8 THK, ALUMINUM

FINISH

DO NOT SCALE DRAWING

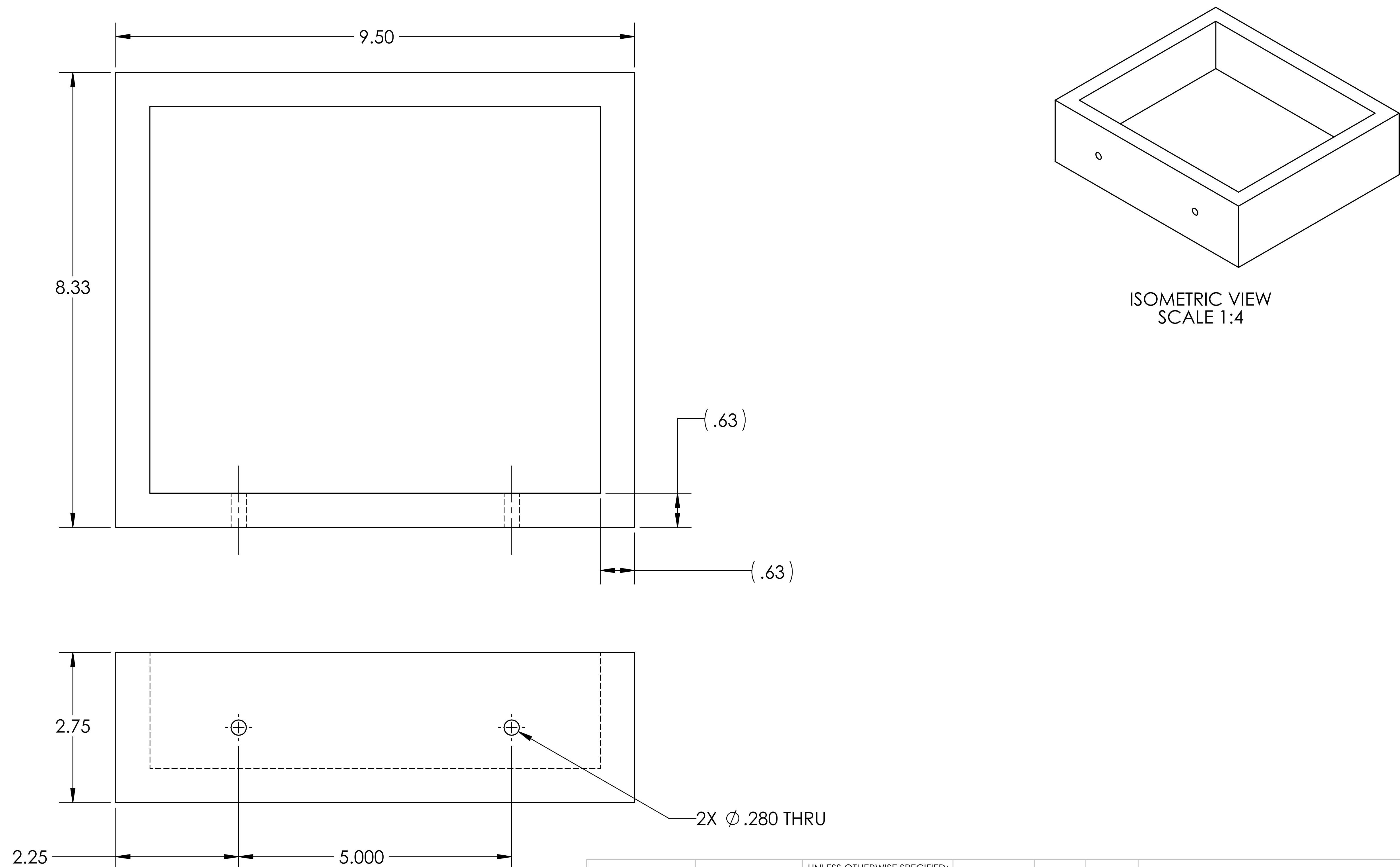
	NAME	DATE
DRAWN	MMY	11-10-17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

HOUSING, SHREDDER

SIZE	DWG. NO.	REV
B	SHREDDER HOUSING	1

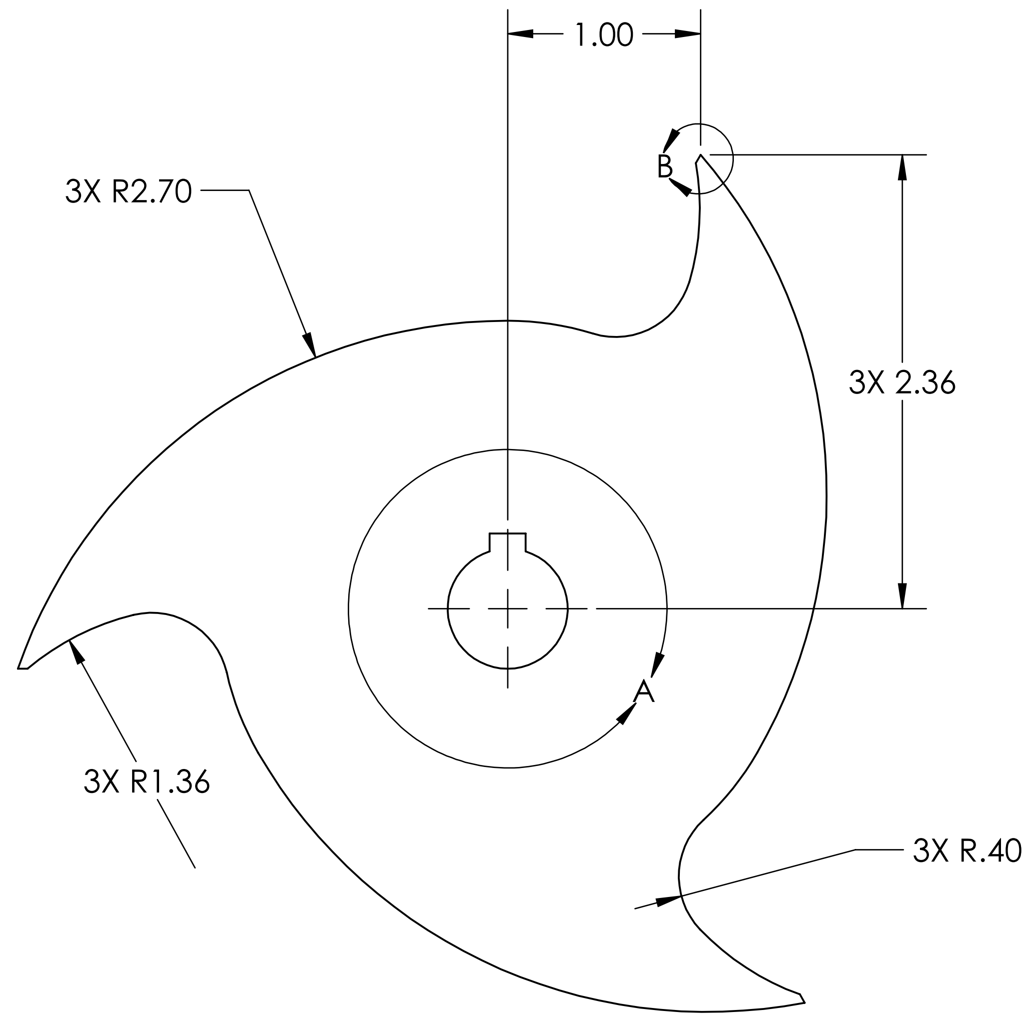
SCALE: 1:4 WEIGHT: SHEET 1 OF 1

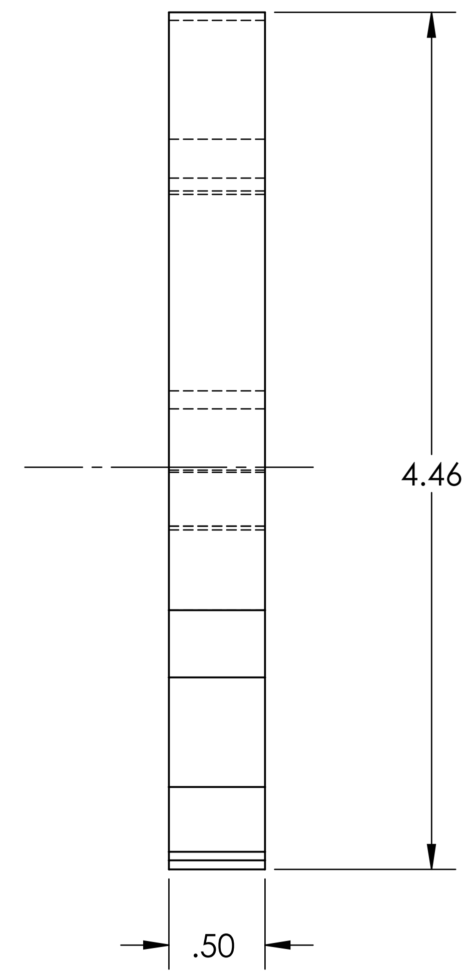


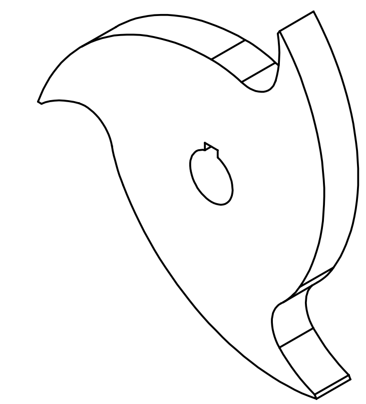
UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: 1° TWO PLACE DECIMAL ±.03 THREE PLACE DECIMAL ±.010	DRAWN	MMY	12-8-17	TITLE: FILAMENT DRAWER, SHREDDER	
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL SHEET METAL, ALUMINUM, 1/8 THK	COMMENTS:			SIZE B DWG. NO. SHREDDER FILAMENT DRAWER	REV 0
FINISH 3				SCALE: 1:2 WEIGHT:	SHEET 1 OF 1
DO NOT SCALE DRAWING					

SHREDDER ASSEMBLY	SHREDDER ASSEMBLY
NEXT ASSY	USED ON
APPLICATION	

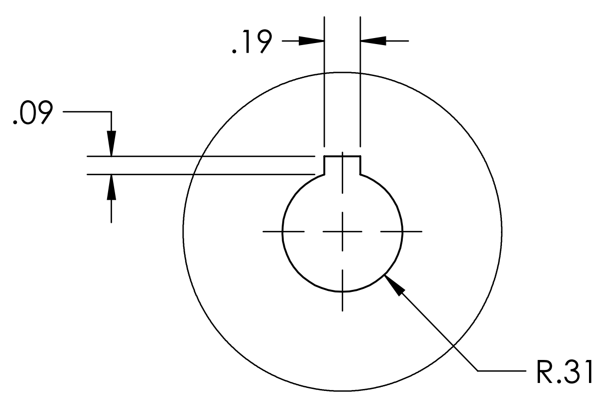
REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
0	ORIGINAL DESIGN FOR MANUFACTURING	11-10-17	MMY
1	REMOVED 1/2" SPACER IN ORIGINAL DESIGN, UPDATED BLADE TIPS/GEOMETRY, UPDATED MATERIAL	3-1-18	MMY



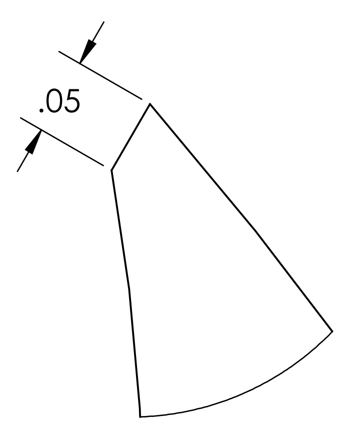




ISOMETRIC VIEW
SCALE 1:2



DETAIL A



DETAIL B
SCALE 8 : 1

NEXT ASSY	USED ON
SHREDDER ASSEMBLY	SHREDDER ASSEMBLY

APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL FLAT BAR, 1/2 THK, ASTM A36

FINISH N/A

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MMY	11-10-17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

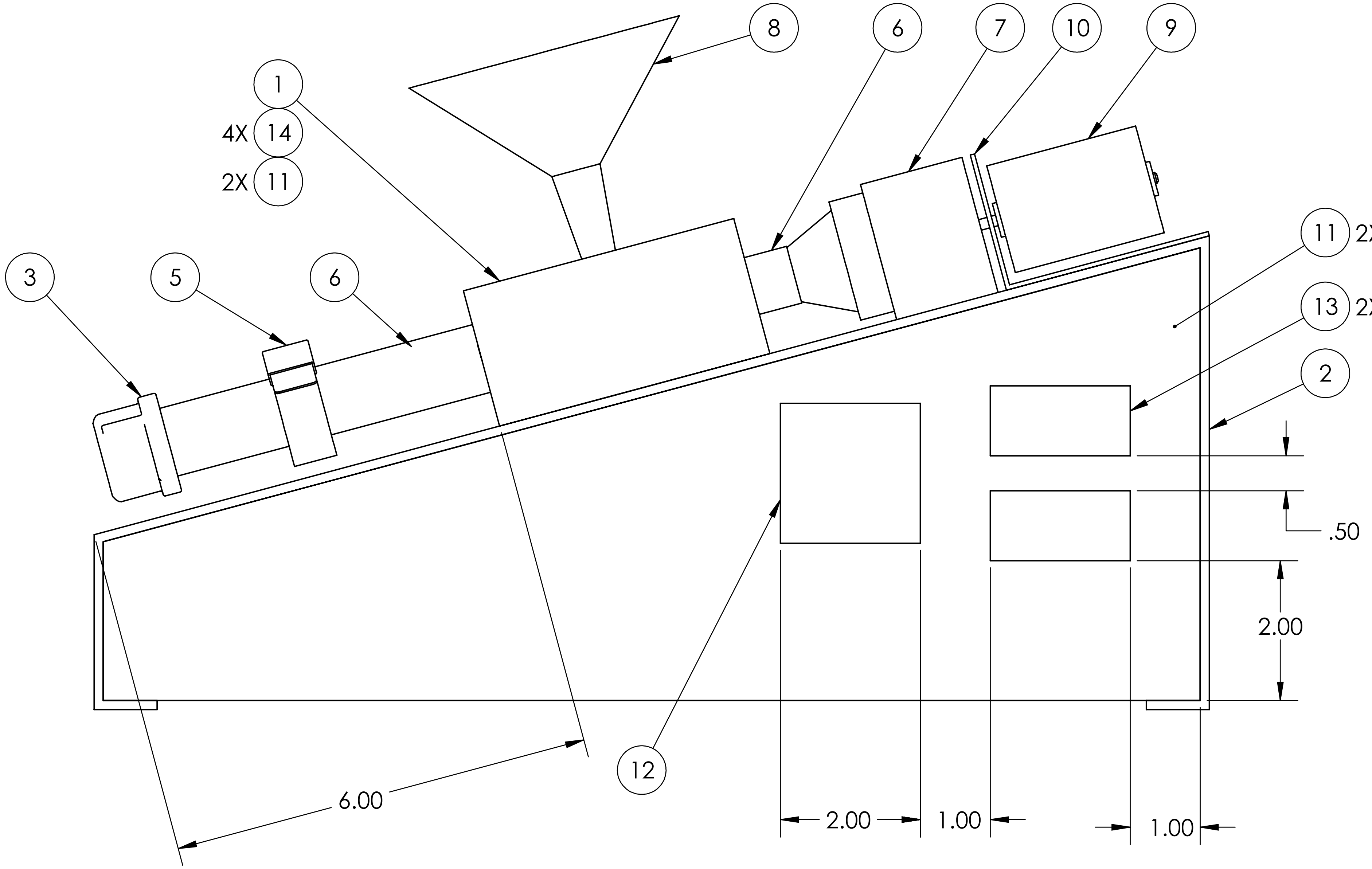
COMMENTS:

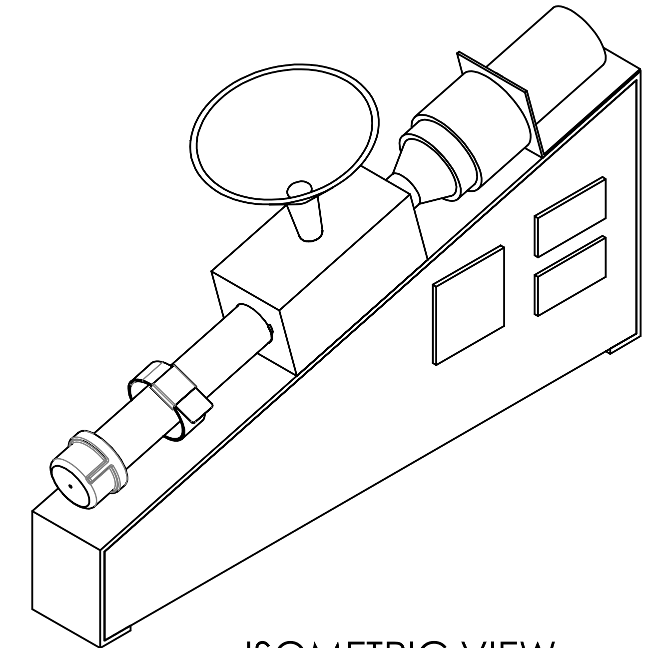
TITLE:

TOOTH, SHREDDER

SIZE	DWG. NO.	REV
B	SHREDDER BIG TOOTH	0

SCALE: 1:1 WEIGHT: SHEET 1 OF 1





ISOMETRIC VIEW
SCALE 1:4

ITEM NO.	DESCRIPTION	QTY.
1	MAIN BODY, EXTRUDER	1
2	MOUNT, EXTRUDER	1
3	NOZZLE, EXTRUDER	1
4	HEATING CHAMBER, EXTRUDER	1
5	HEATING BAND, 1 DIA, 1 LG, 120VAC, 900F MAX	1
6	AUGER, 1 DIA, 18 IN, STEEL	1
7	CHUCK, KEYED, 1"	1
8	FUNNEL, EXTRUDER	1
9	MOTOR, DC, DIMENSIONS OF SOME SORT IDK	1
10	MOUNT, MOTOR, EXTRUDER	1
11	MOUNT COVER, EXTRUDER	2
12	PID CONTROLLER	1
13	MOTOR DISPLAY TOGGLE	2
14	SCREW, 1/4-20, PAN HD, PHILLIPS, SST 18-8	4
15	WASHER, 1/4 ID, SST 18-8, NARROW	4

NEXT ASSY	USED ON
3D FILAMENT RECYCLER	3D FILAMENT RECYCLER

APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: 1°
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.010

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
SEE BOM

FINISH
N/A

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MMY	11-10-17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

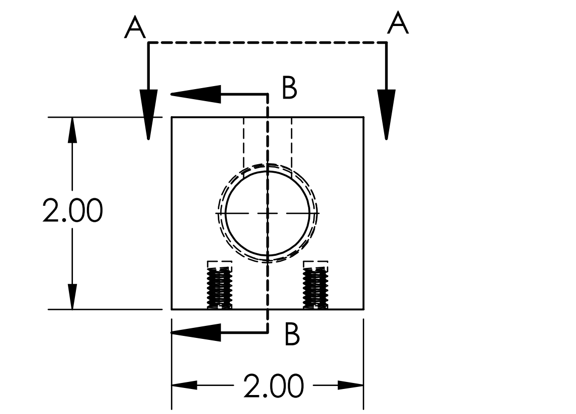
COMMENTS:

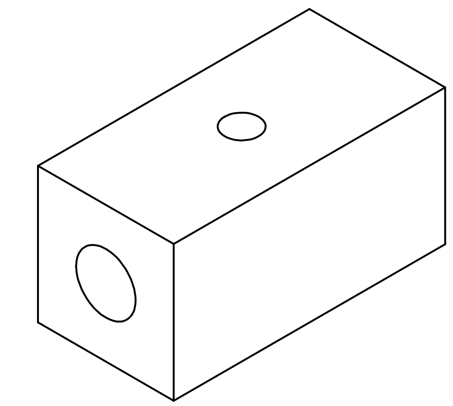
TITLE:

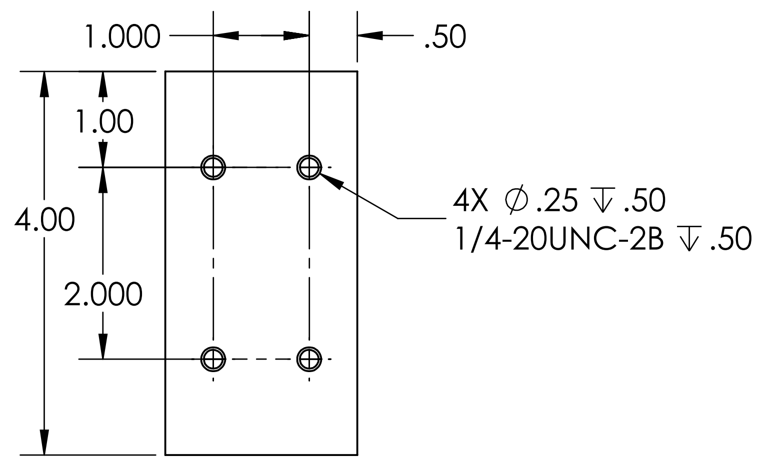
EXTRUDER ASSEMBLY

SIZE B | DWG. NO. EXTRUDER ASSY | REV 1

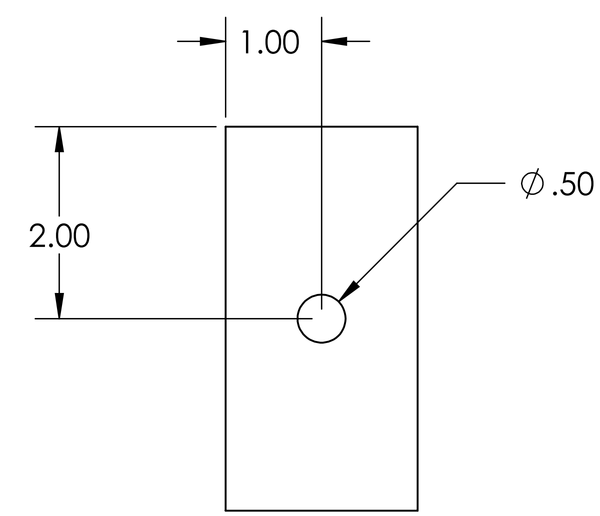
SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1



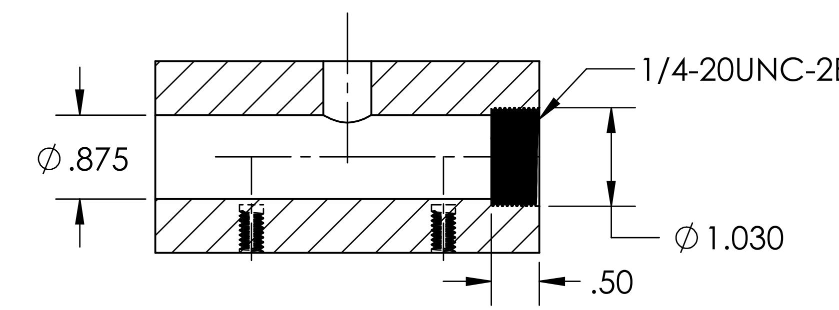




HIDDEN LINES REMOVED FOR CLARITY



SECTION A-A
SCALE 1 : 2



SECTION B-B
SCALE 1 : 2

EXTRUDER ASSEMBLY	3D FILAMENT RECYCLER
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: 1°
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.010
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
BAR, SQUARE, 2X2, SST 304
FINISH
N/A
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MMY	11-10-17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

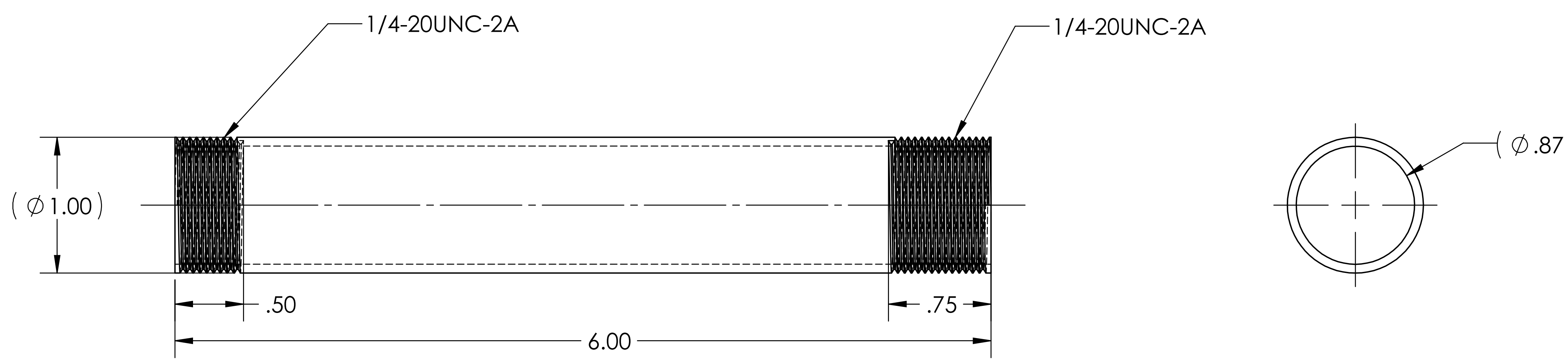
COMMENTS:

TITLE:

MAIN BODY, EXTRUDER

SIZE	DWG. NO.	REV
B	EXTRUDER MAIN BODY	0

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



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NEXT ASSY	USED ON
EXTRUDER ASSEMBLY	3D FILAMENT RECYCLER

APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: 1°
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.010

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
TUBE, ROUND, 1 OD, .065 THK, SST 304

FINISH
N/A

DO NOT SCALE DRAWING

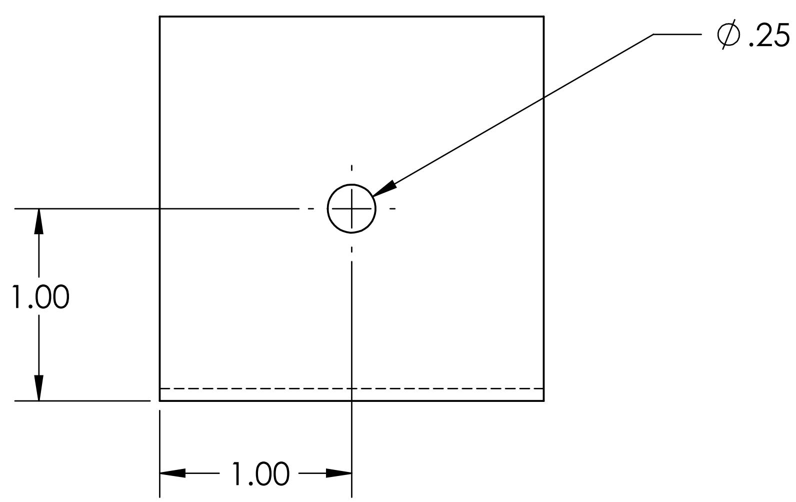
	NAME	DATE
DRAWN	MMY	11-10-17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

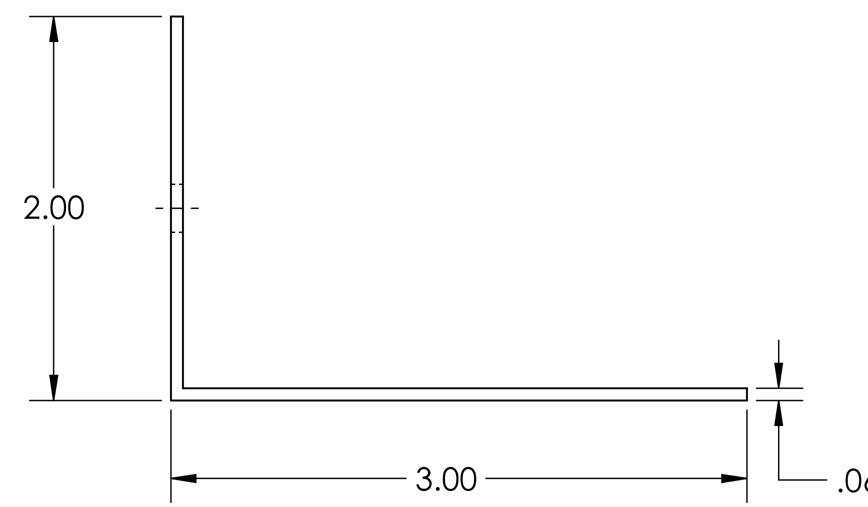
COMMENTS:

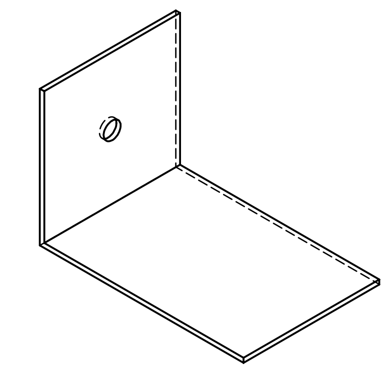
TITLE:
HEATING CHAMBER, EXTRUDER

SIZE	DWG. NO.	REV
B	EXTRUDER HEATING CHAMBER	0

SCALE: 1:1 WEIGHT: SHEET 1 OF 1







ISOMETRIC VIEW
SCALE 1:2

PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
EXTRUDER ASSEMBLY	EXTRUDER ASSEMBLY

APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: 1°
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.010

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
16 GA ALUMINUM SHEET METAL

FINISH

DO NOT SCALE DRAWING

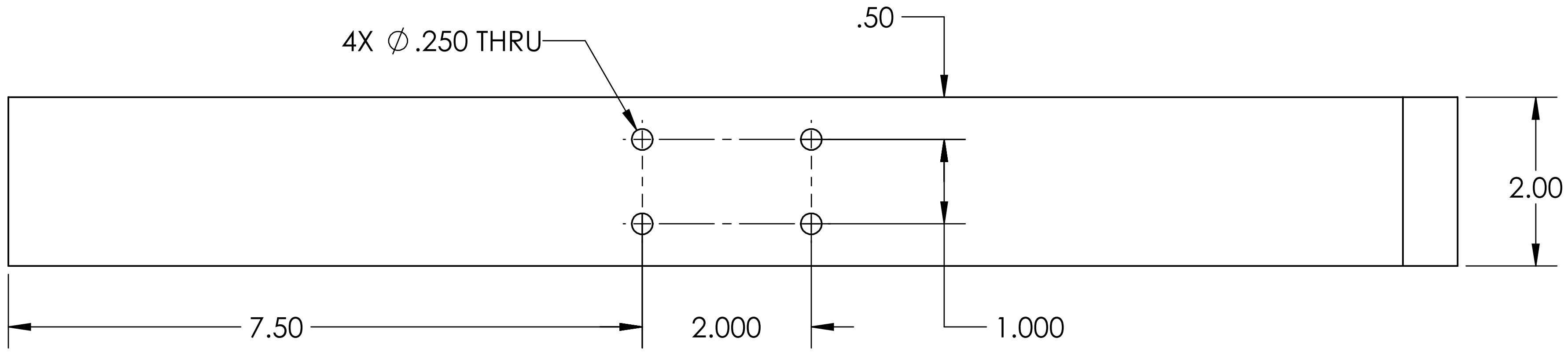
	NAME	DATE
DRAWN	MMY	4-20-18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

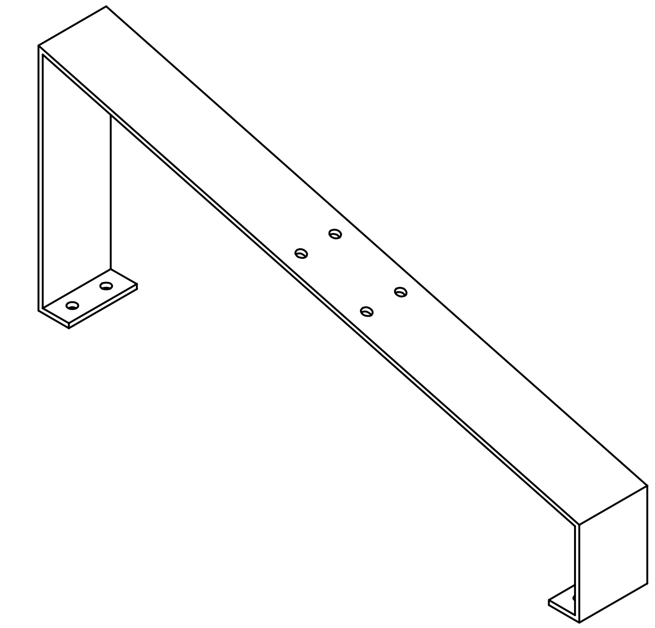
TITLE:
MOUNT, MOTOR, EXTRUDER

SIZE	DWG. NO.	REV
B	EXTRUDER MOTOR MOUNT	0

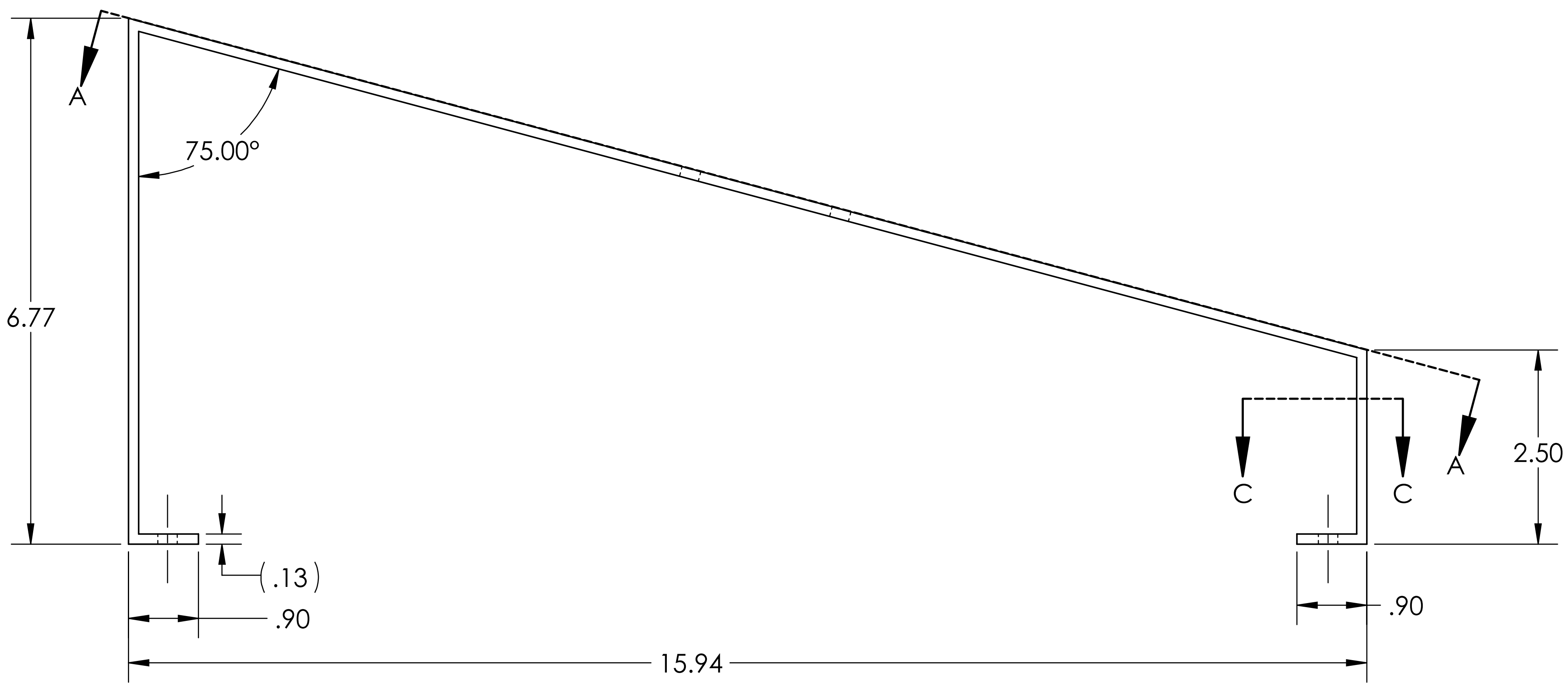
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

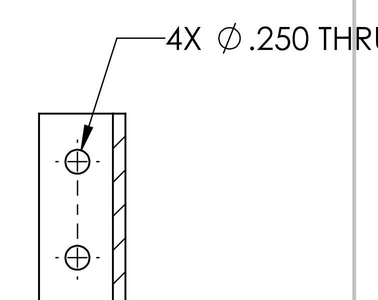


SECTION A-A
ROTATED 15° AND HIDDEN LINES
REMOVED FOR CLARITY



ISOMETRIC VIEW
SCALE 1:4





SECTION C-C

1 BEND SHEET METAL PER GIVEN DIMENSIONS.

NEXT ASSY	USED ON
EXTRUDER ASSEMBLY	3D FILAMENT RECYCLER

APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: ±1°
TWO PLACE DECIMAL ± .03
THREE PLACE DECIMAL ± .010
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
SHEET METAL, ALUMINUM, .125 THK
FINISH
N/A
DO NOT SCALE DRAWING

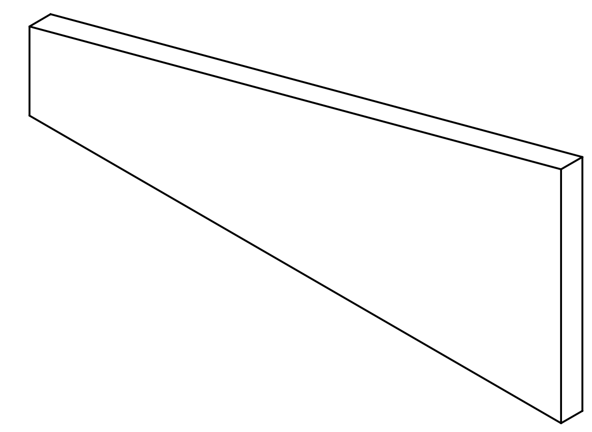
	NAME	DATE
DRAWN	MMY	12-8-17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

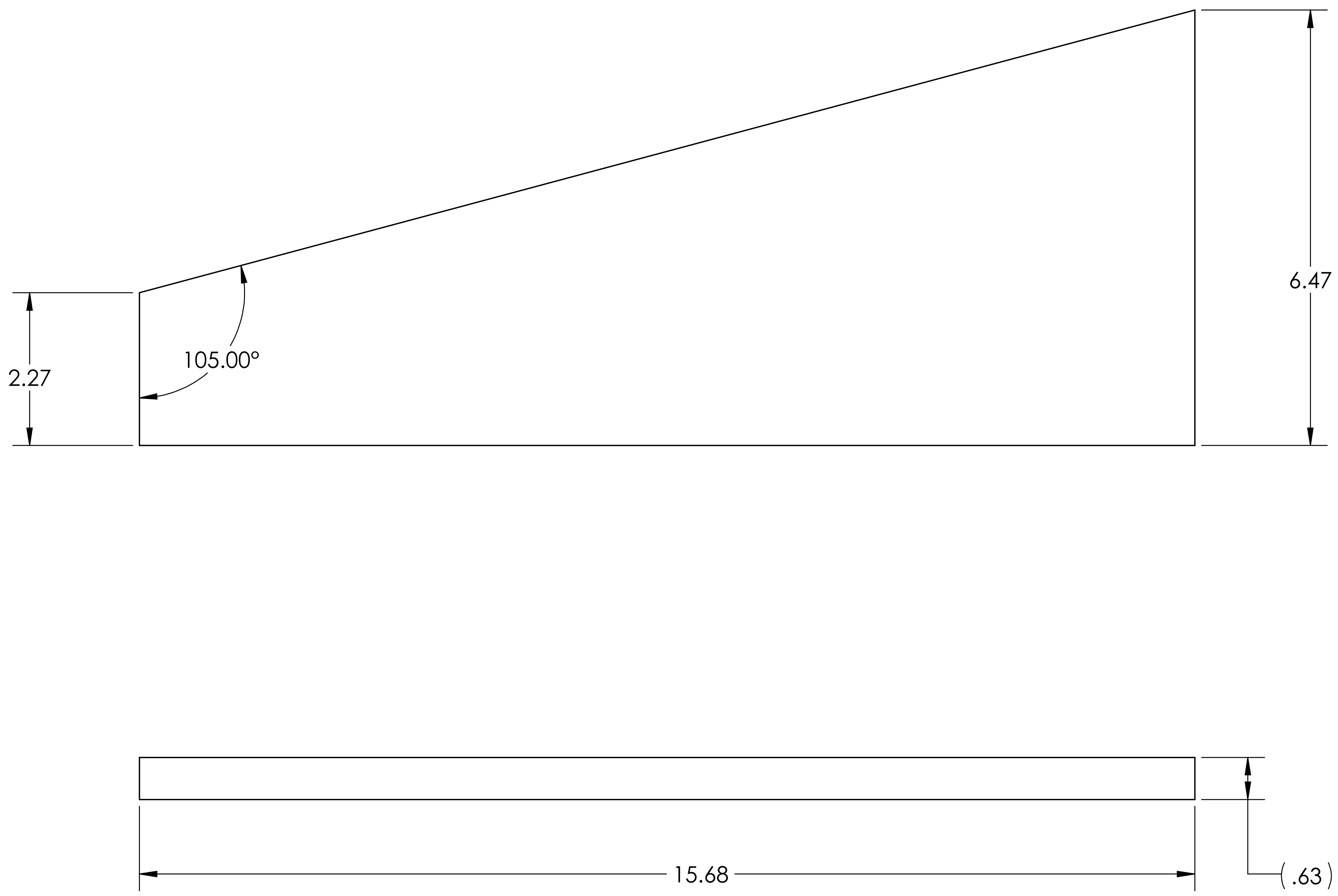
TITLE:
MOUNT, EXTRUDER

SIZE B | DWG. NO. EXTRUDER MOUNT | REV 0

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



ISOMETRIC VIEW
SCALE 1:4



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EXTRUDER ASSEMBLY	EXTRUDER ASSEMBLY
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: 1°
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.010

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
5/8 THK PARTICLE BOARD

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MMY	4-20-18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

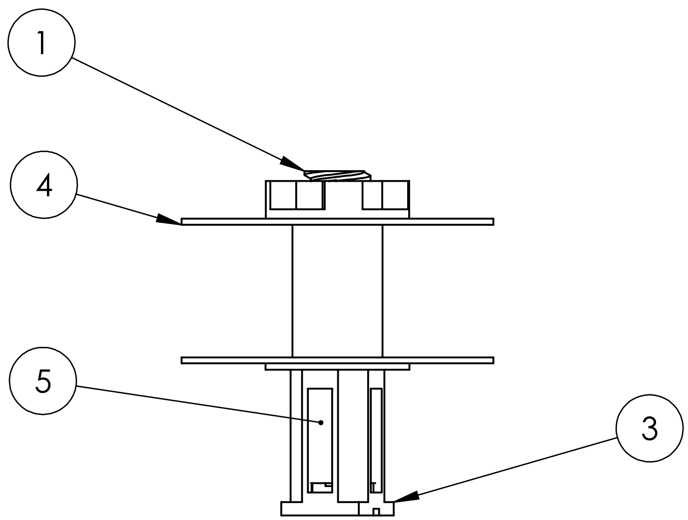
COMMENTS:

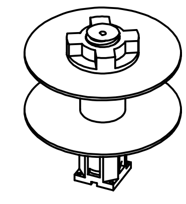
TITLE:

MOUNT, EXTRUDER

SIZE C | DWG. NO. EXTRUDER MOUNT COVER | REV 0

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1





ISOMETRIC VIEW
SCALE 1:8

ITEM NO.	DESCRIPTION	QTY.
1	SHAFT, SPOOLER	1
2	LOCK NUT, SHAFT, SPOOLER	1
3	MOUNT, SPOOLER	1
4	1 KG SPOOL	1
5	MOTOR, DC, DIMENSIONS OF SOME SORT IDK	1

PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
3D FILAMENT RECYCLER	3D FILAMENT RECYCLER

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:

ANGULAR: 1°
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.010

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: SEE BOM

FINISH: N/A

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MMY	11-9-17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

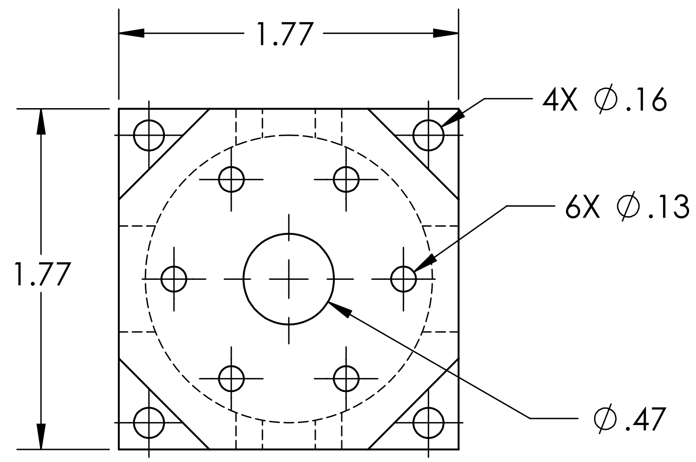
COMMENTS:

TITLE: SPOOLER ASSEMBLY

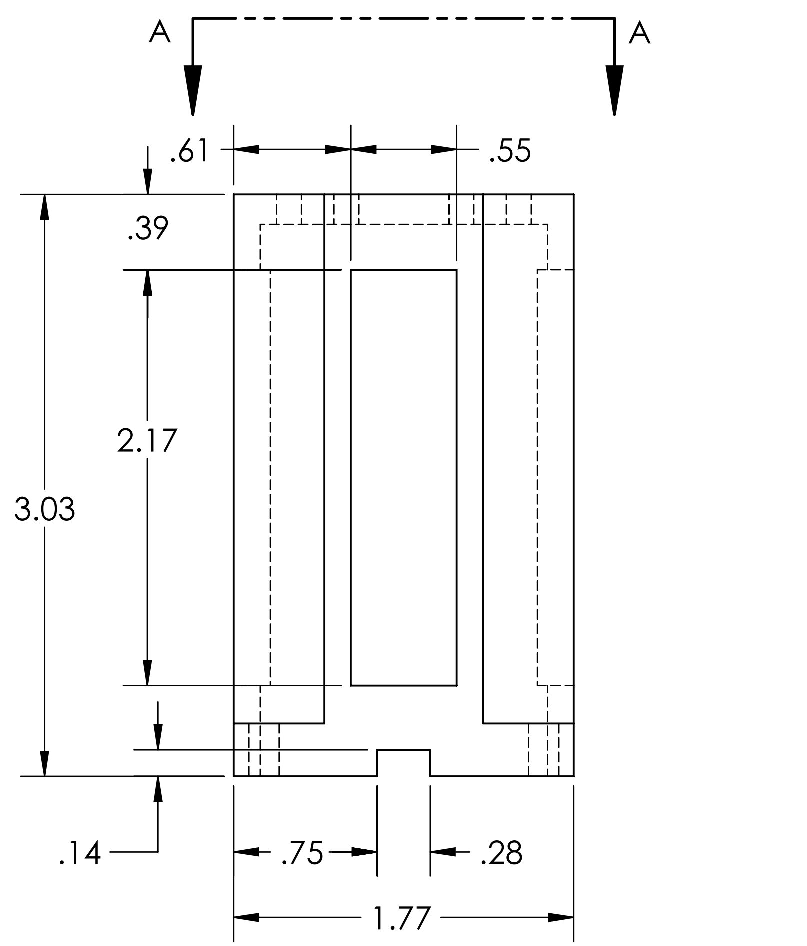
SIZE: A
DWG. NO.: SPOOLER ASSY
REV: 1

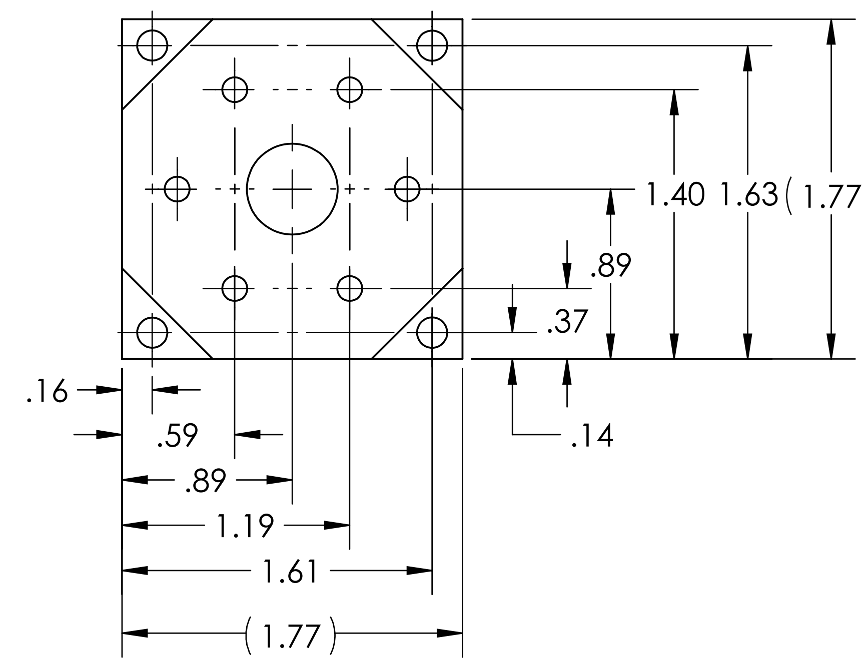
SCALE: 1:4 WEIGHT: SHEET 1 OF 1

4	3	2	1

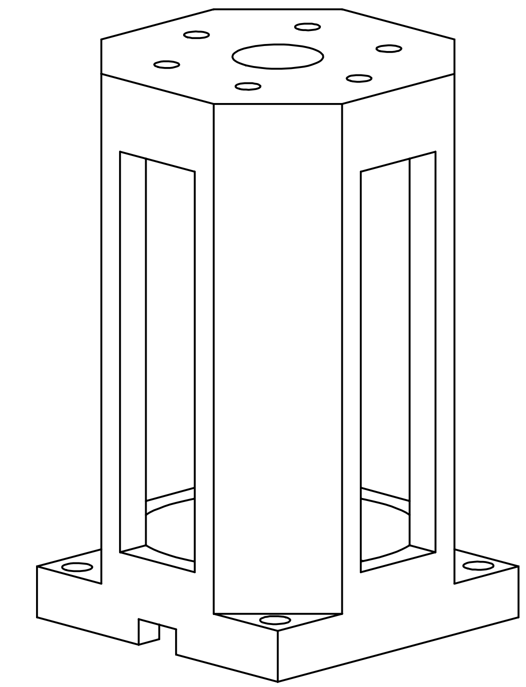


SEE SECTION A-A FOR HOLE PATTERN





SECTION A-A



ISOMETRIC VIEW

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
SPOOLER ASSEMBLY	SPOOLER ASSEMBLY
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: ±1°
TWO PLACE DECIMAL ±0.03
THREE PLACE DECIMAL ±0.010
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

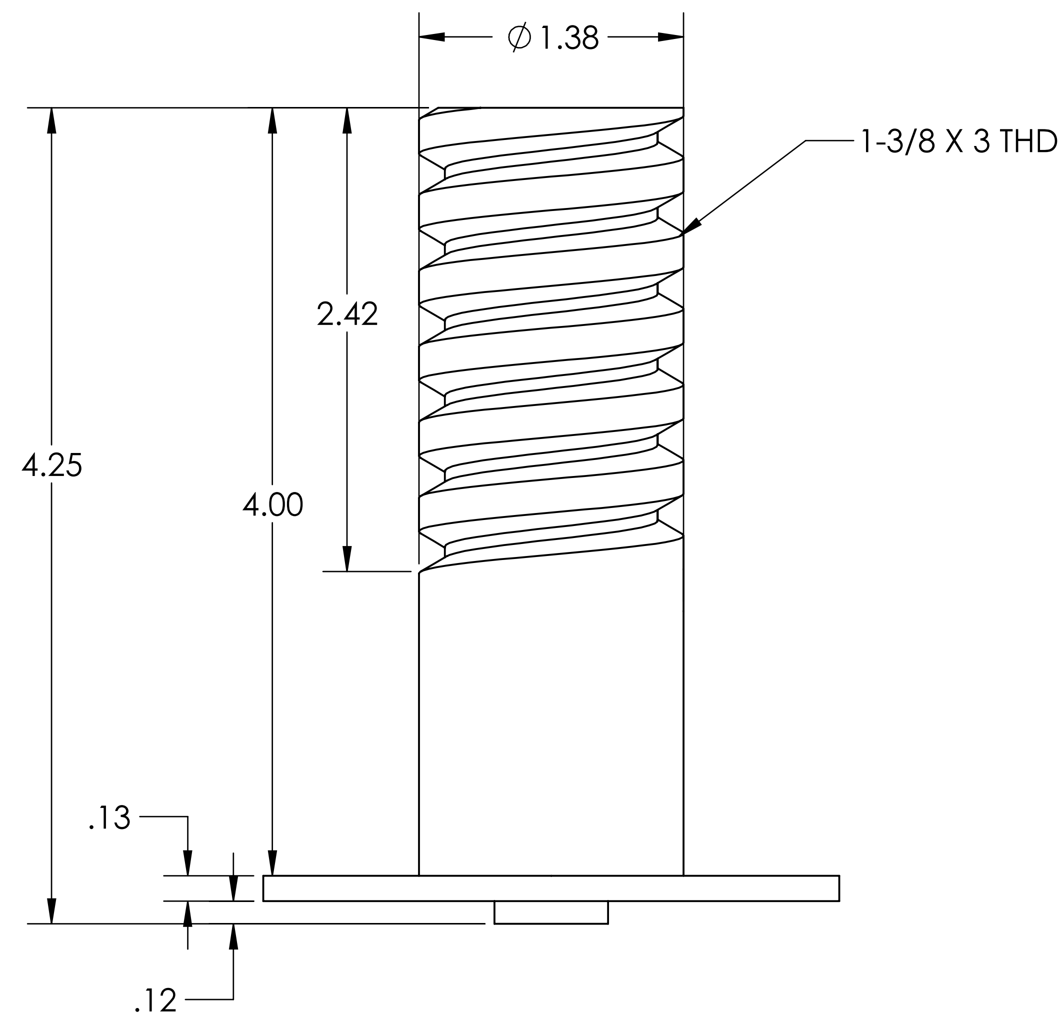
	NAME	DATE
DRAWN	MMY	3/15/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

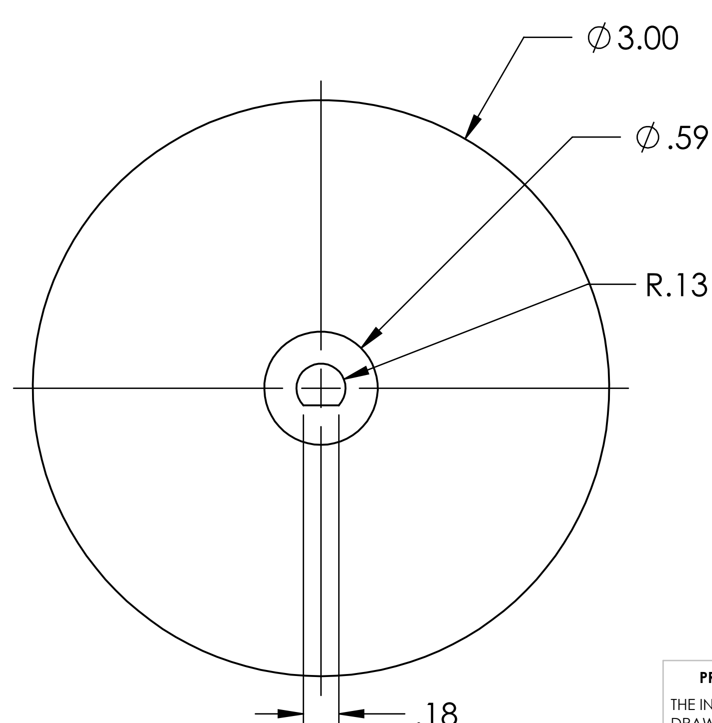
TITLE:
MOUNT, MOTOR, SPOOLER

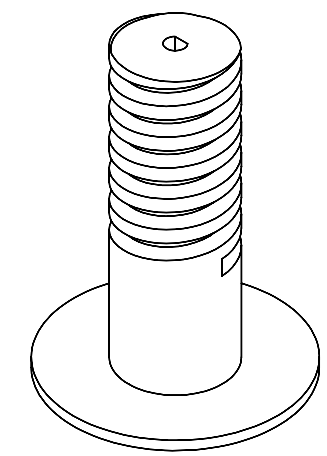
SIZE	DWG. NO.	REV
B	SPOOLER MOUNT	1

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

4	3	2	1







ISOMETRIC VIEW
SCALE 1:2

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

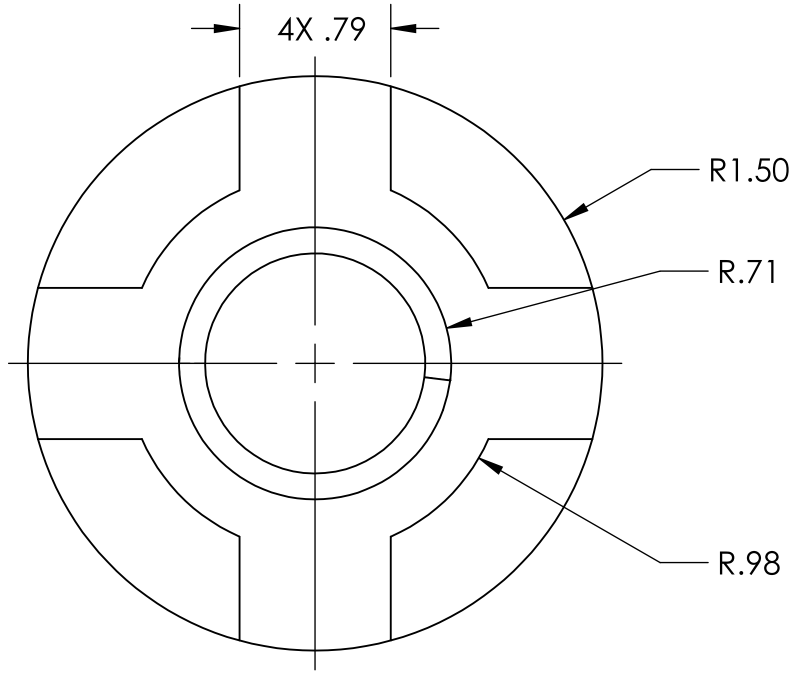
COMMENTS:

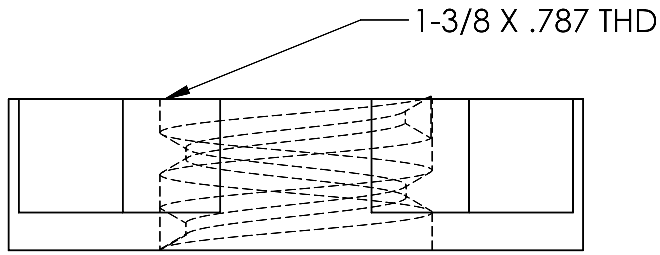
TITLE:

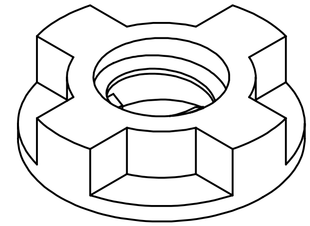
SHAFT, SPOOLER

SIZE	DWG. NO.	REV
B	SPOOLER SHAFT_REV3	0

SCALE: 1:1 WEIGHT: SHEET 1 OF 1







ISOMETRIC VIEW
SCALE 1:2

PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
SPOOLER ASSEMBLY	SPOOLER ASSEMBLY

APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.010
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

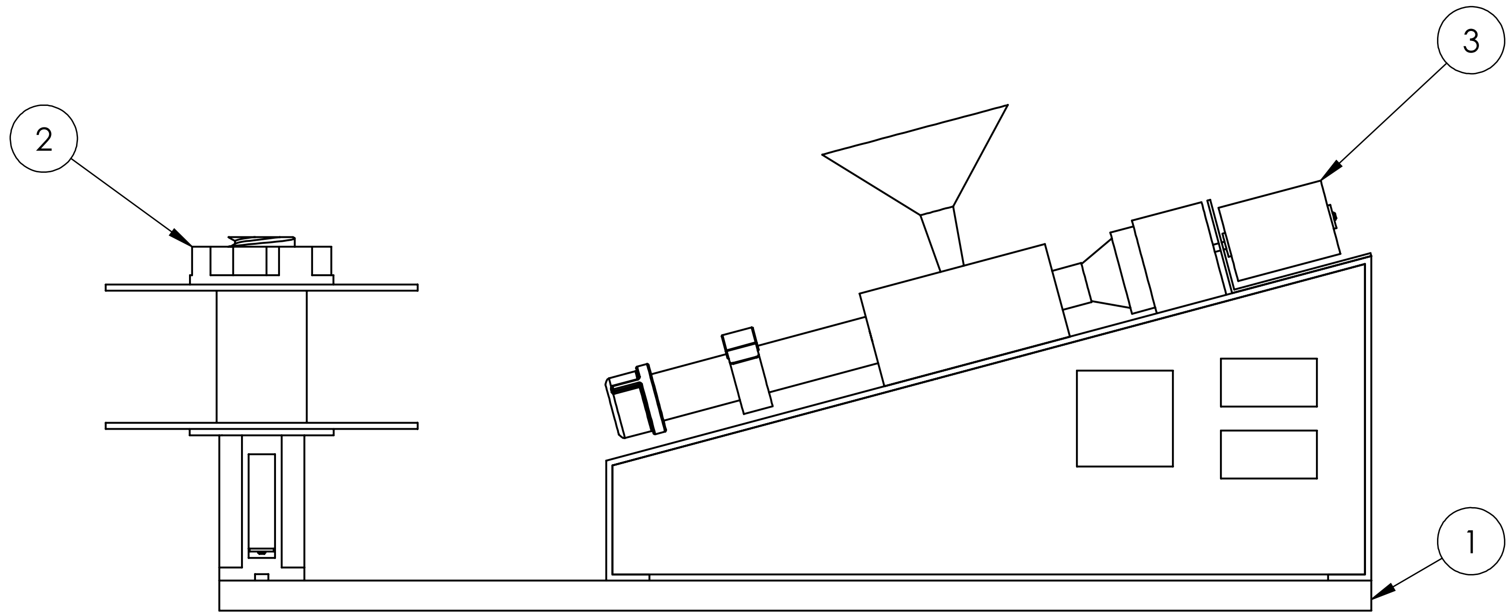
	NAME	DATE
DRAWN	MMY	3-28-18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

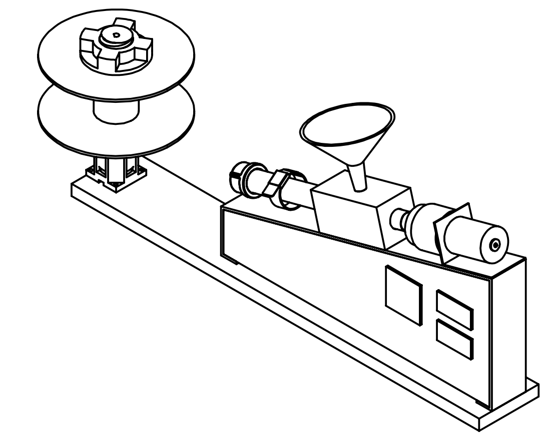
COMMENTS:

TITLE:
NUT, SHAFT, SPOOLER

SIZE A | DWG. NO. SPOOLER NUT | REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1





ISOMETRIC VIEW
SCALE 1:8

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1		PARTICLE BOARD, 5/8 THK	1
2		SPOOLER ASSEMBLY	1
3		EXTRUDER ASSEMBLY	1

NEXT ASSY	USED ON
3D FILAMENT RECYCLER	3D FILAMENT RECYCLER

APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: ±1°
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.010

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: SEE BOM

FINISH: N/A

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MMY	12-8-17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

3D FILAMENT RECYCLER

SIZE: **B**
DWG. NO.: EXTRUDER SPOOLER MOUNT
REV: 0

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

APPENDIX D: Bill of Materials (BOM)

	PARTS	MODEL	RAW MATERIAL	CNT	SOURCE	MATERIAL DESCRIPTION	COST	TOTAL
SHREDDER	Shredder Box	SHAL063PS	5052 Aluminum	1	Southwest Steel Sales, LLC	Sheet Metal, 16 GA (.063 THK), 4' x 5'	$64.96	$64.96
	Motor	a13110400ux0709	N/A	1	Amazon	Gear Box Motor 12V 30RPM	$48.15	$48.15
	Shaft	887480024678	Round Steel Rod	2	Home Depot	36" Long, 5/8" Diameter	$10.97	$21.94
	Blades	N/A	A36 Steel Bar	2	Southwest Steel Sales, LLC	0.5" x 10" x 24" 68.8 LBS	$35.30	$70.59
	Blades Handmade	N/A	A36 Steel Bar	1	Machine Shop	Manufacture Hand Work	$800.00	$800.00
	Spacers	8110000132753	PVC Pipe	1	Home Depot	3/4" x 2' PVC Pipe	$1.64	$1.64
	Gears	N/A	PLA	2	3D Print	PLA, Part from Solidworks	$0.00	$0.00
	Flange Bearings	66625-E	N/A	2	HomeCo	5/8" ID, 1-3/8" OD	$4.79	$9.58
	Precision Bearings	72828	N/A	2	HomeCo	0.9843" ID (measured 0.983"), 2.0472" OD (2.048")	$9.99	$19.98
	Shaft Collars		N/A	2	HomeCo	5/8" ID, with Set Screw, Steel	$2.99	$5.98
	Flat Washer	MF50721	N/A	1	HomeCo	3/4 SAE Flat Wash Zinc	$4.69	$4.69
	Bumpers	39003495650	N/A	1	Home Depot	Bumper Vinyl 3/4" Square	$2.98	$2.98
	Bumper	39003491317	Rubber	2	Home Depot	Bumper Rubber 7/8" WHT	$2.27	$4.54
	Nonglare	74507996562	N/A	1	Home Depot	Nonglare Picture Glazing .05" x 11" x 14"	$5.98	$5.98
	Shaft Collars		N/A	1	HomeCo	3/4 ID, with Set Screw, Steel	$3.94	$3.94
	Handles	885785322710	Steel	2	Home Depot	3 1/2" Wire Handle	$2.98	$5.96
	Scooper	N/A	Plastic	1	Dollar Tree	N/A	$1.00	$1.00
							SUB TOTAL	**$1,071.91**
EXTRUDER	**PARTS**	**MODEL**	**RAW MATERIAL**	**CNT**	**SOURCE**	**MATERIAL DESCRIPTION**	**COST**	**TOTAL**
	Motor	US-SA-AJD-190575	N/A	1	Amazon	DC Motor 12V 30RPM	$15.99	$15.99
	Flange Bearing	66623-C	N/A	1	HomeCo	1/2" ID, 1-1/8" OD	$4.69	$4.69
	Chuck	33287166404	N/A	1	Home Depot	1/2" 20 Drill Chuck & key	$15.97	$15.97
	Auger	DW1685	N/A	1	HomCo	7/8 Auger Bit, 17" long	$30.99	$30.99
	Hopper	N/A	Funnel	1	Dollar Store	Plastic Funnel	$1.00	$1.00
	Extruder Housing	DW1685	6061 T6 Aluminum	1	Machine Shop	2" x 3" x 7" Block	$29.00	$29.00
	Heating Chamber	HPI/75040	Hot Rolled Steel	1	Metal Supermarkets	Pipe, 0.75" ID, 12"	$3.20	$3.20
	Nozzle	32888405660	Steel	1	Home Depot	3/4" Galvanized Cap	$2.54	$2.54
	MDF Board	90489149949	Wood	1	Home Depot	0.216" x 23.75" x 47.75" Flat Board	$7.42	$7.42
	Heating Band	2VXV4	N/A	1	Grainger	900F, 120VAC, Watts 100, Inside Dia. 1", Width 2"	$28.50	$28.50
							SUB TOTAL	**$139.30**
SPOOLER	**PARTS**	**MODEL**	**RAW MATERIAL**	**CNT**	**SOURCE**	**MATERIAL DESCRIPTION**	**COST**	**TOTAL**
	Motor	US-SA-AJD-190575	N/A	1	Amazon	DC Motor 12V 30RPM	$15.99	$15.99
	Spool	N/A	N/A	1	Donated	N/A	$0.00	$0.00
	Shaft	N/A	PLA	1	3D Printed	Conical Shaft	$0.00	$0.00
							SUB TOTAL	**$15.99**
EXTERNAL	**PARTS**	**MODEL**	**RAW MATERIAL**	**CNT**	**SOURCE**	**MATERIAL DESCRIPTION**	**COST**	**TOTAL**
	Arduino Uno	B074WMHLQ4	N/A	1	Amazon	Uno Project Super Starter Kit	$31.99	$31.99
	PID Controller	B01KNXETWS	N/A	1	Amazon	Temperature Thermostat Controller	$31.99	$31.99
	PID Controller	B01KNXETWS	N/A	1	Amazon	Temperature Thermostat Controller	$33.99	$33.99
	SSR	N/A	N/A	1	Amazon	Solid State Relay	$13.99	$13.99
	LED Power Supply	26100000	N/A	3	Amazon	LEORX LED Transformer LED Power Supply	$12.99	$38.97
	Small Cooling Fan	5382968	N/A	2	Fry's Electronics	SilenX IXP-11-14 40 x 40 x 10 mm	$9.99	$19.98
	Outlet Wire	7800	N/A	1	Surplus Property Office	3 Prong Wire	$1.00	$1.00
	Base Board	N/A	Pallet Wood	-	Home Depot	Home Depot Gives Them Away	$0.00	$0.00
							SUB TOTAL	**$171.91**
HARDWARE	**PARTS**	**MODEL**	**RAW MATERIAL**	**CNT**	**SOURCE**	**MATERIAL DESCRIPTION**	**COST**	**TOTAL**
	Screw	43824	-	3	NAU Machine Shop	M3 Button Head Socket Cap Screws	$0	$0
	Washer	302	-	4	NAU Machine Shop	Small Neoprene & Fiber Washers	$0	$0
	Cap Screw	-	-	4	NAU Machine Shop	#6, 3/8 in Long, SST 18-8, Socket Head	$0	$0
	Wood Screw	-	-	6	NAU Machine Shop	1/4, 1 in Long, SST 18-8, Hex Head, Self-Tapping	$0	$0
	Cotter Pin	-	-	4	NAU Machine Shop	1/8 in Wire Dia., 5/8 in Eye Dia., 2.5 in Long	$0	$0
							SUB TOTAL	$0.00
TESTS	**PARTS**	**MODEL**	**RAW MATERIAL**	**CNT**	**SOURCE**	**MATERIAL DESCRIPTION**	**COST**	**TOTAL**
	3D Filament	N/A	PLA Filament	1	N/A	PLA	$14.99	$14.99
							SUB TOTAL	**$14.99**
TOTALS							**SHIPPING & HANDLING**	**$39.89**
							TAX	**$26.49**
							GRAND TOTAL	**$1,480.48**
							BUDGET ALLOTED	**$2,000**
							DIFFERENCE	**$520**