2016

3D Printer Filament Extruder

Senior Design - Spring 2016
IPFW – Mechanical Engineering Technology
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Table of Contents

PROPOSAL – A New Option for 3D Printing Recycling

The task our group has decided on for our senior design project is to build a 3-D printer filament recycler. The filament is a polymer which is fed into the machine and used to print whatever object is being made. Our device will use the scrap material from other 3D printing projects and recycle it into a new and usable spool of material.

The machine functions by placing scrap filament pieces into a tube via a funnel which then is driven through the tube with a spiraled auger, powered by a small stepping motor. The material will travel through the tube towards the "hot end" which will contain a heated die – this is essentially a very small tunnel, just under two millimeters in diameter. Once the material reaches the end of the tube with the die, the heaters attached to the cap will supply a hot environment which will melt the scrap pieces of filament and then they will be forced through the die and extruded into a new strip of recycled filament, ready for future use in printing.

Manufacturing is a major contributor to the voracious consumption of resources available to human beings. Devices which can recycle material and help slow the depletion of natural resources and make engineering and manufacturing a more ecological-friendly practice are very beneficial in the industry. For the surrounding area of northeast Indiana there are a substantial number of manufacturing plants, especially in the medical business, that use 3D printing in their daily production. With every part produced, there is a percentage of scrap that comes with the finished product, and this means wasted expenses. The goal of this project is to reduce the scrap from 3D printing, lower the overall cost of printing production via material cost, and offer an efficient and useful device to the printing industry.

There are many different materials used in the 3D printing industry, but one specific example is polylactic acid, or PLA. There are several ways PLA products can be disposed of, such as: added to landfills, combusted for energy, composted, or lastly - what the group is working to achieve - recycled. "In accordance to Shen, the best PLA end-of-life option is recycling, just like other plastics. In a European study it appears that the environmental impact of recycling PLA is over 50 times better than composting and 16 times better than combusting PLA!" PLA can be burned which will produce energy, but at the cost of the environment rather than being reused. To compost PLA it can take one to three months at high temperatures in an industry setting, whereas at home it can take six months or even longer. Out of all the options recycling is by far the best choice, and this is what the extruder project aims to achieve.

DESIGN/CONCEPT – What Is The Device Comprised Of

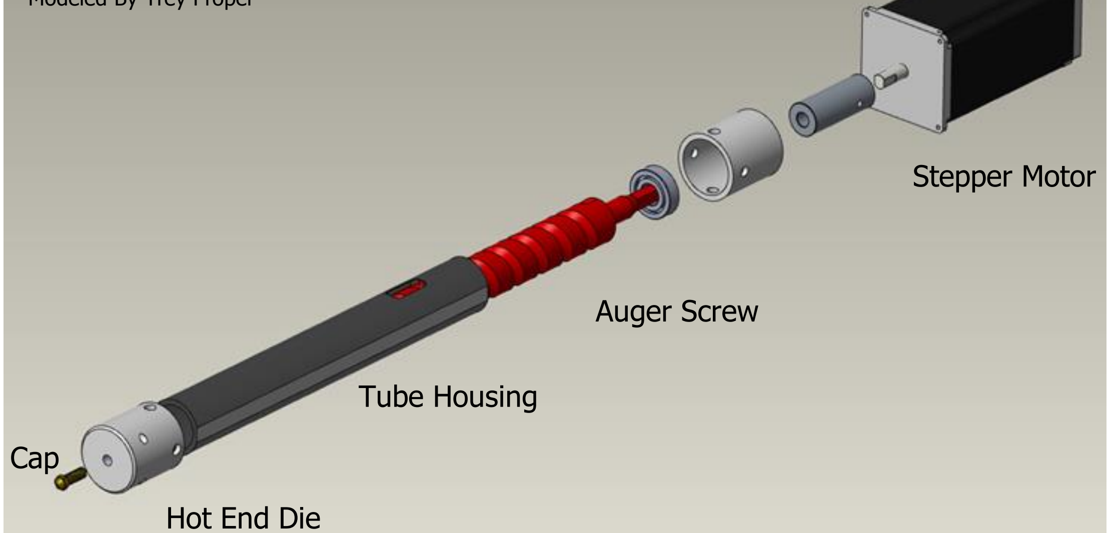
The extruder machine is 18 inches in total length, and the main tube being used is one inch internal diameter, resulting in a very small and portable device. It contains six primary components:

- Power Supply – The device runs according to software settings controlled by a laptop computer that is hooked up to an electronic board.
- Stepper Motor – The motor is energized via the Arduino Mega 2560 microcontroller and provides enough force to turn the auger screw.
- Auger Screw – The helical spiral will act as a conveyor for the filament pieces and push them towards the end of the tube.
- Tube Housing – the one inch internal diameter tube is used to guide the scrap pieces
- Cap – Custom fabricated cap to fasten onto the end of the tube to collect all of the filament pieces at the end of the conveyor.
- Hot End Die – Purchased component with a 1.75 millimeter hole. Hot, liquid material is forced through the hole to extrude a small diameter wire of filament.
- Bearing – Isolates motor from axial loading caused by CCW turning of the auger

The current focus for the project is polylactic acid, or PLA – a common material that filament is made from with a lower melting temperature compared to other polymers. If the machine is able to extrude PLA successfully, other materials will be tested in the future to broaden the applicability of the machine.

MODEL/COMPONENTS – Created With PTC Creo Parametric 3.0

FIGURE 1
Modeled By Trey Proper



Scrapped pieces of plastic will be funneled into the circular cutout in the tube housing and be pushed through the tube by the spinning of the auger screw powered by the motor. The pieces will travel down into the cap where they will be heated up and melted. As the pieces melt down, the liquid plastic is forced through the hot end die, and extruded with a diameter that matches the inside of the die.

*See bulleted list above for details of components.

POTENTIAL CONSUMERS - Who Would Benefit From This Project?

- In-House Creations

With newer technologies rapidly evolving, 3D printers have shrunk down to an easily portable size, opening the door to the individual, rather than being exclusive to professional organizations. Hobby printing has now became readily available to the public. People will often experiment with smaller, more home-friendly 3D printers and create their own inventions and projects from their homes. In this case, without being funded by a manufacturing process, a hobby printer will have limited resources for sustaining their in-home printing.

- Reusing Materials

With each mistake from a novice printer comes two things: experience from that mistake, and the cost of the mistake from wasted material. Being that they are self-funding their materials to print, the hobby printer could recycle old prototypes or mistakes in their own printing processes and lower costs for the project that is being ran.

- Avoiding Unnecessary Expenditures

The 3D printer filament recycler project has the ability to leave a profound impression on the 3D printing industry. The ability to recycle old and used filament directly equates to lowered material costs and rework costs. Reworking is a term used in manufacturing when there is a mistake in production and in order to salvage the bad product, a sub-process must be applied to correct the issue. Examples of reworking would include: repainting a finished product, correcting the angle of bends in sheet metal, or grinding off excess weld spatter from parts.

- Mass Production

The ability to recycle product is extremely beneficial to a manufacturing company. The number one goal for a manufacturer is to have product rolling off of the production line. The more goods a manufacturer can produce, the more profit yield they can achieve. This means sending large amounts of material through their machines, and although an engineer’s goal is to perfect the efficiency of a process, problems will inevitably occur with the products or the processes.

Instead of having to rework a mass load of product, they would just be recycled into the next batch of parts.

EXAMPLES/SCENARIOS OF USE

- The Issue With Polymers

When a problem arises, whether it be an incorrectly formed part, or an issue with the process, the best choice is to rework that part. With 3D printing, a majority of the printed product is made from plastic, which has difficulties with reworking because of the way that the molecules bond during the printing process – the finished product is very hard and cannot be manipulated by hand without tools. It also tends to be brittle, meaning that if a piece is hit with enough force, the plastic will snap right off. This gives little hope for reworking printed parts.

- A Solution To The Issue

The recycler project provides the opportunity for printing manufacturers to recycle any bad part rather than scrapping it without any restrictions. Regardless of what is being printed, the process always starts with the spools of filament - the base material. So although product A may be an entirely different shape than product B, product A can be melted down and reused to produce product B.

- Organization Benefits

Although this technology does not have an effect on every employee of a printing manufacturer, it does directly affect the quality department through waste management and scrap percentages form processes. Any motion towards a leaner, more efficient process is a positive motion in manufacturing. Quality engineers oversee how the process is being carried out and if the correct steps are being taken to ensure that even if something may happen to go wrong, there is an available solution to the problem. This is where the recycler project could make a difference. Perhaps an operator runs a machine with the wrong settings and does not realize his error for one whole hour. Each part that is produced within that time period is considered to be bad and must be accounted for. With the filament recycler, there is an opportunity for a new process that in the event of having bad parts, they can be cut down and melted through the machine, and recycled into a new and reusable filament to continue production without having to purchase additional material to compensate for the operator's mistake.

CAUSES OF CONCERN: LONG TERM EFFECTS OF RECYCLING PLASTIC AND THEIR MATERIAL PROPERTIES

Some causes of concern are whether the heat will change the molecular structure of the material being melted. If re-melted several times the plastics could begin to bond together and oxidize, forming a very hard block of plastic. If this happens it is nearly impossible to extrude. This also may cause the desired characteristics of the material to change, and then not function as needed for the design of the product. A good option to combat this is introduce a small amount of virgin plastic to the recycled pieces. Another cause of concern is the change in coloring. If heated too much it may cause the part to burn or become discolored, which also could have a negative impact on the application of the product.

HOW FILAMENT IS COMMERCIALLY PRODUCED – What Sets Our Project Aside From Mass Production

Producing 3D printing filament follows a specific set of conditions to have the process be successful. Using a system of machinery, the plastic resin is treated through four primary zones and extruded into spools of wire.

The pictures below show bags of pellets of the material that will be made into the rolls of 3D printing material. All pellets start out clear or white. If a color is desired, pigments are added and mixed in with the resin until it is uniform. Once it is uniform it will be put in a dryer for around two hours. The dryer will be set between 60-80 degrees Celsius depending on the resin being used.

FIGURE 2 – Bags containing resin pellets

FIGURE 3 – Resin pellets

Once the plastic is mixed and fully dried it will be put in a container like the one below. This will preheat and funnel the plastic into a single screw extruder device.

FIGURE 4 – Funneling & Hopper System

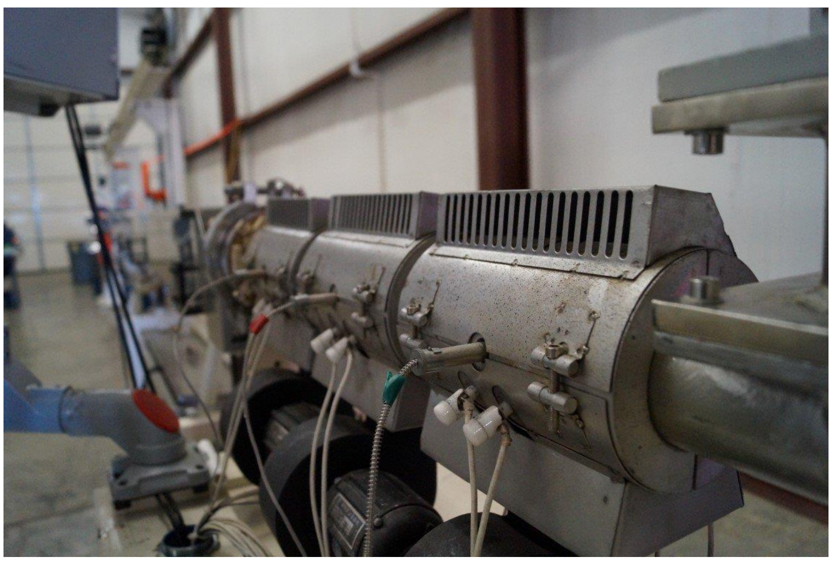


FIGURE 5 – Screw Extruder Device

Here the pellets are melted down and pushed through the extruder. The tension on the filament, or how quickly it is pulled out of the extruder directly has an effect on the size and shape of the filament strand. This can be manipulated by adjusting the speed of which the filament comes out of the machine.

FIGURE 6 – Lines Of Filament Passing Through A Series Of Pulleys.

This filament is then pulled through a warm tank to help cool the material slowly. If the temperature is incorrect the material will be oval rather than round. Once ran through the warm water it will be ran through a cold water section, then rolled up into the desired spools.

Precision and Resolution of 3D printers

The resolution of a 3D printer can be determined by 2 values: Layer Thickness and Feature Size. First, layer thickness is a measure of the height of each added layer. Thinner layers can provide greater precision, but will also cause the time of printing to drastically increase. The increased time will consequently increase cost of the part being created. As for the feature size this is the length and width of the filament. This can be looked at similar to a normal printer that is commonly used in industry every day. The resolution (layer thickness and feature size) that can be achieved by a 3D printer is restricted by its physical capabilities, rigidity and electronic capabilities.

Printer / Technology	Layer Thickness
Professional fused deposition modelling for production (Stratasys, etc.)	0.17 mm to 0.33 mm (0.007" to 0.013")
Office or fablab fused deposition modelling (Makerbot, Ultimaker, etc.)	0.10 mm to 0.33 mm (0.004" to 0.013")
Selective laser sintering (SLS) - (EOS, 3D System)	0.060mm to 0.150 mm
Resin deposit (Stratasys Polyjet)	0.016mm to 0.028 mm
Material binding (3D Systems ZPrinter)	0.1 mm
Stereolithography, DLP, resin hardening by light or laser	0.05 mm to 0.15 mm
Wax deposition by piezoelectric head (Solidscape)	0.005 mm to 0.10 mm

FIGURE 7 – Shows machine capabilities on filament geometry and accuracy.

Progress of the Project

Assume:
Ti=68°F
Uniform heating of steel pipe (1" Section)
Ksteel= 43 w/m^2*kg
Kplastic= .17 w/m^2*kg
External insulation so effective, approaching adiabatic.

$$\dot{Q} = K \times Ac \times \frac{\Delta T}{L} = \frac{\Delta T}{Rtotal}$$

Rtotal = Rsteel+ Rpla $\quad$ Rcyl= $\frac{\ln\left(\frac{R2}{R1}\right)}{2\pi Lk}$

R total=ln[(1.32/2)/(1.0/2)]/(2π*1*43)+ 1/(.17*π*.5^2)
R total= .00102+7.4896

$$\dot{Q} = (374°\text{F} - 68°\text{F})/7.49$$

$$\dot{Q} = 40.85\ Watts$$

FIGURE 8 – Calculations of energy required to reach a desired temperature

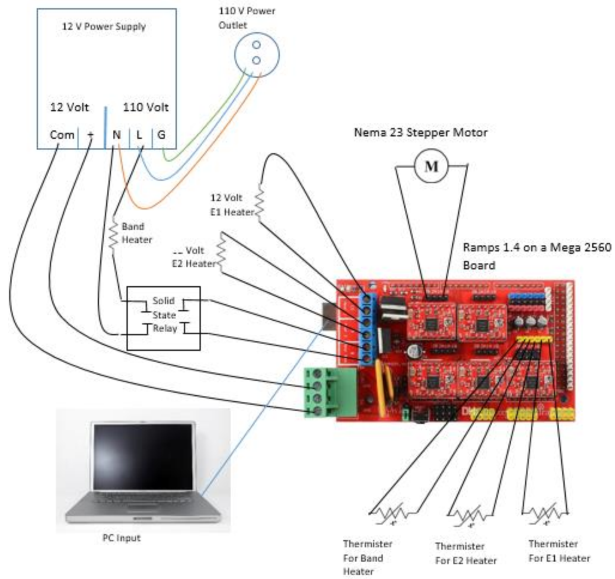


FIGURE 9 –Circuit diagram of the electronics used.

Figures 8 and 9 show the beginning stages of planning for the project. First we had to determine the rate of energy required to meet the melting temperature of the plastics we tested. Then we laid out the design of the devices overall (this is where the early model was implemented, shown in Figure 1, page 5).

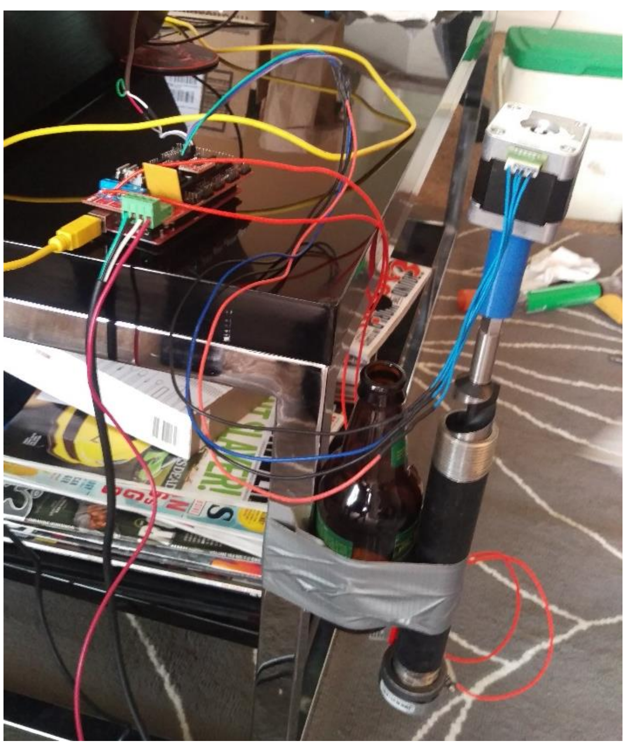
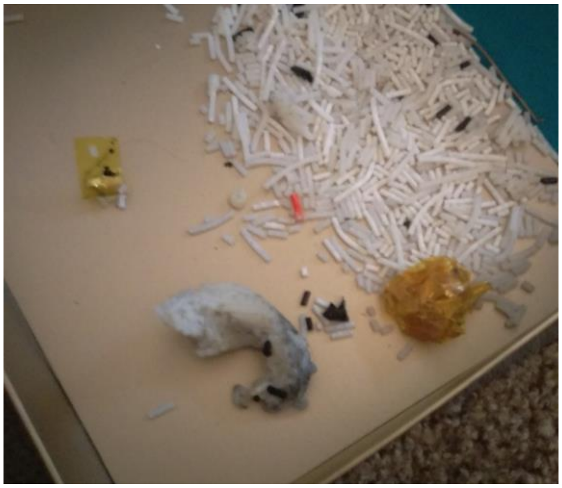


Figure 10 shows the device in development. In the beginning we tried mounting the extruder vertically so we could work with gravity having the filament come straight out of the bottom of the device. The bottle is acting as a dampener between the table and the tube that is being heated. The small red device with the bright yellow cable plugged into it (upper left) is the electronics board that controls the operation via software on a laptop computer. The variables we focused on testing were heat and feed rate, or how quickly we pushed filament pieces through the tube.

FIGURE 10 – Early Testing (3/9/2016)



At the bottom of Figure 11 there is a large solid piece of plastic that was a result of one of our first test runs. As mentioned previously, if the rate of heating is not ideal, the plastic will bond together and become very hard and brittle from oxidization. We wondered if the motor we implemented just did not have enough torque to spin the plastic inside the tube until we discovered that this was happening and clogging our conveyor system through the tube. (3/16/2016)

FIGURE 11 – If it melts, we can extrude it.

Figure 12 was the first night we had success with extrusion. We designed and machined a new cap for our extruder that fit more securely and had a smoother and more symmetrical inside geometry than our first purchased cap that we tried. The blue filament strand exiting the extruder is not straight and has an inconsistent diameter. It was determined that our feed rate of extrusion was not linear, or held at a constant rate and this was the cause of our inconsistencies. (3/20/2016)

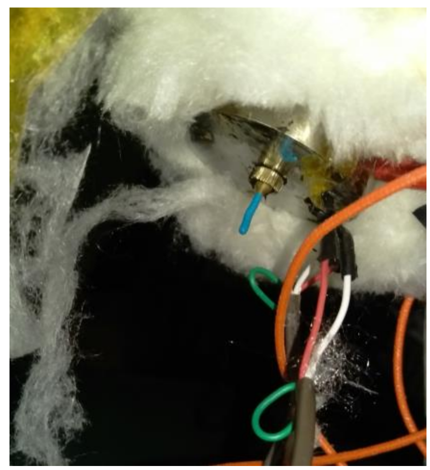


FIGURE 12 – The Sweet Glimpse of Success

Torque Measurements:
Necessary torque measured at 22.5 in-lbs of torque using an in-lb torque wrench.
Nema 23 stepper motor rated at 26.56 in-lbs of torque
Leaving us with a safety factor of 1.15.

Testing the device was further advanced with the implementation of a fixture; duct taping the extruder to the table was neither very safe, nor practical. We also upgraded to a larger motor with higher torque to ensure we had the capability of continuously pushing plastic through the tube.

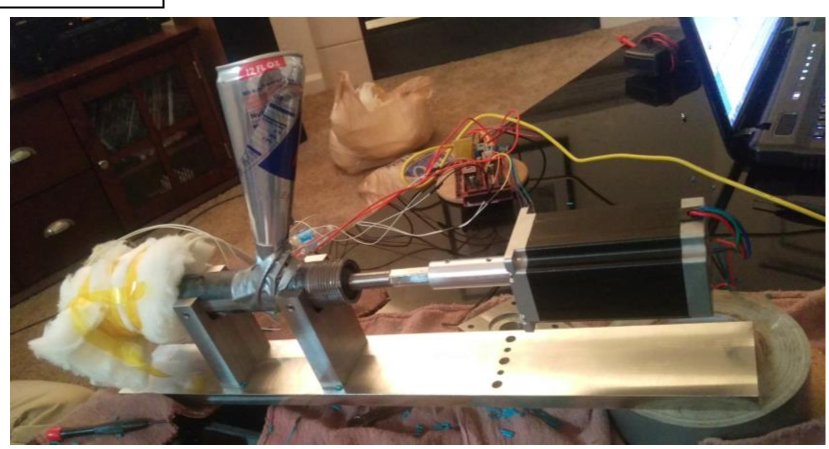


FIGURE 13 – Advanced Testing Stages (4/13/2016)

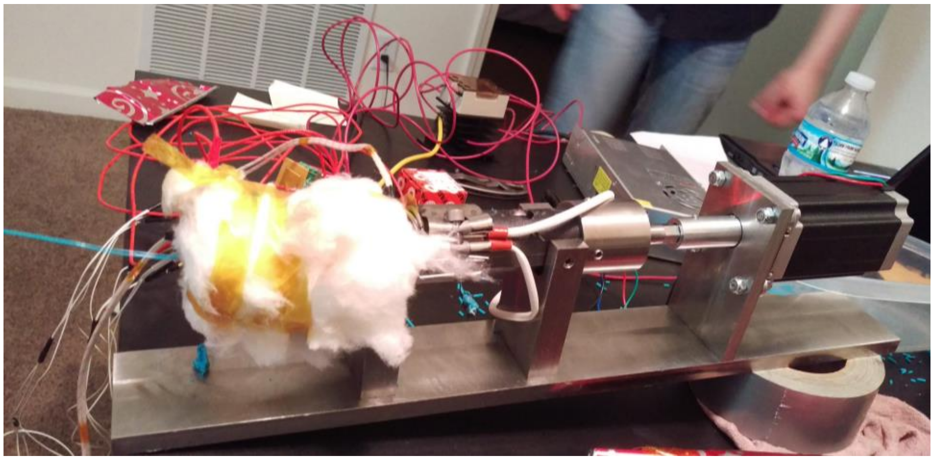


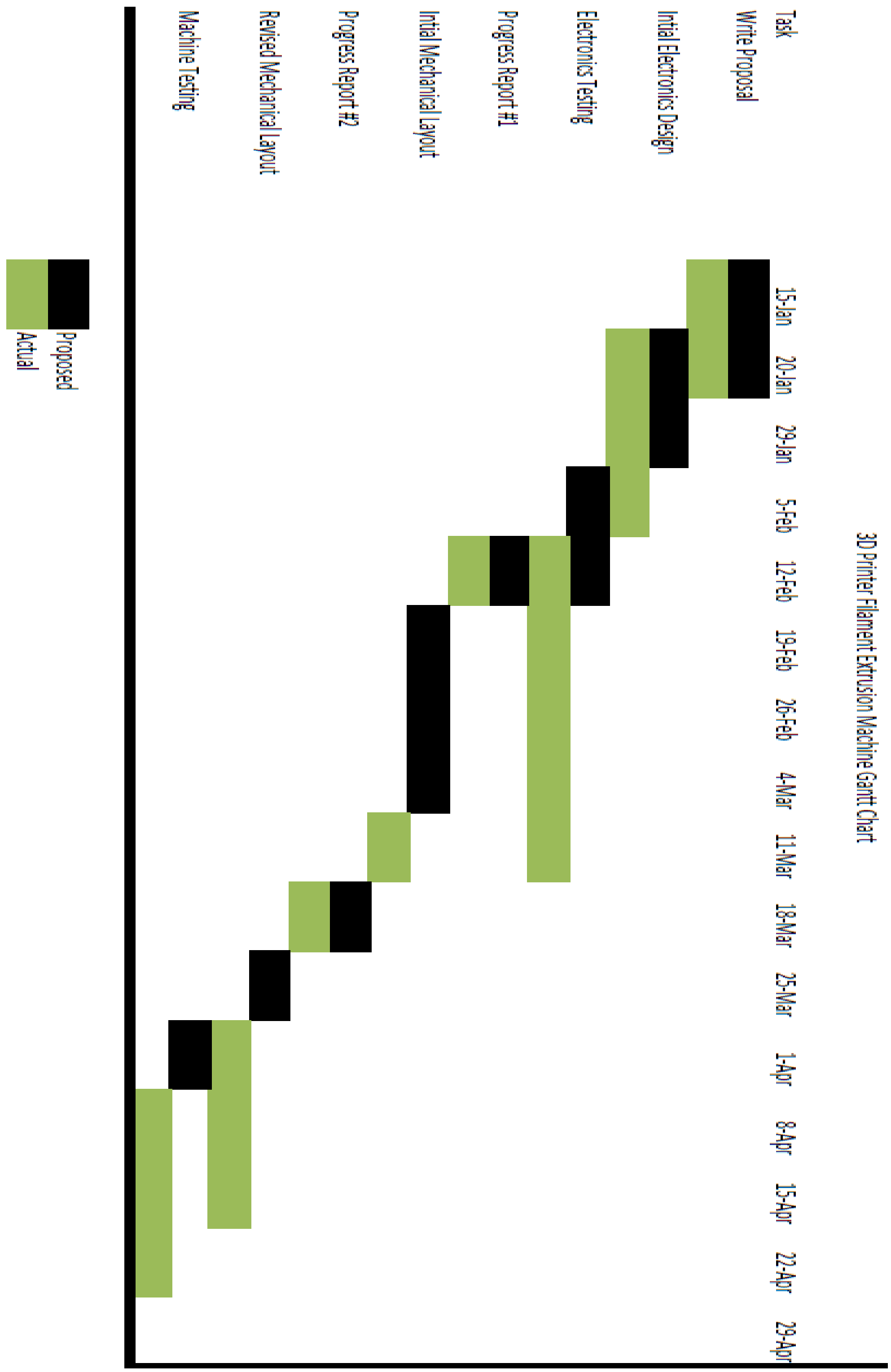
FIGURE 13 – More Updates and Full Extrusion!

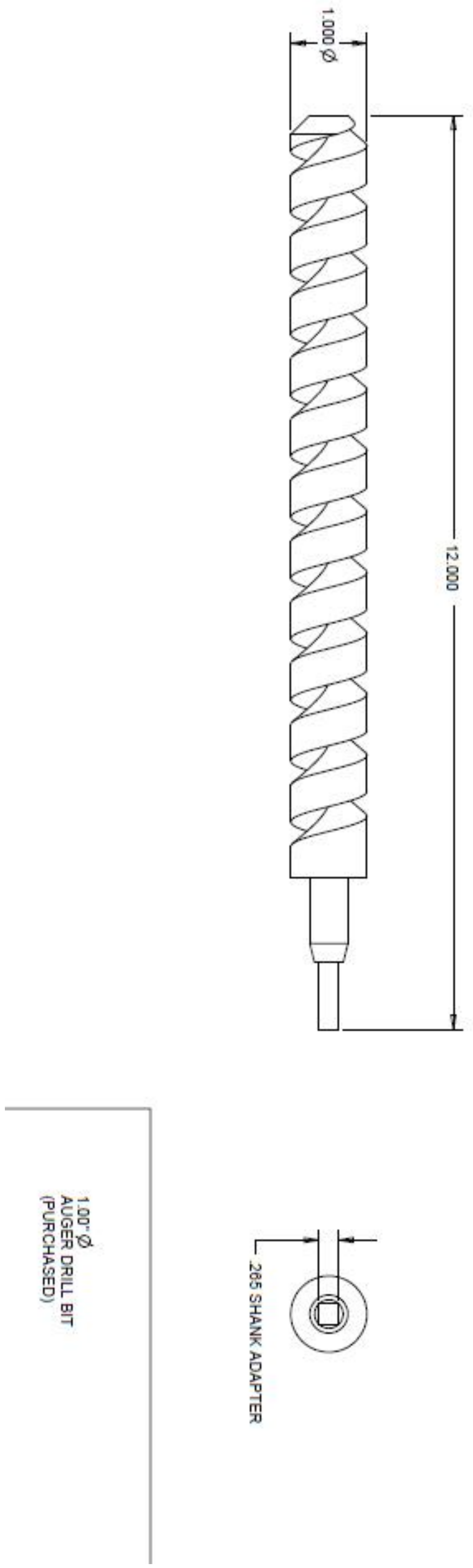
(4/18/2016)

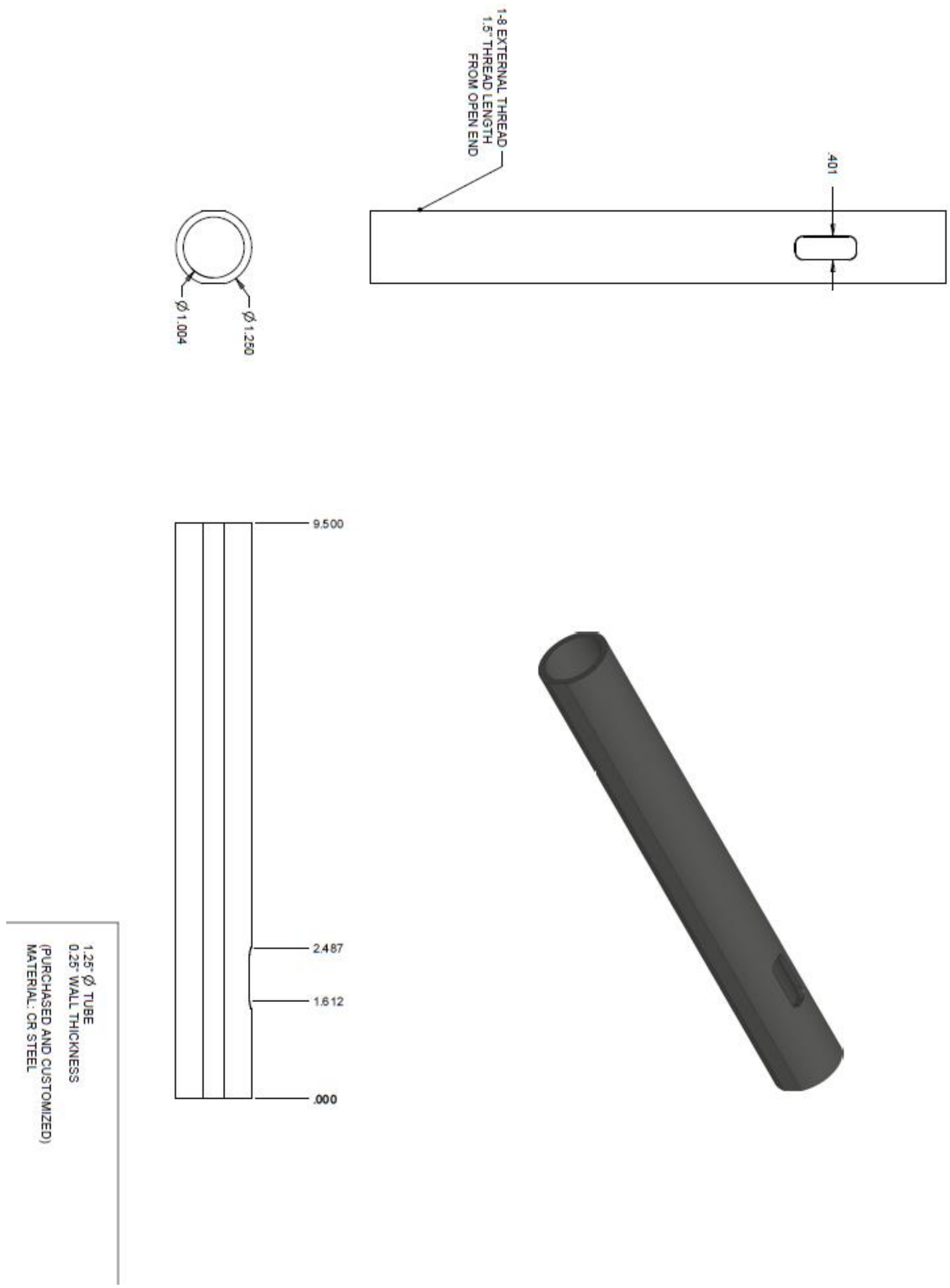
The light blue string coming out of the front of the device (left side of image) is recycled filament! Just to the right of the fiberglass insulation, there is a clasp wrapped around the tube which is a third heater we implemented. This solved the issue of the plastic bonding together inside of the tube and causing a blockage internally.

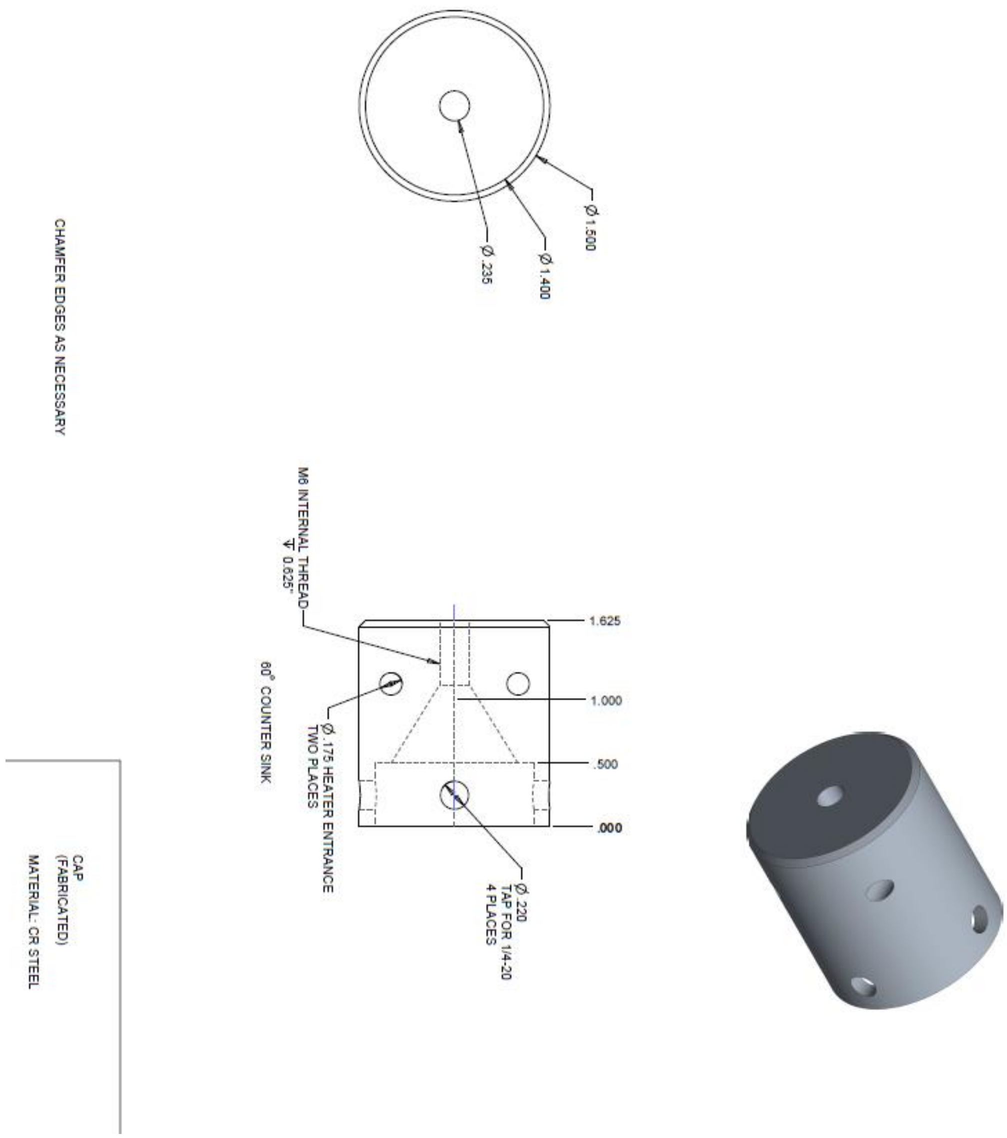
FIGURE 14 – During a successful run we managed an extrusion rate of roughly 12 inches per minute. We found that running the motor at a lower RPM would provide more torque to push the material through the device. Shown on the floor here is a single strand of filament continuously extruded.

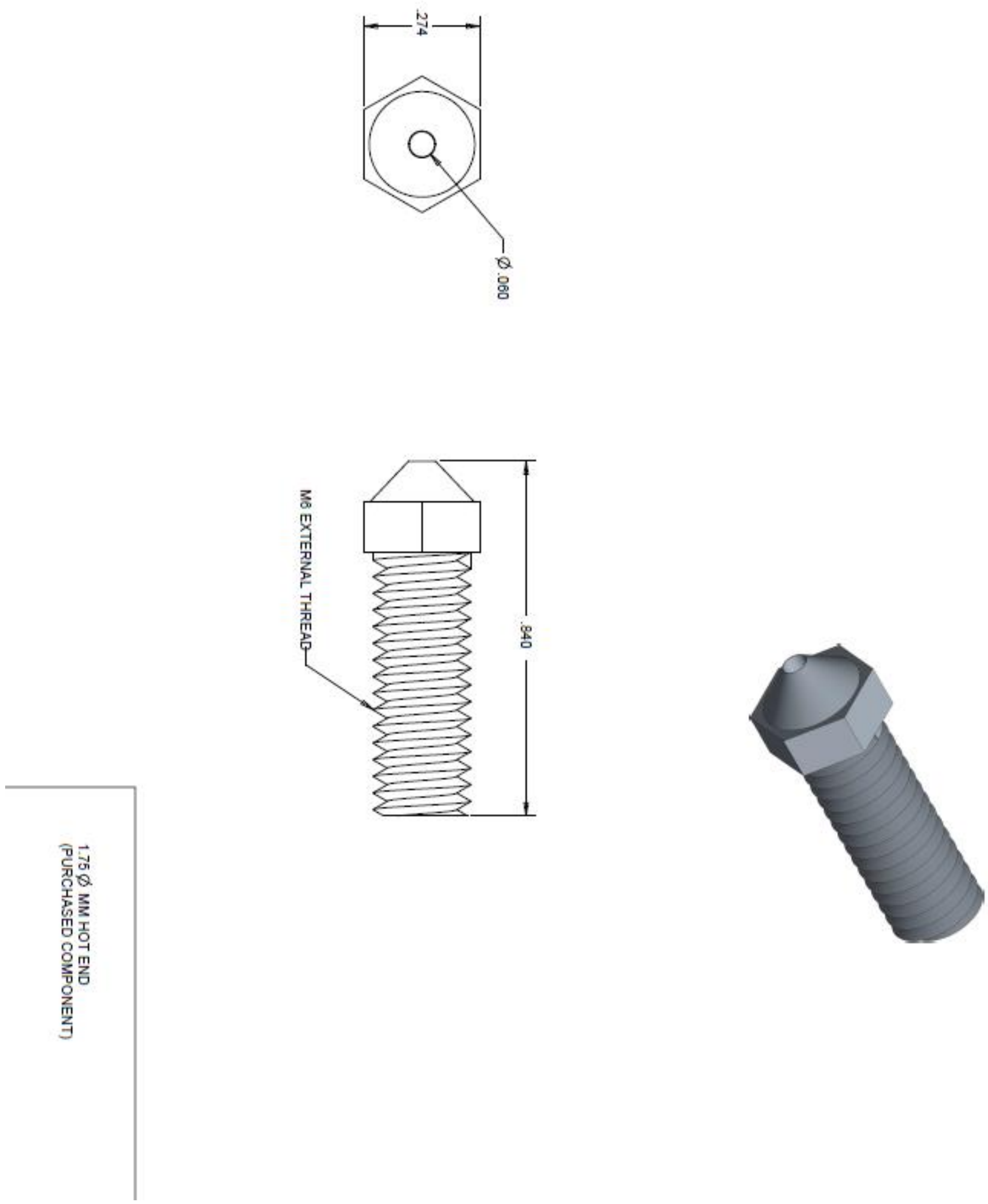
FIGURE 15 – Shown here is a long, single piece of extruded filament coming out of the device during operation. (4/19/2016)

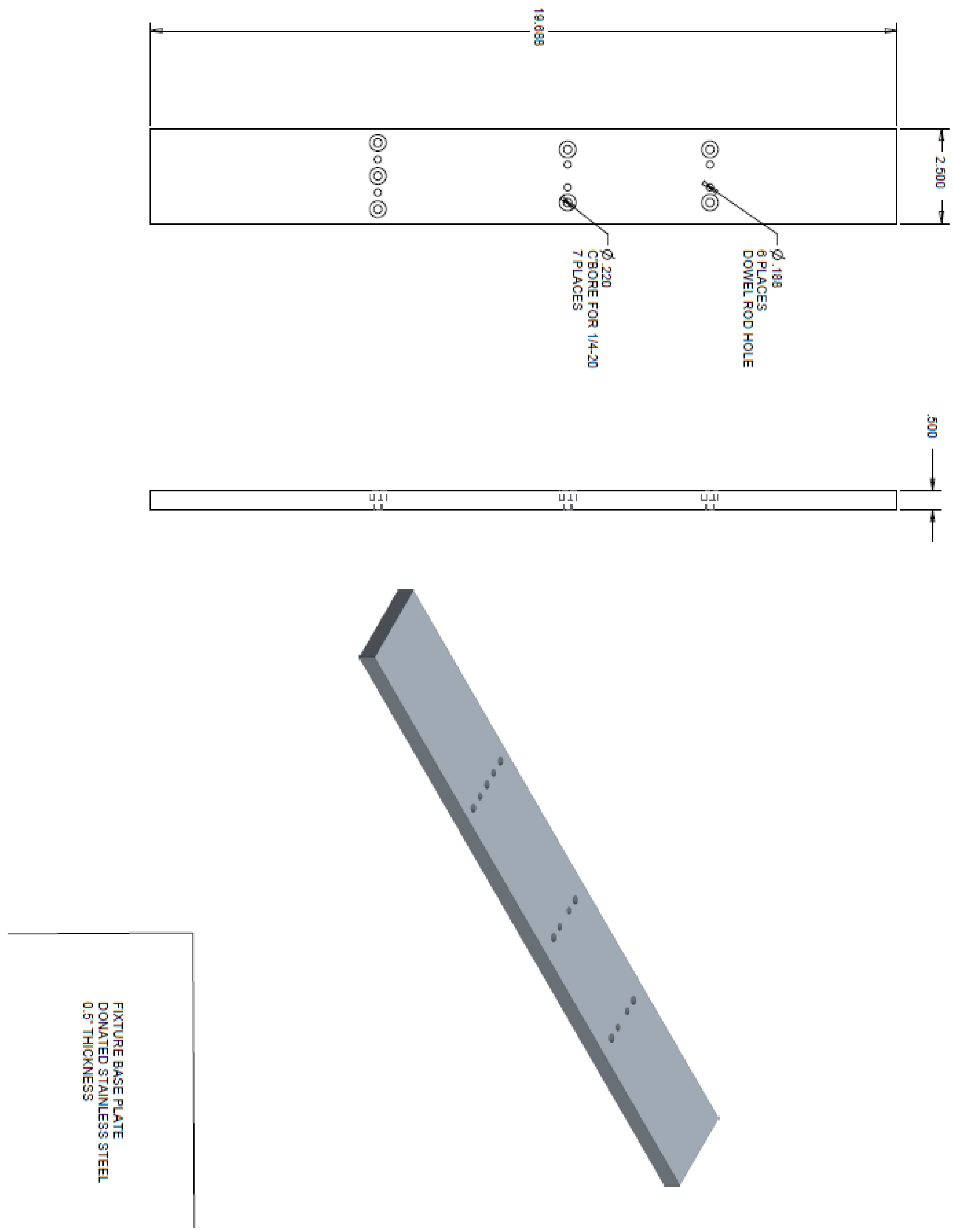

3D Printer Filament Extrusion Machine Gantt Chart
Task
Write Proposal
Intial Electronics Design
Electronics Testing
Progress Report #1
Intial Mechanical Layout
Progress Report #2
Revised Mechanical Layout
Machine Testing
15-Jan
20-Jan
29-Jan
5-Feb
12-Feb
19-Feb
26-Feb
4-Mar
11-Mar
18-Mar
25-Mar
1-Apr
8-Apr
15-Apr
22-Apr
29-Apr
Proposed
Actual


1.000 Ø
12.000
.265 SHANK ADAPTER
1.00" Ø
AUGER DRILL BIT
(PURCHASED)

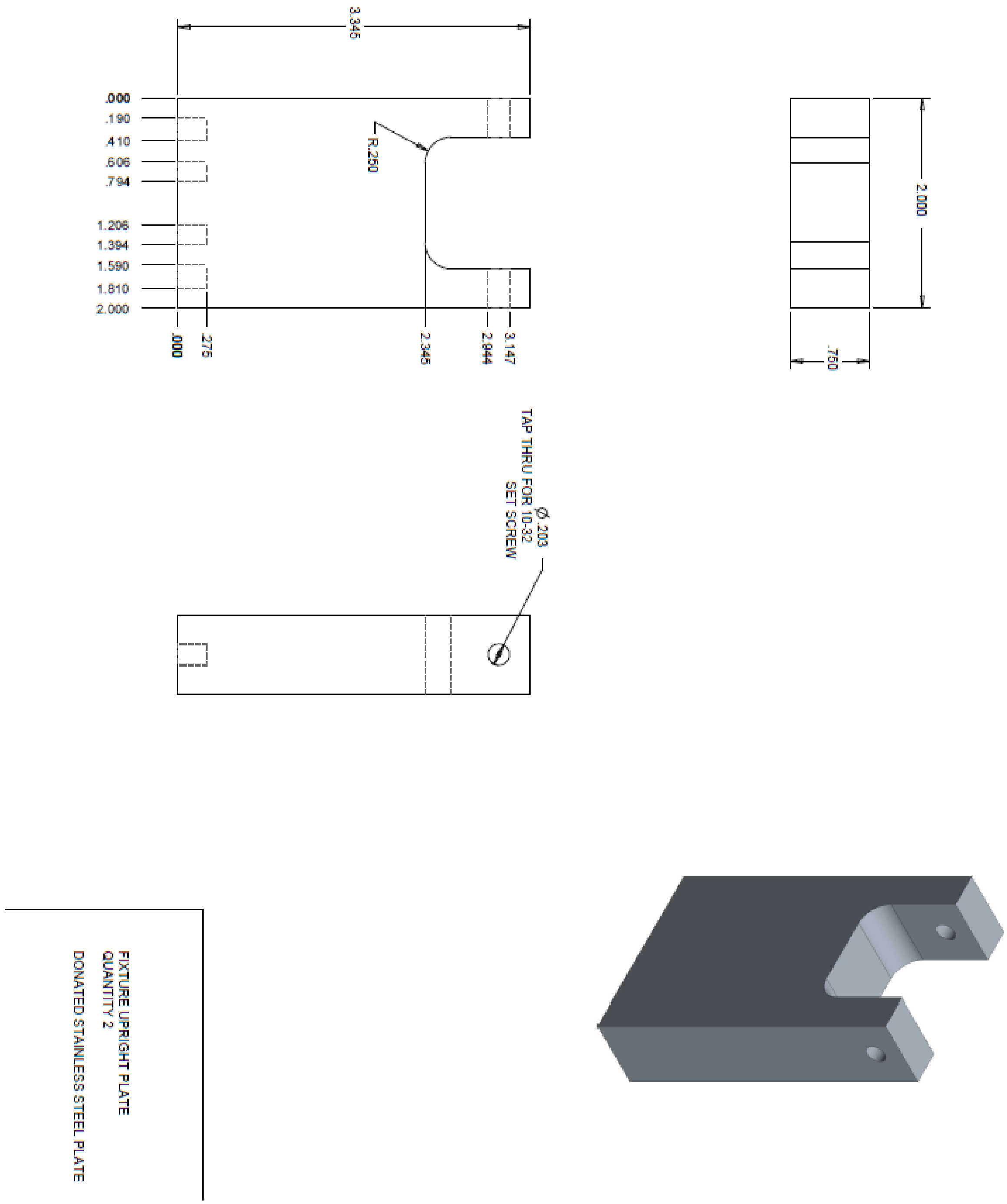

1-8 EXTERNAL THREAD
1.5" THREAD LENGTH
FROM OPEN END
.401
Ø 1.004
Ø 1.250
9.500
2.487
1.612
.000
1.25" Ø TUBE
0.25" WALL THICKNESS
(PURCHASED AND CUSTOMIZED)
MATERIAL: CR STEEL


Ø 1.500
Ø 1.400
Ø .235
1.625
1.000
.500
.000
Ø .220
TAP FOR 1/4-20
4 PLACES
Ø .175 HEATER ENTRANCE
TWO PLACES
M6 INTERNAL THREAD
⊽ 0.625"
60° COUNTER SINK
CHAMFER EDGES AS NECESSARY
CAP
(FABRICATED)
MATERIAL: CR STEEL


.274
Ø .060
M6 EXTERNAL THREAD
.840
1.75 Ø MM HOT END
(PURCHASED COMPONENT)



19.688
2.500
Ø .188
6 PLACES
DOWEL ROD HOLE
Ø .220
CBORE FOR 1/4-20
7 PLACES
.500
FIXTURE BASE PLATE
DONATED STAINLESS STEEL
0.5" THICKNESS


3.345
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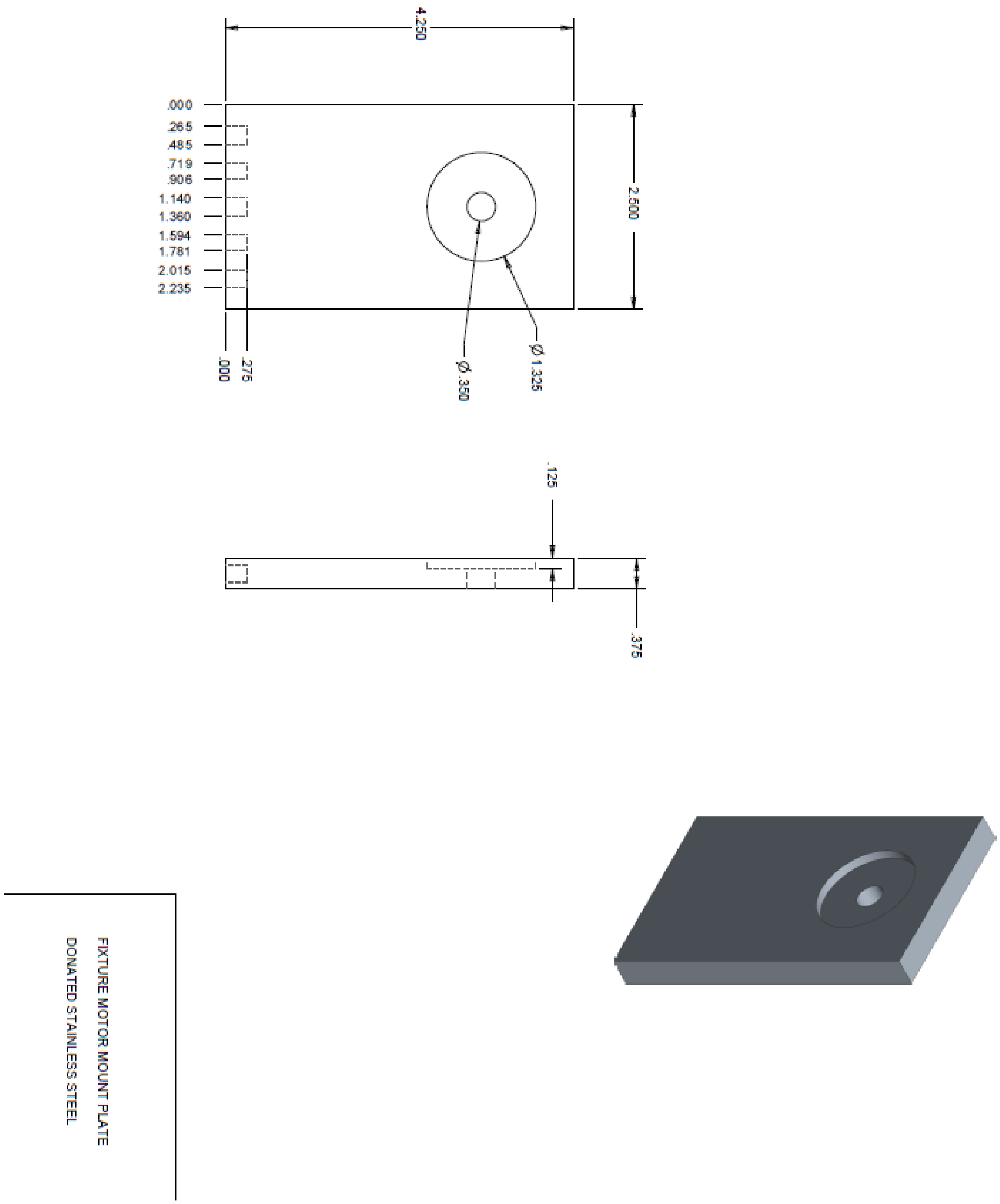
.410
.606
.794
1.206
1.394
1.590
1.810
2.000
.000
.275
2.345
2.944
3.147
R.250
2.000
.750
Ø.203
TAP THRU FOR 10-32
SET SCREW
FIXTURE UPRIGHT PLATE
QUANTITY 2
DONATED STAINLESS STEEL PLATE


4.250
.000
.265
.485
.719
.906
1.140
1.360
1.594
1.781
2.015
2.235
2.500
.000
.275
Ø .350
Ø 1.325
.125
.375
FIXTURE MOTOR MOUNT PLATE
DONATED STAINLESS STEEL

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