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Medallion Manufacturing

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MET Medallions

By

Luis Perez

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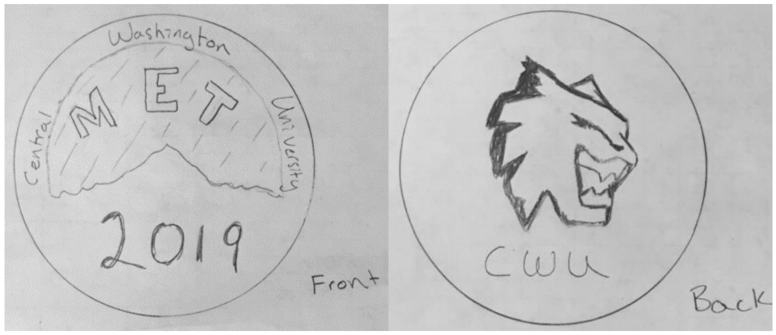
Abstract

A more efficient manufacturing process is needed to create the approximately 30 MET medallions, given to the graduating class. The process must be repeatable, consistent, and efficient. The objective is to create a method that can remain the same year to year, save time, and be repeated by anybody. Two approaches were developed: a casting method, and a machining method involving a computer numerically controlled (CNC) mill. The casting method began with a match plate was developed by attaching 3D printed models and runners to plywood. The design was evaluated before the pour using SolidCast software. Special attention was directed at the runners to see if they would solidify before the medallion being fully filled. Melted aluminum was poured into the cavity that the match plate left in the sand packed flask. The machining method cut and faced blanks from a 3.5 diameter round using a horizontal band saw and a lathe. Various tools in the CNC mill were used to create the design. While both methods created successful products, the processes were less efficient than originally estimated. The machining method took four more hours than predicted, and the casting method took one hour more than expected. However, more improvements could be made to improve the efficiency in future methods.

1: INTRODUCTION



Description:

The current process for creating the Program's medallion keepsake can be improved. Currently, the machining process is time consuming to create one side of a medallion. Additionally, only one side of the coaster is decorated and they are created one at a time. While this can be done, it takes away faculties time.

Motivation:

The keepsake process presents an opportunity to apply lean manufacturing practices in combination with good machining practices to improve the efficiency and quality of the project. Additionally, the hope for this project is to help the faculty that produces the medallions as mementos for the students because it is not required for them and the hope is to help those who have already helped the students so much.

Function Statement:

A manufacturing process is needed to create the CWU medallions. The process must be repeatable, consistent, and efficient.

Requirements:

- From start to finish, the time it takes to complete one coaster should take 25% less time than the benchmark (total time -excluding the laser- takes 312 min or less)
- Each medallion should and stay within a tolerance of:
    - If the circularity of the medallions is within .003
    - If the outside diameter is 3.5" +/-.002
    - If the thickness is .25 +/- .002
    - If the total time (excluding the laser) takes 312 min or less
- Over all the total cost should be under $200
- Total weight of the medallion be under .3lb

Engineering Merit:

Analysis of the clamps so that it is known that they can withstand the forces from a CNC. Calculation of the tool cutting forces.

Scope:

A minimum batch of 25 keepsakes for the graduates.

Benchmark:

The current processes to manufacture the product, the production rate of which "4 or 5 per hour" is according to Mr. Bramble.

Success of Project:

Thorough instructions for the process and use of jigs so that a future student can make the customized coasters for their own class with the same efficiency.

Design and Analysis

The first step to complete the requirements given above was to create a base line. The requirement states that to be successful a 25% time reduction from the current process must occur. To accomplish this, time analyses were completed to estimate the time needed for each step in the process. The steps, in order, are: band sawing raw blanks, facing the blanks, and the CNC operation, these processes can be found in Appendix A (A1, A2, and A3 respectively). The outcome of all the steps together creates a baseline of approximately 415min to complete a batch of 25 medallions. The result of this calculation is that the new method must complete the same batch of 25 in 312 min or save nearly 1 hour and 45 minutes overall. One necessary component in completing the previously stated requirement is the use of proper Speeds and Feeds in the CNC. For this, information from the Machinists Handbook was gathered to determine the optimum RPM of 5000 and a feed rate of 151inches per min. These calculations can be seen in Appendix A5.

Another process possible for creating the same medallions is casting. In order to end with the same dimensions the drawings, the volume of the casting model needs to be increased by 6%. The resulting starting dimensions can be found in Appendix A7 and A8 and B3. A preliminary adjustment bases on a uniform addition of the thickness and radius of the Blank gave a uniform value increase of .01" (A8). However, because the shrinkage of the model is based on volume, another methods was used to create the item because of the asymmetry found in the front. By using the scale function in Solid Works adjustments were made until the total volume was six percent larger; that value coincides with each dimension being enlarged by 2% rather than a set nominal value (A9). The casting models are to be 3D printed out of PLA for a match plate to assist in the casting process. The cycle time, and the quality of the product will be compared to decide which method to use in the future.

Additionally, there are sheer analysis done on the weakest part of the 3D printed model to determine the strength of the piece and to indicate the amount of care it required when handling. There is another shear analysis of the same portion of the aluminum part for reference. These analysis are located in Appendix A6 and A7 with the plastic let braking after 140lb. The shear value of the letter is acceptable because the model is not likely to break through handling of the item.

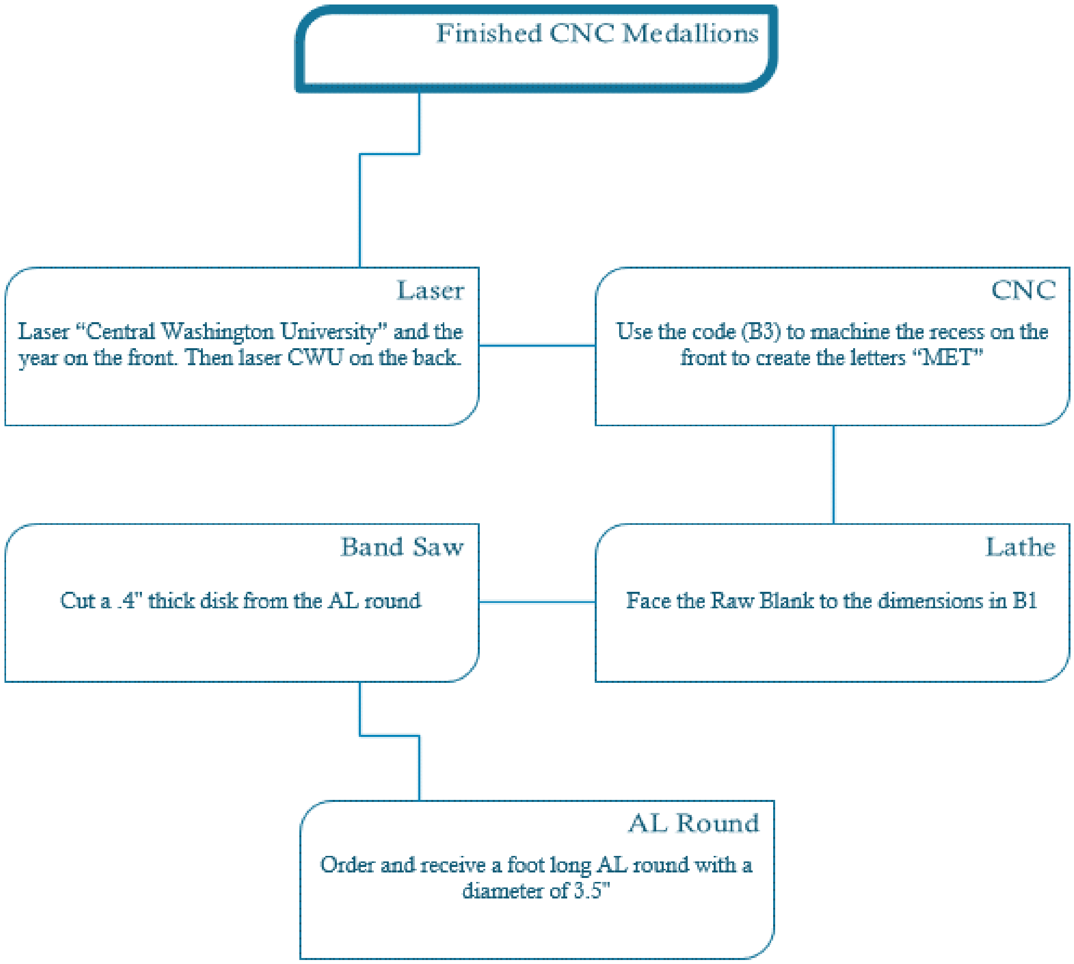
The last analysis (A10) is concerning the amount of volume needed for the pour of 6 medallions. Using the Solid Works Evaluate function, the volume of both the runners, and a medallion –multiplied by six- were added to the estimate of the volume of the cylinder in the cope. By then multiplying the volume with the density, the weight of the aluminum needed was calculated to be 11 lbs. This was converted to pounds for ease. One could just weigh the aluminum to be melted, this could be useful if the aluminum came in an irregular shape.

After the design of the match plate, an STL file was created for the Solid Cast program. This was done for analysis before pouring. The useful soft wear could simulate the temperature gradient, solidification time, and many other analysis. Particular interest was taken in the runners to the parts. As the runners are relatively small a possible failure of the part could occur if the runners solidify before the parts get filled. The Solid Cast's simulations showed that the runners were sufficiently large and their size would not need to be modified. The simulations can be found in Appendix K.

Methods and Construction

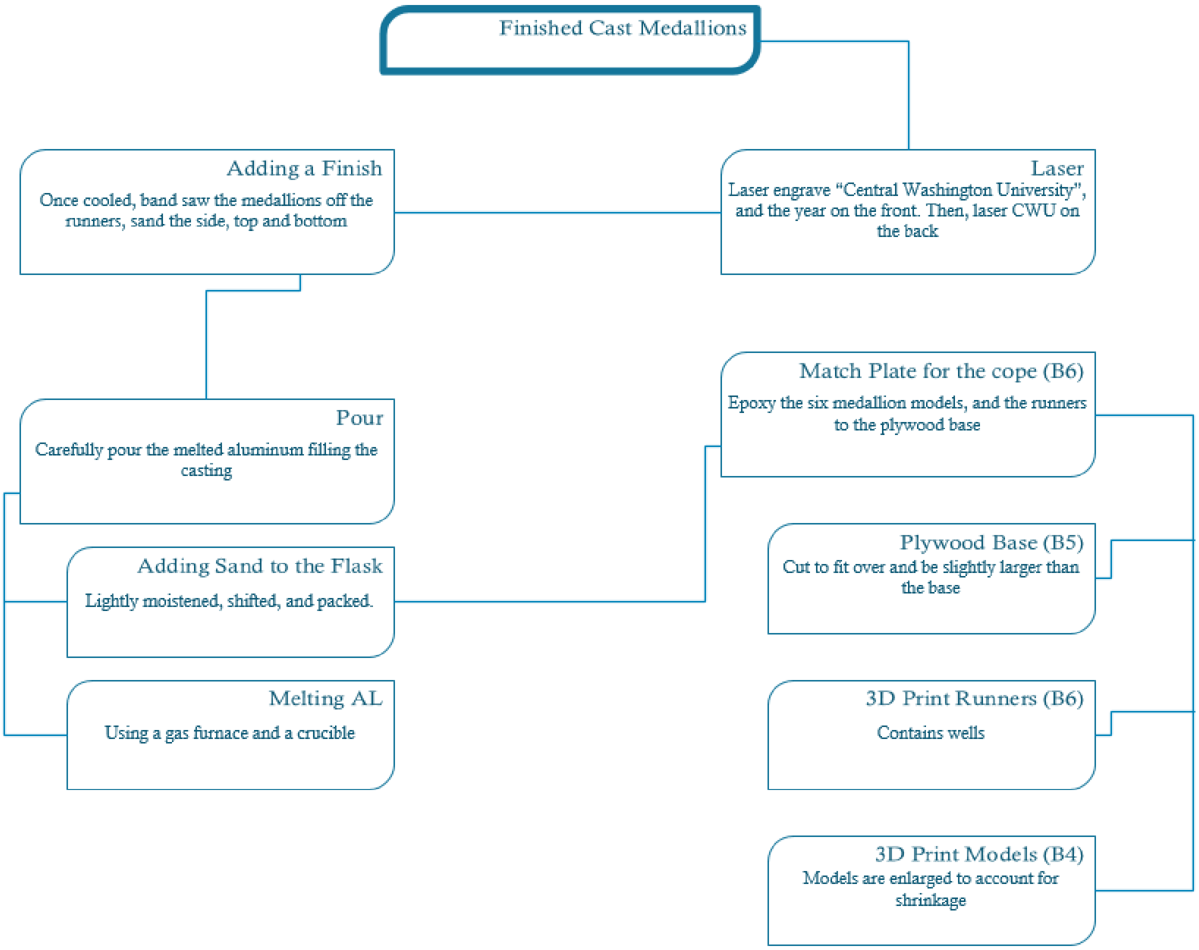
Fortunately, Central Washington University contains a wide variety of machines and tooling for its students to use, and those are what the project will be constructed with. For the medallions the Machining lab –which contains the horizontal band saw, lathes, and the CNC mills- as well as the foundry for the casting portions. Additionally, there are multiple 3D printers available in different locations on campus. The process will be broken into two sections, the CNC portion, and the casting portion. Before any planning was done the material of the medallion needed to be decided. Steel, brass and aluminum were evaluated basis of the cost, finish, weight, and machinability. Using a decision matrix the best metal for the application was aluminum.

To begin, below is a drawing tree that gives an overview of the process to create the medallions through the CNC method. The proses of the tree will be described in further detail afterwards.



The first step is gathering all the tools and material and ordering each item found in the parts list located in Appendix C. Once all the material has arrived, building The CNC Blank (Drawing B1) is the next step. This will be done by using the horizontal band saw to cut a small disk of the large aluminum round that will then be faced on a lathe to the desired dimensions. Afterwards, the blank will be loaded in a 3-jaw chuck and using the program created (Drawing B3) the base of the medallion will be made (Drawing B2). 25 of the finished medallions will be completed after they have been laser engraved.

An overview of the process to create the medallions through the casting method can be seen in the drawing tree below. The proses of the tree will be described in further detail afterwards.



Alternatively, a casting process can be chosen to create the medallions. To pour the castings one first needs to create a mold. To increase efficiency and produce more medallions at the same time, a match plate will be created that can be reused. The first step for creating the match plate is 3D printing six models of the medallion. This model has been enlarged to accommodate the shrinkage that occurs during cooling and is described in drawing B4. Next, the printing of the runners (Drawing 6), followed by cutting of the plywood base (Drawing 5). Once all parts have been created, the next step is assembly. The medallion models and the runners will then be epoxied into place according to drawing B7. Afterwards the pouring process can begin by shifting the sand. Then the match plate is attached to the drag, where sand is then added and packed. Sand is also packed into the cope, and a gate is created in the sand to pour the melted aluminum into. Then, the match plate is removed from the drag and the flask is put together. Next the aluminum will be melted in a furnace, and using a crucible, pour the metal into the casting. After some time the cast will be broken free from the sand, and cooled in water. Then, each of the medallions needs to be cut free from the runners using a band saw. Then, the medallions can be sanded. Finally the product can be taken to the last process and be laser engraved. The flask size constrains the number of medallions to six per flask, so then the best method to produce the medallions is to have multiple flasks ready when the pouring occurs.

Another key point to remember are any manufacturing issues. For this project there are three major issues: accessibility, broken bits, and three-man-jobs. First, the machine lab is used for classes. Most likely, the restricted times will not be an issue but mean that the constructed medallions will be done later in the day and with the coordination of a faculty member. Next issue is if a bit brakes in operation. Additional mill bits will be purchased as back up if the borrowed bits brake to ensure that the machining processes will not be delayed and to replace inventory. Lastly, the pours in the foundry required three personnel, two complete the task and one for safety. The pour will need the cooperation of two peers and take place at a time that works for everyone.

As is with each step, the date and the time needed to complete each task will be recorded to complete the Gantt chart and to compare the estimated time to the actual time. ‘

In the beginning of the construction, the first construction of the casting was done out of order. The spontaneous decision was made to capitalize on an opportunity to complete one pour. Foundry Educational Foundation (FEF) needed a video of a pour and it could be the medallions. First the medallion models were 3D printed and were freely placed in the sand without the match plate. The runners were then made by hand and without a match plate which took longer. After the aluminum was heated in the furnace, and the crucible filled, the aluminum was poured. Once cooled, the excess aluminum was cut off using the band saw and ground with a sander.

Afterwards, since the models were already printed, and the test pour proved successful, the next step was to create the match plate for future pours. The plywood was purchased at from the woods lab for convince (2’x18” for $5). The extra width of the plywood was cut with a table saw for convenience, and half inch holes were drilled. However, there was not enough clearance for the pins so the holes were widened to ¾” to fit. Then the solid works file of the runners was saved as an STL and taken to the 3D printer services provided by the school because temporary technical difficulties were occurring with the 3D printer in Houge. The cost of 3D printing from the school is $0.50/hour which made the total cost of the runners $2.50. Then, all components of the match plate were gathered, located and traced. The PLA parts were epoxied into place, and the match plate was completed.

Then, another pour was completed. The same steps to prepare the sand and to melt the aluminum occurred. However, the space for the runners was created with the match plate saving time and creating even indents in the sand.

As the batch before, the medallions needed to be separated from the runners. As the wells and sprue created an awkward piece to cut with a band saw the medallions were broken off by hand leaving approximately one inch of runner attached. Then, the excess was removed from the medallions. Unlike the parts before, the flash was removed with the band saw instead of a sander to save time.

The medallions were then placed in the tumbler to be polished. The parts were left in the machine for approximately two hours before being removed.

The first step of the CNC construction method was to create raw stock blanks. The horizontal band saw with a stop was bolted to the table to cut small disks from a 3.5” aluminum round bar. After being cleaned and deburred with a file the blanks were ready to be faced with a lathe.

The CNC lathe already had programs to face and chamfer embedded into the machine, thus only imputes needed to be defined such as the depth of cut and the zeros. Each disk were to be faced .03inches and given a chamfer as well. However, approximately halfway through the operation the saw marks had not been removed from two disk so the depth of cut was increased by .01inches for the rest of the operation to prevent any reoccurrence.

Testing Method

The requirements are based on the consistency of the medallions and the speed of which they are produced. A Stopwatch and a traveler will be used to time each step to be compared with the benchmark. Calipers and a dial will be needed to judge the dimensions and circularity of the medallions. Additionally the medallions will be weighed to see if the weight is less than .4lb. The following measurements will make up the success criteria of the medallion:

- If the circularity of the medallions is within .003
- If the top is parallel to the bottom within +/- .002
- If the outside diameter is 3.5” +/-.002
- If the thickness is .25 +/- .002
- If the total time (excluding the laser) takes 312 min or less

These requirements will apply to both the CNC and the casting medallions. All of the dimensional measurements will be measured from the datums on the back and the center of the piece. The datums can be seen in drawing B2 for the CNC version, as well as B4 for the casting version of the medallions. The measurements of thickness will be conducted with a mic and be taken in four locations each 90 degrees apart. Both the circularity and parallelism will be measured with a dial. The time will be recorded from a stop watch, and the weight with a scale.

The results can be found in the deliverables section.

Budget/Schedule/Project Management

The projected materials required to complete this project is estimated to be $172. Fortunately, the use of the machine shop and the equipment within do not cost students money. Additionally, the bits needed are already ones that are in the shop, however, extras will be purchased for replacement incase a bit brakes in operation. For more details on the specific parts needed including: identification, specifications, sources and cost see Appendix D. The funding for the parts needed will be an out of pocket cost. Additionally, there no expected cost for labor. However, there is an expected labor cost in the Gantt chart for comparison. Using a labor rate of $15/hour, and the estimated time of 83 hours, the labor cost would be $1240. If the labor cost is included it would bring the total estimated cost would be $1412.

The deadline for all aspects of this project coincides with the end of the MET 489 series. To help facilitate the scheduling a Gantt chart was created to both record the expected schedule and the actual times that this project required. The chart also has task identifiers to show when the scheduled start and end time, as well as the dates the item was worked on. The Gantt chart is provided in Appendix E. The major mild stones are the proposal, assembly, and testing, each deliverable’s deadline is corresponding to the end of fall, winter, and spring quarters respectively. The estimated time for the entire project is 83 hours.

The risk in this project is relatively low. There is inherit danger of using machines in the machine shop, however, to use said machines one must receive training and approval by an instructor. Additionally, there no technical expertise or tools that are required that cannot be found in the school. For the CNC portion, Mr. Bramble, and Mr. Bervee will be able to provide their expertise. Dr. Johnson will be able to provide technical knowledge for the casting portion. If procedures are followed the operators will not be in harm's way. Additionally, there is no specialty parts that cannot be provided by the school or expressed ordered through the mail. The expected cost, and if more unexpected cost occur, it could still be covered out of pocket.

The project has consistently been under budget. This has mostly been achieved by using materials already at the school, for example the tooling already in the machine shop. Additionally, by purchasing the materials from the school in the minimum quantity needed, the price was generally lower and without shipping. This can be seen in the price difference of the PLA material. Instead of buying a whole spool of the material for 20 dollars and having extra, the parts were printed at the Samulson lab for 50 cents an hour. The project, up to the pour, has only used approximately 30 percent of the projected budget. A table with the projected prices, as well as the actual prices of the parts needed can be found in Appendix D.

The part of the project with the most scheduling difficulty associated with it is the casting portion. The way this difficulty is mediated is by scheduling the use of the foundry for a Friday. The day was chosen because the process needs faculty to unlock the lab, and a minimum of two student helpers to complete, Friday is clear of scheduled classes. Additionally, upon the discovery that the shop lab contains the aluminum round needed for the CNC portion, ordering could be done later as shipping was eliminated. The casting portion of the project never went behind schedule, however the CNC portion has which can be seen visually by the gantt chart. In general, the time spent on tasks are longer than predicted.

Overall the testing occurred during the scheduled time. The largest delay came from the unexpected time needed to print the modified runners. The runners were sent to the Multimodal Education Center to be created. The runners were submitted on 5-2-19 and were expected to be created by 5-7-19 at the latest. The runners were received on 5-9-19. The delay in receiving the parts resulted in a delay of the pour. The pour was preformed to confirm the results from the SolidCast simulation that a reduction in runner size could still create an acquit part. The date and duration of each task can be seen in the gantt chart.

Overall the project was under budget for the entire length of the project. The final cost was 53.50$ out of the 172$ predicted, which is 31% of the allotted budget. Testing added an unexpected 7.50$ to the PLA costs. To prove that the solidcast simulation was accurate, an additional pour was needed. The modified gating system and additional medallions were sent to Samulson to be printed. An additional wood board was not needed as the back side of the original was used for the new set up. No errors were made during testing and thus did not require additional funds.

Discussion

Originally, the only the CNC process was considered to be improved. This process was to be shortened by creating lettering that could be completed with efficient tool paths, as well as a change in the product. Changing the design from the year (i.e. 2018) to a generic MET. The new model was chosen because the code will not have to be reprogramed each year as well as less geometry to machine.

Then, an opportunity presented itself. The Foundry Educational Foundation requested a video of a pour from another student, this was a chance to initiate another type of manufacturing process for the medallions. The design was modified to include slight drafts and then 3D printed to use as molds, additionally the lettering was widened to create less delicate features in the sand and for strength. Original tall and thin lettering was used in the printing of the first medallion where a letter broke off during transportation. The letter width was more than doubled to prevent such failure from happening again.

The pour resulted in a product that indicates that the pouring process is a plausible method for creating the medallions. However, while overall successful, there is still issue to be addressed with the pouring method. The surface finish is rough as the 3D printed lines still are visible. One possible solution would to be fill the gaps of the 3D printed model before placing the models in the sand. If done correctly the amount of time sanding the casted medallions could be reduced. Another opportunity for improvement is creating a Match Plate. During the casting the runners were created by hand, and the models were carefully removed by hand. If a Match Plate was created the set up time before the pour could be greatly reduced from the current time of one hour. The models printed were just a concept when created. They are geometrically centered, however, visually are asymmetrical. The lettering on the models will likely be adjusted, and then reprinted before being adhered to the match plate.

For the most part the planning of this project has been successful, however the most unsuccessful part would be the estimated times in the Gantt chart. More specifically the time estimated for updating the website, the time for writing up the proposal, and the rework times for modifications of the drawings. The reason for these differences is most likely the under-estimation of the amount of writing or the un-familiarity of the software medium.

Manufacturing issues/Modifications

A manufacturing issue that was not anticipated in the original proposal was the limitations of the 3D printers. The largest printer the school had was a 9x9 inch base, while the runners to be printed were 11 inches long. This caused the runners to be split into two smaller sections, and nested in the program to be printed in one attempt.

Another modification to a printed part was investigated. The original 3D printed models for the casting created ridges in the parts. To create a nice surface finish, one would have to grind the ridges off. Thus, a filler was added to an extra medallion to see if the filler could create a more level surface in the final product. Spackle was used to fill the ridges of the part. Then, the spackle was scraped off with a straight edge. When scraped perpendicular to the print lines the spackle was completely removed, as was the case for parallel to the print orientation. However, at an angle of 45 degrees the spackle filled the valleys. However, this method was not pursued because of the possible inconsistencies and the time constraints.

Conclusion

Two processed have been designed to create the medallions which have been analyzed to meet the requirements. The requirements are concerning consistency, and time. Both processes have been optimized for time and the use of the CNC and 3D printing the molds should provide the consistency. The CNC method was optimized for time by tool selection, and reducing the geometry needed to be processed. The casting method has been optimized though the addition of the match plate and by the plan to pour multiple flasks at once.

Acknowledgement

A special thanks goes out to the Central Washington University faculty as well as the University itself. The faculty for their expertise and guidance, including Professor Pringle, Dr. Johnson, Dr. Choi, and Mr. Burvee. The University for providing the means to complete such project including the Machining Lab, the Foundry, and the Computer Lab. Without the cooperation of both groups such learning and creation would not be possible.

Appendix A: Analysis

A1: Time analysis of Step 1: Band saw Raw Blanks

Luis Perez | Sr Proj 10/10/18

Overview

Step 1: Cut 3in AL Round in Bandsaw

Step 2: Lathe the Both sides to Be smooth and Chamferd

Step 3: Machine in CNC, currently 4/Hour are produced

New + Step 4: Take to Lazer

-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-

Step 1: Time Aprox.

- Setup the stop @ .5" ≈ 3 min
- Oppen the Back door, move Roller table, and position Long Round Stock ≈ 2 min
- Test cut & Measure accuracy of stop Location/Adjust ≈ 3 min
- Cut 25 Blanks ≈ 1/Blank = 25 min
- Reset Material For next cut ≈ 30 sec each ≈ 12 min

Total time for Blanks = 45 min

A2: Time analysis of Step 2: Facing blanks

Luis Perez	Sr Proj	10/11/18

- Step 2: face Both sides of Blank
  - Rough Pass - ≈ 40 sec
  - finishing Pass ≈ 40 sec
  - chamfer ≈ 5 sec

  85 sec / Part for Side A

- Change Over time

  ≈ 15 sec / Part

- Side B = Side A

  85 sec / Part for Side B

- Reset time

  ≈ 20 sec / Part

Step 2 - facing - total time

= 205 sec / Part

or 5,125 sec for a Batch of 25 (85.4 min)

A3: CNC time analysis.

Luis Perez | Sr Proj 10/18/18

- Step 3) CNC
  - Load the program on the floppy 2:30sec
  - Load the program on the CNC 45 sec
  - Verafy the program 2:30 sec
  - Load the CNC 45 sec
  - Zero the X, Y, and Height offsets 12:00 Min
  - Runtime 10m + 20sec each 258min 20sec
  - Reloading @ 20sec each 8min 20sec

Total Time 285min + 10 sec

4H, 45min, 10 sec

A4: Laser time analysis.

Luis Perez	SR - P	A 4

Step 4 - time analysis - Lazer

Set up time : 10 min
Lazer side 1 : 4 min
Lazer side 2 : 6 min
QTY. 25 250 min
Total time : 260 min

A5: Speeds and Feeds Analysis

Speeds & Feeds Analysis for 1/8" bit

$$RPM = \frac{12 \cdot V}{\pi D} \qquad fpm = \frac{V \pi D}{12}$$

Table Feed Rate = ipt × # of teeth × RPM

For 6061-T651 AL.

For HSS:

	Opt	
Feed	15	.001"/tooth
Speed	165	Ft/min

$$RPM = \frac{12(165)}{\pi(1/8)} = \boxed{5042 \text{ Rpm} \mid \text{Spindle Speed}}$$

.015"/Tooth × 2 teeth × 5042 Rpm = 151 in/min

Table Feed Rate

Tool Life (min)	Milling with HSS		
	f_s	f_m	f_L
45	1	1	1
90	.94	.89	.83
180	.69	.69	.69

$f_s \le 1/2 \, f_{opt}$

$f_s < f_m \le 3/4 \, f_{opt}$

$f_m < f_L < f_{opt}$

Source: Machinery's HandBook 30th ed. (Tool Box) Pages 1078 and 1086

A6: Shear Analysis of aluminum letter

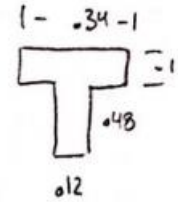
Luis Perez	SRP	Shear

Analysis: Sheer of the weakest letter (AL)(T)

Given) Dimensions of letter

Yeild of AL

Area of letter is .095 in²



Find) Max shear

Assume) AL 295.0-T4, Sand Cast

Yield = 13000 psi

Solve) $S_{ys} = S_y/2$

$S_{ys} = 13000/2 = 6{,}500$ psi

$\tau = F/A$

$6{,}500\ psi = F/.095\ in^2$

$F = 6500 \cdot .095$

F = 617.5 lbs

A7: Shear analysis of PLA letter

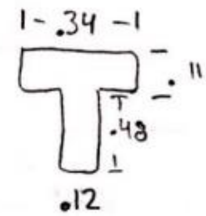
Luis Perez	SRP	Shear

Analysis: Sheer of the Weakest Letter (PLA) (T)

Given) Dim of Letter

Yield of PLA is 2950 psi (From toner plastics)

Area of letter is $.095 \, in^2$



Find) max shear

Solve) $S_{ys} = S_y / 2 \qquad S_{ys} = \frac{2950}{2} = 1475 \text{ psi}$

$\tau = F/A$

$1475 = F / .095 \, in^2$

$F = 1475 * .095 = \boxed{140.13 \text{ lb}}$

A8: Shrinkage, Blank mathematical.

Luis Perez | SR-P

Shrinkage analysis – mathematical Blank

Given) current volume = 2.387 in^3

AL volume shrinks by 6%

current Dimensions thickness = .25 & 3.5 OD

Find) Dimensions adjusted Before shrinkage

Assume) uniform Dim increase

Solution)

$2.387 \cdot 1.06 = 2.530$

2.53 = target volume

$V = [\pi \cdot r^2] \cdot t$

$2.530 = \pi \cdot (1.75 + x)^2 \cdot (.25 + x)$

$2.530 = \pi \cdot (1.75 + x)(1.75 + x) \cdot (.25 + x)$

$2.530 = \pi \cdot (x^2 + 3.5x + 3.0625)(x + .25)$

$2.530 = \pi \cdot (x^3 + 3.75^2 + 3.9375x + .765625)$

$0 = \pi \cdot (x^3 + 375^2 + 3.9375x + .765625) - 2.530$

↳ $x = .0999$

$x = .01$

check

$V = \pi \cdot (1.75 + .01)^2 \cdot (.25 + .01)$

$V = 2.528$ ✓

New dimensions

Thickness	= .26 in
OD	= 3.52 in

A9: Shrinkage, Solid Works scaling method.

Luis Perez | SR-P |

Shrinkage analysis - Solidworks model (By Scaleing)

Given) Original OD = 3.5
Thickness = .25 inches

AL Shrinks By 6%
Original Volume = 2.027 $inches^3$

Find) Adjusted dim

Assume) uniform Adjustment

Solution) By scaling compleated Solidworks model

$V_1 \cdot 1.06 = V_2$

$2.027 \cdot 1.06 = 2.14862 \ in^3$

Scale all Dim gives a new Volume of $2.151 \ in^3$

By measuring

$OD_2 = 3.546$ in

Thickness = .255 in

(Uniformly scaled by 1.02)

A10: Analysis of the volume of aluminum needed for a pour.

Luis Perez | SR-P1

Find) Amount of AL Required to acomplish 1 pour. (6 Med)

- Volume of the Runners & wells = 5.51 in^3
- Volume of the Medalions = 2.15 in^3 x 6 = 12.9 in^3
- Aprox of gate volume

$(\pi \cdot r^2) \cdot H = (\pi \cdot .75^2) \cdot 5 = 8.84 \; in^3$

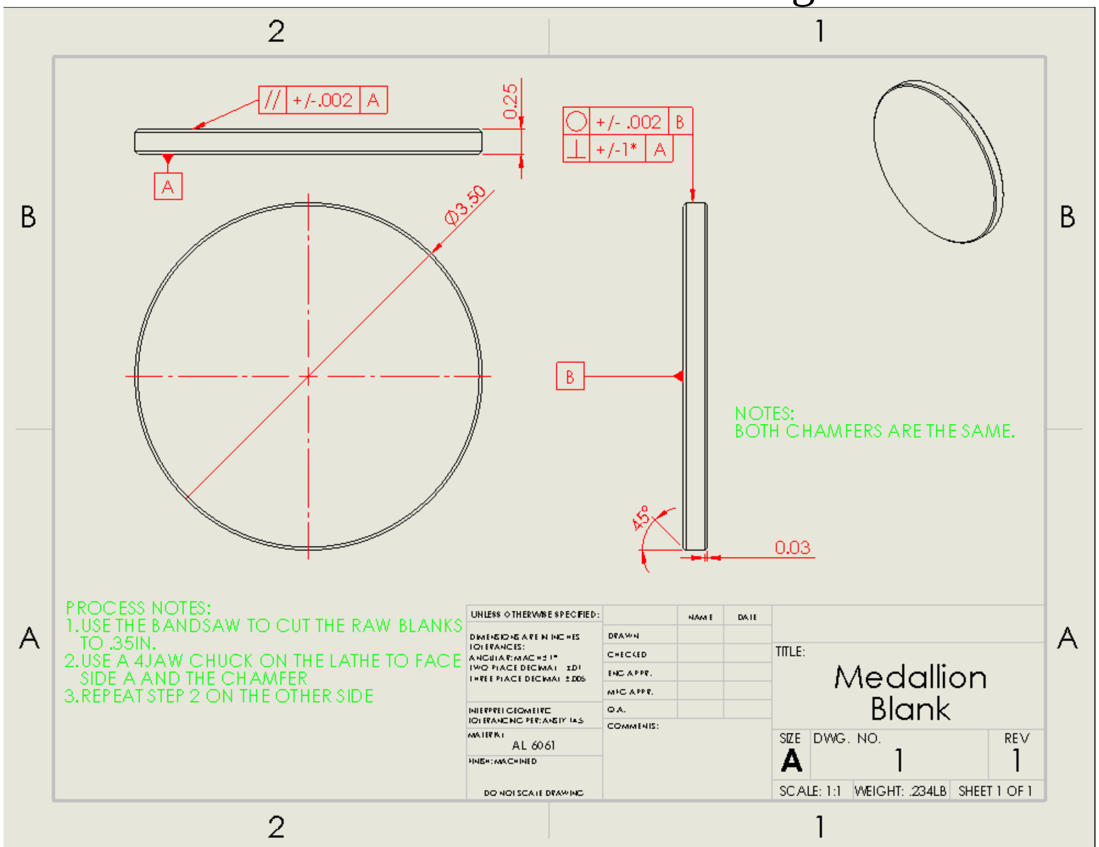
Total vol. ≅ **27.21 in^3**

- Density of AL is .098 lb/in^3

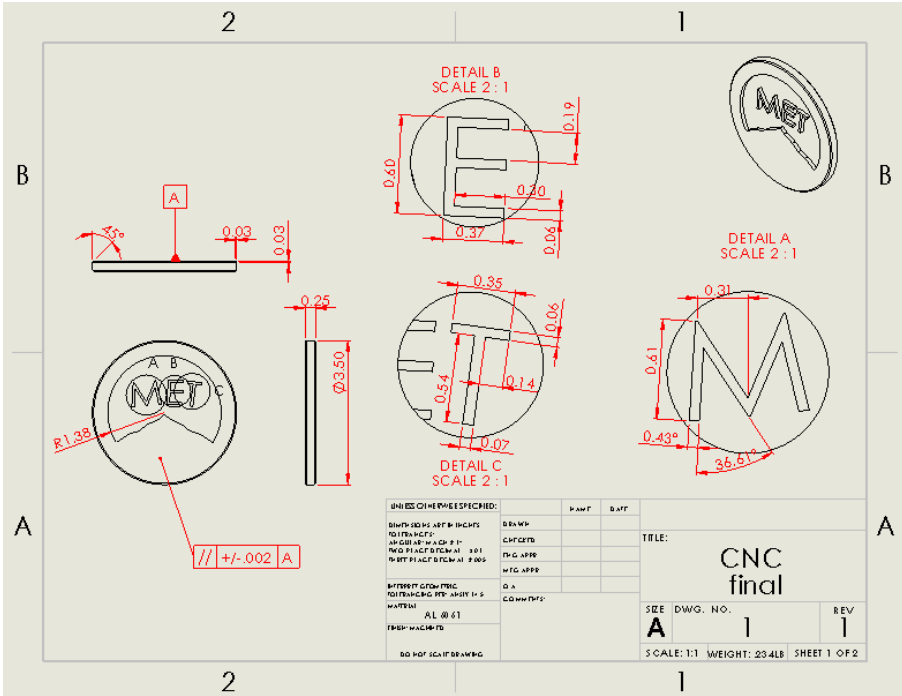
Weight = $.098 \frac{lb}{in^3} \cdot 27.21 \; in^3$ = **2.67 lb**

Appendix B Drawings

B1: Blank Drawing



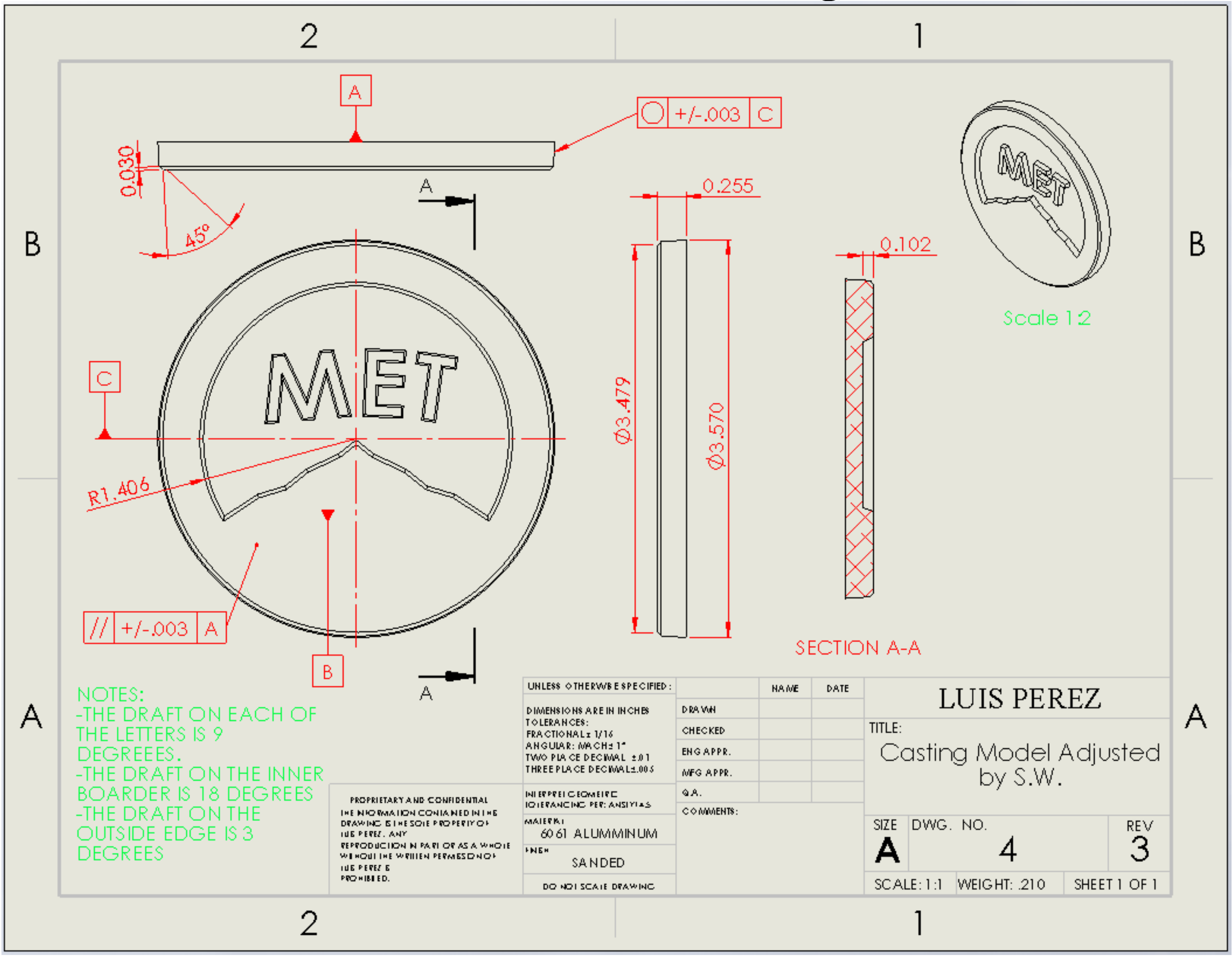
B2: CNC Finished Medallion



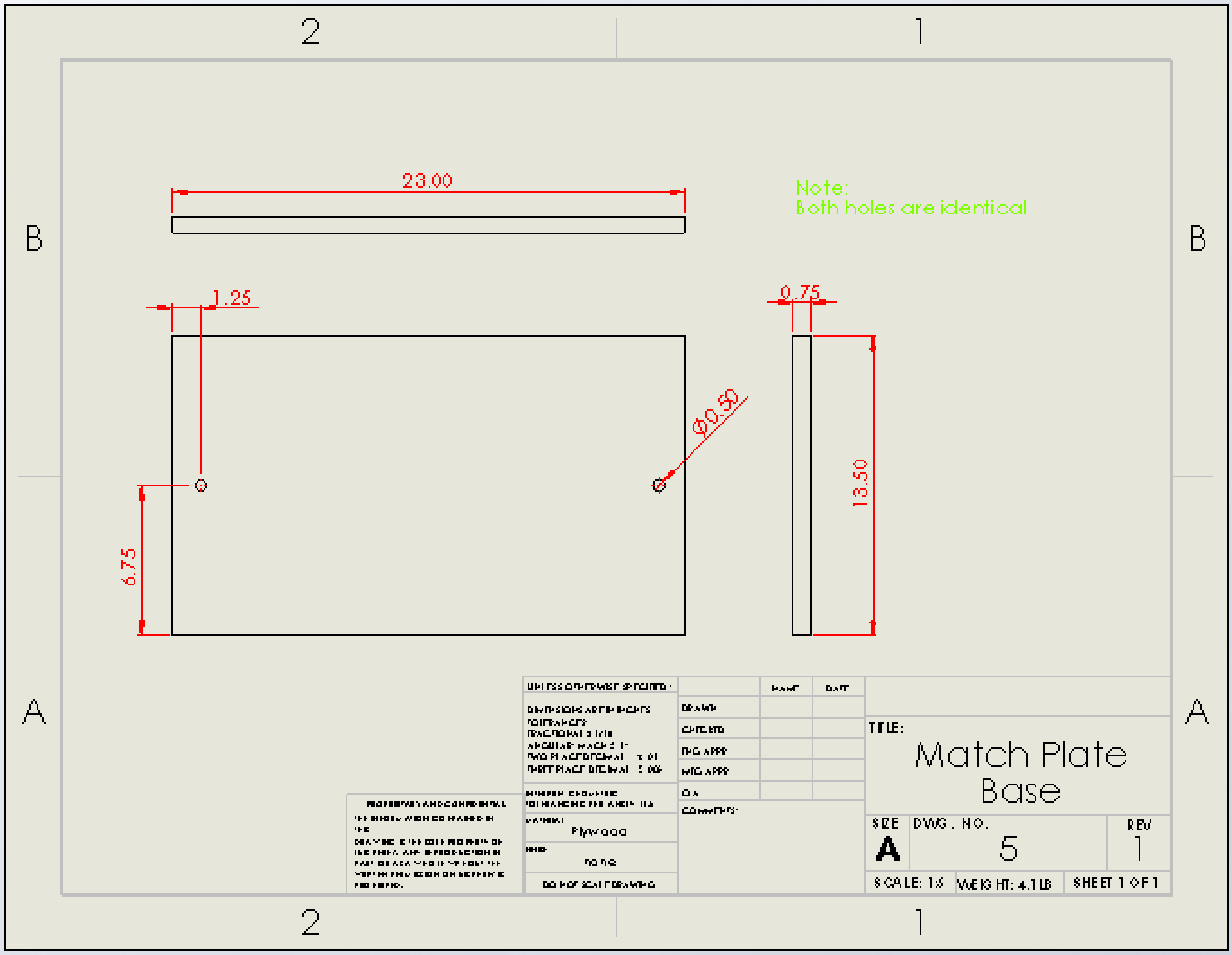
B3: CNC Code for top (partial).

```
O0001 (NR)
(T1  D=0.125 CR=0 - ZMIN=-0.1 - BALL END MILL)
(T3  D=0.1875 CR=0 - ZMIN=-0.1 - FLAT END MILL)
N1 G90 G94 G17
N2 G20
N3 G32
(ADAPTIVE1)
N4 M9
N5 T3 M6
N6 T1
N7 S10000 M3
N8 G54
N9 M8
N10 G0 X-0.9624 Y-0.2625
N11 G43 Z0.6 H3
N12 G0 Z0.2
N13 Z0.1
N14 G3 X-1.0269 Y-0.0965 Z0.0902 I-0.0323 J0.083 F45
N15 X-0.9624 Y-0.2625 Z0.0805 I0.0323 J-0.083
N16 X-1.0269 Y-0.0965 Z0.0707 I-0.0323 J0.083
N17 X-0.9624 Y-0.2625 Z0.0609 I0.0323 J-0.083
… … …
N9952 X0 Y0.1741
N9953 X-0.0002 Y0.1745
N9954 X-0.0011 Y0.1773
N9955 X-0.0019 Y0.18
N9956 X-0.0026 Y0.1827
N9957 X-0.0029 Y0.1845
N9958 X-0.0031 Y0.1854
N9959 X-0.0036 Y0.1882
N9960 X-0.0039 Y0.1909
N9961 X-0.004 Y0.1936
N9962 X-0.0041 Y0.1963
N9963 X-0.0039 Y0.2018
N9964 X0.001 Y0.3093
N9965 G3 X-0.0095 Y0.3206 I-0.0108 J0.0005
N9966 G0 Z0.6
N9967 M9
N9968 G32
N9969 G28 G91 X0 Y0
N9970 G90
N9971 M30
```

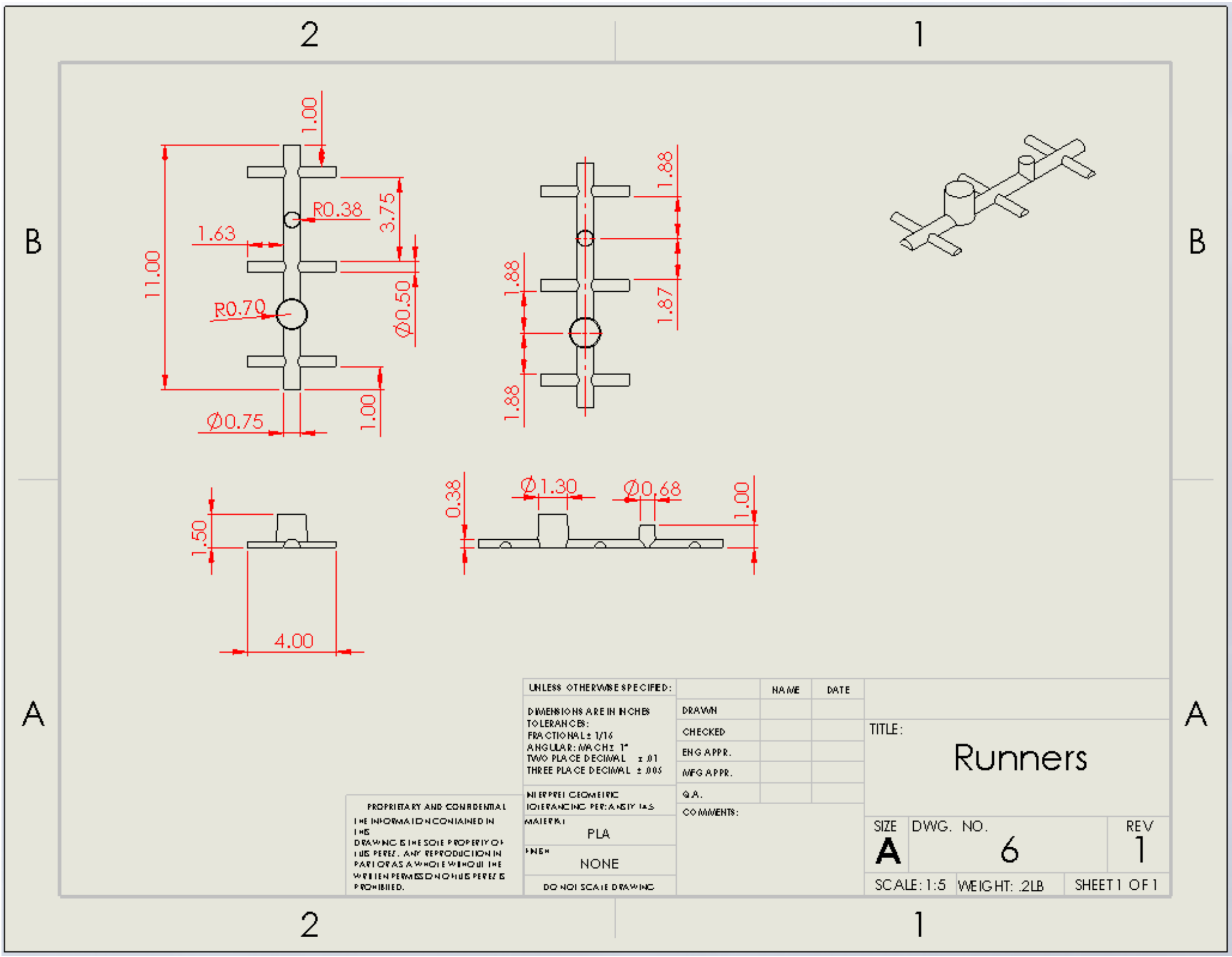
B4: 3d mold for casting



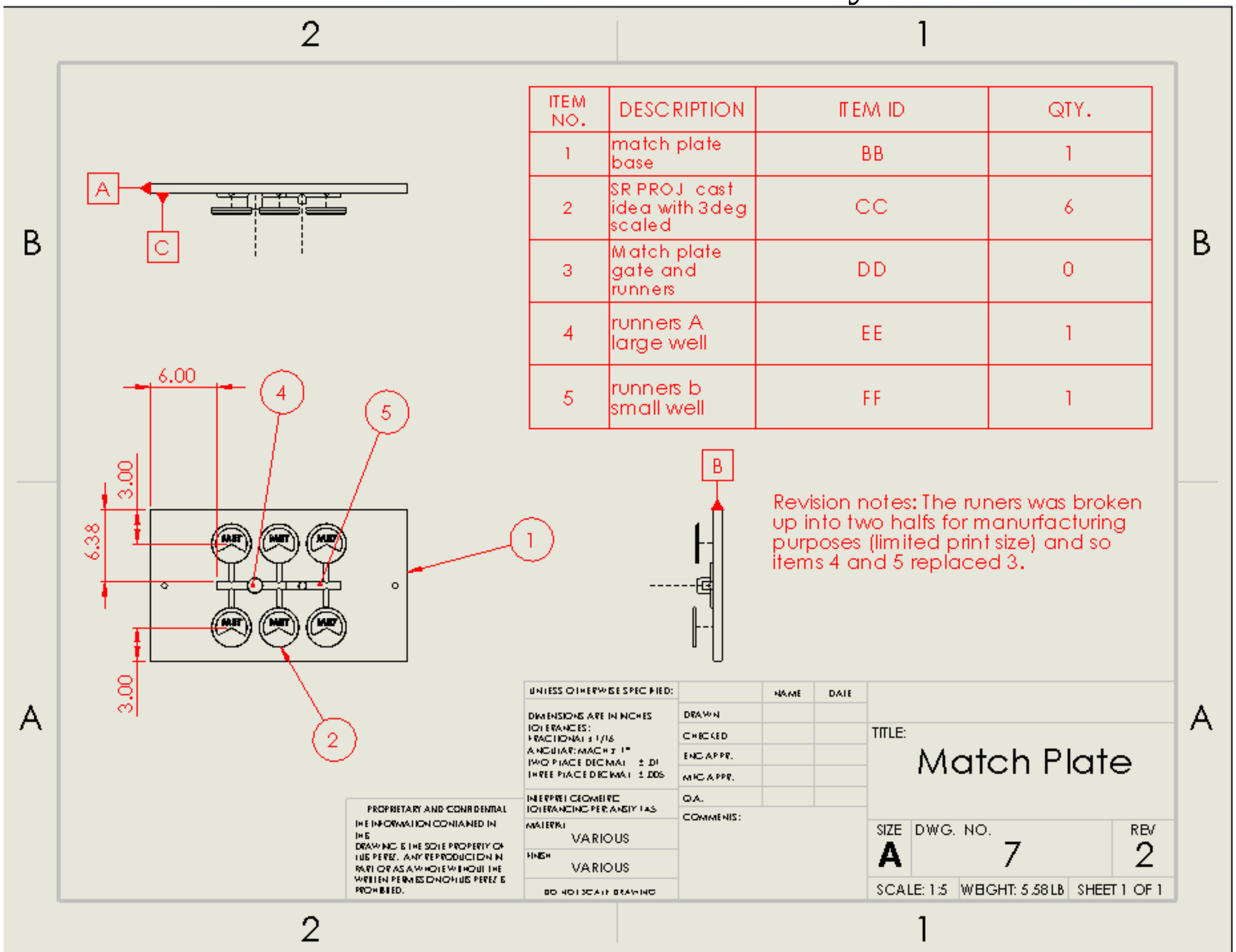
B5: Match Plate Base



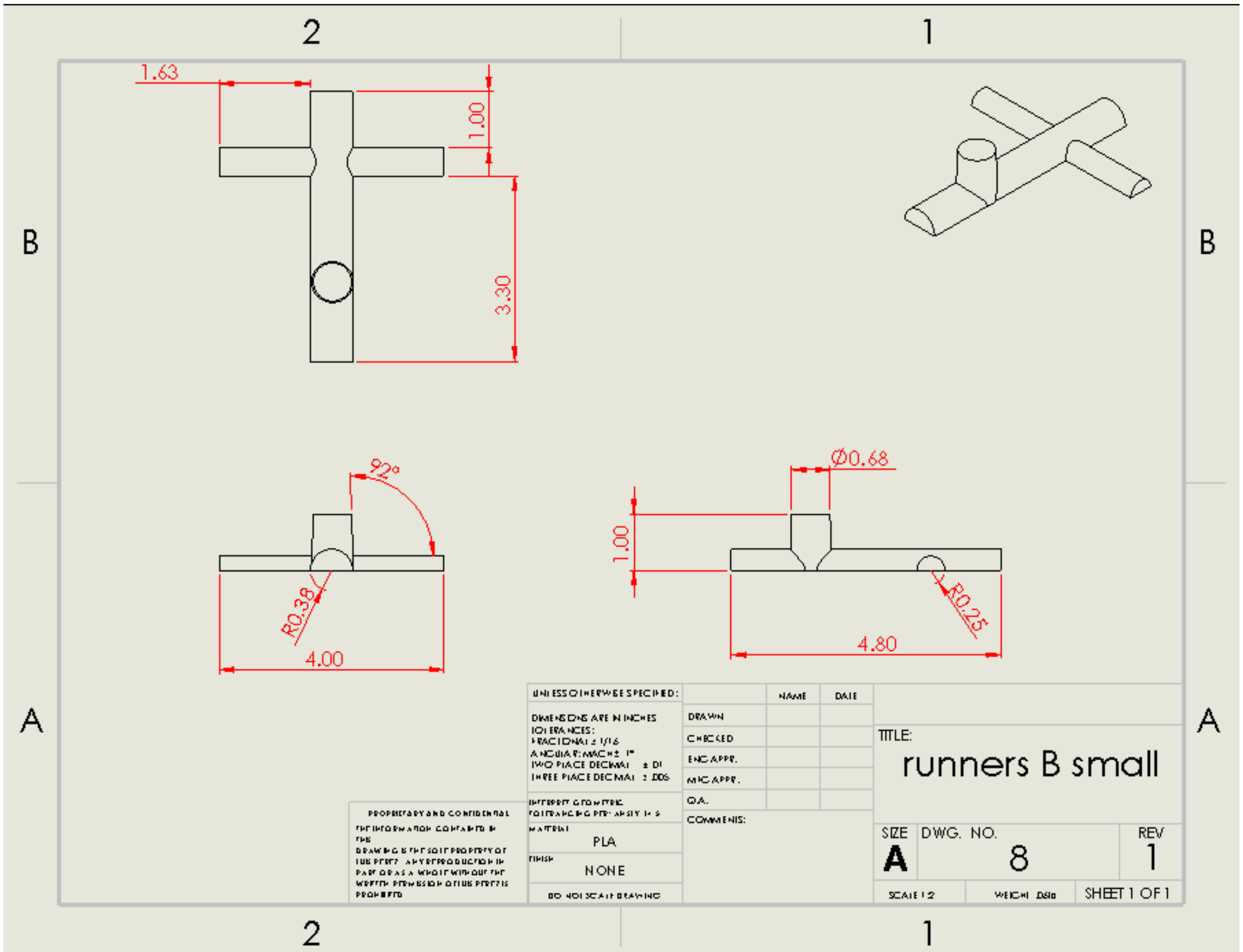
B6: 3D Print of runners



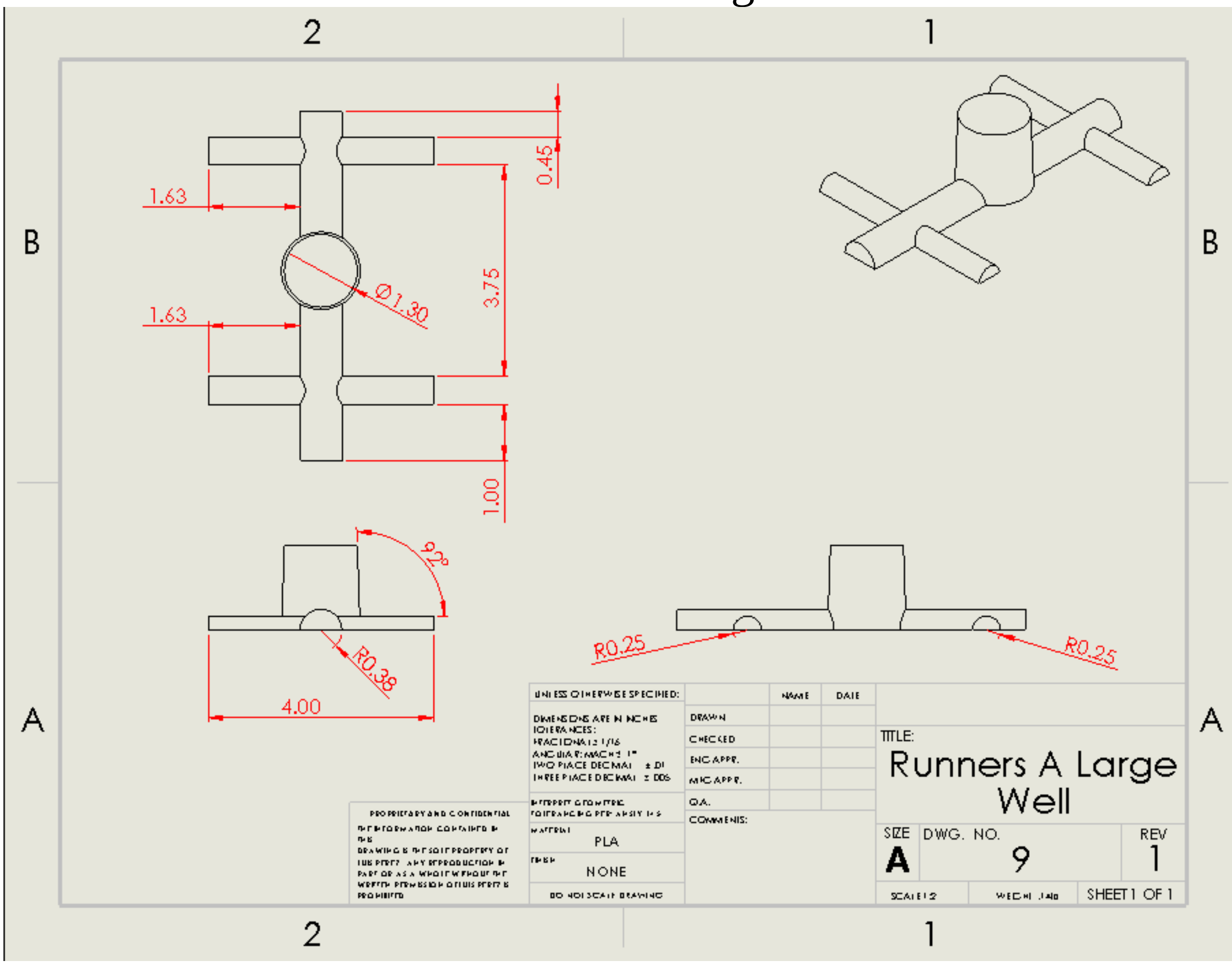
B7: Match Plate Assembly



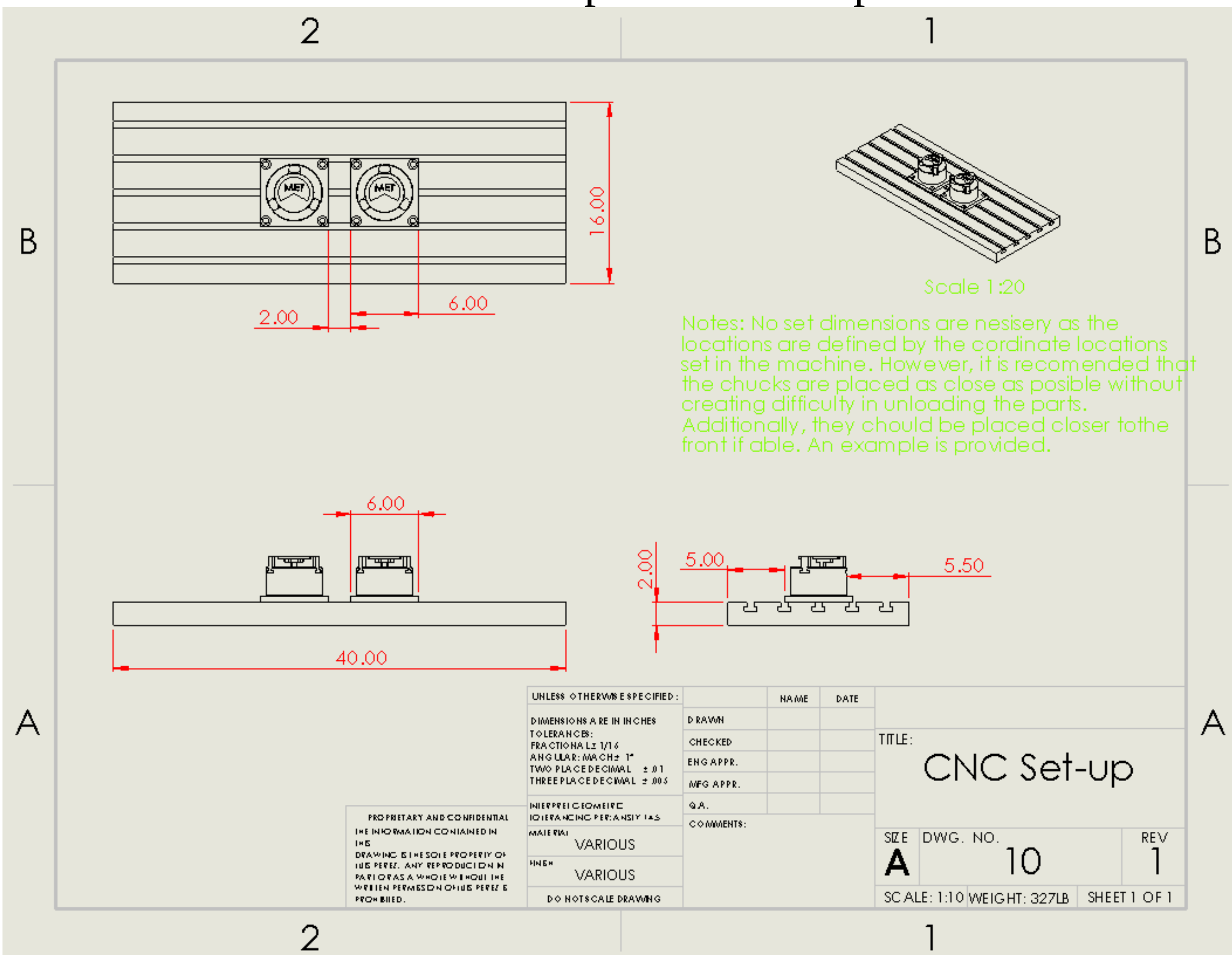
B8: Runners B Small half



B9: Runners A Large Well



B10: Example CNC set up



Appendix C Parts List

C1: Parts List

Parts List		
Item ID	Item Description	QTY
AA	AL Round	1
BB	3/4 Plywood	1
CC	3D cast models	6
DD	3D print runners	1
EE	Green Sand	1
FF	PLA spool	3
GG	AL ignets	11lb

Appendix D Bill of Materials

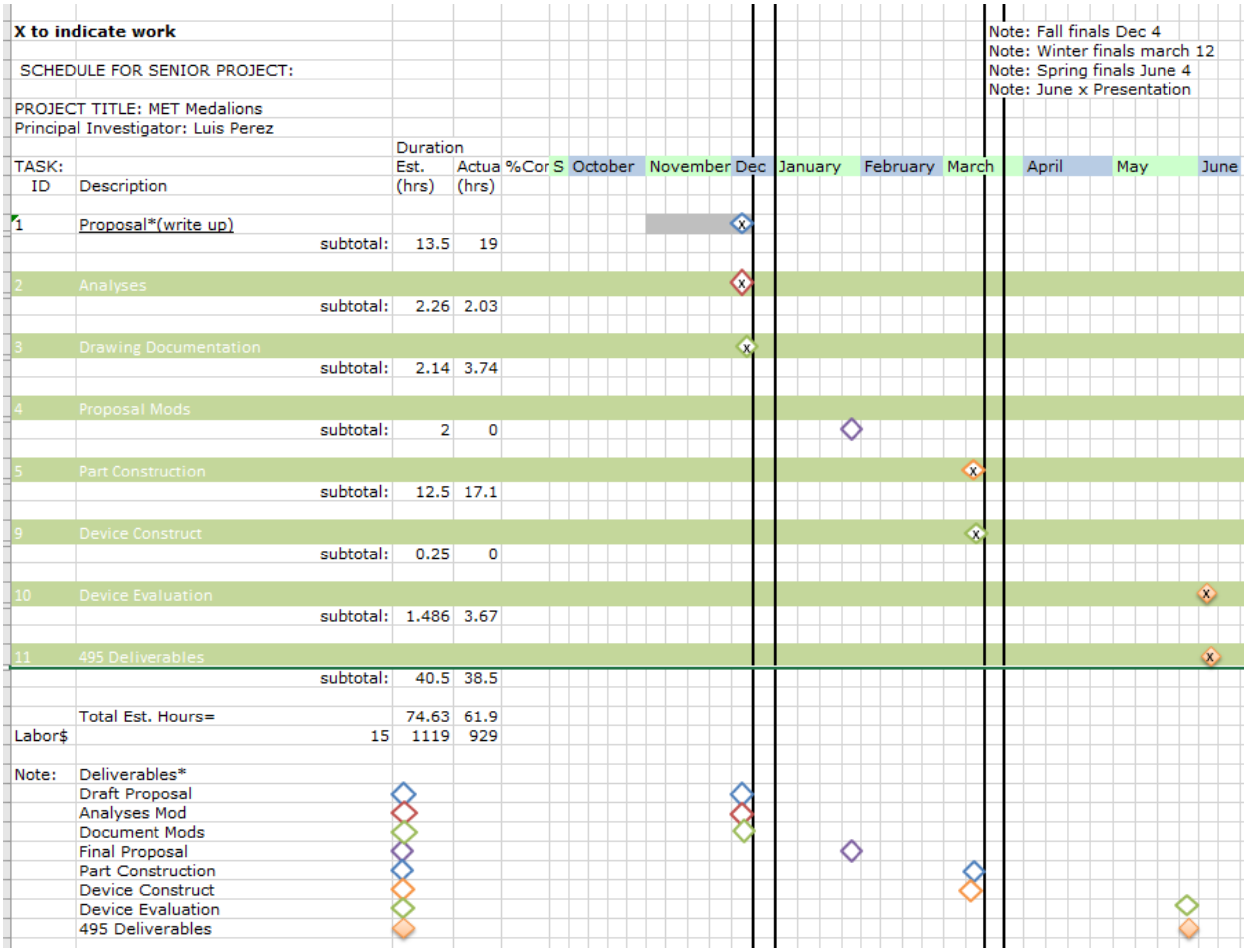
D1: Bill of Materials

Budget							
MET Medallions							
Item ID	Item Source	Brand	Model/SN	Part Description	Qty.	Estimated Price	Actuall Price
1	Metals Depot	NA	Stock #R3312	AL Round	3.5x12"	89.75	41
2	MSC Industrial Direct CO.	Made in USA	MSC #:01787399	1/8 Ball mill	1	18.66	0
3	MSC Industrial Direct CO.	Accupro	MSC #:67940205	3/6 End mill	1	33.59	0
4	Amazon	AmazonBasics	AML1011755-10	PLA spool	1	19.99	2.5
5	Home Depot	Home Depot	NA	3/4 plywood	2'x2'	10	5
6							
7							
						171.99	48.5 Total

Appendix E Scheduling

E1: Full Gantt chart SRP Gantt time chart LGP.xlsx

E2: Screenshot overview of Gantt chart



Appendix F: Expertise and Resources

1. Expertise
   a. Professor Pringle
   b. Dr. Johnson
   c. Dr. Choi
   d. Mr. Burvee
2. Resources
   a. Machining Lab
   b. Foundry
   c. Computer Lab

Appendix G Safety

G1: Horizontal Band Saw Hazzard Analysis Form

JOB HAZARD ANALYSIS
Horizontal Band Saw

Prepared by: Luis Perez	Reviewed by: Approved by:

Location of Task:	Machine Shop (Hogue)
Required Equipment / Training for Task:	Safety Glasses, Appropriate Attire, Documentation of Machine Training, Gloves optional.
Reference Materials as appropriate:	Machine Manuel

Personal Protective Equipment (PPE) Required
(Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)

Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☐	☐	x	☐	x	☐	☐

Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	Cutting	Entanglement	Remove loose articles of clothing, jewelry, and long hair.
		Ejected Materials	Safety glasses.
		Braking Blade	Turn on lubricant. Set proper tension in blade band. Inspect blade if clicking sound occurs.
		Cutting	Keep hands away from blade while in operation.
		Crushing	Turn off lowering mechanism before making adjustments. Never place hands on machine body.

File Name: MS-01
Page 1 of 1

Revision No. 1
Revision Date: November 2018 Revised MET489

Appendix J: Decision Matrix

J1: Decision Matrix

Decision Matrix for Material Choice										
				Options:			1-3 scoring			
Category	Weight		Steel	Score	Brass	Score	Aluminum	Score		
Weight (lbs.)	1	3	2	2	2	2	3	3		
Appearance	3	9	2	6	3	9	3	9		
Cost	3	9	1	3	1	3	2	6		
Machinability	1	3	1	1	3	3	2	2		
Availability	3	9	1	3	3	9	3	9		
Corrosion Res.	1	3	3	3	2	2	2	2		
	total	36		18		28		31		

Specifications:	Best 3 Points
Weight (lbs.)	3 points for anything < .3lbs | 2 points for anything <.6lbs | 1 point for anything over .6lbs final weight
Appearance	3 Points for a smooth, shiny, metallic finish without polishing| 2 Points for a smooth metallic finish from machining | 1 Point for needing polishing for a final finish.
Cost	3 Points for anything <100$\| 2 Points for anything <200$ |1 Points for anything >200$ (for a 3" dia 2ft length round)
Machinability	According to the website: Excellent, Good, Moderate, Fair, and Poor will correspond to 3,2,1,.5,.25
Availability	3 Points for anything that can be stock ordered| 1 Points for anything that has to be machined down or special ordered.
Corrosion Res.	3 Points for anything with excellent |2 Points for good | 1 Points for anything with a tendency to corrode

	https://www.met	https://www.meta	https://www.metalsdepot.com/aluminum-products/aluminum-round-bar						
References	Steel (stainless)	Brass C36000, CD	Al 6061						
Weight (lbs.)									
Appearance						Volume	density	lb.	
Cost 2ft 3"dia	290.32	585.9	108.74			1.76625	0.286	0.505148	steel
Machinability	Moderate	Excellent	good			1.76625	0.1	0.176625	al
Availability	yes	yes	yes			1.76625	0.3	0.529875	brass
Corrosion Res.	superior	good	good			1.76625			
	"Durable, dull, mill finish"								

Appendix K: Solid Cast Simulations

Figure K1: Temperature

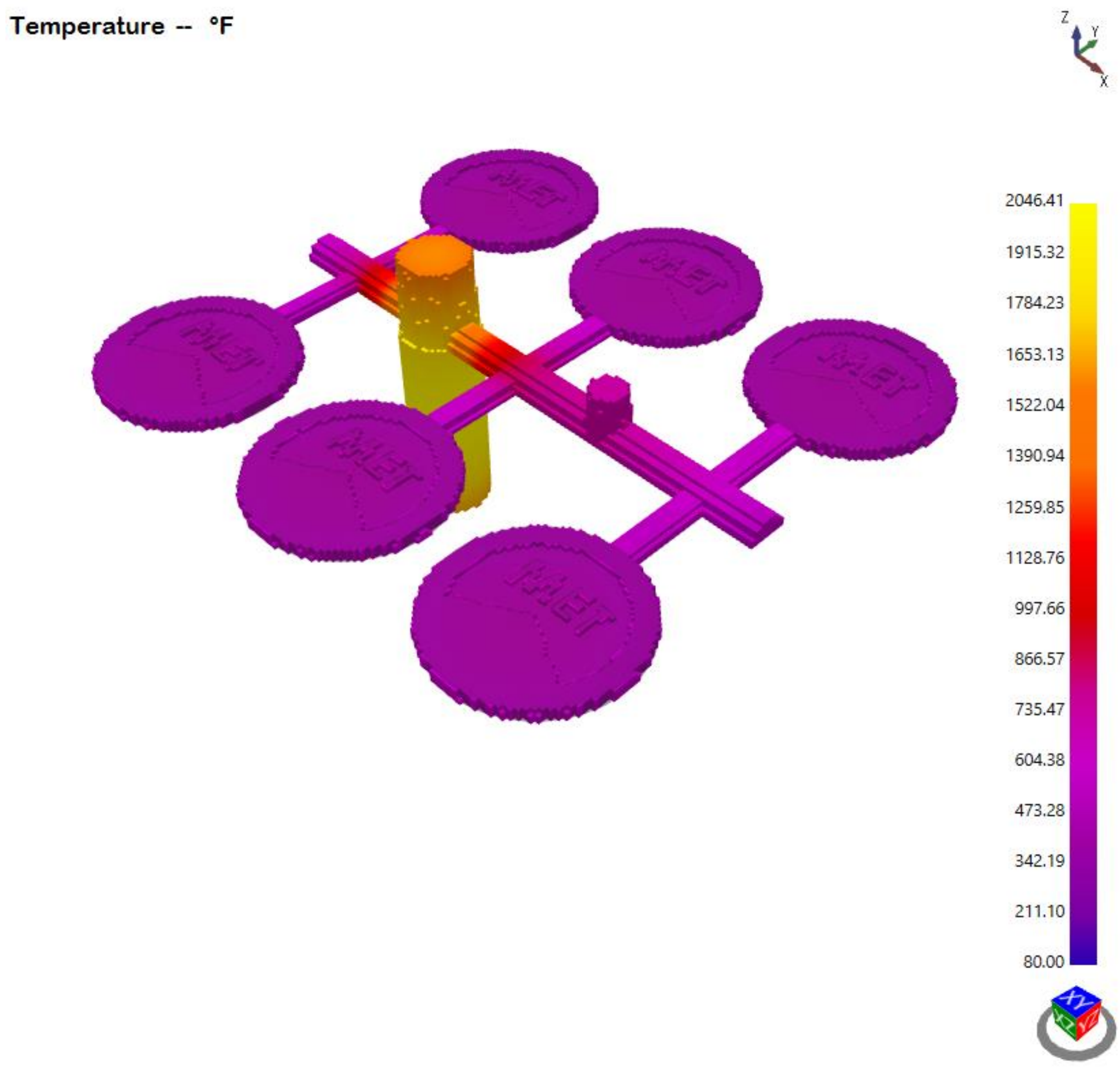


Figure K2: Niyama Criterion

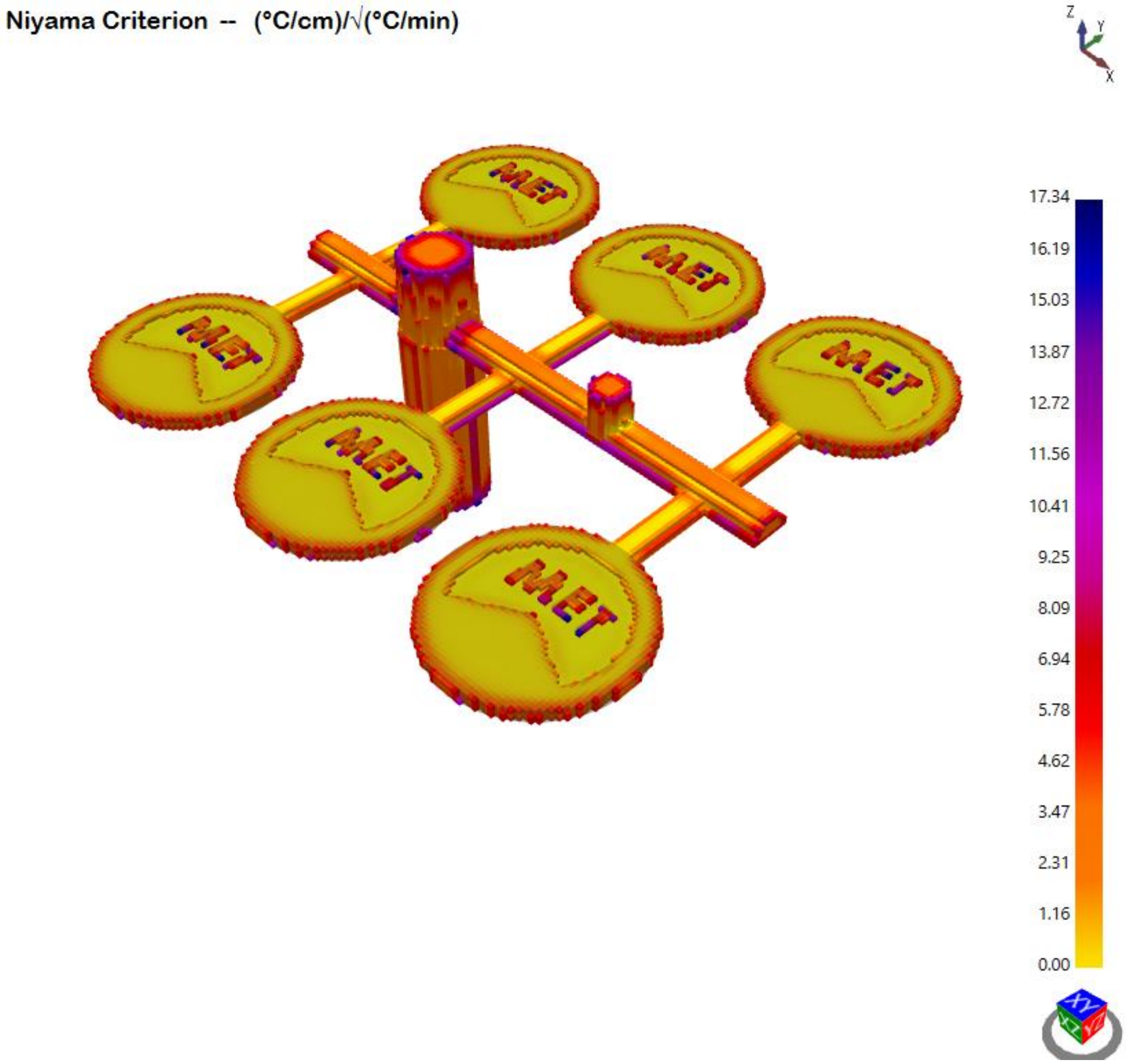


Figure K3: FCC

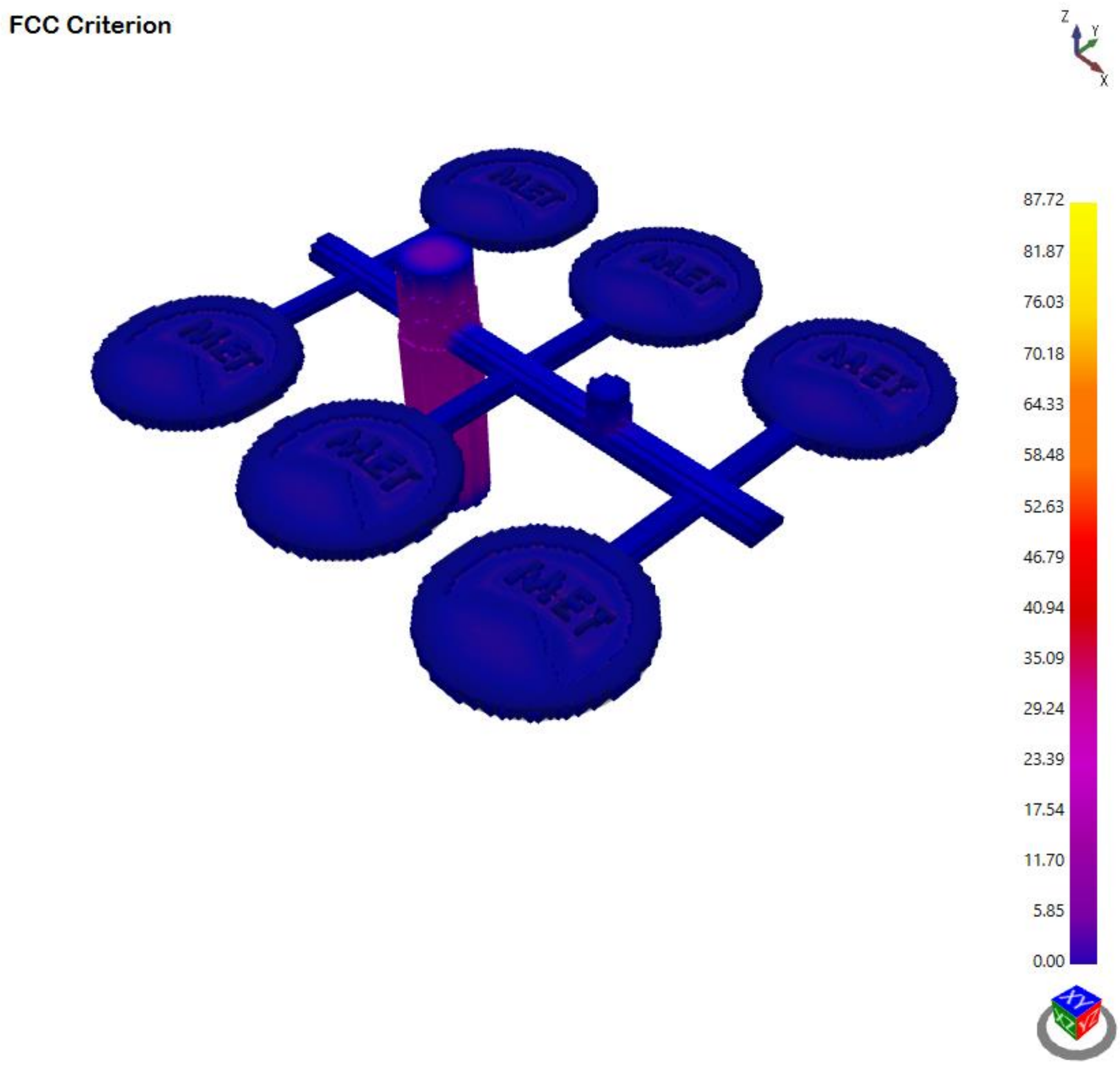


Figure K4: Density

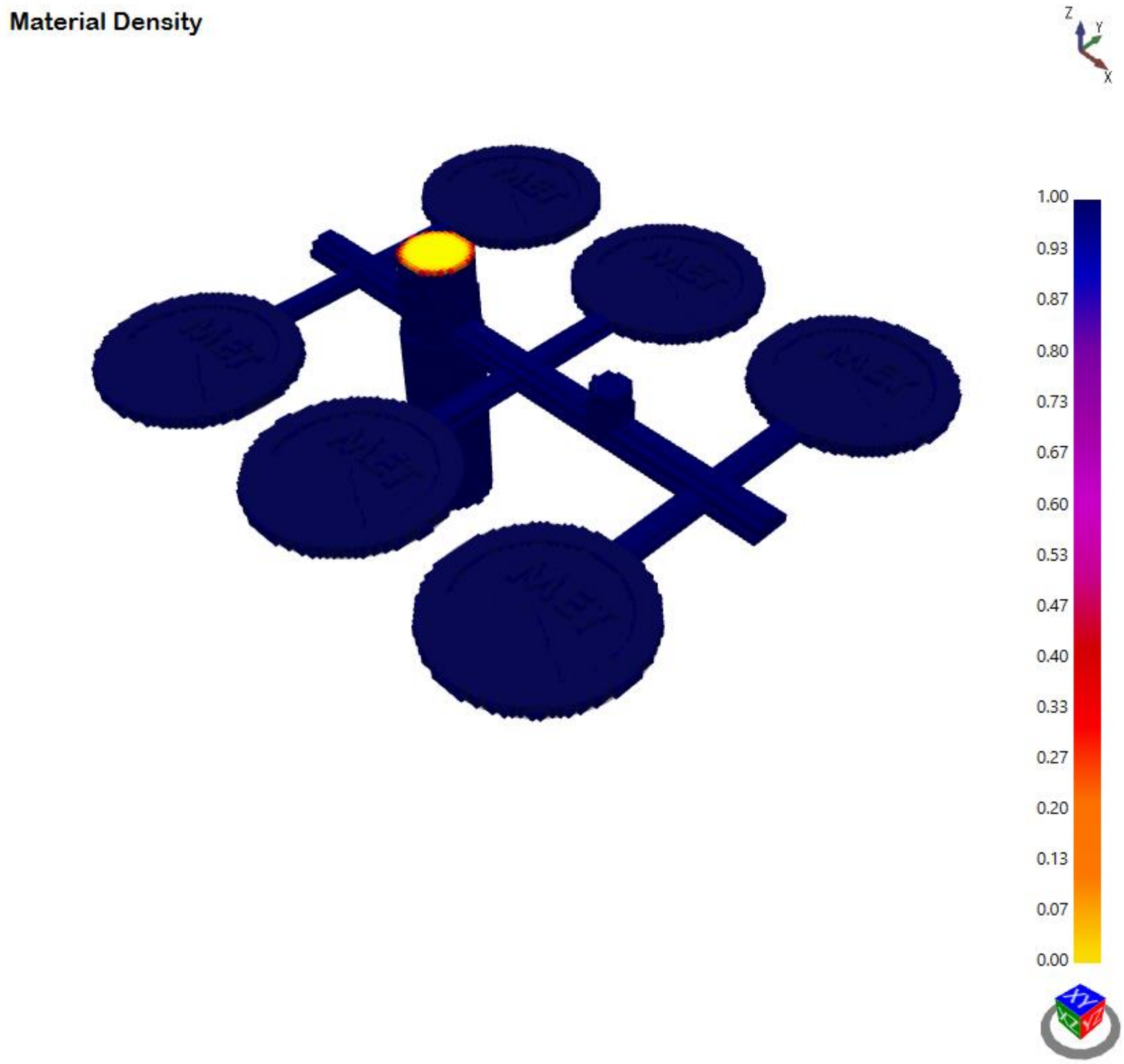


Figure K5: Solidification Time

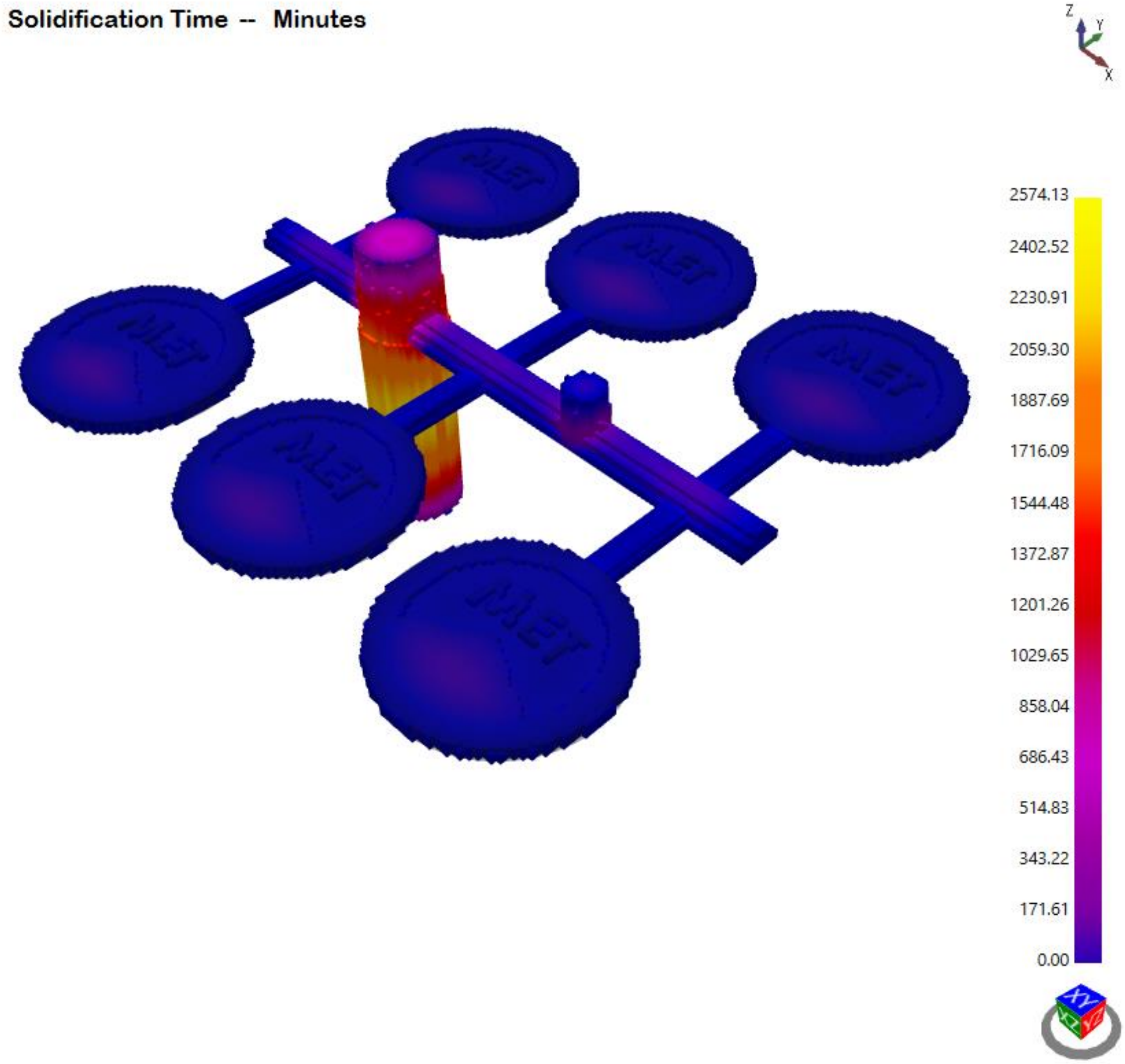


Figure K6: Cooling Rate

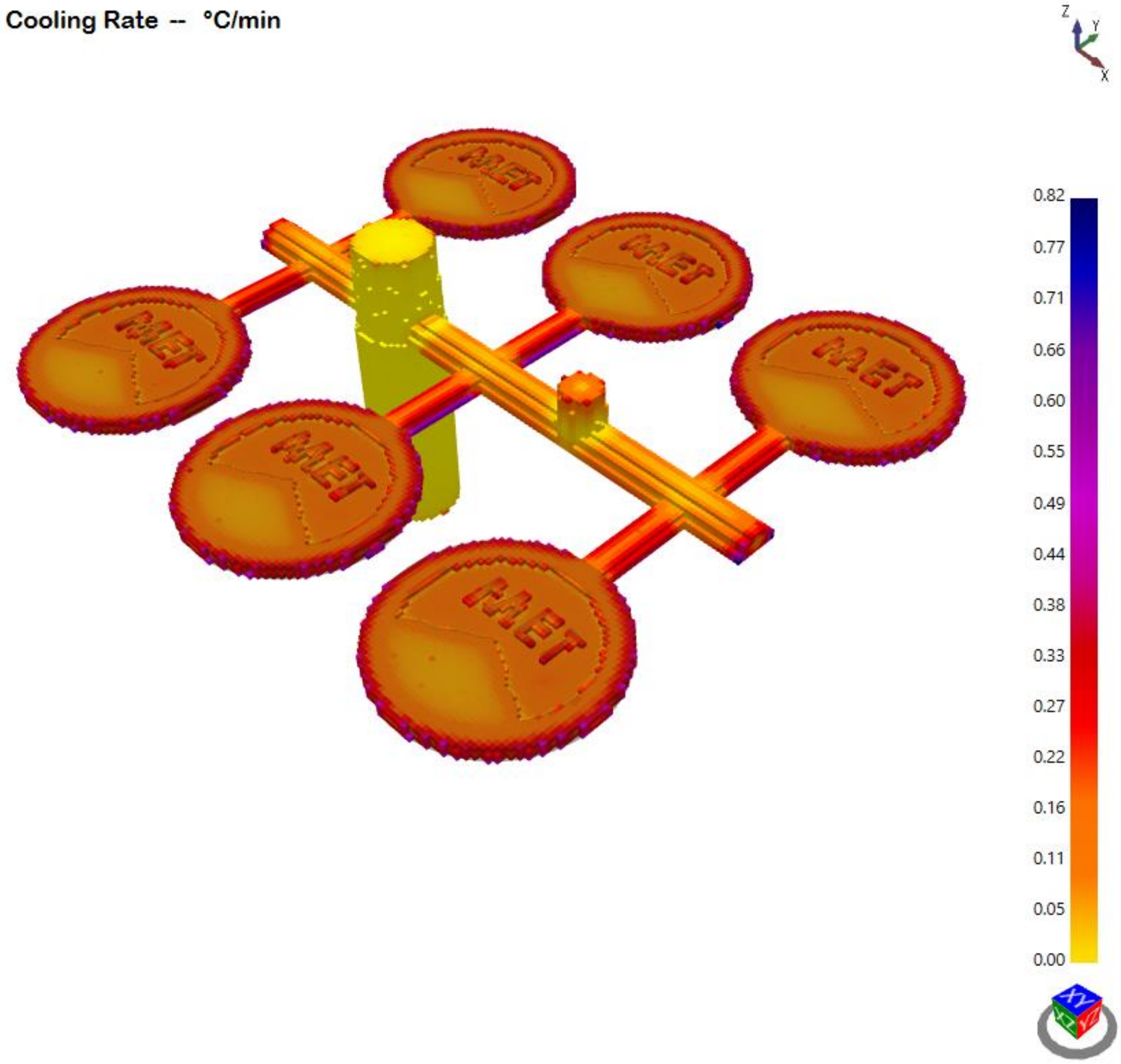


Figure K7: Liquidus Time

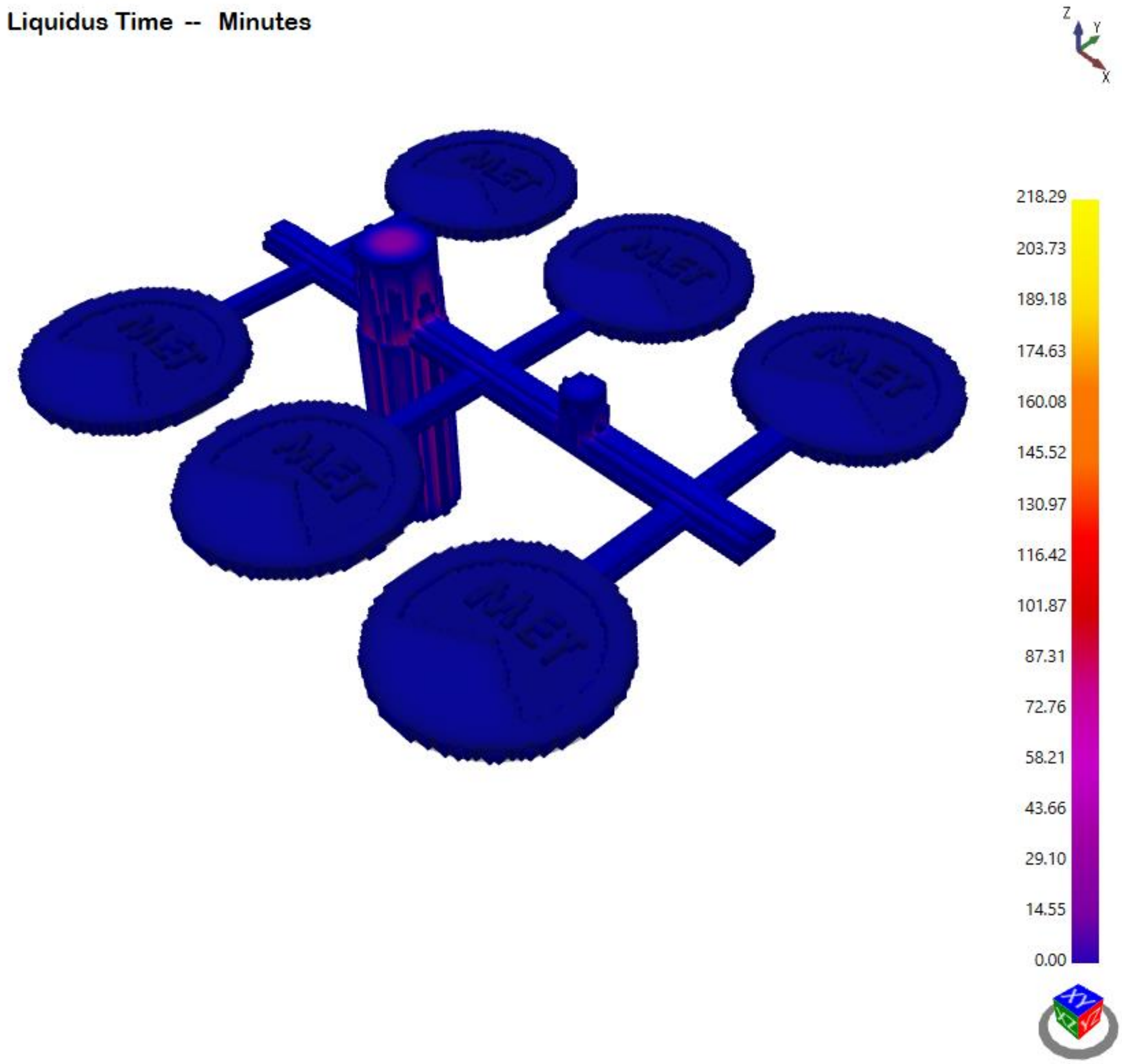


Figure K8: Hot Spot

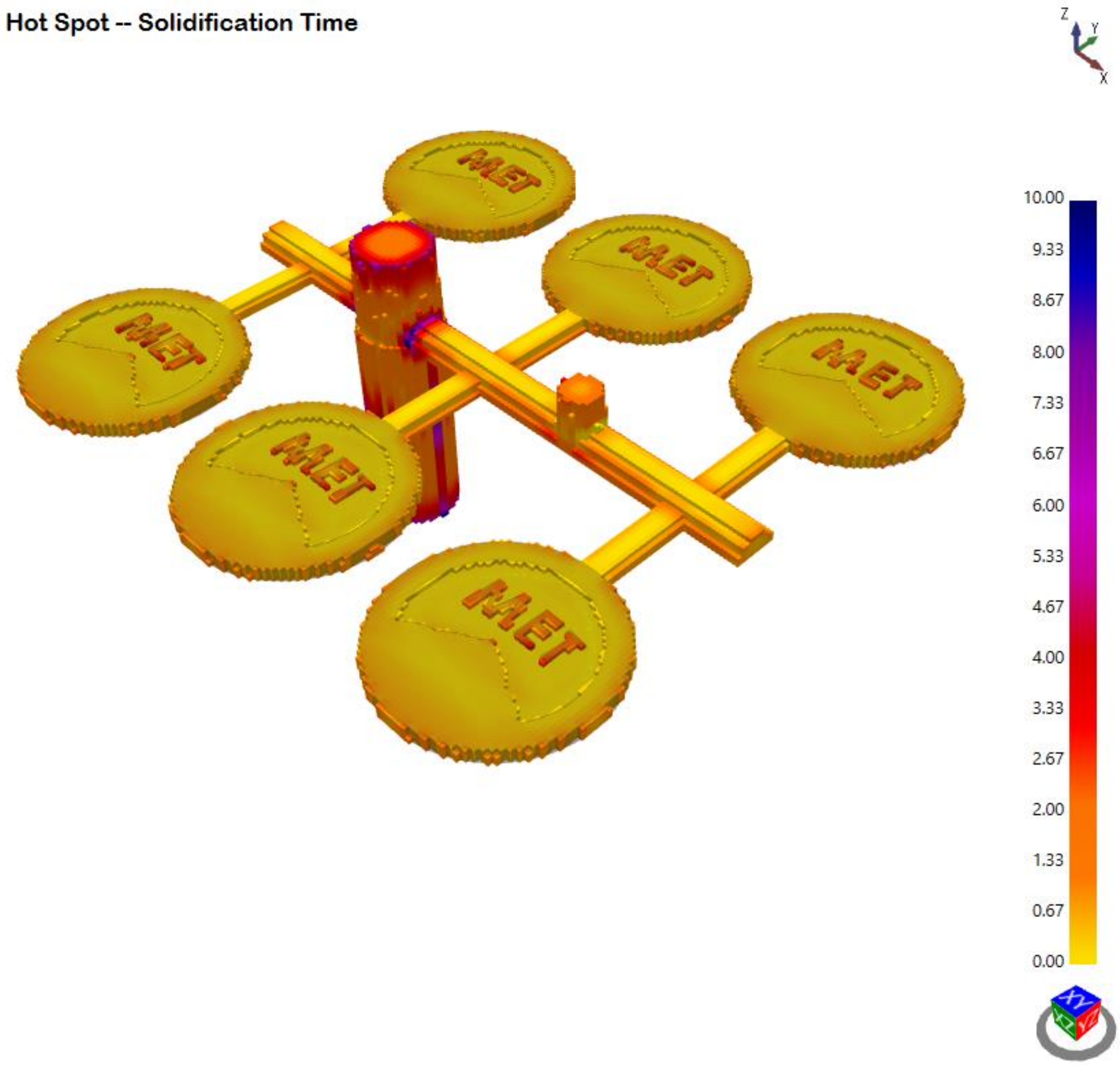


Figure K9: Modulus

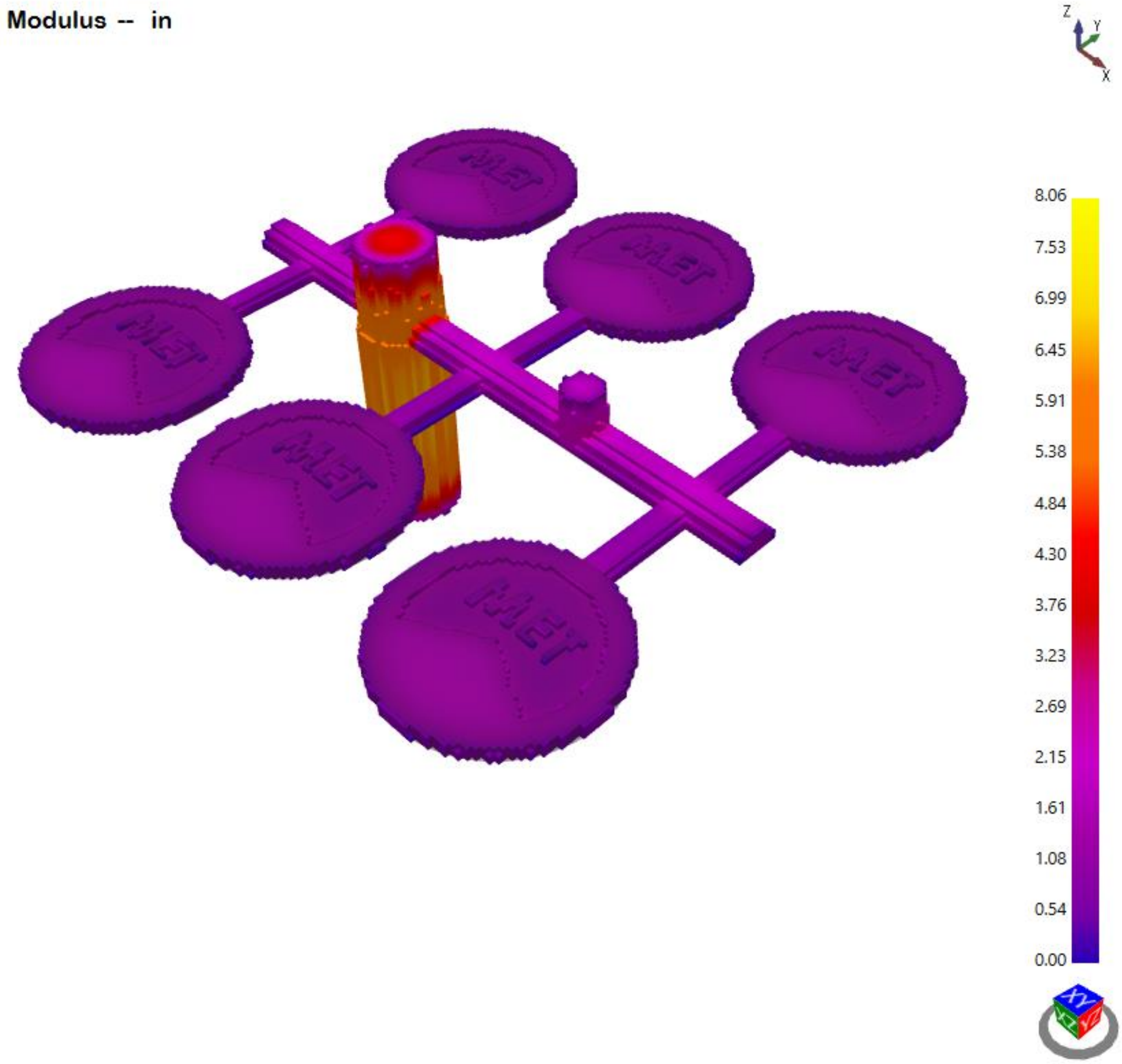


Figure K10: Critical Fraction

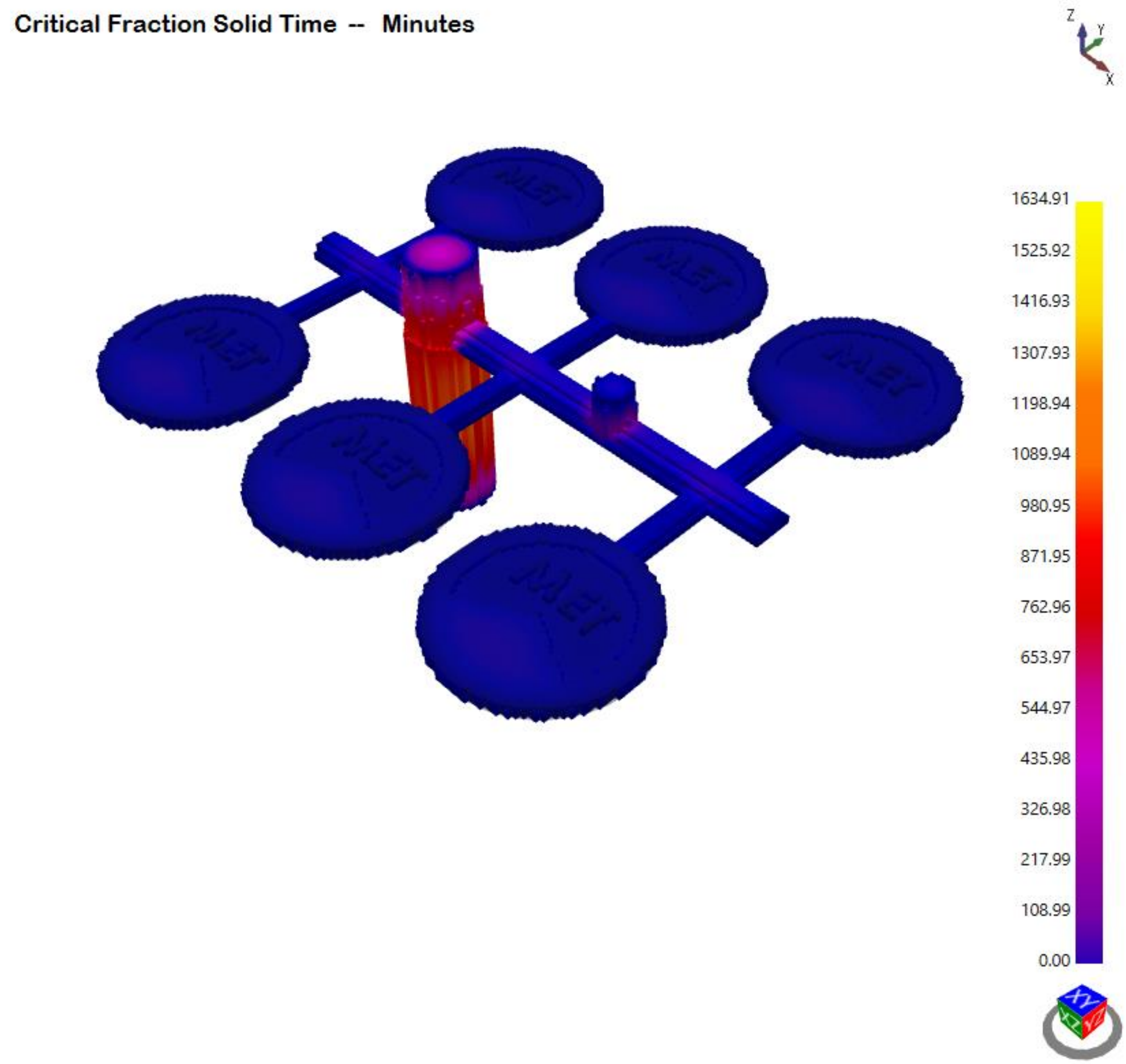
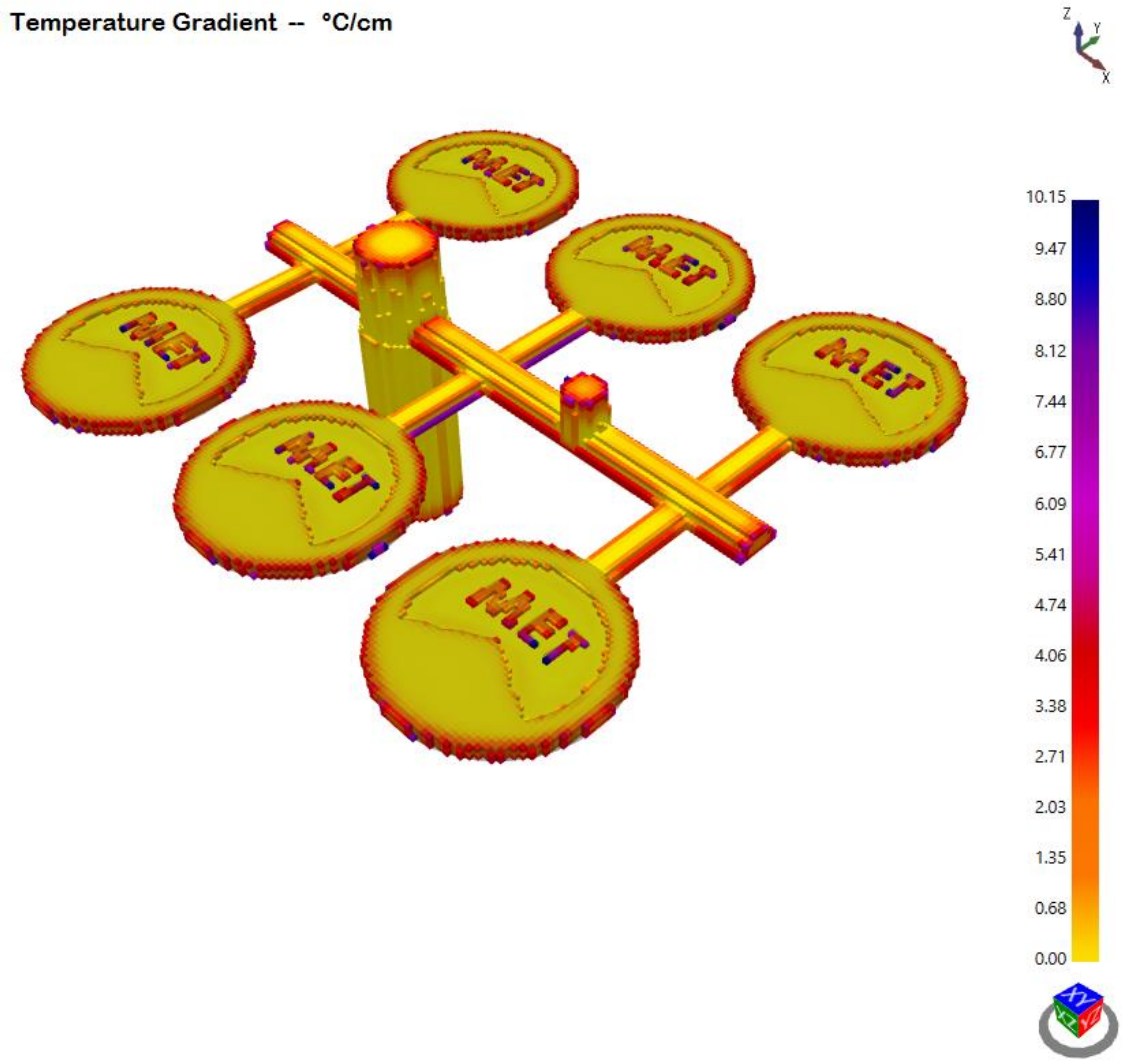


Figure K11: Temperature Gradient



Appendix L Contact Information

L1: Website

https://luisperezwa.wixsite.com/website

L2: Resume

LUIS PEREZ
(509) 637-4203 • luisperezwa@gmail.com
1060 S. Indian Lane White Salmon WA 98672

Objective: To become a part of a team which builds useful projects. More specifically, to collaborate on innovative designs that will be reliable, efficient, and inspiring.

Education

Central Washington University GPA: 3.3 — **Ellensburg, WA**
BS. Mechanical Engineering Technology — *Expected graduation date 2019*
Awards: Washington State Opportunity Scholarship

Columbia High School GPA: 3.57 — **White Salmon, WA**
AP English, AP US History, Spanish III — *Class of 2015*
Class Representative (2014)
National Honors Society (2014)

Skills

AutoCad, Machining, SolidWorks (CSWA), Lean Bronze Certified.

Work Experience

Polehn Farms — **The Dalles, OR**
Position: Product handler — *Summer-2014*
Supervised 20 workers in a cherry orchard.
Oversaw field quality control of produce.

Dakine — **The Dalles, OR**
Position: Warehouse worker — *Summer-2015*
Unloaded trucks among various tasks.

Ryan's Juice — **Hood River, OR**
Position: Press operator — *Summer-2016*
Operated industrial juice presses.
Moved and packaged product.

Capriotti's Sandwich Shop — **San Diego, CA**
Position: Team Member — *Summer-2017*
Preparing and cooking food.
Cleaning and cashiering.

Extra-Curricular

Joshua of a bible study group.
Volunteer at a cold-weather shelter.
10-week church leadership program.
Church missions trip to Tijuana Mexico.
American Society of Mechanical Engineers Senator.
Society of Manufacturing Engineers Vice President Senator.

References available upon request.

Appendix M: Testing Report

Introduction

Test Procedure: Circularity

The variation in the radial distance from the center of the piece, or the circularity, is one characteristic to be measured. The feature is often important in rotational parts, however, for this project the characteristic is important for a symmetrical appearance.

The test will be done on April 5th (Friday) for approximately two hours in the machine lab. For the test, a v-block along with a dial indicator is needed.

Order of operations:

1. Gather the dial, medallions and a v-block on a flat and smooth work bench.
2. Insert a medallion into a v-block so the axis of rotation is parallel to the surface of the workbench.
3. Place the dial indicator on the rim of the medallion.
4. Slowly rotate the medallion while making note of the variation of the dial.
5. Record the variation in Table XYZ.
6. Repeat steps 2-5 as needed.

This test does not involve any machines, or sharp tools, and thus carries no risk. The objective is that each has a circularity of .003 inches.

As expected the machined medallions were consistent in circularity. This result was expected because the outer edge of the medallion was not changed, except for a chamfer. The only opportunity for the circularity to be affected would come from the chuck being excessively tightened and deforming the medallion. The chance of deformation was minimal as the pieces were thicker when held by the three jaw chuck as compared to the custom jaws. The custom chuck applied the force over an area because both had same radius which created more contact between the two.

As for the casted medallions, the circularity was less than desired. Due to the draft, needed for extraction of the model from the sand, the medallions could not easily be set on the v-block. The solution was to firmly hold the medallion against a 3-2-1 block that is perpendicular to the v-block. The added support ensured that the medallion remained vertical during the test. The flash and the remainder of the runner that occurred during the casting process needed to be removed. To do so quickly, the flash was removed with a band-saw by hand. The variability of the operator, as well as the flat portion created by the runner, decreased the circularity. While the results for the machined medallions met the requirements, the circularity for the casted medallions was out of the specifications. As the function of the medallions is not dependent of the circularity of the bottom edge of the piece, but rather the top edge, it is not concerning that the casts are less circular.

Test: SolidCast

New methods have created opportunities in all areas of life and casting is no different. The SolidCast simulation strives to recreate a cast to illustrate the results to indicate to the pattern maker if changes need to be made. The test is using SolidCast to analyze the effects from creating a three-degree taper on the stretch of runner between the largest channel and a medallion. The taper decreases the end by .21 inches changing the value from .5 inches to .29 inches.

The test will take place in the computer lab and the metal lab, SolidWorks is needed from the first and the SolidCast software from the later. The change in the runners is done in Solidworks and then is saved as an STL file for the SolidCast to use. Then a model is created in SolidCast by uploading the assembly and building a flask around it. Then by designating where the sprue is the simulation can begin and results are given. There is no risk associated with the test because no materials or tools are needed.

The results from SolidCast indicate that the 42% reduction of the connection between the runner and the piece would not significantly impact the pour. The results of the temperature the medallions reached during the pour would not change according to SolidCast. The other critical factor in the simulation’s results was the solidification time. The new end solidifies quicker, as was expected, but not before enough aluminum was allowed to flow into the medallion to fill it. New runners can be printed that would be less invasive on the profile on the medallions, diminishing the impact that the runners have on the circularity of the medallions. Additionally, the runners would be broken off closer to the medallion reducing the time taken for grinding the edge.

Test: Machined molds

The casted medallions retained the lines from the 3D printing. The roughness of the models limits the surface finish on the pieces. By using the medallions that were machined, which produces a surface finish of 125 down to 32 micro inches, the surface finish can be improved. Additionally, the change of lettering between the two designs would be easier to form the mold because of the increased space in between the letters. Traditionally the model needs a draft, however, because of the thin nature of the part the it may be possible to not have one.

The test needs to take place in the foundry. By packing the green sand in both the cope and the drag the mold and runners will be created by hand. The test will need approximately 2 hours to complete, and the help of two additional people.

The results were promising. The quality of the cast improved greatly. The surface is free of the ridges the 3D printer would create, as well as defined lettering. Some of the previous casted pieces trapped sand in between the letters allowing metal to form where it should not have, ruining the piece. However, this was not the case for the casted medallions that came from the machined model. The only issue with the new set of medallions was a small amount flashing around the back edge of the medallion, which was likely caused by the removal of model by hand. If a new model was machined with a draft and added to a match-plate, then the issue would likely disappear.

Appendix N: Data Forms

Circularity Data Form			
Type (Cast/Machined)	Piece number	Runout	Pass/Fail
Machined	1	.003	Pass
Machined	2	.003	Pass
Machined	3	.002	Pass
Machined	4	.003	Pass
Machined	5	.003	Pass
Machined	6	.003	Pass
Cast	7	.012	Fail
Cast	8	.015	Fail
Cast	9	.013	Fail
Cast	10	.013	Fail
Cast	11	.02	Fail
Cast	12	.018	Fail

Aluminum usage	
Category	Weight (lbs)
Predicted	2.6
Actual	2.3
Gating system	1.0
Deviation	13%

Shrinkage	
Category	Value inches
Predicted A8 Mathematical	.02
Predicted A9 SolidWorks	.046
Actual	.02
Deviation A8	0%
Deviation A9	56%

Weight	
Category	Value inches
cast	.215 – pass
machined	.22 –pass