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Flexor Casting

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By: Courtney Lehrman

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Abstract

Flexor: Strain Gauge Base

by Courtney Lehrman

Abstract: Strain gauge bases (Flexors) are scarce in the Mechanical Engineering Department. Flexors are used for MET lab classes to collect and analyze data so it is important for there to be more Flexors available. In order to acquire more, resources are available on campus such as the foundry and the machine shop in order to support the manufacturing of more Flexors in-house at a much lower cost. By creating a pattern that can be used numerous times in a foundry, not only will there be an opportunity to make more castings for students to use, there will not be a financial burden on the MET department in the production of more Flexors. The first step to this project included redesigning an existing Flexor to be compatible with the foundry. This included making many dimensional calculations to the pattern such as how wide and long the runner should be or the shrinkage rate of the Flexor after being poured. The next step was to manufacture these designs to a matchplate board in order complete the pattern. This involved manufacturing the designs into 3D models using ABS. Once the prints were complete, the assembly to the matchplate was then able to take place. With the pattern accommodating two Flexors at a time in production, pattern will then be able to be used in the foundry on campus to produce a dozen Flexors to support the MET lab needs.

Introduction

Description

This project will be consisted of designing, building, and testing of a Flexor Strain Gauge Base. The casting process will be used for the completion of this project. The purpose of this project is to increase the number of flexor strain gauge bases for use in CWU Mechanical Engineering lab classes. The overall focus of this project will be in the pattern making portion of the casting process with an emphasis in the dimensional aspects of the pattern.

Motivation

There is a lack of funding towards the strain gauge bases themselves. Being able to design and build the structure of the strain gauge bases would create a low-cost investment to produce multiple strain gauges. This project will also be able to be used to improve the casting process at CWU by finding the most effective process. With the available resources from Central Washington's Foundry and outside foundry support, this project will be able to be completed by June of 2020.

Function Statement

A device is needed to support the function of the strain measurement for existing pre-gauged beams. The focus of this project is on the base of the strain gauge.

Requirements

- Must obtain a 0.250in thick gauged beam
- The Flexor base must weigh no more than 5 lbs.
- Ends of base must be able to incorporate micrometer and clamp for testing
- Must be compatible with existing pre-gauged beams

Engineering Merit

There are many steps through the casting process that will be used in the engineering of the Flexor strain gauge base. There will be calculations made to support the patternmaking process and achieving the correct dimensions of the strain gauge base. Location of the gating and the orientation of the cope and the drag for the mold will be taken into account. Calculations towards shrinkage will also be considered as metal shrinks as it cools inside the mold. There will be an incorporation of two Flexors in a 12in by 16in flask.

Scope of Effort

- Start from scratch; this includes free body diagrams, rough sketches, and more than one design of the Flexor.
- Pick out the material that will be used for the structure of the strain gauge.
- Calculate the appropriate dimensions for the strain gauge to incorporate the design requirements.
- Use calculations to create a gating design for the casting mold.

Success Criteria

There has been a complete assembly of the 3D prints to the matchplate in which the matchplate is then used to pour. Once there has been a complete pour that will be able to support existing micrometer, clamp, and pre-gauged beams. The success of this device will also be able to check off all requirements made.

Design and Analyses

Approach: Proposed Solution

The calculations made towards the Flexor base and the gating design will result in an overall casting design that will be used to pour Flexor bases for the CWU MET lab classes. There will be an improvement in the Flexor base to not only incorporate a strain gauge but a clamp on one end of the Flexor and a micrometer on the other side.

Design Description

The following image depicts the existing Flexor. As one can see, the incorporation of the clamp is on the left side and the micrometer is on the right.

The dimensions for this part improve throughout this report as the design of the part improves. To break down this Flexor, there are two main extrusions from the body. The left extrusion shows an incorporation of a clamp which is used to hold down an existing strain gauge. The right-side extrusion includes the incorporation of a micrometer that is used in the deformation of the strain gauge during testing. If the existing Flexor design was used in the casting process, it would be impossible to have a clean pattern because of the “lip” that the micrometer side makes. The improvement of this side excludes that “lip” and the addition of an extrusion to be able to incorporate the micrometer after a pour. This makes the casting process easier as this side includes the same draft size as the overall part and an easier inclusion of the micrometer.

Benchmark

Some of the major benchmarks for this project are to get the parts 3D printed and attach it to the matchplate. This will also include another benchmark of getting the parts attached in a way that will make this casting successful. One of the other benchmarks is getting the match plate and design over to the foundry where it will be eventually poured. Over all, there are a lot of benchmarks when it comes to this project. Each benchmark is one step closer to having a finalized product.

Performance Predictions

There are a few predictions that could be made regarding the performance of the Flexor part. One prediction is that the dimensional aspect of the Flexor will be inconsistent in the gating design. This may be caused by the pour or by the calculations in the design itself. Either way, this can be fixed by a different design in gating if the pour does fail. If the dimensions for the gating and the design of the Flexor do work, another prediction that can be made is that the pour will be close to "perfect" and the work that will need to be included after the pour is the machining finishes and the addition of the clamp and micrometer.

Description of Analyses

The analyses involved in this project directly relate to the dimensional design of the Flexor, gating system, and matchplate. The focus of this project was mostly on the gating system itself. This explains the numerous pages that go towards this focus in design. The additional analyses are in support of the casting process. The Flexor and match plate design were based off existing material with a few design changes to support the improvement of the Flexor's casting process.

Scope of Testing and Evaluation

The scope of testing and evaluation for this project will be directly related to the design requirements made for the Flexor. For the testing aspect of this project, it is predicted that the testing will consist of proving that the incorporation of the clamp, micrometer, and existing strain gauges works for the Flexor. The main outcome of this project is in the ability of the device to be able to incorporate the clamp, micrometer, and existing strain gauges. If the Flexor does not incorporate any of these design requirements, the evaluation will show that this part has failed.

Analyses

The following description of each analysis is listed below. Each description explains the calculations made in each analysis along with why each analysis is being made. Green sheet analyses relating to each figure can be found in Appendix A.

Figure A-1: Shrinkage Allowance

This analysis had to do with shrinkage allowance for the Flexor part. In castings, foundries typically use 5/32 in per foot as a "shrinkage rule." This then led to a 1.0130 multiplier value. With these given values, one can then apply a scaling value of 1.0130 to the entire part about the centroid. This then increases the part to then compensate for the shrinkage of aluminum during the cooling process of the Flexor. In this figure, there are sketches that denote this analysis and shows that there is an increase in the dimensional values when the Flexor is scaled by the 1.0130 multiplier. By doing this, the volume and mass changed for the Flexor as well. The original volume and mass of the Flexor was 35.77in^3 and 3.49lb respectively. The scaled volume and mass of the Flexor is 37.18in^3 and 3.63lb respectively.

Figure A-2: Flask and Gating Design

This figure displays the possible designs that will accommodate the design of the Flexor. Option 1 in the figure would be able to create one Flexor whereas Option 2 would create two. There is a predicted use of a 12” by 14” flask for both designs. The Flexor(s) will also be placed top down in the drag of the flask. This assumption stems from assurance that the Flexor’s structure will be improved from “working with” gravity rather than against it. This orientation will also have less negative draft.

Figure A-3: Continuation of Gating Design

This figure is a continuation of Figure 1-2. These gating designs are dependent on if Solidcast incorporates one or two Flexor designs. Option one shows that the runner will extend to the ends of the Flexor. The sprue has been placed in the middle of the runner to theoretically spread the molten metal evenly among the Flexor. This design could also incorporate the sprue on the left-most side or right-most side of the Flexor instead. Option two shows that are two Flexors in the flask with a runner in between the two of them with smaller gates connecting to both ends of both Flexors. The sprue has been placed on the left-most side of the flask; however, the sprue could also be placed in the middle of the runner as well.

Figure A-4: Gating Design

This figure displays the gating design that will be used in the making of this Flexor casting. The well will be that of a cone shape with a flat bottom rather than a semi sphere. This is to prevent turbulence in the well which could interfere with the casting. This concept follows through with the runner design as well. The design must be a step-down runner rather than a straight runner. The runoff that a straight runner produces interferes with the casting as well. The cone shaped well, and the step-down runner will be the best options as to improve the design of this casting.

Figure A-5: Properties for SolidCast

This is a small yet growing list of the values and properties that will be involved in the SolidCast software. The idea behind listing out these values is to not only be able to locate all these values in one place, but to be able to clearly identify what properties that will be used in the making of this casting. The use of SolidCast will be beneficial in the design of the gating system that will be used for the Flexor’s pattern. This is arguably the most important part in this project.

Figure A-6: Matchplate Design

This Matchplate design originated from an existing matchplate from CWU’s Foundry. The dimensions that are included in the design of this matchplate can incorporate a 12in by 14in flask. The two holes on both ends of the matchplate can fit the pegs of the flask for the cope to attach to the drag. The calculated weight of the matchplate was determined to be 2.25lb which is relatively light. The volume of the matchplate was calculated to be 184.08in^3 which is just enough to be able to support the green sand in the making of the Flexor’s pattern. The material that was determined for the matchplate is white pine. Pine is relatively light in weight with smooth, straight, and even grain. This material is often free from knots which can improve the finish of the casting as well as support the green sand mold to be structurally sound. Other material could have been used in the design of the matchplate, but this seemed to be the best regarding this project.

Figure A-7: Volume of Sand

This figure relates to the volume of sand that will be needed in this casting process. This analysis started by evaluating the total volume of the cope and drag combined which came to a total of 1175 in^3 (588in^3 each for the cope and drag). Then, the volume of the part (Flexor) was determined through solidworks which was 35.77in^3. After these values were found, the total volume was then found by subtracting the Flexor's volume from the total volume which was found to be 1140.23in^3. These values are estimated values as this analysis does not include the gating design. Therefore, the 1140.23in^3 is a higher estimated value from the real value.

Figure A-8: Machining Finishes

This analysis breaks down the machining finishes after the Flexors have been poured. As far as finishes goes, there is an overall machining finish of the part that is 3/32 in. There then must be a slot formed for the clamp portion of the Flexor this can be achieved by the use of a milling machine with the assistance of Ted Bramble and Matt Burvee. Once the overall finish and slot has been applied to the Flexor, there then must be a tapped hole to incorporate the clamp feature. Once these finishes have been applied, then the testing portion of this project can begin.

Figure A-9: Riser Design

The riser design of this project was designed based on the dimensions of the runner in the drag portion of the Flask. The bottom of the riser that will encounter the parting line has a diameter of 1.9. This again was determined by the pre-existing dimensions of the runner. The well, runner, ingates, and down sprue were designed by the suggestion of Jim Justin. The length of the runner was determined based of the 14 in length limit of the Flask.

Figure A-10: Gating Dimensions

The gating dimensions were determined by collaboration of Jim Justin. These dimensions were suggested through Jim Justin's experience as a pattern maker. After some interpretation and revision, this analysis was then able to represent the dimensional aspect of the gating system. Each dimension takes into consideration the number of parts (two Flexors) and the ability of the molten aluminum to flow evenly into the two parts.

Figure A-11: Momentum and Impulse of Hammer on Sand

This analysis involves the calculation relative to the momentum and impulse of a hammer on sand. The reason that this analysis exists is to predict the amount of force that the hammer will extrude onto the sand and onto the pattern itself. This can help to calculate the max amount of force that can be used to pack down sand without breaking the pattern.

Figure A-12: Volume of Feed Metal

This is the Volume Feed Metal that will be used specifically for this project. Once the feed metal %, density of alloy, and casting weight was determined, the Volume of Feed Metal was then calculated to be 1.75 in^3. Since V_F has been determined, the thickness of the molten metal insulating wall and riser design then can be calculated. This calculation is important to determine remaining gating/riser designs.

Design Issue: 1, 2, 3, …

The following list depicts a few design issues that arose throughout this project:

1) Limited access to the on-campus foundry: this was a bit of a challenge to work around as there are many resources in the foundry that could have helped the process of this project. With the foundry shut down, there were some design constraints with auxiliary components such as dimensional aspects inside a flask.
2) The incorporation of the micrometer: this issue arose after realizing that the micrometer side of the Flexor was not able to be supported with one extrusion. After some thought, the design was able to be improved by adding an addition extrusion parallel to the first one in order to fully support the addition of the micrometer.
3) The design of the clamping side of the Flexor: there is a design issue with this end because of the "lip" that the Flexor's clamp side creates which makes the original design of the Flexor unusable in a casting process. The design fix for this is to "fill in" that "lip" to make a full draft. Then, the excess material can be machined out.

Calculated Parameters

All calculations made were in support of the design of the pattern for the Flexor. This entails a focus on the calculations made for the gating design. Components of the gating design include the shape and calculation of the sprue, runner, gate(s), runner(s), and well. These calculations must be in "harmony" with each other. If one calculation is off regarding the gating design, the overall Flexor part will be affected in the casting process.

Best Practices

Best practices for this product include double checking work and constantly making improvements to the Flexor device to make the design the best that it can be. Throughout the process of designing the Flexor's pattern, there have been many mistakes made in calculations and design. Along with that, however, there has been constant improvement. Some best practices have been included in the following list:

1) Double checking work
2) Reaching out to outside sources for support in design improvement
3) Reworking calculations if needed
4) Having others double check/change work to ensure correct improvements

With all these best practices, there should be optimal improvements made to the Flexor's pattern design overall.

Device: Parts, Shapes and Conformation

The overall device of this project is the Flexor Strain gauge base. This project focuses on the pattern making that will be used for the casting process. Components of this design are included in the following list:

1) Flexor's structure
2) Runner
3) Gate(s)
4) Sprue
5) Well

Shapes of this design are inclusive in the calculations made. One of the main features that are important in the pattern making is the use of fillets. This can be considered in the part and in the gating design. The use of fillets in these designs helps improve the flow of metal and the finish of the overall part. If there are rigid edges to components of this pattern, there are issues that can surface such as an inconsistent flow of metal, lack of material in the finishing part, and/or rough or incomplete surfaces on the Flexor.

Device Assembly, Attachments

The assembly for this device will include the appropriate Flexor part, gating design, and match plate. This will illustrate how the Flexor will be poured. To further explain this concept, the "topside" (cope side) of the matchplate will not have any components other than the sprue to feed the metal to the drag side ("bottom" of the matchplate). In the drag, there will be two Flexors with a gating design in between them. This helps improve the balance among the metal and will be more efficient in producing more product with one pour.

Tolerances, Kinematics, Ergonomics, etc.

The tolerances that were used in this project are included in each of the drawings found in Appendix B. The kinematics involved in this project involves volume of feed metal as well as the dynamic velocity of the metal as it is being poured. The goal of this project is to have the design of the gating system precise enough to achieve a successful pour.

Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation Limits

Some technical risks that can happen during the construction of the Flexor can include lack of access to machines. One example of this is not having access to the machine shop at Central Washington University due to the lack of instructors in the classroom itself. Another example is a faulty dimensional calculation. This can mean that a dimension in a drawing or analysis is either incorrect or inefficient. This can create a technical risk which can push back the manufacturing of the Flexor. A failure of the part that can occur can include an incomplete pour. This could be caused for multiple reasons. One reason can include an inefficient dimensional analysis that creates turbulence. Another failure that could occur is a miscalculation in the machining finished. If there is a technical failure with a machine or if there is a technical accident such as taking off too much material. This can cause issues as far as time management and efficient manufacturing goes. Some safety factors to take into consider include pinch points, extremely hot material, and rotating cutters. Operation limits include availability of the machine shop access and time management of sending/receiving products from outside sources.

Methods and Construction

Methods

The following list illustrates just a few methods that will be used in the making of this project.

1) Sketches
2) Solidworks drawings
3) Multiple analyses
4) 3D printing

These methods help to bring together calculations and data that are needed for the construction of the Flexor. This will be completed with the help of CWU's professors, 3D printing system, and outside sources.

The main method that will be used to create the pattern for the Flexor is with the use of the 3D printer available on campus. This is the most effective method to use as it saves time and money to print in house rather than using an outside source. This also makes the process easier to monitor and evaluate any mistakes or issues related to the 3D printed part itself.

Construction

Description:

The construction of the Flexor's parts has been manufactured and assembled at Central Washington University. With the help of CWU's MET lab classrooms and machine shop, the Flexor's pattern has been 3D printed and most of those parts have assembled. The pattern includes the 3D prints of two Flexors, the runner and ingates, the riser, and the downsprue. The matchplate was also manufactured, however, it was manufactured to the wrong dimensions therefore a new matchplate was needed to take the place of the incorrect one. When the pattern is completely assembled, it will be shipped to an outside source to be used for the casting process. Once the castings have been poured and arrive back at Central, the machining finishes will be added in Central Washington University's Machine shop with the assistance of Matt Burvee.

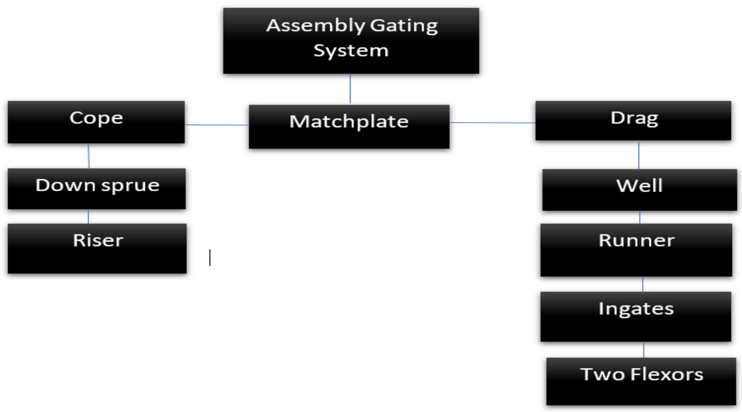
Manufacturing issues: One manufacturing issue that has stemmed from the process is the closure of Central Washington's foundry. With the doors being shut, there is no access to the equipment for the design or analysis process of the Flexor project. Another manufacturing issue could be in the mailing process for both the pattern and/or the casting itself. This process might take quite some time in order to be completed. This makes for a less efficient process.

Another manufacturing issue that can occur is focused on the 3D printing process. The main issues that are taken into consideration include factures or warping after a print, incomplete print, or even the 3D printer itself breaking down. If there is an issue with the 3D printing portion of the lab, there will be even more manufacturing issues down the road when the device is poured.

One way to prevent this is making smaller 3D prints at one time in order to achieve a successful print.

Drawing Tree

The drawing tree consists of the assembly of the two Flexors, gating design, and matchplate at the top of the drawing tree. Then the drawing tree splits into the cope and the drag with the matchplate separating the two Flask components. Under the cope and drag, there is a list of parts that are respectively in their place.



Parts list and labels

The parts that are listed above and below include the parts that will be used in the gating system as well as the material used for each part. Appendix C contains a better illustration of this.

Discussion of assembly, sub-assemblies, parts, drawings (examples)

The assembly includes the following parts necessary for the casting process to occur:

1) Well (ABS Material)
2) Runner (ABS Material)
3) Ingates (ABS Material)
4) Down sprue (ABS Material)
5) Riser(s) (ABS Material)
6) Two Flexors (ABS Material)
7) Matchplate (ABS Material)

There are two assemblies that represent the orientation of all these parts. These assemblies can be found in Appendix B, in drawing 20-0007 and drawing 20-0008. Drawing 20-0007 shows the assembly of parts with the matchplate whereas 20-0008 shows the assembly of parts without the matchplate. For both assemblies, it is important to note the there is an invisible parting. To help visualize where the parting line is, for drawing 20-0007 it is where the matchplate encounters the ABS material in both the cope and drag side. The down sprue and riser on the runner will be placed in the cope whereas the well, runner, and ingates will be placed in the drag. This is also true for drawing 20-0008 where the bottom of the down sprue and riser encounters the top face of the well and runner.

Testing Method

Introduction

The testing that will be produced in this project will be in the ability of the part to incorporate the clamp, micrometer, and existing strain gauge. This project's focus is in the dimensional aspects of the Flexor's pattern to complete a successful pour. The testing will also reflect the engineering outcome of the design requirements discussed earlier in this report.

Method/Approach

The testing method that will be conducted on this part will be after the Flexor has been poured and machining finishes have been made. Once this portion of this project is complete, the inclusion of the clamp, micrometer, and strain gauge will be added to the part. One testing outcome will be in the addition of these parts to the Flexor and the Flexor's ability to include these parts. The other testing outcome that will be conducted is in whether strain gauge data is able to be recorded in the accuracy of the existing strain gauge. There will be a comparison between the new Flexor to the existing one in order to conclude whether the improvement of the Flexor has been completed correctly.

Test Procedure description

This section will be a discussion of what the procedure of testing will be along with why these decisions in the testing process are being made. The procedure that is planned on being used for this project will involve a pass/fail strategy. As explained before, the testing will involve the successfulness of the attachment/performance of the clamp, micrometer, and strain gage components. The successfulness of this portion of the project will be determined by the stability in the components and that they perform the way that they were intended to. Another testing procedure that will be conducted after this portion of the Flexor will include testing the accuracy of the strain gauge readings. This is basically taking the first testing procedure one step further and conducting strain gauge readings on a cantilever beam to further ensure that the data readings are accurate and the function of the clamp and micrometer are successful.

Deliverables

There are a few stages that will take place in the testing of the Flexor. The incorporation of the clamp, micrometer, and strain gauge beam determined the pass/fail component of the Flexor. Leading up to that point, however, there needed to be an evaluation on the shrinkage of the Flexor to determine if the dimensional aspects of the Flexor would still be compatible before incorporating the clamp, micrometer, and strain gauge beam. There was machine finishes that also had to take place after the Flexor had been poured to help with the assembly of the remaining pieces.

Issues that have occurred in the process of testing have included slow shipping/communication with the outside foundry. Because this occurred, the Flexor was off schedule and evidently "pushed" the schedule back quite a bit. Unfortunately as well, the pattern used for the castings cracked and in some areas, broke off during the shipping process back to Central. To fix this, there will be efforts to adhere the broken pieces back onto the pattern. Another issue occurred due to lack of access of the machine shop on campus. Due to the campus being shut down, access has been very limited. In order to fix this issue, Jim will be on campus in order to complete any machining finishes necessary to the Flexor.

Budget

Discuss part suppliers, substantive costs and sequence or buying issues

Part supplier include material provided from Central Washington University's Mechanical Engineering Technology department, the casting process from an outside foundry, as well as the supplies and resources from Central Washington University" machine shop. Some issues that can occur in the budget section of this project can include multiple 3D prints, issues with dimensioning for the matchplate, and multiple pours for the final product. These issues can be solved by ensuring that the dimensioning and prints are as successful as possible to avoid having to redesign and print or buy more material afterwards.

As far as budget goes for the testing portion of this project, there have been no additional purchases. The equipment used for the testing procedures were either provided by Central Washington University such as a caliper while other testing equipment was used from home such as a scale. With that being said, there were no additional costs towards the testing that took place for the Flexor.

Determine labor or outsourcing rates & estimate costs

No labor costs are being associated with this project. Being in contact with Jim Justin has helped in the donation of pours by outsourcing to a foundry off campus. With this being said, there are no estimated labor costs due to the donations.

Labor

The labor that is involved in this project includes the design process (the entirety of this proposal), the making of the pattern, and assembling the ABS gating system to the matchplate. Most of the labor towards this project is involved in the casting process. Once the labor of the pattern is complete, the pattern will be sent to a foundry outside of Central Washington University where the casting portion of the project will be complete. Once the casting(s) come back to Central from the foundry, there will be more labor in completing the machining finishes on the products. The amount of labor (time spent) can be found in the Gantt Chart in Appendix E for the design portion of this project. The amount of labor that is contributed to the completion of this project is projected to be about the same amount of hours as the design process.

Estimate total project cost

The breakdown of cost for individual parts is found in the parts list of Appendix C. The total estimated cost for this project (without labor costs) is estimated to be $589.46. This is reasonable for this project because the cost of printing ABS here at Central Washington University is $6 per cubic in. When the entirety of the gating system is assembled the volume and the dollar amount adds up quickly; $573.48 to be exact. The cost in the entirety of the ABS gating system then gets added to the cost of the matchplate. The material and size for the matchplate that is needed comes out to be $15.98. Therefore, coming to a grand total of $589.46.

Over the course of the manufacturing quarter, there has been a change in the budget. As described above, there were estimated costs to be $589.46. Through the progression of the quarter, more and more material was able to be donated rather than purchased. For example, the ABS material that was being used per print was donated as there are no additional costs associated with a lab project. This helped to cut down the budget costs significantly. There was only a 0.1% portion of the budget used which ended up being the purchase of the matchplate. Therefore, this project was way under budget.

Funding source(s)

Funding sources will stem personally, from Central Washington University and from donations from outside sources. Most of the funding came from Central Washington University since the final product of the Flexors will be used for future labs here at Central in the MET department.

Schedule

PROJECT TITLE: Flexor Casting																												
Principal Investigator.: Courtney Lehrman																												
		Duration																										
TASK:	Description	Est.	Actua	%Con	S	October				November				Dec		January				February				March				Ap
ID		(hrs)	(hrs)																									
1	Proposal*			100																								
1a	Outline	1	2		x																							
1b	Intro	1	3		x																							
1c	Methods	2	13			x	x	x	x	x																		
1d	Analysis	25	31.5		x	x	x	x	x	x	x	x	x	x														
1e	Discussion	2	7					x	x	x	x	x	x															
1f	Parts and Budget	1	4					X	X	X	X	X	X	X														
1g	Drawings	20	19.5		X	X	X	X	X	X	X	X	x	x														
1h	Schedule	0.5	1.5								x	x	X	X														
1i	Summary & Appx	1	2										X	x														
	subtotal:	53.5	83.5																									
2	Analyses			100																								
2a	Dimensions based off Shrinkage	2	4		x	x																						
2b	Gating design part one	2	2.5		x	x																						
2c	Gating design part two	2	3			x	x																					
2d	Well, runner, ingate shape	2	1.5			x	x																					
2e	Aluminum heat flow	3	3				x	x	x	x																		
2f	Matchplate dimensions	3	3				x	x	x	x																		
2g	Volume of sand	1	1.5					x	x	x	x																	
2h	Matching dimensions for complete flexor	3	2					x	x	x	x																	
2i	Riser dimensions	2	2.5						x	x	x	x																
2j	Gating dimensions	2	2.5						x	x	x	x																
2k	Impulse of hammer on sand	2	3.5							x	x	x	x	x														
2l	Volume of feed metal	1	2.5							x	x	x	x	x														
	subtotal:	25	31.5																									
3	Documentation			100																								
3a	Original flexor part	0.5	1		x	x																						
3b	Flexor design	1	3		x	x																						
3c	Matchplate	0.5	1.5			x	x																					
3d	Gating system in drag	2	3			x	x	x	x	x																		
3e	Down sprue in cope	2	3				x	x	x	x																		
3f	Riser on runner in cope	1	3.5				x	x	x	x																		
3g	Assembly with matchplate	1	2					x	x	x	x																	
3h	Assembly without matchplate	1	2.5					x	x	x	x																	
	subtotal:	9	19.5																									
4	Proposal Mods			100																								
4a	Safety Hazard	0.5	2		x	x																						
4b	Budget Lists	1	3.5		x	x	x	x	x	x																		
4c	Part List	0.5	2		x	x	x	x	x																			
	subtotal:	2	7.5																									
7	Part Construction																											
7a	Buy matchplate material	0.5	0.5												X	X												
7b	Make matchplate	1	1												X	X												
7c	Manufacture 3D printed Runner	3	4														X	X										
7d	Manufacture 3D printed Ingates	3	4														X	X										
7e	Manufacture 3D printed downsprue	1.5	3													X	X											
7f	Manufacture 3D printed Flexor (2x)	2	3															X	X	X	X	X	X	X				
7g	Manufacture 3D printed Riser	1.5	3													X	X											
7h	Update Website	1	1																	X								
7i	SolidCast	2	2																	X								
	subtotal:	15.5	21.5																									
9	Device Construct																											
9a	Assemble Runner	1	4																		X	X	X	X	X	X		
9b	Assemble Ingates	1	4																		X	X	X	X	X	X		
9c	Assemble downsprue	0	0																									
9d	Assemble Flexors	1	4																		X	X	X	X	X	X	X	
9e	Take Dev Pictures	0.5	2																		X	X	X	X				
9f	Update Website	1	2																		X	X	X					
	subtotal:	4.5	16																									

The schedule is structured to illustrate the design, manufacturing and testing of the Flexor. The design portion of the project consisted of building the proposal and designing components needed for the pattern for the Flexor. There were roughly 135 hours that made up the design portion of this project. In the manufacturing stage, there has been roughly 30 hours put into the construction of the parts for this project. Some setbacks that have stemmed through the construction of this project has included issues with the 3D printer. Warping and incomplete prints have occurred in the printing of the Flexor causing this project to fall behind schedule. There is, however, still progress being made to the other components and the assembly of this project is underway. Once these parts are assembled, the pattern will be shipped to an outside source to complete the pours for the Flexor. Once these castings are received after pouring, machining will take place and the manufacturing portion of this project will be back on schedule.

After the completion of the manufacturing quarter, there was a total of roughly 64 hours spent on the manufacturing of the Flexor's pattern. These hours did not include the production of 3D parts as the prints averaged 12 hours to print at a time. These hours were intentionally left out in order to gauge the actual amount of time that was spent on constructing and assembling the parts.

Testing issues that created a fallback in the testing quarter's schedule included a slow shipping/retrieval process of the Flexor's castings. This setback was due to the unfortunate events of the coronavirus. Because of this setback, there was a large time spent waiting for the Flexors to be shipped back to Central Washington University. Upon retrieval of the castings, there then needed to be a wait time for the castings to be machined to the desired finish as well as the inclusion of the clamp and micrometer attachment pieces. Once these were complete, the Flexor was then ready to be completely assembled with a clamp and micrometer as well as a completion of the testing evaluation.

Project Management

Human Resources

The support of this project could not have been completed without the help of Jim Justin, Matt Burvee, Dr. Johnson, Professor Pringle, Dr. Choi, and Mechanical Engineering Technology's students. With the collaboration of these sources, the project was then able to be successful. All levels of experience regarding the casting process and multiple view points helped to shape the success of this project. Without the resources from Jim Justin, there would have been more difficulty in finding foundry/pattern resources.

Physical Resources

Physical resources in support of this project include a mill, drill press, grinder, a foundry, 3D printer, and every component in the casting process. All these resources listed stem from Central Washington University. There is an emphasis on the casting process and machining processes for this project as they are the main scope in the making of the Flexors.

Soft Resources

Solidworks is the main support in the Flexor's drawings for each component. This software was also essential for volumetric and dimensional analysis to assist the design process of the Flexor and its components. Solidworks not only helps with the analysis of parts, but it also provides ways to make engineering drawings to illustrate parts in a technical way. Web support was used to verify calculations to ensure that they were accurate and consistent in the design of the Flexor.

Financial Resources

As far as financial resources go, there is one main source of donations has been included into this project. Jim Justin, President of Puget Sound Pattern Works has generously supported this project with the donation of pattern making based off this projects Flexor drawings as well as the casting of the Flexor itself. These donations help to support the improvement of this project.

Discussion

Design Evolution / Performance Creep

The design of this project stemmed from an existing strain gauge base from Central Washington University's Mechanical Engineering Technology department. There has been a demand for more Flexor strain gauge bases for not only demonstration purposes but for applicable reasons such as use in labs. With an existing strain gauge, dimensions were able to be easily analyzed and evaluated towards the improvement of the project. The original design of the project has a micrometer end that has a "lip" that had to be removed for the design of the casting. This then lead to the inclusion of another support for a micrometer attachment once the Flexor is poured. Once the shape of the Flexor was determined, then the dimensional aspect of the gating system could be determined. So as far as the design goes, there is a major improvement in the shape and analysis towards the casting process. There will be more of an evolution in the building process of this project as there will be redesigns made as parameters of the product changes.

Project Risk analysis

Some technical risks that happened during the construction of the Flexor included the lack of access to machines. One example of this is not having access to the machine shop at Central Washington University due to the lack of instructors in the classroom itself.

Another example is faulty dimensional calculations. This meant that a dimension in a drawing or analysis is either incorrect or inefficient. Placement of the 3D prints onto the matchplate can also take part in faulty dimensional calculations. This would be due to a misplacement or misuse of adhesive material while joining the 3D prints to the matchplate. During a practice assembly of parts, the 3D prints had a tendency to move while being pressed into place. Because there is a large tolerance on the Flexor pieces themselves, it should not be too large of an issue when it comes to the pour.

Another technical risk that has occurred was during the shipping process of the Flexor to and from the outside foundry source. Upon receiving the Flexors that have been poured, as well as the pattern, it became evident that the pattern had been mishandled during the shipping process back. This observation was made due to the casting coming back complete but the pattern did not. This is unfortunate but there will be efforts made to attach the pieces of the 3D prints back together that were broken off due to the shipping.

A final technical risk that occurred involved the unfortunate event of Coronavirus. With resources shut down such as on campus machine shop and foundry, there was a difficult time in being able to meet requirements that were made during the design process of this project. There was also a setback in the scheduling during this time as there was quite a big wait time for the shipping of the pattern and the castings to return on campus.

Successful

The completion of the Flexor's pattern was successful. All components of the 3D prints involving the Flexor's gating design was successful towards the end of the manufacturing quarter and was then able to be assembled with the use of bondo adhesive and epoxy. The pattern was sent to an outside foundry where they successfully poured the castings. These castings were then sent back to campus where they were machined to remove flashing and to incorporate the clamp and micrometer attachment pieces that will be used to help evaluate the successfulness of the Flexor further.

The incorporation of the clamp and micrometer attachment pieces was vital to determining the success of the Flexor project. Without these pieces, there would not be a functioning Flexor. In order to achieve the success of this project, the help of Jim Helsius and Professor Pringle was needed in order to arrange that the machining steps were in place to produce an assembled and successful Flexor.

Project Documentation

Project documentation involves the 12 analyses, Drawing tree, 8 drawings and this proposal itself. All aspects of this project are documented in some way, shape, and form to clearly express all design aspects that follow in the completion of this product. There are many sketches and notes that are associated with the final products of documentation as they are all in an engineering sketchbook that has been kept on hand throughout the progression of this report.

Next phase

The next phase of this project includes collaboration with outside sources for the manufacturing of the Flexors. This will possibly involve some redesign aspect as well as sending and receiving sample products to help improve the design further. Once the manufacturing of the castings are completed, then there will be a machining process involved to help finish the part. Once the pattern has been assembled and the manufacturing has been completed, this project can then advance to the testing portion.

Conclusion

This project will be consisted of designing, building, and testing of a Flexor Strain Gauge Base. This includes the design and redesign of the Flexor's existing dimensions in order to achieve success in the manufacturing portion of the project. The casting process will be used for the completion of this project. Upon retrieval of the castings, the Flexor can then be evaluated for the success in the incorporation of the micrometer and clamp. The purpose of this project is to increase the number of flexor strain gauge bases for use in CWU Mechanical Engineering lab classes.

Important analyses that contribute to the success of this project includes:

- Flask and Gating Design
- Matchplate Design
- Gating Dimensions
- Shrinkage Allowance

While analyzing the components of this Flexor project, it is important to recalculate dimensions or additional calculations in order to ensure that the pour/casting will be successful. With these analyses taken into consideration this project can then advance the design and manufacturing process of this project.

The predicted performance of the Flexor is for the Flexor to be able to incorporate a micrometer and clamp for accurate testing of pre-existing strain gauges. The actual performance will be rated later in the testing process of this project. This process will include the manufacturing/assembly of the micrometer and clamp to the castings upon retrieval.

Acknowledgements

Acknowledgements towards the support of this project go to Jim Justin, Matt Burvee, Central Washington University's machine shop, the Mechanical Engineering Technology faculty and students. Without these helpful resources and interactions, the project would be more difficult to complete. The support that has been given towards this project has been incredible and much appreciated.

Appendix A- Analysis

Figure A-1: Shrinkage Allowance

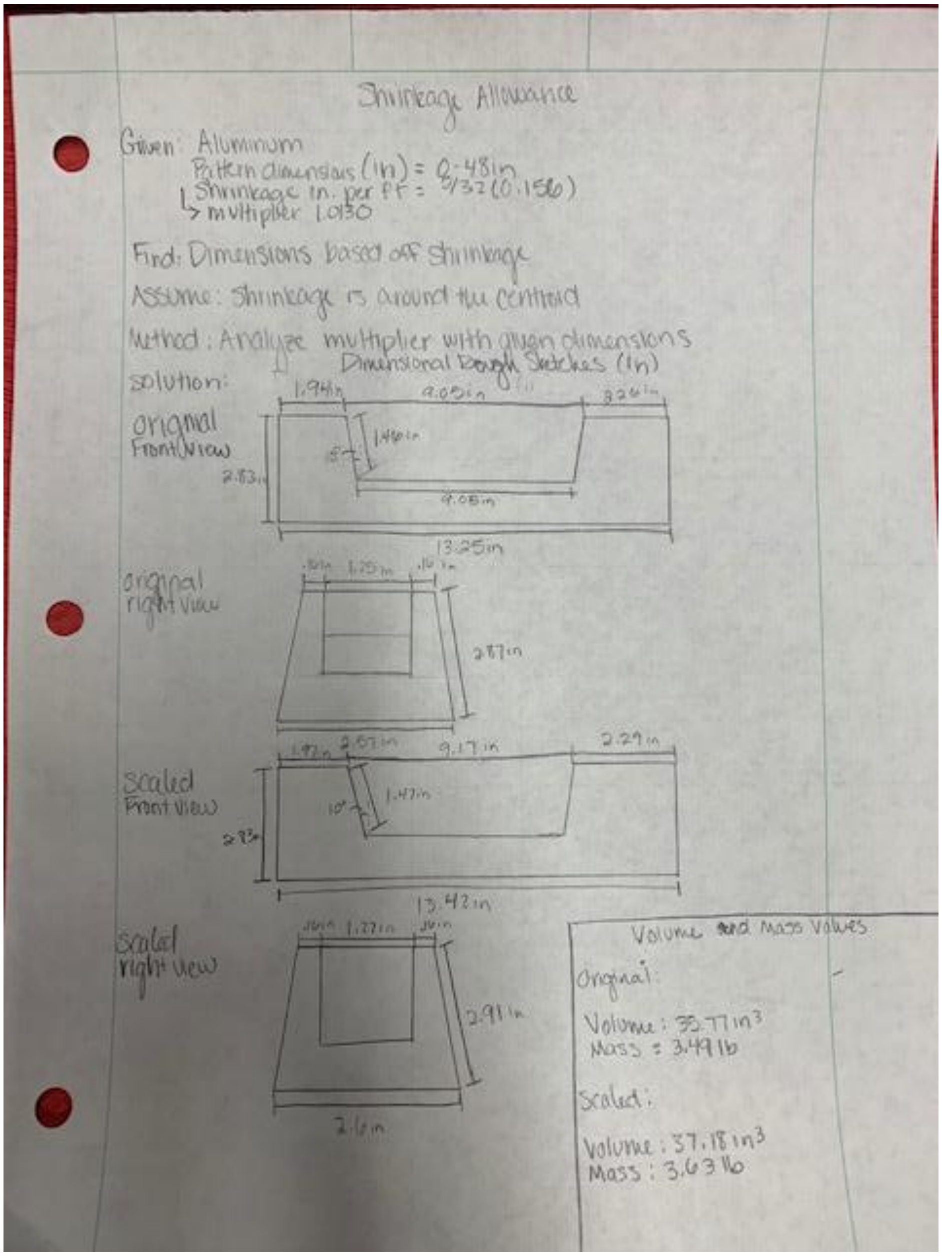


Figure A-2: Flask and Gating Design

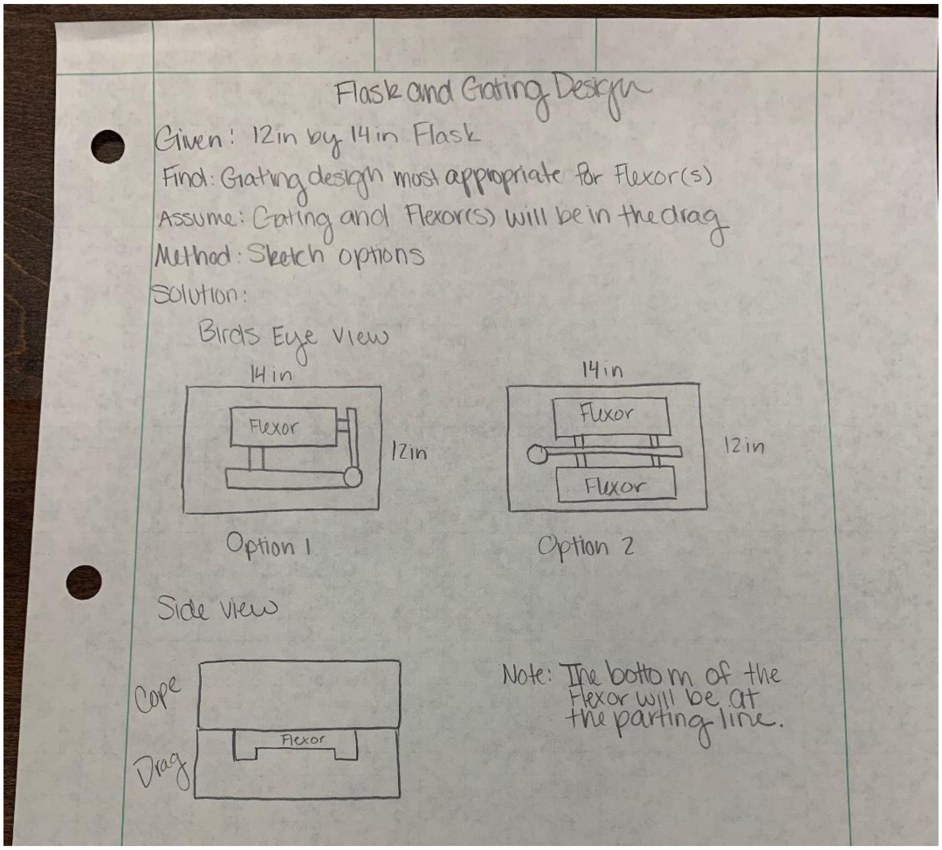


Figure A-3: Continuation of Gating Design

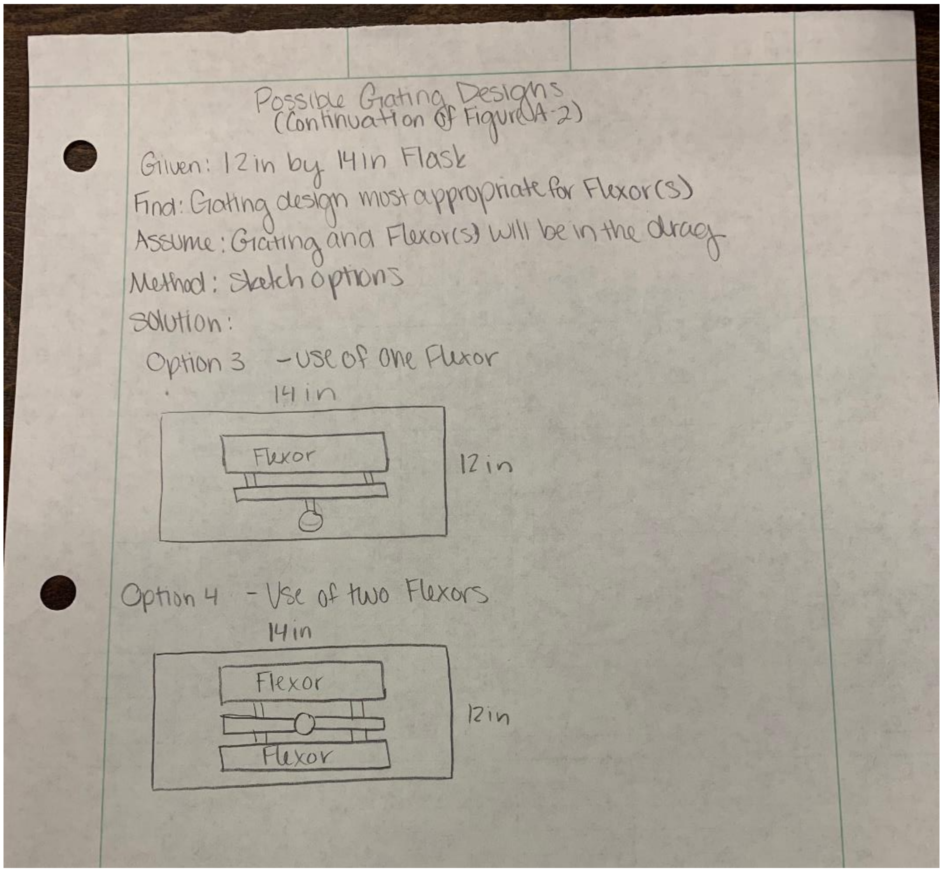


Figure A-4: Gating Design

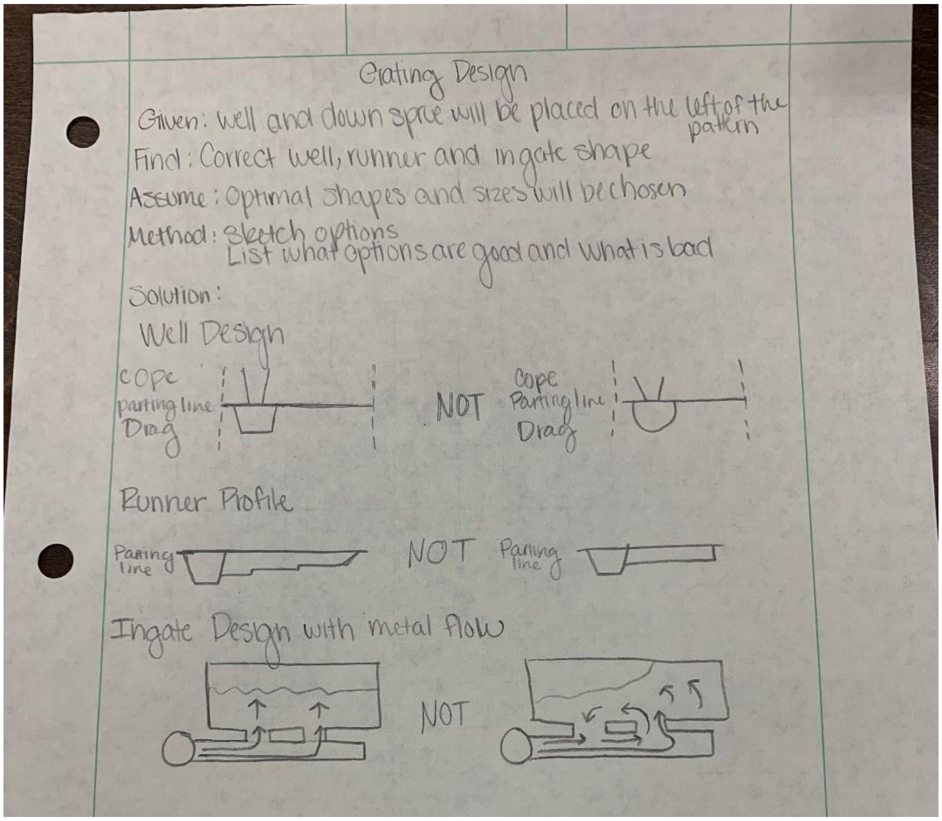
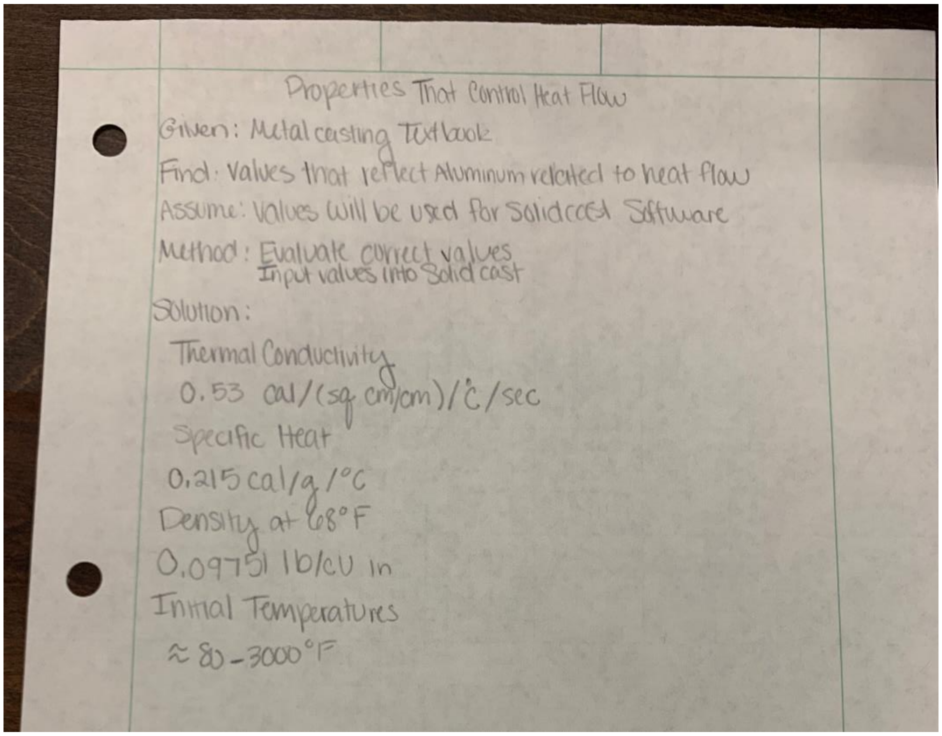


Figure A-5: Properties for SolidCast



Properties That Control Heat Flow

Given: Metal casting Textbook

Find: Values that reflect Aluminum related to heat flow

Assume: Values will be used for Solidcast Software

Method: Evaluate correct values
Input values into Solid cast

Solution:

Thermal Conductivity

0.53 cal/(sq cm/cm)/°C/sec

Specific Heat

0.215 cal/g/°C

Density at 68°F

0.09751 lb/cu in

Initial Temperatures

≈ 80 - 3000°F

Figure A-6: Matchplate Design

Match Plate Design

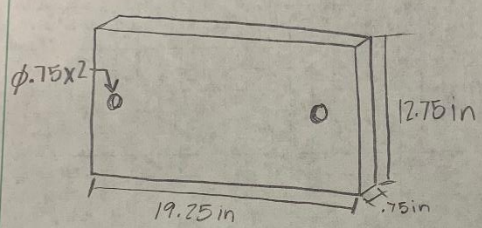
Given: Pine material

Find: mass, volume, and Dimensions of Matchplate

Assume: Dimensions are compatable with a 12in by 14in Flask

Method: Sketch Matchplate
Apply dimensions
Analyze weight and volume

Solution:



Volume values

Volume of Matchplate without holes

$V = (19.25in \times 12.75in \times .75in)$

$\boxed{V = 184.08\,in^3}$

volume of matchplate with holes

$\boxed{V = 183.42\,in^3}$

Solid works Calculated mass

$\boxed{Mass = 2.25\,lbs}$

Figure A-7: Volume of Sand

Volume of Sand

Given: 12in by 14in Flask

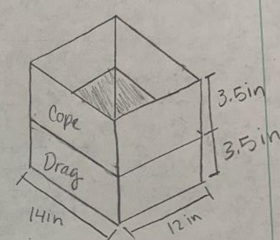
Find: Volume of sand compatible with 12in by 14in Flask

Assume: Green sand
height of cope and drag are 3.5in each

Method: Sketch Flask
Apply dimensions
Calculate volume based off existing Flask and Parts

Solution:

Flask Dimensions



Volume of Flexor (V_p)

$V_p = 35.77 in^3$

$2V_p = 2(35.77 in^3)$

$\boxed{2V_p = 71.54 in^3}$

Volume of Cope and Drag (V_T)

$V_{C,D} = (3.5 in \times 14 in \times 12 in)$

$V_{C+D} = 588 in^3$ (each

$\boxed{V_T = 1176 in^3}$

Volume values for gating system

Vol. of downsprue: $\boxed{4.60 in^3}$
Vol. of Riser: $\boxed{5.58 in^3}$
Vol. of gating in drag: $\boxed{11.07 in^3}$

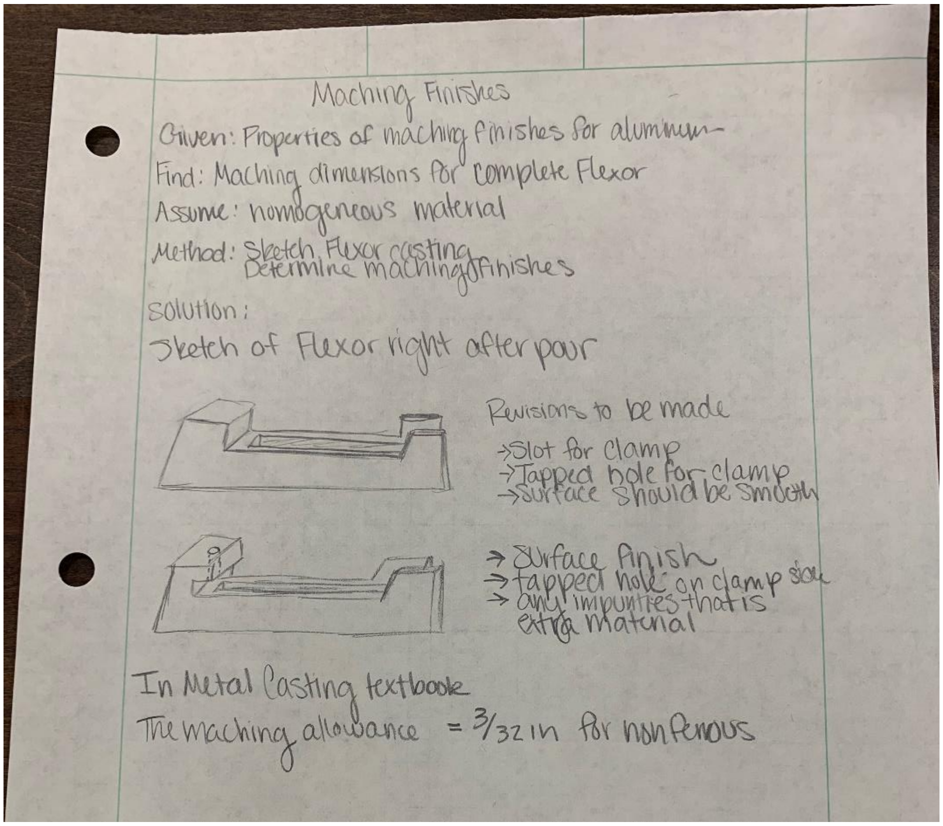
Volume of sand =>

Total vol. − vol of 2 Flexors − vol. downsprue. − vol. riser − vol of gating in drag

$1176 in^3 - 71.54 in^3 - 4.60 in^3 - 5.58 in^3 - 11.07 in^3$

$\boxed{\text{Volume of sand} = 1083.21 in^3}$

Figure A-8: Machining Finishes



Maching Finishes

Given: Properties of maching finishes for aluminum

Find: Maching dimensions for complete Flexor

Assume: homogeneous material

Method: Sketch Flexor casting
Determine machining finishes

Solution:

Sketch of Flexor right after pour

Revisions to be made
→ Slot for clamp
→ Tapped hole for clamp
→ Surface should be smooth

→ Surface finish
→ tapped hole on clamp side
→ any impurities that is extra material

In Metal Casting textbook

The maching allowance = 3/32 in for nonferrous

Figure A-9: Riser Design

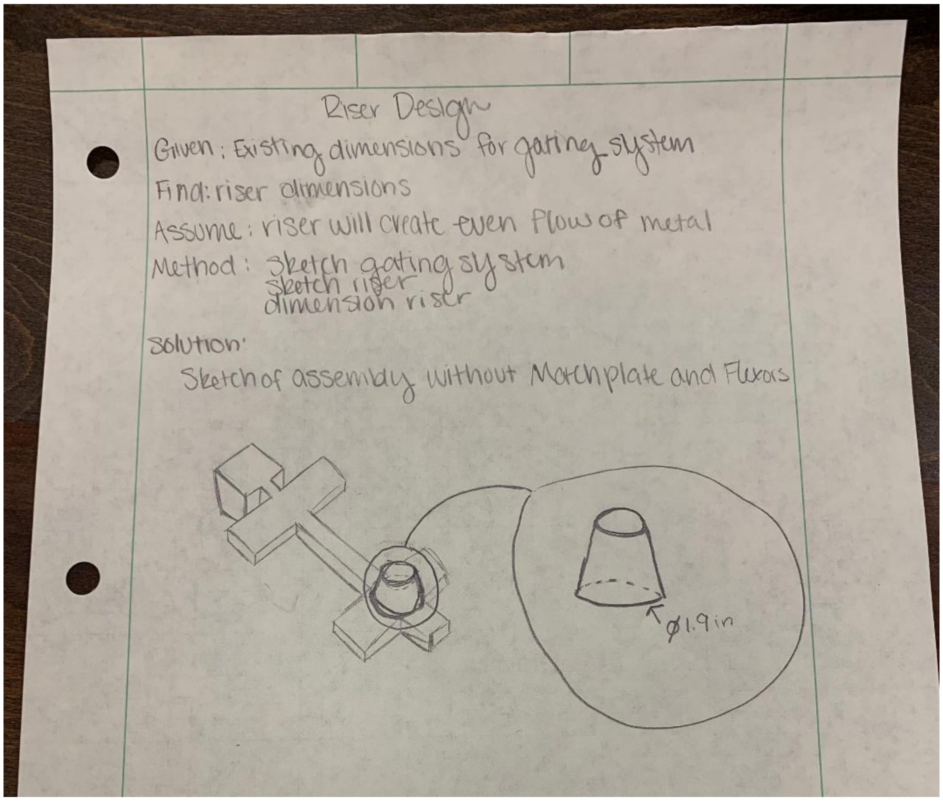


Figure A-10: Gating Dimensions

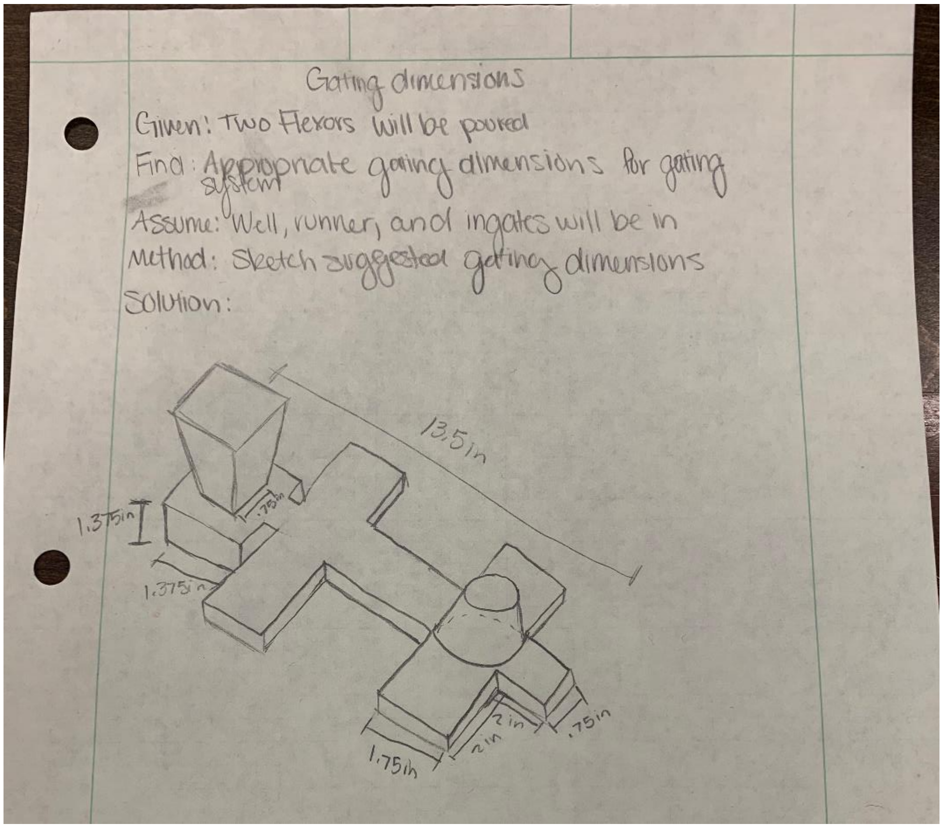
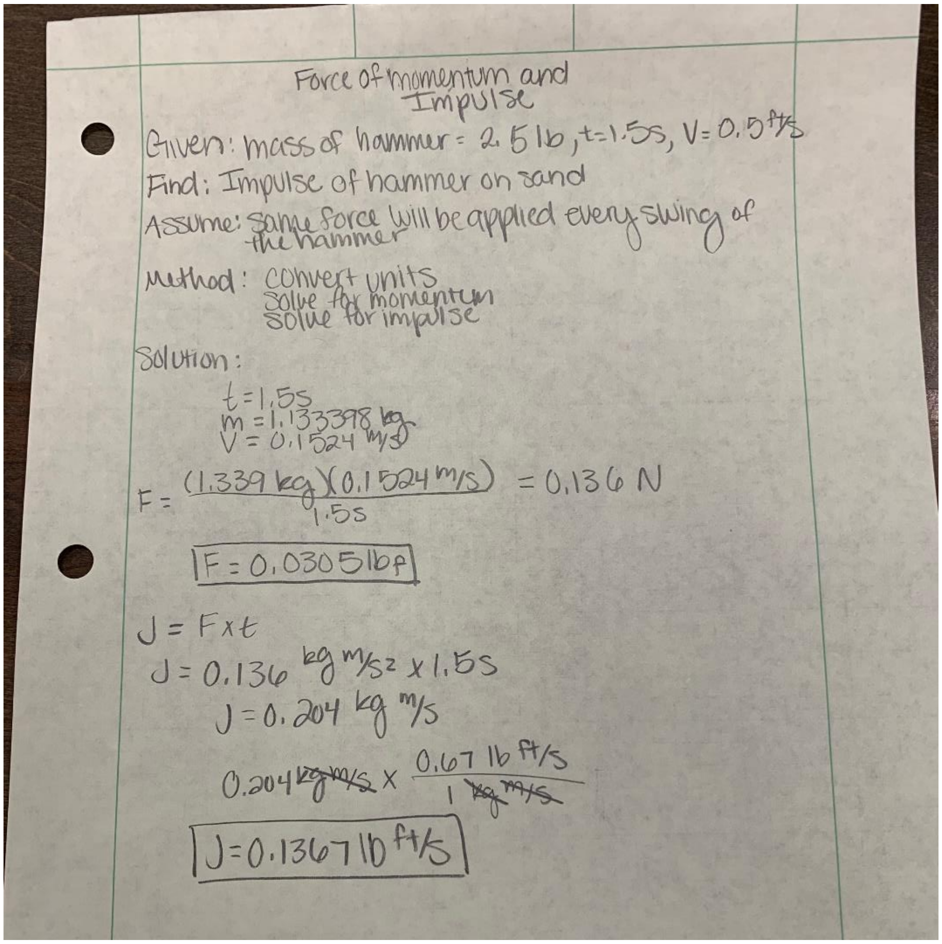


Figure A-11: Momentum and Impulse of Hammer on Sand



Force of momentum and Impulse

Given: mass of hammer = 2.5 lb, t = 1.5s, V = 0.5 ft/s

Find: Impulse of hammer on sand

Assume: same force will be applied every swing of the hammer

Method: convert units
solve for momentum
solve for impulse

Solution:

$t = 1.5s$
$m = 1.133398\ kg$
$V = 0.1524\ m/s$

$$F = \frac{(1.339\ kg)(0.1524\ m/s)}{1.5s} = 0.136\ N$$

$$\boxed{F = 0.0305\ lbf}$$

$J = F \times t$

$J = 0.136\ kg\ m/s^2 \times 1.5s$

$J = 0.204\ kg\ m/s$

$$0.204\ \cancel{kg\ m/s} \times \frac{0.67\ lb\ ft/s}{1\ \cancel{kg\ m/s}}$$

$$\boxed{J = 0.13671\ lb\ ft/s}$$

Figure A-12: Volume of Feed Metal

Volume of Feed Metal

Given: Material is Aluminum alloy

Find: Volume of Feed metal (V_F)

Assume: homogeneous material

Method: Gather values for aluminum alloy

Solution:

$$V_F = \frac{\text{Casting weight} \times \text{feed metal \%}}{\text{Density of alloy}}$$

From Metal casting Textbook

Feed metal %: Al-Si with Total volumetric shrinkage % of 3.5%

Density of Alloy: 0.1 lb/in^3

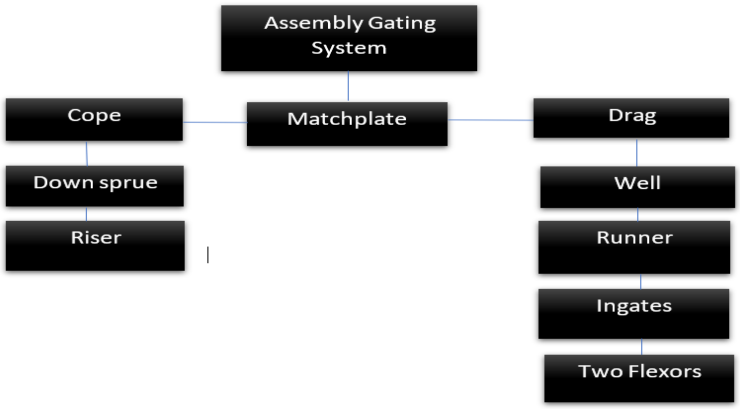
Casting weight: 3.63 lbs

$$V_F = \frac{(3.63 \cancel{\text{lbs}})(3.5\%)}{0.1 \cancel{\text{lb}}/\text{in}^3} = 1.2705 \text{ in}^3$$

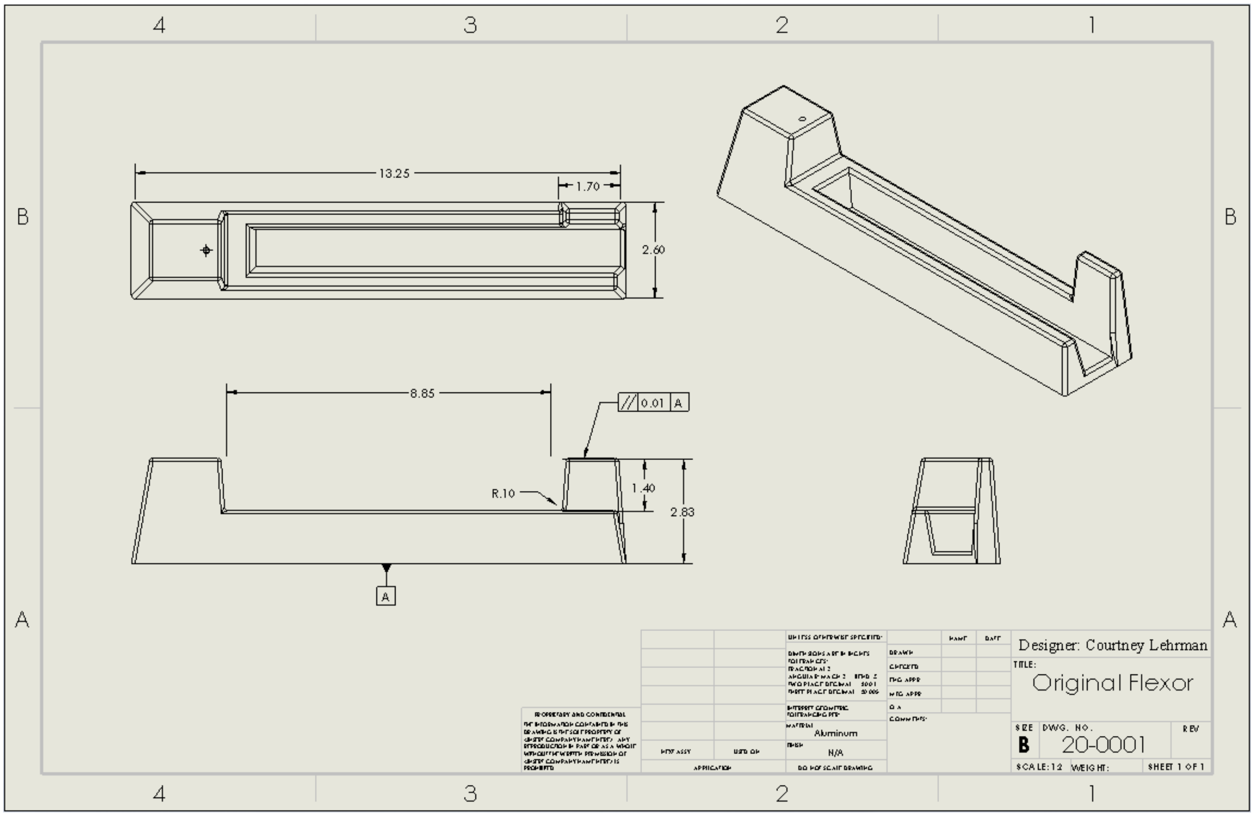
$$\boxed{V_F = 1.2705 \text{ in}^3}$$

Appendix B- Drawings

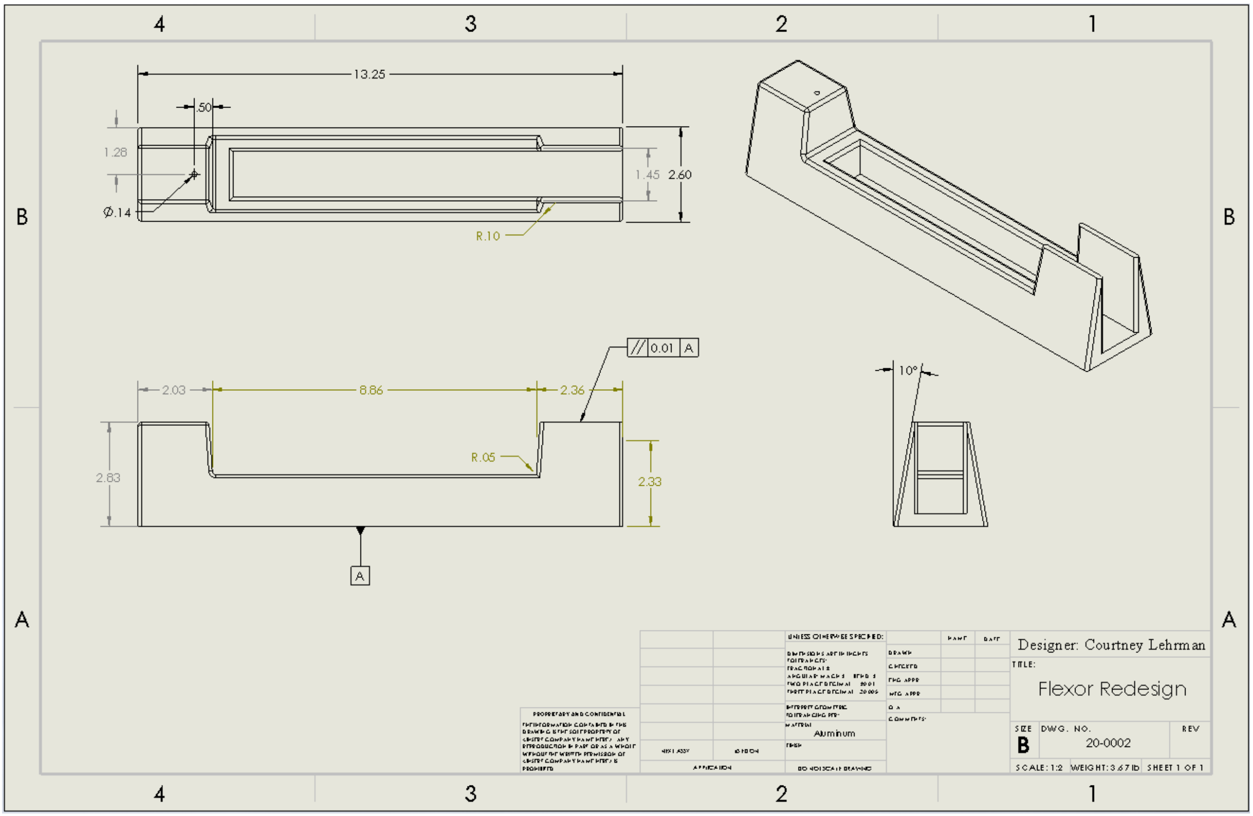
Drawing Tree



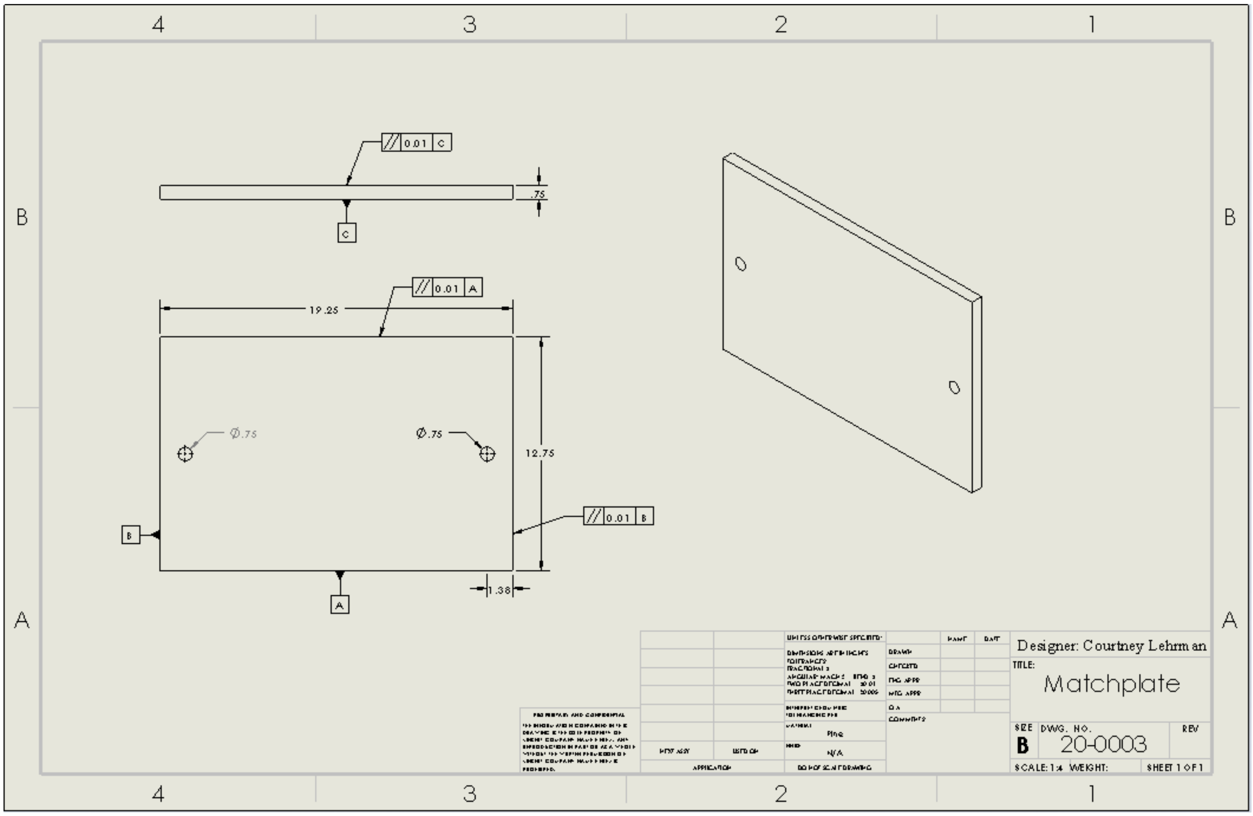
Drawing B-1: Flexor Part Original



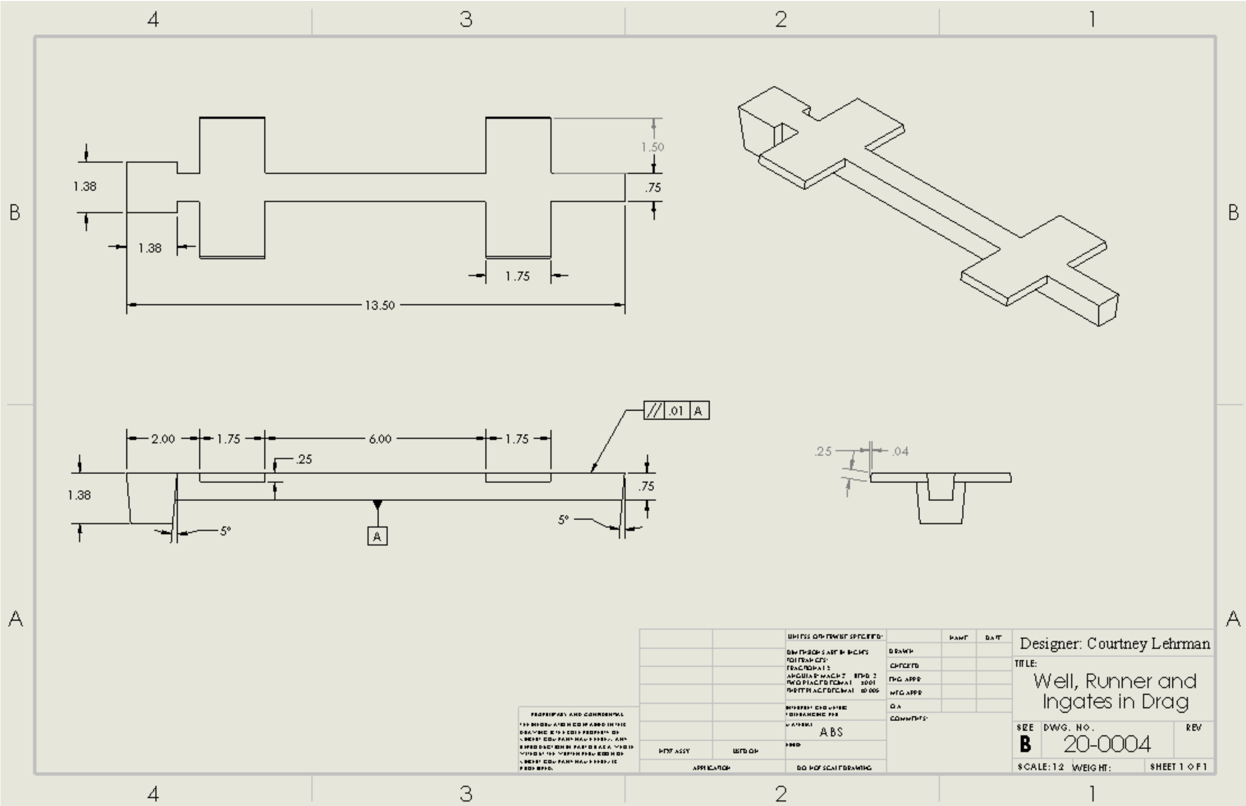
Drawing B-2: Flexor Design



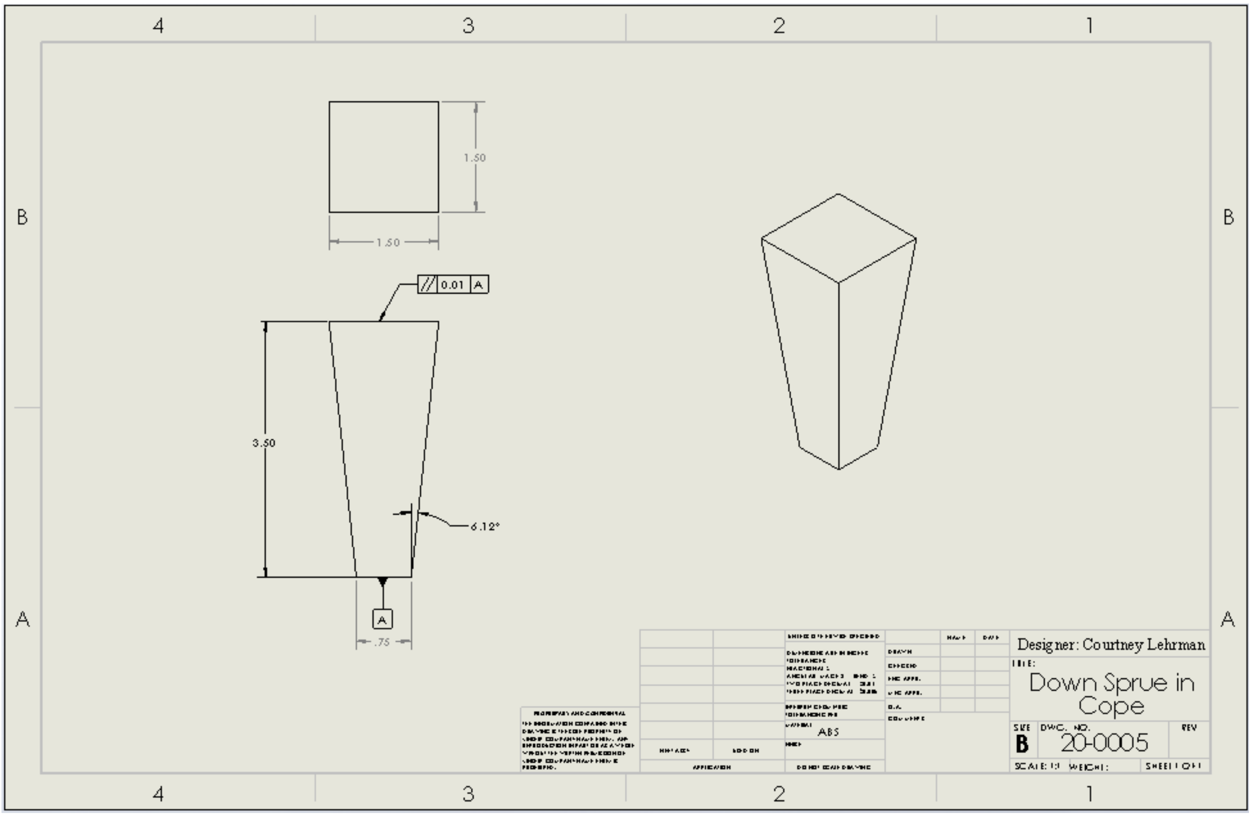
Drawing B-3: Matchplate



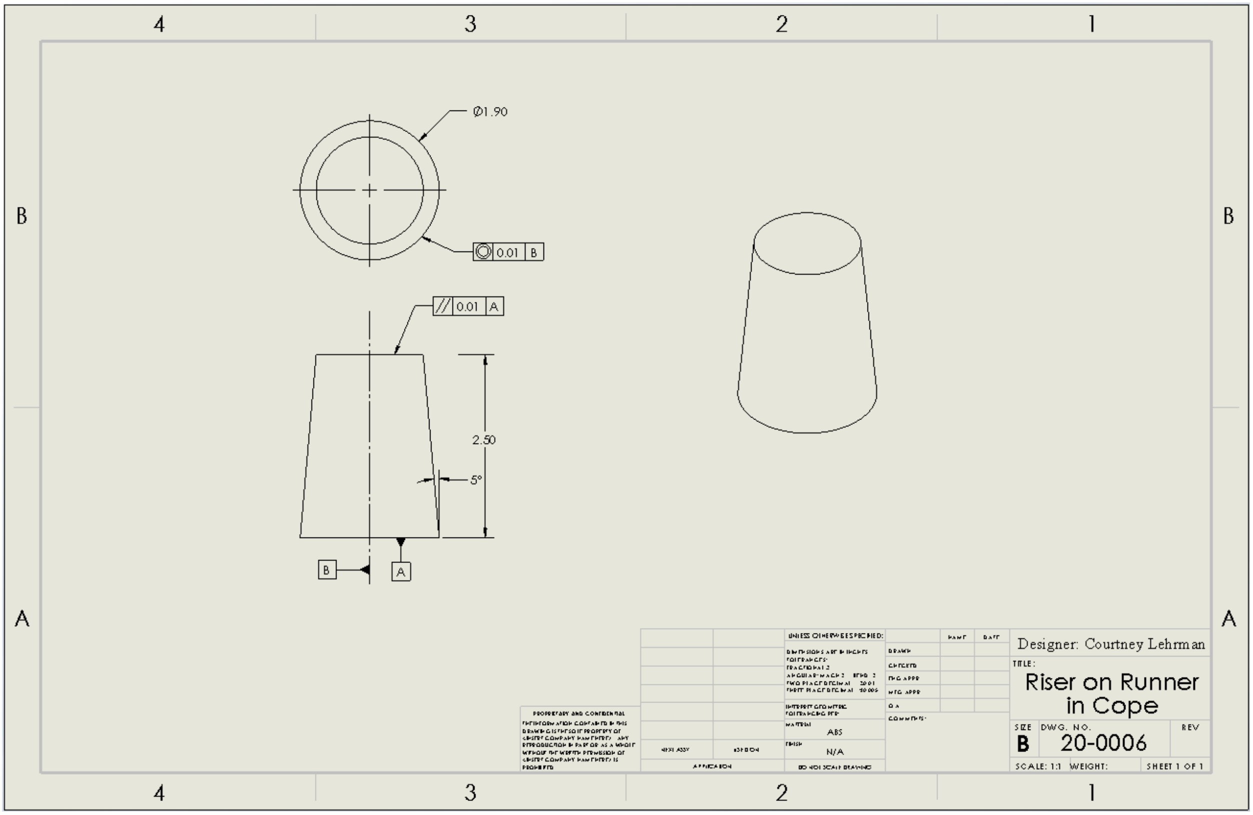
Drawing B-4: Gating System in Drag: Well, Runner, and Ingates



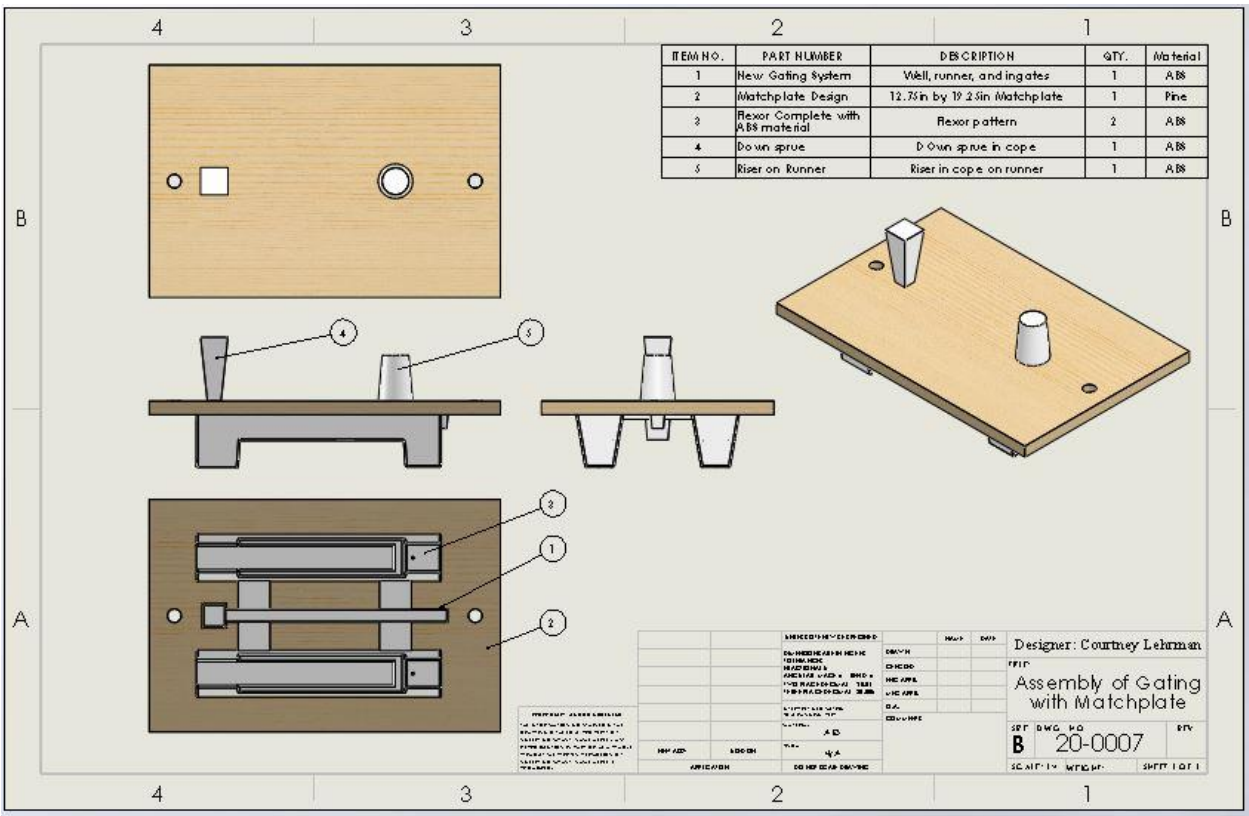
Drawing B-5: Down Sprue in Cope



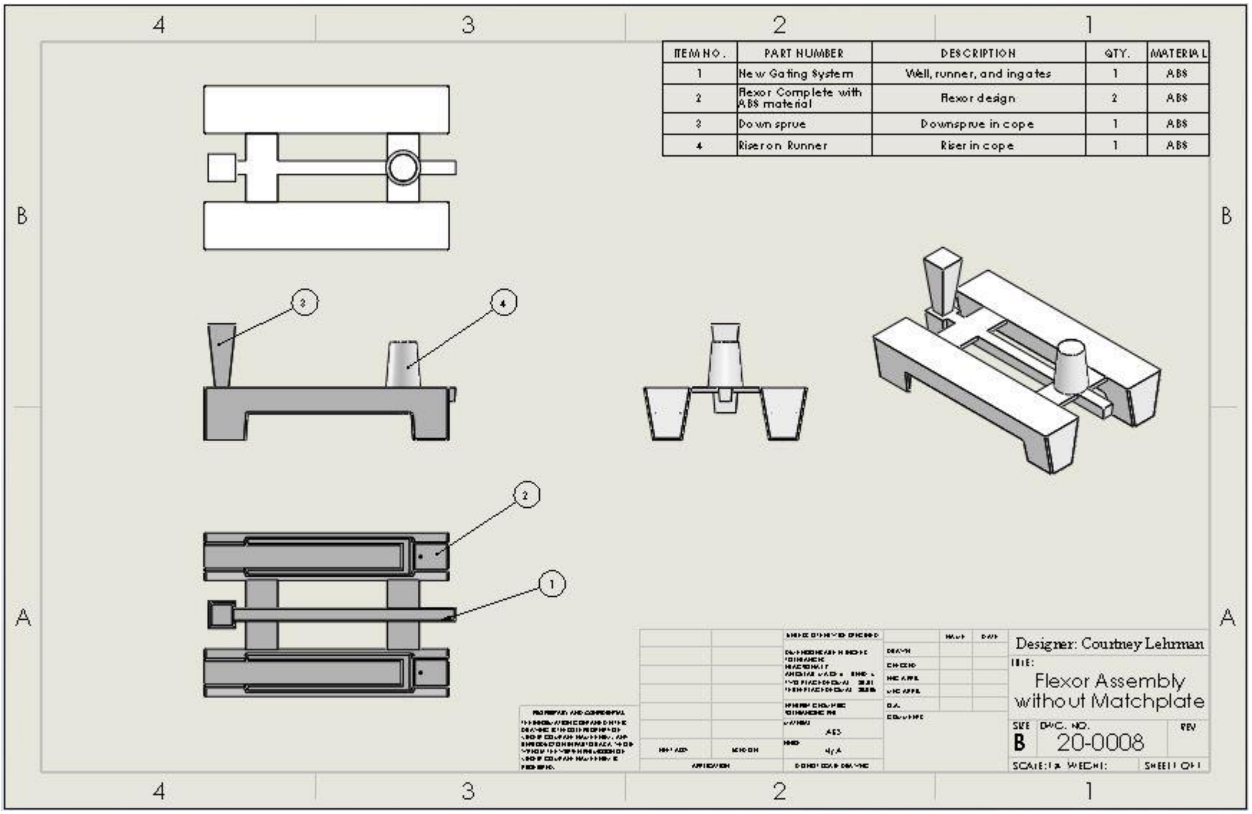
Drawing B-6: Riser on Runner in Cope



Drawing B-7: Assembly of Gating with Flexors and Matchplate



Drawing B-8: Assembly of Gating with Flexors without Matchplate



Appendix C- Parts List

Based off analyses and drawings, here is a list of parts that will be needed to complete this project.

ITEM	QTY	Description	PART NUMBER	MATERIAL
1	1	Well	P-001	ABS
2	1	Runner	P-002	ABS
3	4	Ingates	P-003	ABS
4	1	Down sprue	P-004	ABS
5	1	Riser(s)	P-005	ABS
6	2	Flexor	P-006	ABS
7	1	Matchplate	P-007	Pine

Appendix D- Budget

Estimated Budget:

ITEM	QTY	DESCRIPTION	PART NUMBER	MATERIAL	COST	VOL. OF PART	TOTAL COST OF PART	SOURCE
1	1	Well	10-001	ABS	\$6 per in^3	$1.5in^3$	\$9.00	Central Washington University
2	1	Runner	10-002	ABS	\$6 per in^3	$6.90in^3$	\$41.40	Central Washington University
3	4	Ingates	10-003	ABS	\$6 per in^3	$2.64in^3$	\$15.84	Central Washington University
4	1	Down sprue	10-004	ABS	\$6 per in^3	$4.60in^3$	\$27.6	Central Washington University
5	1	Riser(s)	10-005	ABS	\$6 per in^3	$5.58in^3$	\$33.48	Central Washington University
6	2	Flexor	10-006	ABS	\$6 per in^3	$74.36in^3$	\$446.16	Central Washington University
7	1	Matchplate	#856050	Pine	\$15.98	----	\$15.98	Lowes

Total Cost: \$589.46

Actual Budget:

ITEM	QTY	DESCRIPTION	PART NUMBER	MATERIAL	COST	VOL. OF PART	TOTAL COST OF PART	SOURCE
7	1	Matchplate	#856050	Pine	$15.98	----	$15.98	Lowes

Total Cost: $15.98

Appendix E- Gantt Chart

Estimated and actual schedule for design quarter:

PROJECT TITLE: Flexor Casting
Principal Investigator.: Courtney Lehrman

TASK: ID	Description	Duration Est. (hrs)	Actua (hrs)	%Con	S / October / November / Dec / January / February / March / April / May / June
1	Proposal*			100	
1a	Outline	1	2		x
1b	Intro	1	3		x
1c	Methods	2	13		x x x x x
1d	Analysis	25	31.5		x x x x x x x x x x
1e	Discussion	2	7		x x x x x x
1f	Parts and Budget	1	4		X X X X X X X
1g	Drawings	20	19.5		X X X X X X X X x x
1h	Schedule	0.5	1.5		x x X X
1i	Summary & Appx	1	2		X x
	subtotal:	53.5	83.5		
2	Analyses			100	
2a	Dimensions based off Shrinkage	2	4		x x
2b	Gating design part one	2	2.5		x x
2c	Gating design part two	2	3		x x
2d	Well, runner, ingate shape	2	1.5		x x
2e	Aluminum heat flow	3	3		x x x x
2f	Matchplate dimensions	3	3		x x x x
2g	Volume of sand	1	1.5		x x x x
2h	Matching dimensions for complete flexor	3	2		x x x x
2i	Riser dimensions	2	2.5		x x x x
2j	Gating dimensions	2	2.5		x x x x
2k	Impulse of hammer on sand	2	3.5		x x x x x
2l	Volume of feed metal	1	2.5		x x x x x
	subtotal:	25	31.5		
3	Documentation			100	
3a	Original flexor part	0.5	1		x x
3b	Flexor design	1	3		x x
3c	Matchplate	0.5	1.5		x x
3d	Gating system in drag	2	3		x x x x x
3e	Down sprue in cope	2	3		x x x x
3f	Riser on runner in cope	1	3.5		x x x x
3g	Assembly with matchplate	1	2		x x x x
3h	Assembly without matchplate	1	2.5		x x x x
	subtotal:	9	19.5		
4	Proposal Mods			100	
4a	Safety Hazzard	0.5	2		x x
4b	Budget Lists	1	3.5		x x x x x x x
4c	Part List	0.5	2		x x x x x
	subtotal:	2	7.5		

Estimated schedule for design and manufacturing quarter:

7	Part Construction		
7a	3D print gating system in drag (well, runne	10	0
7b	3D print down sprue	3	0
7c	3D print riser on runner	2	0
7d	3D print 2 Flexors	20	0
7e	Cut out dimensions for matchplate	1	0
	subtotal:	36	0
9	Device Construct		
9a	Assemble gating system in drag	2	0
9b	Assemble gating system in the cope	1	0
9c	Assemble gating system with matchplate	2	0
9d	Take Dev Pictures	1	0
9e	Update Website	1	0
	subtotal:	7	0
10	Device Evaluation		
10a	Ability to incorporate clamp	0.5	0
10b	Clean finish on casting	0.5	0
10c	Ability to incorporate micrometer	0.5	0
10d	Make test sheets	2	0
10e	Plan analyses	5	0
10f	Take Testing Pics	1	0
10g	Update Website	2	0
	subtotal:	11.5	0
11	495 Deliverables		
11a	Get Report Guide	3	0
11b	Make Rep Outline	1	0
11c	Write Report	4	0
11d	Make Slide Outline	3	0
11e	Create Presentation	5	0
11f	Update Website	3	0
11g	Project CD*	1	0
	subtotal:	20	0
	Total Est. Hours=	164	2023
Labor$	100	16400	
Note:	Deliverables*		
	Draft Proposal		
	Analyses Mod		
	Document Mods		
	Final Proposal		
	Part Construction		
	Device Construct		
	Device Evaluation		
	495 Deliverables		

=Total Actual Hrs

Actual schedule for manufacturing quarter:

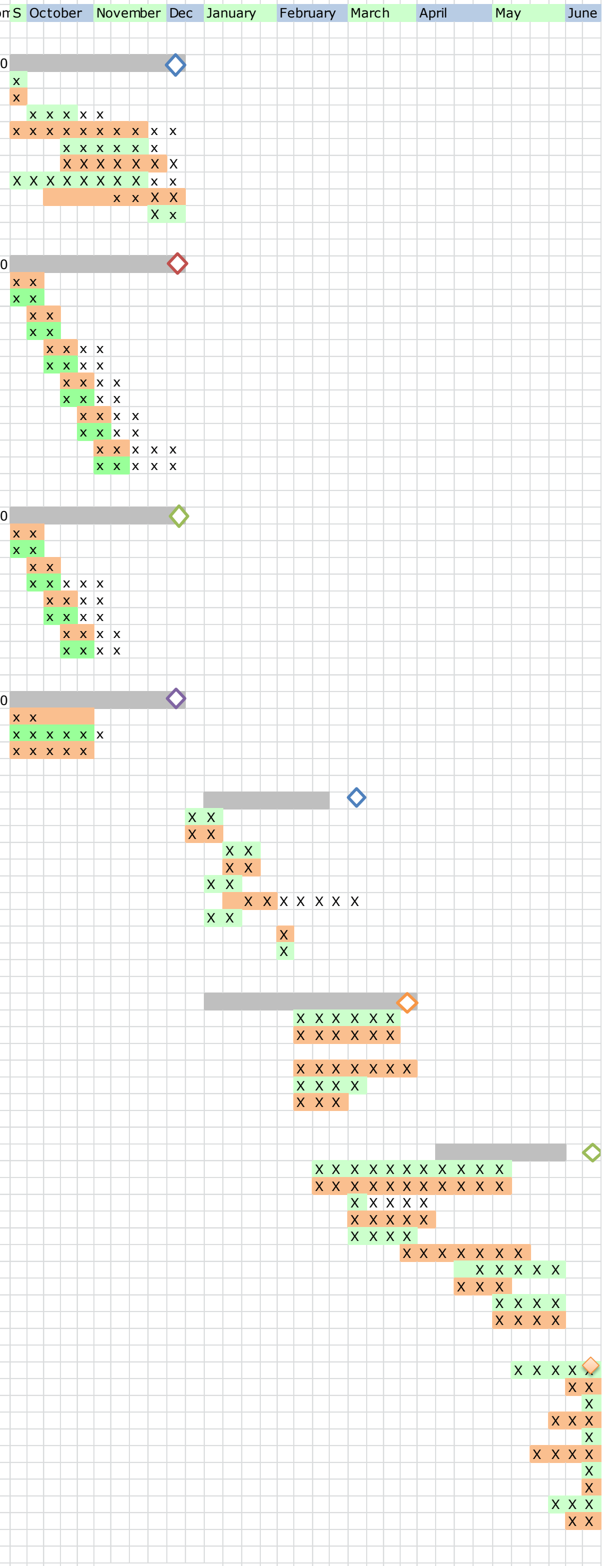
PROJECT TITLE: Flexor Casting
Principal Investigator.: Courtney Lehrman

TASK: ID	Description	Duration Est. (hrs)	Actua (hrs)	%Com	S / October / November / Dec / January / February / March
1	Proposal*			100	
1a	Outline	1	2		x
1b	Intro	1	3		x
1c	Methods	2	13		x x x x x
1d	Analysis	25	31.5		x x x x x x x x x x
1e	Discussion	2	7		x x x x x x
1f	Parts and Budget	1	4		X X X X X X X
1g	Drawings	20	19.5		X X X X X X X X x x
1h	Schedule	0.5	1.5		x x X X
1i	Summary & Appx	1	2		X x
	subtotal:	53.5	83.5		
2	Analyses			100	
2a	Dimensions based off Shrinkage	2	4		x x
2b	Gating design part one	2	2.5		x x
2c	Gating design part two	2	3		x x
2d	Well, runner, ingate shape	2	1.5		x x
2e	Aluminum heat flow	3	3		x x x x
2f	Matchplate dimensions	3	3		x x x x
2g	Volume of sand	1	1.5		x x x x
2h	Matching dimensions for complete flexor	3	2		x x x x
2i	Riser dimensions	2	2.5		x x x x
2j	Gating dimensions	2	2.5		x x x x
2k	Impulse of hammer on sand	2	3.5		x x x x x
2l	Volume of feed metal	1	2.5		x x x x x
	subtotal:	25	31.5		
3	Documentation			100	
3a	Original flexor part	0.5	1		x x
3b	Flexor design	1	3		x x
3c	Matchplate	0.5	1.5		x x
3d	Gating system in drag	2	3		x x x x x
3e	Down sprue in cope	2	3		x x x x
3f	Riser on runner in cope	1	3.5		x x x x
3g	Assembly with matchplate	1	2		x x x x
3h	Assembly without matchplate	1	2.5		x x x x
	subtotal:	9	19.5		
4	Proposal Mods			100	
4a	Safety Hazard	0.5	2		x x
4b	Budget Lists	1	3.5		x x x x x x x
4c	Part List	0.5	2		x x x x x
	subtotal:	2	7.5		
7	Part Construction				
7a	Buy matchplate material	0.5	0.5		X X
7b	Make matchplate	1	1		X X
7c	Manufacture 3D printed Runner	3	4		X X
7d	Manufacture 3D printed Ingates	3	4		X X
7e	Manufacture 3D printed downsprue	1.5	3		X X
7f	Manufacture 3D printed Flexor (2x)	2	3		X X X X X X X
7g	Manufacture 3D printed Riser	1.5	3		X X
7h	Update Website	1	1		X
7i	SolidCast	2	2		X
	subtotal:	15.5	21.5		
9	Device Construct				
9a	Assemble Runner	1	4		X X X X X X
9b	Assemble Ingates	1	4		X X X X X X
9c	Assemble downsprue	0	0		
9d	Assemble Flexors	1	4		X X X X X X X
9e	Take Dev Pictures	0.5	2		X X X X
9f	Update Website	1	2		X X X
	subtotal:	4.5	16		

Final Gantt Chart

PROJECT TITLE: Flexor Casting
Principal Investigator.: Courtney Lehrman

TASK: ID	Description	Duration Est. (hrs)	Actua (hrs)	%Com
1	Proposal*			100
1a	Outline	1	2	
1b	Intro	1	3	
1c	Methods	2	13	
1d	Analysis	25	31.5	
1e	Discussion	2	7	
1f	Parts and Budget	1	4	
1g	Drawings	20	19.5	
1h	Schedule	0.5	1.5	
1i	Summary & Appx	1	2	
	subtotal:	53.5	83.5	
2	Analyses			100
2a	Dimensions based off Shrinkage	2	4	
2b	Gating design part one	2	2.5	
2c	Gating design part two	2	3	
2d	Well, runner, ingate shape	2	1.5	
2e	Aluminum heat flow	3	3	
2f	Matchplate dimensions	3	3	
2g	Volume of sand	1	1.5	
2h	Matching dimensions for complete flexor	3	2	
2i	Riser dimensions	2	2.5	
2j	Gating dimensions	2	2.5	
2k	Impulse of hammer on sand	2	3.5	
2l	Volume of feed metal	1	2.5	
	subtotal:	25	31.5	
3	Documentation			100
3a	Original flexor part	0.5	1	
3b	Flexor design	1	3	
3c	Matchplate	0.5	1.5	
3d	Gating system in drag	2	3	
3e	Down sprue in cope	2	3	
3f	Riser on runner in cope	1	3.5	
3g	Assembly with matchplate	1	2	
3h	Assembly without matchplate	1	2.5	
	subtotal:	9	19.5	
4	Proposal Mods			100
4a	Safety Hazard	0.5	2	
4b	Budget Lists	1	3.5	
4c	Part List	0.5	2	
	subtotal:	2	7.5	
7	Part Construction			
7a	Buy matchplate material	0.5	0.5	
7b	Make matchplate	1	1	
7c	Manufacture 3D printed Runner	3	4	
7d	Manufacture 3D printed Ingates	3	4	
7e	Manufacture 3D printed downsprue	1.5	3	
7f	Manufacture 3D printed Flexor (2x)	2	3	
7g	Manufacture 3D printed Riser	1.5	3	
7h	Update Website	1	1	
7i	SolidCast	2	2	
	subtotal:	15.5	21.5	
9	Device Construct			
9a	Assemble Runner	1	4	
9b	Assemble Ingates	1	4	
9c	Assemble downsprue	0	0	
9d	Assemble Flexors	1	4	
9e	Take Dev Pictures	0.5	2	
9f	Update Website	1	2	
	subtotal:	4.5	16	
10	Device Evaluation			
10a	List Parameters	1	1	
10b	Design Test&Scope	1	1	
10c	Obtain resources	1	2	
10d	Make test sheets	0.5	1	
10e	Plan analyses	0.5	0.5	
10f	SOURCE preperation	1	4	
10g	Test Plan*	1	1	
10h	Perform Evaluation	1	3	
10i	Take Testing Pics	1	1	
10j	Update Website	2	3	
	subtotal:	10	17.5	
11	495 Deliverables			
11a	Get Report Guide	2	2	
11b	Make Rep Outline	1	1	
11c	Write Report	1	2	
11d	Make Slide Outline	1	1	
11e	Create Presentation	3	4	
11f	Make CD Deliv. List	1	1	
11e	Write 495 CD parts	1	1	
11f	Update Website	1	2	
11g	Project CD*	1	1	
	subtotal:	12	15	
	Total Est. Hours=	131.5	212	
Labor$	100	13150		



Appendix F- Expertise and Resources

The support of this project could not have been completed without the help of Jim Justin, Matt Burvee, Dr. Johnson, Professor Pringle, Dr. Choi, and Mechanical Engineering Technology's students. With the collaboration of these sources, the project was then able to be successful. All levels of experience regarding the casting process and multiple view points helped to shape the success of this project. Without the resources from Jim Justin, there would have been more difficulty in finding foundry/pattern resources Physical resources in support of this project include a mill, drill press, grinder, a foundry, 3D printer, and every component in the casting process. All these resources listed stem from Central Washington University. There is an emphasis on the casting process and machining processes for this project as they are the main scope in the making of the Flexors. Solidworks is the main support in the Flexor's drawings for each component. This software was also essential for volumetric and dimensional analysis to assist the design process of the Flexor and its components. Solidworks not only helps with the analysis of parts, but it also provides ways to make engineering drawings to illustrate parts in a technical way. Web support was used to verify calculations to ensure that they were accurate and consistent in the design of the Flexor. As far as financial resources go, there is one main source of donations has been included into this project. Jim Justin, President of Puget Sound Pattern Works has generously supported this project with the donation of pattern making based off this projects Flexor drawings as well as the casting of the Flexor itself. These donations help to support the improvement of this project.

Appendix G- Testing Report

This section of the project will be completed in spring quarter. There is no way of having a testing report until the testing for this project has been completed.

Appendix H-Resume

OBJECTIVE

I am seeking an engineering position that integrates coursework to build field experience.

SKILLS & ABILITIES

- Communication
- Production line experience
- Software (AutoCAD, Solidworks, and Microsoft Office)
- Solidworks Certified
- Machining (lathes, mills, and drill press)

EXPERIENCE

Cam Trim- Internship Position, Kenworth Trucking Company — **June 7, 2019-September 6, 2019**

With this job, I extended my skills and knowledge in this hands-on industry. I expanded on my skills to work in fast pace environment safely.

Cab Assembler- Internship Position, Kenworth Trucking Company — **June 11, 2018-September 7, 2018**

Gained an understanding and execution of safety procedures to look out for others and provide help when needed in multiple areas. Ability to be punctual and work in rush conditions in a timely and safe manner.

Employee, Baskin Robbins — **April 3, 2016-July 31, 2017**

Utilized clear communication between co-workers, customers, and bosses. Gained the ability to act quickly and efficiently during rush hours and organizational skills.

EDUCATION

BS in Mechanical Engineering Technology in Progress, Ellensburg, WA, Central Washington University — **September 2017-Present (Expected to Graduate in 2020)**

Associate in Arts (AA), Auburn, WA, Green River Community College — **September 2015-June 2017**

LEADERSHIP

Strong technical communication and written skills through course work, sports teams, and professional experiences.

Appendix J- Job Hazard Analysis

JOB HAZARD ANALYSIS
Casting Process

Prepared by: Courtney Lehrman	Reviewed by: Approved by:

Location of Task:	Machine Shop
Required Equipment / Training for Task:	Operation of drill press Operation of milling machine First aid
Reference Materials as appropriate:	https://ehs.berkeley.edu/job-safety-analysis-jsas-listed-topic

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

JOB	TASK DESCRIPTION	HAZARDS	CONTROLS
Drill Press	Clean the table	Eye injury from metal debris	Wear eye protection. Do not use compressed air.
	Load the vise	Foot injury if the vise falls Finger pinching while sliding the vise	Secure the vise on the table with T-pins. Keep your eyes on the task
	Lock the table in place	Back strain	Don't lean over the table to twist the lock

			handle
	Load the bit	Hand injury from the bit	Wear gloves. Don't hold on the end of the bit
	Start the drill.	None foreseen	
	Feed the drill with the feed.	Injury caused by breaking the bit Eye or skin damage from cutting oil Hand injury from the exposed pulley near the feed handle	Feed with the appropriate pressure. Use the appropriate bit for the type of metal. Wear eye protection. Use the lowest RPM. Wear eye protection. Wear a long sleeved shirt Make sure a pulley guard is in place. Don't push the feed handle toward the pulley
	Unload the vise.	Foot injury if the vise falls Finger pinching while sliding the vise	Leave the vise secure on the table with T-pins until it is unloaded. Don't let your fingers get under the vise unless you're lifting it from the table. Keep your eyes on the task
	Clean the table	Eye injury from metal debris	Wear eye protection. Do not use compressed air
Mill	Load the pug mill with recycled clay. Cut the Use proper	Lifting large pieces of clay from the floor up into the top of the machine can put strain on the back and other muscles. The spinning	Use proper lifting techniques to execute the job. Watch out for the blade and stay away from the spinning

	lifting techniqu es to execute the job. recycled clay using a wire tool. Check the consiste ncy, making sure to rid of any garbage or other clays that can contami nate the batch. Aim under the spinning blade at the top and toss cut pieces into the pug mill.	blade can catch on hands, hair, and/or clothing, causing bodily harm.	blade, keeping hands and clothing away, hair tied back. Be aware of what the spinning blade is cutting.
	Unload the pugged clay. Measur e the pugged clay with a yardstic k. Cut the clay with a blade. Pull out	Heavy lifting of the measured clay and bagging it can put strain on the back and muscles.	Use proper lifting techniques to execute the tasks

	measur ed clay and place into bags.		