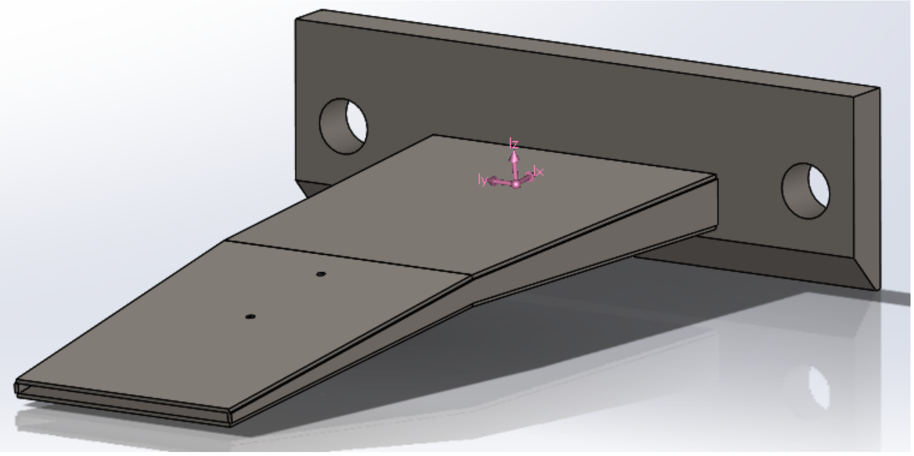

Low-Flow Lead Snout
Deliverable: Final Design Review Report

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Low Flow Snout
Project: 23
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Client: Hazelett Corporation

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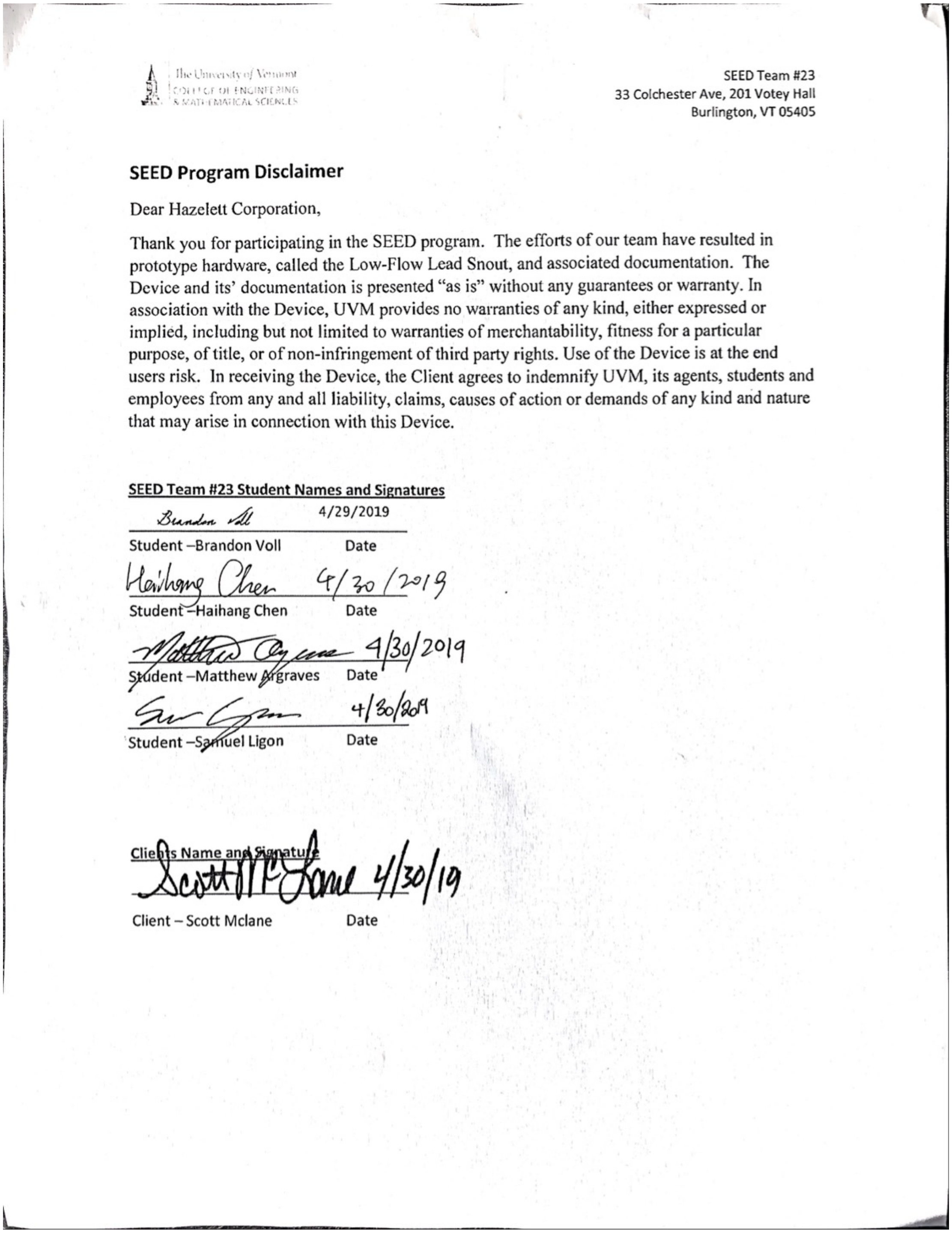
Date	**Revision**	**Notes**
5/1/19	01	Initial Release



The University of Vermont
COLLEGE OF ENGINEERING
& MATHEMATICAL SCIENCES

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SEED Program Disclaimer

Dear Hazelett Corporation,

Thank you for participating in the SEED program. The efforts of our team have resulted in prototype hardware, called the Low-Flow Lead Snout, and associated documentation. The Device and its' documentation is presented "as is" without any guarantees or warranty. In association with the Device, UVM provides no warranties of any kind, either expressed or implied, including but not limited to warranties of merchantability, fitness for a particular purpose, of title, or of non-infringement of third party rights. Use of the Device is at the end users risk. In receiving the Device, the Client agrees to indemnify UVM, its agents, students and employees from any and all liability, claims, causes of action or demands of any kind and nature that may arise in connection with this Device.

SEED Team #23 Student Names and Signatures

Brandon Voll 4/29/2019
Student –Brandon Voll Date

Haihang Chen 4/30/2019
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Student –Matthew Argraves Date

4/30/2019
Student –Samuel Ligon Date

Clients Name and Signature

Scott McLane 4/30/19
Client – Scott Mclane Date

Memo

From SEED Team 23, we would like to thank you for participating in the SEED program this year. It has been a pleasure working with you on a project that was both challenging and rewarding. Your support has allowed the project to be a success and we look forward to seeing how it performs in the future.

Following is a list of deliverables and their completion status. Each deliverable will be available on EduSourced under a folder name ”Final Deliverables”.

- FDR Report - Complete
- Technical Design Documentation - Complete
- Verification Plan and Results - Complete
- Operation Manual - Complete
- SolidWorks Parts and Drawings - Complete
- Engineering Specifications - Complete
- Cost and Time Analysis - Complete

Abstract

Low flow lead casting is advantageous due to the premise that it allows for a better grain structure to form in the solidified lead. However, Hazelett Corporation does not have a snout that is optimized for the required speeds and therefore less than satisfactory casts are produced due to open channel flow and intrusive ribbing features. A new snout design that is optimized for low flow speed was designed and tested. Some of the features that allowed for an optimized design include new ribbing and new dimensions in key areas of the snout. Results from testing show that this snout passed all requirements, some of which include obtaining closed channel flow and achieving certain flow characteristics. The next step for this project is to take the manufactured snout and use it on a real lead casting device at the low flow speed.

Contents

1 Problem Statement

In the casting industry, pour nozzles are used to channel flow from a molten pooling area onto a casting belt for solidification into a strip. Hazelett Corporation currently uses a horizontal pouring nozzle referred to as a snout in their lead casters. The objective of this project is to design a snout which works at a lower casting speed than the current design. Casting at a lower speed is desirable because it improves surface quality and grain structure, but it introduces issues with open channel flow and the distribution of turbulence in the flow when using the current snout. The current design utilizes rib features which are necessary to maintain a constant cross-sectional area in the snout at high thermal loads. However, the ribs unevenly distribute turbulence when casting at a low speed with open channel flow. The new design will strive to distribute the turbulence more evenly and achieve closed channel flow by changing the geometry and ribs, while still preventing changes in the cross-sectional area. If turbulence distribution and head height can be controlled, it will allow Hazeletts clients to cast effectively at low speeds.

2 Design Options Comparison

The poor cast quality at low-flow speeds was originally assumed to be caused by the ribbing features of the standard 362626 snout model. This was because regions of poor quality aligned with the two prominent ribs that ran through the snout. An image of the cast quality produced at low-flow speeds was provided by Hazellet Corp. and can be seen in Figure 1.

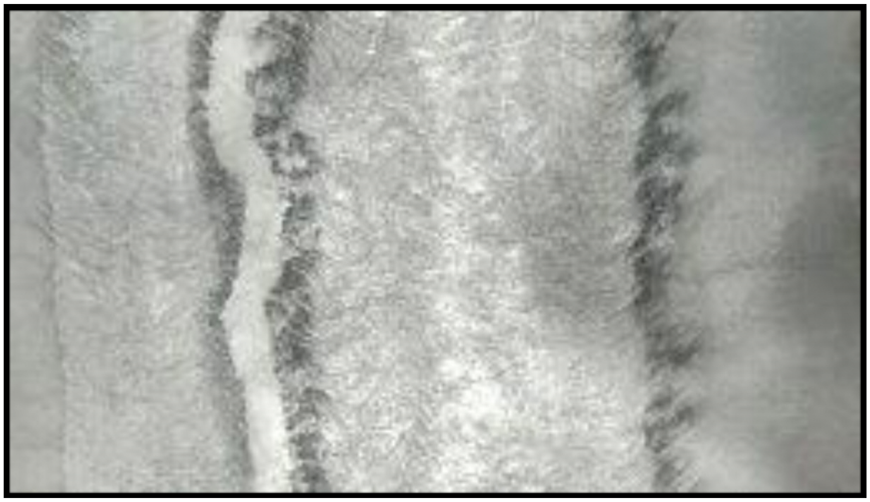


Figure 1: The poor cast quality produced from standard 362626 snout has waves that align with its ribs

This assumption that the ribs were the dominant cause of poor cast quality was investigated. Using Fluent FEA simulations, the X-Velocity, Y-Velocity, and pressure characteristics of the flow were analyzed around the standard 362626 snout model as well as designs with other rib configurations and geometries. These included using pillars in a vertical and horizontal configuration as well as cases with shortened ribs and a decreased number of ribs. Figures 2 through 4 show some of these original design concepts that were analyzed.

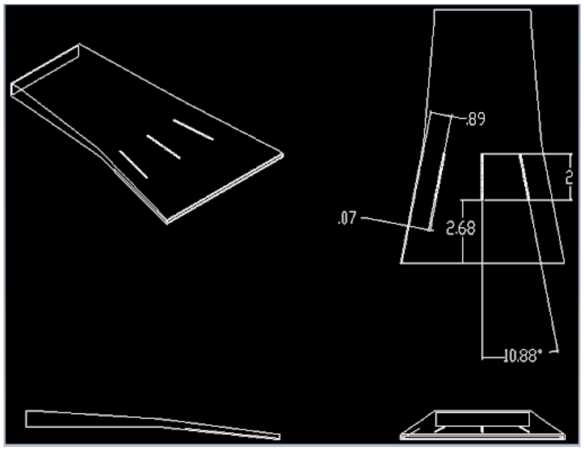


Figure 2: Shortened rib feature design concept

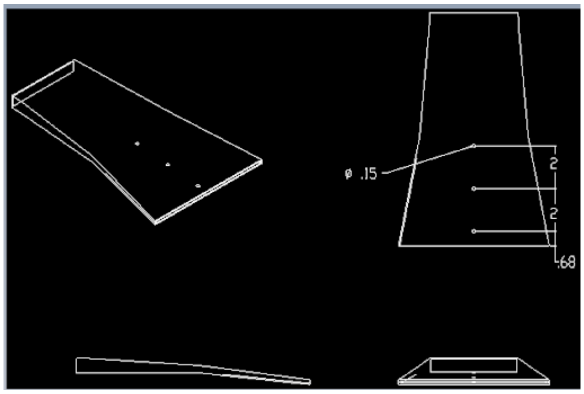


Figure 3: Vertical pillar rib feature design concept

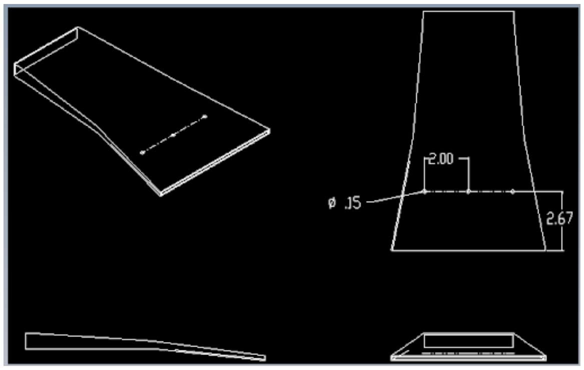


Figure 4: Horizontal pillar rib feature design concept

The analysis showed clearly that the rib features were not the dominant cause of poor cast quality because there was no outstanding flow characteristics arising around the rib features.

To continue with finding the cause for the poor cast quality the team decided to do real world testing. A 362626 acrylic model was then made for water testing in order to determine if any remarkable issue could be going on with the ribs or otherwise. When the required flow rate of 2.41 gallons per minute (gpm) was passing through the snout it became obvious what the issue was that was causing such a poor cast quality. Due to the 362626 snout being so large in size, because it was designed for a rapid cast rate, the water in testing was not able to rise above the snout entrance and fully fill the snout. Air pockets would form due to only half of the entrance being filled and the other was exposed to air, this allowed air pockets to form in the snout and bleed into the cast. These air pockets can be clearly seen in Figure 5.

Figure 5: Air pockets form in 362626 snout at desired flow rate

These air pockets would regularly split apart and pass with the flow creating a fluctuation at the exit. This fluctuation would create a wave which is similar to the issues in the cast quality seen by Hazelett's client. Our team was then convinced that the new snout design would have to be smaller in size to compensate for the low-flow rate and achieve closed channel flow.

To continue, Bernoulli's equation was used to determine the decrease in overall geometry that would be needed to restrict the flow to raise the liquid level at the entrance and achieve open channel flow. With this accounted for a new first prototype acrylic model was made for water testing. The results were somewhat promising. Air-pockets no longer formed and bled into the cast, however, the reduction in size made the snout unable to be cleaned by current on-site practices. Operators will use what is effectively a ramrod and shove it into the entrance of the snout during casting to remove solidified material and drauss build up. But due to the reduction in size a rod would no longer fit all the way to the exit of the snout. Figures 6 shows the small flange inlet height for the design concept.

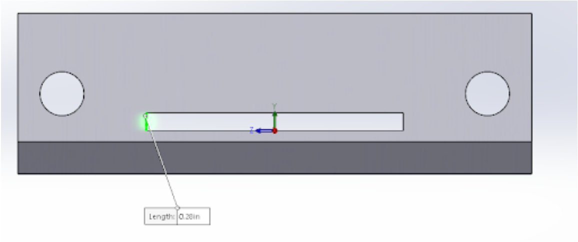


Figure 6: Design Concept Flange

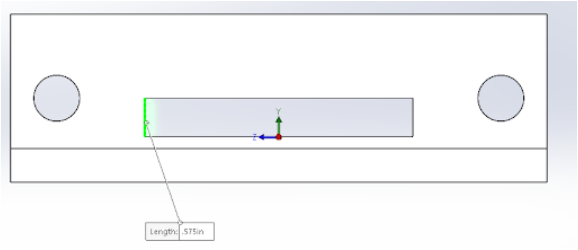


Figure 7: Standard Flange

This inlet height was too narrow to allow cleaning by current on-site methods. To adjust for this issue our team decided to have our new design maintain the same inlet height as the standard model to avoid issues with cleaning. This flange can be seen in Figure 7. Another issue that arose was even though the liquid level had risen to achieve close channel flow, the height of fluid was not close to the calculated head height that was expected.

Through discussion with our teams advisers' it became apparent that frictional losses were necessary for this type of nozzle. The reason being that the aspect ratio of the snout exit thickness versus length was so large that frictional loses would play a huge part in the exit conditions of the snout. Normally, a pipe or duct is so large compared to a boundary layer formation that frictional loses can be disregarded. With this information frictional losses were added using the Colebrook equation to make adjustment to the snout geometry. An acrylic snout model was made and tested that achieved the desired head height that was determine in our analysis.

Finally, a decision was made to use only one small rib and place it far away from the exit of the snout. This seemed ideal based on simulation tools used to analyze the flow conditions and thermal deformations. Fluent was used and showed that by pushing the rib back from the exit it gave the fluid time to re-converge to a more uniform flow regime compared to ribs that practically touch the exit cross-section of the snout. This re-convergence of flow can be seen in Figure 8.

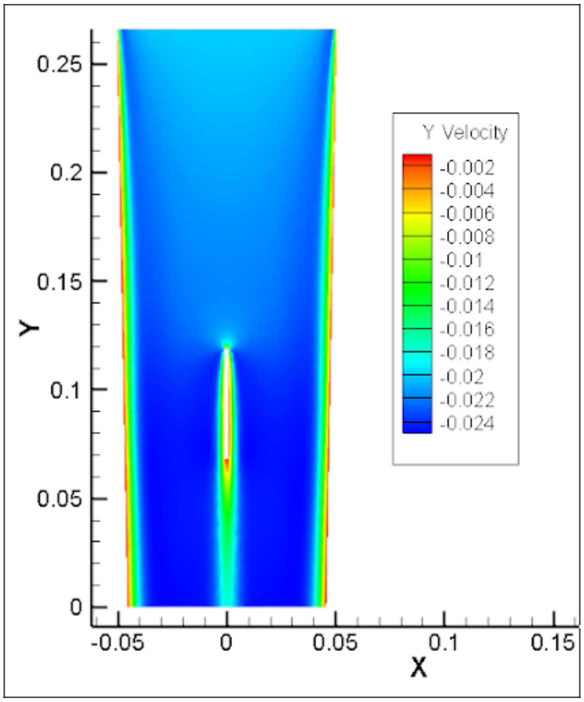


Figure 8: Y-Velocity Plot for one rib design

Figure 8 shows that their is negligible differences in velocity uniformity at the snout exit. The Y-veloicty ranges has at maximum of 0.022 m/s difference across the snout exit. Abaqus was used and showed that one small rib was sufficient to maintain the rigidity of the snout under the thermal loads produced from molten lead. One rib was able to keep the deformations less than the specification target and well below the current snout model's deformation under loading.

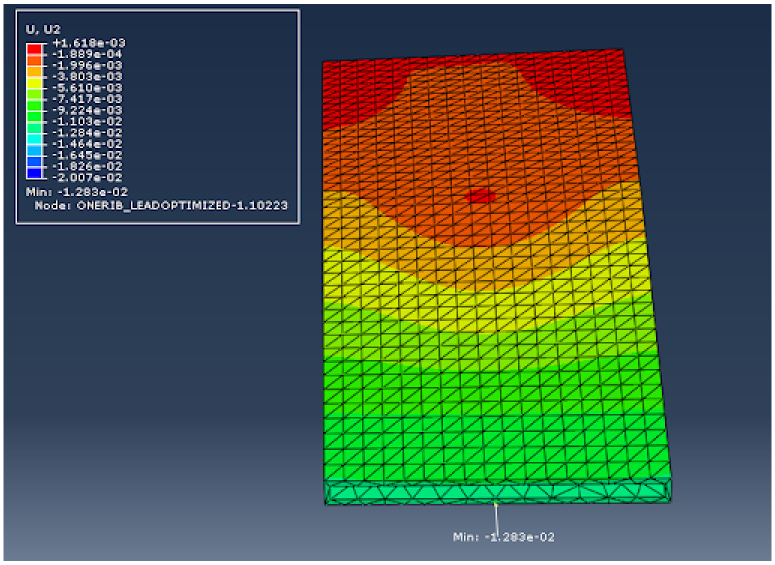


Figure 9: Deformation in one rib design

Figure 9 shows that the maximum deformation in the vertical direction is well below the specification requirement and significantly less than the standard 362626 snout. The vertical deformation was the important deformation to record because an operator can make adjustments to change the snout position, however if the snout deforms vertically beyond the threshold it will make contact with the casting belts and damage them.

There were multiple iterations for size, rib configuration, and inlet/ exit areas that led to a final design that was made for Hazelett to produce for its RND project. This final design concept can be seen in Figure 10.

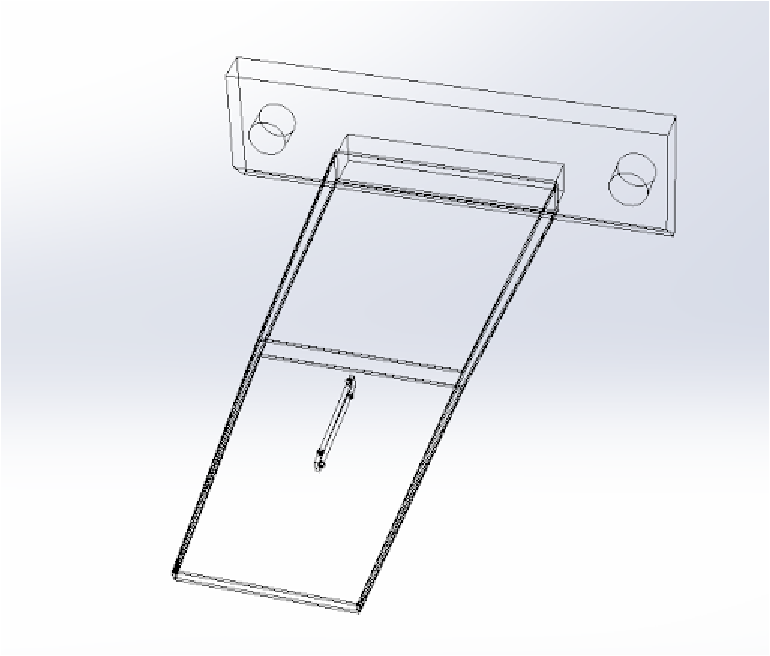


Figure 10: Wireframe image of final snout design

3 Design Functionality

The final design was determined to be successful because it met all the specification criteria through methods of physical analysis, computer simulations, and real world models testing. The new design has a few differences from the standard 362626 snout that make it optimized for low-flow speed conditions. The 362626 snout flairs outward from its entrance to a length of 7.5in at the exit which make it ideal for high speed casting. The new design smoothly converges at its exit to a length of 3.05in. This tight exit length was essential for restricting the flow upstream to cause the liquid height to rise and fully enclose the entrance of the snout at low speeds. Figure 11 shows the dimension of the exit length calculated from analysis with the Bernoulli equation.

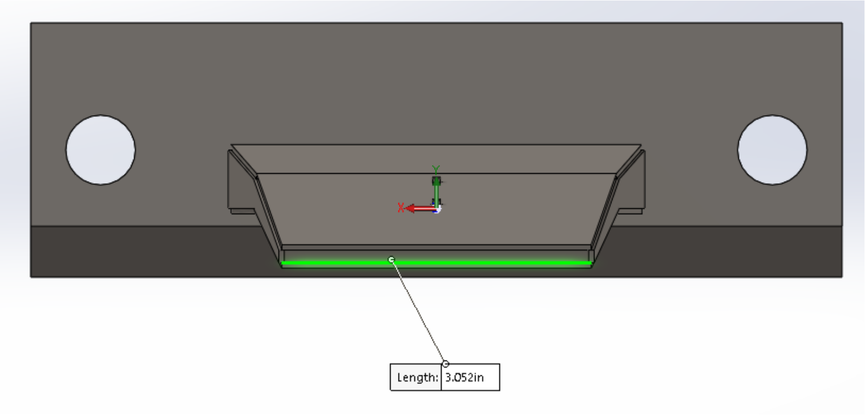


Figure 11: Exit Length of Low-Flow Lead Snout

The final length was determined using the Bernoulli equation as well as friction head metrics, which found the exit area needed to get the liquid height to be at an eighth on an inch above the snout entrance. The exit height was a constraint to be consistent with the 362626 in order for the snout to fit properly between the casting belts and produce the desired three-eighths inch thick cast slab. Another important feature is the shortening of structural ribs and reduction from two to one. It was determined that by shortening the rib, more ideal flow characteristics at the snout exit could be achieved to produce a better quality cast while not sacrificing the rigidity needed to bear large thermal loads. Figure 12 shows the structural rib feature and its position in the snout.

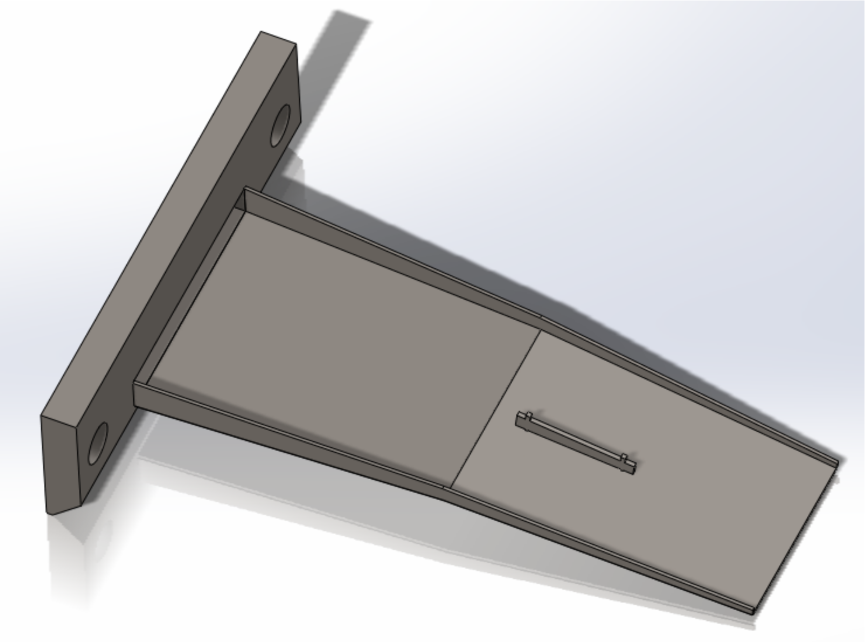


Figure 12: A structural rib of length 2in pushed back 2.75in from the snout exit

By pushing the rib further back in the snout it will allow lead flow to re-converge to a more uniform velocity at the exit. Additionally, a shorter rib would reduce material needed and welding necessary for the design, making it easier to produce. The final design has a rib length of 2in while the 362626 design has a rib length of 3.6in. The inlet height of the snout was chosen to remain at 0.58in. This decision was made because it was discovered during experimentation that should it have been reduced, the cleaning procedure would have proven impossible. This is because an operator will stick a cleaning rod in through the snout entrance during operation and needs a significant entrance height to angle the rod down to the exit of the snout. To avoid complications with cleaning the entrance height was left the same as the 362626 snout design.

4 Analyses

4.1 Head Calculation Analysis

The height at which the lead lies above the inlet condition provides all the power for the snout system. Because of this, being able to calculate and predict where that head will lie is of the utmost importance for the operation of the snout. This primarily pertains to specification 60, because 60 actually tests for the head height accuracy, but also pertains to specifications 10 and 70 in a less direct way as the uniformity of the flow can be related to close channel flow, and likewise head height. This old analysis has been updated with the inclusion of the friction head calculation, which is integral to the accuracy of the equation. The analysis assumes uniform velocity is encountered.

The known parameters are the thickness, width, and speed of the cast, represented by t, w, and x, respectively. With these parameters alone, it is possible to calculate the volumetric flow rate. This is represented by equation 1.

$$\dot{V} = twx \tag{1}$$

Volumetric flow rate is valuable because it can be used to calculate the velocity with a simple relation represented below in equation 2. This can be calculated with any cross sectional area along the snout, and will change based on the changes made to geometry with each snout prototype.

$$v_{in,out} = \frac{\dot{V}}{A_{in,out}} \tag{2}$$

When velocity is known, it can be used to calculate head with a derivation of the Bernoulli equation, shown in equation 3. The head calculated from this will be important primarily at the inlet and exit of the snout due to the sharp edges and dramatic changes in flow condition at these points.

$$h_{in,out} = \frac{v_{in,out}^2}{2g} \tag{3}$$

The head calculation would not be accurate with only the inlet and exit head as calculated above. As it happens, friction has a calculable effect on head height in this particular problem. This is likely because of the large aspect ratio associated with the exit geometry. To determine the frictional head, one uses the Colebrick equation represented in equation 4 to determine a friction factor. Values of roughness ϵ, hydraulic diameter D_h, and Reynolds number Re, must be known for this to be possible.

$$\frac{1}{\sqrt{f_D}} = -2log_{10}(\frac{\frac{\epsilon}{D_h}}{3.7} + \frac{2.51}{Re\sqrt{f_D}}) \tag{4}$$

Once the friction factor is known, the head due to friction can be found with equation ??. The friction is determined at the inlet and exit, then central differencing is used to find an average friction across the system. Note that the length scale was slightly adjusted to accommodate the large aspect ratio of the system. The friction will be so much larger at the exit than the inlet that to use the full length of the snout would be a misrepresentation of the system's behavior. A scale factor of .65 was attached to the length scale because this was determined in experimentation to best represent the real life case.

$$h_f = \frac{f_D L v_{in,out}^2}{2gD_h} label fric \tag{5}$$

The sum of the head due to friction, the exit head, and the inlet head lead to an accurate measurement of total head.

4.2 Dimensionless Parameters Analysis

One of the overall problems of this project is that the actual working fluid is molten lead, which cannot be tested with due to access limitations of equipment and training. For this reason water was used for the testing. It is necessary to verify that the properties of water are similar enough to lead to be used as a test medium. The specification that this analysis corresponds with are specification 70 and 80, because it verifies that the flow characteristics seen in these specifications is valid.

This analysis was done in the fall but it has since been updated. Originally only the Reynolds number was found but since than another dimensionless parameter, the Froude number, has been added.

The following assumptions were made: the characteristic length in the Reynolds number is the hydraulic diameter and the characteristic length in the Froude number is the hydraulic depth.

4.2.1 Reynolds Number

The Reynolds number is generally the first dimensionless parameter examined in fluid engineering. Similarity in Reynolds number indicates a similar momentum in the system, and can indicate whether a flow is turbulent or laminar. A characteristic length must be known to understand the Reynolds number. When ducts are being used, hydraulic diameter is the most appropriate substitute for diameter. It is the diameter of a circle which has the same area as the duct.

$$D_h = \frac{4A}{P} \tag{6}$$

Reynolds number can then be calculated using the density ρ, the viscosity μ, and the velocity.

$$Re = \frac{\rho v_{in,out} D_h}{\mu} \tag{7}$$

The Reynolds number for water proved close to 20,000, while the Reynolds number for lead was closer to 4,000. This indicates what both are in the turbulent region, which is beneficial for the comparison of the two. The large discrepancy, however, cannot be ignored. Other dimensionless parameters were examined to seek a closer resemblance.

4.2.2 Froude Number

Froude number was examined because it is generally a better representation of open channel flow than Reynolds number as a dimensionless parameter. This is because it has to do with inertia rather than momentum flux. The hydraulic depth was used in this calculation.

$$D = \frac{A}{l} \tag{8}$$

Following the calculation of the detph, Froude number could be determined.

$$Fr = \frac{v_{out}}{\sqrt{gD}} \tag{9}$$

The Froude number for water was determined to be 6.61, meanwhile for lead Froude number was 6.93. This is less than a 5 percent difference, and can be trusted more than Reynolds number in many respects because this problem concern open channel flow.

4.3 Thermal Expansion of Snout Analysis

The following analysis looks into the thermal expansion of the snout. This pertains specifically to specification 50. The premise is that the snout cannot deform more than 30 thousandths of an inch in the vertical direction otherwise it will contact the casting belts and damage them.

This analysis is new and was not done in the fall semester. The approach is to simplify the snout model to something can be analyzed numerically. Than, the correct equations are used to find values for thermal expansion and forces on the snout. Values are found for both the control snout and the prototype snout, so this test mainly uses comparison to verify its results.

The following assumptions are made; the snout is simplified to a slender member fixed at both ends, which can be seen in figure 13, the outside average temperature is room temperature ($72°F$), and the inside of the snout is assumed to be $650°F$.

The first step in the analysis is to determine the temperature difference, ΔT. With the assumed values this is found to be 578 F. With a known length (L) in the control snout of

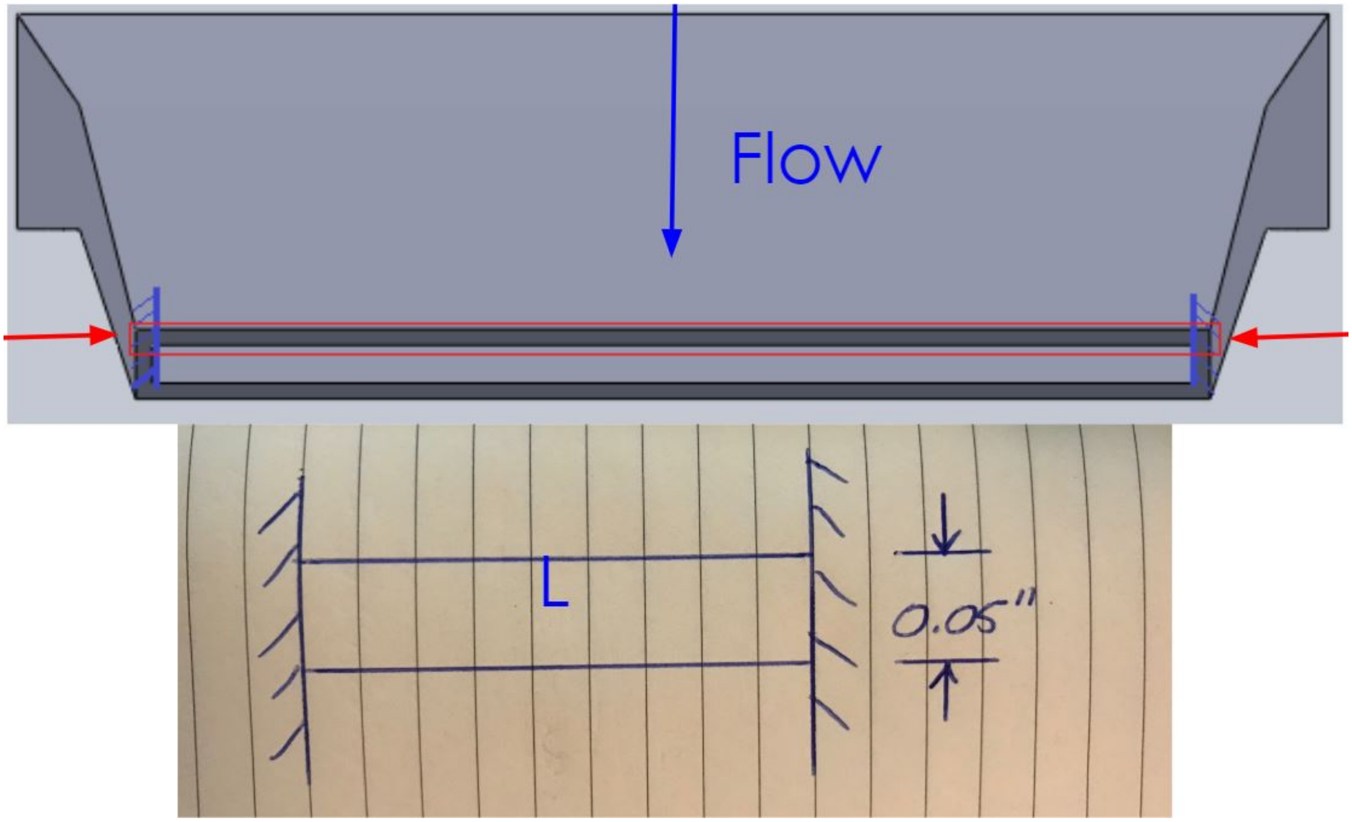


Figure 13: Thermal Expansion Simplification

6.89 inches and 2.99 inches in the prototype snout, as well as an expansion coefficient (α) value of $7.2e^{-}6$, the thermal expansion of each snout can be found using equation 10.

$$\delta = \alpha \Delta T L \tag{10}$$

The deformation of the control snout is found to be 0.0287 inches and the prototype snout is found to be 0.0124 inches. After the thermal expansion is found, the forces on either snout can also be found. This is done using equation 11, where F = force, E = modulus of elasticity ($200e^9 Pa$) , and A = cross-sectional area ($0.0025in^2$).

$$F = \frac{\delta A E}{L} \tag{11}$$

The forces found for the control snout are 302 lbf and 279.9 lbf for the prototype snout.

In both cases the control snout has higher values. Since the control snout is known to perform thermally already, these results show that the prototype snout will perform even better and therefore will pass the specification.

4.4 Pump Specification Analysis

This analysis is looking specifically into the testing apparatus that was created for this project, and the pump that creates a flow of water. One of the constants of this project was that the flow rate of the liquid moving through the snout is 2.41 gallons per minute (gpm). To achieve this, a utility pump was purchased that could meet this minimum flow requirement. If a different pump is purchased or if another testing apparatus is created, the user will have to make sure that the pump they purchase can meet the minimum flow requirement. The problem arises from the fact that the pump does not only need to overcome the vertical distance from itself to the tundish, but also the head loss that occurs within the tubing from the pump to the tundish. This problem is especially relevant if the user is attempting to purchase a pump that only just meets the specified 2.41 gpm. The specification that this pertains to is specification 60, inlet head height.

This analysis is new and has been done recently. The approach for this analysis is to first start with the known flow rate and determine a few constants from this known value. Using these values, other values can be obtained from a chart. Then, a specific equation can be used to find the parameter in question.

The assumptions made for this analysis are as follows: the total length of the tubing is 12 feet, and the flow meter is assumed to be 0.5 inches in diameter, even though it is varying in diameter. The first step in the process is to begin with the equation for volumetric flow rate, which can be seen in equation 12, where Q = volumetric flow rate, D_c = diameter of tubing, and v = velocity of the flow.

$$Q = \frac{\pi}{4} D_c^2 v \tag{12}$$

This equation can be rearranged to solve for the velocity of the flow. This can be seen in equation 13.

$$v = \frac{4Q}{\pi D_c^2} \tag{13}$$

After the flow velocity is found, the Reynolds number of the water in the tubing can be found. This can be done using equation 14, where Re = Reynolds number and ν = kinematic viscosity of water.

$$Re = \frac{v D_c}{\nu} \tag{14}$$

After the Reynolds number is found, the relative roughness of the tubing can be found. This is done with equation 15, where ϵ = roughness of pvc tubing. This is a constant accepted value that is easily found online.

$$RelativeRoughness = \frac{\epsilon}{D_c} \tag{15}$$

With all of these known values, the moody chart can be used to determine the darcy friction factor. This can be seen in figure 14.

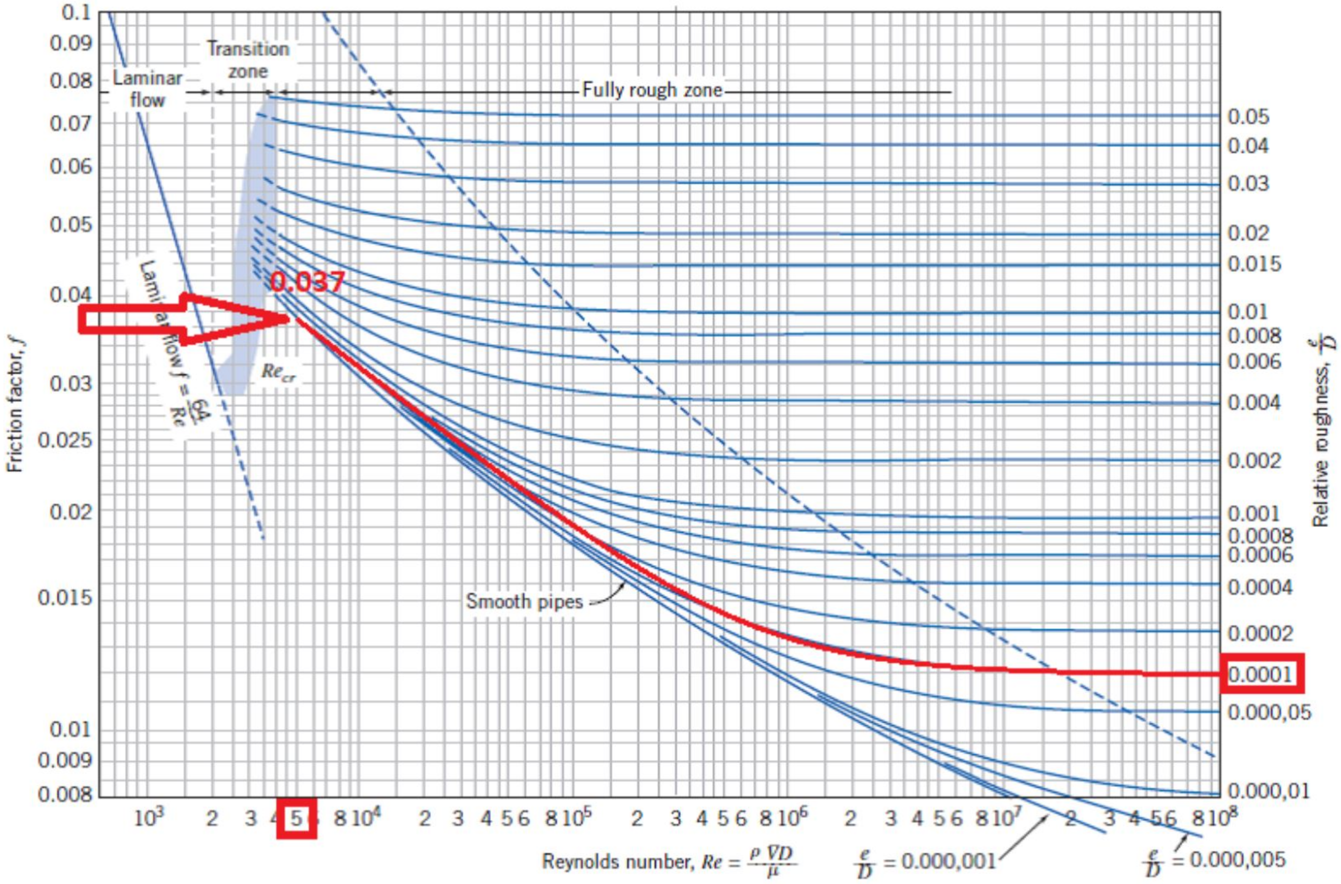


Figure 14: Moody Chart

After finding the darcy friction factor, the Darcy-Weisbach equation can be used to find the head loss per unit length. This can be seen in equation 16, where S = head loss per unit length of tubing and f = darcy friction factor.

$$S = f\frac{8}{\pi^2 g}\frac{Q^2}{D_c^5} \tag{16}$$

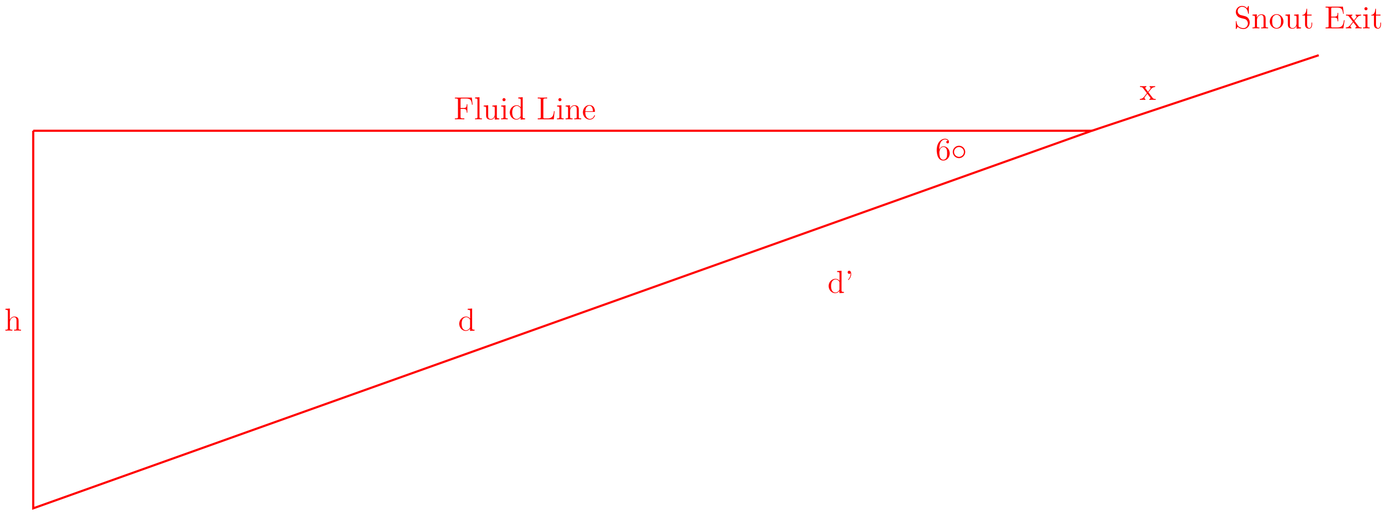
With the assumption that there is 12 feet of tubing, the total head loss is calculated to be about 2.7 feet. This can be added to the vertical displacement of the water to find the total head loss of the system, and the total head loss that the pump will need to overcome.

The code that was used to determine all of the previous values can be seen in Appendix F.

4.5 Hydraulic Jump

A hydraulic jump was introduced to the system to more closely mirror the flow behavior on the casting belt. This was a new analysis, and was an addition to the requirements of the project outlined at the beginning of the semester. This addition primarily impacts specification 80 as it was an effort to better understand flow characteristics outside the snout, including turbulence gradient. Its primary assumption is that no solidification of the cast liquid occurs on the casting belt within 12 inches of the snout exit.

The analysis is performed to determine the necessary height of a dam which would pool water to a certain distance below the snout exit. This would create a pool where wave behavior and turbulence would be observed. The pool takes shape on the casting belt as a triangle with a 6 degree angle.



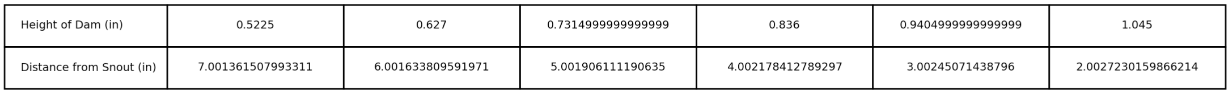
If d is defined as the triangle's hypotenuse, and d' is the arbitrary point where the dam is placed relative to the snout exit, then x will be the distance of the pool from the snout exit.

$$x = d' - d \tag{17}$$

d can be determined based on the height of the dam using basic trigonometry, outlined in equation **??**.

$$d = \sqrt{h^2 + (\frac{h}{tan(\theta)})^2} label d \tag{18}$$

The result is the distance from the snout exit. In the real case, this distance is variable



Height of Dam (in)	0.5225	0.627	0.7314999999999999	0.836	0.9404999999999999	1.045
Distance from Snout (in)	7.001361507993311	6.001633809591971	5.001906111190635	4.002178412789297	3.00245071438796	2.0027230159866214

Figure 15: Table displaying the dam height as compared with the distance from the snout.

and can be anywhere between 2 and 7 inches from the exit. Figure 15 is a table of values which correlate the dam height and the distance from the snout exit.

5 Engineering Specifications

5.1 Thermal Deformation - Specification 50

The standard 362626 snout has two very prominent rib features that extend almost halfway through its entire length. These ribs are needed to maintain the components rigidity in order to prevent deformations caused by large thermal loads from molten lead. Since the snout sits tightly between a twin casting belt located 0.03in above and below its exit lips the snout cannot deform above this limit or else it would make contact with the belts and cause damage to expensive equipment. Since our new design has changes to the snouts overall geometry and supportive rib features it was essential to analyze the deformations that would occur when our snout design was used in the real world. Information was gathered from our client on the lead temperature, heat transfer coefficient, and the material properties of the snout in order to produce an accurate thermal circuit that represented the conditions the snout was under.

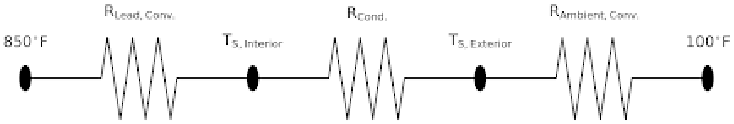


Figure 16: Thermal circuit that represent the heat transfer through the snout

Figure 16 shows the thermal circuit devised from information given by our client. The team was given the lead temperature of 850 °F, the convective heat transfer coefficient from the lead flow of 1700 $\frac{W}{m^2K}$, the sheet metal used for the snout is A36 Low carbon steel, an estimate on the ambient temperature of 100 °F, and the ambient heat transfer coefficient from natural convection. In Abaqus FEA the snout geometry for the 362626 snout and new design concept were imported and these conditions were applied to the geometry to determine the deformations that were occurring. The simulation used 30,000 temperature-displacement type finite elements to look at the deformations occurring from temperature. The deformation in the vertical direction was looked at to determine if the part would deform less than the threshold.

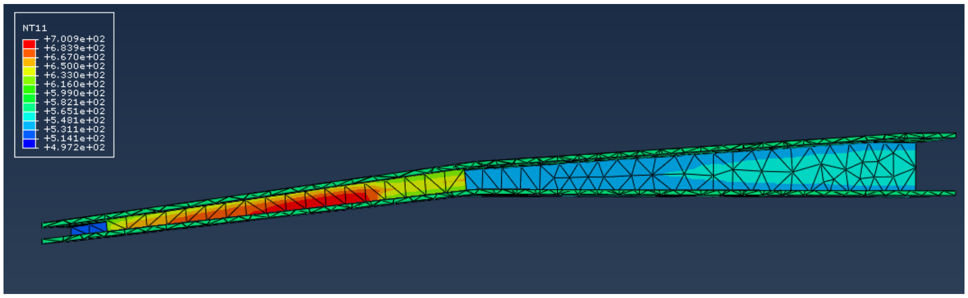


Figure 17: Cut View of Temperature Distribution through Snout

The simulation showed a realistic temperature distribution, shown in Figure 17, through the sheet metal of the snout ranging from approximately 500°F to 700 °F. A temperature difference from the inside walls to the outside walls was approximately 9 °F in the majority of regions for the snout.

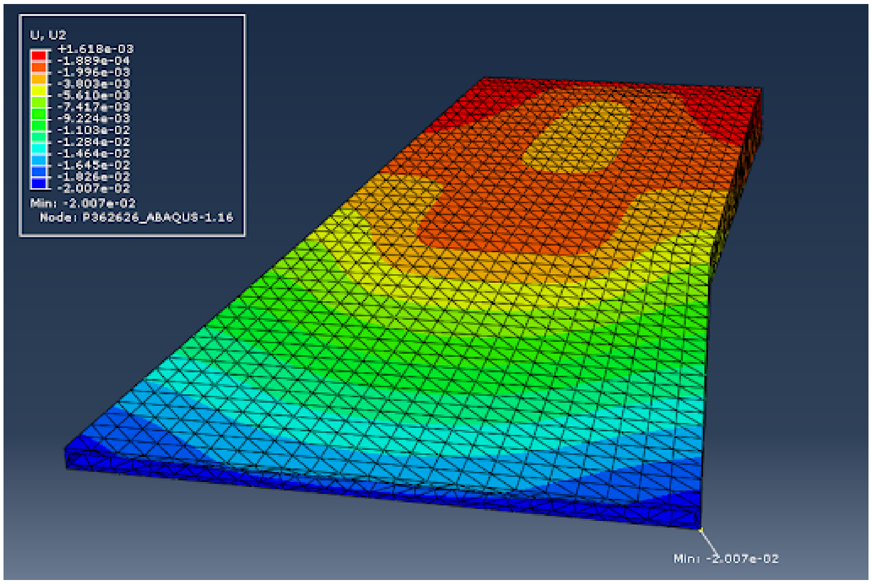


Figure 18: Vertical Deformation Plot of 362626 Snout

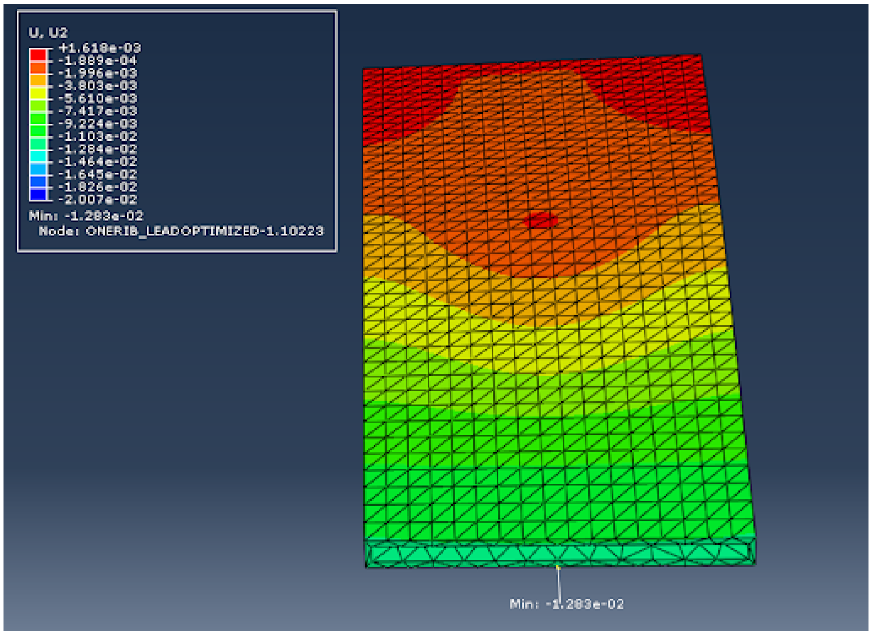


Figure 19: Vertical Deformation Plot of Design Concept

The simulation results, shown in Figures 18 and 19, conclude that both snouts will deform with the highest magnitude at the snout exit. The new design will deform 0.0128in outward while the 362626 will deform 0.020 in downward. The teams design had a 36 % reduction in deformation produced from thermal loads. This simulation assured the team the design would be safe to operate and would not fail and damage the equipment it was surrounded by. Note that only the vertical displacement was recorded because the displacement in this direction is what would cause failure.

5.2 Fluid Head Height - Specification 60

The fluid head height specification is one of the most important specifications for this project. If the head height is not at the correct point, then all of the other tests cannot be verified. The reason that the head height is important is because there has to be closed channel flow in the snout. Open channel flow is the main reason for bad cast quality so preventing it is key to a successful project. The point where the head level is measured from is the top inlet of the snout. This can be seen in figure 20. This figure also shows where the target and pass threshold are for the specification. The pass threshold is the range between 0 and 0.361 inches. If the head height is lower than 0 inches than there will be open channel flow. If the head height is above 0.361 inches than the tundish will overflow and material will be wasted. The target is 0.179 inches. This is just about 1/8 inches. This creates closed channel flow and also is far enough away from the top end of the pass threshold that it will hopefully not be an issue.

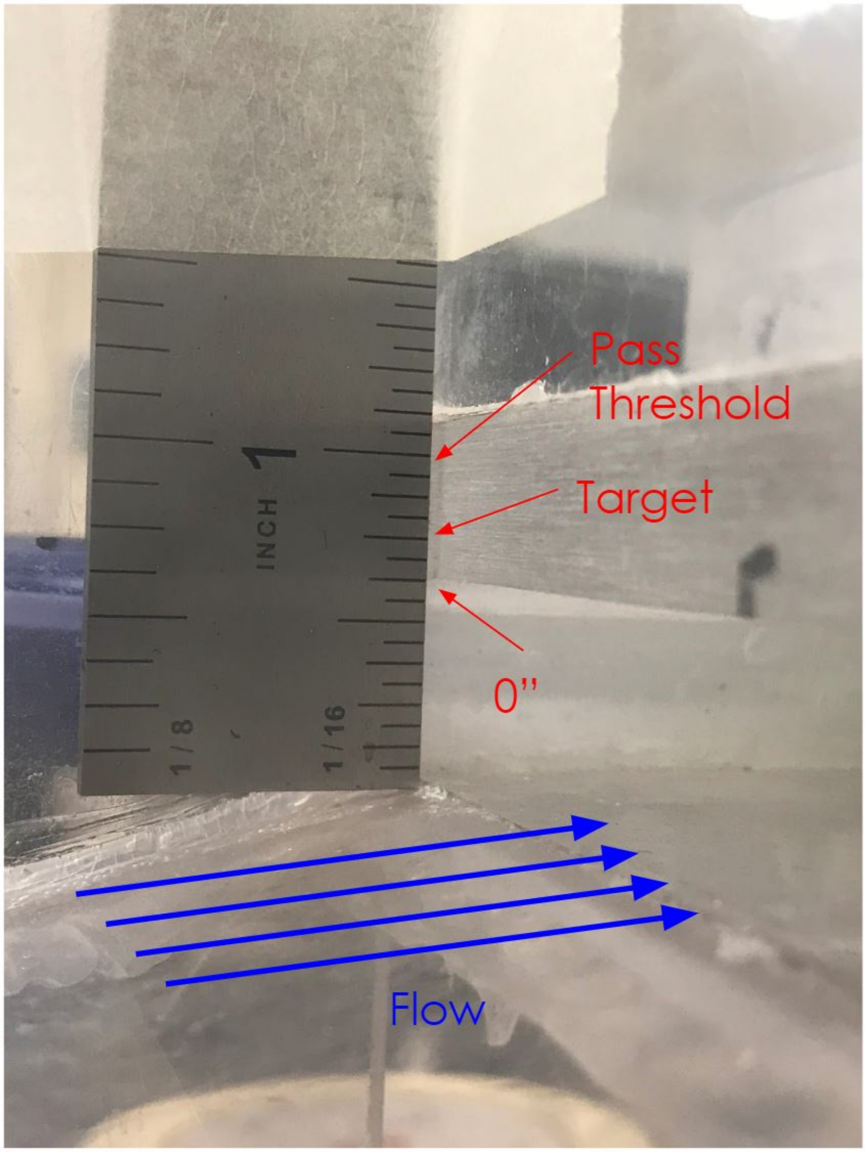


Figure 20: View of How Head Height is Measured

It is important to note that with this specification the flow needs to be running at 2.41 gpm, which is the constraint to cast at the desired flow rate.

The results of this test were that the average head height was 0.203 ± (1/32) of an inch. This shows that the specification passed.

5.3 Turbulence Distribution - Specification 70

This specification was important because it was the best indicator of what the flow characteristics were doing. It was important in the design that the best flow was achieved because this would result in the best cast quality after the lead solidified. The method for determining what the flow characteristics were was to look at the velocity gradient of the flow. It was desirable to have as much of the velocity of the fluid in the y direction as possible. This meant that there was fairly uniform turbulence distribution in the system and that the flow was not experiencing any dynamic changes that caused it to change direction suddenly.

The best way to determine what the velocity gradient in a flow is experimentally is to use streamers, otherwise known as tell tales. These streamers are made from a very thin string that is placed in the flow and allowed to follow the flow freely. The streamers that were placed in the flow of the snout began at the inlet of the snout and extended through the entire snout. This can be seen in figure 21. Using picture editing software, lines could be drawn on the picture and a triangle could be created. The pixels of the lines could be counted resulting in a length of the line, and the inverse tangent function could be used to find the angle of the streamer from vertical.

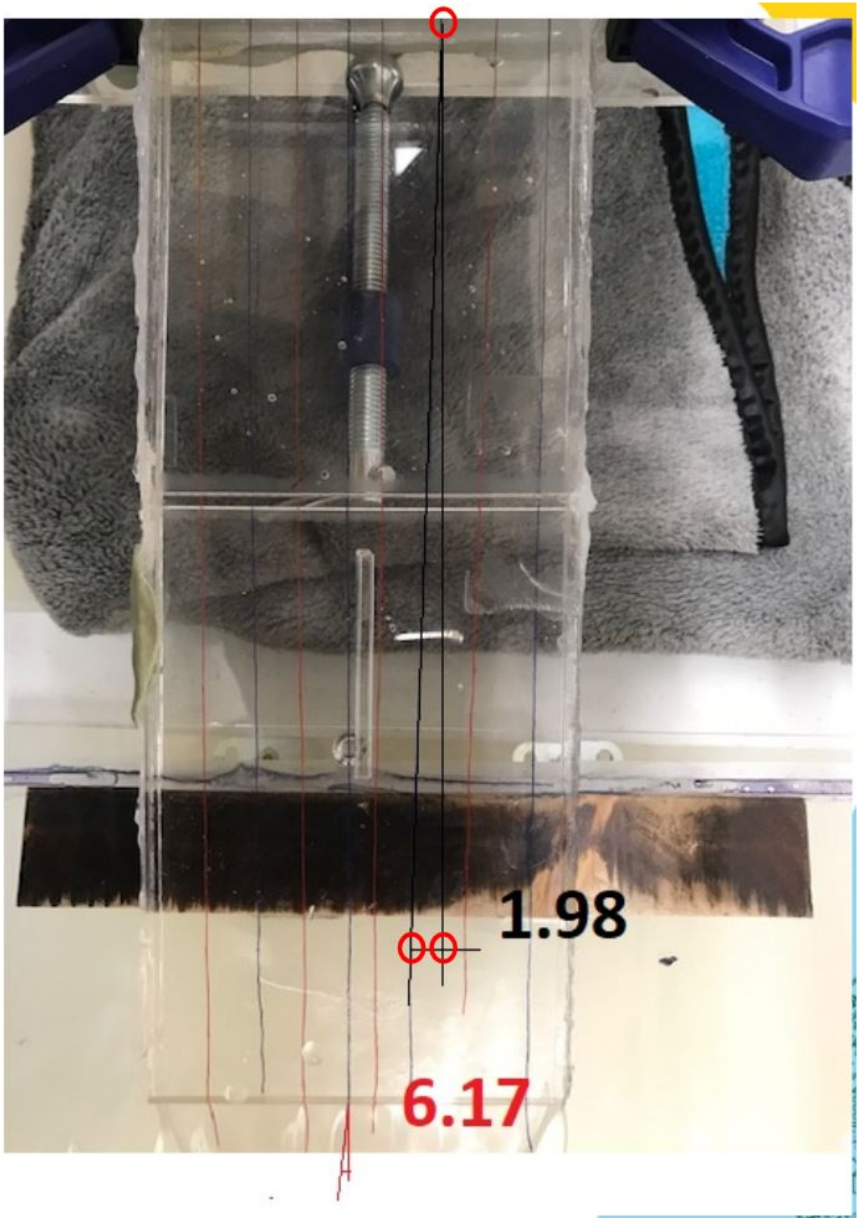


Figure 21: A View of the Streamers in the Prototype Snout

The first snout that this method was used on was the control snout. This allowed for a method to see what the worse result should be from the new snout. The angle from the control was found to be about 14°. Based on this result, the pass threshold for this test was determined to be ± 10°. The target is for the streamers to be completely vertical. The results of these angles were averaged and the value of the average angle was found to be about 5.7°. This means that this specification passed.

5.4 Engineering Specifications Summary

Overall, the design that the group determined was found to meet the requirements of the client well. This can be seen in the pass rate of the specifications. The relative pass rate at the end of the project was 100%.

Specification 10 passed with a result greater than 5 inches. The target for this specification was 5 inches and the pass threshold was 1 inch.

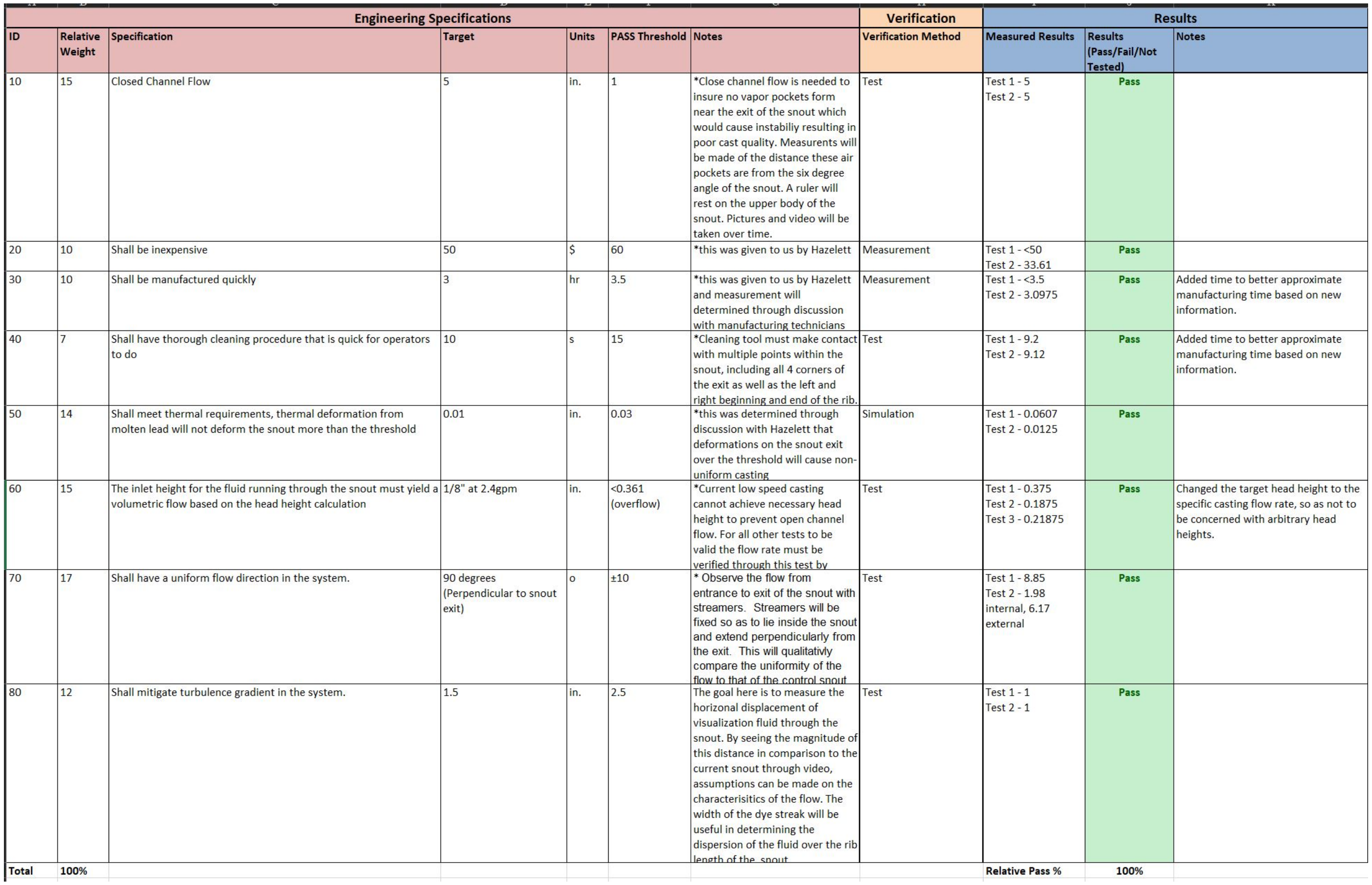
Specification 20 passed with a result of $33.61. The target for this specification was less than $50 and the pass threshold was less than $60. The specifics of this specification can be seen in the cost and time analysis deliverable.

Specification 30 passed with a result of 3.1 hours. The target for this specification was 3 hours and the pass threshold was 3.5 hours. The specifics of this specification can be seen in the cost and time analysis deliverable.

Specification 40 passed with a result of 9.12 seconds. The target for this specification was 10 seconds and the pass threshold was 15 seconds.

Specification 80 passed with a result of 1 inch. The target for this specification was 1.5 inches and the pass threshold was 2.5 inches.

The specifics of these specifications can be seen in the engineering specifications document and the method for testing can be seen in the verification plan and results.



Engineering Specifications							Verification	Results		
ID	Relative Weight	Specification	Target	Units	PASS Threshold	Notes	Verification Method	Measured Results	Results (Pass/Fail/Not Tested)	Notes
10	15	Closed Channel Flow	5	in.	1	*Close channel flow is needed to insure no vapor pockets form near the exit of the snout which would cause instabiliy resulting in poor cast quality. Measurents will be made of the distance these air pockets are from the six degree angle of the snout. A ruler will rest on the upper body of the snout. Pictures and video will be taken over time.	Test	Test 1 - 5 Test 2 - 5	Pass	
20	10	Shall be inexpensive	50	$	60	*this was given to us by Hazelett	Measurement	Test 1 - <50 Test 2 - 33.61	Pass	
30	10	Shall be manufactured quickly	3	hr	3.5	*this was given to us by Hazelett and measurement will determined through discussion with manufacturing technicians	Measurement	Test 1 - <3.5 Test 2 - 3.0975	Pass	Added time to better approximate manufacturing time based on new information.
40	7	Shall have thorough cleaning procedure that is quick for operators to do	10	s	15	*Cleaning tool must make contact with multiple points within the snout, including all 4 corners of the exit as well as the left and right beginning and end of the rib.	Test	Test 1 - 9.2 Test 2 - 9.12	Pass	Added time to better approximate manufacturing time based on new information.
50	14	Shall meet thermal requirements, thermal deformation from molten lead will not deform the snout more than the threshold	0.01	in.	0.03	*this was determined through discussion with Hazelett that deformations on the snout exit over the threshold will cause non-uniform casting	Simulation	Test 1 - 0.0607 Test 2 - 0.0125	Pass	
60	15	The inlet height for the fluid running through the snout must yield a volumetric flow based on the head height calculation	1/8" at 2.4gpm	in.	<0.361 (overflow)	*Current low speed casting cannot achieve necessary head height to prevent open channel flow. For all other tests to be valid the flow rate must be verified through this test by	Test	Test 1 - 0.375 Test 2 - 0.1875 Test 3 - 0.21875	Pass	Changed the target head height to the specific casting flow rate, so as not to be concerned with arbitrary head heights.
70	17	Shall have a uniform flow direction in the system.	90 degrees (Perpendicular to snout exit)	o	±10	* Observe the flow from entrance to exit of the snout with streamers. Streamers will be fixed so as to lie inside the snout and extend perpendicularly from the exit. This will qualitativly compare the uniformity of the flow to that of the control snout	Test	Test 1 - 8.85 Test 2 - 1.98 internal, 6.17 external	Pass	
80	12	Shall mitigate turbulence gradient in the system.	1.5	in.	2.5	The goal here is to measure the horizonal displacement of visualization fluid through the snout. By seeing the magnitude of this distance in comparison to the current snout through video, assumptions can be made on the characterisitics of the flow. The width of the dye streak will be useful in determining the dispersion of the fluid over the rib length of the snout	Test	Test 1 - 1 Test 2 - 1	Pass	
Total	100%							Relative Pass %	100%	

Figure 22: Engineering Specifications for Low Flow Lead Snout

6 Design for Environment/Sustainability

Metal is one of the most widely used building materials on the planet. It has seemingly unlimited uses and is also the only material that can be used in many cases. Hazelett Corporations defines one of the first steps in the process of the metal industry. Because of this, it is important to make sure that the products that are created from their machines are as environmentally sustainable as possible.

The client that is specifically requesting to have a low flow lead snout makes the lead grids that go inside car batteries. Car batteries are known to be quite bad for the environment, but at this point in time are still a very necessary product. With a better quality metal being produced from Hazelett's casting machines, the quality of the batteries that are produced will be better. This means that the batteries in cars should last longer and be more reliable. Less wasted batteries is a huge plus for the environment.

A better quality cast also has another benefit. Sometimes there is material that cannot be used because the quality of the cast is too bad. If the quality can be maintained at a much higher level, than there will be much less waste of material that comes straight from the casting machines.

Finally, the snout that was designed is designed in a manner that is much more form fitting to the stock that it is water jet from. Since the wall pieces that make up the snout do not flair out like the 362626 design they can fit tightly together on a stock piece for water jet cutting. This may allow for more snouts to be produced from one piece of stock material. This will produce much less waste than other snouts.

7 Conclusions

The team believes the final snout design will be successful for producing a quality lead cast at low-flow speeds because it met specification criteria based on physical analysis, computer simulations, and real world model testing. The liaisons for the sponsor, Hazelett Corp., were satisfied with our methods for reaching the final product, our analyses ran to determine the snouts geometry, our Fluent and Abaqus simulations to look at flow characteristics and deformations, and were very satisfied with the testing procedure and results. The low-flow lead snout project had success in meeting the criteria laid out when the project began as well as meeting our clients requirements and specifications. A final model was sent to Hazelett Corp. and manufactured to be used for lead casting. The snout will be sent over to their client in China for testing and to continue to RND on a low-flow lead snout. The issue still remains of how this product will preform during real world testing with lead. While the team believes the snout produced should preform well due to judgments made from testing results, one can never be 100 % positive on anything until it is actually testing. In the coming months our clients plan to reach out and inform us on how our snout design preformed at low-speed flow conditions. Regardless of the product being a success or not, this is just the first design in an iterative process that Hazelett will have to undergo in an effort to produce the most ideal snout for low-flow conditions. Adjustments can be made to the snout geometry or rib features to achieve a better cast or make corrections once information is gathered on how this first iteration preforms.

8 Lessons Learned

Over the span of this project there were many successes and failures that the team has learned from to become better engineers. One of the big issues ran into was confusion around what acrylic model needed to be manufactured. Since we had so many models to be made for testing, all with only slight variations in geometry, and made by different team members it became unclear which was the exact model to be made. We ran into the issue once or twice of actually making the wrong part and wasting time. This could have been avoided if we had planned out a model revision system that included more detailed labels about the revision number, date made, and other pertinent details to make sure the expected design was produced. If our team had planned out a model revision system some valuable time would have been saved throughout the course of this project. Another lesson learned was to never be afraid to ask for help from advisers and those more rehearsed in what you are trying to understand. When our team ran into issues with test results are first step wasn't to talk with our advisor for help. We tried to figure things out ourselves and that ended up wasting time because our advisor was able to explain the issues we were running into very quickly. If we had made the decision to email our advisor instead of brewing on a problem for a while we would have saved valuable time. In terms of failures we learned from, our team underestimated our overall time needed for testing by a large amount. When we planned on completing our tests for the 30 % and 100 % witness test in a short period but testing ended up giving us some very long and stressful days to work through. It would have been more convenient for the team to have made a better estimation upfront so that we understood coming into testing that it would be a difficult and long process. Our team learned to ask more knowledgeable people like advisers or our client when making schedules. Finally, our team ran into the classic "measure twice cut once" issue a few times. We ordered parts that ended up being useless because we had faulty calculations. This could have been fixed if we didn't rely on one group member to run the analysis for specing out a part, but instead had an extra teammate check their work and run an analysis independently. Our team learned it is never a good idea to put the full burden on one person because it can lead to errors and just isn't good engineering practice.

Our team also have many success from this project that we can take away and use in the future. We had a very direct line of communication between team members on Slack that was useful and efficient for sharing ideas and scheduling meetings. Our team also met with out client almost every week. This kept the up to date with our project but also helped us understand what we were doing right or wrong to guide us down a good path for designing a final working concept.

References

[1] Briley, W. Roger. "Numerical Method for predicting three-dimensional steady viscous flow in ducts." Journal of Computational Physics, January 1974. PP8-28.

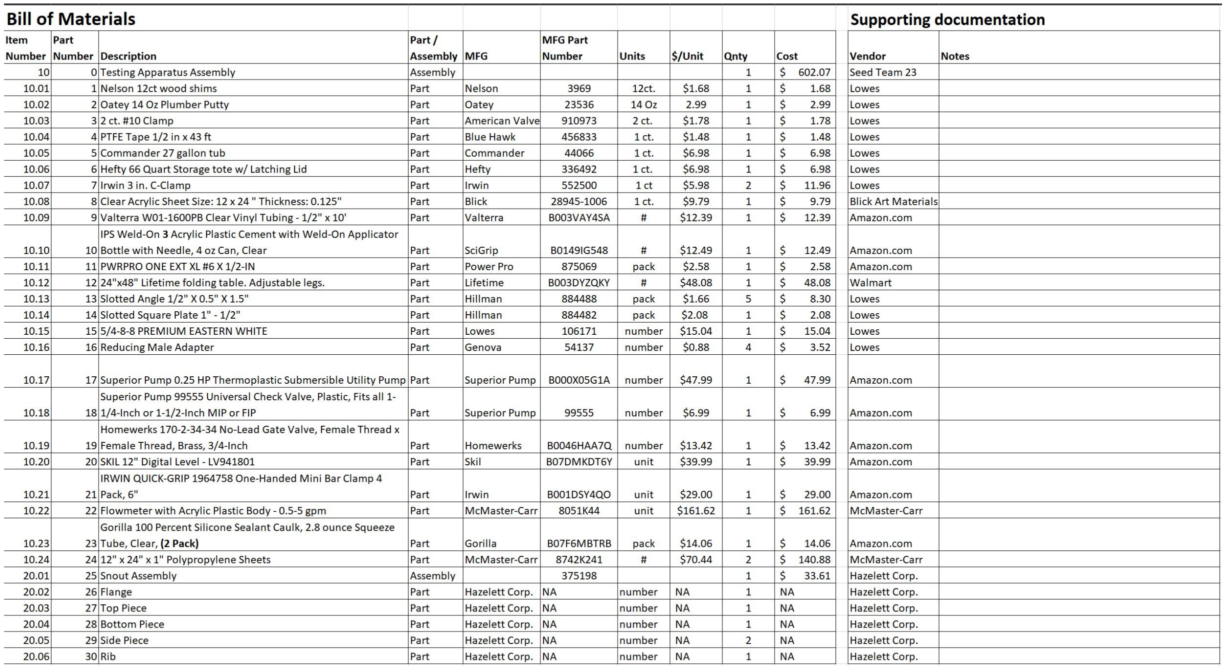
[2] Standard specification for lead and lead alloy strip, sheet and plate products. Oct 1 2014.

[3] J.D. Hwang, H.J. Lin, W.S. Hwang, C.T. Hu. "Numerical Simulation of Metal Flow and Heat Transfer during Thin Roll Strip Casting." ISIJ International, Vol. 35, 1995. PP170-177.

[4] Li, Nai-Yi, et al. Nozzle for Continuous Slab Casting. 16 Jan. 2001.

[5] Romeo, Michael. CONTINUOUS LEAD STRIP CASTING LINE , CASTER , AND NOZZLE . 15 Mar. 2018.

9 Appendix A: Bill of Materials

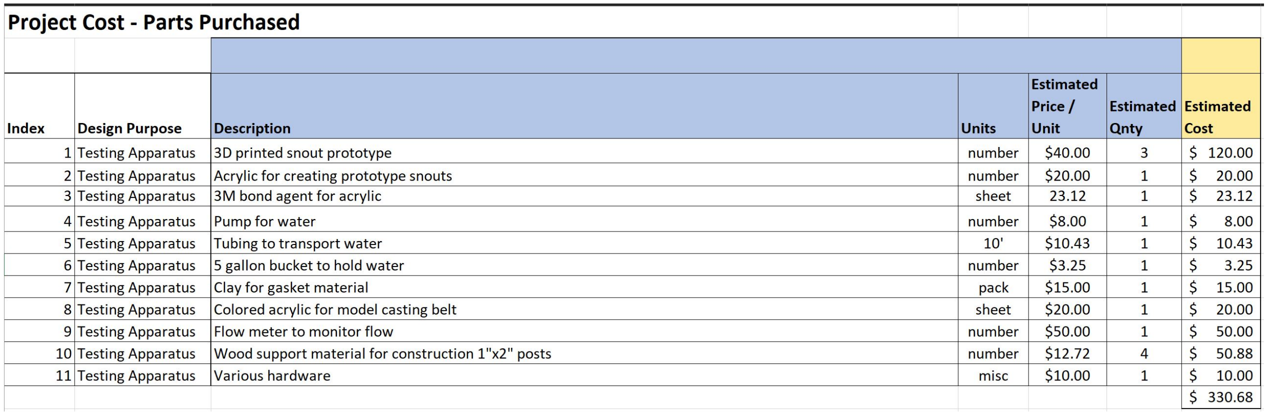


Bill of Materials / **Supporting documentation**

Item Number	Part Number	Description	Part / Assembly	MFG	MFG Part Number	Units	$/Unit	Qnty	Cost	Vendor	Notes
10	0	Testing Apparatus Assembly	Assembly					1	$ 602.07	Seed Team 23	
10.01	1	Nelson 12ct wood shims	Part	Nelson	3969	12ct.	$1.68	1	$ 1.68	Lowes	
10.02	2	Oatey 14 Oz Plumber Putty	Part	Oatey	23536	14 Oz	2.99	1	$ 2.99	Lowes	
10.03	3	2 ct. #10 Clamp	Part	American Valve	910973	2 ct.	$1.78	1	$ 1.78	Lowes	
10.04	4	PTFE Tape 1/2 in x 43 ft	Part	Blue Hawk	456833	1 ct.	$1.48	1	$ 1.48	Lowes	
10.05	5	Commander 27 gallon tub	Part	Commander	44066	1 ct.	$6.98	1	$ 6.98	Lowes	
10.06	6	Hefty 66 Quart Storage tote w/ Latching Lid	Part	Hefty	336492	1 ct.	$6.98	1	$ 6.98	Lowes	
10.07	7	Irwin 3 in. C-Clamp	Part	Irwin	552500	1 ct	$5.98	2	$ 11.96	Lowes	
10.08	8	Clear Acrylic Sheet Size: 12 x 24 " Thickness: 0.125"	Part	Blick	28945-1006	1 ct.	$9.79	1	$ 9.79	Blick Art Materials	
10.09	9	Valterra W01-1600PB Clear Vinyl Tubing - 1/2" x 10'	Part	Valterra	B003VAY4SA	#	$12.39	1	$ 12.39	Amazon.com	
10.10	10	IPS Weld-On **3** Acrylic Plastic Cement with Weld-On Applicator Bottle with Needle, 4 oz Can, Clear	Part	SciGrip	B0149IG548	#	$12.49	1	$ 12.49	Amazon.com	
10.11	11	PWRPRO ONE EXT XL #6 X 1/2-IN	Part	Power Pro	875069	pack	$2.58	1	$ 2.58	Amazon.com	
10.12	12	24"x48" Lifetime folding table. Adjustable legs.	Part	Lifetime	B003DYZQKY	#	$48.08	1	$ 48.08	Walmart	
10.13	13	Slotted Angle 1/2" X 0.5" X 1.5"	Part	Hillman	884488	pack	$1.66	5	$ 8.30	Lowes	
10.14	14	Slotted Square Plate 1" - 1/2"	Part	Hillman	884482	pack	$2.08	1	$ 2.08	Lowes	
10.15	15	5/4-8-8 PREMIUM EASTERN WHITE	Part	Lowes	106171	number	$15.04	1	$ 15.04	Lowes	
10.16	16	Reducing Male Adapter	Part	Genova	54137	number	$0.88	4	$ 3.52	Lowes	
10.17	17	Superior Pump 0.25 HP Thermoplastic Submersible Utility Pump	Part	Superior Pump	B000X05G1A	number	$47.99	1	$ 47.99	Amazon.com	
10.18	18	Superior Pump 99555 Universal Check Valve, Plastic, Fits all 1-1/4-Inch or 1-1/2-Inch MIP or FIP	Part	Superior Pump	99555	number	$6.99	1	$ 6.99	Amazon.com	
10.19	19	Homewerks 170-2-34-34 No-Lead Gate Valve, Female Thread x Female Thread, Brass, 3/4-Inch	Part	Homewerks	B0046HAA7Q	number	$13.42	1	$ 13.42	Amazon.com	
10.20	20	SKIL 12" Digital Level - LV941801	Part	Skil	B07DMKDT6Y	unit	$39.99	1	$ 39.99	Amazon.com	
10.21	21	IRWIN QUICK-GRIP 1964758 One-Handed Mini Bar Clamp 4 Pack, 6"	Part	Irwin	B001DSY4QO	unit	$29.00	1	$ 29.00	Amazon.com	
10.22	22	Flowmeter with Acrylic Plastic Body - 0.5-5 gpm	Part	McMaster-Carr	8051K44	unit	$161.62	1	$ 161.62	McMaster-Carr	
10.23	23	Gorilla 100 Percent Silicone Sealant Caulk, 2.8 ounce Squeeze Tube, Clear, **(2 Pack)**	Part	Gorilla	B07F6MBTRB	pack	$14.06	1	$ 14.06	Amazon.com	
10.24	24	12" x 24" x 1" Polypropylene Sheets	Part	McMaster-Carr	8742K241	#	$70.44	2	$ 140.88	McMaster-Carr	
20.01	25	Snout Assembly	Assembly		375198			1	$ 33.61	Hazelett Corp.	
20.02	26	Flange	Part	Hazelett Corp.	NA	number	NA	1	NA	Hazelett Corp.	
20.03	27	Top Piece	Part	Hazelett Corp.	NA	number	NA	1	NA	Hazelett Corp.	
20.04	28	Bottom Piece	Part	Hazelett Corp.	NA	number	NA	1	NA	Hazelett Corp.	
20.05	29	Side Piece	Part	Hazelett Corp.	NA	number	NA	2	NA	Hazelett Corp.	
20.06	30	Rib	Part	Hazelett Corp.	NA	number	NA	1	NA	Hazelett Corp.	

Figure 23: Bill of Materials for Testing Apparatus and Snout

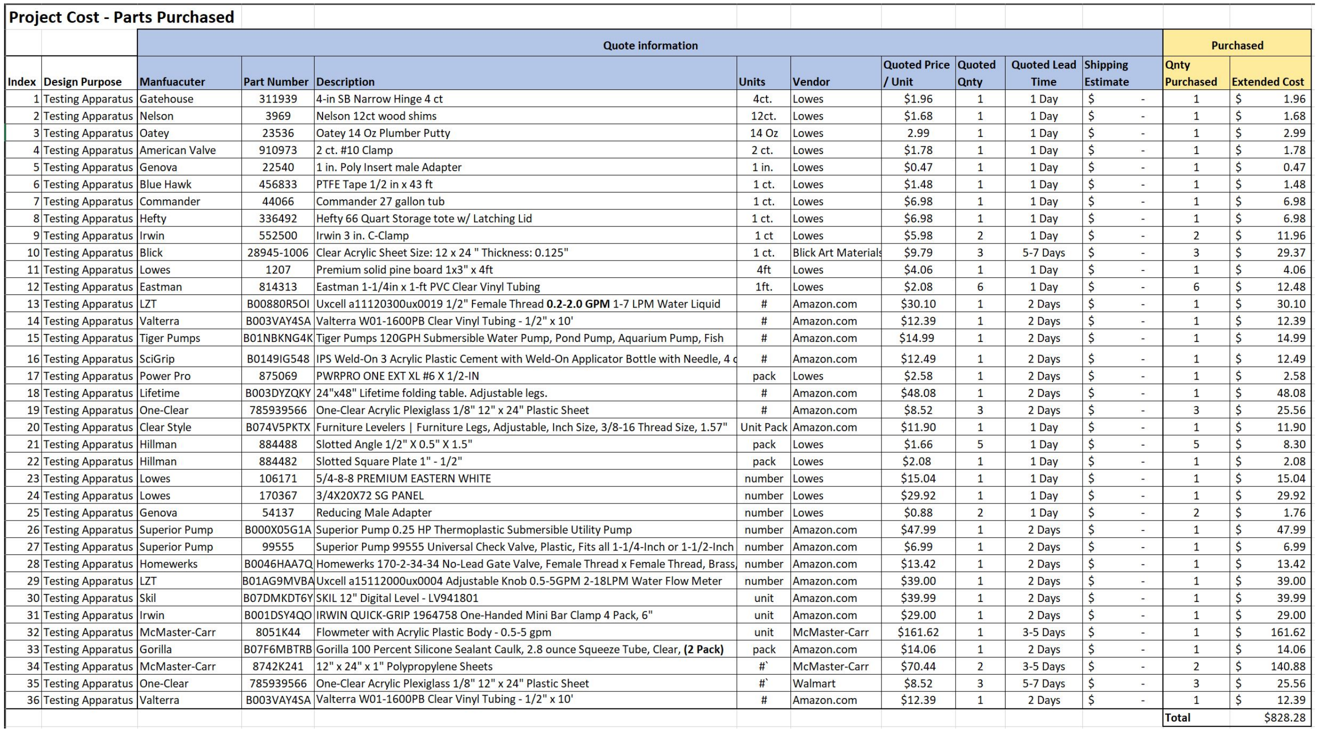
10 Appendix B: Budget



Project Cost - Parts Purchased

Index	Design Purpose	Description	Units	Estimated Price / Unit	Estimated Qnty	Estimated Cost
1	Testing Apparatus	3D printed snout prototype	number	$40.00	3	$ 120.00
2	Testing Apparatus	Acrylic for creating prototype snouts	number	$20.00	1	$ 20.00
3	Testing Apparatus	3M bond agent for acrylic	sheet	23.12	1	$ 23.12
4	Testing Apparatus	Pump for water	number	$8.00	1	$ 8.00
5	Testing Apparatus	Tubing to transport water	10'	$10.43	1	$ 10.43
6	Testing Apparatus	5 gallon bucket to hold water	number	$3.25	1	$ 3.25
7	Testing Apparatus	Clay for gasket material	pack	$15.00	1	$ 15.00
8	Testing Apparatus	Colored acrylic for model casting belt	sheet	$20.00	1	$ 20.00
9	Testing Apparatus	Flow meter to monitor flow	number	$50.00	1	$ 50.00
10	Testing Apparatus	Wood support material for construction 1"x2" posts	number	$12.72	4	$ 50.88
11	Testing Apparatus	Various hardware	misc	$10.00	1	$ 10.00
						$ 330.68

Figure 24: Estimated Budget for SEED Team 23

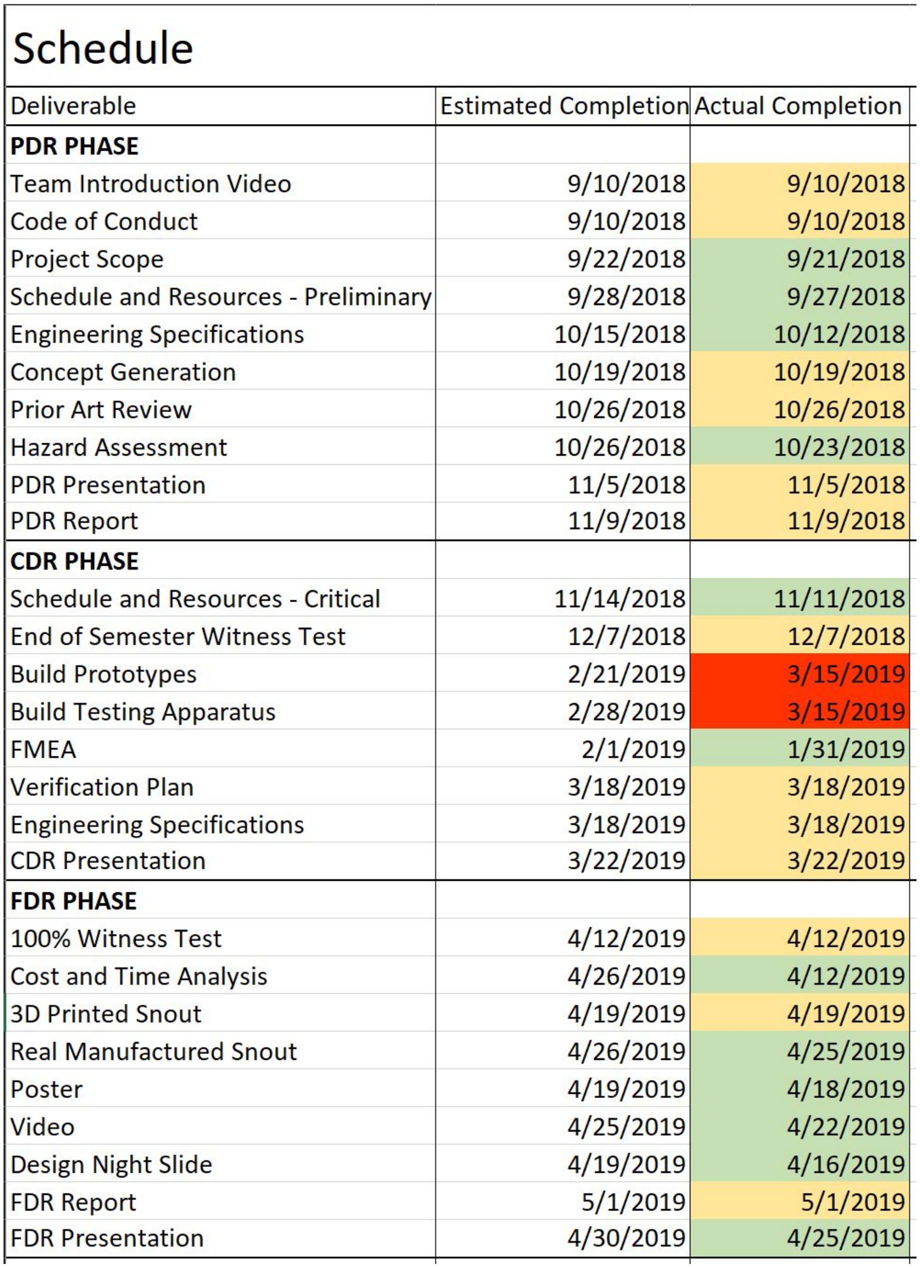


Project Cost - Parts Purchased

		Quote information									Purchased	
Index	Design Purpose	Manfuacuter	Part Number	Description	Units	Vendor	Quoted Price / Unit	Quoted Qnty	Quoted Lead Time	Shipping Estimate	Qnty Purchased	Extended Cost
1	Testing Apparatus	Gatehouse	311939	4-in SB Narrow Hinge 4 ct	4ct.	Lowes	$1.96	1	1 Day	$ -	1	$ 1.96
2	Testing Apparatus	Nelson	3969	Nelson 12ct wood shims	12ct.	Lowes	$1.68	1	1 Day	$ -	1	$ 1.68
3	Testing Apparatus	Oatey	23536	Oatey 14 Oz Plumber Putty	14 Oz	Lowes	2.99	1	1 Day	$ -	1	$ 2.99
4	Testing Apparatus	American Valve	910973	2 ct. #10 Clamp	2 ct.	Lowes	$1.78	1	1 Day	$ -	1	$ 1.78
5	Testing Apparatus	Genova	22540	1 in. Poly Insert male Adapter	1 in.	Lowes	$0.47	1	1 Day	$ -	1	$ 0.47
6	Testing Apparatus	Blue Hawk	456833	PTFE Tape 1/2 in x 43 ft	1 ct.	Lowes	$1.48	1	1 Day	$ -	1	$ 1.48
7	Testing Apparatus	Commander	44066	Commander 27 gallon tub	1 ct.	Lowes	$6.98	1	1 Day	$ -	1	$ 6.98
8	Testing Apparatus	Hefty	336492	Hefty 66 Quart Storage tote w/ Latching Lid	1 ct.	Lowes	$6.98	1	1 Day	$ -	1	$ 6.98
9	Testing Apparatus	Irwin	552500	Irwin 3 in. C-Clamp	1 ct	Lowes	$5.98	2	1 Day	$ -	2	$ 11.96
10	Testing Apparatus	Blick	28945-1006	Clear Acrylic Sheet Size: 12 x 24 " Thickness: 0.125"	1 ct.	Blick Art Materials	$9.79	3	5-7 Days	$ -	3	$ 29.37
11	Testing Apparatus	Lowes	1207	Premium solid pine board 1x3" x 4ft	4ft	Lowes	$4.06	1	1 Day	$ -	1	$ 4.06
12	Testing Apparatus	Eastman	814313	Eastman 1-1/4in x 1-ft PVC Clear Vinyl Tubing	1ft.	Lowes	$2.08	6	1 Day	$ -	6	$ 12.48
13	Testing Apparatus	LZT	B00880R5OI	Uxcell a11120300ux0019 1/2" Female Thread **0.2-2.0 GPM** 1-7 LPM Water Liquid	#	Amazon.com	$30.10	1	2 Days	$ -	1	$ 30.10
14	Testing Apparatus	Valterra	B003VAY4SA	Valterra W01-1600PB Clear Vinyl Tubing - 1/2" x 10'	#	Amazon.com	$12.39	1	2 Days	$ -	1	$ 12.39
15	Testing Apparatus	Tiger Pumps	B01NBKNG4K	Tiger Pumps 120GPH Submersible Water Pump, Pond Pump, Aquarium Pump, Fish	#	Amazon.com	$14.99	1	2 Days	$ -	1	$ 14.99
16	Testing Apparatus	SciGrip	B0149IG548	IPS Weld-On 3 Acrylic Plastic Cement with Weld-On Applicator Bottle with Needle, 4 c	#	Amazon.com	$12.49	1	2 Days	$ -	1	$ 12.49
17	Testing Apparatus	Power Pro	875069	PWRPRO ONE EXT XL #6 X 1/2-IN	pack	Lowes	$2.58	1	2 Days	$ -	1	$ 2.58
18	Testing Apparatus	Lifetime	B003DYZQKY	24"x48" Lifetime folding table. Adjustable legs.	#	Amazon.com	$48.08	1	2 Days	$ -	1	$ 48.08
19	Testing Apparatus	One-Clear	785939566	One-Clear Acrylic Plexiglass 1/8" 12" x 24" Plastic Sheet	#	Amazon.com	$8.52	3	2 Days	$ -	3	$ 25.56
20	Testing Apparatus	Clear Style	B074V5PKTX	Furniture Levelers | Furniture Legs, Adjustable, Inch Size, 3/8-16 Thread Size, 1.57"	Unit Pack	Amazon.com	$11.90	1	1 Day	$ -	1	$ 11.90
21	Testing Apparatus	Hillman	884488	Slotted Angle 1/2" X 0.5" X 1.5"	pack	Lowes	$1.66	5	1 Day	$ -	5	$ 8.30
22	Testing Apparatus	Hillman	884482	Slotted Square Plate 1" - 1/2"	pack	Lowes	$2.08	1	1 Day	$ -	1	$ 2.08
23	Testing Apparatus	Lowes	106171	5/4-8-8 PREMIUM EASTERN WHITE	number	Lowes	$15.04	1	1 Day	$ -	1	$ 15.04
24	Testing Apparatus	Lowes	170367	3/4X20X72 SG PANEL	number	Lowes	$29.92	1	1 Day	$ -	1	$ 29.92
25	Testing Apparatus	Genova	54137	Reducing Male Adapter	number	Lowes	$0.88	2	1 Day	$ -	2	$ 1.76
26	Testing Apparatus	Superior Pump	B000X05G1A	Superior Pump 0.25 HP Thermoplastic Submersible Utility Pump	number	Amazon.com	$47.99	1	2 Days	$ -	1	$ 47.99
27	Testing Apparatus	Superior Pump	99555	Superior Pump 99555 Universal Check Valve, Plastic, Fits all 1-1/4-Inch or 1-1/2-Inch	number	Amazon.com	$6.99	1	2 Days	$ -	1	$ 6.99
28	Testing Apparatus	Homewerks	B0046HAA7Q	Homewerks 170-2-34-34 No-Lead Gate Valve, Female Thread x Female Thread, Brass,	number	Amazon.com	$13.42	1	2 Days	$ -	1	$ 13.42
29	Testing Apparatus	LZT	B01AG9MVBA	Uxcell a15112000ux0004 Adjustable Knob 0.5-5GPM 2-18LPM Water Flow Meter	number	Amazon.com	$39.00	1	2 Days	$ -	1	$ 39.00
30	Testing Apparatus	Skil	B07DMKDT6Y	SKIL 12" Digital Level - LV941801	unit	Amazon.com	$39.99	1	2 Days	$ -	1	$ 39.99
31	Testing Apparatus	Irwin	B001DSY4QO	IRWIN QUICK-GRIP 1964758 One-Handed Mini Bar Clamp 4 Pack, 6"	unit	Amazon.com	$29.00	1	2 Days	$ -	1	$ 29.00
32	Testing Apparatus	McMaster-Carr	8051K44	Flowmeter with Acrylic Plastic Body - 0.5-5 gpm	unit	McMaster-Carr	$161.62	1	3-5 Days	$ -	1	$ 161.62
33	Testing Apparatus	Gorilla	B07F6MBTRB	Gorilla 100 Percent Silicone Sealant Caulk, 2.8 ounce Squeeze Tube, Clear, **(2 Pack)**	pack	Amazon.com	$14.06	1	2 Days	$ -	1	$ 14.06
34	Testing Apparatus	McMaster-Carr	8742K241	12" x 24" x 1" Polypropylene Sheets	#`	McMaster-Carr	$70.44	2	3-5 Days	$ -	2	$ 140.88
35	Testing Apparatus	One-Clear	785939566	One-Clear Acrylic Plexiglass 1/8" 12" x 24" Plastic Sheet	#`	Walmart	$8.52	3	5-7 Days	$ -	3	$ 25.56
36	Testing Apparatus	Valterra	B003VAY4SA	Valterra W01-1600PB Clear Vinyl Tubing - 1/2" x 10'	#	Amazon.com	$12.39	1	2 Days	$ -	1	$ 12.39
											Total	$828.28

Figure 25: Actual Budget for SEED Team 23

11 Appendix C: Schedule



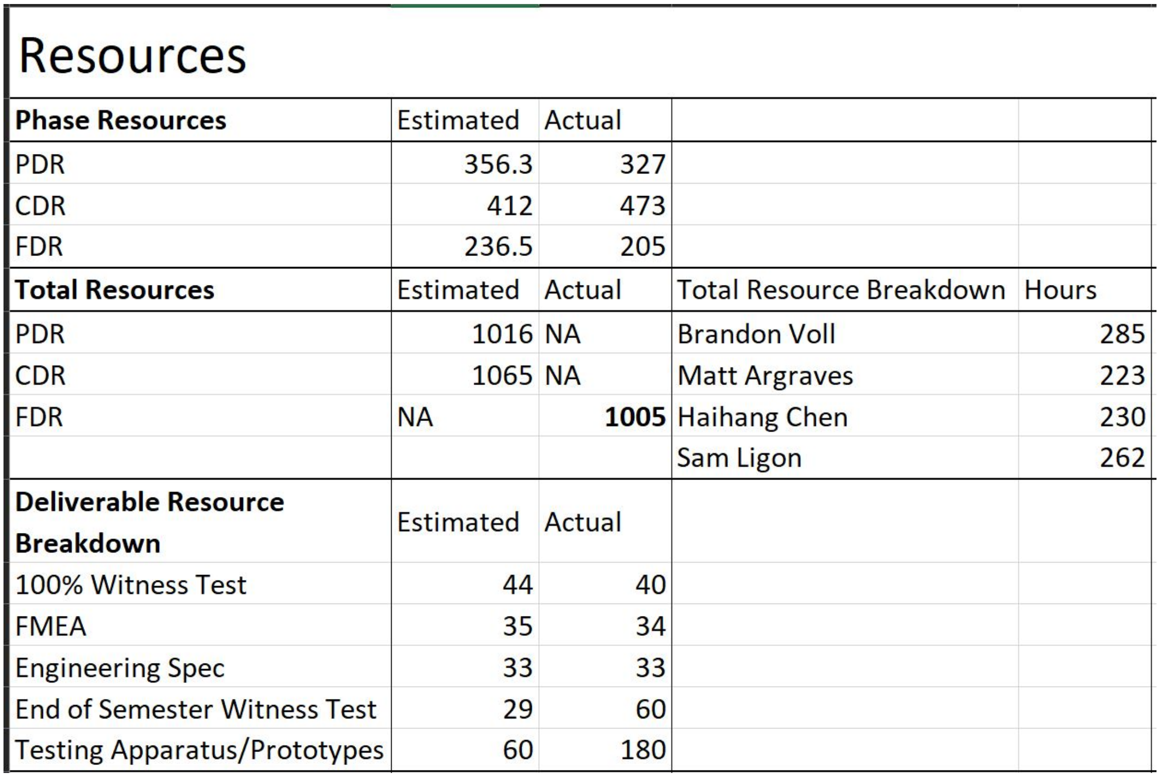
Schedule

Deliverable	Estimated Completion	Actual Completion
PDR PHASE		
Team Introduction Video	9/10/2018	9/10/2018
Code of Conduct	9/10/2018	9/10/2018
Project Scope	9/22/2018	9/21/2018
Schedule and Resources - Preliminary	9/28/2018	9/27/2018
Engineering Specifications	10/15/2018	10/12/2018
Concept Generation	10/19/2018	10/19/2018
Prior Art Review	10/26/2018	10/26/2018
Hazard Assessment	10/26/2018	10/23/2018
PDR Presentation	11/5/2018	11/5/2018
PDR Report	11/9/2018	11/9/2018
CDR PHASE		
Schedule and Resources - Critical	11/14/2018	11/11/2018
End of Semester Witness Test	12/7/2018	12/7/2018
Build Prototypes	2/21/2019	3/15/2019
Build Testing Apparatus	2/28/2019	3/15/2019
FMEA	2/1/2019	1/31/2019
Verification Plan	3/18/2019	3/18/2019
Engineering Specifications	3/18/2019	3/18/2019
CDR Presentation	3/22/2019	3/22/2019
FDR PHASE		
100% Witness Test	4/12/2019	4/12/2019
Cost and Time Analysis	4/26/2019	4/12/2019
3D Printed Snout	4/19/2019	4/19/2019
Real Manufactured Snout	4/26/2019	4/25/2019
Poster	4/19/2019	4/18/2019
Video	4/25/2019	4/22/2019
Design Night Slide	4/19/2019	4/16/2019
FDR Report	5/1/2019	5/1/2019
FDR Presentation	4/30/2019	4/25/2019

Figure 26: Schedule for SEED Team 23

The schedule as seen above in figure 26 was followed mostly well. The green shows deliverables which were completed ahead of schedule, the yellow shows deliverables which were completed on the due date, and the red shows deliverables which were completed late. There are only two deliverables which were late, but they were very important deliverables. The completion of the prototypes and the testing apparatus were paramount to the success of the project and took a large amount of hours to complete. This required that some adjustments were made for other deliverables. The main change was that all of the testing that was going to be done over the course of a few weeks was condensed to a much shorter time span. It was still completed but not with as much time to spare in case something went wrong. The original plan was to hopefully complete many of the deliverables in the FDR much earlier than they were due. Many of them were still completed early, but not as early as the team had originally hoped. The late completion of the prototypes and testing apparatus caused these later dates to occur, and subsequently pushed the whole project back. It was important that a buffer was added originally, because with these changes the project was still completed satisfactorily in an acceptable time.

12 Appendix D: Resources



Resources

Phase Resources	Estimated	Actual		
PDR	356.3	327		
CDR	412	473		
FDR	236.5	205		
Total Resources	Estimated	Actual	Total Resource Breakdown	Hours
PDR	1016	NA	Brandon Voll	285
CDR	1065	NA	Matt Argraves	223
FDR	NA	**1005**	Haihang Chen	230
			Sam Ligon	262
Deliverable Resource Breakdown	Estimated	Actual		
100% Witness Test	44	40		
FMEA	35	34		
Engineering Spec	33	33		
End of Semester Witness Test	29	60		
Testing Apparatus/Prototypes	60	180		

Figure 27: Resources for SEED Team 23

The main difficulty that our group had in terms of estimating resources for the project was estimating the design and building of the prototypes and the testing apparatus. It can be seen above in figure 27 that the actual hours for testing apparatus and prototypes were much higher than estimated. In some cases the actual time was tripled from the estimated. One of the reasons for this was that initially there was a difficulty in building the snouts. The acrylic needed to be heated and bent to create a 6 degree bend. The first method to do this did not work and another method needed to be designed. Also, learning a good process to put the snouts together was trial and error. A few snouts needed to be manufactured before the team figured out a good process to manufacture the acrylic snouts. The reason that the building of the testing apparatus took much longer than expected was due to error on purchasing and calculation errors. At first, the group tried to purchase to save money but this was the wrong direction to go. Buying quality parts right off the bat would have been the smart choice. Also, a few wrong parts were purchased because of calculation errors. This cost money but more importantly valuable time while the problem was resolved and new parts were purchased.

13 Appendix E: Prior Art Review

The first relevant patent that was found was Patent No.: US 6,173,755 B1. This patent discussed information on an improved casting nozzle for continuous slab casting machines.[4] This patent describes a few different methods of reducing turbulence in the flow, which is extremely important for the project. It also summarizes the method of using a thermal insulation layer to prevent back flow, as well as a friction reducing layer.[4] Finally, the patent describes the versatility of the nozzle as it can be used in different configurations and with different equipment.[4] Another patent that was found was Pub . No . : US 2018 / 0071816 A1. This patent discussed information on not only the nozzle but also the ladle and the rollers, which are upstream and downstream from the nozzle respectively.[5] The material used for casting in this patent is strictly lead, which is the same material as the lead casting snout for the project. The patent goes on to describe all of the previously mentioned parts in detail, and provides relevant information on the nozzle which the group is working on.

By and large the most relevant research article found in regards to numerical simulation described the simulation of metal casting.[3] This article outlined initial conditions, boundary conditions, grid information, and numerical methods of a successful transient simulation of metal casting. It answered extremely relevant questions such as the outlet conditions, on a moving belt physical model (Something which was proving difficult to determine). The information from this article works in tandem with the information found in the internal flow in a duct article.[1] This was most useful in helping solidify understanding of three-dimensional internal flow simulation.

The relevant standard which was found was ASTM-B749-14. This standard covers lead sheet, strip and plate of various alloys intended for use in chemical plants, sound attenuation, roofing, vibration damping, flashing and weather stripping, waterproofing and radiation shielding.[2] It stated a lot of data table about the lead properties. There is also some experiment about test tension and hardness on the standard. It is a specification of the lead.

There are a few major things that were learned from the patents that could apply to the project. The first learned piece of information is that the molten metal could be shrouded in an inert gas to create better meniscus stability.[4] The next piece of information is to reduce the cascade height of the molten metal. The cascade height is the distance the molten metal falls from the end of the nozzle to the rollers below. A large cascade height causes turbulence. It was learned that a desirable cascade height is less than 0.0625 inches and the angle of the sloped surface ranges from 5 to 85 degrees with the desired angle being between 15 and 80 degrees.[4] It was also confirmed that having a controlled laminar flow will cause the surface quality of the metal slab to be of superior quality.[4] Another point of information found in the patents is that adding flow straighteners was confirmed to be a good way to reduce turbulence in the flow.[5]

The learned sum of the research with regards to numerical methods included the general conditions needed to set up a proper simulation. Grid constraints were addressed, alongside boundary conditions. Both will prove salient in the model developed for the design of this project. Another important discovery was in regard to the physical properties of lead. These will be well used in the future, at least until a better estimate of the lead alloy is returned to us by Hazelett. The standard provides most of definition of lead. It is helpful on theoretical simulations on design process. It also states a clear rules about casting lead. It is useful on knowing how the project work.

14 Appendix F: Head Loss Calculation Code

```
””” Created on Thu Apr 18 16:31:30 2019

author: Brandon Voll ””” import math

Q = .0001520469 m3̂/s flow rate

Dc = 0.0127 m diameter of tubing

Dcmm = 12.7 mm diameter of tubing

g = 9.81 m/s2̂

Find the velocity so the reynolds number can be found

v = (4*Q)/(math.pi*Dc**2)

print(’Velocity of fluid =’, v)

Now find the reynolds number of the water in the tube

kv = 0.0000010023 m2̂/s kinematic viscosity

R = (v*Dc)/(kv)

print(’Reynolds Number in tubing=’, R)

if R¿2000:

print(’The flow is turbulent’)

else:

print(’The flow is laminar’)

Find the relative roughness
```

```
e = .0015 epsilon

rr = e/Dcmm Relative Roughness

print(’Relative Roughness of tubing =’, rr)

Use Moody Chart to find fd

fd = 0.037 darcy friction factor

Calculate head loss S

S = fd * (8/((math.pi**2)*g)) * ((Q**2)/(Dc**5))

print(’Head Loss per Length of Tube=’, S)

ml = 3.302 larger tube length

ll = 3.1369 smaller tube length

lwfm = 3.81 Length of all tubing including flow meter

mtube = ml*S

ltube = ll*S

alltube = lwfm*S

print(’The head loss with current tubing is (meters)’, mtube)

print(’The head loss with previous tubing is (meters)’, ltube)

print(’The head loss with all tubing including flowmeter (meters)’, alltube)

lossfeet = alltube*3.28084

print(’Head loss in feet’, lossfeet)
```