SFSA Cast In Steel 2025 – George Washington's Sword Technical Report

Purdue University - Hammer Down

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I. Introduction

SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available. For the 2024-2025 university calendar year, SFSA has challenged North American universities to manufacture a replica of one of George Washington's swords provided by the Mount Vernon Society [1]. Of the swords provided, the Purdue team replicated the "Silver Lion-Headed Cutthoe" as a submission for this competition.

The Purdue team has identified a set of milestones that are crucial to competition success and foundry design. Pictured in Figure 1, this flowchart dictated the decisions the team made, how each step was accounted for along the way, why specific pivots or changes were decided and will outline the flow of this report [2]. Working with Kimura Foundry America, many of these steps were iterated on to produce a successful casting.

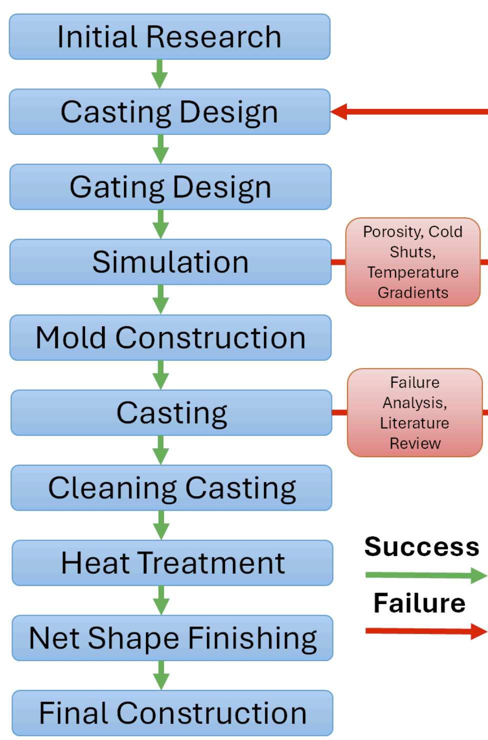

Figure 1: SFSA Cast in Steel flow chart of competition milestones.

Foundry design employs a multitude of different software for many different applications. A combination of Fusion 360, Solidworks, Maya, and MAGMASOFT can be used together for individual needs in the design process. Fusion 360 and Solidworks are CAD programs focused on constructing geometric designs for engineering purposes and designs. This software helped to make exact specification drawings for constructing patterns. Maya is another modeling software, however, focused on creating organic and artistic designs for computer assets and visual effects. Complex meshes from Maya can be imported into other software, allowing for both software's advantages to be used to create a complex and geometric mesh. Together, modeling portions where engineering tolerances are needed and artistic liberty became easy to couple. Finally, MAGMASOFT is a finite volume method software for modeling computational fluid dynamics, solidification, and predicting casting defects that can import meshes from previous applications and simulate a metal fluid [3].

Two modern casting methods were used in manufacturing the blade. The first is additive manufacturing and molding. The disadvantages of sand molding include needing a pattern with a parting line and draft angles for removing the positive mold from the sand [4]. Incorporating additively manufactured sand molding allows for this limitation to be overcome while still having the lost cost of materials and reliability of bound sands used in the printing process. Fast prototyping allows for patterns to be generated, simulated, and printed in a matter of days while achieving high fidelity, even in thin regions [5]. The second method utilized was the lost wax investment casting approach that replaces traditional wax patterns with 3D‑printed PLA, commonly termed "lost PLA." This technique retains the precision and superior surface finish of conventional investment casting while leveraging the rapid prototyping and design flexibility inherent to additive manufacturing. Central to the process is the formation of a robust ceramic shell around the PLA pattern and a carefully controlled burnout cycle, which ensures the complete removal of the sacrificial material without compromising mold integrity. Although the method offers clear benefits in terms of complex geometry fabrication, cost reduction, and reduced development time, it requires temperature management during burnout to reduce issues such as shell cracking [2,4]. Utilizing specific casting methods for the roles of either large, rapidly iterated patterns or small, very precise castings allowed work in parallel that suited the application.

When considering a sword the steel needs to maintain a balance between strength and ductility to not allow for a major failure when yielding. Two methods are proposed for achieving these mechanically favorable properties: alloy selection and heat treatment. An ideal blade is composed of a fully tempered martensite structure due to its high strength and toughness which is important for high-impact testing. Selecting the correct alloy and tempering schedule offers the greatest resilience toward strengthening the blade [4,6].

Before heat treatment, an as-cast dendritic microstructure of the billet was composed of cementite and ferrite phases. Cementite is very strong but lacks any flexibility, unlike ferrite which is quite malleable. The large range in grain sizes and carbides formed along grain boundaries are poor for mechanical properties and can be improved during forging and subsequent heat treatment [6,7]. To homogenize the structure normalization is needed, which consists of bringing a sample above its austenization temperature of 900ºC and allowing it to air cool [8,9]. When austenite transforms slowly through a slow cooling rate, carbon can diffuse into a pearlite structure which is malleable and soft. By rapidly cooling the steel in oil, the carbon is trapped within the transforming lattice resulting in a stressed martensite structure. While strong, martensitic structures are brittle, resulting in an increased likelihood of sudden fracture and minimal toughness [4,6]. Through reheating the martensitic steel, diffusion can occur allowing carbide precipitants to form. The stress must be relieved and the carbon allowed to precipitate into carbide to provide strength to the iron matrix. Optimal heat treatments favor the distribution of fine precipitants to ensure dislocations are impinged during deformation events, not allowing the metal to flow. The final product is a fully tempered martensite blade with high tensile strength and hardness [4,7].

Figure 2: Cast steel showing a solidification microstructure (left) and normalized steel(right)

(Figure Images adapted from Bergman) [3]

II. Historical Background

The cuttoe is a European hunting weapon from the seventeenth century, whose name originates as an anglicization of the French term “couteaux de chasse” meaning “hunting knife.” It became a popular secondary weapon for many European infantrymen in the late seventeenth to early eighteenth century [10]. Despite being an infantry-level weapon, the decorative elements of the sword would have affirmed George Washington’s status while aiding him in battle. The ivory grip, fine knuckle chain, and silver pommel were commonplace for cuttoes of the era, with the choice of a lion for the pommel being distinctly British in style [11,12].

The length of traditional cuttoes is typically between 24 and 27 inches, vastly smaller than the 30 to 33-inch small swords used by many officers of the British and French armies. Due to George Washington's impressive stature of six foot two, he requested the length of the blade be an abnormally long length of 30 inches. The blade features a slightly curved blade with a single edge, concluding in an asymmetrical point on the inward curve, which is matched by the asymmetry of the rest of the sword to guide the grip of the user [10]. The sword is an American-made version of the popular British style as he obtained it from Jacob Gooding in 1770, who likely acquired it in Philadelphia, during the Virginia Nonimportation Resolution that asked that Virginians not buy or import goods from Great Britain, which Washington was a staunch supporter of [10,11].

III. Casting and Gating Design

A. As Cast Blade Design

To create the design for the as-cast sword, the image of the cuttoe on the Mt. Vernon website was imported into Solidworks and traced over to get an accurate profile. The team attempted to reach out to the curators to get measurements or scans of the sword but were unable to, as the cuttoe is currently in a private collection. Dimensions were instead gathered by scaling the image based on the 30” blade measurement provided by the Mount Vernon website and taking pixel measurements using the ImageJ software as seen in Figure 3 [1,13].

Figure 3: Sword profile and reference image. Rought shapes drawn and estimated in ImageJ. (Figure adapted from Mount Vernon Society) [13].

The body of the sword was created by lofting between profiles at several points along the blade, which allowed for a smooth transition in and out of the primary and secondary fullers images in Figure 4. The edges of the blade were rounded off to a radius of 5/16” to allow the molten steel to fill the edge during casting and be ground down post-casting.

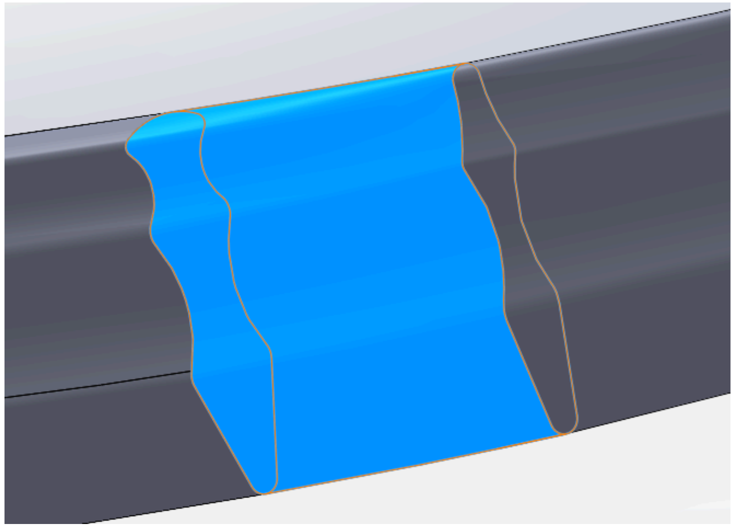

Figure 4: Blade profile lofts

The first iteration of the blade was intended to be cast vertically and was designed with a large, conical sprue at the end of the tang displayed in Figure 5. The tang was also extended to allow for piping, or solidification shrinkage, to occur during casting without impacting the final structure of the blade [2,4]. The base of the blade was also lofted into the tang, to limit the sharpness of the corner at the transition point and limit the potential for misruns, a feature which was retained in future iterations of the design.

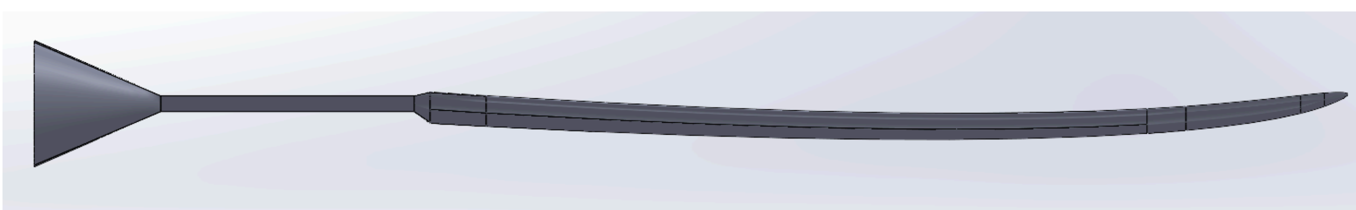

Figure 5: Vertical casting design

Another gating setup was simultaneously designed for horizontal casting, consisting of a large runner along the back of the sword, with tapered gates going into the sword at several points down the length and a riser above each gate.

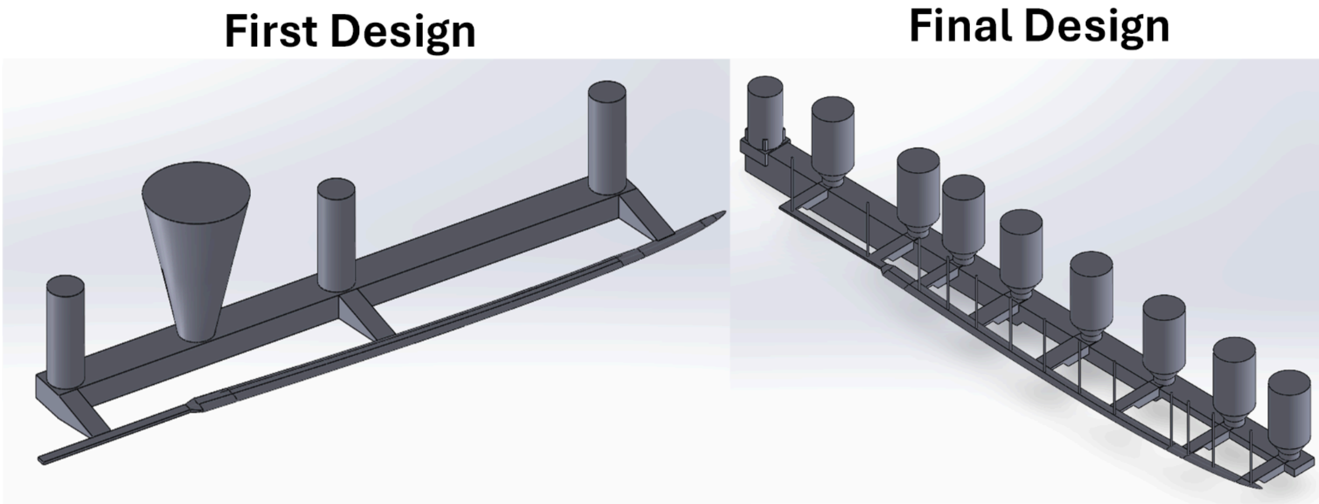

Figure 6: Horizontal casting design. First iteration (left) and final iteration (right) of horizontal design. Collaboration with Kimura.

These two designs were sent to the Kimura Foundry for simulation and advice for improvements, who recommended the horizontal design. Kimura helped us with making MAGMA simulations and provided feedback which was used to produce the design in figure 6. This design increased the number of gates into the sword and the corresponding risers to help fill the casting more evenly and added vents to the top of the blade to draw out porosity and let out trapped gases. The runner was also changed to a tapered design, becoming thinner along its length to increase the yield of the casting by limiting the scrap material.

B. Forge Billets Design

The billets were designed to be slightly overweight to allow sufficient material removal and loss in hot working. As these billets were designed to be mechanically deformed rather than cast to shape, a rectangular prism design was settled on. Using the project weight limit of 4.4 lbs and the density of steel at roughly .28 pounds per cubic inch, we decided on billets of 18 cubic inches to arrive at roughly 5 lb billets which was deemed sufficient working room for the sword. After brief Magma bare cast simulations and consulting with the team members in charge of forging out the billets, we decided on 1.5”x1.5”x8” billets as a balance of castability and forge work. Kimura Foundry America helped immensely with their time and expertise with the rigging of the billets for casting.

C. Lion-Headed Pommel and Floral Guard Design

The lion pommel was historically a symbol of the British Empire. The king of beasts is a common charge in heraldry as a traditional symbol of strength, courage, and royalty. It thus would have been common to see on a sword made to replicate a standard English-made mid-18th-century civilian cuttoe, used to dispatch wild boar or foxes during a hunt and a style which Washington favored while on active service, despite the sword being American-made. Additionally, reaching out to multiple historians at Purdue University, including Allie Brandt and Dr. T. Cole Jones, different perspectives on the style of the lion head emerged, claiming it was either an example of Chinoiserie, a traditional English style, or grotesque [12,14].

The case for the lion being an example of Chinoiserie, the European imitation of Chinese and East Asian art, came from Allie Brandt, a professor of art history, who noted the lion was likely engraved by a blacksmith attempting to recreate the image of a lion from a Chinese or imitation print. She emphasized that the blacksmith was likely a smith first and not a trained artist, explaining the odd appearance from a modern perspective. Foreign trade was restricted to Guangzhou after 1757, where Chinese artists there engaged directly with Western drawings, copperplate engravings, and other sources as models for export objects. Thus, a large number of goods in this style in the European and American markets weren’t originals from China but simply replicated from prints. While the resemblance is there and the time aliens, there simply isn’t enough concrete evidence to distinctly claim that was the style this lion was created in [14,15,16].

Dr. T. Cole Jones, a professor of early American and Revolutionary War history, simply saw the lion as being in a traditional English style. While this was a straightforward interpretation, the symbolism was a bit more vague and hard to research as lions have been so frequently depicted in Engish art that the scope of the artistic style had a lot of variety, and finding a similar piece proved difficult. Especially as much of the focus of lions in 1700s English art is in heraldry, where the lion is depicted from a side view instead of head-on or in sculpture. In researching similar swords from the era, we realized the lion could also be an example of grotesque, which is derived from the Italian *grotteschi,* and was common on 17th-century English and American case furniture. A product of Raphiel during the High Renaissance, decoration art involved mixed animal, human, and plant forms, came into fashion and spread throughout Europe in the 1600s. While there is a resemblance, the evidence to say this was the style the lion was designed in is still lacking [12,14].

Historical research left the pommel's design with the challenge of representing a symbol of Washington's biggest political enemy on his sword [12]. As there was no doubt that the sword itself was British, but reclaimed by one of America's greatest leaders, thus the Purdue team decided to reclaim the symbol of the lion with a symbol of one of America's greatest accomplishments. After the Civil War, the United States expanded access to education with the Morrill Acts of 1862 and 1890, which created land grant universities, a symbol of American innovation and education. One of these universities is Purdue, founded in 1869, created to bring agricultural research to Indiana, and has since gone on to become an engineering powerhouse, the first college to offer a degree in aviation, and has sent the most astronauts to the moon including the first, Neil Armstrong, and the most recent, Eugene Cernan [17]. On Purdue's campus, a lion fountain has become a symbol of good luck to the student body, promising luck for exams if you drink from it. Thus, instead of trying to recreate a symbol of British imperialism, the Purdue team chose to honor Washington's legacy by using symbolism from one of America's greatest establishments by using a scan of the lion fountain for the pommel [18].

The S-shaped quillon design of the original sword was a well-known English style that was often copied in the colonies. The shape was for the function to be hung from the user's belt. However, we chose to keep but slightly modify the flower engravings on the guard to honor some of the many flowers grown at Mount Vernon. The center flower on the guard loosely blends the original design while taking inspiration from the French Striped Marigold that resides on the upper level of the president's former residence [10,12].

Attempting to model the lion from scratch in Maya was disadvantageous. Just using references to guide the polygonal modeling proved to be inefficient in getting accurate proportions, adjusting the artistic style, and overall aesthetic appearance. Luckily, the Visualization and Research Center at Purdue had an STL file of a scan of the lion fountain, which was cleaned and made into the pommel's shape [18]. Reconstruction of the model was necessary as the scanned STL was mostly flat against the fountain only showing the lion's face while its mane flowing back from its face around its head needed to be added. While this posed issues with cleaning up the polygon mesh it was overall easier and provided a more detailed result. 3D modeling software Maya helped sculpt the organic flow of hair so that the detail of the original scan could be replicated on the back of the head. Additionally, the flower detailing of the guard was also modeled in Maya, which allowed for that organic and smooth shape that would have been achieved by hand-engraved detailing, while allowing for a more realistic depiction of a French Striped Marigold [19]. This was able to be entirely modeled within the software which could lead to less post-processing later in the assembly process. Thus, we were able to achieve the details of the hand engravings entirely through the process of investment casting.

IV. Casting

A. Sand Casting

Casting a long, thin object proved to be a difficult challenge. Designing the risers and gating for something that can not handle a lot of feed while also maintaining a near-net shape is a tough balance to hold. The sand casting was ultimately not successful due to two casting defects we could not avoid.

The first casting defect was the frequency of having misruns along the blade due to the lack of a material to feed the tin region or having material freeze before filling this thin cavity. As seen in Figure 7, a misrun between the tip and the rest of the sword caused a failure due to the feed metal not making it between two frozen fronts. No signs of fracture were found at these sites, confirming the misrun [2,7]. Kimura advised two solutions to these problems. The first was additional risers along the blade length and placed along the gates, rather than the large runner. This plan sought to add more heat and feed material along the thin length to ensure there were no frozen fronts. Risers were placed on the gates specifically to keep the feeders closer to the sword and ensure the hot spot created by the riser did not fall into the sword's body. The second was to add many vents along the fuller of the sword, allowing more airflow out of the sword and acting as mini-risers for additional feed.

Figure 7: Tip misrun in first batch of as-cast blades.

The second solidification defect encountered was stress cracking from the solidification of the sword and the runner seen in Figure 8. As the runner would solidify and thermally contract, the compressive stress from the riser imparted a tensile stress on the blade, fracturing it frequently in multiple areas [2,4,7]. To counter this, the runner was redesigned to follow the curve of the blade, and the sprue was relocated to the center of the runner to ensure even feeding and a more uniform solidification.

Figure 8: Stress fractures sling the blade width. One is seen near the tip and the other at the base of the tang.

Unfortunately, despite incorporating the added risers, updated riser positions, and curved runner, this final design was unsuccessful in preventing cracks or misruns. The final blades, one shown in Figure 9, each had cracks near the middle of the blade, and most near the handles as well, and three of the four blades had a misrun near the tip. No observation on porosity was performed on these blades. It was concluded that welding would be the method for making a sand casting method for the sword to work. Our team did not have a welder experience enough for this task, especially for high carbon and chromium steel. Given this, the Purdue team ultimately dropped the cast sword from our submission and focused our efforts entirely on the forged sword.

Figure 9: Final sword casting, showing a detachment from the tang due to cracking from runner solidification.

B. Investment Casting

The floral guard and lion-headed pommel model trees were investment cast to achieve the fine details required for these components. The team used Ransom & Randolph SuspendaSlurry and Ranco-Sil silica refractory to build the ceramic shell molds. Since direct manufacturer guidance was unavailable, the dipping procedure was developed through published technical literature, industrial/hobbyist forums, and YouTube.

Table 1: Ransom and Randolph Suspenda Slurry dipping schedule and procedure.

Dip #	Slurry-Dilution	Sand Applied
1	50% slurry 50% DI Water	None
2-3	No Dilution	50/100 Sand Mesh (Fine)
4-11+	No Dilution	30/50 Sand Mesh (Coarse)

Table 2: Ransom and Randolph Suspenda Slurry Burnout Schedule

Step	Ramp (C/min)	Temp (C)	Hold (min)
1	1	200	120
2	1	460	120
3	1	760	240
4	-2	RT	END

A preliminary test was conducted using an FDM-printed PLA cylinder to evaluate the planned shell-building process. The mold was dipped 11 times in the slurry, with silica sand coating the wet shell to form a stucco listed in Table 1. The mold underwent burnout following a staged heating schedule listed in Table 2. While burnout was successful, a vertical hairline crack formed along the mold. To create a plan in case of cracking when casting the trees, using recommendations from an experienced graduate student, a repair method was implemented using a thick slurry paste reinforced with a fiberglass mat. The paste was applied as an adhesive and sintered with a propane torch to restore shell integrity.

For the final investment molds, PLA 3D prints of the guard and pommel trees were produced. The initial prints were severely undersized, requiring rescaling in slicing software. SLA printing was initially considered but proved unreliable due to repeated failures, likely caused by improper resin curing conditions in a low-temperature environment. FDM printing was used instead. After support removal and sanding, a sandable high-build primer was applied to minimize visible layer lines.

Due to the complex geometry of the components, there were initial concerns about cold shuts. These were mitigated through controlled pouring parameters, preheating the molds, and holding the molds in sand to regulate cooling. Due to limited options and time constraints, a new tree with optimized sprue geometry was not feasible. Instead, the top of each tree was manually modified using a Dremel to create a sufficient opening for pouring the CuAl5 bronze alloy at a high enough rate to ensure complete cavity filling. While deep piping was viewed along the center of risers due to the narrow solidification range of the alloy, the final castings met acceptable dimensional and surface quality requirements, demonstrating the viability of the investment casting process for these components [4,7]. Castings were sent to final construction to be further polished and sectioned.

V. Heat Treatment and Alloy Selection

Kimura foundries offer a multitude of steel grades for many applications. For a sword that will take a few high-impact events, a castable steel that offers high strength and toughness is the objective. Of the grades Kimura offers, 9260 was selected as the best candidate for the cuttoe. This alloy offers high strength due to the higher amounts of chromium, silicon, and carbon added and is a heat-treatable alloy. 9260 steel is unique due to its high chromium concentration thus by heating to tempering at these values one can take advantage of chromium carbides forming in the iron matrix. One disadvantage of this alloy is its low weldability which makes repairing large cracks unfeasible for this alloy [4,20].

Metallographic analysis was performed on the as-cast billet samples. One of the billets was sectioned into 8 test samples for heat treatment trials, micrographs, and hardness. After a trial, the sample was sectioned, mounted, and either etched or indented for hardness measurements. Samples were ground to 2µm using diamond paste, sonicated, and etched using a 2% nitric acid-ethanol solution. Rockwell hardness C measurements were done using a diamond indenter on as-cast samples and subsequent heat treatments.

The 9260 billets, before heat treatment, had an as-cast dendritic microstructure composed of cementite and ferrite phases. Some lamellae are pictured in Figure 10. A high pore fraction can be seen in the black dots that distribute the microstructure. To homogenize the structure normalization is needed. Samples were brought above its austenization temperature of 900ºC allowing it to air cool, relieving all stresses, and allowing for recrystallization[4,6,9].

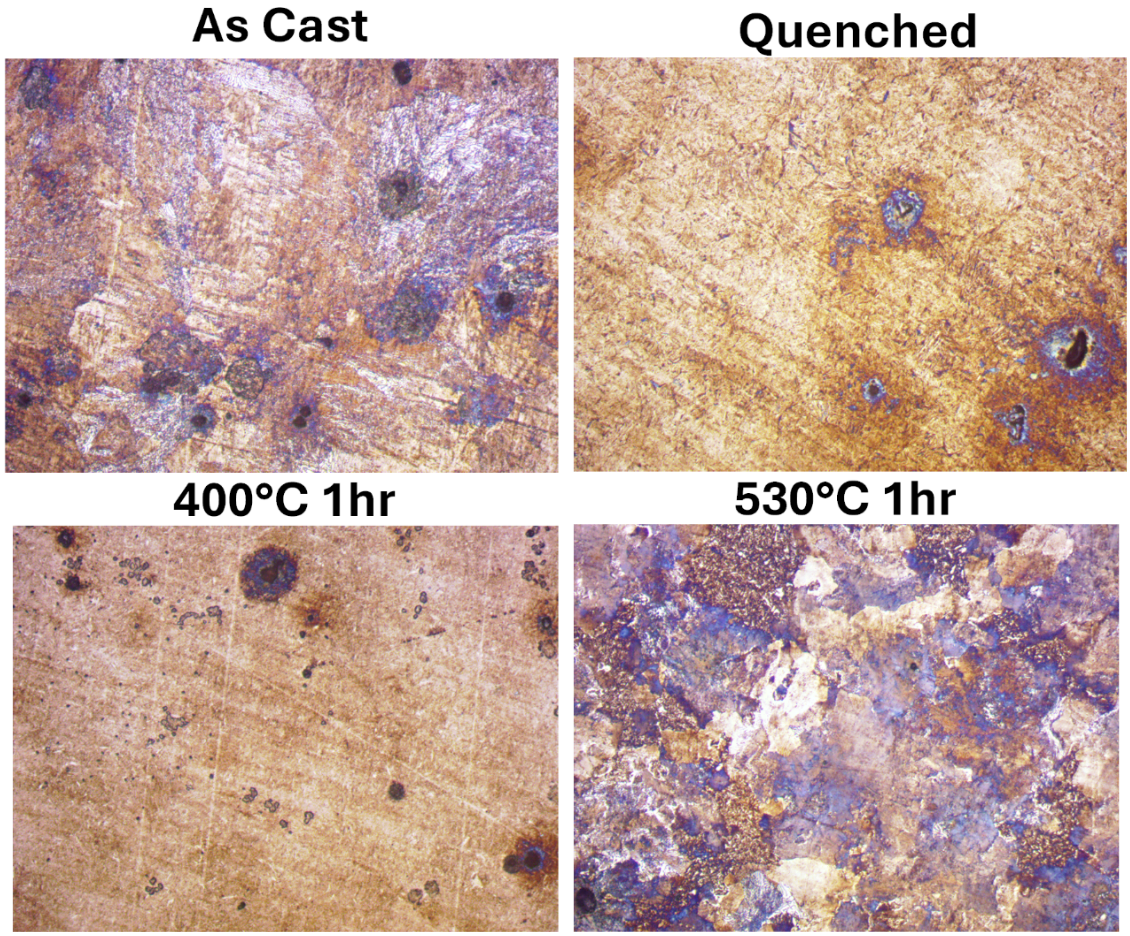

Figure 10: Etched microgrpahs of 9260 steel at different temperings. All at 20x magnification.

Post-normalized samples were then reheated past their austenization temperatures and held at 900°C and held for 20 minutes. Samples were rapidly taken out and quenched in soybean oil, and slowly moved around to prevent warping and ensure a steam/smoke jacket did not form around the sample. Soybean oil was used in place of petroleum-based oils for its biodegradability, ease of disposal, and comparable heat transfer [21]. Finally, samples were reheated and tempered in a box furnace in separate trials to view the effect of hardness and individual microstructure. The tempering schedule used and resulting Rockwell C hardness values are seen in Table 3.

Table 3: Rockwell Hardness C values of soybean oil quench and tempering trials.

Tempering Tests	Temperature (ºC)	Time (Minutes)	Average Hardness (Rockwell C)
Test 1	0	0	55.7 ± 3.27
Test 2	400	60	53.3 ± 0.85
Test 3	500	60	34.6 ± 3.00
Test 4	530	30	27.32 ± 2.52
Test 5	530	60	24.4 ± 2.03

Once tempering was complete each sample's hardness was tested and an average was computed. While tests 1 and 2 had the highest hardness values it is important to recognize that these microstructures had little to no stress relief thus they are still mostly composed of martensite and very brittle. Discussing the results with Professor Milan Rakita, he advised the team to have the final tempering at 200ºC for a roughly 5-10 minute hold would take advantage of chromium carbide formation and form a high-strength metal while not overaging the precipitants. While the average hardness would be lower than those previously shown the blade would be flexible enough to not shatter on impact thus improving its lifespan.

VI. Forging, Finishing, and Final Construction

A CNC face mill was used to remove excess material from the rough-forged sword after initial shaping with a power hammer. However, several challenges arose due to the billet's complex and initially unknown dimensions, as well as the size constraints of the Haas VF2 CNC mill. Given the limited time to develop a rigid workholding solution, a temporary fixture was fabricated using a 1-inch thick, 4-inch wide, and 48-inch long high-density polyethylene (HDPE) bar.

Before selecting CNC milling, consultation with Teng Lee, a Polytechnic machine shop supervisor, led to initial considerations of using a surface grinder and belt sander for finishing. However, the belt sander was too slow, and the surface grinder proved impractical due to excessive vibration caused by an insufficiently large magnetic bed. Additionally, the depth of the cut resulted in scorch marks, which could negatively impact later heat treatment. Given these constraints, CNC milling was determined to be the preferred method.

To prepare for machining, the HDPE bar was cut down to 36 inches to fit within the Haas VF2 bed. Holes were drilled to accommodate bolts that secured a steel plate over the billet, creating a clamping effect intended to reduce vibration. This assembly was then held in two vises in the machine. The fixture was bolted with a steel plate and secured in two vises to reduce vibration. Manual G-code programming was employed for efficiency and accuracy, as available CAM software contained incorrect machine and tooling parameters. Key G-code details include an initial tool offset at Z6, a first pass with a 1/16-inch depth of cut (Z = –0.0625″), and a second pass reaching a total depth of 3/16 inches (Z = –0.1875″), using a 2-inch face mill with indexable carbide inserts and coolant.

During machining, workholding complications arose due to the billet's irregular shape. The HDPE bar exhibited bowing, creating a 0.030-inch gap at its lowest point. To counteract this, a ¼-inch thick, 2-inch wide steel plate was inserted on the opposite side of the HDPE bar to act as a stiffener. The bar was positioned with the bow facing upward, as the most severe curvature was concentrated at the ends, which would later be trimmed.

The first face-milling pass was moderately successful. However, when machining the second side, the increased gap in the center of the blade introduced additional vibration and harmonic issues, leading to severe chatter. Washers were used to provide additional support, but residual gaps remained. To further mitigate the issue, plastic sheet shims were inserted to supplement the washers. Despite these adjustments, machining required highly conservative speeds and feeds, resulting in cycle times of nearly 10 minutes per 26–27 linear inches per side. The second face exhibited more chatter than the first but remained within acceptable tolerances for subsequent finishing and construction.

A fuller, or blood groove, was planned to be forged into the blade using a specialized tool, but the tool was unavailable. CNC machining with a ball-nose end mill was considered as an alternative, but the lack of time prevented the development of a suitable work-holding solution to accurately index the blade and achieve a symmetrical and precise groove along its length. The milled billet was cut to match the curved profile of the cuttoe. This was cut rather than forged to prevent cold shuts from forming at the tip of the blade and causing a failure during quenching. The billet was further ground to a thickness of 1 ¼ in with a tang cut to match the reduced width. The sword was reheated again and lightly forged to put in the deflection of a typical saber-style cuttoe. After the heat treatment, final sanding and sharpening were done to put in a full edge, cutting edge, and false edge for thrusting.

Bronze investment castings were milled to slot the rectangular tang and threaded to screw onto the tang's base. A brass wire wheel polished the surface of the investment casting to give a smooth, defect-free surface. Brass spacers were used to imitate the same silver pieces seen separating the guard from the blade edge and the handle. The handle was constructed from stained cherry wood, an homage to the myth of the George Washington and the Cherry Tree, and glued after the final tang dimensions were known. The brass chain was added through a drilled hole in the lion's mouth and the blade end of the guard. All copper-based components were further polished to have similar appearances and give a shiny luster. A threaded pommel was opted for instead of the traditional rivet design for modularity and easy editing between pommel pieces cast.

Figure 11: Final constructed sword.

VII. Conclusion

The Purdue team used a multitude of foundry, metallurgical, and artistic techniques to construct the final Lion-Headed Cuttoe. Additive sand molds and investment casting allowed us to quickly iterate and make exact castings quickly. While the near-net-shape casting did not work, the forging techniques would be preferred to the more robust manufacturing and reduced porosity from hot working. The alloy selection was vetted through heat treatment trials to ensure the optimal mechanical properties were achieved to prevent failure in the upcoming competition.

We want to give a thank you to Kimura Foundry America and our two advisors Maxwell Brewer and Jake Espinosa. They provided us with our steel, access to their foundry for casting, and months of sword design iterations. They were a great partner to have for the competition and we look forward to working with them again.

From the Purdue Polytechnic Institute, we want to thank Dr. Milan Rakita, Teng Lee, and Clayton Kibby for their help. Together they provided our group with access to lab spaces, advice on MAGMA simulations, machining assistance, various materials, and overall advice towards manufacturing the sword. We thank them all for their patience and letting us work crazy hours throughout the week.

We would like to thank other contributors to our project that did not serve a direct advisory role. Thank you to Dr. Kevin Trumble of the Materials Science Engineering Department for helping us with the bronze casting and providing us with materials. Thank you to Clayton Barlow and Emma Samepy from Caterpillar for their help in getting us started this year in finding a local foundry partner. Thank you to Allie Brandt and Dr. T. Cole Jones for guiding the historical research and providing sources on the art styles of the era.

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