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

Trine University – Foundry of Freedom

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Executive Summary

The final George Washington Sword created for the Cast in Steel 2025 competition is a historically inspired replica, designed and cast by the Trine University Cast in Steel team. The sword incorporates a high-carbon steel alloy, with silicon, manganese, chromium, and molybdenum additives for improved strength and durability. Drawing on historical references, the design of the sword blends both aesthetic and functional elements, with the team using advanced manufacturing techniques to ensure its structural integrity.

Multiple iterations of the sword's blade, handle, and guard were developed throughout the project, with each iteration undergoing rigorous testing and refinements. The blade underwent Finite Element Analysis (FEA) to simulate real-world usage scenarios such as slashing, stabbing, and blocking. These simulations provided valuable insights into the design's potential weaknesses, particularly with stress concentrations and material behavior. Adjustments were made in subsequent iterations to improve the blade's performance, particularly around areas of high stress.

The handle and guard were carefully crafted with historical accuracy in mind, incorporating traditional elements like gadrooning and recurve arms, as well as ergonomic considerations for comfortable handling. Multiple iterations of the handle were developed, focusing on both historical accuracy and manufacturability.

The final casting of the sword was completed using a medium-carbon steel alloy. After casting, the sword underwent a series of post-processing steps, including secondary processing, heat treatment, and polishing up for final touches. The sword's dimensions are 30 inches in blade length, with a total weight of 2.2 lbs. (1.00 kg.). The final composition of the sword is 0.53% C, 0.305% Si, 0.151% Mn, 0.68% Cr, and 98% Fe.

The completed sword successfully passed all physical testing, including sharpness, strength, and durability tests. This successful combination of historical design, modern manufacturing techniques, and rigorous testing has resulted in a functional and aesthetically accurate replica of a 18th-century sword, prepared for the Cast in Steel 2025 competition.

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Cast in Steel: Trine University

The 2025 Cast in Steel competition, hosted by the Steel Founders' Society of America (SFSA), is more than just a challenge—it's an opportunity for students to push the boundaries of steel casting technology. This competition encourages participants to apply their engineering skills, creativity, and technical knowledge to design and manufacture steel products using advanced casting techniques. SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available. By working hands-on with steel, students gain invaluable experience in metallurgy, manufacturing processes, and innovative problem-solving. The competition challenges them to think critically, collaborate effectively, and utilize cutting-edge technology to create functional, high-quality cast steel products. Beyond skill development, the Cast in Steel competition serves as a platform for inspiring the next generation of engineers and metallurgists. SFSA is committed to fostering talent and preparing students for careers in steel manufacturing by immersing them in an environment that mirrors the challenges and advancements of the industry. By participating, students not only develop practical expertise but also connect with industry professionals, opening doors to future opportunities. In essence, the 2025 Cast in Steel competition is about innovation, education, and the future of steel. It's a celebration of craftsmanship and engineering excellence, ensuring that the next wave of industry leaders is equipped to drive the evolution of steel manufacturing.

Historical Background

George Washington owned several swords throughout his lifetime, each reflecting the style and craftsmanship of its era. His earliest known sword was an onyx-handled cuttoe, dating back to the 1690s. Though the exact circumstances of its acquisition remain unclear, it was likely passed down through his family. As Washington's status grew, so did his collection. He obtained swords from Europe, often selecting elegant yet practical designs suited for a gentleman and military officer. Some were personal purchases, while others were presented as gifts or tributes in recognition of his leadership. Despite owning multiple swords, Washington rarely wielded them in battle. During both the French and Indian War and the Revolutionary War, his sword functioned more as a symbol of command rather than a weapon. In portraits and public appearances, it completed his authoritative presence, much like a modern leader might wear a distinguished watch or tailored suit to convey status and professionalism. His swords were not just tools of war but emblems of his role in shaping the nation [1].

Following Washington's death in 1799, his swords were passed down to his descendants, remaining family heirlooms for decades. The first to leave the Washington lineage was the Bailey cuttoe (Figure 1), donated to Congress in the 1840s as a historical artifact. However, the aftermath of the Civil War altered the fate of these prized relics. Many branches of the Washington family had sided with the Confederacy, and after the South's defeat, they faced severe financial hardships. With fortunes lost and resources dwindling, some descendants made the difficult decision to sell these treasured swords. Over time, what were once personal symbols of America's first president became scattered among collectors, museums, and institutions, serving as tangible links to the legacy of George Washington.

Figure 1 - Bailey Silver & Ivory-Hilted Cuttoe

George Washington's Sword Design

The final sword design brings together the blade, scabbard cap, guard, a transition piece, handle, and pommel, carefully crafted to reflect the distinctive form of George Washington's Silver Lion-Headed Cuttoe (Figure 2). Before diving into the details of the finished piece, it is essential to understand the thought process behind each individual component. Every element of the sword was designed with both historical accuracy and manufacturability in mind.

Another key consideration in designing the blade was achieving the right balance between strength and weight. Washington's Silver Lion-Headed Cuttoe was a light, agile sword, more symbolic than combat-oriented. To stay true to the original while ensuring manufacturability, the team carefully adjusted the blade's thickness, taper, and material distribution. A blade too heavy would feel unwieldy, while one too thin could compromise durability. This is especially the case with using casting rather than forging. Thoughtful design in both geometry and alloy selection ensured the final blade maintained the elegance of Washington's cuttoe while remaining practical to cast and assemble. [1][4]

Figure 2 - Washington's Silver Lion-Headed Cuttoe

Blade

The blade of a sword is crucial as it directly influences the weapon's effectiveness in combat. Its material, design, and sharpness determine not only its cutting and piercing capabilities but also its durability and balance. A well-crafted blade can mean the difference between victory and defeat, allowing the wielder to execute precise strikes and defend against incoming attacks. The blade's key dimensions; thickness, length, and edge geometry; are carefully chosen for optimal performance. The blade thickness starts at 0.25 inches at the tang and tapers to 0.1 inches at the tip, ensuring strength and balance. At 30 inches long with a 7-inch tang, the length was selected for historical accuracy, with the tang size determined for the handle design. The edge geometry features a simple taper to maximize sharpness and slicing efficiency. These design elements combine to create a blade that is both historically accurate and highly functional for combat and cutting tasks (Figure 3). [6]

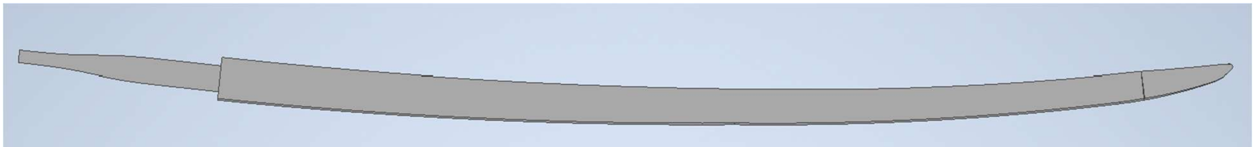

Figure 3 - Selected Cuttoe Blade Design

The blade underwent four design iterations, primarily refining the tang for improved functionality. The first iteration established the overall shape and included a small lip at the start of the blade. In the second iteration, this lip was removed to create a smoother transition between the blade and tang. The third iteration modified the tang's shape to better fit the handle design, ensuring a more secure and ergonomic connection. Finally, the fourth iteration introduced fillets to improve geometry, reducing stress concentrations and enhancing durability. Figures 4 and 5 showcase the final iteration of the blade and tang, illustrating the refinements made throughout the design process.

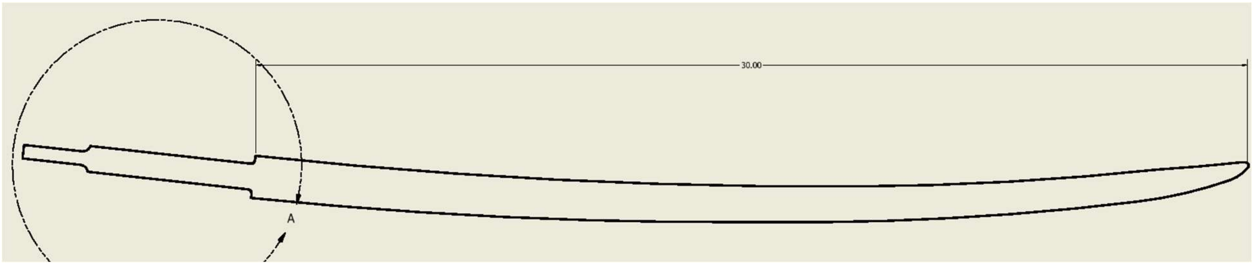

Figure 4 - Iteration 4 of Blade

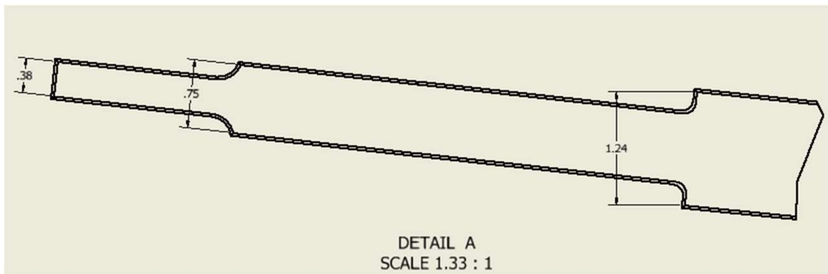

Figure 5 - Iteration 4 of Tang

Sheath Cap

Inspired by the Bailey Silver & Ivory-Hilted Cuttoe and other cuttoes featured in Swords and Blades of the American Revolution, the sheath cap (Figure 6) was designed to be both decorative and functional. It features a flat, oval shape with three distinct ridges and a thick plate, maintaining proportional consistency with the guard and transition piece. Additionally, carefully placed fillets allow the cap to seat securely onto the bottom of the sword, aligning with the tang for a seamless fit.[4]

Figure 6 – Sheath Cap

Guard

The design of the guard prioritized both elegance and historical accuracy, incorporating a sleek, flowing “S” curve alongside intricate gadrooning. The recurved or angled arms of the cuttoe were a defining feature of many swords from this period, whether crafted from a flat piece of metal or shaped through artisanal techniques. Gadrooning, characterized by repeating ridges or spiral fluting, was at the height of fashion in the mid-18th century. Given George Washington’s keen awareness of contemporary styles, including this detail was essential in capturing the refined aesthetic of the era. [3][4]

Figure 7 - Guard CAD (Top) and Guard Final (Bottom)

As shown in Figure 7, the final guard design features shorter, bulbous ends—still historically justifiable, though not as long and elegant as the original concept. During assembly, peening was chosen as a secondary fastening method in case the epoxy failed. However, this process introduced an unexpected challenge. The force of peening sent shockwaves up the tang and through the guard, which, due to its small cross-section and the brittleness introduced by the casting process, resulted in one arm breaking off completely while the other cracked catastrophically. This failure highlighted the limitations of the initial design and provided a valuable learning experience. To address the issue, the guard was redesigned with more robust, gently sloping bulb ends while maintaining the distinctive recurve style characteristic of the cuttoe.

Transition Piece

The transition piece (Figure 8) serves a fundamental yet crucial role in ensuring a seamless visual and physical flow from the guard to the grip. Designed with a focus on proper proportions and a low-profile aesthetic, it enhances both the sword's structural integrity and its historical authenticity. Its subtle curvature and refined edges contribute to a comfortable grip while maintaining the elegant design language of the overall piece.

Figure 8 - Guard to Grip Washer

Grip

Ideally crafted from bone or ivory, traditional grips often featured gadrooning in the form of spiral fluting. Beyond its decorative appeal, this design enhanced grip by allowing the flutes to "bite" into the hand, preventing slippage. While green-dyed ivory and natural horn or bone were among the most popular historical choices, an undyed ivory grip offered the perfect balance of authenticity and elegance. However, for legal and manufacturing considerations, a resin-based imitation ivory was selected (Figure 9), ensuring both practicality and historical accuracy.

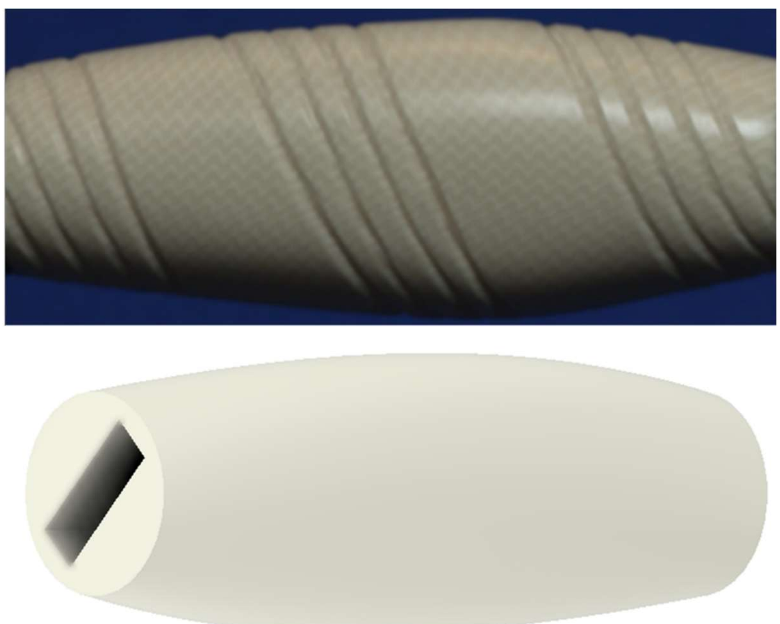

Figure 9 - Grip CAD (Bottom), Final Grip (Top)

Pommel

The pommel design draws inspiration from the phrases “Grimacing Lions” and “Gargoyle,” reflecting the stylistic depictions of lions found in Swords and Blades of the American Revolution. Historical representations often emphasized the essence of a lion rather than strict anatomical accuracy, capturing an elegant yet fierce aesthetic. This approach balanced ferocity with artistic refinement, creating a commanding presence on the sword. The initial shape was developed in CAD, then further sculpted in Blender to enhance its intricate details and expressive form (Figure 10).

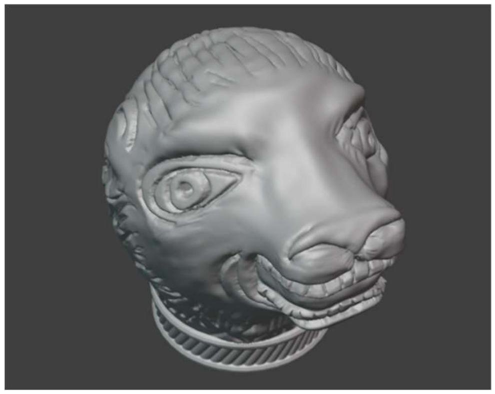

Figure 10 - Blender Lion Head Pommel Model

Overall Design

Throughout the project, three iterations of the handle components and four iterations of the blade were developed. Each iteration of the handle components had the overwhelming focus of historical accuracy, then manufacturability, then ergonomics. The main parts that had significant changes were the guard, grip, and pommel. Each started barebones and basic, before becoming drastically more detailed or comfortable with each iteration. The only testing done for strength or durability was on breaking parts out of molds post casting. If the parts couldn't survive being broken out of the investment molds, they weren't worth looking over or processing to the next step.

The first blade iteration underwent finite element analysis (FEA) in ANSYS software to simulate real-world usage. Three distinct tests—slashing, stabbing, and blocking—were conducted to evaluate the blade's structural integrity. In each test, a force of 300 pounds was applied at or along point B in the diagram, while the blue-shaded area (A) remained fixed. The slashing test applied force along the blade's edge (Figure 11), the stabbing test directed force at the blade's tip (Figure 12), and the blocking test simulated a clash by applying force along the flat side (Figure 13). These initial simulations suggested the design would be only partially successful, as the simulated material failed to accurately replicate the properties of the heat-treated material intended for the final blade.

Figure 11 – Parameters for Slashing on the Edge

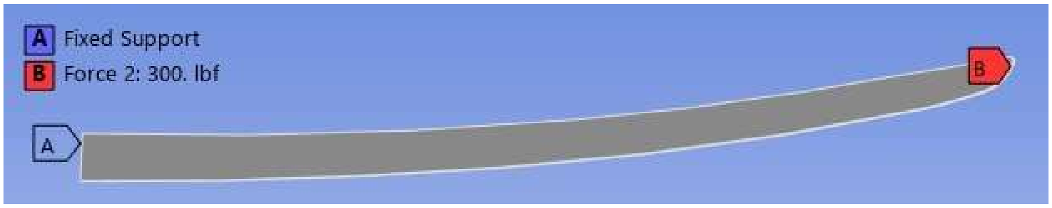

Figure 12 - Parameters for Stabbing with the Tip

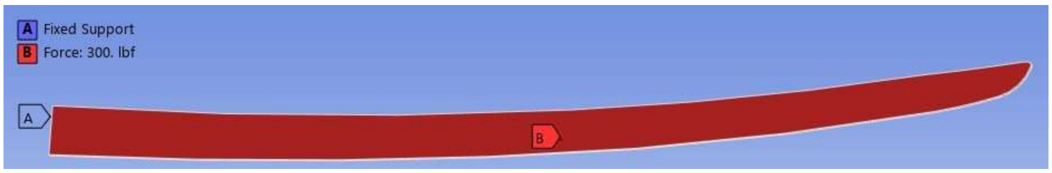

Figure 13 - Parameters for Blocking with the Side of the Blade

Gating System

A preliminary gating system was introduced in the first design iteration and refined over three iterations to optimize the casting process (Figures 14 and 15). To ensure the castability of the sword design, MAGMA simulations were conducted using 4340 steel, as MAGMA doesn't include material definitions for 5160 steel.

For all simulations, a low pouring temperature of 1500˚C was used, with a feeding efficiency of 30%. The focus was on analyzing the filling temperature and velocity to ensure proper material flow and minimize casting defects. Early iterations revealed temperature drops that could cause incomplete filling or cold shuts, leading to adjustments in the gating system to improve thermal consistency. By iteration 2 (Figure 16), the system was functioning well, but additional reinforcements were added to ensure the design would hold up under real-world conditions. Velocity simulations showed areas of excessive turbulence in early iterations, potentially leading to defects. By iteration 2 (Figure 16), the velocity profile was optimized to reduce turbulence. A test button was then added to allow material testing and ensure the final product met the desired mechanical properties.

Through these refinements, the gating system was optimized for a structurally sound blade with minimal defects. The controlled filling temperature, velocity, and added reinforcements ensured a more reliable and high-quality final product.

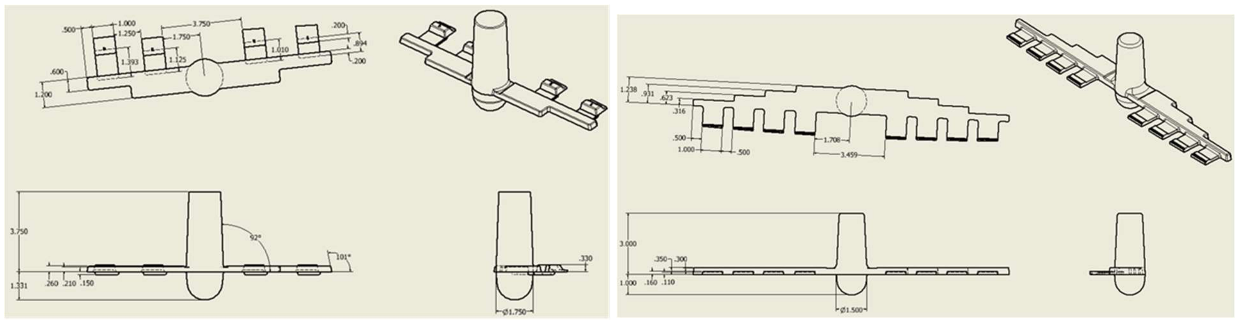

Figure 14 - Gating for Iterations 1 and 2

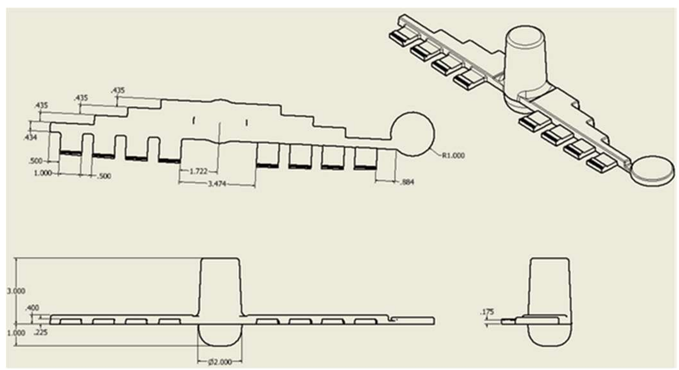

Figure 15 - Gating for Iteration 3

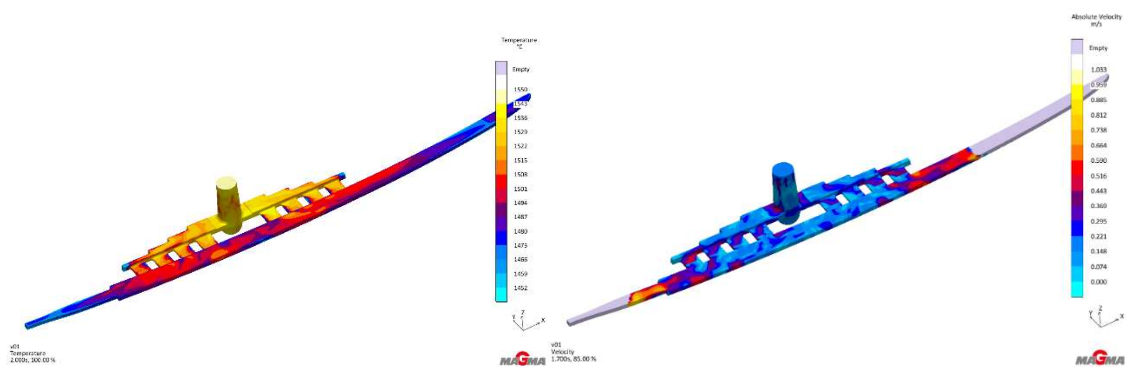

Figure 16 - Iteration 2 Temperature and Filling Velocity

Casting Process

Every iteration of the sword and handle was cast in the Trine University foundry by the Cast in Steel team, with guidance and training from the foundry manager and the team's advisor. Green sand casting is the most commonly used process at the Trine University foundry due to its quick turnaround and ease of operation. However, for this project, investment casting was also utilized to produce the more intricate components of the handle. To ensure each design iteration was both moldable and castable, the team conducted multiple pours using both casting methods, refining the process with each iteration.

Investment Casting Process

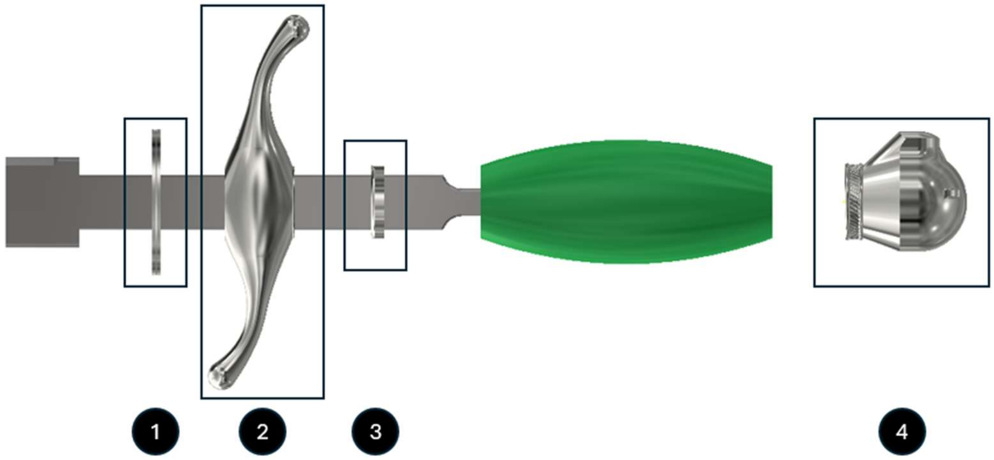

Figure 17 - Investment Casting Produced Parts

For this project, the parts that will be cast using investment casting are the sheath cap (1), guard (2), transition piece (3), and lion head pommel (4) (Figure 17). These parts are to be made using Polymaker polycast filament rather than a wax mold to allow for rapid adjustment to design and process as necessary. It was quickly found when 3d printing the part, print the runners as a part of each part, rather than needing to attach wax runners to the 3d print. The runners should be at a 45-degree angle attached to the sprue to allow for the smoke and fire to rise out, and metal to be poured in. Over several pours multiple procedures, iterations, and materials were tested. Brass, tin-bismuth, and zinc where used to produce parts. More or fewer perimeters, lower infill percentages, creative design for reducing chances of hydraulic stress caused cracking, and researching how quickly layers can be added to the investment trees without losing necessary strength or trapping moisture. Any significant loss in strength or trapped moisture could easily cause catastrophic cracks during preheat or burnout.

Figure 18 - Depiction of General Process and Iterations

The upper left five images depict the first investment casting run, which utilized a wax pouring cup, down sprue, runners, and PolyCast parts. However, bonding the wax components to the PolyCast proved difficult, leading to the quick adoption of a generic PolyCast down sprue. Additionally, the runners were redesigned to be printed as a single piece with the cast part, streamlining the process. The bottom row showcases the second investment casting attempt, which exclusively used PolyCast components bonded with superglue. Tin-bismuth was selected for casting, but the resulting parts were both too weak and brittle, making them unsuitable.

The top right image illustrates a failed burnout from the third casting attempt, which used hot glue and featured very small internal cross-sections within the pommel. The failure is believed to have resulted from insufficient drying time inside the inner cavity or excessive hoop stress due to pressure buildup. This pressure may have been caused by trapped air without a proper escape path, exacerbated by excessive perimeter layers restricting airflow and causing uneven heating. However, a similar yet unpictured casting run—where all components except the pommel were successfully cast—also used hot glue without failure. This suggests that the adhesive choice between hot glue and superglue was not the determining factor in the burnout failure.

Green Sand-Casting Process

Over the last seven months, a variety of metals were used to pour the sword blades based on material availability. Initially, aluminum was used for a single test pour to evaluate the castability of the first design iteration. The exact composition is unknown due to the use of scrap aluminum, which was melted in the McEnglevan industrial gas furnace at the Trine University foundry. Before pouring, the crucible and furnace were inspected for cracks, and green sand was mixed to a compactability of 52%. Scrap aluminum was melted while the pouring zone was cleared, and molds were packed and placed. Once the metal reached 1300–1340°F, it was poured into the molds, with excess metal cast into open-faced ingots. After cooling, equipment was inspected, and the furnace and work areas were cleaned. Figure 19 shows the aluminum sword poured by the team, which came out roughly 9 inches short.

Figure 19 - Aluminum Sword Outcome

Though the initial aluminum pour was unsuccessful, the team transitioned to using the Inductotherm Power-Trak 28-30 R furnace for all subsequent castings, as the castings class, which included three of the five members of the team, was ready to operate it. This shift allowed for more consistent pours with the intended materials, reducing reliance on scrap aluminum and ensuring better control over the final sword composition. Once the general design was adjusted, the team moved to iron-based metals. For these pours, silica sand with bentonite clay was mixed with water to a compactability of 45%. As with the aluminum pours, the exact composition of the iron-based metals was unknown due to the use of scrap materials. The casting process began by clearing the area around the furnace. Heating elements in the furnace and ladle were removed, and ceramic wool coverings (K-wool) were placed on top to minimize heat loss. The selected metal and additives were then weighed, cleaned, and prepared before turning on the furnace. The charge was added while molds were positioned in the pouring area, secured with weights to counteract metallostatic and dynamic pressure. While the furnace was in use, temperatures of the supports and surrounding areas were monitored to prevent unintended coupling. At the predetermined pouring temperature, the furnace was tapped to a ladle, and the molten metal was poured into the molds, prioritizing the sword casts before any excess was poured into open-faced ingots. Figure 20 shows an iron sword produced by the team. Once cooled, all equipment was inspected, and the furnace and pouring areas were cleaned.

Figure 20 - Cast Iron Sword

As the project progressed into January 2025, the team prepared to pour steel for the sword blades. The composition of each pour varied based on the available materials, primarily sourced from scrap steel. To ensure consistency and desired material properties, specific alloying recipes were followed. Steel punchings and high-carbon iron ingots were first added to the furnace, with additives introduced afterward to refine the final composition. One significant change implemented during the transition to steel casting was the inclusion of tensile bars in each pour. These bars were cast alongside the swords to provide material samples for mechanical testing, allowing the team to assess the steel's strength and durability. For each steel pour, two swords and three tensile specimens were produced, ensuring both the blade's structural integrity and material performance could be evaluated. Figure 21 and 22 shows a completed steel sword along with the corresponding tensile bars cast by the team.

Figure 21 - 5160 Steel Sword

Figure 22 - Tensile Bars

Match Plate Design

Match plates were constructed for each iteration of the blade to improve mold accuracy and casting quality. In the first iteration, the blade was split along its centerline, creating a parting line that allowed for a tapered profile on both sides leading to the tip (Figure 23). To accommodate the print bed size, the blade pattern was divided into four 9-inch sections. Alignment holes were incorporated into the design to prevent misalignment during assembly. Each section was then printed using PLA filament on a Bambu Lab A1 printer, deburred, and sanded to smooth printing lines and ensure a precise fit on the match plate.

The four sections on each side, along with the gating system, were assembled using epoxy and alignment pins to create two complete halves. The drag half of the pattern was first centered and affixed to the match plate with epoxy, after which a drill press was used to create perpendicular alignment holes. The cope half was then attached in the same manner, with alignment pins inserted before the epoxy fully set to guarantee proper positioning. The assembly was left to cure for 24 hours before the excess pin length was trimmed. Wood filler was applied to smooth over seams and alignment pin holes, while wax fillets were added around the perimeter to facilitate easy removal from the mold.

Following the first iteration, a significant design improvement was implemented to enhance casting quality. Instead of splitting the blade along the parting line, the entire blade was positioned in the cope, with most of the gating also placed in the cope (Figure 23). This adjustment eliminated the parting line from the final cast, ensuring a cleaner and more uniform blade surface. Additionally, this modification improved metal flow during pouring, allowing the molten material to fully fill the tip of the blade and reduce defects. By refining the match plate design through each iteration, the team successfully optimized the mold setup for better casting results.

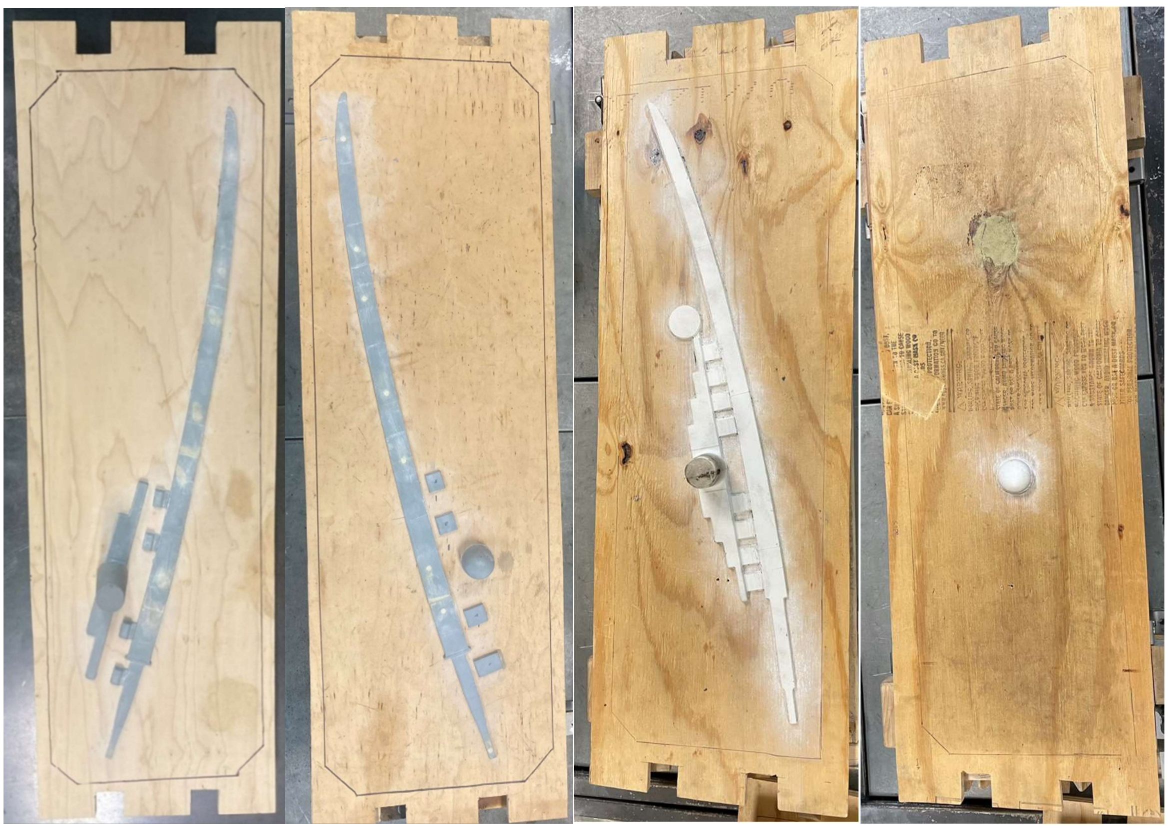

Figure 23 - Iteration 1 (On Left) and Final Iteration (On Right)

Flask Design

The final flask design was achieved through a series of refinements, addressing material efficiency, mold integrity, and safety concerns encountered in previous iterations. Initially, the team utilized flasks from the previous year’s competition (Figure 24), which, while functional, proved excessive for the current project’s requirements. These flasks required approximately 80 pounds of sand per mold, making them cumbersome to handle and inefficient for repeated use.

Figure 24 - Last Year's Flask

To optimize material usage, the second iteration introduced flasks constructed from ¾-inch plywood, reinforced with 2x2 boards for stability and ease of transportation (Figure 25). This redesign significantly reduced sand consumption and worked successfully for the first pour. However, during the second pour, a critical flaw emerged: mold blowout. The flasks failed to contain the molten metal, resulting in structural degradation, fires, and an overall unsafe casting environment (Figure 26). These failures rendered the flasks unsalvageable, necessitating a complete redesign.

Figure 25 - Iteration 2 Flask

Figure 26 - Iteration 2 Flasks Catching Fire

The final iteration addressed these challenges by incorporating a snap flask system constructed from 2x4 boards and secured with door hinges. This design effectively eliminated mold blowout and prevented fire hazards, ensuring a more reliable and reusable casting setup. The snap flask's improved structural integrity allowed for secure mold containment while simplifying the demolding process (Figures 27 and 28).

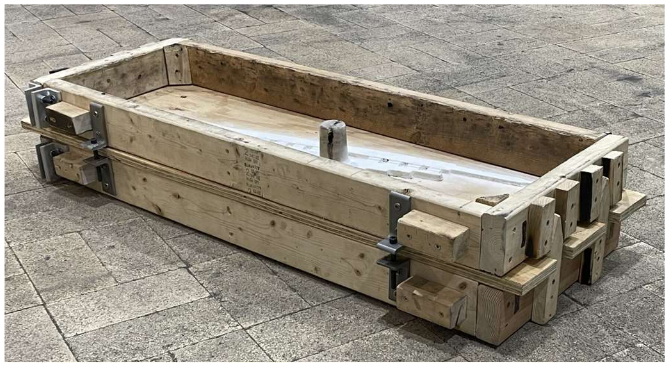

Figure 27 - Final Iteration Flask Closed

Figure 28 - Final Iteration Flask Opened

Alloy Determination

The final selection for the sword material was 5160 steel, based on its composition which is illustrated in Table 1.

Element	Carbon	Manganese	Silicon	Chromium	Iron (Fe)
High %	0.64%	1.00%	0.30%	0.90%	97.84%
Low %	0.56%	0.75%	0.15%	0.70%	97.09%

Table 1 - Desired Alloy Composition

A Microsoft Excel spreadsheet was developed to calculate the required weight of alloying elements based on the base material weight. This calculation involved determining the necessary amount of steel disks to reduce the carbon content of the Sorel ingots. To ensure accuracy, the steel disks were analyzed using an arc spectrometer, which provided precise data on their composition. This information was then used to determine the exact quantities of alloying elements needed to achieve the desired final composition.

Secondary Processing

After the sword was removed from the mold, the gating system was carefully cut off using a cut-off wheel. The blade then underwent extensive secondary processing, primarily on an AMK Tactical belt grinder, to refine its shape and surface finish. The first step was to remove any remaining flash, ensuring a clean profile. Next, the blade's surface was flattened to eliminate residual sand and establish a smooth, even reference for subsequent grinding steps. The sides of the blade were then carefully ground down to remove the draft angles necessary for mold release during casting. With the basic shape refined, the tapering process began to bring the blade to its final dimensions. Both the edge and the lengthwise profile were tapered, maintaining a deliberate non-sharp profile for safe handling (Figure 29). The target dimensions for the taper were 0.1 inches at the tip and 0.175 inches at the midpoint of the blade. Throughout the process, a dial caliper was used frequently to ensure precision, allowing for even material removal and a symmetrical taper on both sides.

Figure 29 - Tapered Blade

Once the blade was shaped to its final specifications, a fuller was machined into each side to enhance structural integrity and aesthetic appeal. Using an OBM fuller-grinder attachment, a precise and consistent groove was established along the blade. Material was then removed from the bottom of the fuller to the edge, shaping the bevels while maintaining a dull profile. This preserved enough material to keep the blade strong throughout the heat treatment process. Post-heat treatment, the blade was precisely sharpened to establish a definitive cutting edge, and then methodically refined by continuously increasing the grinder grit from 120 to 5000 until the finish was perfectly smooth and the edge exceptionally sharp.

Heat Treatment

The swords were heat treated in-house at Trine University using the Evenheat KF Extreme 49.5 furnace (Figure 30). After secondary processing was completed to achieve the final net shape, the blades underwent a normalization process to minimize the risk of warping during quenching.

This involved heating the swords to 1650°F for 20 minutes, followed by air cooling. Once normalized, the swords were austenitized at 1550°F for 15 minutes before being quenched in oil (Figure 31). To achieve the desired mechanical properties, the blades were then tempered at 400°F for 2 hours. This heat treatment process resulted in a final hardness of 50 HRC, ensuring a balance between durability and toughness suitable for functional use.

Figure 30 - Evenheat KF Extreme 49.5

Figure 31 - Quench Tank Set Up

Material Testing and Analysis

Material testing was performed on each completed sword, including arc spectroscopy, hardness, and tensile testing. Arc spectroscopy was conducted using a SPECTROMAX Metal Analyzer (Figure 32). The specimens were removed from our gating system and ground flat using a belt grinder. This ensured that the pieces were flat enough to get accurate readings for spectroscopy.

Figure 32 - SPECTROMAXx Metal Analyzer

Hardness testing was performed on each sword after heat treatment using a LECO LR310 Rockwell Hardness Tester (Figure 33). This was done to determine whether the heat treatment was successful.

Figure 33 - LECO LR310 Rockwell Hardness Tester

Tensile testing was performed with each pour to gather the tensile properties of each pour. Tensile specimen and machining were assisted by a local Iron Foundry called Metal Technologies, located in Auburn Indiana (Figure 34). This test was used to determine the strength and the elongation.

Figure 34 - Tensile Specimen

Physical Testing

The goal of testing was to ensure that the sword could withstand rigorous use without breaking, while also maintaining a lethal level of sharpness throughout. Three primary testing methods were employed: a slashing motion test, a stabbing motion test, and a certified sharpness test. The slashing and stabbing tests were conducted using a testing rig designed to replicate realistic combat swings, utilizing different target materials based on past Cast in Steel competition standards. Additionally, the blade's sharpness was quantitatively measured using an Edge-On-Up industrial edge tester, which is BESS-certified.

Stab Test

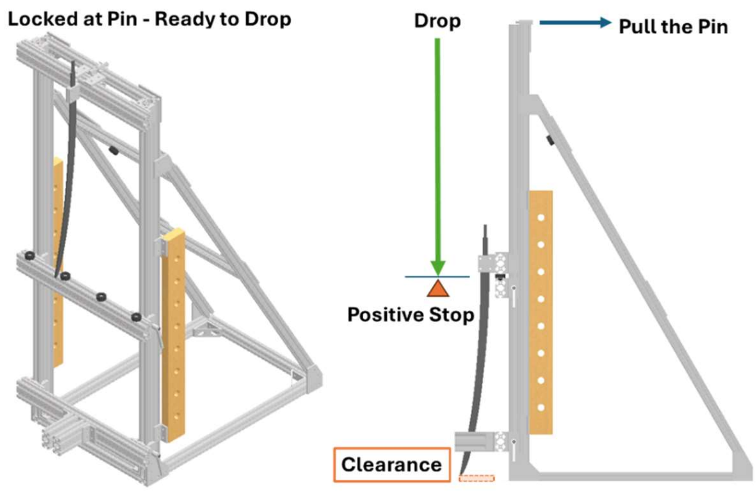

Figure 35 -Drop Test Rig Set-up

The stab test (Figure 35) evaluated the sword's ability to pierce aluminum sheet metal at least 1-2 inches without rolling the edge or breaking the tip, requiring three successful repetitions. The aluminum sheet was chosen to be at least as thick as a #10 aluminum can, though it was likely misestimated at approximately 0.032” due to its stiffness and visual thickness upon arrival. This test assessed not only the tip’s sharpness and edge geometry but also edge retention and the sword’s structural integrity under stress, ensuring it could bend and deflect without failure. Even with the preliminary sharpening—before the final honing—the blade consistently penetrated between 1.5 and 3 inches into the sheet metal. Figure 36 showcase each of the three successful stabs, illustrating the clean punctures and the durability of the tip after repeated impacts.

Figure 36 - Stab Test Results

Slash Test

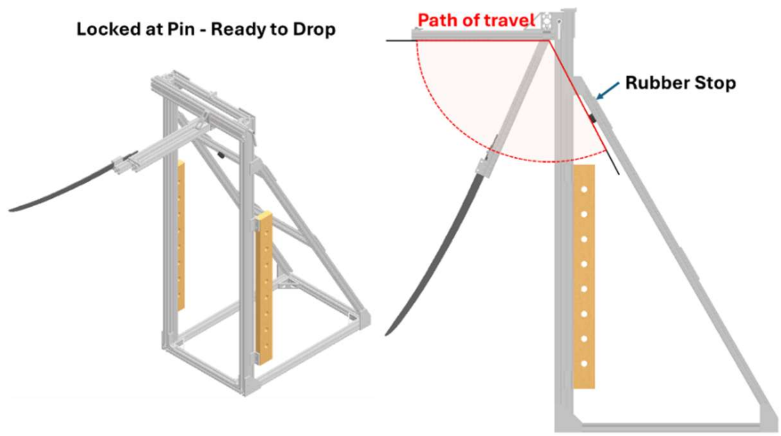

Figure 37 - Swing Test Rig Set-up

The swing test (Figure 37) utilized both wood and pool noodles to evaluate the blade's sharpness and durability. To pass, the blade had to cleanly cut through a pool noodle on the first swing both before and after striking wood. Testing began at the tip—where the blade had the highest cutting velocity—and progressed in 3-inch increments along its length. During testing, we observed that the last quarter of the blade lacked sufficient inertia to generate the force needed for a clean cut. Notably, this was before the final sharpening. Once the test reached this section, the blade was struck against a wooden backer every 3 inches down its length, simulating heavy use. Following this, another round of pool noodle cuts was performed, demonstrating that the blade maintained its cutting ability even after repeated impacts against wood.

Sharpness Test

To evaluate the sharpness of the blade, a BESS-certified Edge-On-Up Industrial Edge Tester was used to measure the force required to sever a standardized test wire (Figure 38). The blade was tested at multiple points along its length, including the tip, midsection, and base, to ensure a consistent edge profile. During testing, the blade was gently lowered onto the test wire with minimal force, allowing the wire to break naturally under the sharpest part of the edge. This method provided an objective measurement of sharpness, with lower numbers indicating a finer edge. The results ranged from 245 grams at the sharpest point to 300 grams at the least sharp section, demonstrating a well-honed but durable edge across the entire length of the blade. These values align with industry standards for a functional cutting edge, balancing sharpness with the toughness required for impact and durability.

Figure 38 - BESS-Certified Edge-On-Up Industrial Edge Tester

Conclusion

The Cast in Steel 2025 project resulted in the successful creation of a historically accurate and functional George Washington sword (Figure 39). Through three iterations of handle components and four iterations of the blade, the team refined the design with a focus on both historical authenticity and practical usability. The blade underwent rigorous testing, including finite element analysis (FEA) and physical tests, ensuring its structural integrity and sharpness met the desired specifications.

The sword was cast using a combination of green sand molds and investment casting, an approach that proved effective in achieving precision and durability. The final blade, measuring 30 inches in length, was crafted from a high-carbon alloy steel composed of 0.53% C, 0.305 Si, 0.151% Mn, 0.68% Cr, and 98% Fe, which contributed to its strength and performance. The completed weapon, with a total weight of 2.2 lb (1.00 kg), achieved a hardness of 50 HRC and successfully passed strength and durability tests.

Ultimately, the sword not only meets historical standards but also stands as a testament to the team’s dedication to craftsmanship, precision, and continuous improvement throughout the project.

Figure 39 - Completed Sword

References

[1] Mount Vernon. (n.d.). *Washington's swords: An interview with Erik Goldstein*. Retrieved from https://www.mountvernon.org/preservation/collections-holdings/washingtons-swords/washingtons-swords-an-interview-with-erik-goldstein

[2] Distel, Zachary. Telephone Interview. 8 October. 2024

[3] Goldstein, E., Mowbray, S. C., Hendelson, B., & Cadou, C. B. (2016). The swords of George Washington. Mowbray Publishing.

[4] Neumann, G. C. (1973). Swords & Blades of the American Revolution. Harrisburg, Pa. Stackpole Books.

[5] Neumann, G. C. (2011). Battle Weapons of the american revolution: The historian's complete reference. Mowbray Publishers.

[6] Williard, Kyle. Telephone Interview. 16 September. 2024