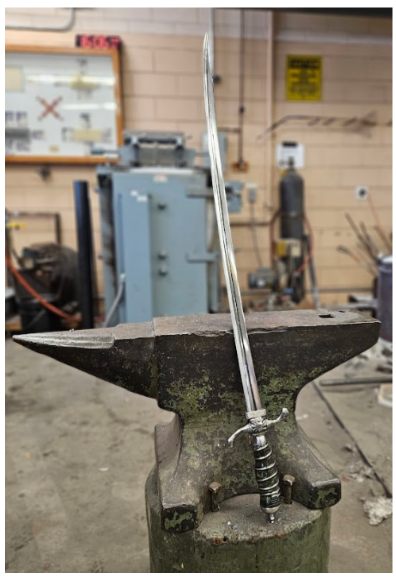
SFSA Cast In Steel 2025 – George Washington Sword Technical Report

Georgia Southern University – Southern Steel Company



Team Members:

Drew Kuiters, Nathaniel Giddens, Nathan Holmes, Alexander Juarez, Michael Jones

Advisor:

Dr. Mingzhi Xu

Foundry Partner:

Carolina Metal Casting

Table of Contents:

1. **Introduction** (School Library, Google Scholar)

"A free people ought not only to be armed, but disciplined; to which end a uniform and well-digested plan is requisite; and their safety and interest require that they should promote such manufactories as tend to render them independent of others for essential, particularly military, supplies." vocalized by George Washington, the first President of the United States, in his first State of the Union address. President Washington instilled in himself an innate drive to stay disciplined in pre-planned logical thinking which set him apart as a leader. Washington, a man whose heart was set on the greater good of his country, held this same approach from the battlefield to the head of office and was praised highly for it. For Washington attention to detail was not only important in how he led, but also in how he lived. The day to day decisions Washington was forced to make held the weight of countless men's lives as well as the country's future and Washington knew it. Therefore if a sword were to be made for Washington it was made meticulously, ensuring that it would both serve a purpose of celebrating Washington's leadership and most importantly functionality.

Swords, known as a means of weaponry in hand to hand combat, are now formally known as artifacts both for their historical significance as well as their artistic craftsmanship. One of the most prominent sword collections in US history belongs to the great George Washington. As the first president of the United States, Washington was a fitting candidate for well-made swords. Although each sword owned by Washington could be argued as the greatest, one of, if not the greatest sword Washington ever wielded was the Bailey Silver & Ivory-Hilted Cuttoe.

This sword, crafted by the English native John Bailey, was the sword Washington primarily used at the end of the Revolutionary War. Despite the fact Washington did not receive this sword until an approximate 1778, he is famously depicted with it at his side in Emmanual Luetze's well-known 1851 painting "Washington Crossing the Delaware." This painting portrays the strategic attack of commander-in-chief George Washington performing a risky maneuver that would eventually lead to a victory in war. This iconic play in battle took place December 25th-26th, 1776 at least an entire year before Washington received this sword. It can only be believed that the artist chose this sword to be placed in the picture due to its significance to Washington and the pure craftsmanship it displayed.

Figure 1: Emmanuel Luetze's "Washington Crossing the Delaware"(1851)

Furthermore this sword was a perfect combination of both style and functionality. The sword could be described as a cuttoe. A traditional cuttoe, derived from the French term *Couteaux de Chasse* translating to “hunting knife,” measured around 24 to 27 inches–living up to its title of a hunting knife. The sword made for Washington was, however, 36 ¼ in long, attesting to his significantly taller height at the time of 6’ 2”. This sword features a curved grip made from ivory with intricate weaving of silver band. Engraved in the crossguard, made also of silver, various heads of animals are depicted as well as a grouping of military arms. John Bailey also added green-stained accents to the ivory which descends down the handle in a spiral like pattern with the silver. A rainguard is also attached at the top of the blade, a fairly uncommon feature on a sword, and a silver pommel is placed at the opposite end of the blade to keep the handle intact. These minor details portrayed the significance of the person who wielded it and George Washington was nothing short of deserving a sword of this stature.

Figure 2: Bailey Silver & Ivory-Hilted Cuttoe and Sheath

Copying the rich history and characteristics of George Washington in his behaviors of preparation and attention to detail, the “Southern Steel Company’s” team from Georgia Southern **has recreated the famous Bailey Silver & Ivory-Hilted Cuttoe**. Careful planning and research was at the forefront of our process and like President Washington we took the time to do it right. SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available. This paper will further discuss the relentless efforts of our team through brainstorming, CAD iterations, Magmasoft simulations, mold creation, mold assembly, casting processes, post-processing, heat treatment, sharpening, and handling assembly all completed to create the final product of our sword.

2. Design

2.1 Process Consideration

The sword was designed into six separate components : the blade, the hilt, the handle, the pommel, the rainguard, and the top cap. The blade was designed to be casted using a no-bake sand process with the necessary gating required to produce the blade. The hilt was casted using an investment casting process to allow for the desired detail in the hilt to historically match the original hilt. The rainguard, top cap, and pommel were machines on a cnc lathe and milling machine.

One of the main challenges with casting a sword such as a cuttoe is the thinness of the blade. The blade being so thin and long would likely result in misrun or cold shut due to inadequate flow or temperature. For this reason, the gating system was designed to use horizontal gating and a designed system to allow for metal to arrive at an adequate temperature and velocity to avoid premature solidification. The tongue of the blade was designed to be thicker and forged out to the desired length to match up with the true dimensions of the bailey silver and ivory cuttoe. A fuller was added into the design of the sword rather than forging the fuller into the blade. This allowed for a strong contrast between the original cast surface and the machined portions of the blade.

The hilt of the sword was designed to be casted using investment casting process to acquire the desired level of detail and superior surface finish. One side of the hilt used Bailey's original signature to honor the original blacksmith who forged the cuttoe. The other side of the hilt displays Georgia Southern's logo, highlighting our pride in our university. The hilt was casted out of stainless steel to best match the finish of the silver from the original hilt.

The pommel, rainguard, and top cap were designed to be machined on a HAAS lathe and mill to achieve the appropriate dimensions and surface finish. This process allowed us to easily and rapidly manufacture the final components of the sword with a high degree of precision and a high quality surface finish. The parts were made of stainless steel to match the finish of the silver on the original cuttoe.

The handle would be turned on a lathe to match the dimensions of the original cuttoe, along with grooves carved into the handle for the steel wire. A dremel was used to carve the grooves into the handle for placement of the steel wire and a polishing wheel was used to obtain the desired finish on the handle, ensuring the sword replicated the original handle as closely as possible. The handle was then coated with a clear epoxy finish to create a nice finish on the handle.

2.2 Sword Design Considerations

The sword that was selected to be casted was the Bailey Silver & Ivory-Hilted Cuttoe. The goal of the team was to as closely match the original Bailey Silver & Ivory-ilted Cuttoe as possible. For the design of the blade, the blade was designed to have a blade length of 30" with a total length of 34". While the original length of the blade was 36", the tongue of the blade would be forged out and grinded to the desired final length. A fuller was also added into the sword to highlight the contrast between the original cast surface to the grinded surface.

The hilt was designed in Blender software with the goal of matching the original hilt as much as possible with one small change. On one side of the hilt, the Georgia Southern logo was added, while the other side of the hilt shows Bailey's original signet. This change was done to display our pride in our university prominently on the hilt of the sword.

The pommel, rainguard, and top cap of the sword were designed to match up to the originals as much as possible. The intricate designs on the components were added with a dremel after manufacturing to closely match up to the original sword as possible.

The handle of the sword was designed to be green tinted epoxy to match the ivory material as much as possible. Stainless steel wire, as opposed to silver wire, was used for cost effectiveness while still providing a similar color and finish to the original handle. Black lines were also added around the steel wire to accent the handle further and better replicate the original handle.

2.3 Alloy Selection

For the chemistry of the sword, 5 steels were considered for casting the steel: 1045, 1095, proprietary 8630, 5160, and 9260. To determine the optimal material for the sword, a decision matrix was developed that evaluated the materials based on tensile strength, ductility, hardness, and cost. Each category was normalized and summed together with the reciprocal of the cost added to the calculation as a lower cost is beneficial. The material with the highest final calculated score was then selected. Table 1 shows the decision matrix with the selection of materials.

Table. 1 : Decision matrix for the material of the George Washington Sword

	Tensile Strength (MPa)	Hardness (HB)	Ductility (%)	Cost	Calculations				Final Score
1045	650	195	8	29.76	0.00	0.00	0.00	0.83	**0.83**
1095	685	197	10	71.03	0.16	0.09	0.17	0.00	**0.42**
Proprietary (8630)	680	200	20	33.33	0.27	1.00	1.00	0.75	**3.03**
5160	724	197	17	21.08	0.34	0.09	0.75	1.00	**2.18**
9260	870	210	15	67.43	1.00	0.68	0.58	0.07	**2.34**

Due to the working conditions of this component, the selected alloy would need to possess great hardness, strength, toughness and work hardenability. A proprietary steel that was custom designed for ground engaging tool applications was selected to meet the required mechanical properties of the sword. The target composition of the steel is 0.3C-1.1Mn-1.6Si-2.1Cr-051Ni-0.32Mo. This metal is typically heat treated at an austenitization temperature of 1688°F followed by agitated oil quench and tempering at 392 °F. The expected properties of this steel after heat treatment are 52 HRC hardness, 252 ksi tensile strength, and 15 ft-lb impact toughness. The actual composition and properties were tested in our university's labs and can be found in section 3.8.

3. Manufacturing

3.1 Gating Design and Simulation Methodology

Three main factors are critical to the successful filling of the mold: temperature, velocity, and air pressure. The metal must be at an adequate temperature to flow through the gating system and fill the casting without premature solidification. The gating system must also be designed to control the flow of the metal and push air out of the cavity. When the metal fills the mold, liquid fronts which meet must be above liquidus to mix and not result in a cold shut. The gating system must control the flow of the liquid metal, allowing for head pressure to fill the cavity without turbulent flow characteristics. This occurs ideally at a velocity of around 20 inches per second, under 40 inches per second, and can be controlled by runner cross sectional areas. It is also crucial to design the gating system to solidify evenly to avoid hot tearing in the casting during solidification. Vents can be added as needed for areas of the casting which build pressure from the rising liquid surface. The goal is to pour hot enough and fast enough to fill the mold without creating inclusions in the metal from turbulence or mold erosion.

A horizontally parted mold design was chosen for easy assembly of the molds. The top of the downsprue was fitted to our foundry's typical pouring basin inlet and drafted downwards with a decrease in area by 20%. Calculations were conducted to determine the necessary cross section area for the downsprue, runner, and gates and modeled accordingly. To simulate the metal flowing through the gating system, MAGMAsoft was used for its superior simulations and analysis. 12 iterations of the gating system were simulated to achieve the desired results of adequate temperature within the mold, optimal velocity of the metal, zero predicted porosity, and minimal hot spots.

For the pouring results, the initial pouring temperature was set to 3000 degrees fahrenheit (1650 degrees celsius) based on the capabilities of our foundry. The liquidus temperature was set to 2775 degrees fahrenheit (1525 degrees celsius) in the scales to determine potential area for cold shut or other temperature related defects. Figure 3 shows the Magma result for the pouring temperature showing that the gating system fills the mold well above the liquidus temperature.

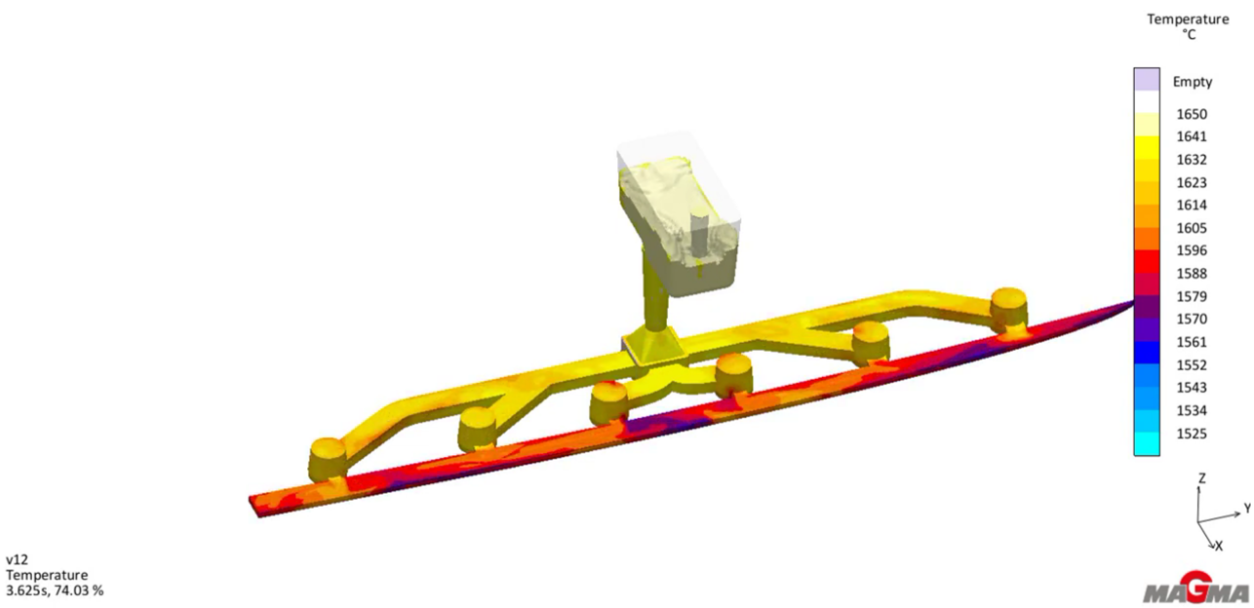


Figure 3. Image of the temperature result perspective at the time when metal has filled the mold

For the velocity result, it is generally accepted that the velocity of molten steel in the mold be held at around 20 inches per second (0.5 meters per second) and not go above 40 inches per second (1.0

meters per second) to achieve good filling. Using the gating system presented in Figure 3, the velocity remains between the recommended speeds, ensuring the mold fills in an appropriate time to minimize defects. Figure 4 shows the velocity results from the magma simulation.

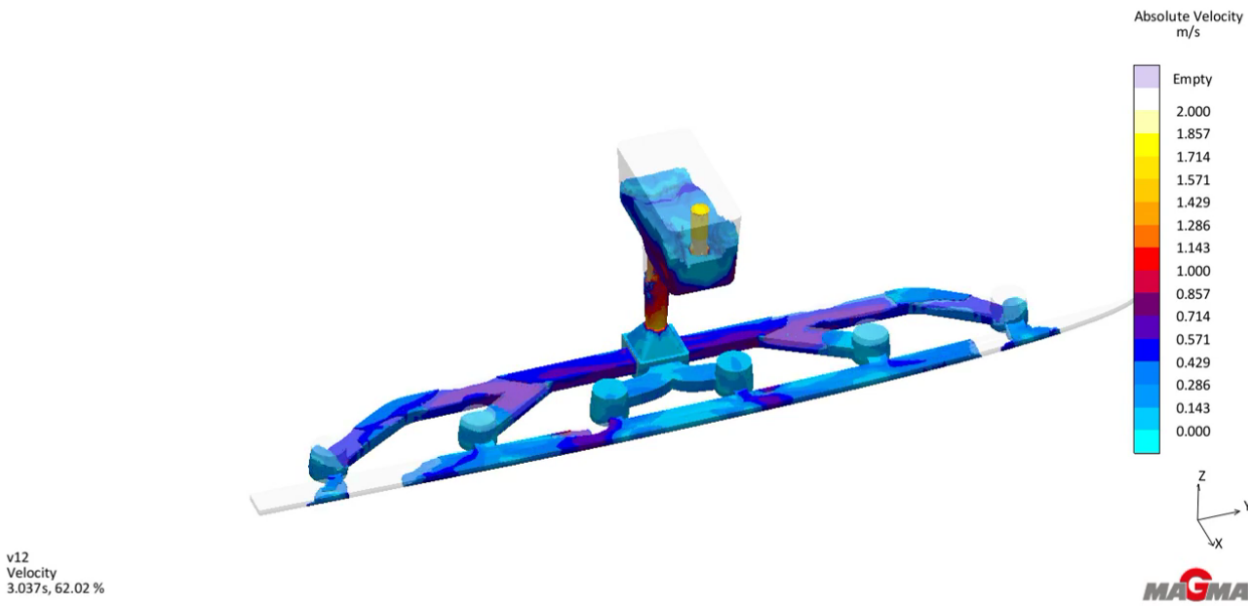


Figure 4. Image of the velocity perspective once metal has entered the casting

Another major factor in the gating design is the elimination of porosity within the blade. Locations of high chance to form porosity are last to freeze locations. Meaning, locations in the casting that solidify last, with no liquid metal to feed them, will have a chance to shrink and cause porosity. With the utilized gating system, porosity in the casting is reduced to a minimum and shows low values of porosity in a single location of the part geometry. Figure 5 shows the porosity result of the simulation and that the single point of porosity was a 5% chance. While porosity is not the only indication of a good casting, the results showed that the mold will fill properly and minimize any potential porosity in the blade. Sequential forging and heat-treatment steps will improve and ensure that the blade will be strong and durable.

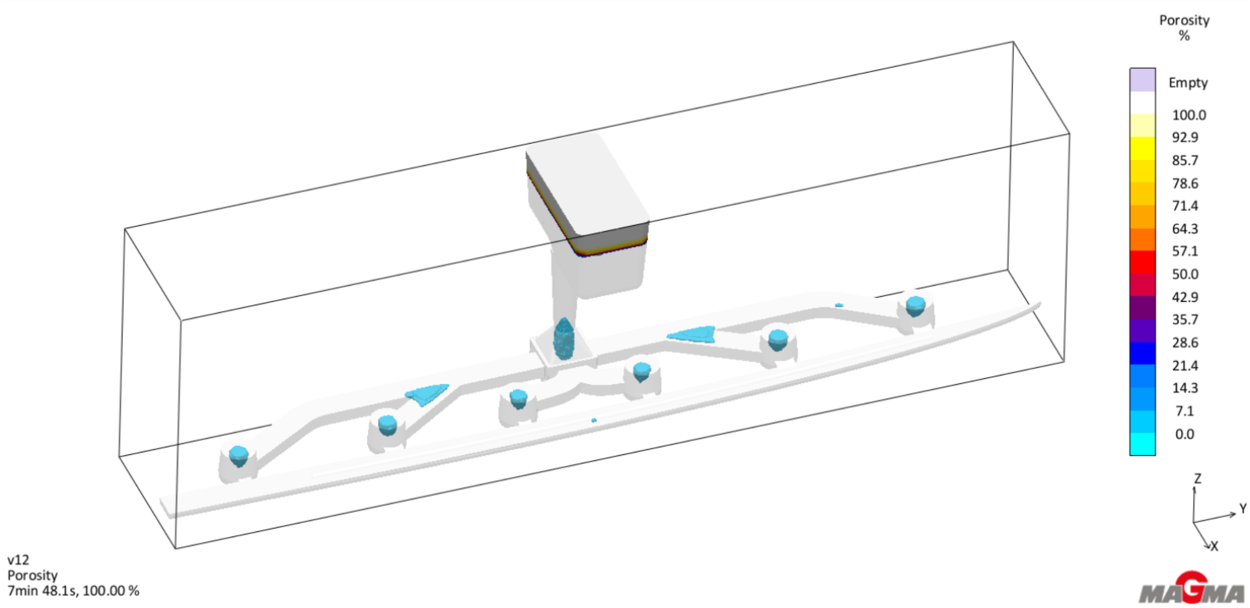


Figure 5. Image of the porosity result to highlight areas of potential porosity formation

3.3 Pattern and Flask Production

Once the final iteration of the pattern had been simulated with the desired results from MAGMA, the pattern was exported and 3-D printed on a fused deposition modeling printer to create the cope and drag patterns, as shown in Figure 6. The patterns were printed in several pieces due to the space limitations on the build plate of the printer. The flasks were created using 0.5 inch birch plywood and 2" wood screws, allowing for a 2" coverage on all sides of the pattern to ensure the molds held together during pouring. A 5 degree draft was added to the walls of the flask for easy removal of the flask.

Figure 6. the 3-D printed pattern with the cope pattern assembled and the drag pattern waiting to be assembled

Pattern for the hilt of the sword was printed using a special low-ash PLA filament and smoothed out using a 70% isopropyl alcohol solution. The prints were then hot glued onto a styrofoam gating system and then dipped in an alternating pattern of slurry and stucco to create the investment shell. The first two layers of the stucco were fine zircon to ensure the shell encapsulated all the details in the hilt. Once the first two layers were dried, an additional six layers of coarser silica stucco were added to the shell to complete the process. Figure 7 shows the final investment shell ready for pouring. The investment shell was fired at 1562°F (850°C) for one hour to remove the pattern, and preheated to 1700°F (927°C) right before the pouring

Figure 7. the final investment shell ready for the mold to be burned out and prepared for pouring

3.4 Mold Production

The loose-piece pattern and flask were aligned manually and placed on a flat table. The mold was produced using no-bake sand with a 1.5% phenolic-urethane resin to sand and 35% hardener to resin mixture. These mixtures were chosen based on manufacturer recommendation and previous success in molding. The molds were allowed to sit overnight assembled to ensure the resin and hardening agent have achieved full strength and reduce any parting line gaps between the cope and drag.

Figure 8. No bake sand being poured into the flask with the 3-D printed pattern

3.5 Sand Casting Process

Once the cope, drag, down sprue extension, and pouring basin were set and had cured for a minimum of eight hours, the molds were moved over to the furnace to assemble for pouring. Several vent holes were drilled into the cope of the mold to allow for trapped air in the mold to escape based on high pressure areas from the Magma simulation. An acetone-based mold glue was applied on the drag before assembling the two halves. A downsprue extension was then glued to the cope with a pouring basin on top to provide the required pressure head for proper metal filling. A total of two molds were manufactured in the case of any defects during the manufacturing, pouring, and post processing defects.

Figure 9. Molds being assembled with acetone glue applied

Figure 10. The molds fully assembled ready for casting

The castings were poured in Georgia Southern's foundry lab. The steel was melted in a 100-lb induction furnace under argon atmosphere. Aluminum was added during tapping to kill the steel. The molten steel was tapped at 3,100 °F and poured at an estimated 3000 °F. All personnel followed safety protocols to ensure a safe and efficient pour. Following pouring, the castings were kept in the molds to cool overnight and avoid any uneven cooling rates. Figure 11 shows the pouring of the first mold. Figure 12 shows the final blade after post processing and heat treatment.

Figure 11. Liquid metal being poured into the sword mold

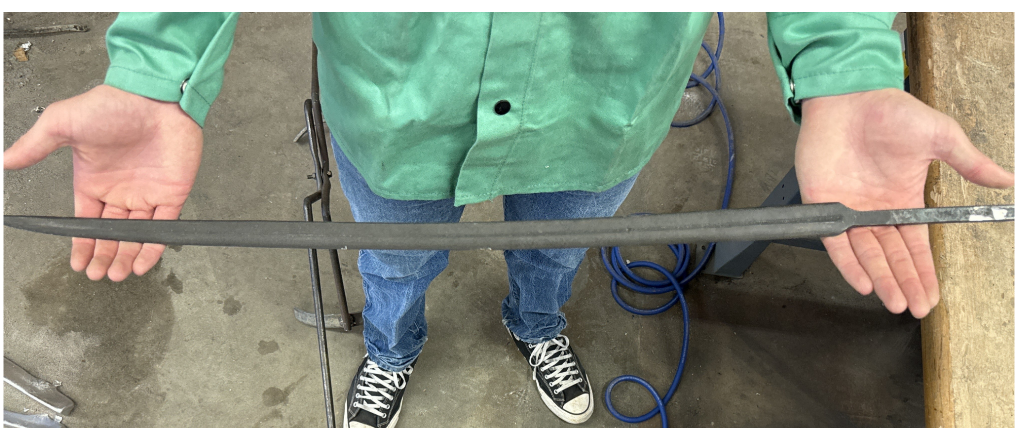


Figure 12. The final blade after post processing and heat treatment

3.6 Post Processing and Forging

Angle grinders were used to remove the gating from the blade. To forge the handle out, the end of the handle was placed in a propane forge till it reached a bright red color before being worked. The handle was then worked with a 5-lb hammer to extend the length of the handle by 1.5 inches, as shown in Figure 13. . After forging, the sword was then shaped to the desired dimensions using a bench grinder and belt sander. The belt sander was used to establish the general edge of the word, followed by sharpening with diamond and ceramic grind stones. The angle of the edge used was a 30 degree angle, a typical edge angle for cuttoes giving the blade a good mix of durability and sharpness. Figure 14 shows the blade being grinded on the belt sander.

Figure 13. The tongue of the blade being extended by forging

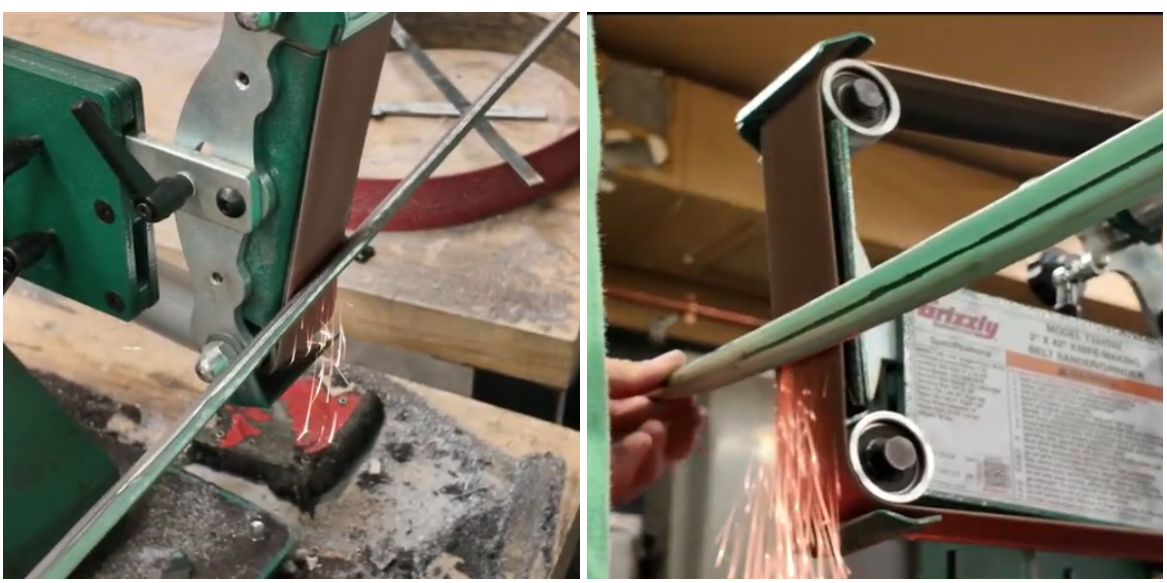


Figure 14. grinding the sword on the belt sander.

The hilt was poured with 304 stainless using a 20-lbs induction furnace in house. After solidification, the hilt of the sword was cut from the gating using a vertical bandsaw. A half inch diameter was drilled into the hilt to allow the hilt to be assembled onto the sword. From there, the hilt was then polished using a white rouge metal polishing compound. This produced an excellent finish on the hilt and highlighted both the Georgia Southern logo and Bailey's stamp. Figure 15 shows the polished stainless steel hilt.

Figure 15. the hilt of the sword after the hole was drilled and polished

3.7 Heat Treatment Considerations

The blade was first normalized by austenitization at 1700 °F for 15 minutes followed by air cooling. This normalization cycle was to homogenize the grain structure of the blade, relieve the internal stresses, and refine the grain sizes. A second round of normalization at 1700 °F for 15 minutes was performed followed by quenching in non-agitated oil to promote martensite formation. The sword was then tempered at 400 °F for 1 hour. This is to precipitate fine carbides from the martensite, forming a tempered martensite microstructure in the blade, as shown in Figure 16.

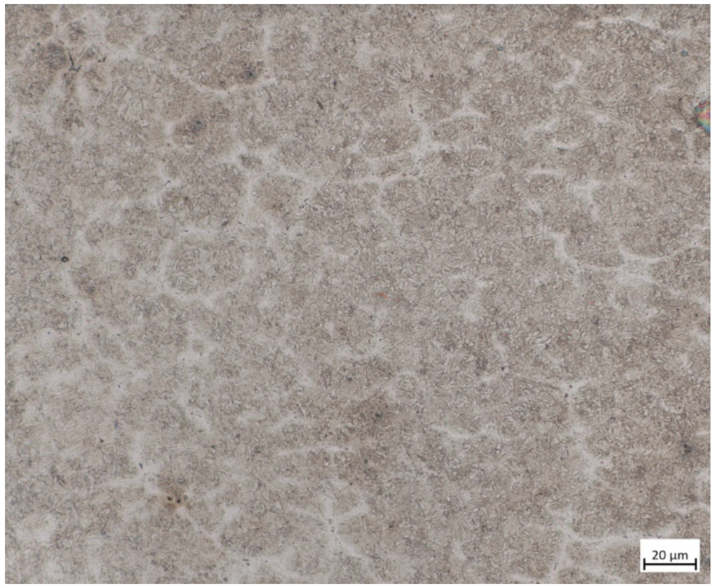


Figure 16. Microstructure of the Steel after all Heat Treatment with notable fine lath martensite

3.8 Final Result

All the components of the sword were finally brought together for assembly. The sword components were laid out together and pressed fit to hold all the components onto the blade. An epoxy was also used to ensure the components were secured to the blade and that no movement would occur during testing. The final blade length of the team cuttoe was 29.75 inches with a total overall length of 36.125 inches, easily meeting the requirements set out for the competition within the defined tolerances. The sword weighed in at 2.51 pounds, well below maximum weight of 4.4 pounds. The blade was made of a proprietary 8630 steel, the rain guard, top cap, pommel, and hilt were made of 304 stainless steel, and the handle was made of a green stained epoxy with stainless steel wire wrapped around it. Figure 17 shows the final assembled replica of Baileys Silver and Ivory hilted cuttoe.

Figure 17. the cuttoe assembled and after all post processing and finishing

3.9 Testings

The steel chemistry was measured with an optical emission spectrometer and a Carbon/Sulfur combustion analysis machine. The chemistry measured is listed in Table 2. The chemistry meets the specifications for our modified 8630 steel.

Table 2. Composition (wt. %) of the steel

	C	Si	Mn	Cr	Ni	Mo	Al
wt. %	0.35	1.60	1.01	1.99	0.49	0.325	0.0103

For the actual testing of the sword, several tests were performed to determine the thrusting and slashing capabilities of the cuttoe. The first tests involved testing the blade against a full bag of sand by first stabbing the bag and then slashing the bag open. This proved that the sword could easily puncture a target as well as perform slashing attacks. Figure 18 shows the testing against the sand bag.

Figure 18. Images of the blade stabbing and slashing through a bag of sand

More rounds of testing were performed against an old milk crate. The milk crate was chosen to test the slashing capabilities of the sword against a more solid material and provide more resistance to the swords slashing. Figure 19 shows the slashing against the milk crate.

Figure 19. the sword slashing against an old milk crate

The sword was also tested against an old tire. The tire was chosen to test the capabilities of the sword to stab a tougher material. The sword easily penetrated the tire, proving the cuttoes stabbing power. Figure 20 shows the blade penetrating the sword.

Figure 20. The blade penetrating the tire with ease

4. Executive Summary

Our sword was designed with the intent of replicating Bailey's silver and ivory hilted cuttoe. The design replicates the major components of the blade while also adding a bit of Georgia Southern's flair, mainly to the hilt of the cuttoe with one side matching Bailey's signet and the other side promptly displaying Georgia Southern's logo. Our alloy was selected among a variety of steels based on their mechanical properties and cost effectiveness. The rain guard, hilt, top cap, and pommel were selected to be made of stainless steel to best mimic the finish of silver and provide better mechanical properties to the sword.

The blade of our cuttoe was designed to be sand casted using no bake sand and to forge the tongue out to meet the length requirements of the blade to best replicate the original cuttoe. The hilt was designed to be investment casted to best capture all of the details in the hilt. The rainguard, pommel, and top cap were machined using a HAAS lathe and mill. The handle was made using an epoxy and cut down to the desired dimensions with a steel wire placed in the grooves to best recreate the original handle. All components were polished to obtain the best possible finish.

The gating system for the blade went through several simulations to ensure the optimal pattern had been developed and a high quality casting would be produced. The blade was casted in horizontally parted molds and forged to meet the final dimensions of 29.75 inch blade length and 36.0 in total length.

After post processing, the blade was then heat treated with a normalization cycle at 1700 degrees fahrenheit for 15 minutes and air cooled, followed by a quenching cycle at 1700 degrees fahrenheit for 15 minutes followed by a quench in non agitated oil. The blade was finally tempered at 400 degrees fahrenheit for 1 hour giving the blade a final microstructure of fine lath martensite. After heat treatment, the blade and other components went through a final polish and were assembled using press fits and an epoxy to ensure the blade would withstand the toughest testing conditions.

The sword was tested on a variety of objects and materials to determine the sword's slashing and thrusting capabilities. The cuttoe was able to slash and piece the sand bags, as well as the old milk crate and the old tire. Many difficulties were encountered during this project, ranging from pouring issues to machining and post processing issues. Our team would like to thank our industry partner, Carolina Metal Castings, as well as our faculty advisor, Dr. Mingzhi Xu, for guiding us through our trouble and mistakes, and helping us to produce such a fantastic piece of history. Our sword was able to meet all the requirements with a 29.75 in blade length, 36.0 in total length, 2.51 lbs weight, and using 8630 steel for the blade, 304 stainless steel for the rain guard, hilt, top cap, and pommel, and a green stained epoxy handle with steel wire wrapped around in a spiral.

5. References

- *10 facts about Washington's crossing of the Delaware River*. George Washington's Mount Vernon. (n.d.-a). https://www.mountvernon.org/george-washington/the-revolutionary-war/washingtons-revolutionary-war-battles/the-trenton-princeton-campaign/10-facts-about-washingtons-crossing-of-the-delaware-river

- *American officer's sword made by John Bailey*. The American Revolution Institute. (2022, May 2). https://www.americanrevolutioninstitute.org/masterpieces-in-detail/american-officers-sword-made-by-john-bailey/#:~:text=The%20name%20%E2%80%9Ccuttoe%E2%80%9D%20is%20an,of%20the%20armies%20of%20Europe
- Miller, J. (2024, November 5). *The sword of freedom: How George Washington's most iconic blade symbolizes the spirit of Independence Day*. BRUTE de FORGE. https://brutedeforge.com/articles/george-washingtons-sword-of-freedom/#:~:text=His%20most%20iconic%20sword%2C%20the%20Bailey%20Silver,the%20Continental%20army%20during%20the%20Revolutionary%20War
- Smithsonian Institution. (n.d.). *George Washington's Battle Sword and scabbard*. https://www.si.edu/object/nmah_434865
- *Washington's swords*. George Washington's Mount Vernon. (n.d.-b). https://www.mountvernon.org/preservation/collections-holdings/washingtons-swords#:~:text=The%20Bailey%20Silver%20%26%20Ivory%2DHilted,years%20of%20the%20American%20Revolution