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

Georgia Southern University – The Three Musketeers

Team Members:

James Votava, Shamsul Alam, Adnan Adib Ahamed, Andrew Rose

Advisor:

Dr. Mingzhi Xu

TABLE OF CONTENTS

1 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

George Washington is the first president of the United States and known for his exceptional character and leadership skills. He owned a range of edged swords spanning the attributes of both civilian and military. This was due to several contemporary factors, including form, function, and fashion. Some of his swords were gifts, offered as tributes, or acquired by descent, and reflect no choice of him, assuring that an interesting mixture of weapons came into his possession over the course of his life. However, all of them were deemed by Washington as the apparatus of his masculinity which had to be chosen to wear with a good deal of thought.

Washington viewed all his swords as tools for self-defense and defense for his Country's rights, not tools for bloodshed. This information is from a quote in his last will and testament, Washington says, "To each of my Nephews, William Augustine Washington, George Lewis, George Steptoe Washington, Bushrod Washington and Samuel Washington, I give one of the Swords or Cutteaux of which I may die possessed; and they are to choose in the order they are named. These Swords are accompanied with an injunction not to unsheath them for the purpose of shedding blood, except it be for self defence, or in defence of their Country and its rights; and in the latter case, to keep them unsheathed, and prefer falling with them in their hands, to the relinquishment thereof."

One of George Washington's sword given to his nephews in the will was the Model 1767 French officers epée. Rumor of how Washington got the sword was that his mother Mary Bell Washington gave him the sword. This rumor is not backed up with historical evidence. The most accepted theory is that he was given it as a gift or bought it somewhere. Washington was given another epée by Marquis de Lafayette in 1780, which is not this sword. This sword was considered Washington's mourning sword because he purposely wore it to funerals. It was a rather conventional sword and was one of the fourth inherited by Washington's nephew Bushrod.

Figure 1. Model 1767 French officer's epée of George Washington at the Mount Vernon Collections

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 technical report is going to discuss the CAD modeling, material selection, gating design, casting simulation, mold preparation, casting, post processing, and heat treatment performed to create the team's version of the George Washington sword.

For the competition, **the Model 1767 French officer's epée was chosen by the Georgia Southern University team "Three Musketeers" as an inspiration to produce an original sword that would be fitting for George Washington**, should he be gifted a sword to match his stature and personality as a tribute from Georgia Southern.

2 DESIGN AND MATERIAL SELECTION

2.1 PROCESS CONSIDERATIONS

Thinness of the sword was a big consideration to the design process. The epee being essentially a fencing sword and being lightweight is a big aspect of its functionality. The sword being thin would check the lightweight parameters. A big discussion with the design was how thin the sword can get without the metal freezing before the sword is filled. The sword dimensions were within dimensions for thin wall filling. The first iteration was made and filled well. The problem was the sword was very heavy, and the post process would take immense time due to the metal alloy chosen. After a discussion with the advisor the sword width and thickness would be reduced for being lightweight and increasing the ridge of the sword.

2.2 DESIGN OF THE SWORD

The ridge of the epee was crucial to the aspect of differentiating the sword out of the other George Washington swords. The first iteration of the sword blade design was made with a straight rhomboidal cross section. It was later redesigned to be a curved surface to minimize the mass of the sword and to minimize grinding requirements in post processing. So in the final iteration, a concaved rhomboidal cross section was incorporated in the CAD modeling and patterns to cast as close as possible to the final design. The blade was designed to be 33 inches and the overall length of the final sword was 39.5 inches which met the SFSA requirement of a maximum of 35 inches blade length and 43 inches of overall length. The handle of the sword was redesigned to incorporate the Georgia Southern logo in the pommel instead of the melon shaped pommel in the 1767 model. For the traditional guard used, it was changed to eagle wings to represent a bald eagle which represents our mascot and America's mascot.

In the post process, the increased angle of the ridge in the CAD model helped significantly to promote a good filling during the pour. During grinding, the ridge was not grinded away and held the shape well. The blade was sharpened to an angle of approximately 30 degrees. Figure 2 illustrates the CAD models of sword components and the final assembly.

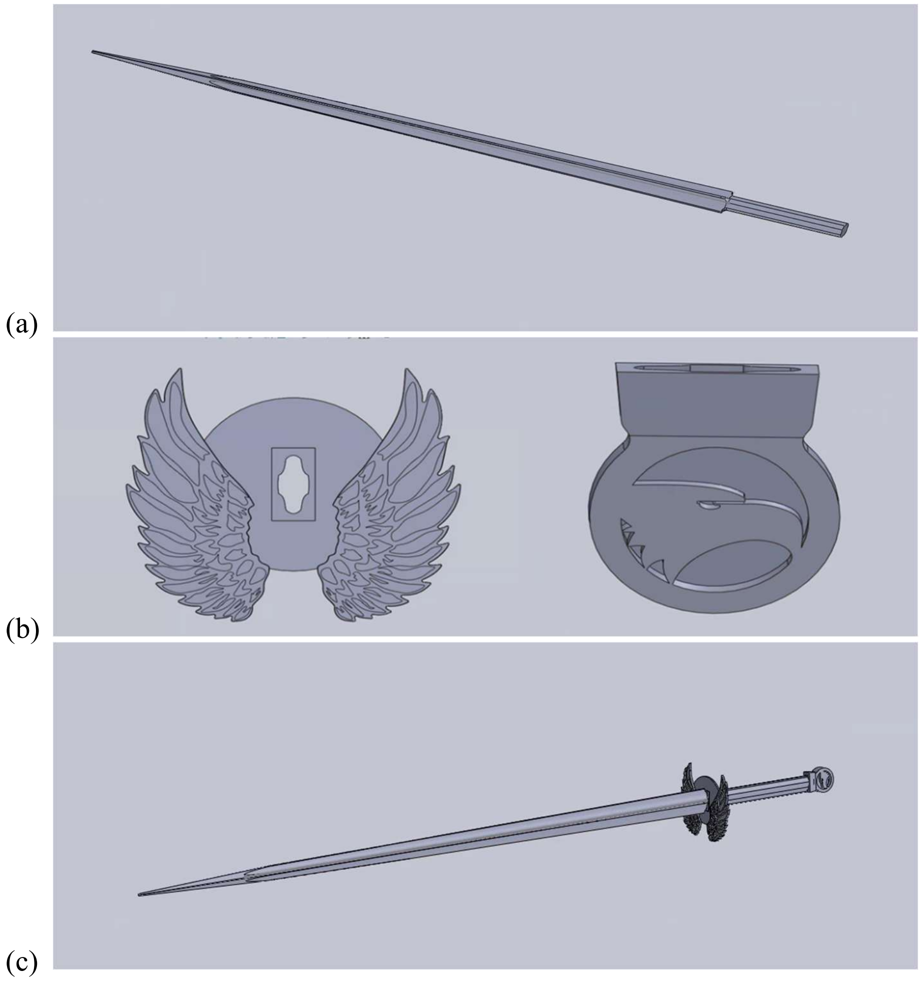


Figure 2. CAD model of the (a) sword blade, (b) crossguard,and pommel, (c) full sword assembly

2.3 Material Selection

For the blade of the sword, the selected steel would require high hardness, strength, as well as toughness to perform all its intended purposes. A steel composition that was custom designed for high strength and hardness applications was selected to meet the required mechanical properties of the sword blade. The target composition of the steel was 0.35C-1.1Mn-1.6Si-2.1Cr-0.35Ni-0.35Mo. To achieve this composition, the charge mix was prepared according to **Table 1**.

Table 1. Charge table and composition of the charge materials (wt.%) for the steel casting

Charge	Mass (lbs)	C	Si	Mn	P	S	Cr	Al	Ni	Mo
Steel	81.70	0.18	0.29	0.96	0.011	0.018	0.14	0.003	0.083	0.034
FeCr	2.56						70			
FeSi	1.72	0.08	75	0.19	0.054	0.007				
C	0.17	100								
FeMn	0.31	0.078	0.28	80						
Ni	0.24								99.95	
FeMo	0.42									70
Al (ladle)	0.017							99.95		
FeSi (ladle)	0.03	0.08	75	0.19	0.054	0.007				
Total	87.15									

The stock material for making the cross guard and the pommel were ingot cast in the university foundry in a propane furnace with the following composition stated in **Table 2**. A brass alloy C87500 was chosen based on its great strength and corrosion resistant properties. The composition of this alloy is shown in Table 2.

Table 2. Chemical composition of the brass alloy for handle components

Elements	Cu	Sn	Pb	Zn	Ni	Fe	P	Al	Mn	Si	Sb
wt. %	0.78	0.30	0.09	20.90	0.20	0.10	0.20	0.005	0.10	3.40	0.10

3 GATING DESIGN AND CASTING SIMULATION

3.1 CONSIDERATIONS FOR GATING DESIGN AND SIMULATION

Three major factors are critical to a successful filling of the mold during steel pouring. They are temperature, velocity and air pressure. The steel must be hot enough to flow through the gating system and fill the entire casting without any premature solidification. Additionally, the gating system controls the flow and allows the air to escape the mold cavity. As the metal fills the mold, the metal that fills the entire area of the cavity and the liquid fronts that meet must be above liquidus to mix with each other and avoid any cold shut. The gating system must control the liquid flow to allow the head pressure to fill the cavity without significant turbulence. Ideally, the velocity of the liquid steel should be around 20 inches per second and under 40 inches per second, even though there is no set value for target velocity of liquid steel, just a general rule of thumb to avoid a poor filling. This can be controlled by the runner cross section and the goal is to pour the molten steel hot enough and fast enough to fill the mold without creating inclusions or defects in the metal from turbulence or mold erosion. Vents are added as needed for areas with high pressure buildup from the rise of the liquid surface.

With these considerations in mind, the first iteration of the gating system was made with a basic downsprue, filter and runner design with a 1:4:4 area ratio and theoretical calculations for the area of the choke, runner and gates. The top of the downsprue was fitted to the typical pouring basin inlet at the foundry and a draft of 5° downwards was applied. This was to ensure that the downsprue remained full and did not entrap air during filling. Additionally, the filter at the bottom of the downsprue serves as a choke, greatly reducing the air entering the mold. Initially the number of gates was set at 4 at equal spacing with hot risers atop each of the gates and then the simulation was conducted in Magmasoft 5.4.1. Simulation definitions were chosen based on the university foundry capabilities. The pouring temperature was set at 3000°F and guided by the pouring basin filling level of 70%. The target chemistry was taken into consideration and the temperature that was expected for a complete filling. The simulation result showed minimal porosity in the sword blade and the handle.

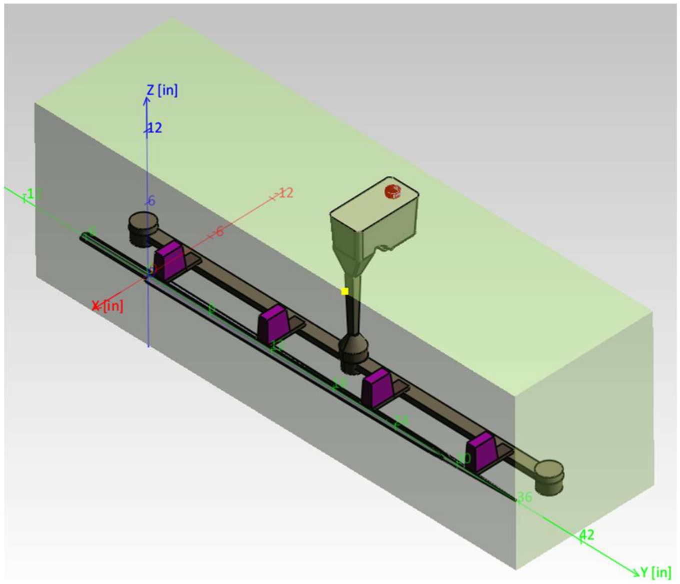


Figure 3. Geometry perspective of the initial casting and gating design in Magma

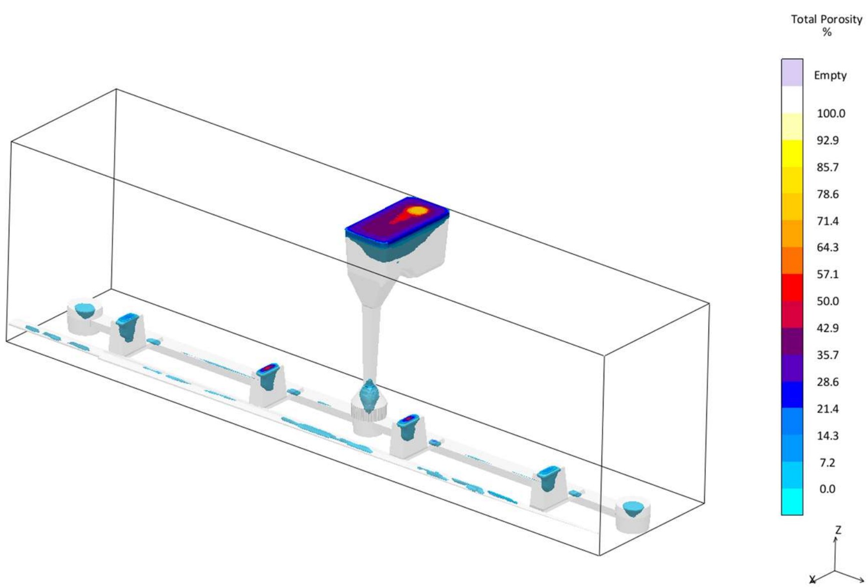


Figure 4. Solidification simulation result for total porosity from the initial gating design

3.2 Final Gating Design and Simulation Results

Several iterations were tried in magma to achieve the desired filling and solidification results. Based on the findings, the casting system design was adjusted by modifying the size and positioning of the risers, increasing the number of gates to 6 and adding the vents. The downsprue area at the connection with the filter was increased by roughly 5% and the size of the gates increased slightly while maintaining the gating ratio to approximately 1:4:4 with the choke at the filter.

The final geometry perspective is shown in **Figure 5**. With this design, the runners had sufficient cross-sectional area to fill the casting quickly without causing any significant turbulent flow inside the mold cavity.

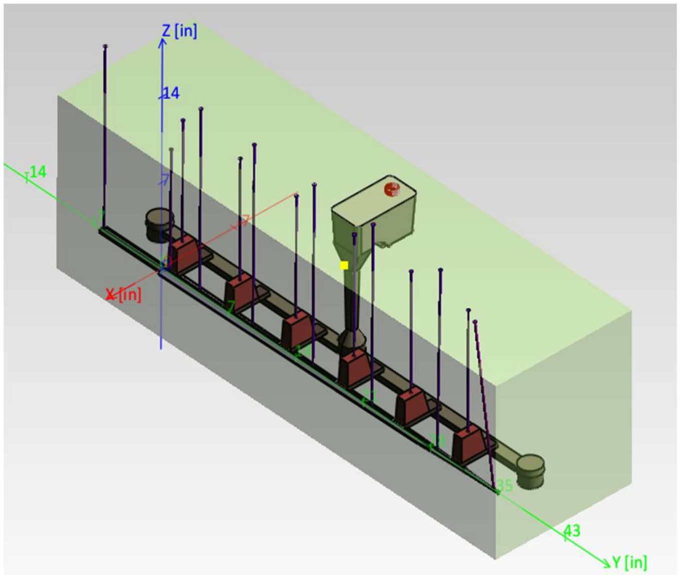


Figure 5. Geometry perspective of the final casting and gating design in Magma

The velocity simulation result during pouring when the liquid metal enters the casting is illustrated in **Figure 6**. The velocity of the liquid steel in the runners at this time was around 19 inches per second with the maximum velocity being between 20 to 27 inches per second just as the liquid metal entered through the gates into the casting.

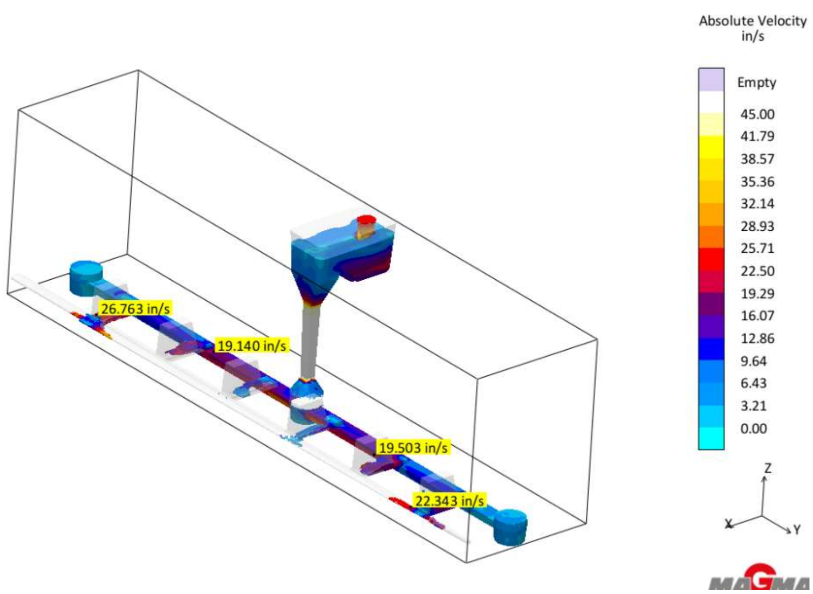


Figure 6. Velocity simulation results at the time when metal enters the casting, upper limit of the velocity scale set at 45 inches per second

A critical consideration during the simulation was to find out the temperature of the liquid steel when the liquid fronts meet. It is critical to ensure that the temperature at the time of mix is sufficiently high to promote a mix among the liquid fronts rather than solidifying on each other. The results, as in **Figure 7**, showed that the temperature at the liquid front was around 2915°F, roughly 200°F above the liquidus temperature. Under these conditions, it was expected for the casting to fill with the gates continuing the feeding and a good mix at the liquid fronts to avoid any cold shuts.

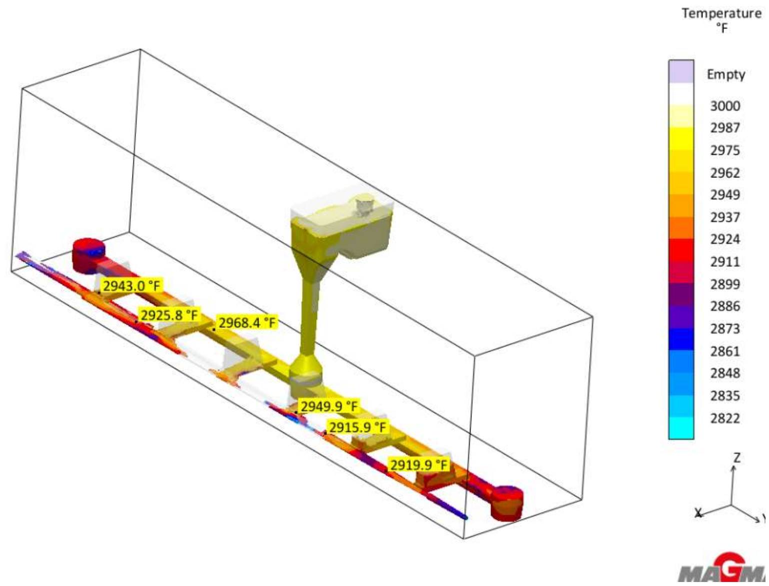


Figure 7. Temperature simulation result during pouring as the liquid metal begins to mix and fill the casting

The temperature at the tip of the blade and the thinnest section after the casting is filled with liquid metal was found to be still higher than the liquidus temperature indicating all the casting had a good filling with the metal still being liquid and that they do not begin to solidify until after the entire casting has been filled with metal. The temperature points at the tip and the handle ends of the casting are shown in **Figure 8** as the casting was filled with liquid metal.

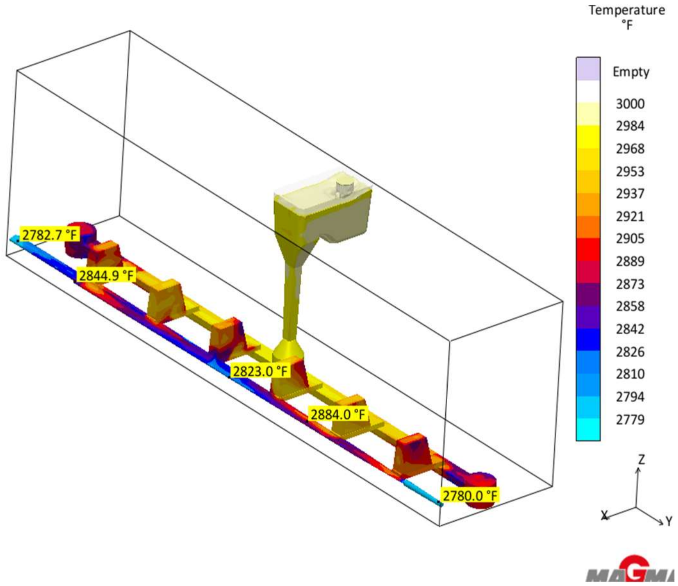


Figure 8. Final temperature simulation result showing point temperature readings at some of the critical areas

Since there is a gradual increase of the liquid steel surface inside the mold cavity, the presence of varying heights in different areas would determine the areas where vents would be required to release the air pressure. Where the height of the casting is higher than neighboring part geometries, air pressure would build. **Figure 9** shows the simulation result with increasing air pressure build up. This result indicated low pressure build up due to the presence of the vents. Additional vents were added at the extremities of the casting to help determine a complete filling of the mold cavity during pouring.

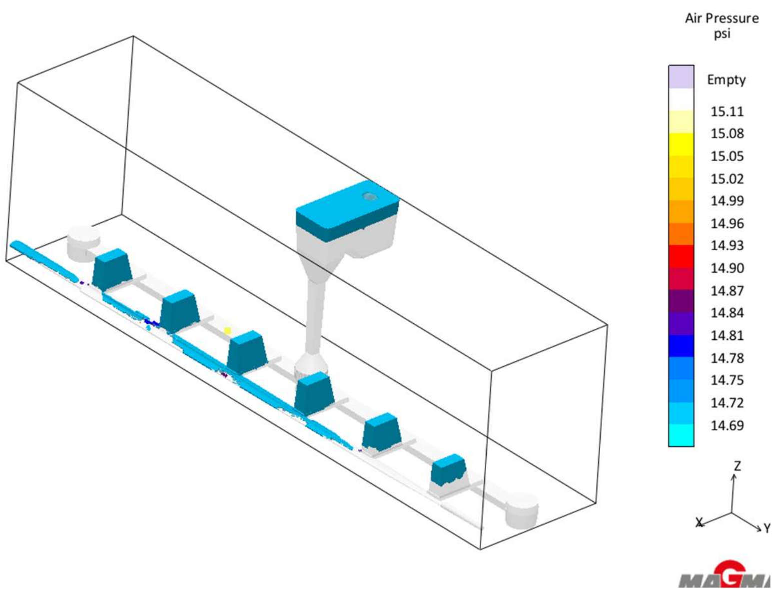


Figure 9. Air pressure showing the positions with increasing air buildup and placement of vents to release the air

A major consideration of the casting quality is determined by the porosity in the casting. It is determined by the solidification process. The locations where the metal is last to solidify are the high probability areas to form porosities due to the absence of liquid metal to feed them. Steel is more likely to experience dendritic micro porosity due to the dendrites closing out small pockets of metal that undergo isolated solidification. The total porosity simulation was generated considering these micro porosities and probable macro porosities that might occur. Most of the porosities occurred onto the surface or close to the surface of the casting. An X-ray filtering of 0-2% total porosity as shown in **Figure 10** yielded a porosity free casting indicating the present porosities were below 2%, hence the chances of porosity was at a minimum and in case of any present, those could be removed as the casting undergoes post processing operations through grinding and polishing.

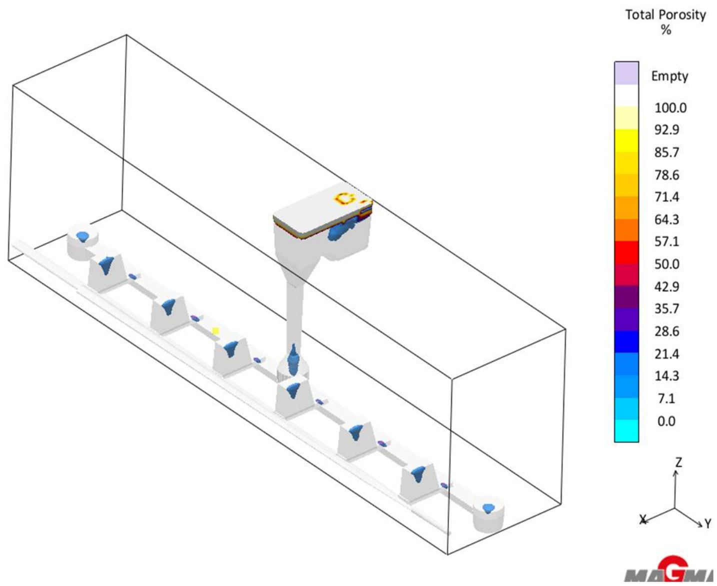


Figure 10. Total porosity with 0-2% filtered out by x-ray

While porosity is not the only indication of a sound casting, the results showed proper filling and gating to design a casting free from any major porosity. Sequential processing steps like heat treatment, grinding and polishing would improve the casting quality and ensure that the sword would be strong and hard as well as impact resistant at the tip and the blade to perform as intended.

4 MOLD PREPARATION AND CASTING

4.1 PATTERN AND FLASK

The pattern of the sword was made using a fused deposition modeling 3D printer by slicing the CAD model after splitting into multiple sections so that the parts could be accommodated within the printer bed size of 10” by 10”. It would also help in the event of the replacement of any damaged sections should that be necessary. Each of the printed sections were sanded down to smoothen the surface, aligned and glued down to a 42”x12”x0.5” birch plywood. The flask was coated with zip-slip to improve the removal of the pattern from the sand mold. The cope and the drag flasks were made using ½ inch birch plywood and a draft angle of 3 degrees to allow for an easy removal of the mold and it was joined with the match-plate pattern board with 2-inch wood screws. 6 alignment pegs were installed on the match-plate to ensure alignment of the cope and drag during mold making and assembly.

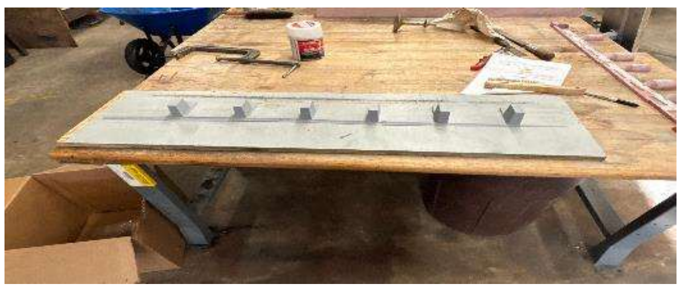


Figure 11. The 3D printed pattern for the sword assembled on the match-plate

4.2 MOLD MAKING

No-bake sand mold was made for the casting with a 1.5% phenolic-urethane resin to sand and 35% hardener to resin mixture. The selection of these mixtures was based on previous practice and successful molding in the university foundry. The cope and drag were molded separately by placing the flasks on a flat table and the cope was aligned on top of the cope with the help of the alignment pegs on the match-plate pattern. The molds were assembled and left to sit overnight to ensure the resin and hardener achieved full strength and to reduce any parting line gaps between the cope and the drag. Vents were drilled through the cope based on the magma simulation. Some additional vents were drilled at the two ends and at the intermediate positions to provide more paths to release the entrapped air and to get an idea of the filling quality during the pour. The cope and drag were then cleaned from any debris blowing compressed air before setting a zirconia ceramic foam filter below the downsprue in the filter slot. An acetone-based mold glue was applied on the drag before assembling the two halves, followed by a downsprue extension and a pouring basin being glued together on the cope. Three molds were made, allowing for multiple castings to be poured in case of any problems or defects occurring to any of the molds during casting. **Figure 12** shows the mold being made inside the flask and the final mold assembly ready for casting.

(a) 

(b) 

Figure 12. (a) the sand mold making process, (b) the assembled mold ready for casting

4.3 CASTING

The sword was cast in-house at the Georgia Southern University foundry lab by the team members. The steel was melted in a 100-lbs induction furnace with argon blowing to minimize atmosphere contact and the killing was performed with aluminum during tapping. Molten steel was tapped at 3150°F and poured at approximately 3000°F into the molds.

All necessary safety measures were taken during the melting and pouring of the heat and every team member ensured adequate PPE to ensure a safe and efficient pour. The castings were allowed to cool overnight in the mold. **Figure 13** shows the pouring of steel into the mold at the university foundry and the final casting upon shakeout after the casting had cooled.

(a) 

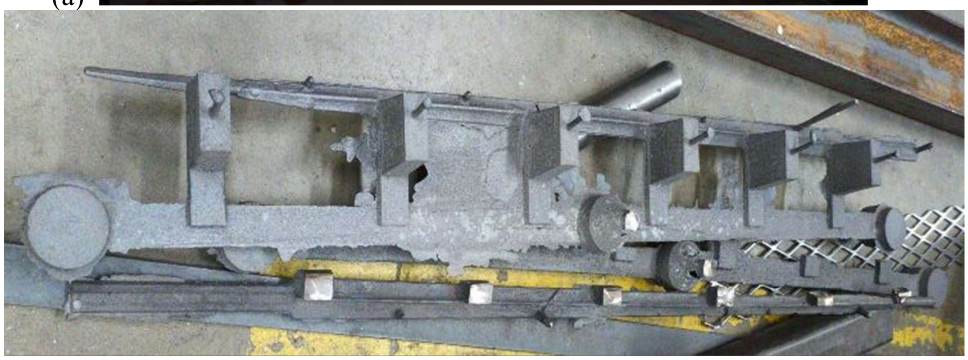
(b) 

Figure 13. (a) Liquid steel pouring into the molds, (b) the casting after mold shakeout

5 POST PROCESSING AND HEAT TREATMENT

5.1 POST PROCESSING

After the casting cooled down to room temperature, the gating system was separated from the sword casting with an angle grinder. The as-cast sword was placed inside of a shot blast machine to clean any dirt and burnt sand residue off the surface for two minutes. After shot blasting, the casting was inspected and the remaining parts of the gatings were removed from the blade surface with an angle grinder.

Figure 14. As-cast sword blade after removing the gating system

The blade was shaped by gradually grinding and sanding to the final profile. Caution was practiced ensuring the desired curved cross section and the gradual taper from the base of the sword to the tip. Any minor surface irregularities or apparent porosities were grinded away and confirmed through visual inspection that the defects did not deep into the core of the blade. Once the desired surface finish was achieved in terms of the geometry, the edges were sanded to sharpen the blade after the heat treatment, and the blade was etched with ferric chloride solution (10g $FeCl_3$+100ml H_2O) along the ridge until a darkened appearance was achieved.

Figure 15. Sword appearance after etching with ferric chloride solution

The cross-guard and the pommel, due to the design intricacies, were CNC machined from the cast brass ingot to obtain the desired contours and then was subjected to ultrasonic cleaning and buffing on a polishing wheel to retain a shiny surface finish. The handle was carved out of cocobolo wood to the desired finish and the sword was assembled with equal parts epoxy resin and hardener mix.

Figure 16. Cross guard preparation for the Epee made from brass alloy

5.2 HEAT TREATMENT

The steel blade was heat treated in two stages, first by austenitizing at a temperature of 1700°F and normalizing in still air to homogenize the as-cast microstructure and grain refinement followed by re-austenitizing and quenching in oil, and tempering at 400°F. The schematic of the heat treatment cycle is illustrated in **Figure 17**.

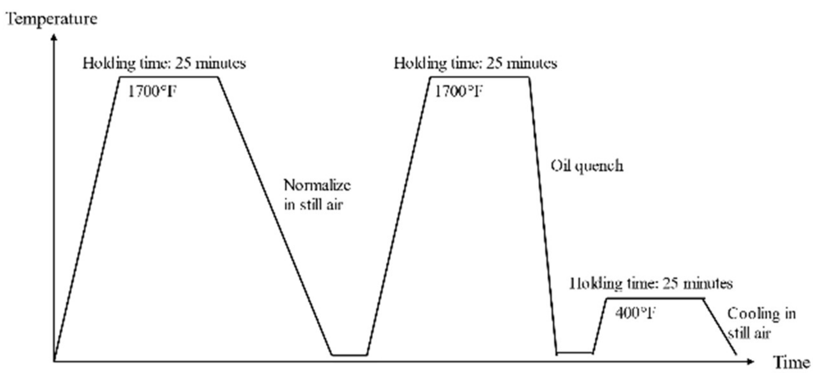
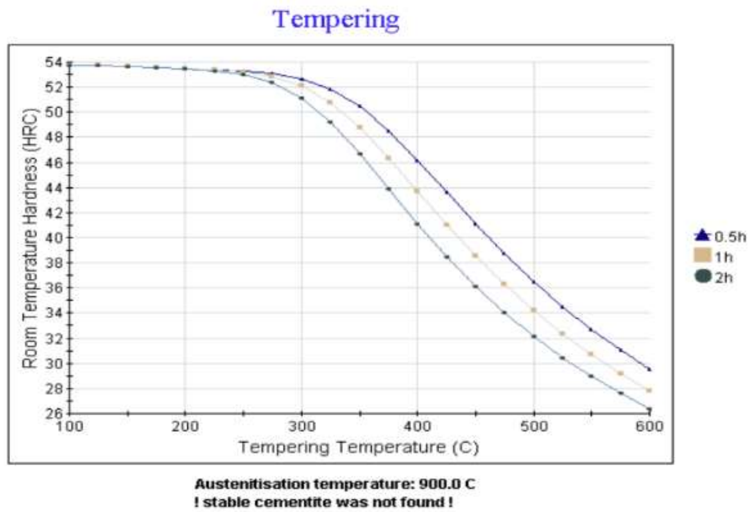
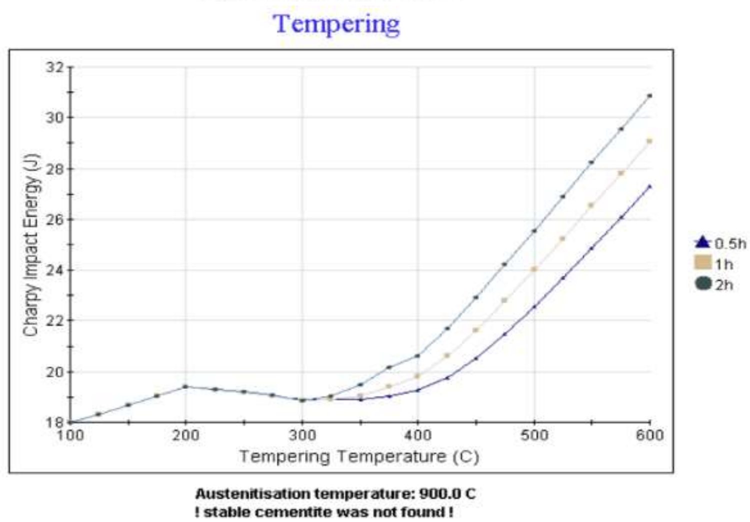


Figure 17. Heat treatment cycle for the steel

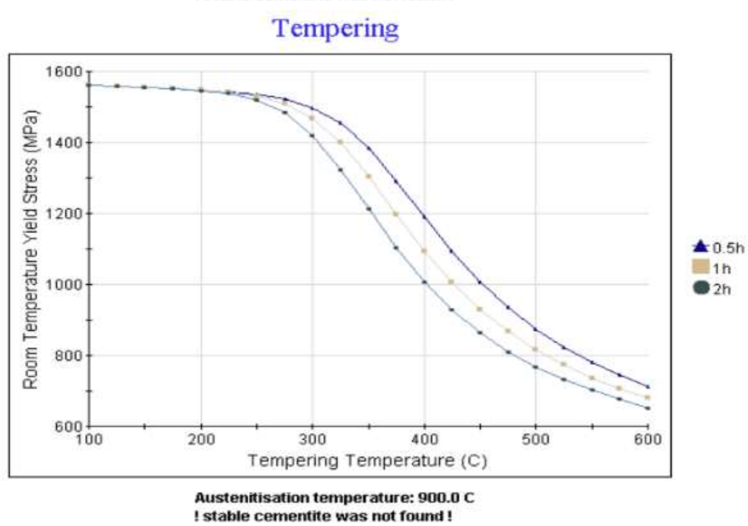
The holding time inside the furnace was governed by the thumb rule for heat treatment (1 hour for every inch of steel thickness) and was defined to be 25 minutes since the maximum thickness of the blade was 0.4 inches. The holding time for tempering was validated by simulating the tempered hardness and other mechanical properties of the steel composition in the thermodynamic calculation software JMatPro. The hardness, impact toughness and yield strength were assessed for three different holding times, namely 30 minutes, 60 minutes and 120 minutes. The plots are illustrated in **Figure 18**.



(a)



(b)



(c)

Figure 18. (a) Room temperature hardness, (b) Charpy impact energy, (c) Yield strength versus tempering temperature plots

Stage I tempering was performed on the steel at 400°F and the expected properties of this steel after heat treatment found from JMatPro are tabulated in **Table 3**. The properties resembled the desirable properties for typical sword blades.

Table 3. Expected properties of the selected steel after heat treatment

Hardness	53.5 HRC
Tensile strength	1550 MPa
Charpy Impact toughness	19.5 J

6 INSPECTION AND TESTING

Optical emission spectrometer was used to measure the chemical composition of the steel. The resultant chemical composition is tabulated in **Table 4**.

Table 4. Chemical composition (wt. %) of the steel

Elements	C	Si	Mn	P	S	Cr	Ni	Mo	Al	V
wt. %	0.40	1.71	1.11	0.012	0.015	1.97	0.38	0.33	0.012	0.028

Additions made to the steel melt in the induction furnace and ladle to customize the composition and enhance the hardenability according to the anticipated requirement for the blade of the sword. Slightly higher carbon content compared to the desired (0.35 wt. %) was found in the test but otherwise the composition was satisfactory to the intended modification.

The sword was physically inspected thoroughly to identify any potential irregularity or defect on the surface and no significant abnormalities were detected. The measurements were performed to confirm the sword dimensions and mass properties met the competition criteria and the measurements are listed in **Table 5**.

Table 5. Physical dimensions and mass of the sword

Parameter	Measured Value
Blade length (in)	33.0”
Overall sword length (in)	39.5”
Mass (lbs)	2.37 lbs

The microstructure of the steel is shown in **Figure 19** showing the presence of fine lath tempered martensite after the heat treatment cycle.

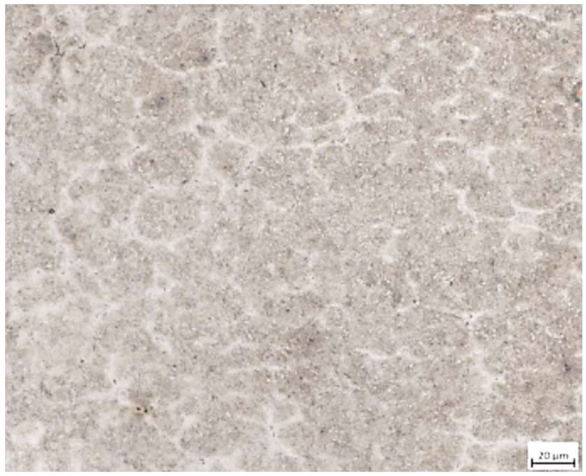


Figure 19. Microstructure of the steel after heat treatment showing presence of fine lath tempered martensite

The sword was vigorously tested by the team members with a series of performance tests to assess the thrusting capability and sharpness of the sword being carried out on sacks of sand, reinforced tires and steel/aluminum sheets. Both the blade edges and the tip were able to resist deformation and pass through the tests. A picture of the tests and aftermath are illustrated in **Figure 20**.

Figure 20. Student tests of the Epee sword

7 EXECUTIVE SUMMARY

The model 1767 French Officers Epée inspired sword was made with 100% in-house resources at the Georgia Southern University foundry during the competition time. The design of the epée was inspired by the original model itself, with modifications in the design for blade, and the handle parts with some contemporary features but with the suitability for George Washington in mind.

The ridge of the epée is what makes sword geometry special, so that was a top concern in designing. The guard and pommel were designed to represent if George Washington were to be presented with it from Georgia Southern. This is why the guard is designed as eagle wings and the pommel is the logo of Georgia Southern. The alloy for the blade required high hardness, strength and toughness so a composition of 0.35C-1.1Mn-1.6Si-2.1Cr-0.35Ni-0.35Mo was chosen.

The steel was designed for durability and strength. Sand casting was chosen because the geometry of the sword needed no cores, the lower manufacturing costs, and the prior experience and expertise of the team members with it. No-bake sand molds were used for castings opposed to green sand. No-bake was chosen due to its higher strength and lower moisture content compared to green sand.

The gating system for epée was designed for simplicity and ability to fill the sword with taking in the fact of the thinness of the sword. Several iterations were simulated in the MAGMA software. The gating system was adjusted by modifying the size and positioning of the risers, increasing the number of gates and adding the vents. The final design had the downsprue area that was connected to the filter increased by around 5%. The size of the gates increased slightly but still maintained 1:4:4 with the choke and filter.

Heat treatment and time selection was aided by thermodynamic software JmatPro. The steel blade was heat treated in two stages, first by austenitizing at a temperature of 1700°F and normalizing in still air to homogenize the as-cast microstructure and grain refinement followed by re-austenitizing and quenching in oil, and tempering at 400°F. The schematic of the heat treatment cycle is illustrated in. The holding time inside the furnace was defined to be 25 minutes since the maximum thickness of the blade was 0.4 inches. The hardness, impact toughness and yield strength were assessed for the tempering time in the simulation.

For testing the sword, we sliced and destroyed sandbags and 26 qt styrofoam coolers with ease. The epée also did hack and slicing motions on a black crate and aluminum scrap. The blade damaged the crate and went unscathed with the aluminum. The sword was not damaged during any of the tests. Most difficulties encountered in manufacturing the epée came from redesigning the pattern and grinding the casting to bring about the curvature on the blade.

Our team would like to thank our faculty advisor, Dr. Mingzhi Xu for assisting us in improving our designs, casting and post processing of the epée. This was a great learning experience throughout the project for this competition. The finished epée weighs 2.4 lbs. and 39.5 inches long which met the requirements of the 2025 SFSA Cast in Steel Competition.

8 REFERENCES

[1] George Washington's Last Will and Testament, July 9, 1799

https://www.mountvernon.org/education/primary-source-collections/primary-source-collections/article/george-washingtons-last-will-and-testament-july-9-1799

[2] Model 1767 French officer’s epée

https://emuseum.mountvernon.org/objects/294/model-1767-french-officers-epee

[3] Sword Blade Hardness: A look at the current research

http://myarmoury.com/feature_bladehardness.html

[4] Sword Steels 101

https://www.sword-buyers-guide.com/sword-steels.html