SFSA Cast in Steel 2025- George Washington Sword Technical Report - “The Paul Revere’s…The Broncos Are Coming”

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Table of Contents

1. **Executive Summary**

The 2025 Steel Founders' Society of America (SFSA) Cast in Steel competition has created this event to encourage students to learn about making steel products using the casting process and applying the latest technology available. The 2025 Cast in Steel competition requires our team to create a new George Washington sword while implementing our gained knowledge as manufacturing engineering students at Cal Poly Pomona.

George Washington's sword was an iconic weapon that was heavily sought after in the 1700s. Washington owned many different types of swords for various encounters, which were classified as civilian and military-like. Our sword takes strength and weight into account so it can be tough but somewhat lightweight to meet design requirements.

As a team, we will make sure to meet all design constraints and requirements given for the sword. Our group is pleased to have the opportunity to compete in this year's Cast in Steel Competition, as it serves as our senior project, the final key requirement to completing our Manufacturing Engineering degrees. The main goal we wish to achieve is a fully developed George Washington sword that shows off its intricate characteristics that surpass the expectations of the judges.

We set out to design a sword that can be put to the test to survive the challenges given by adding post processing. Our sword will also feature a couple areas of customization, including the handle and blade itself. The team ended up all pitching in on ideas for what features we would include on our sword. Once we came up with the final model of our sword, further analysis was done to ensure that the sword didn't have any weak spots that would cause it to fail when tested. We used a flow simulation to make sure that the pattern and gating would come out as uniform as possible. Once we had the model completely ready, we designed the 3D printed production pattern to be made out of wax while using a P1S Bamboo PLA printer. Following the next week, our team then reached out to Miller Casting, our industry partner, to be made into a mold and then to be casted. The sword would then undergo post processing and heat treatment to achieve a smooth final finish. The George Washington sword ended up weighing 3.4 lbs, length of 34 in, width of 3 in, made of 15-5 Stainless Steel. With our design, we intend to achieve the best casting award by incorporating an intricate gating system that would help guide the right amount of metal with the least amount of shrinkage. We also included various decorative features and one that even represents the Cal Poly Pomona mascot, Billy Bronco. Our team believes that our iteration of George Washington's sword incorporates historical and cultural significance that creates an impression that would win best design and process award.

2.Introduction

2.1 Objective and Constraints

The Cast in Steel competition is a competition that allows students to receive hands-on experience with the manufacturing process. These student-led teams must create their own design, video documentary, technical report, and casting of their steel product.The team will work alongside a faculty sponsor and a casting industrial partner throughout the process.

Physical constraints of George Washington's sword include the sword weighing no more than 2 kg (4.4 lbs), and the overall sword length to not exceed more than 1.09 m (43 in). It should be a single edged replica with a tolerance of 2 inches, that is in the style and is appropriate for George Washington. The sword should be longer than 25 inches overall with at least 20 inches of blade length and less than 43 inches overall with a maximum blade length of 35 inches.

A technical report must be included and has to contain the design process, historical accuracy, material selection, and the final results of the sword. A video documentation of the creation of the sword will be submitted alongside the physical casting and the technical report. The awards will be based on the top 5 rankings from 1-5 above. Weighting of the scores will be (1) Design and Process 25%, (2) George Washington Sword Utility 15%, (3) Casting 25%, (4) Video 10%, and (5) Performance 25%

2.2 Summary of the design process

For the purpose of ensuring that the project was completed and delivered on time, The Paul Revere's…The Broncos are Coming, had weekly team meetings. We first met up in August of 2024 to go over the scope of the project and to assign different roles to the team members. We wanted to fill the following roles: team leader, design team, industry liaison, videographer, manufacturing team and technical report editor. With most of the team members having more than one role to fill. After assigning the team roles, we began researching the George Washington sword that we could replicate for the competition. We looked at the different types of swords that George Washington used in the various battles he fought and some that he received as gifts.

We decided that we should use investment casting with a 3D printed pattern. Keeping this approach in focus, we started developing the CAD design for our manufacturing templates. Through a step-by-step refinement process, we enhanced the sword's appearance and casting feasibility, verifying its structural integrity through load simulations to confirm its reliability in use. After finalizing the sword design, we incorporated gating pads and divided the design into separate sections to prepare it for 3D printing.

We used a P1S Bamboo PLA 3D printer to make our pattern, which printed the guard, grip, pommel and blade, in sections which could be re-assembled during the waxing process. We included an engraving on the inside of the handle, which required us to print two iterations of the handle, one positive and the other negative.With the best version of the two being used in the final design.The 3D printed parts also included gating pads, which we had incorporated through the use of simulation software. With the consultation of our industry partner we had different iterations of the gating system to ensure the best pour for our sword. Using Solidcast we conducted metal pour simulations to guarantee the absence of shrinkage, voids and porosity. After the waxing and shelling process we poured our casting, the sword underwent heat treatment and post process finishing.

2.3 Literature Review

George Washington's first sword that we know of dates back to the early 1690s, and was most likely used as an ancestral piece. His next sword didn't come about till 1753, which was the English *Silver-Hilted Smallsword*, one of our inspirations to our final casting. His sword had a major impact on masculinity for that time period as he decided which sword to have on him depended on how appropriate the occasion was. Washington's sword that hung on his left hip was a direct reflection of him and the people he was in attendance with. His sword could be a direct comparison to a man's decision on which luxury timepiece or what pair of custom shoes to wear for that day.

George Washington's sword consists of three main components: the blade, hilt, and guard. The blade is the longest and thinnest part of the casting, with one of the sides sharpened. It is also the main component where the blade holds the sword's strength, which is why the blade needs to be as complete as possible. The hilt is used to hold and wield the sword. The weight distribution is important to take into account when designing the handle compared to the blade. The guard is attached to the hilt and protects the hand while the sword is being wielded.

Many of George Washington's swords were made from American settlers or European friends given as gifts. This is why his swords vary in different styles and designs. A lot of his swords differ between a hanger and spadroon style of swords which can give hint to its origin. His swords all varied in purpose. Some were gifts, ceremonial, and more practical for combat. During that time, Washington had selected five of his swords to be directed to five of his nephews under the terms of his will. There had been a certain order that he chose to give which sword to which nephew. Each nephew would gratefully accept each sword due to how important Washington's swords were to him.

Design

3.1 Design Selection

For our sword design, we spent some time looking at multiple swords used by George Washington and discussed which parts of each sword we liked and didn't like. We knew that more elegant ideas were used for ceremonial swords, while actual field swords were more basic and designed for functionality. Another aspect we had to keep in mind was what is feasible and manufacturable using investment casting, thus we kept in contact with our foundry sponsor throughout the design process. With this in mind, we started choosing what we wanted to incorporate into our design.

The first thing we agreed on is we wanted to make our sword a single-edged sword, as we found that this was used most often. We took inspiration from "*The Bailey Silver and Ivory-Hilted Cuttoe"* sword, and designed our blade with some curvature included. The second design we agreed upon was the handle. We knew this was where a lot of our creative ideas could shine as a lot could be done with the handle. Using inspiration from both the previously mentioned sword and *"The 1767 Silver-hilted Smallsword",* we added spiral grooves into our handle for comfort. We also referenced the latter and included a knuckle-bow to protect the user's hand during combat. An original idea we came up with was including an inscription on the inside of the handle that includes a segment of the United States Pledge of Allegiance during the time period of the Revolutionary War. On the blade we also included the Washington Family coat of Arms as a nod to George Washington's roots. Finally, using inspiration from *"The Silver Lion Head Cuttoe"* sword, we decided we wanted to add a little animal head onto the pummel of our sword. However, since our school mascot is a bronco, we decided to use a horse head instead of a lion.

3.2 Final design

The big decision we had to make for our final design was whether or not to make all of the detail we wanted to add, meaning the coat of arms on the blade and the inscription inside the handle, either positive or negative detail. What this means is we needed to decide if we were going to cut material off of our sword, or add material onto it for these two designs. We decided to first discuss this with our industry partner to get their opinion on which outcome would come out cleaner. They let us know that by using investment casting, either option was possible, but through past experiences they knew that using positive detail for lettering came out best. Since we were providing them with the first two 3D printed parts, we decided to print out one sword with positive detail, and one sword with negative detail, hoping both would cast cleanly and we'd get to pick from there. What we did not originally take into account was whether or not the detail could be printed using a 3D printer. The 3D printer was able to print the positive detail with great accuracy and cleanliness, but the negative detail, especially the lettering under the handle, did not print as clean. Thus we were forced to proceed with positive detail for both the coat of arms, and for the lettering underneath the handle.

The second big decision we had to make was how we were going to gate these swords. The initial plan was to have two swords laying horizontally with the handles on the bottom. We also only included 4 gates, one connecting to the handle and three the blade. However, after running simulations on Solidcast, we realized this wasn't enough gating as it was resulting in multiple hot spots in the blade and handle. Thus we experimented on the number of gates to include and the sizing of each gate. After discussing with the foundry, we came to a consensus that 8 gates of different sizes depending on its location would be sufficient for the metal to properly flow and not leave any hotspots in the blade. The next big issue we came across though was brought to us by the foundry. After giving them our dimensions for our gating system, they came back to us and reported that it would be best to gate the swords standing up vertically, as the horizontal gating system wouldn't fit in their dipping tanks and would have needed to be dipped at an angle to fit, which was a bit of a hassle. Thus we shifted to a vertical system. At this point in time, the company also mentioned we should include 2 more gates, one connecting to the horse head pommel, and one directly onto the knuckle-bow portion of the handle. Thus we added two more gates for a total of 10 gates connecting our swords.

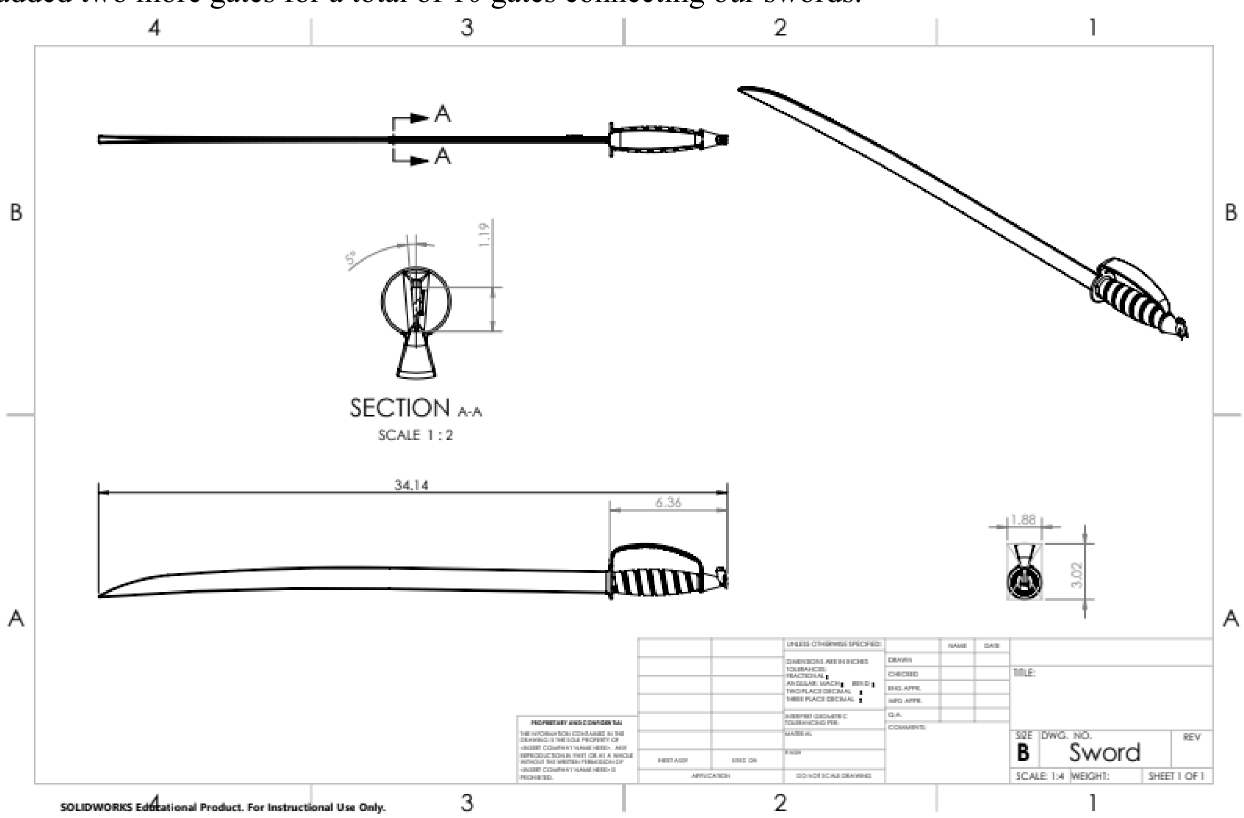


Fig 1.1: Drawing For Sword

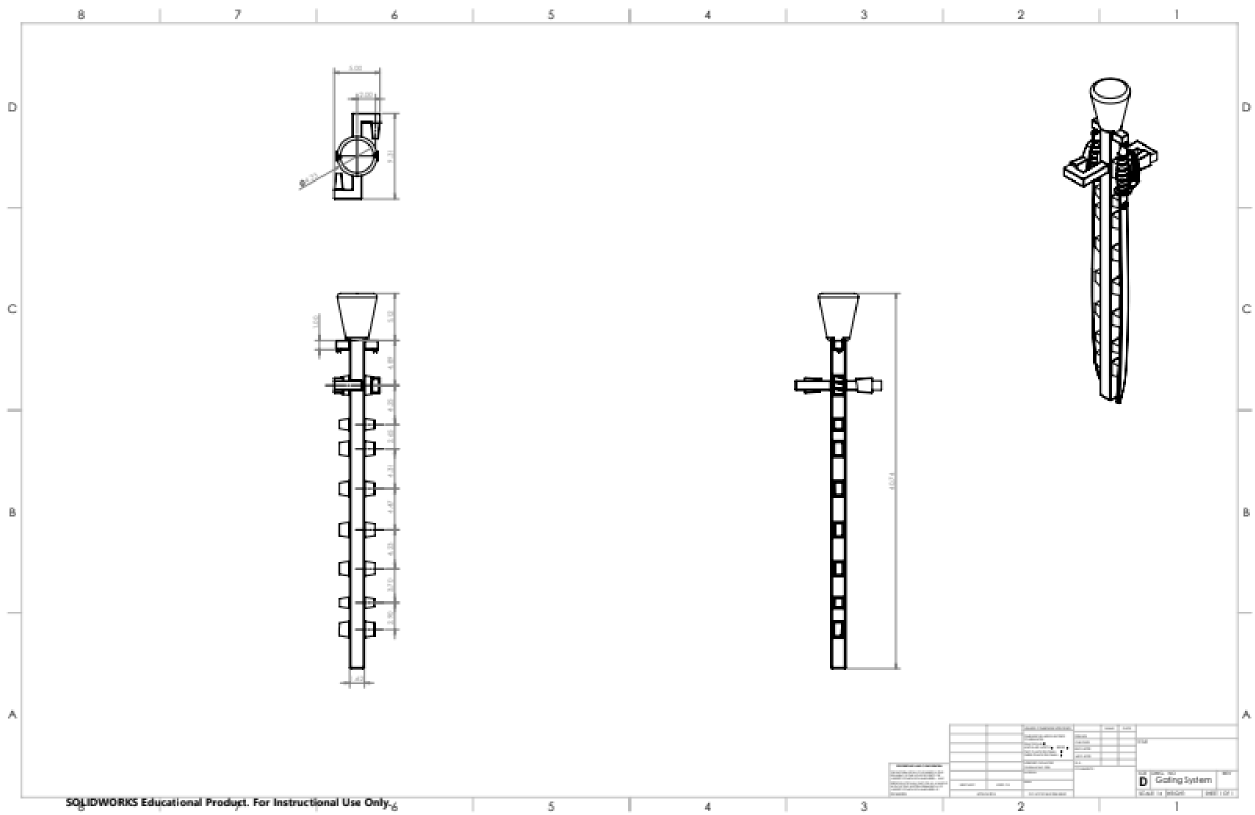


Fig 1.2: Drawing For Gating

4. Manufacturability

4.1 Alloy Selection

When selecting the appropriate alloy for our sword we thought it would be appropriate to look into what makes a military sword functional and exceptional. Having great cutting ability to deliver powerful shearing was important. Also its thrusting ability for our sword to make penetrating stabs with its points. We wanted our sword to have astonishing speed to have the ability to be moved to perform defensive and offensive actions to deliver hits or impede blows. Finally durability of the sword to resist breaking or becoming bent was of the utmost importance, Our industry partner provides us with a wide range of alloys.that we were able to select from.

There were a number of things we wanted from our alloy. We looked into their tensile strength, hardness and yield strength. Also because we wanted our sword to have an aesthetically pleasing finish and a shining metallic look we felt that having good corrosion resistance was very important, From the list of alloys provided we began looking at each one by one and looking at their chemical composition and its mechanical properties. After intense study of these alloys we narrowed it to our top three and decided to use a trade matrix to help us visually see which alloy was best for us.

Trade Matrix: 17-4 PH SS vs. 15-5 SS vs. Inconel 718

Property	17-4 PH SS	15-5 SS	Inconel 718
Material Type	Precipitation-Hardened SS	Precipitation-Hardened SS	Nickel-Based Superalloy
Strength (Tensile, ksi)	~190 ksi (H900)	~190 ksi (H900)	~200-230 ksi (Aged)
Yield Strength (ksi)	~170 ksi (H900)	~170 ksi (H900)	~180-210 ksi (Aged)
Hardness (HRC)	~38-44 (H900)	~38-44 (H900)	~42-47 (Aged)
Toughness	Moderate	Better than 17-4 PH	Excellent
Corrosion Resistance	Good	Slightly better than 17-4 PH	Superior (High-temperature & Oxidation)
Operating Temperature	Up to ~600°F (316°C)	Up to ~600°F (316°C)	Up to ~1300°F (704°C)

Machinability	Good in solution-annealed	Better than 17-4 PH	Difficult (Gummy & Work Hardens)
Weldability	Good (Requires PWHT for best properties)	Better than 17-4 PH	Poor (Requires special techniques)
Cost	Moderate	Slightly higher than 17-4 PH	High
Best Applications	Aerospace, Marine, Chemical	Aerospace, Nuclear, Medical	Aerospace, Gas Turbines, High-Temp Applications

After going through the alloys that our industry partner offered us we began looking at them individually. We began looking up manuals and data sheets from metal suppliers to compare the alloys with one another. After researching those alloys as a group we thought that 17-4 PH ss, 15-5 PH SS, and Inconel 718 were our best options.Each alloy offers unique advantages depending on the application.The first trade matrix is an overview of each alloys properties, 17-4 and 15-5 stainless steel, both precipitation-hardened alloys, are very similar when it came to Ultimate tensile strength and Yield strength, Also when it came down to hardness the were similar, but 15-5 SS has slightly better toughness and corrosion resistance. Alloy 718, a nickel-based super alloy, has higher UTS and yield then the other two as well as in high temperature performance, and oxidation resistance but it is the most expensive of the three and also difficult to machine, which is something we took into consideration if we decided to do any machining post processing. Even though 15-5 offers a light advantage over 17-4 in impact toughness it does not completely justify the increase in processing challenges, Alloy 718 has although it has superior properties for extreme environments, it is over engineered for this application that does not require high-temperature resistance.

Castability Comparison: 17-4 PH SS vs. 15-5 SS vs. Inconel 718

Property	17-4 PH SS	15-5 SS	Inconel 718

General Castability	**Good** – Used in investment casting and sand casting	**Moderate** – Less commonly cast than 17-4 PH	**Difficult** – High shrinkage, prone to hot cracking
Fluidity	Good	Moderate	Poor – High viscosity
Shrinkage	Moderate (~2%)	Slightly lower than 17-4 PH	High (~3-5%)
Hot Tearing Susceptibility	Moderate	Lower than 17-4 PH	High (due to high Ni content)
Porosity Risk	Moderate (Gas porosity possible)	Lower porosity than 17-4 PH	High (Susceptible to micro-porosity)
Post-Casting Heat Treatment	Solution treatment + Aging	Solution treatment + Aging	Solution treatment + Aging
Typical Casting Processes	Investment casting, sand casting, centrifugal casting	Investment casting (less common in sand casting)	Investment casting (but challenging)

17-4 PH stainless steel stands out as the best alloy among the others when it comes to castability. It has good fluidity and moderate shrinkage. Because we worked with a foundry that specializes in investment casting this alloy is suited perfectly for that process. 15-5 was not a terrible choice but according to our industry partner it can pose additional process challenges. Inconel 718 will be difficult to cast because it has a higher shrinkage, poor fluidity and susceptible to hot cracking, Which could have been prevented it would required vacuum investment casting but we did not want to make things difficult for our industry partners, Because we wanted a strong, corrosion resistance, and castable allow for our sword we came to the conclusion that 17-4 PH Stainless Steel was our best choice. It balances high strength with good machinability, making it ideal for casting and post processing. Also an important thing to note is that its precipitation hardening capability allows for heat treatment adjustment to improve the final mechanical properties which will ensure a durable and historically inspired weapon without excessive cost and manufacturing challenges.

4.2 Production Selection

Our team opted for investment casting for the production of our George Washington sword. We 3D printed our mold patterns with multiple PLA parts. We were also considering using a SLA printer as an alternative to producing parts with a higher quality and detailed designs, but due to time constraints and cost we were unable to use this method. After finalizing our designs and production plan, we contacted Miller Casting Inc., a foundry specializing in investment casting services.

4.3 Manufacturing Process

We first designed George Washington's Sword in Solidworks, and worked out the flaws through multiple iterations.After deciding on our final design we 3D printed it, and sent our parts to Miller Casting and they began the casting process which included gating system(s), pouring, cutting and grinding of the sword. Which then went onto testing and inspection, and then finally post processing including sharpening, shining, and powdering.

4.4 Prototyping

For the prototyping stage of our sword, we heavily utilized the use of 3D printing to create our prototype. We decided that using a PLA 3D printer would be the best option to use due to the precision of detail it gave. It allows the text we had on the underside of the guard to look sharper and more visible. 3D printing our prototype for our sword would also be the best way for the foundry we partnered with to create the wax mold from it. Since our sword is created using investment casting, the PLA material allows for precise dimensions and good surface finish. Polylactic Acid (PLA) is a biodegradable and thermoplastic polymer made from renewable resources and is widely used for 3D printing. PLA is easy to use and is able to print at a lower temperature (around 180-220℃).

4.5 Production Processing

Production Processing required one member to handle the 3D printing of the sword and another to handle the SLA printing. There was consideration for the detail that would be allowable to be shown by investment casting. Due to the size of the sword we 3D printed the pattern **(See Fig 1.3)** into multiple parts. We made sure that the pattern would be easy and efficient for assembly.

Fig 1.3: 3D printed Pattern Parts

Because of George Washington sword's long design, we found it best to cast each sword vertically. This decision allowed us to cast multiple and was more compatible with Miller Castings workflow. The vertical orientation also allows the steel to fill the more critical parts of the sword, the blade, to minimize any defects. This orientation also allowed us to include more gating allowing a greater amount of steel to flow in. Gating was placed alongside the flat part of the blade as well as the handle. The bronco pommel needed its own gate to ensure its features came out. For the assembly of the pattern, melted wax was used to smooth mold lines and attach it to the main sprue provided by Miller Cast **(See Fig 1.4)**.

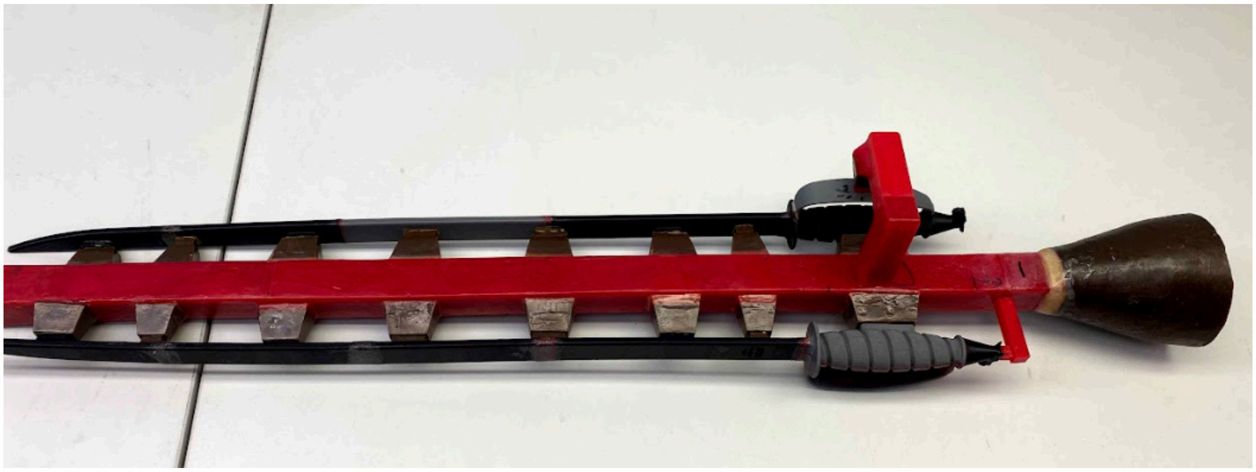


Fig 1.4: Sword Attached To The Main Sprue

The part was then dipped for its first coating of ceramic slurry and then sent to dry before being redipped for another coat **(See Fig 1.5)**. After this process was finished, the mold was ready for pour **(See Fig 1.6)**. After the pour, our casting went through the knockout **(See Fig 1.7)** and sandblast process. The sword then had its gates cutoffed and grinded. Then the sword goes through inspection and testing (explained further in 5.2). At this point the sword was ready for heat treatment.

Fig 1.5: Sword After Dip And Fig 1.6: After Pour

Fig 1.7: Sword After Knockout

Miller Cast was able to perform the heat treatment process for our sword. They also did a wax on the blade and powdered the handle.

5. Quality and Performance

5.1 Chemical Composition

The Chemical composition of our final George Washington sword is a 17-4 PH stainless steel. The results below display the composition of the 17-4 PH stainless steel alloy requirements.

Manufactured Part / Description:	CD-17-4-CHEMA
Alloy Type:	17-4
Batch No.:	AA-814
Specification:	AMS 5355 Rev. J, AMS 5342 Rev. F, AMS 5343 Rev. F, AMS 5344 Rev. G, 7372174 Rev. J, B50TF36 Rev. S13, HS2073 Rev. CR 1, CPW-S-5355 Rev. N/C, PWA LAB MANUAL SECTION F-23, ASQR-01 REV. 14
Cust Part No. / Our Part No.:	CD-17-4-CHEM

CHEMICAL ANALYSIS

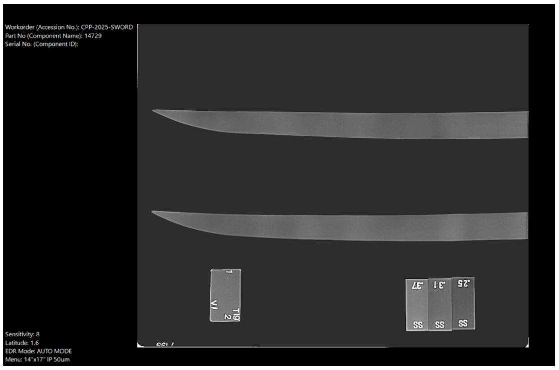
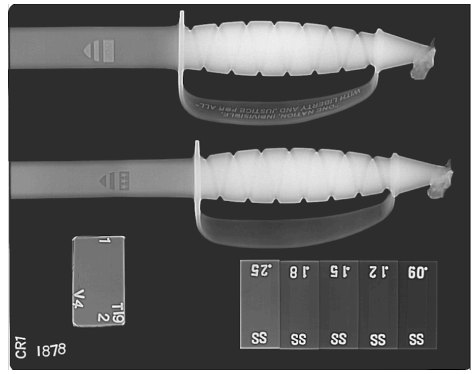
Element		Result %	Min %	Max %
C	=	0.04	0.00	0.06
Mn	=	0.51	0.00	0.70
Si	=	0.75	0.50	1.00
P	=	0.018	0.000	0.025
S	<	0.005	0.000	0.008
Cr	=	15.60	15.50	16.70
Ni	=	3.97	3.60	4.60
Cb	=	0.21	0.15	0.40
Ta	=	0.01	0.00	0.05
Cb+Ta	=	0.22	0.15	0.40
Cu	=	2.98	2.80	3.50
Al	<	0.01	0.00	0.05
Sn	<	0.01	0.00	0.02
N	=	0.01	0.00	0.05
Fe	=	Balance	Balance	Balance

Chemical Analysis performed by Optical Emission per SOP 2.02, Revision 31
Carbon and Sulfur by Combustion per SOP 7.00, Revision 21
Nitrogen by Fusion per SOP 14.00, Revision 9
Tested in Accordance with P&W Lab Manual F-23 Rev. H (1/10/2024)
GE GT193 Approval for Vendor Code 71790, Expiration Date 05/31/2026
GE S-400 Issued 02/18/2021, GE S-1000 Issued on 07/12/2024
Element Huntington Beach meets the requirements defined in ASQR-01 Rev 14

Nadcap
Administered by PRI

5.2 Inspection and Testing

Our team and Miller Casting performed inspection on the George Washington sword and marked out imperfections to be smoothed out by polishing and grinding. Our foundry partner also conducted a series of digital x-ray tests to inspect the sword and check for voids and imperfections.

Miller Casting also performed Magnetic particle testing on the sword to detect any surface defects on the sword.

We performed a series of puncture tests by driving the blade into a variety of fruits and wooden boards. After completing the performance testing, we inspected our sword again and found no surface imperfections or deformities.

6. Final Product

6.1 Basic Requirements

Our team's final George Washington Sword design complies with the length and weight constraints dictated by the competition. The overall assembly measures 34 inches in length and weighs 3.4 lbs. It was manufactured as a single unit through investment casting using 17-4 PH stainless steel. The selected alloy and heat treatment meet our requirements and mechanical strength.

We believe that The Paul Revere's...The Broncos are coming, George Washington Sword is a distinctive and historically inspired piece. The blade and hilt incorporate intricate detailing, including a patterned cylindrical grip, symbolic engravings reflecting Washington's legacy, and design elements inspired by 18th-century craftsmanship. These features create a visually striking contrast of textures and add depth to an otherwise traditional form. The powder coating finish provides the sword with a smooth, refined appearance, enhancing the clarity of the engravings and ensuring a balanced, polished aesthetic.

7. Improvements

Throughout our project process, we did come across a concern that affected our final design and product and will be kept in mind for future projects. The time spent on designing and printing our pattern took a good portion of our time. We had set deadlines for ourselves to complete the mold and turn it in to our foundry partner. We severely underestimated the time it took for the 3D printing process. It became our bottleneck that we experienced in our casting operation. We had a few changes in the pattern which greatly delayed our timeline for production. Because of this we didn't have much time after production to do more testing and improvements to the sword independently from our foundry partner. More time must be given for the 3D printing process and pattern production in future projects.

8. Conclusion

Overall, our group was pleased to be able to participate in SFSA Cast In Steel this year as it is our final project before graduation. Being able to use our previous knowledge and skills into making our George Washington sword was a really exciting experience all together. A couple of us have never participated in this competition before so it was a pleasure being able to. The most difficult obstacles we faced were making sure that the production of the letters on the sword would come out clean and easy to read. Time limitations were also a tough spot in our project as we submitted our 3D printed model of the sword a little later than we wanted to. In the end, it worked out as our team was able to put the finishing touches on the sword in time. The Paul Revere's… The Broncos Are Coming were able to create an artful blend of beauty and lethality with our sword and we couldn't do it without the help of Miller Castings. We are very thankful for the opportunity to participate in this competition and overall it was an awesome experience for all of us.

9. Acknowledgements

We extend our sincere gratitude to our Foundry partner, Miller Casting, for their invaluable guidance throughout the manufacturing process of our project. A special thanks to Eric Miller for meeting with our team and providing continuous support along the way. Lastly, we deeply appreciate our advisor, Dr. Victor Okhuysen, for his mentorship in developing our project for the Cast in Steel 2025 Competition. We are truly grateful for the time and effort everyone has dedicated from their busy schedules to help prepare our team for the competition in Atlanta, Georgia.

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