SFSA Cast In Steel 2025 – George Washington Sword Technical Report

Wentworth Inst. Of Technology: Stars and Steel

Team Members:

Jacob Forrette (Leader), Fabrice Fouron, Brady McDonald, Jake Elias, Luis Leins

Faculty Advisor:

Serdar Tumkor, Ph.D.

Associate Professor, William E. Roberts Professor, FEF Key Professor

Sponsor Foundry:

D.W. Clark

Table Of Contents

Introduction:

The **Steel Founders Society of Americas (SFSA) Cast in Steel 2025 Competition** challenged university teams to design and manufacture a functional replica of a historical sword using modern casting techniques (Steel Founders' Society of America, 2025). Our team, **Stars and Steel** from **Wentworth Institute of Technology**, selected **George Washington’s Bailey Silver & Ivory Hilted Cuttoe** as the inspiration for our entry. Initially crafted by John Bailey, this sword symbolizes leadership, craftsmanship, and American heritage (Mount Vernon Ladies’ Association, 2025).

Our project involved extensive **historical research**, **computer-aided design (CAD) modeling**, **material selection**, and **precision casting** to replicate the cuttoe while enhancing its **structural integrity** with modern metallurgy. The team selected **17-4 precipitation-hardening (PH) stainless steel** for its preferred **strength, hardness, and corrosion resistance**, ensuring optimal durability. **Precision sand casting** using **3D-printed sand molds** captured the sword’s finite details (D.W. Clark, 2025). Post-casting processes, beginning with **heat treatment, CNC machining, surface finishing, and engraving**, were implemented to achieve a similar but modern reproduction of the original design.

The finished sword was subjected to rigorous **mechanical testing**, evaluating **sharpness, strength, and durability**. The team collaborated with **D.W. Clark Foundry** for casting expertise and **Iron Mountain Forge** for real-world performance testing. Results demonstrated the effectiveness of our material and design choices, meeting historical accuracy and functional requirements.

This practice explores the design process, casting techniques, testing results, and overall project outcomes, highlighting the connection between historical craftsmanship and modern engineering. Throughout this project, the team gained hands-on experience in metallurgy and manufacturing while learning the value of teamwork and collaboration. Overcoming challenges along the way strengthened our problem-solving skills and reinforced the importance of engineering innovation in bringing a historical artifact to life.

Historical Review:

George Washington's **Bailey Silver and Ivory Cuttoe** is a ceremonial sword that served practical purposes and symbolized leadership and authority during the Revolutionary War. As a noticeable connection to Washington's military career, the culture represents his ideals and a nation's ideas. This exemplifies the historical context, craftsmanship, significance, and legacy of George Washington's Bailey Silver and Ivory Cuttoe, reflecting its role in shaping American identity.

A **cuttoe** is a short, slightly curved sword originating from European weapons, widely adopted by military officers in the 18th century (Mount Vernon Ladies' Association, 2025). Its design came from a hunting tool transformed into a symbol of military rank and personal valor, essential for utility in close combat and as an emblem of status. Officers/leaders like Washington would wear such swords during formal reviews, diplomatic gatherings, and in battle as part of their uniform. Swords, like Washington's cuttoe, are a staple of officer attire, representing authority, discipline, honor, and leadership (Smithsonian Institution, 2025).

The Craftsmanship and Design of the Bailey Cuttoe sword was crafted by John Bailey, an English immigrant cutler who settled in Fishkill, New York. Bailey was known for producing high-quality swords for Continental Army officers (Mount Vernon Ladies' Association, 2025), blending European craftsmanship with American patriotism . The cuttoe features:

1. Slightly curved, grooved steel blade, designed for both elegance and efficiency.
2. A silver-mounted cross guard and pommel, being an addition to durability and aesthetic appeal.
3. A beautiful green-dyed ivory grip, decorated with an inlaid silver strip, showcasing both creativity and luxury (Smithsonian Institution, 2025).
4. Leather cover with silver trim, achieving the refined presentation of the weapon (Smithsonian Institution, 2025).

Bailey's craftsmanship signifies a balance of artistry and functionality. The extravagant material shows Washington's status while maintaining the sword's purpose, making it both a weapon and a symbol of pure leadership. Washington likely acquired the Bailey cuttoe during the latter years of the Revolutionary War. It may have been carried during significant military events, symbolizing his leadership role (George Washington's Mount Vernon, 2025). Beyond its military function, the sword embodied ideals of virtue, honor, and patriotism. Washington's choice of such a finely crafted weapon reflected his leadership philosophy—balancing strength with moral integrity.

The cuttoe is believed to have been featured in several portraits of Washington, reinforcing its status as both a personal and national symbol **(**HathiTrust Digital Library, n.d.). In these depictions, the sword is not merely an accessory but a representation of Washington's readiness to defend the fledgling nation and his embodiment of the republican virtues that defined his era. After Washington's death, the Legacy of the Cuttoe was inherited by his nephew, **Samuel T. Washington**, with instructions to draw it only "in self-defense or in defense of [the] country and its rights" ((Mount Vernon Ladies' Association, 2025). This directive underscores Washington's belief in the just use of power, emphasizing restraint and moral responsibility.

Samuel's son later donated the sword to the United States government, where it remains a treasured historical artifact. It is currently preserved in the **Smithsonian Institution's National Museum of American History** (Smithsonian Institution, 2025), serving as a symbol of America's revolutionary heritage and the enduring legacy of its first president.

George Washington's Bailey Silver and Ivory Cuttoe serves as more than just a military relic. It is a testament to the values, leadership, and personal character of America's first president. Through its craftsmanship, historical journey, and symbolic weight, the sword continues to connect modern audiences with the ideals upon which the United States was founded. As both a weapon and an artifact, it encapsulates the spirit of a leader whose influence design menace still resonates in American history.

Design Methodology:

While often associated with modern technology like software, web design, and information systems, it can also be applied to historical artifacts, such as Bailey Silver and Ivory Cuttoe, to understand the craftsmanship and design principles behind its creation. The objective was to craft a ceremonial sword that symbolizes leadership, prestige, and personal valor, reflecting Washington's status while being functional and aesthetically remarkable.

Artisans studied available materials, traditional sword-making techniques, and the symbolic preferences of military leaders in the 18th century, considering Washington's stature, role, and personal tastes to ensure alignment with his image. Swordsmiths and designers generated numerous ideas regarding the blade design, hilt ornamentation, and choice of materials, exploring combinations of silver, ivory, and steel to achieve both elegance and durability. They selected the most suitable design elements, focusing on a balance of form and function, prioritizing the use of silver for symbolic prestige and ivory for a refined grip, ensuring the sword met both ceremonial and practical needs. Skilled craftsmen meticulously turned the conceptual designs into reality, forging the blade with precision while adorning the hilt and scabbard with intricate silver details and ivory inlays, showcasing superior artistry.

While not tested like modern prototypes, the sword underwent careful inspection for balance, grip comfort, and overall aesthetics, with adjustments made to meet the highest standards of craftsmanship. Applying a design methodology helps guarantee the artifact's superior craftsmanship, historical authenticity, and symbolic value, promoting efficiency as artisans work methodically to ensure each detail contributes to the sword's overall excellence. This structured approach mirrors methodologies like the Waterfall methodology, akin to the linear, step-by-step process used in historical craftsmanship, where each phase is completed before moving to the next. Although more modern, Agile methodology concepts of iterative refinement can be seen in how artisans adjusted their work based on feedback and evolving requirements.

Design thinking methodology focuses on understanding the user's needs—in this case, George Washington—and creating an artifact that reflects empathy, prestige, and utility. Even the Shape-Up development approach, which aligns with small, focused teams working on specific projects with clear timeframes and goals, is evident in the collaborative efforts of the artisans crafting the Cuttoe. By applying methodology principles, the team gain a deeper appreciation of the meticulous planning and craftsmanship behind historical artifacts like George Washington's Bailey Silver and Ivory Cuttoe.

Cast In Steel Guidelines:

The Cast in Steel 2025 competition invites university students to creatively design and produce a functioning replica of a sword inspired by George Washington's collection, using modern casting tools and techniques. Participants can either replicate one of Washington's actual swords or design a new sword that aligns with his known preferences and needs. This year's competition adds an exciting element: the entire process will be documented as a made-for-TV series for a major streaming service, providing an opportunity for teams to showcase their work to a broader audience.

The competition will include qualifying rounds to test sword performance and select finalists for the Grand Finale. These rounds allow multiple teams from the same school to participate in different sessions, ensuring more opportunities for advancement. Seeding for these rounds will prioritize teams from schools with a history of competition success.

Teams must perform all aspects of creating a George Washington sword, from design conception to manufacturing and performance testing, using casting as the primary manufacturing process. To register, teams are required to submit a preliminary plan to ensure effective communication throughout the competition. The sword must meet specific requirements: it should weigh no more than 2 kg (4.4 lbs) and be no longer than 1 meter (40 inches) in overall length.

Participants can choose to replicate a historical sword or create an original design that reflects Washington's style. Historical swords include the 17th Century Cuttoe, the Silver Lion Cuttoe, the Silver and Ivory Cuttoe, the French Officer's Epee, and the Alte Presentation BroadSword, with overall lengths ranging from 23.75 inches to 41.75 inches. For custom designs, the sword must be single-edged, with an overall length of 25–43 inches and a blade length of 20–35 inches, excluding double-edged small swords. Teams must justify their design choices in the technical report.

Each team must submit three deliverables: a completed George Washington sword prototype, a professional technical report (limited to 30 pages), and a project video (not exceeding five minutes). The project video should document the team's journey and follow the guidelines outlined in the student filming guide. Teams must also submit a signed waiver from the guide to authorize the use of their footage for the TV series. For questions regarding the filming guide, participants can contact Luke Ellis at Luke@WorkaholicTV.com.

The competition provides students with a unique opportunity to combine engineering skills, creativity, and historical knowledge. All submissions, including swords, technical reports, and videos, will become the property of the Steel Founders' Society of America (SFSA).

Inspiration:

George Washington's Bailey Silver and Ivory Cuttoe because it represents more than just a weapon—it symbolizes leadership, resilience, and the spirit of the American Revolution. Unlike the other swords, which were often ceremonial or influenced by European designs, the cuttoe perfectly balances elegance and practicality. Its silver and ivory style highlights its readiness for battle. This was not just a decorative piece; it was a sword he carried during military campaigns, making it a personal artifact tied directly to pivotal moments in American history. While the 1767 and 1753 Silver-Hilted Smallswords are visually appealing, they were more ceremonial and served as status symbols rather than functional weapons for combat.

The 1767 French Epée carries a strong European influence, which lacks the personal American connection that Washington's cuttoe offers. The Steel-Hilted Smallsword is practical but does not have the same unique or historical significance tied to Washington's leadership.

The Silver Lion-Headed Cuttoe, though impressive, lacks a direct connection to military achievements and pivotal roles. Lastly, the Alte Presentation Broadsword is more ornamental and formal, making it less versatile and not as personally significant to military campaigns.

The Bailey Silver and Ivory Cuttoe's unique style and historical relevance as a symbol of authority make it stand out as more than a relic. It represents Washington's dual role as a military leader and a statesman, carrying courage and determination.

Material & Casting Selection:

The sword is cast from a modified **17-4 precipitation-hardening (PH) stainless steel**, enhanced with increased carbon content for improved strength, hardness, and corrosion resistance (Blair, M. 1990). Following heat treatment to the H1075 standard, the material achieves an ultimate tensile strength of **165 ksi (1140 MPa**) and a yield strength of **150 ksi (1040 MPa)**, ensuring high durability under stress (United Performance Metals, 2025). Its elongation of **16%** and reduction of area of **58%** contribute to toughness, while a hardness of approximately 38 HRC (341 Brinell) provides excellent edge retention shown in figure 1. Additionally, the Charpy V-Notch impact resistance of 40 ft-lbs enhances shock absorption, making this alloy an ideal choice for a high-performance sword that balances strength, toughness, and longevity.The addition of carbon enhances hardness and wear resistance by promoting carbide formation, a well-documented strengthening mechanism in metallurgy. Compared to high-carbon steels such as 1095, modified 17-4 stainless steel offers superior corrosion resistance while maintaining sufficient hardness for a sharp, durable edge (Rolled Alloys, 2025). This makes it an ideal material for sword applications, where a combination of toughness, strength, and longevity is required

	H900*	H925	H1025	H1075	H1100	H1150	H1150D	H1150-M
Ultimate Tensile Strength, ksi	200	190	170	165	150	145	140	125
0.2% Yield Strength, ksi	185	175	165	150	135	125	120	85
Elongation % in 2" or 4XD	14	14	15	16	17	19	22	22
Reduction of Area, %	50	54	56	58	58	60	65	68
Hardness, Brinell (Rockwell)	420 (C 44)	409 (C42)	352 (C 38)	341 (C 36)	332 (C 35)	311 (C 33)	294 (C 31)	277 (C 27)
Impact Charpy V-Notch, ft - lbs	15	25	35	40	45	50	55	100

Figure 1: Different Heat Treat Temperatures and properties of 17-4

Chemical Composition

Carbon	0.07% (Max)
Silicon	1.00% (Max)
Manganese	1.00% (Max)
Phosphorous	0.040% (Max)
Sulfur	0.030% (Max)
Chromium	15%-17.5%
Molybdenum	0.50% (Max)
Nickel	3%-5%
Copper	3%-5%

Figure 2: Chemical Composition of 17-4 Stainless Steel

The team has selected precision sand casting using green sand as the manufacturing method for casting our sword. This method was chosen over alternatives such as centrifugal or die casting due to its ability to capture intricate details that would be difficult to achieve with other casting techniques (D.W. Clark, 2025). Green sand casting provides a good surface finish and allows for accurate dimensional control, making it well-suited for producing high-quality cast components.

To further enhance precision and repeatability, the team will utilize an EX1 Sand 3D printer to create the sand mold. This advanced additive manufacturing technique enables the production of highly detailed and complex mold geometries with minimal human error (D.W. Clark, 2025). By leveraging 3D-printed sand molds, The team can achieve greater design flexibility, improved accuracy, and consistent casting quality, ensuring optimal performance for the final sword.

Design of the Sword:

Figure 3: Finalized CAD model

The sword consists of several key components: the blade, a two-piece guard, the handle, and the pommel nut at the end of the handle. To enhance both balance and functionality, our group incorporated a fuller into the blade as seen in Figure 1. Our handguard design, inspired by the Bailey-hilted sword, has additional unique elements introduced to make it unique. By carefully studying the original sword for its dimensions, shape, color, and details of its accessories, the team ensured a blend of historical accuracy and creative originality was constant throughout the piece.

Technical Specifications:

Design Features: The Bailey Silver & Ivory Hilted Cuttoe

The Bailey Silver & Ivory Hilted Cuttoe is a remarkable example of historical weapon design, blending artistry and practicality into a single masterpiece. For our cast and steel project, the team aim to replicate this iconic sword as accurately as possible while enhancing certain design elements to highlight its unique characteristics. This piece will serve as both a functional weapon and a showcase of craftsmanship, worthy of any competition.

Key Features of the Bailey Cuttoe

Hilt Design

The hilt is arguably the most eye-catching feature of the Bailey Cuttoe. It combines silver fittings with a smooth ivory grip, creating a visually striking and luxurious appearance. The silver components often feature engraved patterns like floral designs or heraldic symbols, adding layers of elegance and historical detail. The ivory grip not only feels comfortable in hand but also reflects the status and craftsmanship of its time.

To replicate this, the team will use sterling silver for the fittings and a dyed piece of mahogany wood for the handle ensuring the piece adheres to modern ethical standards while preserving its classic look.

Blade Characteristics

The blade is shorter than a typical sword, making the cuttoe ideal for close-range combat or as a secondary weapon. Its subtle curvature enhances its slicing capabilities, while etched designs near the base add both decorative flair and historical significance.

For our project, the team plan to forge the blade using a modified 17-4 stainless steel to achieve a balance between durability and edge retention. The etching will be replicated using laser engraving for precision, ensuring the blade captures the spirit of the original while meeting modern standards.

Guard and Pommel

The silver guard and pommel are intricately detailed, showcasing patterns that protect the hand and elevate the sword's aesthetic appeal. These elements are not only functional but also serve as symbols of artistry and wealth.

For competition purposes, the team will experiment with enhancing these details, potentially adding small decorative inlays like enamel or stones for a contemporary touch.

Proportions and Balance

The Bailey Cuttoe is carefully designed to feel lightweight and balanced in the user's hand. Its proportions reflect a dual purpose: a weapon for defense and a statement piece for display. This balance of practicality and beauty will be a core focus of our reproduction, ensuring the piece is not only visually stunning but also functional.

Sword Dimensions:

Name	Dimension (Inches)
Sword Blade Length	33
Sword Blade Width	0.25
Sword Blade Hieght	1.25
Tang length	3
Tang Width	0.25
Tang Height	0.5
Fuller Width	0.7
Edge Length	24
Edge Width	0.25
Guard Length	2.175
Guard Diametrer Base	3.125
Guard Diameter Middle	0.87
Guard Diamter TIp	0.5
Guard Height	0.9
Pommel Daimeter Base	0.525
Pommel Diameter Middle	0.548
Pommel Diameter Top	0.15
Handle Length	4.25
Handle Diameter	1.125

Figure 4: Table Identifying Dimensions of parts of the Sword

Dimensions were chosen by the team to maintain continuity with original design, ensure ease in manufacturing and provide the blade with the necessary strength to fit its intended design purpose.

Feature and Design

For the design, the team aimed to stay true to the original while incorporating distinct American-inspired elements. A silver half-dollar coin was embedded at the center of the guard, complemented by engraved stars and other patriotic motifs. The pommel was cast with a seashell design, which was later refined through engraving. The handle was crafted from American black cherry wood, chosen for its historical significance, and was enhanced with Gunstock 731 wood stain to bring out its rich color and grain. To improve grip, carved grooves were incorporated and silver inlay. Additionally, a bald eagle with an American flag was engraved onto the handle to emphasize its patriotic theme. The blade features a fuller to improve balance and reduce weight, along with engraved stars and other symbolic designs to further reinforce the American aesthetic.

Comparative analysis

By utilizing SolidWorks Simulation the model of the sword was subject to bending and impact testing. The sword will be subject to stabbing and impact tests, so it is good to get an idea of the stresses that will be distributed throughout the sword. For bending a load of 25 lbs was applied to the tip of the sword as a representation of forces exerted on the sword through a stab test. Von mises stress plots were then generated to depict an all encompassing plot of the stresses throughout the sword. At the tip of the sword stress of up to 5123 psi was recorded. Across the length of the blade stress of up to 2584 psi was recorded. The larger concentrations of stress were recorded towards the handle of the blade and at the tip of the sword where the impact is taken.

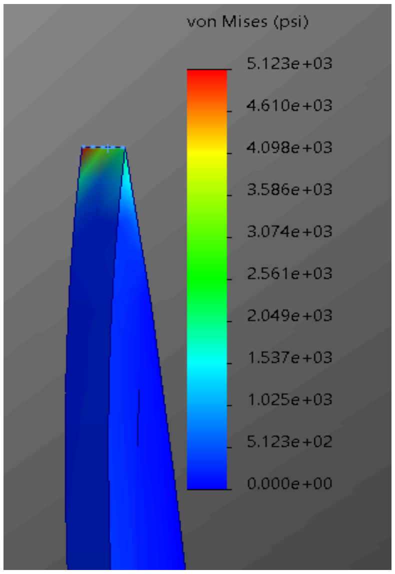

Figure 5: Stress Plot at the tip of the Sword

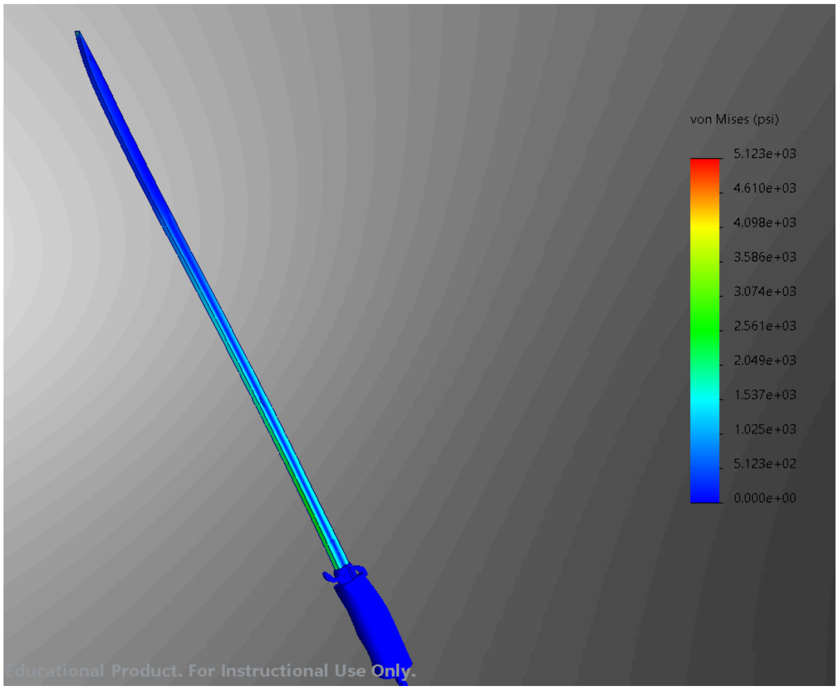

Figure 6: Stress throughout the sword due to stabbing force

Impacting

For impact testing SolidWorks was utilized to conduct a nonlinear analysis of the sword. This provides an idea of the stresses distributed throughout the sword through impact. A 100 lb force was applied for one second towards the middle of the sword to simulate the impact forces it will be subjected to. Split lines 1.7 inches apart were implemented to replicate the diameter of a larger bone like what will be used in the real world testing. Stresses were felt throughout the sword reaching up to 4961 psi along the bottom edge of the blade and 3969 psi towards the bottom of the sides of the sword. The largest stress concentrations were towards the handle of the sword.

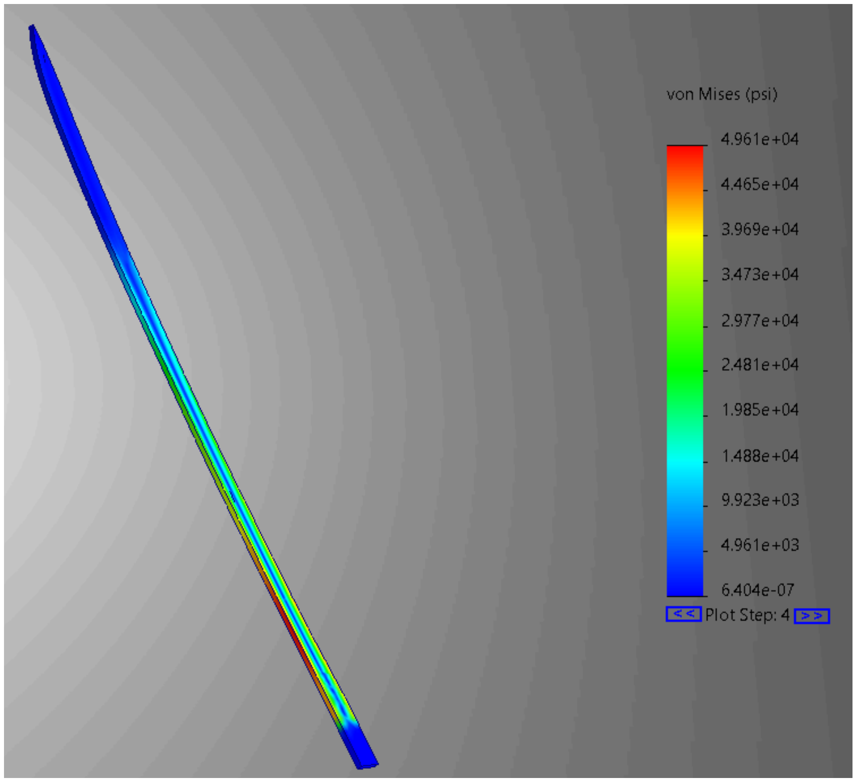

Figure 7: Stress throughout the source due to impact with bone

Casting & Fabrication Process:

Sponsor Foundry:

D.W. Clark was chosen as the foundry for its expertise in advanced casting techniques, extensive material knowledge, and commitment to precision manufacturing (D.W. Clark, 2025). Their centrifugal casting process enhances material integrity by using centrifugal force to evenly distribute molten metal along the mold walls, effectively reducing impurities and gas bubbles. This method supports a broad range of alloys, including specialized materials like Ni-resist, and can accommodate components up to 70 inches in diameter. Complementing this, their sand casting process provides scalability and precision, utilizing a chemically bonded no-bake sand system to produce castings with high dimensional accuracy and refined surface finishes. Capable of producing components weighing 1 to 3,000 pounds while maintaining CT-10 grade tolerances, D.W. Clark is well-equipped to meet the demands of the marine, energy, and industrial sectors, where complex geometries and consistent performance are essential.

In addition to traditional methods, D.W. Clark employs precision sand casting, integrating 3D-printed molds to achieve tolerances that rival investment casting. This innovation allows for intricate geometries while minimizing tooling costs, making it particularly advantageous for aerospace, defense, and turbine applications. Their extensive alloy inventory includes carbon and low-alloy steels, stainless steels, nickel-based alloys (Inconel, Hastelloy), copper-nickel, and cobalt-based materials, all available in rough-machined form to support custom machining, prototyping, and repairs. With over 120 years of industry experience, D.W. Clark has earned a reputation for quality and reliability, holding certifications such as ISO 9001:2015, AS9100 compliance, ITAR registration, PED certification, and recognition as a Navy Level One Supplier. (D.W. Clark, 2025) Their investment in 3D sand mold printing has modernized mold production, increasing both efficiency and precision. With the capability to pour over 100 different alloys monthly, the foundry demonstrates unparalleled versatility in serving diverse industrial needs. Their hands-on collaboration throughout the design and manufacturing process provided invaluable support, particularly in addressing challenges like material separation in the Halligan bar prototype. Working closely with their advanced equipment and processes further deepened our team's understanding of casting, metallurgy, and industrial applications, underscoring the value of industry partnerships in both technical education and real-world engineering development.

Mold Design and Fabrication Collaboration:

Once, the sword development process began by creating a basic model using historical images and verified dimensions from the historical society. This initial model included the blade, guard, pommel, and handle but lacked fine details to facilitate casting. The model was constructed in CAD software, ensuring accurate representation of historical features while considering manufacturing constraints. Upon review by engineers at DW Clark, revisions were made to improve castability, including increasing thickness for machine stock and incorporating fillets to soften sharp corners, reducing stress concentrations and improving metal flow.

Following these adjustments, with the collaboration of the engineers to determine the optimal casting layout. Initially, a vertical pour was considered to concentrate impurities at the top for removal during post-processing; however, concerns arose about the metal freezing due to the long travel distance exceeding 12 inches, which could result in incomplete fills or weak points in the structure. A horizontal pour with a traditional riser at the end was also evaluated but was rejected due to the risk of hot tears forming due to uneven cooling rates. Ultimately, immediately decided on a horizontal pour with a wedge riser on the spine to prevent heavy spots and allow impurities to rise naturally (MAGMA, 2025).

Next, once analyzed solidification using MAGMA software to identify hotspots and optimize the casting process (MAGMA, 2025). The simulation confirmed that a wedge riser was necessary and no chill was required due to the uniform thickness and simple geometry. This analysis ensured directional solidification, where the metal cooled and solidified in a controlled manner to minimize internal stresses and defects. The gating system was designed with a long, thin gate along the blade's spine to minimize metal travel distance and temperature drop, ensuring a consistent fill without turbulence that could introduce defects.

Once then determined the pouring temperature and filling time. Based on engineer recommendations, the metal was poured at 2950-2980°F. The fill time was calculated using the square root of the total pour weight, resulting in approximately five seconds. A filling simulation was conducted to visualize metal flow and confirm proper mold filling. The simulation results guided adjustments to the gating system, ensuring an even flow distribution without dead zones where air pockets or cold shuts could form (Figure 3).

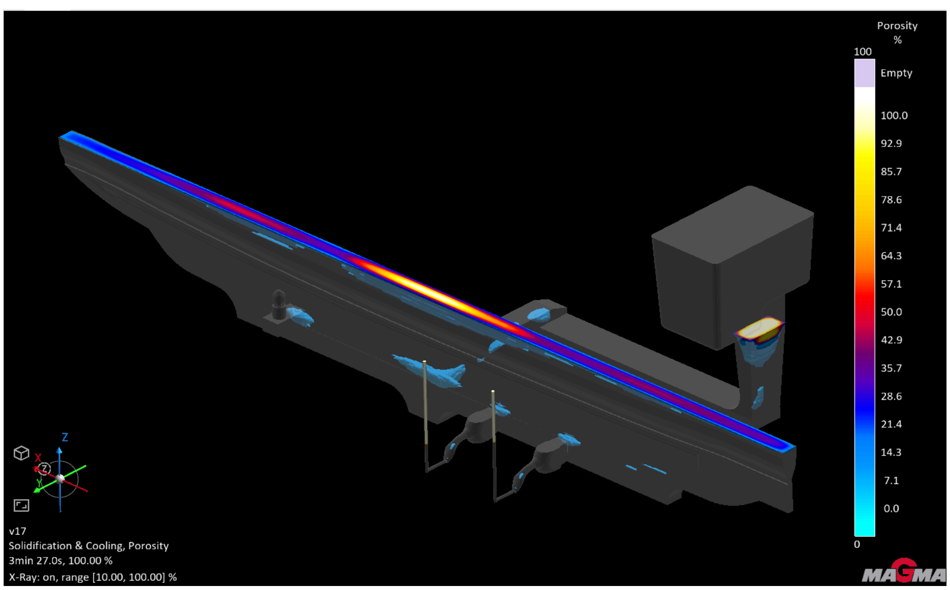

Figure 8: Sword porosity map (warmer colors indicate higher porosity)

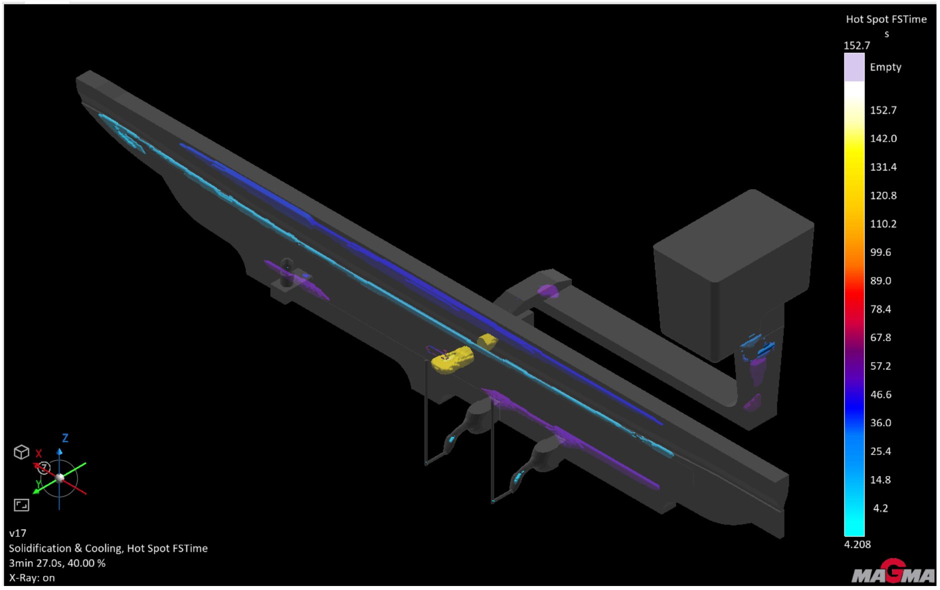

Figure 9: Sword Hotspots map indicating temperature in the sword during the cooling process. This could cause tearing or crackin**g.**

Further evaluations were performed to assess porosity, grain structure, directional solidification, and hotspots. The pouring temperature was validated to ensure the metal remained above its liquidus temperature until the mold was fully filled, preventing premature solidification that could compromise structural integrity. Metal velocity was also monitored, ensuring it remained below 20 inches per second squared to reduce turbulence and oxide formation. Once the simulations confirmed a successful design, the finalized mold was sent to a sand 3D printer. This technology enabled high-precision sand casting using green sand and resin, achieving details that traditional sand casting could not replicate, such as complex surface textures and fine geometrical features. The 3D-printed mold also provided superior dimensional accuracy, reducing post-processing efforts and improving overall efficiency in the production workflow.

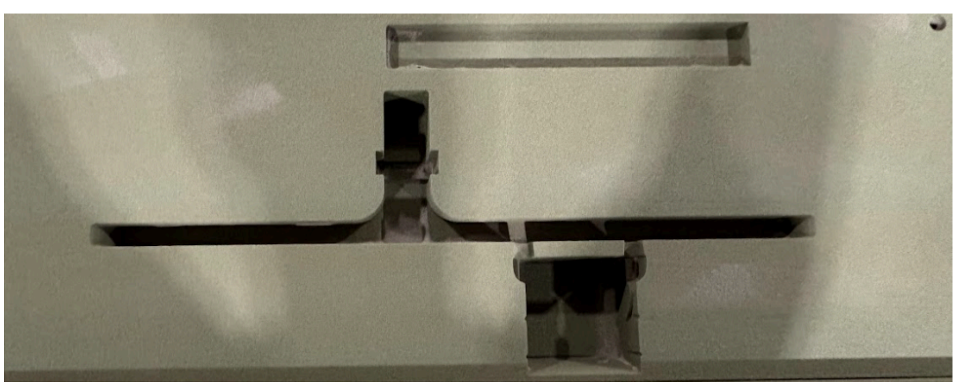

Figure 10: Finalized 3D Printed Mold

Casting Process:

Before beginning the casting process, they conducted a thorough inspection of the mold to identify any defects, such as dings, nicks, or dents, that could compromise the final casting quality. Ensuring the mold was in optimal condition was critical to achieving a high-quality product. They verified that the flask was the correct size and provided a secure fit within the mold to prevent shifting during pouring. Additionally, the guide pins were inspected to ensure they were straight and unbent, maintaining proper alignment between the cope and drag.

When positioning the mold within the flask, the team placed the best-facing part of the pattern in the drag to ensure that impurities in the molten metal would rise naturally to the cope, resulting in a cleaner and more refined casting. The gate work and risers were examined to confirm proper contact with the pattern or mold, ensuring smooth metal flow and minimizing the risk of defects.

To facilitate a clean separation between the casting and the mold, the team applied a releasing agent, such as talcum powder or silver paint, reducing the likelihood of breakage upon removal. The choice of molding sand was also a critical factor. Whether using green sand or silica sand, the team maintained the correct mix and composition, carefully balancing water, silica, and carbon content. Excessive moisture was avoided to prevent porosity in the casting. Environmental factors, such as humidity and temperature, were taken into account to optimize the sand mixture. Additionally, grain size was considered, with finer grains producing a smoother surface finish and coarser grains resulting in a rougher texture.

Once the mold was prepared, the team assembled the two parts of the cope using adhesive and clamps to ensure a secure bond. The core was positioned and affixed within the drag, followed by the attachment of the cope to the drag. After all components were glued together, additional clamps were applied to maintain structural integrity throughout the process.

Using an induction furnace, the team heated the required amount of metal, sourced from either remelted material or product stock. The furnace was activated to bring the metal to its melting temperature before continuing to the desired pouring temperature of 2964 degrees. A ladle was used to transfer the molten metal from the furnace to the mold, ensuring controlled and precise pouring.Throughout this process, they utilized an immersion pyrometer to continuously monitor the metal temperature, ensuring it remained within the specified range.

After pouring, the casting was left undisturbed in the mold for a full 24-hour period to allow for complete solidification and the development of critical mechanical properties, such as strength and elongation. Once fully solidified, the casting was separated from the mold by shaking out the sand using compressed air and a handvibrator This process effectively removed residual sand and ensured the final casting was ready for subsequent finishing operations. The result pre-finishing can be seen in Figure 11.

Figure 11: Casting with gating after shaking out from sand mold

Post-production and Finishing:

Using a saw and arch air, the team removed all the gates, risers and vents. This was the first step from rough casting to a sword.Using a tumble blast to remove residual casting debris as well as start to take the oxidation layer off of the casting. Place the sword into a tumble blast machine with each side facing up once to remove scale and oxidation on each side.

After the sword and its components were rough-shaped, the critical heat treatment phase followed, adhering to the H1075 standard. The material was heated to 1075°F (579°C) and held for four hours, ensuring uniform heat penetration for optimal precipitation hardening. It was then air-cooled to room temperature, achieving an ultimate tensile strength of 165 ksi (1140 MPa), yield strength of 150 ksi (1040 MPa), and hardness of approximately 38 HRC (341 Brinell). This treatment enhanced the sword's toughness and durability, with a Charpy V-Notch impact resistance of 40 ft-lbs, striking a balance between strength, corrosion resistance, and edge retention essential for a high-performance blade.

Using a CNC Mill, the team machined the casting down to the finalized size and shape. This took the majority of the extra material off resulting in a sword.During this step the team milled out the fuller in the blade as well as other basic design features. After the team milled out the sword the team used a surface grinder to get rid of the milling marks

Using a dremal hand engraving tool the team engraved custom designs into the components of the sword including the detail for the pommel and the detail for the guard. The dermal allowed us to get the basic shapes the team wanted while the engraving tool let us get the really fine details. On the handle they cut grooves into it for the silver inlay. This was used to preserve the style of the bailey hilted sword while adding our own touch. For the pummel design the team incorporated a seashell design to add to the similarities.

To assemble all the pieces, the team started with the two pieces of the guard that they had cast. They welded them completely together and then cut a hole to achieve a snug fit with the tang cast along with the sword blade. Next, they welded the tang and the guard together. They cut out a slot in the handle for the tang to fit snugly. Before inserting the tang into the handle, they heated it to burn it into place for a secure fit. The handle also had a threaded hole at the bottom, allowing for the pommel to be screwed in easily.

After fully assembling the sword, they brought it over to the grinding wheel to shape the edge. This process defined the overall shape and size of the edge, enabling them to achieve an incredibly sharp finish without removing excessive material with the grinding wheel. They used a 25-degree angle until about 12 inches from the tip, then opened up to 35-40 degrees. Once the edge was established, they utilized a buffing wheel along with metal polish to create a mirror-like finish on the blade, going over it multiple times with the polish. Additionally, they used a hand buffer to polish the guard and the intricate details on the pommel.

Testing Analysis:

Testing Environment and Collaborators:

They are conducting testing in collaboration with Iron Mountain Forge and Furniture, a respected blacksmithing school located in Providence, Rhode Island. This facility specializes in traditional and modern forging techniques, making it ideal for evaluating the performance and durability of their cast sword. One of its owners and lead instructors has gained recognition through participation in *Ellen's Smash and Sip* and an audition for *Forged in Fire*, both of which highlight their expertise in blade forging and metallurgy (Iron Mountain Forge, 2025). Their experience in working with edged weapons and heat-treated metals will be invaluable in assessing the mechanical properties and structural integrity of our sword.

Iron Mountain Forge and Furniture was chosen for this phase of testing due to the owner's extensive background in blacksmithing, particularly in blade craftsmanship, which closely aligns with our project's focus. Additionally, its proximity to our sponsor foundry allows for efficient coordination between the casting and forging processes. Testing in a blacksmithing environment will provide critical insights into how our cast sword withstands real-world conditions, including edge retention, impact resistance, and overall durability (Iron Mountain Forge, 2025). By working with experts in metal shaping and heat treatment, the team can refine our approach to casting, ensuring that our final product meets both functional and historical expectations.

Equipment and Setup:

To thoroughly evaluate the blade's strength, durability, and sharpness, a diverse selection of objects was chosen for testing. These included a suspended fish, carrots firmly secured in place with screws, a solid block of ice, and a hung pork shoulder. Each of these materials presented a unique challenge, designed to push the blade to its limits and simulate real-world cutting scenarios. The fish tested the blade's ability to make clean, precise cuts through soft yet fibrous flesh. The secured carrots provided a test of its effectiveness against firm, fibrous organic material, requiring both sharpness and resilience. The ice block served as an extreme test of the blade's toughness, gauging its resistance to chipping or dulling when striking a hard, unforgiving surface. Lastly, the hung pork shoulder, with its combination of muscle, fat, and bone, offered an approximation of what the sword might have encountered in historical combat or practical use. These tests not only demonstrated the blade's craftsmanship but also highlighted its ability to withstand demanding cutting conditions, providing a comprehensive assessment of its performance.

Testing Procedures:

Before testing, the blade was meticulously sharpened to a precise 25-degree angle, ensuring optimal sharpness and durability for the challenges ahead. This careful preparation maximized its ability to slice, chop, and pierce effectively. Once the edge was honed to perfection, the first test commenced with a suspended fish, where the blade effortlessly sliced through the soft yet fibrous flesh, demonstrating its keen edge. Next, it was put to the test against a firmly secured carrot, requiring both sharpness and resilience to cleanly cut through the dense vegetable.

Having maintained its integrity through these initial trials, the blade was then subjected to a more rigorous test—a thrusting stab into a hung pork shoulder. This simulated a real-world combat scenario, challenging the sword's structural strength against muscle, fat, and bone. Following this, the blade faced its toughest opponent yet—a solid block of ice. With powerful chopping motions, the sword's durability and resistance to chipping were pushed to the limit.

To conclude the testing sequence, the edge retention was assessed by slicing through a sheet of printer paper. This final test provided a clear visual indication of how well the blade maintained its sharpness after enduring a series of demanding cuts. Through each stage, the sword showcased its craftsmanship, balancing sharpness, strength, and resilience under rigorous conditions.

Results

The sword successfully completed the series of rigorous tests with minimal issues, demonstrating both its sharpness and durability. Thanks to its well-balanced design and lightweight construction, it effortlessly sliced through the suspended fish in just two strikes and cleanly cut through nine secured carrots without hesitation.

One unexpected challenge arose during the ice block test. The blade cut through the ice more efficiently than anticipated, making contact with the 2x4 wooden beam beneath it. This impact was likely the cause of a small chip later discovered on the edge. Despite this minor setback, the testing continued, with the blade excelling in both slicing and stabbing into the pork shoulder, proving its ability to handle more demanding materials.

Even after enduring such intense trials, the final edge retention test—slicing through a sheet of printer paper—was successfully completed, confirming that the sword maintained a sharp cutting edge. Overall, the blade sustained only minimal damage, a testament to its high-quality craftsmanship and well-tempered steel.

Additionally, the handle performed exceptionally well throughout the testing process. While it endured significantly less force than the blade itself, its strength and construction were still crucial factors. Designed with both durability and ergonomics in mind, the handle was slightly larger for enhanced stability and featured silver inlays that not only added to its visual appeal but also provided a secure, grippy texture for the user. This combination of strength, comfort, and practicality ensured that the sword remained easy to wield while maintaining the necessary resilience for heavy use.

Conclusions and Recommendations

The Stars and Steel team from Wentworth Institute of Technology was tasked with designing, casting, and testing a modernized replica of George Washington's Bailey Silver & Ivory Hilted Cuttoe for the SFSA Cast in Steel 2025 Competition. Our approach combined historical research, CAD modeling, precision sand casting, and advanced metallurgy to create a sword that remained true to its historical roots while improving its strength and durability. We modified 17-4 PH stainless steel, heat-treated to H1075, to ensure the blade had the right toughness, hardness, and corrosion resistance balance. We captured the details by utilizing 3D-printed sand molds and MAGMA solidification analysis while reducing consistency and improving cast quality. The finished sword tested well, demonstrating sharpness, impact resistance, and balanced maneuverability. We faced challenges with heat treatment adjustments, machining constraints, and weight distribution along the way. However, each obstacle provided valuable insight that strengthened our understanding of the casting and manufacturing process. Looking ahead, we see opportunities to explore alternative materials, refine casting techniques, and further push performance testing. This competition has been an incredible learning experience, giving us hands-on exposure to traditional craftsmanship and modern engineering while reinforcing the importance of precision, problem-solving, and innovation.

Acknowledgements:

We would like to extend our sincere gratitude to Wentworth Institute of Technology for providing us with the education and resources that made this project possible. From designing the CAD model to conducting comparative analysis, the knowledge and skills we have gained throughout this experience have been truly invaluable. We are especially grateful to our faculty advisor, **Prof. Serdar Tumkor**, for his guidance and support. His expertise, assistance in coordinating with our sponsor foundry, and feedback on our technical report played a crucial role in the professionalism and success of our project.

This project would not have been possible without the generous support of **DW Clark** and the dedication of several skilled individuals. **Josh R**'s knowledge of engineering and mold-making helped ensure precise casting, while **Kevin A**'s attention to detail during the pouring and finishing process played a key role in refining the blade's quality. **Bob M** and **Kevin R** applied their machining expertise to shape the sword blade, add fullers for balance, and fabricate the hilt, guard, and pommel with precision. **Caf** contributed significantly by refining various components of the sword, helping to improve both its structural integrity and craftsmanship. Their combined efforts, from the initial design stages to the final assembly, resulted in a well-crafted sword that reflects both artistry and technical skill.

We would also like to recognize **Readers Hardwood** for generously donating the wood used for the handle, as well as **JLP Machine and Welding** for their skilled machining contributions. A special thank you to **Jim Libby** for his support and guidance, which helped us refine key aspects of the sword's construction. We also appreciate the contributions of **Iron Mountain Forge and Furniture**, whose expertise and assistance with testing added great value to the project.

Additionally, we deeply appreciate the support of the **New England Chapter of the American Foundry Society (AFS)** for their guidance and contributions to the steel casting community. A special thank you to **Will Shambley** of AFS for his assistance with fundraising and for providing valuable insight throughout the competition.

We are incredibly grateful to the **Steel Founders' Society of America (SFSA)** for organizing this competition, which has been both an engaging and educational experience. This event has encouraged innovation while providing us with the opportunity to showcase our craftsmanship and dedication. We would also like to extend our appreciation to the competition judges for taking the time to evaluate our work and offer valuable feedback. A special thank you to **Renee Mueller** for her outstanding coordination and communication, ensuring our team stayed informed and well-prepared every step of the way.

To everyone who contributed to the success of this project—thank you. Your support, expertise, and generosity made this an unforgettable and rewarding experience.

References:

[1] D.W. Clark. (2025). *Precision Sand Castings.* D.W. Clark. Retrieved February 26, 2025, from https://dwclark.com/

[2] George Washington's Mount Vernon. (2025). *Washington's Swords.* Mount Vernon. Retrieved February 26, 2025, from https://www.mountvernon.org/preservation/collections-holdings/washingtons-swords

[3] George Washington's Mount Vernon. (2025). *Washington's Swords Video.* Mount Vernon. Retrieved February 26, 2025, from https://www.mountvernon.org/video/view/pxvqrvfLEF0

[4] Malcolm Blair, Cast Stainless Steels, Properties and Selection: Irons, Steels, and High-Performance Alloys, Vol 1, ASM Handbook, By ASM Handbook Committee, ASM International, 1990, p 908–929

[5] National Museum of American History. (2025). *Small sword owned by George Washington.* Smithsonian Institution. Retrieved February 26, 2025, from https://americanhistory.si.edu/collections/object/nmah_434865

[6] Steel Founders' Society of America. (2025). *Casting in Steel 2025.* SFSA. Retrieved February 26, 2025, from https://www.sfsa.org/subject-areas/castinsteel/

[7] United Performance Metals. (2025). *17-4 PH Stainless Steel Data Sheet.* Retrieved February 26, 2025, from https://www.upmet.com/sites/default/files/datasheets/17-4-ph.pdf

[8] Rolled Alloys. (2025). *17-4 PH Stainless Steel.* Retrieved February 26, 2025, from https://www.rolledalloys.com/wp-content/uploads/17-4_Data-sheet-rolled-alloys.pdf

[9] Iron Mountain Forge. (2025). *Testing and Analysis of Casted Blades.* Retrieved February 26, 2025, from https://ironmtnforge.com/

[10] MAGMA. (2025). *Casting Simulation Software.* Retrieved February 26, 2025, from https://www.magmasoft.com/en/solutions/magmasoft/