SFSA Cast in Steel 2025 – The Bailey Silver and Ivory Hilted Cuttoe

Missouri University of Science and Technology – MSTeel

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Executive Summary

Geroge Washington's most iconic sword, the Bailey Silver and Ivory Hilted Cuttoe, is the perfect union of artistry and functionality – serving as his primary battle sword in the later years of the American Revolution. Hand crafted by John Bailey in Fishkill, New York, this sword features a 30 inch curved steel blade, silver recurved crossguard, green-stained ivory handle, and silver pommel. Though depicted in many paintings with Washington, the sword is most famous for its appearance in *Washington Crossing the Delaware* by Emanuel Leutze in 1851. Though Washington wouldn't have had the sword in 1776 when he crossed the Delaware River, this historical inaccuracy further illustrates how inseparable this sword is from Geroge Washington's image.

The Missouri University of Science and Technology Cast in Steel Team made a point to draw inspiration from every aspect of this renowned sword when manufacturing their replica for the competition. Only one design was created for the blade, crossguard, and pommel as the team found it important to be as accurate to the original sword as possible. Eash of these components were designed using computer-aided design (CAD) software, based on pictures and descriptions available on the internet. No set design was made for the grip as it was carved rather than cast.

Two iterations of gating systems were designed for casting the blade. To decide which system would produce the best results, solidification simulations were conducted within the MAGMASOFT software. The simulation was used to determine potential locations of hotspots, high-risk shrink areas, and the velocity of the liquid metal entering the mold cavity. Simulations indicated that one of the designs was superior as it would reduce the risk of hot tearing and porosity in the blade. A mold incorporating this gating system and the blade design was created in CAD software and printed using the university's ExOne S-Print 3D sand printer. A total of two molds (four swords) were printed and cast in a modified 8630 alloy.

Only one iteration of gating was designed for the crossguard as it was not as demanding. The design for the crossguard was 3D printed in PolyCast and a foam gating system was attached. This combination was used in a traditional investment casting process to create investment shell molds. These molds were poured in aluminum to imitate the silver that was used for the crossguard on the original sword.

While the grip was not cast, it was hand carved out of a green acrylic to mimic the green-stained ivory handle present on the original sword.

The final sword was then cleaned, heat treated, sharpened, and assembled. It measures at an overall length of 36 inches with a 30 inch long blade. The total weight of the sword is 1.8 pounds.

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Cast in Steel: Missouri University of Science and Technology

The Cast in Steel competition has several objectives. The Steel Founders' Society of America (SFSA) has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available. Through this initiative, SFSA aims to create an environment where students not only acquire theoretical knowledge but also develop practical skills in steel product creation. Additionally, the competition provides a platform for students to explore and apply the most recent advancements in steel casting technology. SFSA acknowledges the importance of keeping pace with technological progress and seeks to instill this forward-thinking approach in the participants, equipping them for success in the evolving industrial world. By organizing the Cast in Steel competition, SFSA hopes to inspire and motivate future engineers and metallurgists to pursue careers in steel manufacturing. Offering students hands-on experience and exposure to state-of-the-art technologies, SFSA intends to foster a new generation of skilled professionals who will drive innovation and sustainability within the steel industry. Ultimately, the competition bridges the gap between academia and industry, promoting learning, creativity, and professional growth while advancing the ongoing evolution of steel manufacturing.

Historical Background

The Bailey Silver & Ivory Hilted Cuttoe (Figure 1), a renowned sword once owned by George Washington, is a significant artifact from the American Revolution, crafted by a skilled silversmith named John Bailey at Fishkill, New York in the mid-18th century [1]. The design of the cuttoe, influenced by European naval traditions, was valued for its balance and versatility, making it effective in both close combat and as an officer's weapon. Featuring a distinctive silver and ivory hilt, the sword represented high status, reflecting the growing influence of colonial elites during the revolutionary period. Washington likely acquired the sword either as a gift or through purchase from a wealthy supporter, and it became one of his personal symbols in the later years of the war, representing his leadership as Commander-in-Chief of the Continental Army. After the Revolution, the sword was passed down through Washington’s family – eventually being presented as a gift to the American people in 1843 therefore cementing its cultural and historical significance as a symbol of American resilience. Today, it remains an iconic piece of American history, preserved in museums as a testament to Washington’s legacy and the nation’s fight for independence.

Figure 1 - The Bailey Silver and Ivory Hilted Cuttoe

Sword Design

The overall sword design is an assembly of the blade, crossguard, grip, and pommel created with the purpose of being accurate to the original. No major differences were made to facilitate the fabrication of the replica sword. Before discussing the final assembly, it is important to first reflect on the team's thought process regarding the replication of each individual components.

Blade

The blade is the component of the sword that is most important to its functionality. The overall size and geometry dictate how it is best used. This specific style of sword, a cuttoe, was originally designed as a sidearm for hunting or self-defense that became popular among officers and soldiers. Blades of this style are known to typically have been between 24 and 27 inches in length. However, the extended length of this sword can be attributed to Geroge Washington's rank and height [2].

The team captured the geometry of this blade by outlining a photograph of it inside of CAD software. The know length of the blade (30 inches) was used with the ImageJ software [3] to create a ratio between pixels and inches to determine the other dimensions of the sword. The team was unable to find a photograph containing the thickness of the swords, so this was estimated. A 3D model of the blade was created using the captured geometric profile and dimensions (Figure 2).

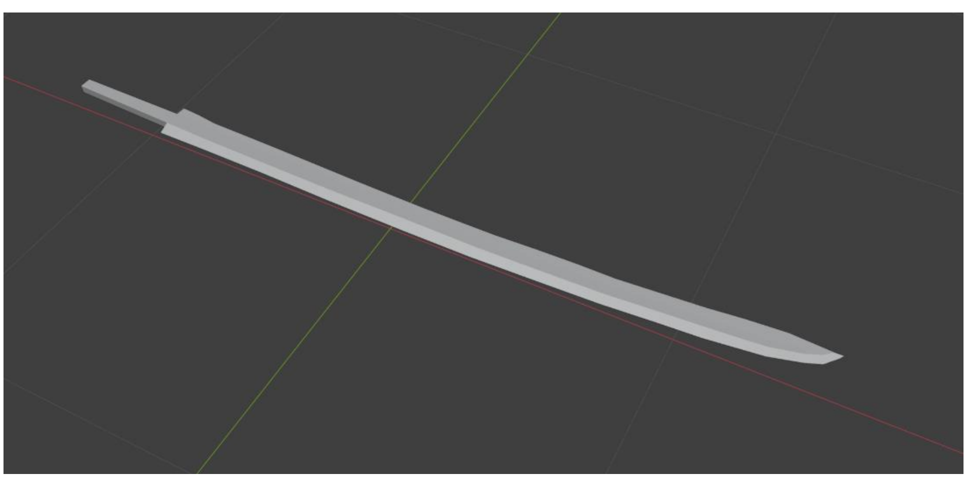

Figure 2 - Blade CAD Model

Crossguard

The traditional purpose of a crossguard is to protect the wielder's hands from their sword and their opponent's. However, it is evident that the significance of this sword, or rather its wielder, led to a more artistic crossguard design. Specifically, this crossguard depicts a trophy of arms in the center with animal heads on each of the extremities. It is also important to note that the crossguard on the original sword is made of silver.

Similar to the blade design, the geometry of the crossguard was captured by outlining available photos in CAD software. The engraving of the trophy of arms and animal heads was also done in this way (Figure 3). The team decided to cast the crossguard out of aluminum for two reasons. Aluminum was more readily available to the team, and it is more historically significant to George Washington. Specifically, the Washington Monument is capped in aluminum because, at the time, it was as valuable as silver and considered to reflect the elegance and strength of the first president [4].

Figure 3 - Crossguard CAD Model (Both Sides)

Grip

The green stained ivory grip featured on the original sword is very prominent and helps the sword to stand out among the others in Washington's collection. The ridges created in the handle by the spiraling silver tape help to improve the grip and control the wielder has over the blade.

As a replacement for the green stained ivory, the team decided to make the grip out of green acrylic and replace the silver once again with aluminum. The grip was hand carved first out of wood in the image of the original. The final grip was carved in the same way out of a block of green acrylic and laced with aluminum wire.

Pommel

The pommel's main purpose is to secure the end of the sword by fixing the grip, blade, and crossguard together. In this instance, it does just that. It is not overly complex or decorative and serves its purpose as intended. The team did not change any aspect of the pommel when they manufactured their replica. The only difference is that aluminum is once again substituted for silver.

Gating System

Two different gating systems were designed for casting two swords per mold (Figure 4). The idea being that a central downsprue can feed two swords at a time, one on each side, and this would help save on molding costs. The main difference in the two designs came from a difference of opinion on riser design. The first riser design featured one long riser down the entirety of each blade. The argument for this design was that the larger riser volume would help to reduce microporosity through the center of the blades. However, after conducting solidification simulations within MAGMASOFT software [5], it was discovered that this posed a great risk for hot tearing along the base of the risers. To remedy this issue, another design was constructed. This time, a series of smaller individual risers were placed along the length of each blade. Solidification simulations showed that this design drastically reduced the risk of hot tearing while not having a large negative effect toward the porosity. This second design was used to cast the blades.

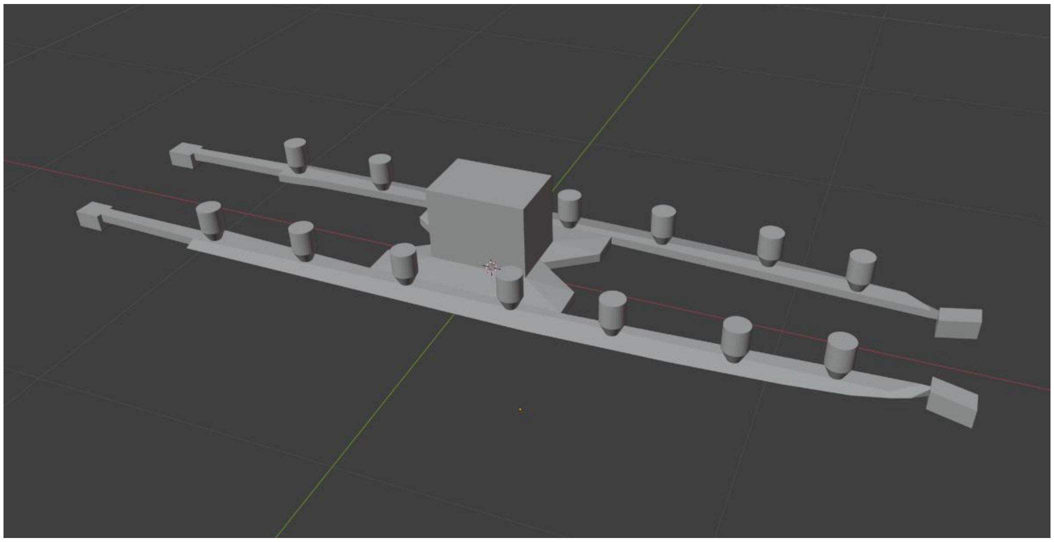

Figure 4 - Finalized Gating System Design

Casting Process

The team's submission of the Silver and Ivory Hilted Cuttoe was cast in the Missouri University of Science and Technology foundry by the Cast in Steel team with the team's advisor providing input and guidance as needed prior to casting. Green sand-casting processes are preferred within the MS&T foundry due to their quick turnaround and ease of operation. For the purposes of the Cast in Steel competition, the blade was cast using a 3D printed sand mold. The guard was cast using an investment shell mold also created in on campus labs. Two heats were conducted due to issues with carbon loss in the first. This led to filling and poor composition within the blade. The second heat was scheduled with necessary adjustments to the composition discussed in later sections.

The Cast in Steel Team used a 200lb Inductotherm induction furnace for both heats. Prior to the heats, the furnaces and crucibles were inspected to ensure no cracks were present and the refractory was in good condition. The 3D sand molds were printed ahead of time as the molds took six hours to print with additional set up being needed for assembly. No-bake resin bonded sand was used to form a pouring cup and seal the gaps within the sand mold to reduce the chances of breaking out. Weights were added to the molds to combat metallostatic and dynamic pressure experienced during filling. A Y-block mold for material testing was also prepared ahead of the heat to minimize the amount of set up required. Sheet metal was clamped around the Y-block mold to hold it secure and keep the mold intact during pouring. The charge material was cut and weighed before being placed in a furnace to bake prior to melting. Temperature probes and immersion samplers were prepared for sampling during the heat. Vermiculite was set prepared for deslagging during the heat. Two pig molds were prepared for excess material.

As part of the ramp up procedure, the furnace periodically increased in power with the purpose of reducing the chance of cracking the crucible and refractory while getting up to temperature.

During this time, the ladle and a hand ladle were set out to be preheated using a propane torch until pouring. An argon shroud was added to the furnace to reduce the oxidation experienced by the melt. Alloying elements were added to the melt and given time to submerge before deslagging. Puck and pin samples were taken so that Optical Emission Spectroscopy (OES) testing could be performed to determine chemistry. The temperature was raised to superheat the melt and it was deslagged with the vermiculite. The ladle was moved in front of the furnace and the furnace was shut off prior to tapping. During tapping, aluminum shot was added for deoxidation. The sword and Y-block molds were filled in that order with any remaining material being poured into the pig out molds. The molds were covered with Kaowool for controlled cooling until fully solidified and break out could begin.

As previously stated, a carbon boil occurred during the first heat which led to complications during the pouring and filling of the sword molds. The carbon boil depleted the melt of most of the carbon shifting the liquidus to be much higher and requiring a much higher superheat than originally anticipated. Further complications arose during tapping as the pouring spout of the teapot ladle froze. An attempt was made to fill the molds using a hand ladle with minimal success. Three of the swords in the two molds failed to fill with the fourth sword having an incomplete tang and tip. After deliberation following the heat, it was decided that another heat should be scheduled to cast a more complete sword with better chemistry. During the second heat, a singular sword mold was created rather than two due to the time constraints. A Y-block mold was prepared along with one pig out mold. The chemistry was altered for the second heat to have greater Silicon and Manganese content to minimize the chance of another carbon boil. This proved to be more successful at reducing a carbon boil with the swords and Y-block mold completely filling. The process for the second pour was identical to the process laid out for the previous pour excluding a second sword mold and premature solidification of the melt before filling the molds. Figure 5 shows the casting resulting from the second heat. The crossguard was cast a week after the sword as the mold was not finished previously and was to be cast out of aluminum. The mold was set out with several other molds which were cast out of aluminum. The crossguard was cleaned up with files and sandpaper to remove residual ceramic.

Figure 5 - Two Blades in the As-Cast Condition

3D Printed Molds

The blade for the replica sword made by the team was cast in a 3D printed sand mold (Figure 6). Traditionally, 3D sand printing is used to manufacture molds or cores that are exceptionally complex or when permitted by economies of scale. In this instance, the geometry of the mold is not complex and could easily be made into a match plate pattern. However, because the team made so few molds over the lifetime of the project, it was advantageous to utilize 3D sand printing. The 3D printed molds are of a much higher quality than the molds that would have been made in a traditional fashion. This is due to the fact that the printer is much more accurate than traditional molding with a handmade match plate would be. Also, the sand grains used by the 3D sand printer are finer than those used in the on campus green sand molding operation and therefore will give a better surface finish. The 3D printed sand molds were made with silica sand and a furan resin binder system. They were printed using the ExOne S-Print on the Missouri S&T campus.

Figure 6 - 3D Printed Sand Mold

Investment Molds

Due to the complexity of the crossguard design, the team decided to create investment shell molds to cast them (Figure 7). Investment shells like the one used by the team are generally used for components where high dimensional accuracy and surface quality are important. With advances in 3D printing technology, this process has been made easier for low volume items like the team's crossguard. Widespread availability of 3D printers eliminates the need for any kind of mold to make lost wax or plastic patterns. It also prevents the necessity of forming patterns by hand. This makes investment casting ideal for the team as it is possible to make an accurate casting with great surface quality in a timely manner.

The crossguard was first 3D printed in PolyCast [6]. Foam risers were attached to make the gating system. Multiple layers of silica investment slurry were added to the exterior of the pattern by a repetitive dipping process. After 5 layers, the final sealing layer was added to finalize the investment molds. The molds were then baked at 1000˚C to burn out the plastic and foam patterns. Every step of the investment shell process was completed on campus in the Missouri S&T labs.

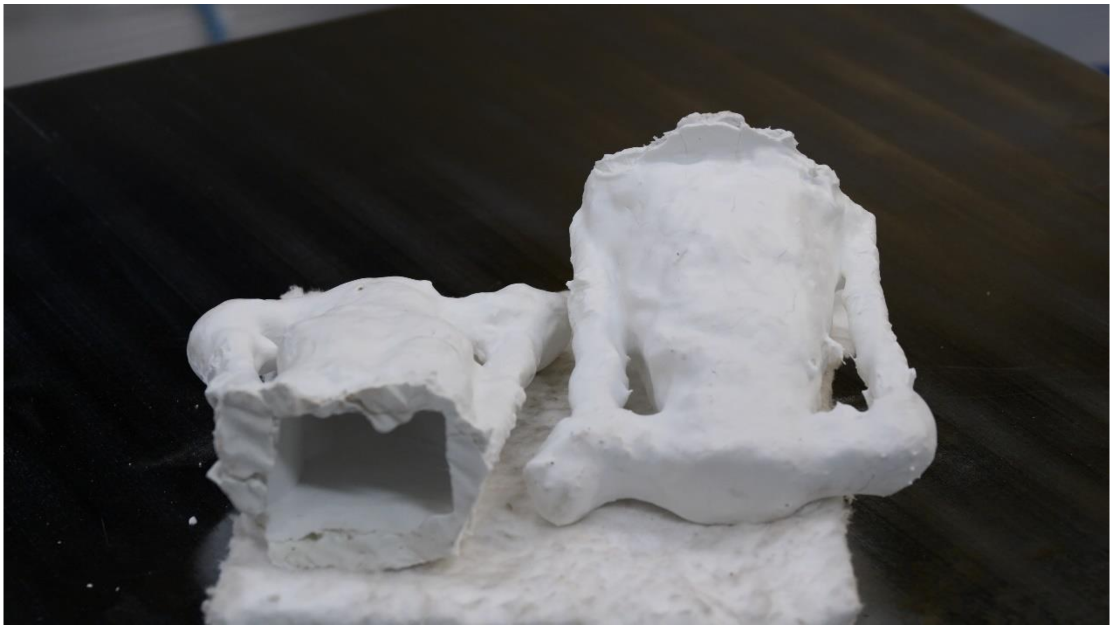

Figure 7 - Investment Shell Molds

Alloy Determination

The final selection for the material used in our George Washington Cuttoe was a modified 8630 steel due to its mechanical properties with compositions specified below. The compositions and charge for both heats are below in Tables 1-4.

Table 1 – Desired Composition of First Heat

	Fe	C	Mn	Si	Cr	Mo	Ni	Cr	P max	S max	N	Al
Range	0	0.28-0.33	0.7-0.9	0.15-0.35	0.40-0.60	0.15-0.25	0.40-0.70	0.40-0.60	0.035	0.04	0.009	0.02
chosen	96.306	0.31	0.88	0.33	0.58	0.23	0.68	0.58	0.035	0.04	0.009	0.02

Table 2 - Charge Material for First Heat

In charge	Weight (kg)	Weight (lbs)
Induction iron	78	171.96
Fe75Si	0.37	0.816
Desulco 9001 Graphite	0.25	0.54
ferromoly	0.29	0.639
electrolytic Mn	0.7	1.543
Low C-FeCr	0.8	1.764
Ni Shot	0.545	1.202
Total charge	**80.95**	**178.46**
In ladle		
Total melt	**80.95**	**178.46**

Table 3 - Desired Composition of Second Heat

	Fe	C	Mn	Si	Cr	Mo	Ni	P max	S max	N	Al
chosen	95.91	0.31	1.6	0.66	0.58	0.23	0.68	0.035	0.04	0.009	0.02

Table 4 - Charge Material of Second Heat

In charge	Weight (kg)	Weight (lbs)
Induction iron	36	79.366
Fe75Si	0.295	0.65
Wupaca	0	0
Desulco 9001 Graphite	0.054	0.119
ferromoly	0.145	0.32
P1020 Al from Bodine	0	0
Dura bar	2	4.41
electrolytic Mn	0.63	1.385
FeV	0	0
FeSiMg	0	0
Low C-FeCr	0.393	0.866
Ni Shot	0.269	0.593

The individual weight of each component was calculated using a charge calculator. The calculator allowed for the input of the desired weight of steel to obtain the necessary quantity of each alloying element so we could achieve the desired composition. Thermocalc and JMatPro were used for phase determination to help determine the solidification of the material as well as the liquidus and subsequently the required superheat for the heats. Table 5 shows the results of the OES testing performed on our puck samples which show our composition after casting.

Table 5 - Actual Composition of the Second Heat (OES)

Element	Fe	C	Mn	Si	Cr	Mo	Ni	P	S	N	Al
Avg. Composition from OES	96.029	0.286	1.37	0.58	0.628	0.248	0.643	0.011	0.006		0.007

Secondary Processing

Once the Cuttoe had been broken out of the mold, the risers, gating, and wells were cut off using a cutoff wheel and an angle grinder. Subsequent grinding on a belt grinder was used to remove most of the sand that was burnt into the material. The belt grinder was also used to clean up the material prior to normalizing and forging. Figure 8 displays the swords following the removal of the risers, wells, and gating while Figure 9 shows the swords after rough shaping and grinding. Any porosity that was found in the blade was welded using a MIG welder with 8630 steel welding wire before being ground flat. The blade then underwent heat treatment and light forging to finalize the general shape. Once the heat treatment was done, the blade was ground using a belt sander to give it a final profile and edge. Final fitting of the handle and guard was done with files to ensure the tightest fit to reduce the risk of any part coming loose. The handle material was attached and glued to the tang with the guard being held in place by the handle.

Figure 8 - Blades in the As-Cast Condition with Gating Removed

Figure 9 - Shaped Blades Prior to Heat Treatment

Heat Treatment

Due to time constraints and delays, the Cuttoe was unable to be taken to Caterpillar for the heat treatment to be performed there. As an alternative, the heat treatment took place at the MFA site in Rolla which serves as the pilot scale rolling mill for the university. The Cuttoe was raised to forging temperature where it was forged to final shape and normalized for the first stage of heat treatment. The whole blade was then placed in the carburizing atmosphere to increase hardness with clay being placed along the spine to prevent carburization and retain ductility. This occurred at 970°C for two hours before being allowed to air cool and served as the second normalization heat treatment. The blade underwent austenitization for 30 minutes at 850°C before being quenched in oil to achieve the desired hardness. Finally, the blade was tempered for two hours at 205°C to reduce residual stress and relax the blades microstructure and increase the ductility slightly following quenching.

Material Testing and Analysis

To test our samples and verify the heat treatment necessary to get the desired mechanical properties, the samples underwent heat treatment before having hardness and room temperature Charpy v-notch testing performed on them. The samples were all wrapped in one stainless steel foil bag together with pack carburized powder for normalization and were subsequently double bagged. During tempering, the samples were double wrapped in their perspective groups and only had carburization power in the outer bag. The samples were normalized twice at 975°C for 30 minutes before being reheated to 975°C for an additional 30 minutes before being immediately quenched in oil. Below in Table 6 are the temper times and quantitative analysis from the testing. Hardness below 20 HRC is unreliable though the values were left in to keep our recording of data honest. Looking at the results of the testing, it was determined that a 650°C temper for 2 hrs would give us the best combination of ductility and hardness for the blade which is why that was selected for the final heat treatment.

Table 6 - Material Testing Data

	Sample #	Hardness 1 HRC	Hardness 2 HRC	Hardness 3 HRC	Average HRC	Charpy (j)	Charpy avg
500°C for 2 hrs	1	37.2	35.5	32.4	38.1	42.5	40.8
	2	41.3	42.2	43.8		38.5	
	3	34.7	38.3	37.4		41.5	
550°C for 2 hrs	4	29.1	34.9	31.9	34.5	49.7	50.2
	5	37.4	35.3	37.2		48.7	
	6	35.6	34.5	34.9		52.2	
600°C for 2 hrs	7	32.3	27.9	32.1	31	64.9	63.7
	8	31.8	32.3	31.8		64	
	9	28.2	30.8	32		62.1	
650°C for 2 hrs	10	26.3	23.5	27.1	27.2	84.5	81.8
	11	28.2	27.3	28.3		81.7	
	12	27.3	27.3	29.5		79.2	
700°C for 2 hrs	13	18.3	20.2	16.2	17.2	90.8	92.8
	14	19.7	20.2	21.7		96.5	
	15	13.4	9.8	15.7		91.1	

Conclusion

The final blade submitted for the Cast in Steel 2025 competition is shown in Figure 10. This sword is a replica of The Bailey Silver and Ivory Hilted Cuttoe owned and wielded by George Washington near the end of the American Revolution. The blade of the sword is cast out of a modified 8030 steel that has been quenched and tempered. The crossguard and pommel were cast out of aluminum to mimic the silver used in the original. The grip was hand carved out of green acrylic to imitate the green stained ivory on the original. The sword measures an overall length of 36 inches with a 30 inch long blade. The total weight of the sword is 1.8 pounds.

Figure 10 - Finalized Blade

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