SFSA Cast In Steel 2025

French Officer Epée
Virginia Tech – Swordy McSword Face

Team Members:
Jon Bergh, Elliot Bevers, Cole Harsa, Thomas Hiep, and Sydney Hulse

Faculty Advisor:
Dr. Sean Corcoran

Industry Advisor:
Mr. Paul Huffman, Dominion Metallurgical

Virginia Tech, Department of Materials Science and Engineering

Materials Engineering Professional Society

Dominion Metallurgical

Abstract

The 1767 French Officer's Epée was gifted to George Washington by his friend, the Marquis de Lafayette around 1780. The original sword was gifted around 1780 after the Marquis' journey to France in 1779 to gather French support and supplies for the Continental Army Infantry during the height of the American Revolution. The Swordy McSwordFace team's sword was modelled based on the original 1767 French Officer's Epée but does have some alterations due to competition goals as well as processing and timeline issues during production. The sword was originally meant to be cast in 80CrV2 steel, but the chemistry was altered during casting and processing, and instead produced approximately 1050 steel which was forged and finished as the blade. The final blade, with competition goals in mind, was changed to be a 4-sided blade to improve cutting properties, rather than the 3-sided original that is primarily used for thrusting. The hilt was cast in a lead-free C89833 red brass that—due to bismuth content—experienced heat tears during casting and broke a part of the original modeled handguard, which was not reattached. A leather-covered 3D printed polymer grip and silver banding were added to contribute to the hilt design found on the original 1767 sword. The final sword, show in Figure 1, weighs approximately 1.8 lbs. and measures approximately 41 inches in length.

Figure 1: Final sword.

Introduction

The 18^{th} century was a period full of disagreements and strife. For the first time ever, conflict stretched across the globe. Smaller, more powerful European countries claimed dominance and imperial control over large, faraway lands. The French and Indian War, one of the pivotal claims of European imperialism, began in 1754 as Great Britain and France raged for control of the new worlds of the Americas. One of the first conflicts was based around the Ohio River basin in now-Pennsylvania, led by a British Lieutenant Colonel George Washington to remove French influence from the area [1]. It took seven years before the conflict concluded, signed and sealed by the Treaty of Paris in 1763. The war between the two nations incurred huge national debts, ones that Great Britain decided would be paid by those they deemed beneficiaries of their war efforts—the colonists in soon-to-be-America [2]. Taxation, like the Sugar or Stamp Acts in the mid-1760s, began decades of unrest amongst the colonists. By the 1770s, the unruly relationship between king and country in the Americas had reached an all-time high, caused by the Boston Massacre in 1770 and the Boston Tea Party in 1773. In 1774, the First Continental Congress was born, and partaking was none other than the former British Lieutenant Colonel George Washington [3].

It was due to the First Continental Congress that George Washington was introduced to a Marquis de Lafayette. Lafayette was one of the richest men in France, whose father had died in the previous Battle of Minden in 1759 as part of the French and Indian War efforts by the French. Growing up pitted against the British for their contributions in the death of his father, Lafayette traveled to join the colonists' war efforts in the 1770s. Due to his connection to the Court of King Louis XVI, Lafayette was appointed the Major General by the First Continental Congress for their fight against Great Britain [4]. Washington and Lafayette became fast friends, with Lafayette referring to Washington as having a "noble affability of his manner." His contributions to the colonists' included a trip to France in 1779 to smooth relations between the two nations, in which he gained French support and supplies [5]. It was this trip that he was likely to acquire a 1767 French Officer's Epée which was later gifted to George Washington by the Marquis.

An épée is a 3-sided blade with a sharpened tip, that was fairly small and narrow in stature [6]. Under Louis IX, it was described that the "Frenchman engaged as close as the nail is close to the skin and pierced them with their short épées" by Guillaume de Nagnis as part of the Battle of Bénévent in the 13^{th} century, until the development of chain mail later caused the blade to be lengthened for improved reach. By Louis XIII's reign, the standard épée evolved into various blade purposes with the most common being a fencing épée. By the 17^{th} century, carrying a sword became the social norm. Epées were a trend found in those of noble birth, especially useful for identifying aristocratic soldiers [6]. After the 1750s, these blades were primarily being carried in courts and salons [7]. The "épée d'officer" was the common sword for a French infantry officer in the 1700s, and it was the Continental Army Light Infantry that Lafayette was procuring supplies for during his visit in 1779.

French sword production by the 1700s had been relegated to foreign weapon factories. Most blades were made in Germany, increasing the costs, but production of the hilts was kept under the control of local manufacturing groups [7]. This led to differences between hilt structures, but several elements were added throughout the course of the 18th century that became central to similar swords. This increased the complexity of many designs and contributed to the épée becoming a weapon carried by aristocrats in social spaces [7]. It is due to these complexities that the swords chosen for the 2025 Cast in Steel competition come from a wide range of designs and unique hilt styles and increasing the craftsmanship that is required for a high-quality sword. SFSA has created the Cast in Steel competition to encourage students to learn about making steel products using the casting process and applying the latest technology available. By enriching the competition with modern day technology and historical proof of concept, the process of creating the 1767 French Officer's Epée began as a passion project that truly tested the innovation of college students and their metal-based casting and technical knowledge.

Design

Of the swords provided as inspiration by SFSA, the hilt of the French Officer's Epee has possibly the most intricate geometry. To create a one-to-one model of this hilt a full-length image of the French Officer's Epee was imported into the 3D modeling software. From the measurements provided by SFSA, and further information obtained from Mount Vernon themselves, the image was resized to fit the length of the blade. To account for potential warpage that could occur from lens distortion, pixel counting was used to corroborate the scale of the image with the measurements provided.

It is important to note that throughout the design process, symmetry was prioritized over accounting for geometrical imperfections in the original blade as we believe in recreating the sword in a way that is idealized when accounting for the precision of modern metallurgical techniques.

The pommel, which was designed separately from the rest of the hilt, would be tapped and joined to the rest of the hilt after the entire blade was assembled. An ellipsoid was created as the main body of the pommel. In the original model, there appeared to be extruded faces of the pommel that go from pole to pole. This detail was replicated by selecting 6 groups of three around the pommel and then extruding, as shown in Figure 2. To finish the rest of the pommel, a cylinder was added to the bottom, acting as the connecting point between the pommel and the handle. And a sphere was added to the top to replicate the decorative knob at the top of the pommel. A finished model of the pommel is shown in Figure 3.

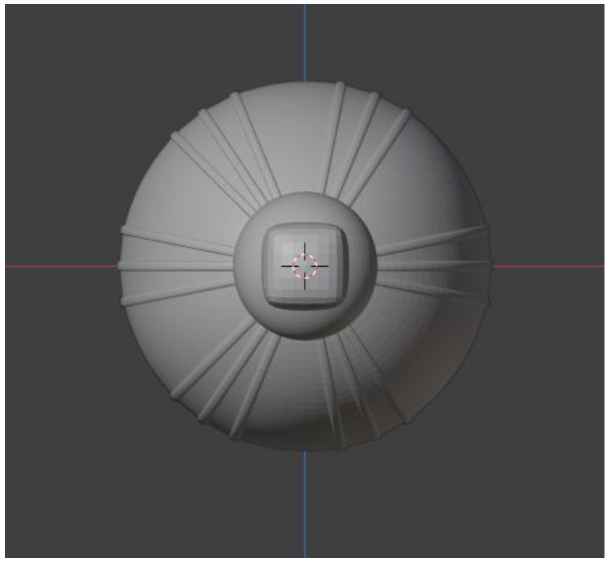

Figure 2: Pommel top view CAD model

Figure 3: Pommel side view with refrence picture.

For the hilt itself, a Bezier curve was created to develop the shapes of the knuckle guard as well as the finger rings. At the various nodes of the curve, the thickness of the cylinder was adjusted to create the tapered shape of the original sword. The thickness throughout these parts was increased slightly to account for any imperfections that could occur from the grinding/finishing process, as well as allowing for a larger channel for the hilt material of choice to fill.

The sweepings of the hilt were made in a similar way to the knuckle guard. A bezier curve was used to produce the shape of the sweeping, and at the very end, the bulb shape was replicated with a sphere. This sphere was deformed using the lattice deform modifier to recreate the teardrop shape of the original hilt. To account for the thickness increase we applied to the knuckle guard, the sweepings were brought further away from the rest of the hilt to ensure separation with the finger rings. The model for sweepings, finger rings, and knuckle guard can be found in Figure 4.

Figure 4: Knuckle guard CAD model with reference picture.

The main guard of the handle required multiple parts that were conjoined later. Around the perimeter of this guard, there is a lip that was recreated by conjoining two bisected toroids with cylinders of the same width creating a bowtie shape. A subdivided plane was then used to fill the bulk of the guard, almost reaching the thickness of the bowtie created, but still allowing for that lip to be visible. A secondary lattice modifier was applied to this now filled bowtie shape, creating the curve that is visible from the side views of the epee which is shown in Figure 5 and Figure 6.

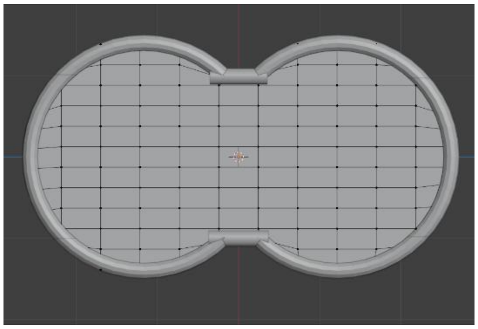

Figure 5: Hand guard top view CAD model.

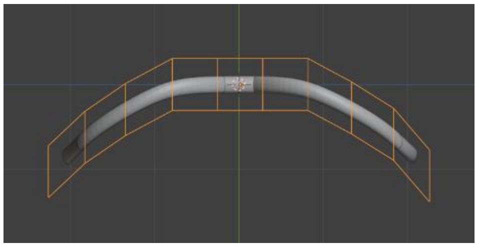

Figure 6: Hand guard side view CAD model.

The main body of the hilt of the original sword consists of a rectangular prism that connects the main guard, the knuckle guard, the finger rings, and the sweepings. This prism also acts as the part of the hilt the tang will be inserted into. After sizing this prism based on the reference image, bevels were added along the length of the prism to replicate the decorative pieces of the original blade.

These various pieces were then joined together to create the entire hilt model. While the join command of the modeling software created the external geometry we wanted, the internal geometry created by the join command made it difficult to work with in other programs, such as MAGMA and SolidWorks. The join command would have these parts create vacancies where the two pieces would intersect. To combat this, a union Boolean modifier was utilized, which joined the pieces into one continuous piece of geometry that could then be exported to other programs. The finished model compared to the original sword can be seen in Figure 7 and Figure 8.

Figure 7: Hilt CAD model with reference photo.

Figure 8: Hilt CAD model with reference photo.

Mold Preparation

To ensure successful casting, a gating system was designed around the 3D models of the hilt and the pommel.

The pommel model was added to a casting tree where the riser had a diameter of 2 inches, ingates were added which connected the pommel models. The pommels were then bottom filled, with venting added out of the tip of the pommel connecting back to the top of the downsprue to prevent air entrapment during casting. Each of these branches were replicated 90° from each other to create a set of four and then duplicated and offset by 45° to create a second layer higher up the downsprue. The creation of eight pommels in this tree gives the team more pommels to play around with to prevent any failures on the final assembly. A picture of the pommel tree is shown in Figure 9 below.

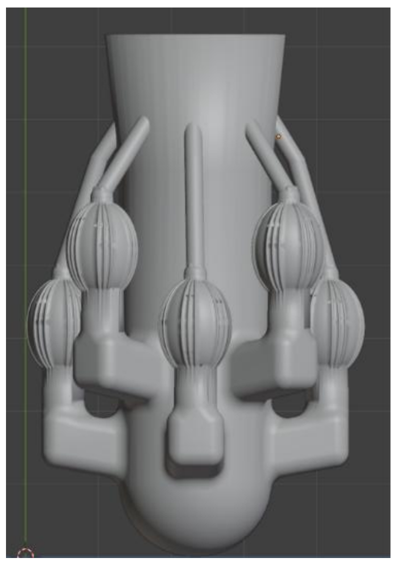

Figure 9: Pommel tree CAD model.

A tree was also created for the gating system of the hilt, with two hilts reflected around the axis of the downsprue. The hilts, similar to the pommel, are also designed in this gating tree to be bottom filled. A runner for each of the hilts extends nearly perpendicular to the downsprue, feeding into the main guard of the hilt. At the main body of the hilt, a cylinder was extruded, which had connections to the knuckle guard to prevent porosity in the hilt.

These gating systems were then taken into a 3D printing slicer to be printed out in Polymaker Polycast 3D printing filament. This filament was used as it is specifically engineered to burnout completely with no residue on the shell. Automatic tree supports were used along with the recommended printing settings from Polymaker’s website. The printed models of the gating systems can be seen in Figure 10 and Figure 11. Polycast proved to be relatively difficult to print with as it had many bed and layer adhesion problems, likely attributed to the lack of drying that was done to the filament before printing. This was overcome by increasing the threshold angles on the support trees, which seemed to assist in achieving a successful print.

Figure 10: Pommel tree pattern 3D printed with Polycast filament.

Figure 11: Hilt tree pattern 3D printed with Polycast filament.

After printing, a ceramic shell was used to coat the patterns. Seven layers of ceramic slurry and stucco were added atop the model: two layers of slurry coat with zircon sand, two layers of slurry with fine-fused silica, two layers of slurry with coarse fused silica, and one coating layer of the slurry with no stucco. A two-hour dry time was allotted between each of the coats. Post drying, the thickness of the ceramic coat was 3/16ths of an inch thick.

Burnout of the Polycast filament and the sintering of the ceramic shell were done simultaneously around 1450°C in a pullout kiln. After burning out and cooling down the shell, it was found that there were hairline cracks around the shell, but not large enough to cause too many issues while casting. The shell was placed back into the kiln to warm up before pouring. The final shell before pouring is shown in Figure 12.

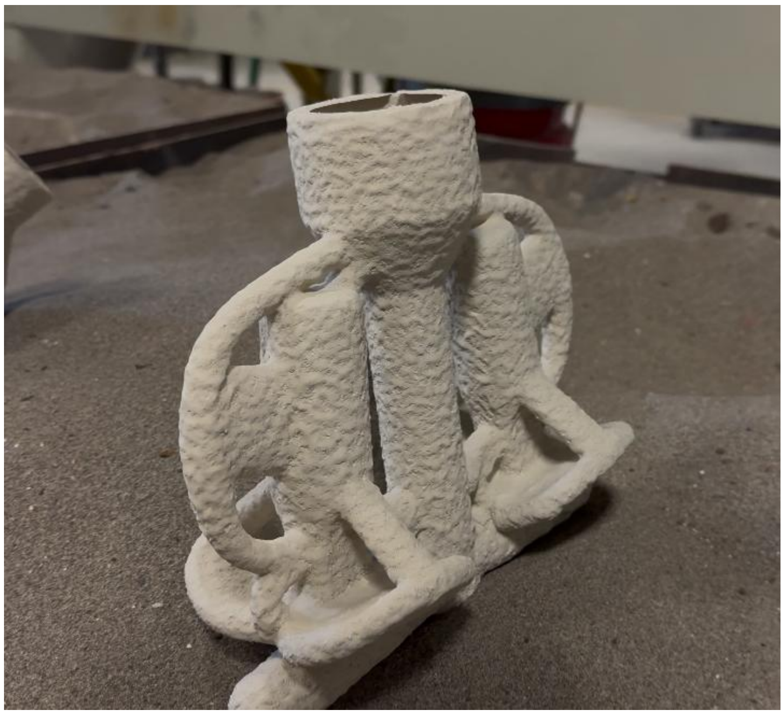

Figure 12: Final hilt shell before casting.

Hilt Material Selection

To match the color and finish of the original sword, the team originally planned to go with Everdur silicon bronze to cast the hilt out of. Ideally, Everdur would be used as it can be welded together, which would be helpful when conjoining the hilt to the pommel, and it has high fluidity, making it easier to cast. However, due to both budget and time constraints, the group pivoted to using a lead-free C89833 red brass. Fifty pounds of this was donated to the team by Graham White Foundry in Salem, Virginia. The composition of this alloy can be seen in Table 1 below.

Table 1: Chemistry range for C89833 [8]

	Elements											
	Cu	Pb	Sn	Zn	Fe	P	Ni	Al	Bi	S	Sb	Si
Min (%)	86.0		4.0	2.0					1.7			
Max (%)	91.0	.09	6.0	6.0	.30	.050	1.0	.005	2.7	.08	.25	.005

Hilt Processing & Finishing

After casting the red brass in our ceramic shell mold and letting it cool, heat tears could be found throughout the casting. The heat tears were likely attributed to two main causes: sharp angles in the gating system and the high bismuth content in the brass. While many of these heat tears appeared to be merely surface imperfections, after cutting off the gates it was found that these tears went fully through and broke off from the rest of the hilt shown in Figure 13.

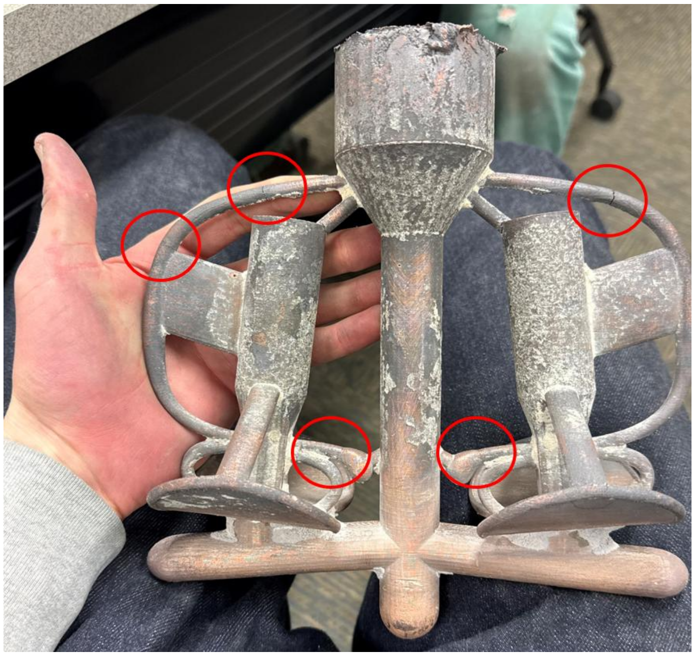

Figure 13: Hilt casting, the red circles indicate hot tear locations.

To repair these heat tears, the hilt was brought to Nick Bedard, a metal worker at Virginia Tech who was able to tig weld the pieces back together with copper filler wire. While the welding was able to reattach the broken off pieces, during the finishing process, the knuckle guard broke off, leading to the group deciding to forgo the knuckle guard, as time was running out and the sword was still aesthetically pleasing.

To fit the tang to the hilt, an ovular hole was milled into the guard and filed straight. The tang was then repeatedly test fitted, and more material removed from the hole as needed, keeping an eye on how the perpendicularity of the blade to the guard. Once the full tang could fit through the guard, the shoulders of the blade were filed square. The inset for the shoulder of the blade was also milled to match the dimensions of our blade to ensure a snug fit upon final assembly.

Due to the original model being 3D printed; layer lines persisted throughout the surface of the cast hilt. While this did not impact the structural integrity of the hilt, it left imperfections on the surface that required further grinding. A sand blaster was utilized to remove any residual oxide layer from the casting process and to get the hilt to a consistent finish. The surface was then ground with a dremel tool with a grinding stone bit to get rid of the layer lines, then followed by various grits of sandpaper, and then finally a polishing wheel and polishing compound to achieve a mirror finish.

Filling & Solidification Analysis

Calculations of the riser for the blade blanks were done manually; the gaiting system was an unpressurized 1:3:2 system where the cross-sectional area of the downsprue, runner, and ingates followed that ratio. To accommodate the geometry of the blanks, the diameter of riser was 2.88" was used. The gaiting model can be seen below in Figure 14.

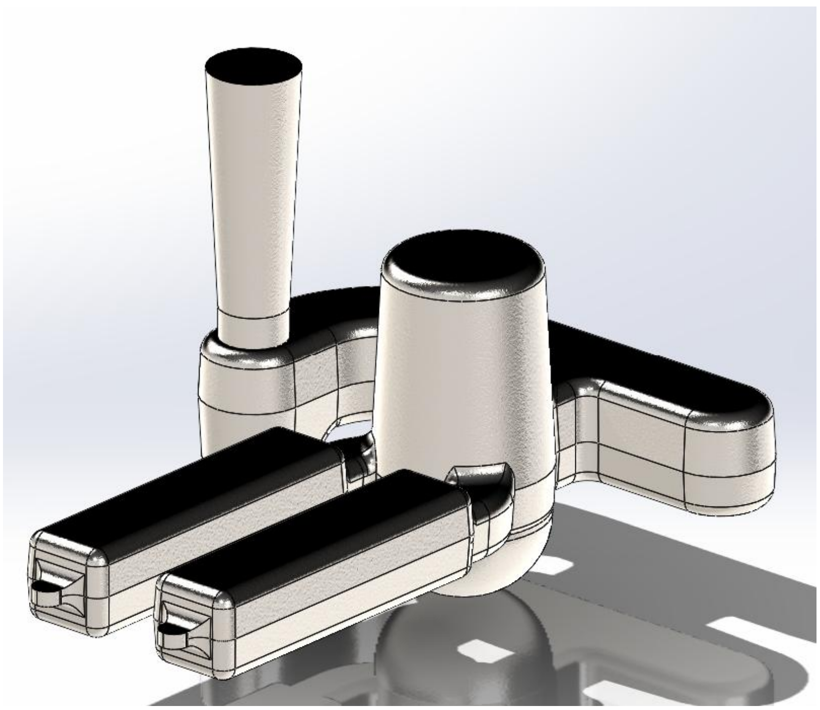

Figure 14: Gaiting system for sword blanks.

Solidification modeling software was used to identify the hottest parts of the model, this informed the design of the gaiting by showing where to place the risers to mitigate shrinkage porosity

Blade Cast Alloy Selection

Three alloys were considered for this blade: S7, 5160, and 80CrV2. S7 was attractive due to its air hardenability, as this would eliminate the need for quenching and reduce the risk of warping the blade. The other two materials, 5160 and 80CrV2, are common steels in knife and sword making and are easily forgeable. The decision of 80CrV2 was made due to its toughness and edge stability over 5160. While looking over the charge calculations for the alloy the vanadium was left out and during the casting carbon also boiled out resulting in a lower carbon content than desired. The desired chemistry vs actual chemistry for our blade alloy is shown in Table 2.

Table 2: Blade alloy chemistry target and actual.

Alloy wt%	C	Cr	Mn	P	Si	S max	V	Fe
Target	0.800	0.500	0.400	0.013	0.250	0.005	0.200	bal
Actual	0.535	0.504	0.401	0.012	0.393	0.013	0.003	

Two castings were poured, each with two blade blanks for a total of four blade blanks. The castings filled completely with little to no casting defects. The final cast weights are shown below in Table 3.

Table 3: Casting weight and yield for sword blanks.

	Total wt (lbs)	Part wt (lbs)	Yield %
Casting A	27.8	7.8	28.058
Casting B	37.5	7.7	20.533

Forging

The effect of forging is an improved grain structure and grain flow within the components being processed. Forging aligns grains in the direction of the highest strength, improving mechanical properties like impact resistance [9]. Grain flow identifies a directional orientation of the metal grains and can determine how the grains will strain when stressed. Through the whole process, it removes voids created during solidification from its cast state, preventing internal crack propagation [9][10].

The cast billets were taken to New Jersey Steel Baron and forged into sword blanks by Gari Jimenez, a professional prop maker with Galactic Army and previous Forged in Fire contestant. A test billet was used to estimate overall forgeability and end hardness. It was elongated with a power hammer, before it was allowed to cool. Two inches by two inches coupons were cut from the test billet. The surface carburization was ground away before four coupons were put through various heat treatment and quenching processes to determine overall hardness of our material. Due to the change in predicted chemistry from the lack of vanadium and range of carbon, the coupons were tested for hardness to determine the results of forging on the metal's properties.

Despite the omission of Vanadium, the oil quenched coupons reached an average hardness of around 62 HRC. This exceeded expectations and the sword blank was subsequentially made. Using a power hammer, the billet was elongated before being manually hammered into a triangle-tipped shape, intermittently placed in the forge when it became too cold to work effectively with. The sword blanks were roughly ground to remove carburization on the surface once the shape was achieved.

Heat Treatment

Heat treating the blade followed the heat treatment procedure used for 1080 steel, 1490°F heat soak then immediate oil quench for 12 seconds. After the blade was pulled out of the oil, it was clamped between two boards to prevent warping. While the blade was still warm, and the warpage that occurred was straightened out using a vice and bending the blade opposite to the warp.

Finishing the Blade

Finishing the blade consisted of sharpening the blade, polishing the guard, fitting the tang, threading the tang and pommel, fabricating the handle, and finally assembling the sword.

To make the sword sharp, it was brought to Baltimore Knife and Sword where a flat edge was put on the blade using a belt grinder with a low grit sandpaper, bringing the edge to around 50 thousandths of an inch. Once the flats were ground onto the blade, it was heat treated. The epée used for reference had a four-sided hollow grind which was implemented on our blade using a small grinding wheel. This is a deviation from the original sword, which had a three-sided blade. This decision was made as a four-sided blade would allow the sword to be suitable for slashing tests the blade would be subjected to during the judging process, while still being suitable for thrusting tests. Quick passes were made along the length of the edge on a slack belt to “acorn” the edge, giving the blade a sharp but strong cutting edge. Time permitted further sharpening, so the rest of the edge was completed back at Virginia Tech, grinding the edge at a 25° angle with 220 grit to define the edge, and 6000 grit to hone the edge.

The handle of the sword was created based off the dimensions produced by the 3D modeling of the hilt. A central grip that retained a hole for the tang was 3D printed with polylactic acid (PLA) plastic at 100% fill for mechanical strength. Strips of leather were cut and spiraled around the grip to create the ribbed handle seen on the original 1767 French Officer Epée. On top of the spiraled leather strip, a full piece of leather was wet formed around the topography before being glued, secured with pressure by juke cord, and left to dry. The seams of the leather were cleaned up to align and glued down to prevent any extra overlap.

The silver banding on either side of the handle was replicated by braiding together silver wire. The leather of the handle was trimmed to the width of these bands so it would be inlayed with the rest of the handle. The silver wire was then secured to the handle with CA glue and silver pins.

To secure the sword together, the pommel and end of the tang were tapped with an m6 tap and die set. During the tapping process of the tang, it was found that the tang was too hard for the die to “catch”. The very tip of the tang was heated with a propane torch, to anneal the metal, making it soft enough to successfully tap the tang. To finish assembly of the sword, the hilt followed by the handle slid onto the tang and finally the pommel was screwed on and secured with Loctite. The final assembly is shown in the appendix.

Current & Future Work

As could be predicted, the sword was only finalized at the last minute due to scheduling problems, delayed casting, and concerns about budget material acquisition. Given an ideal timeline, the sword would have been 80CrV2 steel rather than the resulting composition, cast and checked for any processing issues or concerns prior to forging. The hilt would have been preferred in a single piece, but with casting issues and being at the mercy of gifted material, the specific copper alloy was not in our hands and the timeline did not suit a re-casting to get a whole new hilt cast. Additional work would have potentially included an etched phrase in the blade of the sword, likely Virginia Tech's "Ut Prosim" motto to pay homage to our university and in connection to the etching on George Washington's 1767 French Officer's Epée.

The Swordy McSwordFace team has been incredibly grateful and blessed to have worked with the amazing team members, industry partners, and individuals across the course of the project, which couldn't have done without the guidance of Paul Huffman and his team at Dominion Metallurgical in Roanoke, Virginia. The team would also like to acknowledge the help of Dr. Alan Druschitz and the Kroehling Advanced Materials Foundry, without these facilities this project would not have been possible.

<u>Appendix:</u> Final assembly

Citations

[1] “French and Indian War/Seven Years’ War, 1754-63.” Office of the Historian. https://history.state.gov/milestones/1750-1775/french-indian-war (accessed March 18, 2025).

[2] “Seven Years’ War.” The George Washington Presidential Library at Mount Vernon. https://www.mountvernon.org/library/digitalhistory/digital-encyclopedia/article/seven-years-war (accessed March 18, 2025).

[3] “Timeline of the American Revolution.” Museum of the American Revolution. https://www.amrevmuseum.org/timelines/timeline-of-the-american-revolution (accessed March 18, 2025).

[4] “George Washington and the Marquis de Lafayette.” The George Washington Presidential Library at Mount Vernon. https://www.mountvernon.org/library/digitalhistory/digital-encyclopedia/article/george-washington-and-the-marquis-de-lafayette (accessed March 18, 2025).

[5] “A Revolution in Arms: Weapons in the War for Independence.” The American Revolution Institute of The Society of the Cincinnati. https://www.americanrevolutioninstitute.org/exhibition/a-revolution-in-arms/ (accessed March 18, 2025).

[6] “An epee, a sword.” The World of d’Artagnan. https://www.lemondededartagnan.org/en/cape-sword/sword (accessed March 18, 2025).

[7] C. Aries and M. Petard, “French Military Sword in 18th Century (First period),” Gazette des Armes, vol. 57, Feb. 1978.

[8] “C89833.” Copper Development Association, Inc. https://alloys.copper.org/alloy/C89833 (accessed March 19, 2025)

[9] “Forging and Grain Flow.” Trenton Forging. https://trentonforging.com/grain-flow-in-forging/ (accessed March 20, 2025).

[10] R. Lowe. “Grain Flow — Its Role In The Forging Process.” All Metals & Forge Group. https://steelforge.com/2025/01/grain-flow-in-forging/ (accessed March 20, 2025).