# SFSA Cast In Steel 2025 – George Washington's Sword

# Technical Report

Baylor University Carvers


Team Members:

Andrew Ikeler, Cole Ritter, Gerardo Martinez, Liam Stewart

Advisor(s) Name:

Dr. Brian Jordon

Foundry Partner:

Howell Foundry LLC

# Contents

# COMPETITION MOTIVATIONS

## Reason for the Competition

SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available to create functional components.

## Reason for Choosing Howell Foundry

Dr. Raymond Monroe connected the team at Baylor University with Howell Foundry, as both groups had competed in previous Cast in Steel competitions. Our team chose to partner with Howell Foundry because of their cooperative attitude, customizability to cast parts such as a sword, specialization in custom alloys, and geographic proximity to Baylor University. Each of these aspects is what makes Howell Foundry an exceptional place for any casting needs, as it is only 1 of 2 foundries in Louisiana. Their foundry is also renowned for their speed in lead times, which made the whole process seamless. Our group had a desire to learn more about practical casting processes and the historical aspects of the sword used for fashion and practicality in warfare. The Cast in Steel competition offered a great opportunity to learn more about all aspects of the casting process and an opportunity to collaborate between an industrial foundry and students on a fun and common goal. Our team enjoyed being able to work together to balance the design ideas from different members and incorporate the feedback from Howell Foundry. Their team provided great feedback and was incredibly informative. Our team met with the foundry several times to design the sword and gating system, as well as an incredible visit to the foundry in Louisiana to pour the steel.

# HISTORICAL CONNECTION

## Historical Background of Sword

George Washington's 17th-century cuttoe is not regarded for its conventional style. The sword, also known as the Onyx-handled cuttoe, is likely an ancestral piece that was never used in battle by the General himself [1]. It features both a saw-toothed and flat sharpened edge, giving it a striking appearance that inspired the creation of its replica for this competition.

In 17th-century Europe, cuttoes became popular as lightweight secondary weapons for infantrymen [2]. The word "cuttoe" originates from the French term *couteaux de chasse*, which translates to "hunting knife." These swords were designed to be practical sidearms, known for their compact size and ease of maneuverability.

One of the defining features of a cuttoe is its oppositely curved counterguards, which provide both hand protection and a balanced grip. The blade was typically a single-edged, forged high-carbon steel with a slight curve, making it both durable and flexible. The forging process for these types of blades involved heating the metal to high temperatures, hammering it into shape, and rapidly quenching it to harden the metal. Later, the blade would be tempered to improve its ductility.

Figure 1) George Washington's 17th Century Cuttoe pictured below, Baylor Carver's sword pictured above for a comparison.

## Design Authenticity

Baylor University's team design is a modified replica of Geroge Washington's 17th Century cuttoe.

# Metallurgical Decisions

A487 Grade 10 Class B is a high strength low alloy steel that the team has been closely working with for the past two years. This includes having run multiple tensile, fatigue, hardness, and crack growth tests as well as non-destructive evaluation and postmortem fractography to characterize its fatigue properties. The team's familiarity with this alloy is not overshadowed by its known properties of high strength, ductility, and its medium carbon content of .3% makes the sword heat treatable. All these properties make for a sword with high toughness that can withstand impacts during essential applications, such as hand to hand combat. Our previous A487 Grade 10 Class B casting had a YS of 650 MPa, UTS of 800 MPa, and hardness of 300 HV. The composition of this alloy can be found in Table 2.

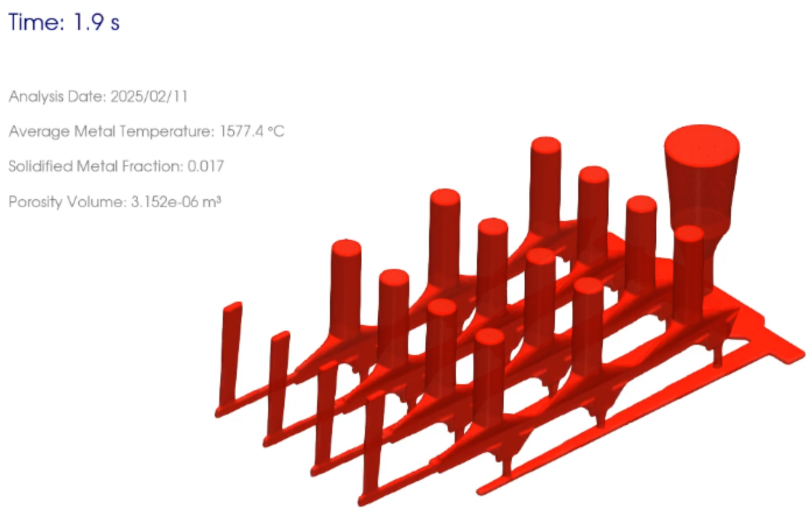
# Timeline and Process

December 02$^{nd}$ : Preliminary Plan Due
December 26$^{th}$ : Initial contact between Howell Foundry and Baylor University, facilitated by SFSA's Dr. Monroe.
January 15$^{th}$ : Production meeting with Jonathan May at Howell Foundry. Presented project goals, initial design, and met the team at Howell Foundry.
January 30$^{th}$ : Meeting with Howell Foundry: Fixed potential casting issues with initial design, learned more about Howell Foundry and operations, and received an in-depth lesson from Mr. May about the casting process.
February 3$^{rd}$ : Meeting with Howell Foundry: Calculations and design for the risers and gating.
February 11$^{th}$ : Meeting with Howell Foundry: Finalized designing the gating to prepare the 3D sand print for the upcoming trip.
February 17$^{th}$–18$^{th}$ : 3D printed mold, poured steel, and heat treatment of sword during visit to Howell Foundry. The team documented the process in-depth and participated in every step of the casting process.
February 19$^{th}$- : Team began writing the report, editing the video, conducting material property tests, and making preparations with Maker's Edge in Waco, TX to forge the blade.
March 21$^{st}$ : Sword, Report, and Video due.
April 10$^{th}$ : Competition in Atlanta, Georgia.

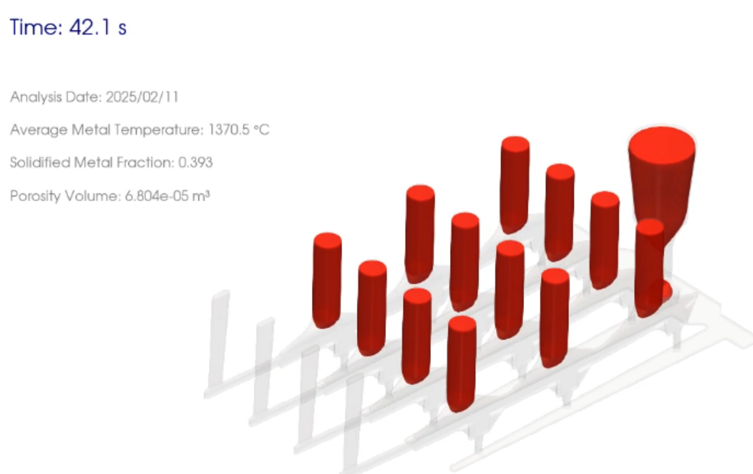
## Design

During several meetings with Howell Foundry, we discussed the motivations behind the casting design, for example, why we place the risers where they are. There are many calculations to determine how quickly the metal will cool which determines how large the gating system and risers should be. Finally, the team used FLOW-3D simulations to visualize how the metal flows from the pour cup to the mold to the risers to the gating. As a precautionary final design, Jonathan expanded the gating system because it may have been too small for the metal to flow. The flow simulations are shown below:

a)


Time: 1.9 s
Analysis Date: 2025/02/11
Average Metal Temperature: 1577.4 °C
Solidified Metal Fraction: 0.017
Porosity Volume: 3.152e-06 m³

b)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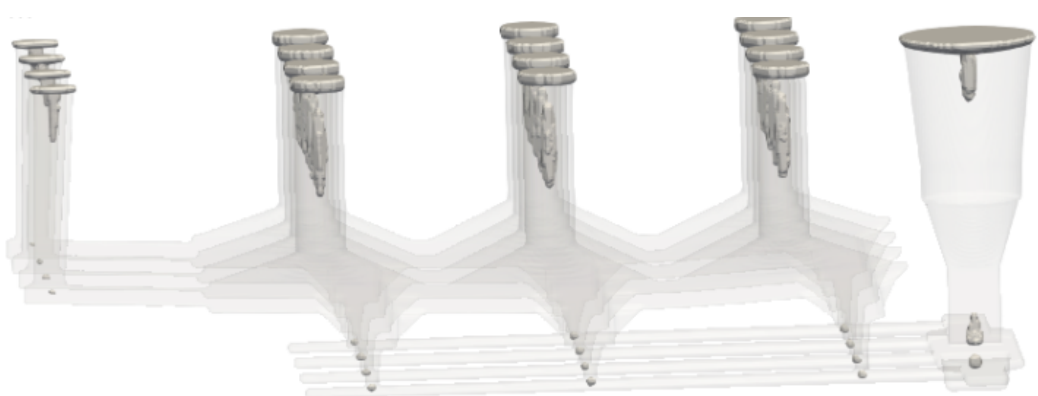
Average Metal Temperature: 1370.5 °C
Solidified Metal Fraction: 0.393
Porosity Volume: 6.804e-05 m³

c)



d)

Figure 2) Solidification model using FLOW-3D to ensure the pour cup, gates, and risers will solidify after the swords. This minimizes shrinking and unwanted materials in the swords. a) shows the initial pour, b) shows the metal cooling in the risers and pour cup after 42 seconds, c) simulated porosity results after solidification, and d) the results of the pour after shaking down the mold.

## 3D Print, wash, and assemble the mold

Howell Foundry 3D printed the mold into four parts with a binder jet S-max printer. The print took approximately 10 hours and is made of 4 parts: cope, drag, core, and cheek. The team cleaned the extra sand off the printed parts and applied a zircon wash to all surfaces that would contact metal. The zircon wash was heat treated to dry and harden. The cores where the sword would pour in were washed twice to ensure sufficient coating. Finally, the 1½" risers were cut to a length of 5¼" to fit into the riser molds. The S-max printer laid down a layer of sand binded with 2% furan, then a module with 20 nozzles solidifies the sand mold with an activator layer by layer.

Figure 3) Applying Zircon wash to cores for smooth surfacing from sand mold.

## Sand

Sand casting was used to make the sword as it is a versatile and effective method to cast many complex designs. The mold was approximately 1” thick of 3D printed silica sand with 2.0% furan resin binder with 4” of backfill using reclaimed sand to help dissipate heat. The reclaimed sand is an investment by Howell Foundry to reuse spent sand from both molds and backfill, reducing waste and costs. This multi-million-dollar investment is one of many upcoming projects for Howell Foundry to expand its casting scale and capabilities. The reclaimed sand first enters a shaker to break the sand back into granules. Then the sand is filtered and goes through a series of hoppers that apply chemicals and electrolysis separators to remove oxides and unwanted particles. Finally, the sand is retreated with the activator to be reused indefinitely. This sand hardens quickly after being exposed to air as its moisture content evaporates.

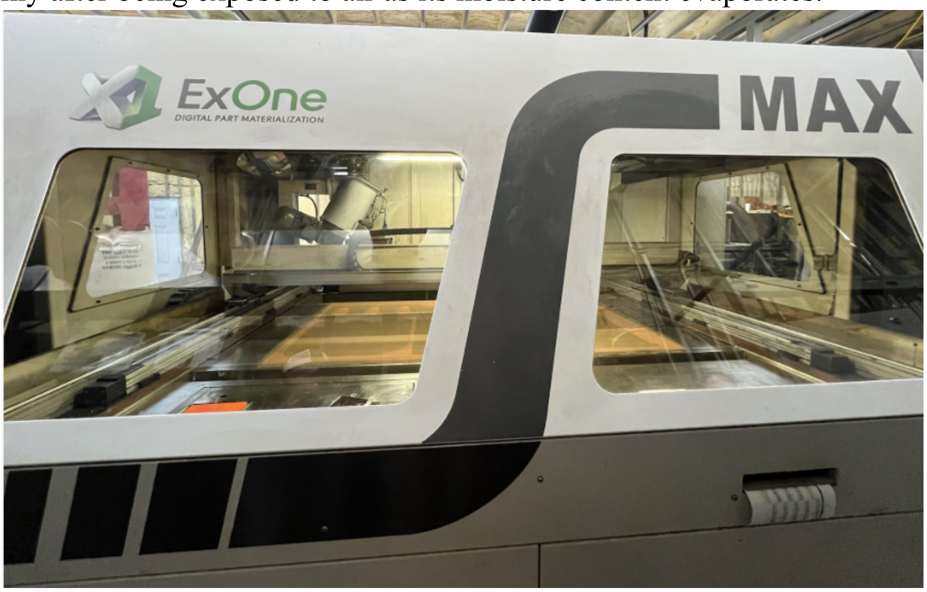



Figure 4) S-max 3D printer allows Howell to easily make custom designs with high resolution.

## Mold Dimensions

The clean weight of each sword was 1.7 lbs. as cast but required 72 lbs. of pour weight for the pour cup, gates, and risers to ensure there were minimal quality details found in the casting. This gives a yield of 10% usable material. Some unused material was cast into test bars for both the Baylor University team and a 3rd party to test and compare material properties. The mold box size was 34.7”x16.5”x13.7” and weighed 433 lbs. The full gating system included the following:

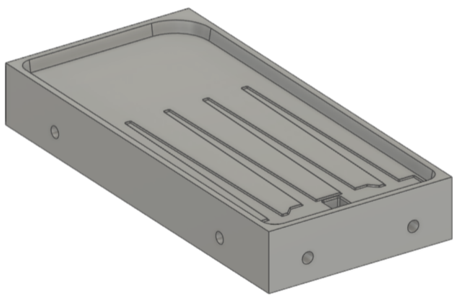
| | Quantity | Diameter (in) | HT/L | Notes |
|---|---|---|---|---|
| Pour Cup | 1 | 3 | 5 | |
| Sprue | 1 | 1 | 3 | |
| Sprue Well | 1 | 3 | 1 | |
| Runner 1 | 1 | 1.1 | 14 | |
| Runner 2 | 4 | .55 | 20 | |

| | | | | |
|---|---|---|---|---|
| Ingate | 12 | .55 | 1 | |
| Core | 16 | N/A | 1.5 | |

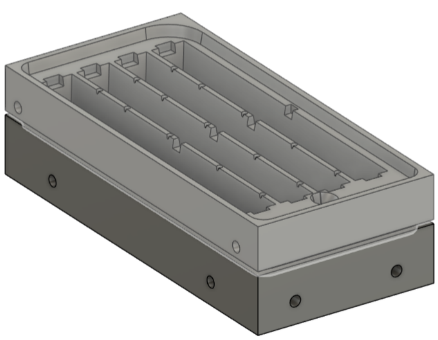
Table 1) Mold Box Components

There were 4 cores and 3 risers for each sword assembled according to the following diagram: Once packed, the sand activates by moisture evaporating from the sand to harden it. To prepare for casting, a pour box was placed on top for the crucible to pour into, and the mold was chained down for transportation. Each of the components of the mold box are shown below:

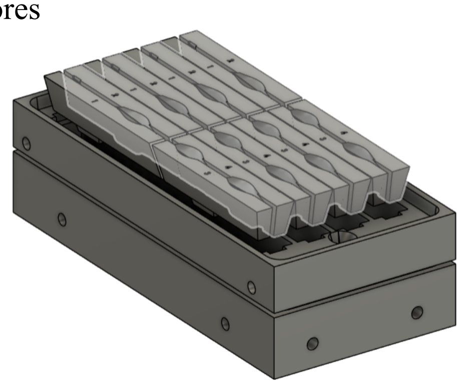
Drag



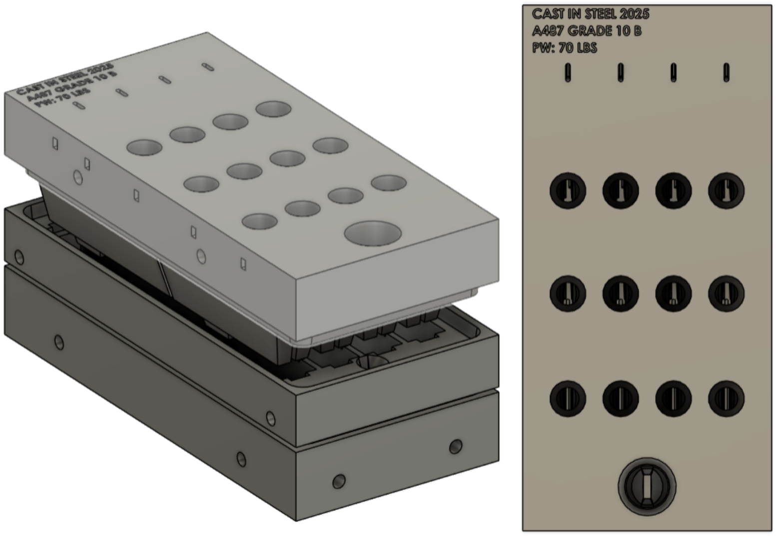
Cheek



Cores



Cope




Full gating system where the metal will flow

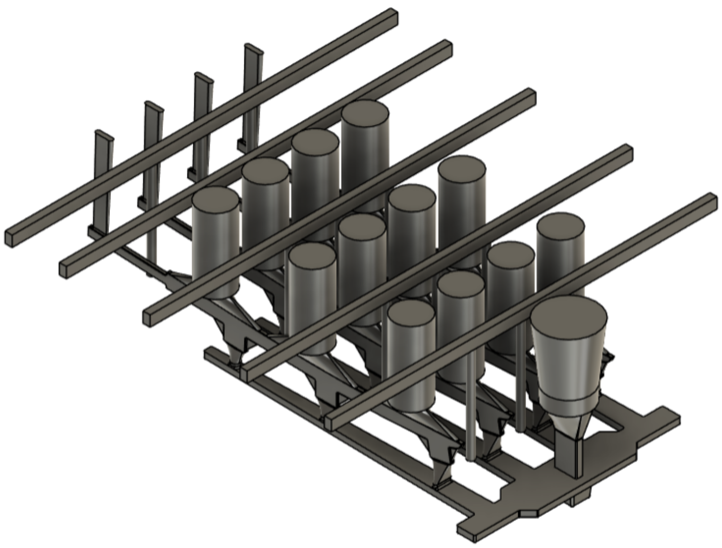


Figure 5) CAD models of the drag, cheek, cores, cope, and gating system.

## Melting and Alloying

Howell uses an induction furnace to melt the metal. The metallurgists use a variety of alloying materials for each cast to meet the customer's specific material requirements. Howell can cast almost any alloy with any mixture of materials. Our team requested A487 Grade 10 Class B because the alloying Cr, Mo, Ni produce a good mixture of corrosion resistance, strength, blade hardenability, and ductility. First, the furnace was charged with low carbon iron and 316L/304L SS. Once the pot was half full of liquid, the low carbon FeCr, Nickel, and FeMo were added.

Then the metallurgist added FeSi and the remaining low carbon iron and 316L/304L SS. The metal alloy has a liquidus temperature of 2550°F resulting in a target pouring temperature of 2880°F. Samples were taken from the molten mixture, polished, and examined in an optical emission spectrometer (OES). The final alloy measured from OES resulted in the following composition:


Figure 6) Optical emission spectrometer used to determine composition of a sample of the molten steel alloy prior to casting.

| | C | Si | Mn | P | S | Cr | Ni | Mo | Al | Cu | Ti | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sword | .292 | .251 | .639 | .018 | .0081 | .792 | 1.688 | .341 | <.001 | .0037 | <.001 | 95.94 |
| ASTM Std. | .3 max | .8 max | .6-1.0 | .035 max | .03 max | .55-.90 | 1.4-2.0 | .20-.40 | NA | NA | NA | rest |

Table 2) Custom composition of A487 Grade 10 Class B, measured from Howell Foundry's optical emission spectrometer.

Once the alloy met the team's requirements, the molten mixture was moved to a crucible via overhead crane and poured into the mold. The mold was left overnight to solidify and was shaken out the next day.

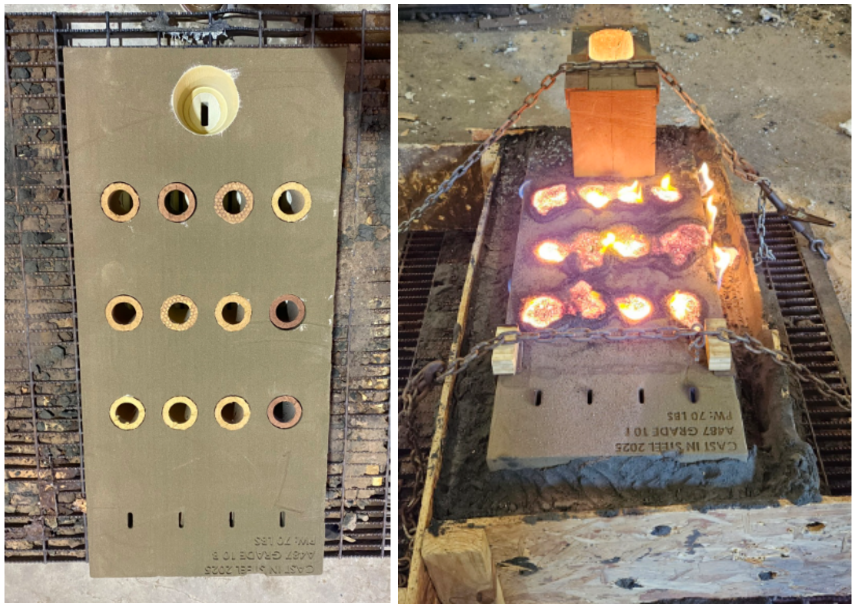


Figure 7) Sword's mold box before and after the pour.

## Heat Treatment

The sword underwent a heat treatment according to ASTM standards for temperature. The sword was held at 1550°F for 15 minutes and immediately quenched in oil. This process transforms the phase into austenite by holding it above its solvus temperature. The rapid oil quench locks the microstructure into an HCP martensitic structure. To temper the brittle martensitic structure, the sword was placed back in the furnace at 1100°F for 30 minutes with a natural oven cool down. The quench process has been used for thousands of years to strengthen the steel. The blacksmiths that built George Washington's sword likely followed a similar process to anneal, quench, and temper his sword.

Figure 8) Insulated furnace used for annealing, quenching, and tempering the blade.

## Machining, Grinding, and Sharpening

To not create additional stress concentrations where the sword could crack from casting, the edge of the blade was left as a square for the casting process. The team forged the cast blade to get an edge, then grinded the edge to sharpen it. However, the forged blade came out too thin, so the team chose to grind the blade down to a point. Looking back, forging the blade from 1/4” thickness to 1/8” would have given the blade forging properties and create a sharper edge. Thus, no welding or forging was applied to this blade. The team opted to grind the side down to get an edge using various belt grinders, angle grinders, bench grinders, and sharpening stones.

The team used a wire fed electronic discharge machine (Wire EDM) to machine the sawback to the sword. An incorrect work slope was applied to one of the swords, so the teeth are not properly cut into the blade. The hilt was made by casting bronze into a sand mold, then machining and polishing it down to a smooth texture.

The team would like to thank Baylor University and its machine shop for lending its equipment to our team during the post processing stage. For more in-depth information on the sword’s post processing, see the 2025 Cast in Steel video submission by the Baylor Carvers.

# FINITE ELEMENT ANALYSIS

A static stress study was conducted in Fusion to approximate the stresses being withstood during a stabbing and slashing motion. First, the case of stabbing with 400 N, which is about the maximum force a human can exert with a sword. There would be .684mm of maximum deflection at the sword tip, with the sawtooth back experienced a maximum stress of 62 MPa. This is a high stress, but the sword thickness and rigid backing ensures our confidence that this sword is well designed to deal with extreme impact. The 62 MPa falls below the infinite fatigue life stress of approximately 190 MPa.

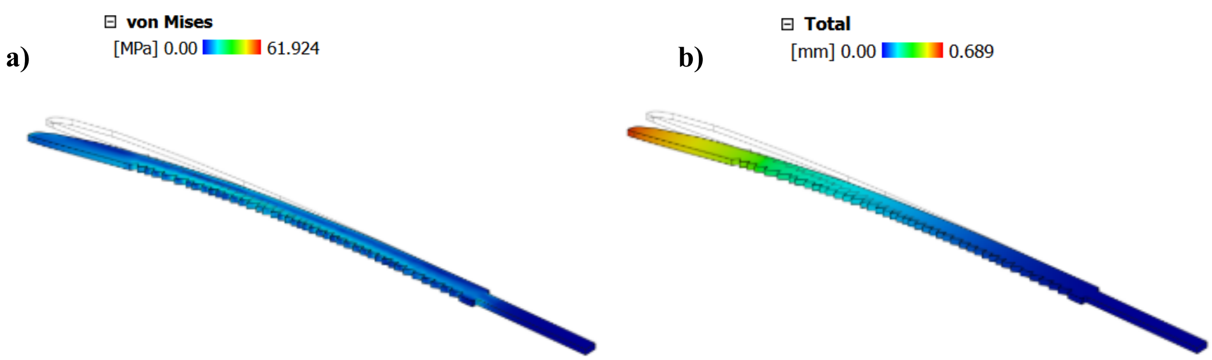



Figure 9: Finite element analysis of stress (a) and displacement (b) after maximum force applied by an average human thrust.

## FINAL RESULTS

The Baylor Carvers had a great experience during this process and are proud of the final sword. The team got to visit the foundry to see the full casting process at Howell Foundry including designing the model, printing the sand molds, preparing the mold box, alloying the steel, and heat treating the blade. Next, the team undertook forging, casting, machining, and grinding the blade in-house at Baylor University. It was an unforgettable experience full of learning to be a part of every step of the process. The team designed and purchased our own forge, furnace, crucible, etc. as none of the infrastructure was previously in place for this metal working. This process has taught our team countless lessons about this work that will last a lifetime. This project has sparked a new appreciation for casting and the capabilities a foundry and university can accomplish when working together.

Figure 10) Final results of a side-by-side comparison of the two swords created by the Baylor Carvers compared to George Washington’s 17$^{th}$ Century Cuttoe.

# REFERENCES

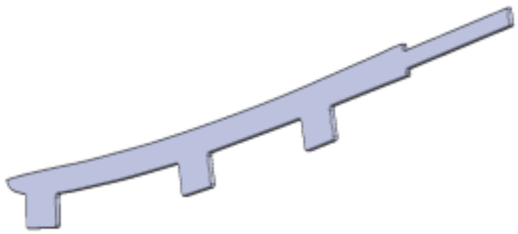
[1] Mount Vernon Ladies' Association. (n.d.). *Washington's swords: An interview with Erik Goldstein*. Retrieved from https://www.mountvernon.org/preservation/collections-holdings/washingtons-swords/washingtons-swords-an-interview-with-erik-goldstein

[2] American Revolution Institute. (n.d.). *American officer's sword made by John Bailey*. Retrieved from https://www.americanrevolutioninstitute.org/masterpieces-in-detail/american-officers-sword-made-by-john-bailey/

## APPENDIX A: HOWELL FOUNDRY DATA SHEETS

| | | | | | | |
|---|---|---|---|---|---|---|
| Howell Foundry | CUSTOMER | Baylor University - Cast In Steel | | MATERIAL | A487 | Grade 10 Class B |
| | PART NUMBER | Cuttoe | | CLEAN WEIGHT | 1.7 | Density: 0.267 |
| | PART DESC. | Sword | | POUR WEIGHT | 70 | YIELD 10% |
| | SHOP ORDER: | N/A | Quantity 4 | POUR HEIGHT | Full | Part Per Mold 4 |
| | MOLD HEATER: | 1 HOUR | | TESTING REQ. | See ITP, pg. 3 | |
| REPORT DATE 2/17/2025 | TEST BAR REQ. | YES | | CUSTOMER PO# | N/A | |
| | POUR TEMP | TBD | | | | |

Pattern Pics



| Rev | Date | Change |
|---|---|---|
| 0 | 2/15/25 | Created by JRM |

| | | Riser | | Contact | | Xtra |
|---|---|---|---|---|---|---|
| RIGGING | | | | | | |
| QTY | DESCRIPTION (Open,Blind,Ins,Exo) | DIA | HT. | DIA | HT. | LBS |
| 12 | Open Riser | 1.50 | 5.25 | 1.50 | 1.5 | |

| BOX SIZE | L | W | H | LB |
|---|---|---|---|---|
| | 34.7 | 16.5 | 13.7 | 433.0053551 |

| | | |
|---|---|---|
| SAND: | Mold - Furan, Backfill - Reclaim | |
| WASH: | 1 Hand OR 1 Spray - 72 Baume | |
| CHILLS: | 0 | N/A |

SPECIAL INSTRUCTIONS

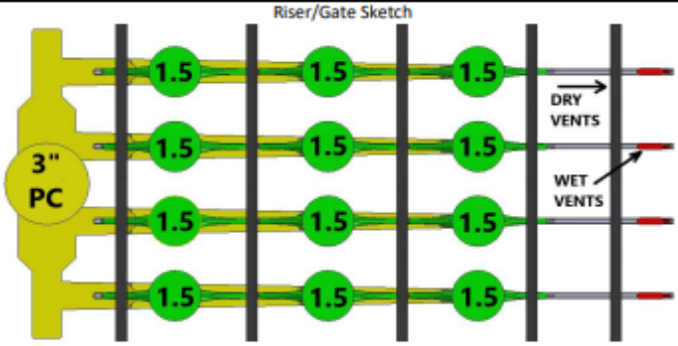
GATE SYSTEM

| | QTY | DIA | x | HT/L | NOTE | Xtra |
|---|---|---|---|---|---|---|
| POUR CUP | 1 | 3 | x | 5 | | |
| SPRUE | 1 | 1 | x | 3 | | |
| SPRUE WELL | 1 | 3 | x | 1 | | |
| RUNNER 1 | 1 | 1.1 | x | 14 | | |
| RUNNER 2 | 4 | 0.55 | x | 20 | | |
| INGATE | 12 | 0.55 | x | 1 | | |
| INGATE | | | x | | | |
| INGATE | | | x | | | |

SPECIAL INSTRUCTIONS

**INSERT 3" FILTER INTO POUR CUP**

Riser/Gate Sketch



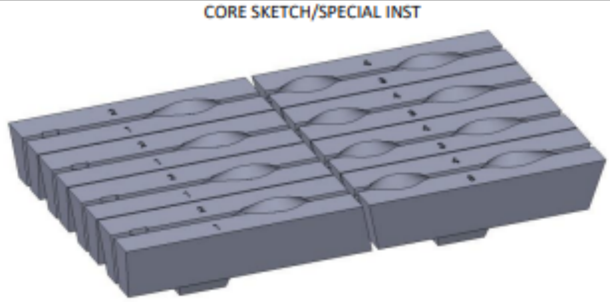

CORE

| | | | |
|---|---|---|---|
| Sand | Furan | Bolt | N/A |
| Rods | N/A | Wash | 1 Hand, 1 Spray - 72 Baume |
| Vent | Clean all vents | Count | 16 |

SPECIAL INSTRUCTIONS

- **4 SET OF CORES. SET EACH CORE IN SEQUENCE (1-4). SEE NEXT PAGE.**

CORE SKETCH/SPECIAL INST



Approved by

Date

FN202002-01 Rev. 4

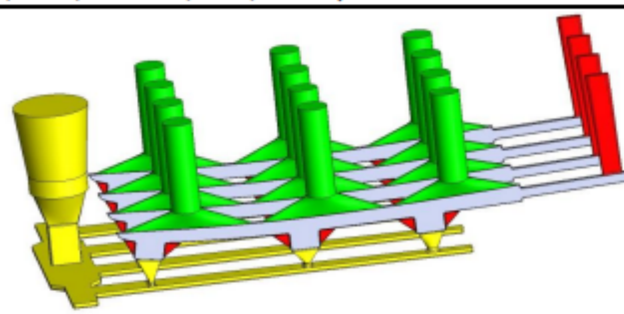
Pg 1 of 4

| Howell Foundry | CUSTOMER | Baylor University - Cast In Steel | | MATERIAL | A487 Grade 10 Class B |
|---|---|---|---|---|---|
| | PART NUMBER | **Cuttoe** | | CLEAN WEIGHT | 1.7 |
| | PART DESC. | Sword | | POUR WEIGHT | 70 |
| | SHOP ORDER: | **N/A** | QTY **4** | YIELD | 10% |
| | MOLD HEATER: | 1 HOUR | | POUR HEIGHT | Full |
| REPORT DATE | TEST BAR REQ. | YES | | TESTING REQ.: | **See ITP, pg. 3** |
| 2/17/2025 | POUR TEMP | TBD | | CUSTOMER PO# | N/A |

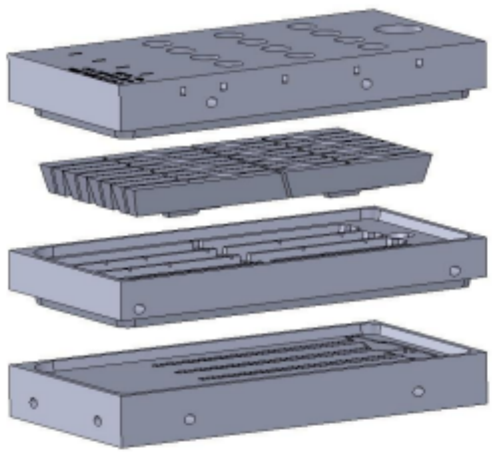
**Additional Special Instruction for Mold, Cutoff, Weldment, Grind, Test Requirement Etc.**

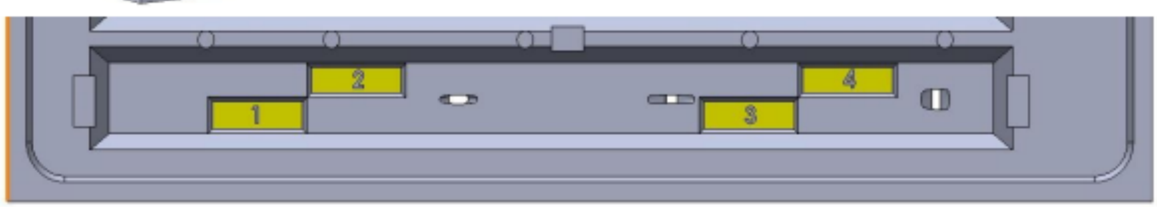
**CLEANING ROOM:**

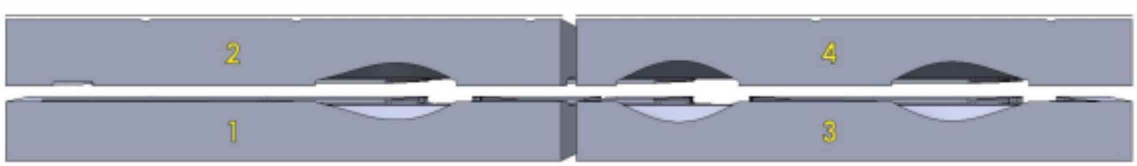
**- CUT OFF GATING (YELLOW)**
**- CUT OFF RISERS (GREEN)**
**- CUT OFF WET VENTS (RED)**
**- CUT OFF CRACKING BRACKETS AFTER HEAT TREAT (RED)**



**Sketch/Notes**



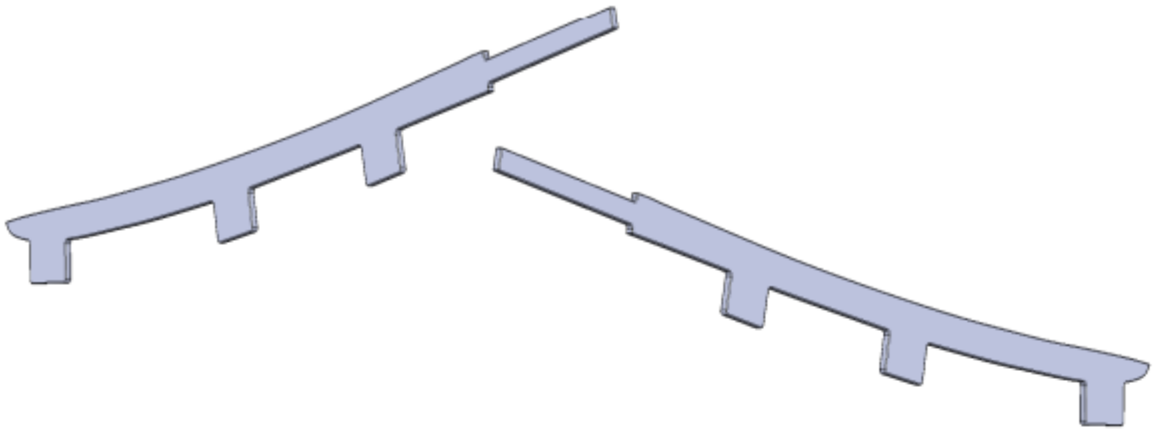



**INSERT EACH SET OF CORES IN SEQUENCE INTO CORRESPONDING CORE PRINTS**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Howell Foundry** | CUSTOMER | Baylor University - Cast In Steel | | | MATERIAL | **A487 Grade 10 Class B** |
| | PART NUMBER | **Cuttoe** | | | CLEAN WEIGHT | 1.7 |
| | PART DESC. | Sword | | | POUR WEIGHT | 70 |
| | SHOP ORDER: | **N/A** | QTY | **4** | YIELD | 10% |
| | MOLD HEATER: | 1 HOUR | | | POUR HEIGHT | Full |
| REPORT DATE | TEST BAR REQ. | YES | | | TESTING REQ.: | **See ITP, pg. 3** |
| 2/17/2025 | POUR TEMP | TBD | | | CUSTOMER PO# | N/A |

**Weld Map/Filler History**



**Inspection and Test Plan (ITP)**

| Howell Foundry | CUSTOMER | Baylor University - Cast In Steel | | MATERIAL | A487 Grade 10 Class B |
|---|---|---|---|---|---|
| | PART NUMBER | **Cuttoe** | | CLEAN WEIGHT | 1.7 |
| | PART DESC. | Sword | | POUR WEIGHT | 70 |
| | SHOP ORDER: | **N/A** | QTY **4** | YIELD | 10% |
| | MOLD HEATER: | 1 HOUR | | POUR HEIGHT | Full |
| REPORT DATE | TEST BAR REQ. | YES | | TESTING REQ.: | See ITP, pg. 3 |
| 2/17/2025 | POUR TEMP | TBD | | HEAT NO. | |

| EST | Process | Name | Date | Hours | Name | Date | Hours | Name | Date | Hours |
|---|---|---|---|---|---|---|---|---|---|---|
| | Solid Model Creation | | | | | | | | | |
| | 3D Print / Clean & Prep Mold | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | Melt/Pour | | | | | | | | | |

Notes:

(Any Deviation from Job Card Instructions must be approved and recorded here)

| LARGEST IS: | 0.25" |
|---|---|

| Mold | Melt | | Mold | Melt | |
|---|---|---|---|---|---|
| ☐ | | Chills | ☐ | ☐ | Bar Holes Filled |
| ☐ | | Cores | ☐ | ☐ | Pour Basin Gap/Flush |
| ☐ | | Mold Labeled Properly | ☐ | ☐ | Check Every Riser for Sand |
| ☐ | | Vents Drill/Cleaned | ☐ | ☐ | Filter |
| ☐ | ☐ | Cope/Drag Gap | ☐ | ☐ | Mold Dryer |
| ☐ | ☐ | Chain/Clamp Tension | ☐ | ☐ | Pig Mold Available |
| ☐ | ☐ | Pour Height Indicator | ☐ | ☐ | Test Bar |
| ☐ | ☐ | Mold Shift | ☐ | ☐ | Risers Nailed/Screwed In |

(Mold Dept.)

(Date)

(Melt Dept.)

(Date)

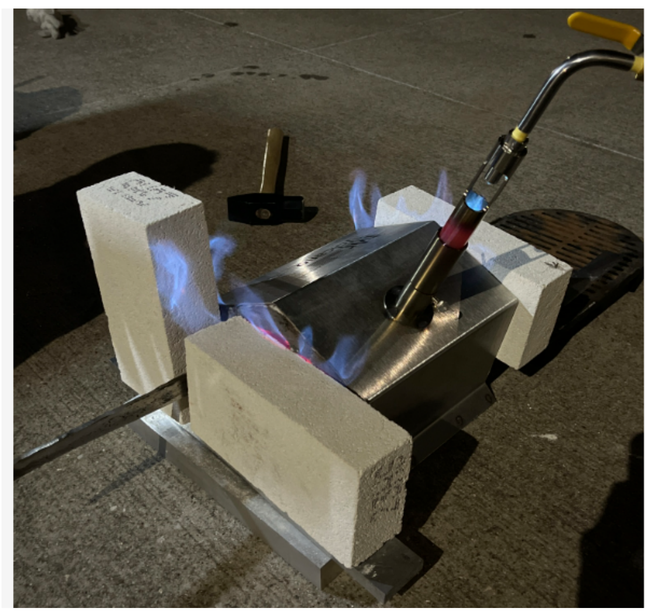
| EST | Process | Name | Date | Hours | Name | Date | Hours | Name | Date | Hours |
|---|---|---|---|---|---|---|---|---|---|---|
| | Shakeout | | | | | | | | | |
| | Visual Insp. | | | | | | | | | |
| | Cutoff | | | | | | | | | |
| | Grind | | | | | | | | | |
| | Visual Insp. 2 | | | | | | | | | |
| | Weld | | | | | | | | | |
| | Grind 2 | | | | | | | | | |
| | Heat Treat | | | | | | | | | |
| | Heat Treat 2 | | | | | | | | | |
| | Blast | | | | | | | | | |
| | Final Insp. | | | | | | | | | |

Notes:

(Any Deviation from Job Card Instructions must be approved and recorded here)

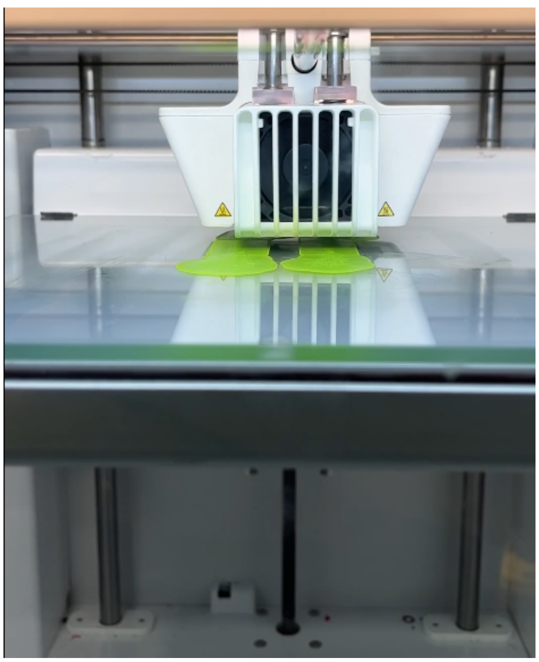
# APPENDIX B: Equipment Used During Post-Processing


**Anvil** used to forge the sword

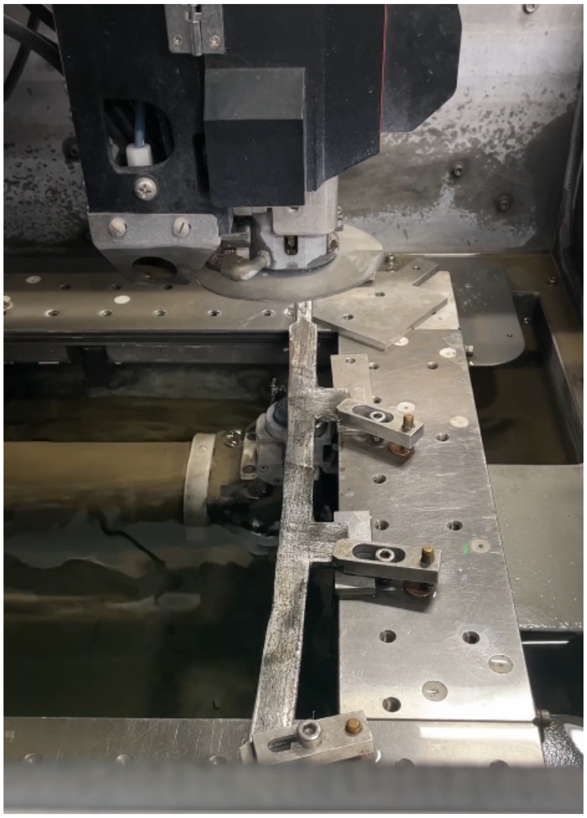


**Furnace** used to heat the steel for forging and melt the bronze for casting


**HAAS CNC machine** used for subtractive machining of the sword.



**Ultimaker S3 Printer** used to create a plastic mold of the sword hilt for sand casting



**Wire EDM** used to cut the sawtooth pattern into the blade using 2D CAM.