FLINTLOCK

University of Massachusetts Lowell

2018 Concrete Canoe Design Report

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Executive Summary

The University of Massachusetts Lowell (UMass Lowell) campus officially became an educational institute in 1895, founded as the Lowell Textile School. At the time it focused on training workers for the city's thriving textile industry. In 1975, the Lowell Technological Institute and Lowell State College merged and became known as the University of Lowell. In 1991, it was integrated into the UMass system and became known as the University of Massachusetts Lowell.

The university has over 17,000 students, it offers 122 bachelors', 43 masters', and 36 doctoral degrees within its six colleges (About UMass Lowell 2018). The Francis College of Engineering has a prominent reputation for its hands-on education. Its students are regarded as hardworking, dedicated, and well-prepared for their future careers (Francis College of Engineering 2018).

Table 1. *Flintlock* Specifications

Weight	200 lbs (estimated)
Length	20 ft 6 in
Width	28.7 in
Depth	13.8 in
Average Thickness	3/8 in
Reinforcement	Basalt Mesh Fiberglass Mesh
Colors	Red, White, Blue, Yellow, Tawny, Weathered Tin

UMass Lowell competes in the New England Regional Competition (NERC). In the last three years, the Concrete Canoe Team at UMass Lowell has had a mix of triumphs and defeats in the NERC - placing 1st in 2015 with *Backfire* (8th at NCCC), 8th in 2016 with *Sockeye*, and 2nd in 2017 with *Jester*.

For the 2018 competition, UMass Lowell sought to improve on the newer construction methods used last year. However, due to complications with the structural integrity of UMass Lowell's canoe, a new mold for a second canoe was made by hand rather than milling (Construction, Page 9).

Further research into the behavior of expanded shale as a lightweight aggregate resulted in a final mix design capable of withstanding the abuse of competition (Table 2). Due to the continued success, improvements were made to the misting system, humidifiers, and cool mist vaporizers previously used.

Table 2. Concrete Properties

Plastic Unit Weight	77.50 lb/ft^3
Oven-Dried Unit Weight	63.70 lb/ft^3
Compressive Strength	1998 psi
Tensile Strength	526 psi
Flexural Strength	432 psi
Slump	½ in
Air Content	24.54%

In addition to the improvements and innovations made by the mix development and testing team, construction and aesthetics team, and design and analysis team, Lowell focused on the recruitment of younger team members due to losing team members to the 2018 graduates. Through focused recruitment, the team was reinvigorated with many students from the freshman and sophomore classes. The involvement of freshman and sophomore students showed significant improvements from previous years.

Inspired by the tactical achievements and amalgamated spirit of the Revolutionary War, Lowell focused on representing freedom, independence, and unity of the Revolutionary War. With these goals accomplished, the 2018 UMass Lowell Concrete Canoe Team is proud to present *Flintlock*.

Project and Quality Management

To simplify the existing system, minor changes to the managerial structure for Lowell was made. The changes made were to simplify the transition of younger members into their newer roles on the management team. Following the 2017 season, one Project Manager, one Field Manager, five team captains, and three officers were selected for the team's 2018 entry. To help expertise and communication grow within the management structure, UMass Lowell had kept one of the 2017 Project Managers in their role. This system allowed the management team to appoint a single person to coordinate between managerial members to avoid miscommunication. The Project Manager worked with the other team members and faculty to schedule team meetings, promote team activities, recruit new members, and manage fiscal matters.

Five team captains directed one of four project subdivisions: design and analysis team, mix development and testing team, construction and aesthetics team, and paddling team. Each captain was responsible for innovation in their area, and management earmarked time for possible innovations in the project schedule while ensuring the milestone deadlines along the critical path were still met (Table 3). The critical path was determined in Microsoft Project by determining tasks that had no slack. The Project Manager held captain meetings as a resource to answer all questions and concerns regarding the project schedule. This kept all captains informed of the progress made by other groups.

Table 3. Major Project Milestones

Milestone	Planned Date	Actual Date	Reasons for Variance
Flintlock* Hull Design	10/1/2017	10/1/2017	-
Mold Cut	10/28/2017	3/23/3018	Placement of a Second Canoe
Placement Day for First Canoe	11/18/2017	12/3/2017	Time Constraints
Placement Day for *Flintlock**	3/3/2018	3/3/2018	-
***Flintlock* Finishing Design Paper Submission**	3/9/2018	3/26/2018	Deadline not known During Planning

*Denotes Critical Path

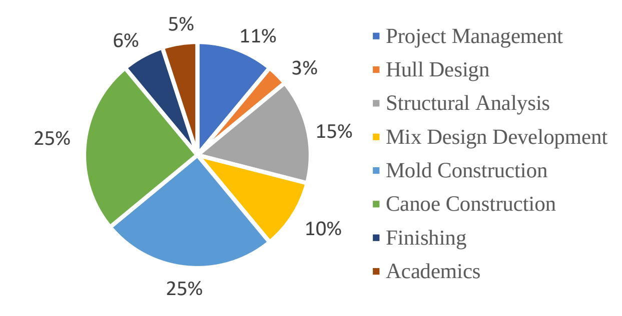


Figure 1. Person-Hour Allocation

Flintlock's team was composed of 22 members accumulating a total of 5,140 person-hours (Figure 1). This represents an increase in the amount of time worked on *Flintlock* versus *Jester* by 30%. This increase in person-hours can be attributed to the team's decision to place a second canoe. *Flintlock*'s financial plan was based upon prior experience, with an operating budget set at $7,466.

After coordinating with the UMass Lowell Senior Safety Specialist, the team selected an experienced team member to be *Flintlock*'s Safety Officer. The Safety Officer organized safety training for all team members, ensuring that no construction or mix work was performed without successful completion of Lab Safety Training and proper safety equipment was worn. Additionally the Safety Officer made sure all MSDS were placed in a notebook that was kept where every member of the mix development and testing team and construction and aesthetics team could easily find it.

UMass Lowell's management team planned and held captains meetings beginning in September following the release of the NCCC 2018 Rules and Regulations. During meetings, team captains provided updates on conducted research, materials that had been tested, techniques that were being used, and calculations that had to be performed. These meetings served as a method for reviewing each other's work, making sure every team was acting in accordance to the rules and keeping on similar schedules. A Quality Control Officer was appointed to oversee all aspects of the project to ensure that standards placed by the management team were met and all teams stayed compliant with the rules.

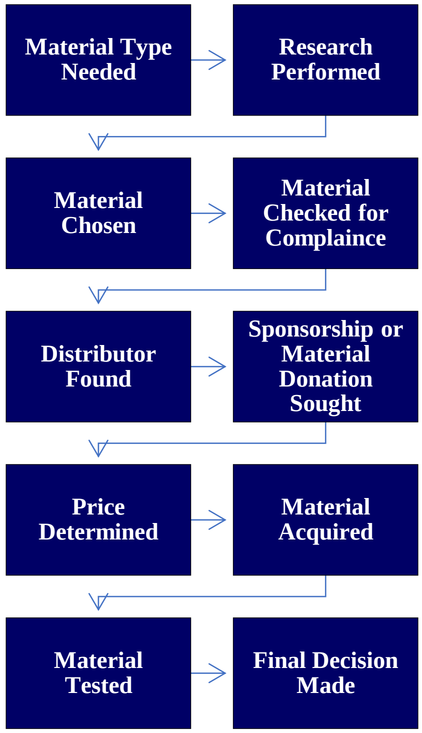


Figure 2. Quality Control Process for all Materials

The majority of materials used this year were purchased during the previous school year. The process by which new materials were chosen, checked for compliance, and acquired is outlined in Figure 2.

Lowell took care to locate, review, and understand the MTDS and MSDS of all materials used. Any important information not provided was found either through testing by the appropriate team or a request to the manufacturer or distributor. MTDS were compiled electronically to be reported in the Project Overview and Technical Addendum. MSDS were compiled in a notebook, which was located where all team members could easily access it at any point during the construction or mixing process.

Team members received operation and safety training on all machinery in Lowell's Lab, as well as training on handling of relevant materials. Those members that did not attend the mandatory meeting with EHS in September were required to meet with them and complete the training before participating. Certification of completion was kept with the MSDS Binder. Lowell's Quality Control Officer and Safety Officer jointly dictated that individuals who did not complete this training could not participate in the construction or mixing processes.

As soon as the NCCC 2018 Rules and Regulations were released, core team members read the rules to ensure compliance in all aspects of the project. Team members took notes of all changes and the Quality Control Officer began checking that all teams were in complete understanding of the rules. With the NCCC providing a Facebook page where all Requests for Information (RFI) were answered publicly, all questions and answers could be analyzed by team members on their own time.

Lowell's design and analysis team double-checked all important calculations and other teams were aware to send calculations to the analysis team whenever they performed any non-routine calculations. The construction and aesthetics captains made efforts to see that the chosen theme was adequately carried out in all aspects of the project. The Quality Control Officer reviewed any documents to be submitted, to confirm that all rules were followed.

Organization Chart

Project Manager

Emily Schneider - Sr

Responsible for budgeting, fundraising, student government relation, business outreach, member recruitment, and setting critical path deadlines.

Field Manager

Chris Cantin - Sr

Responsible for managing captains, scheduling, process documentation, and overseeing daily operations.

Construction and Analysis Captains

Josh Gittings - Jr and David Nguyen - Sr

Responsible for construction and finishing of the mold, canoe, aesthetic elements, stand, sectional, and display.

Construction Team

Campbell Narron
Chris Cantin
Conor West Geary
Courtney Simard
Emily Schneider
Grace Federiconi
Icaro DeAndrade
Kat Evasius
Nicholas Stillwell
Pedro Lopez

Design and Analysis Captain

Campbell Narron - Sr

Responsible for designing the hull, computer modeling, classical two-dimensional analysis, and structural elements design.

Analysis Team

Dylan Shaffer
Emily Schneider
Frank Feltes
Nicholas Stillwell
Pedro Lopez
Shiv Bhardwaj

Mix Development and Testing Captain

Dylan Shaffer - Jr

Responsible for mix research and innovations, material selection, initial and final testing, and sample placement.

Mix Team

Chris Cantin
David Nguyen
Frank Feltes
Nicholas Stillwell
Pedro Lopez
Shiv Bhardwaj

Paddling Captain

Caitlin Kelley - Sr

Responsible for coordinating practices, conditioning paddlers, and coaching proper paddling technique.

Paddling Team

Alanna Grondine
Campbell Narron
Courtney Simards
David Nyugen
Emily Schneider
Frank Feltes
Grace Federiconi
Josh Gittings
Pedro Lopez

Members

Name	Year	Years Involved	Active Participant
Chris Cantin	Sr	4	0
Shiv Bhardwaj	Sr	4	0
Campbell Narron	Sr	3	3
Emily Schneider	Sr	3	3
Nicholas Stillwell	Sr	3	0
Pedro Lopez	Jr	3	2
Zachary Koutonen	Jr	3	0
Alanna Grondine	Sr	2	2
Owen Gannon	Sr	2	0
David Nguyen	Sr	2	0
Arthur Jacques	Jr	2	0
Dylan Shaffer	Jr	2	0
Josh Gittings	Jr	2	2
Grace Federiconi	So	2	0
Kat Evasius	So	2	1
Caitlin Kelley	Sr	1	1
Courtney Simard	Sr	1	1
Conor West Geary	Jr	1	0
Icaro DeAndrade	So	1	0
Steven Fallon	So	1	0
Frank Feltes	Fr	1	0
Shawn Burns	Fr	1	0

Faculty Advisor: Gary Howe & Raj Gondle

Sustainability Officer

Grace Federiconi - So

Responsible for overseeing the team's economic and environmental impact and how to reduce it.

Safety Officer

Frank Feltes - Fr

Responsible for updating MSDS, ensuring proper equipment usage, and instructing safety sessions.

Quality Control Officer

Kat Evasius - So

Responsible for checking calculations as well as ensuring proper placement of concrete and rule compliance.

Hull Design and Structural Analysis

Hull performance was broken down into three basic categories: maneuverability, speed, and stability. Lowell's 2017 entry, *Jester*, was designed to decrease lateral water flow and wetted hull area. This created a canoe that would have better tracking and maneuverability. After studying the hull design from last year as well as previous years, Lowell determined that stability and ability to turn during the race were the more important aspects of the hull. Understanding the limited experience of new paddlers, the team designed for stability and maneuverability and decided to make only small adjustments to fine tune the design from last year.

Canoe stability is directly correlated to the shape of the hull bottom and sidewalls. A flat bottom provides initial stability, giving the vessel a natural tendency to remain parallel to the water surface while moving at slower speeds. A rounded bottom is used for secondary stability, or the steadiness of a hull while moving quickly. As a racing canoe, secondary stability is the more critical parameter, but initial stability cannot be ignored. By using a rounder bottom towards the bow and a flatter bottom towards the stern, as well as harder chines towards the bow and softer towards the stern, an ideal blend of initial and secondary stability was achieved. This hybrid design is ideal for a racing canoe, where initial stability is desired for paddling efficiency and secondary stability is desired to resist heeling during turns (Randall 2010). A V-notched bow was chosen to improve tracking and turning. This V-notch bow decreases lateral water flow, which means better tracking and maneuverability.

The free surface affect was taken into consideration this year. As races progress, paddlers splash more and more water into the canoe. As the amount of water increases, the moment on the canoe increases as the water moves further from the center of gravity (Gudmundsson 2009). This creates problems with listing and slows down maneuverability. UMass Lowell considered using longitudinal ribs to help combat this effect. These ribs would be disruptive to paddlers, however, it was determined that 3D elements placed in the bottom of the hull had a positive effect to combat this issue. Initially, three transverse ribs were considered to prevent longitudinal sloshing of water and for torsional strength. However, the middle rib was detrimental for paddler ergonomics and aesthetics, therefore was removed. A final decision was made to place two transverse ribs approximately 67 inches away from each bulkhead.

Table 4. Design Parameters for Two-Male Loading

Canoe Name	*Backfire*	*Sockeye*	*Jester*	*Flintlock*
Overall Length	238 in	238 in	246 in	245 in
Maximum Depth	13.96 in	13.96 in	13.78 in	13.8 in
Freeboard	8.62 in	8.62 in	8.29 in	8.91 in
Bow Rocker	6.7 in	6.7 in	3.7 in	3.8 in
Stern Rocker	4.6 in	4.6 in	3.9 in	4.3 in
Wetted Hull Surface Area	30.79 ft^2	30.79 ft^2	32.13 ft^2	30.23 ft^2
Prismatic Coefficient, C_p	0.468	0.468	0.446	0.417

Considering the decision to design for maneuverability and stability, an asymmetrical design with the center of gravity located slightly aft of longitudinal center was chosen along with flared sidewalls. Looking towards previous canoes as a starting point, *Jester* had all the desired parameters, requiring only minor changes. The team fine-tuned *Jester* as a baseline hull in Prolines © 7. Focus then shifted to try to decrease prismatic coefficient and wetted hull surface area. Table 4 shows Lowell's three previous canoes compared to *Flintlock.*

UMass Lowell analyzed *Flintlock* in five different loading scenarios: two-male race conditions, two-female race conditions, four-paddler race conditions, two-person carry, and static display. The canoe will be fully supported during transportation and therefore is not subject to loading; transportation analysis was not conducted. UMass Lowell had developed structural analysis spreadsheets in Microsoft Excel to help perform 2D calculations and the analysis team used these spreadsheets to analyze the canoe.

Flintlock was modeled as a simply supported beam subject to bending about the longitudinal axis. Previous UMass Lowell teams found that adding features such as ribs and gunwales reduce critical stresses by up to 43% when compared to a featureless canoe (Moswetuset 2013). Ribs were already in the design of *Flintlock* and the decision had been made to continue to use gunwales to reduce stress in the canoe by increasing the moment of inertia about the longitudinal axis.

Point loads representing paddler weights were applied to all race conditions. Lowell modeled two male loads acting at 48 inches and 192 inches aft of the bow, and two female loads acting at 84 inches and 156 inches aft of the bow. Dead load of the canoe is represented by a uniformly distributed load and two supports representing people carrying the canoe or the supports of the stand. For two-person carry the supports were placed at 49.2 inches and 196.8 inches aft of the bow. For static display, the supports were placed 93.5 inches and 152.5 inches aft of the bow.

The design and analysis team estimated the weight of the canoe of 200 lbs and chose to use 175 lbs for all male paddlers and 145 lbs for all female paddlers. Then, UMass Lowell calculated maximum tensile and compressive bending stresses at critical locations based on the principles of mechanics of materials.

The largest bending moment of 7790 lb-in (M_{max}) was found during two-male race conditions and was located at 123 inches aft of bow. The extreme fiber distances were at C_t = 8.33 inches and C_c = -5.23 inches. The moment of inertia about the X-axis (Ix) was hand calculated using Parallel Axis Theorem. UMass Lowell's design and analysis team calculated maximum tensile and compressive bending stresses (σ_b) using Equation 1.

$$\sigma_b = \frac{M_{max}c}{I_x} \qquad Eq. 1$$

The team then applied a dynamic loading amplification factor of 1.25 (Paradis and Gendron 2007) and a mix design factor of 2.5 to maximum bending stresses to account for factors outside the scope of simple 2D analysis. UMass Lowell compared the magnified stresses alongside *Flintlock*'s failure envelope and determined that *Flintlock* would be strong enough to withstand a combination of tension, compression, and shear. The results of the analysis team's structural analysis are shown in Table 5. A simplified analysis showing Lowell's ability to calculate these requirements is shown in Appendix C.

Table 5. Strength Demand for *Flintlock*

Parameter	Demand (psi)
Tensile	149.82
Compression	94.07

Development and Testing

The placement of the first canoe in early December became a learning experience of how pigment affects concrete. The mix development and testing team made a small volume mix to determine the amount of pigment needed to obtain the vibrant blue desired. On placement day, however, the team struggled to produce a workable mix to place on the mold. This struggle caused a delay between placement of the first and second layers. Moving forward, the mix team was tasked with determining the appropriate amount of pigment that could be added to the mix without affecting the workability and strength.

Flintlock's design and analysis team reported a magnified tensile stress of 149.82 psi, which was used as the governing stress in the canoe. To meet this requirement, Lowell used *Jester*'s mix as a baseline (0.45 w/cm, 40% CP, 61.0 pcf unit weight, 310 psi tensile strength, and 1990 psi compressive strength) to begin the design process as shown in Figure 3.

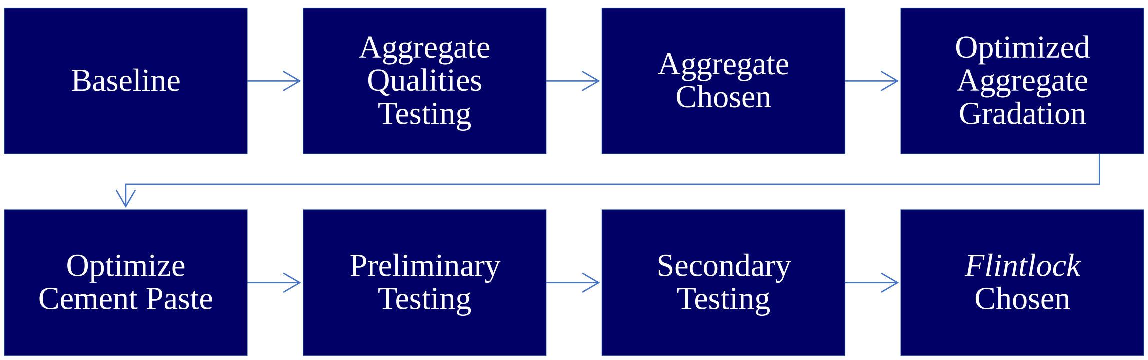


Figure 3. Iterative Design Approach

After selecting a baseline mix to work from, UMass Lowell began investigating different particle sizes the aggregate could be sieved out to, in accordance to the rule that stated 25% of aggregate volume must be complaint with ASTM C330 and without compromising strength and ability to sand the final mix. UMass Lowell determined that sieving expanded shale in a #16 USA Standard Sieve Tray would be ideal. This sieve size was chosen because in the past, larger aggregate sizes hindered the team's ability to obtain a smooth surface. Examples showing the expanded shale in concrete sections are shown in Figure 4.

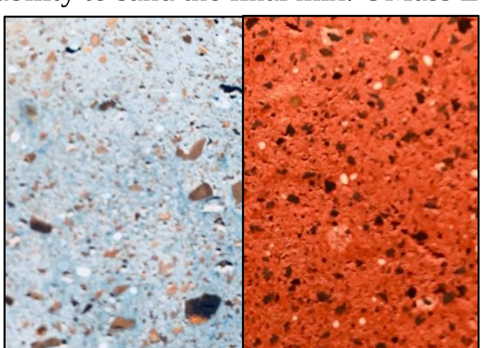


Figure 4. Grain Size of Expanded Shale Examples (Left) Blue Mix and (Right) Red Mix

Next, UMass Lowell determined important material properties of the sieved expanded shale before preliminary mixes could be made. The mix development and testing team calculated the oven-dry specific gravity, saturated surface-dry specific gravity, and absorption in accordance with ASTM C128. Additionally, the team determined as-received moisture content in accordance with ASTM C566. These values were used to calculate the corrections for the hydration source that would be used to produce a consistent mix.

Bond strength of Portland cement-based concrete is related to the hydration of Portland cement. During hydration, reactions of belite (C_2S) and alite (C_3S) produce calcium-silicate-hydrate (C-S-H) and hydrated lime (CH). This is shown in Table 6, Equations 1 and 2.

Hydrated lime is hydrophilic and over time weakens concrete. In a poor concrete matrix, hexagonal hydrated lime crystals stack up on each other and cause weak zones in concrete. However, if colloidal C-S-H gels fill these voids instead of hydrated lime, the overall strength in these zones is increased. Lowell was able to eliminate the impact of hydrated lime by taking the new CH created and using it as the limiting reagent in the pozzolanic reaction shown in Table 6, Equation 3. Lowell minimized the effects of hydrated lime on *Flintlock*'s final mix by using the volumetric combination of 70% type 1 white Portland cement, 20% high-reactivity metakaolin, and 10% silica fume. A comparison of a high lime content cement matrix against an ideal one shown in Figure 5. By decreasing hydrated lime content in the cement matrix, stresses were decreased within the interfacial transition zone (ITZ) – concrete's tensile failure zone – by allowing more bonding potential due to increased C-S-H content (Kosmtaka et al. 2011).

Table 6. Chemistry of Hydration

Hydration Reaction	
Belite	$2C_2S + 7H_20 \rightarrow C - S - H + CH$ (EQ 1)
Alite	$2C_3S + 750 \rightarrow C - S - H + 3CH$ (EQ 2)
Pozzolanic Reaction	
Pozzolanic Reaction	$Pozzolanic + CH \rightarrow C - S - H$ (EQ 3)

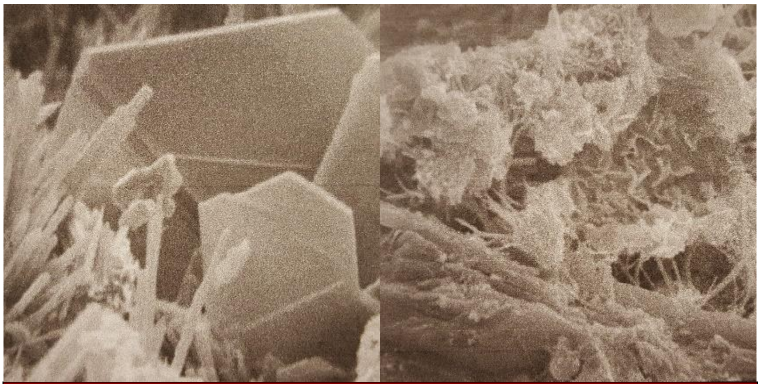


Figure 5. Comparison of (Left) High Lime Content and (Right) Ideally Proportioned Matrix (*Yu*, 2017)

Building upon previous work performed for *Jester* on the topic of aggregate gradation in concrete, *Flintlock*'s mix development and testing team chose to utilize a combination of fine aggregates in the form of expanded shale and glass microspheres. The expanded shale was modified to only include certain fine particle sizes, a major difference from the expanded shale used last year. Due to its relatively high specific gravity, the expanded shale was limited to 25% by volume and K15 taking up the final 75% for total volume of aggregates.

Flintlock's mix was designed to withstand all stresses on its own without flexural reinforcement, save for a 2%, by volume, matrix of 3/8 inch polyvinyl alcohol fibers (PVA) integrated directly to the mix itself. A combination of basalt and fiberglass meshes were added as an extra factor of safety to increase flexural and punching shear in the placed concrete (*Construction*, Page 10).

Eclipse Floor 200 Shrinkage Reducer and ADVA Cast 575 Super Plasticizer were used at the manufacturer's minimum recommended dosage rates to decrease shrinkage and achieve desired workability. Silpro C-21 Liquid Latex with a solids content of 20% was used as the sole hydration source. The dosage of latex was able to entrain air at 24.54% by volume, which proved sufficient in minimizing the unit weight of concrete. Due to the small volumes of shrinkage reducer and super plasticizer per batch, small condiment containers capable of holding and dispensing liquids were utilized in pre-placement day batching.

Before preliminary testing began, *Flintlock*'s Safety Officer performed an inspection of UMass Lowell's Concrete Research Laboratory to ensure all equipment was safe for use. This inspection consisted of posting material safety data sheets (MSDS) and ensuring that personal protective equipment (PPE) was available for all members of the team. Additionally, *Flintlock*'s Quality Control Officer checked material expiration dates, hand sieved cementitious materials, and ensured all mix containers and tools were free of outside contaminants. Once these checks were performed, the mix development and testing team initiated its first rounds of testing.

For preliminary testing, UMass Lowell chose to reduce material costs and limit its environmental footprint by using 2x4 cylinders in place of 3x6 cylinders for tension testing (ASTM C496) and compression testing (ASTM C39). Only 1/5 of the material was required to make these size cylinders, which meant a major decrease in material waste. Flexural beams were tested under third point loading in accordance with ASTM C1609.

Jester's 0.45 w/cm mix was used as a baseline to create a variety of mixes. After continued success with using a 0.45 w/cm ratio, Lowell chose to keep *Flintlock*'s the same. This was due to its workability and high tensile strengths. The final engineering properties of *Flintlock*'s mix were determined from 3x6 cylinders and flexural beams, all of which were cast on placement day. Lowell determined the mix was adequate for all types of stresses. A comparison of this mix with three of Lowell's previous canoes can be found below in Table 7.

Table 7. Comparison of Lowell Mixes

Canoe	w/cm	%CP	Unit Weight (pcf)	Tensile Strength (psi)	Compressive Strength (psi)
Flintlock	0.45	40%	59.4	526	1998
Jester	0.45	40%	61.9	310	1990
Sockeye	0.65	40%	44.3	330	940
Backfire	0.65	40%	40.5	390	1800

Construction

After the success of the 2017 season, UMass Lowell's construction and aesthetics team focused on improvements on mold construction with a CNC milling machine. However, after testing, the 2018 team determined the canoe suffered extensive cracking from complications with placement and the mix; ultimately deciding to place a new canoe. Due to the limited time, the team made a new mold using an effective but labor intensive method of building the mold by hand.

Following the release of the 2018 NCCC Rules and Regulations and the design of the hull complete, the construction and aesthetics team began work on the mold. With the design and analysis team providing a computer model for the male mold and female bulkhead forms, the computer model was sent to be milled in a 3-axis CNC milling machine located in UMass Lowell's Plastics Engineering Department. Two inch rigid XPS foam was chosen for its ability to support the construction process, ease of shaping, and availability.

Following the first placement of UMass Lowell's canoe, the team began to monitor the growing concerns for the first canoe's structural integrity. Following consultations with faculty and alumni, it was determined the best course of action would be to stop work on the original canoe and begin preparations for a second canoe. The construction and aesthetics team immediately began work on the new male mold and female bulkhead forms. Using two-inch interval paper cross sections provided from the design and analysis team, *Flintlock*'s computer model was then transferred to scraps and remaining foam as shown in Figure 6.

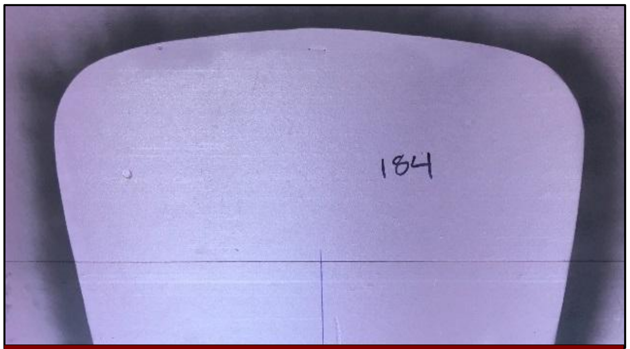


Figure 6. Foam Templates Pre-cutting

This method gave the team high accuracy and a short turn over time for the mold. Using the transferred outlines, the foam sections were cut on a bandsaw. Two ribs (3/4 in x 1 in) were routed into specified sections. The sections were laid together using a centerline, then glued together. The mold was then sanded down to the finished shape. Gunwales were cut using a track system that provided a consistent shape spanning the length of the canoe. Imperfections and pores were filled with drywall compound and sanded smooth. Aesthetic elements were also projected onto the mold and routed in, avoiding areas that would cause major paddler interference. Finally, two coats of release agent were applied and the mold was ready for placement.

The second attempt of *Flintlock* was placed in early March. The week of placement, all cementitious materials were hand-sieved to provide a more consistent mix. The day before placement, all dry and liquid materials were batched out to ensure placement day would run smoothly. All materials were accurately measured by weight, using multiple identical scales that read values to the nearest .00001 pounds.

Placement of the concrete travelled from bow to stern, starting with a 3/16 inch first layer, integrally colored with weathered tin pigment, briefly pausing only to place 3D elements. Wooden depth checkers were used to maintain a constant thickness throughout each concrete layer. Once the first layer was underway, the bow bulkhead began placement using a new innovative female form that helped develop the stem shape without placing unnecessary amounts of concrete. Before the second layer, basalt mesh was placed followed by a smear of concrete so that fiberglass mesh could also be placed immediately before the second concrete layer. As each mesh layer had the same size openings, great care was taken to keep the grids aligned with each other to ensure maximum bonding between the first and second concrete layers. Each rib received a strip of basalt mesh and gunwales received two strips of basalt mesh. This created the skeletal reinforcement structure for the canoe.

Just before the first concrete layer reached the 3D elements, the routed areas received concrete layers of varying thicknesses and color, then covered over by the first concrete layer. The second concrete layer was composed of three different areas of color. As one section of color was finished, two team members worked to give that area a trowel finish. At the completion of the second layer, the total hull thickness was 1/2 inch, providing a buffer to account for irregularities that will be sanded down to complete the average thickness of 3/8 inch.

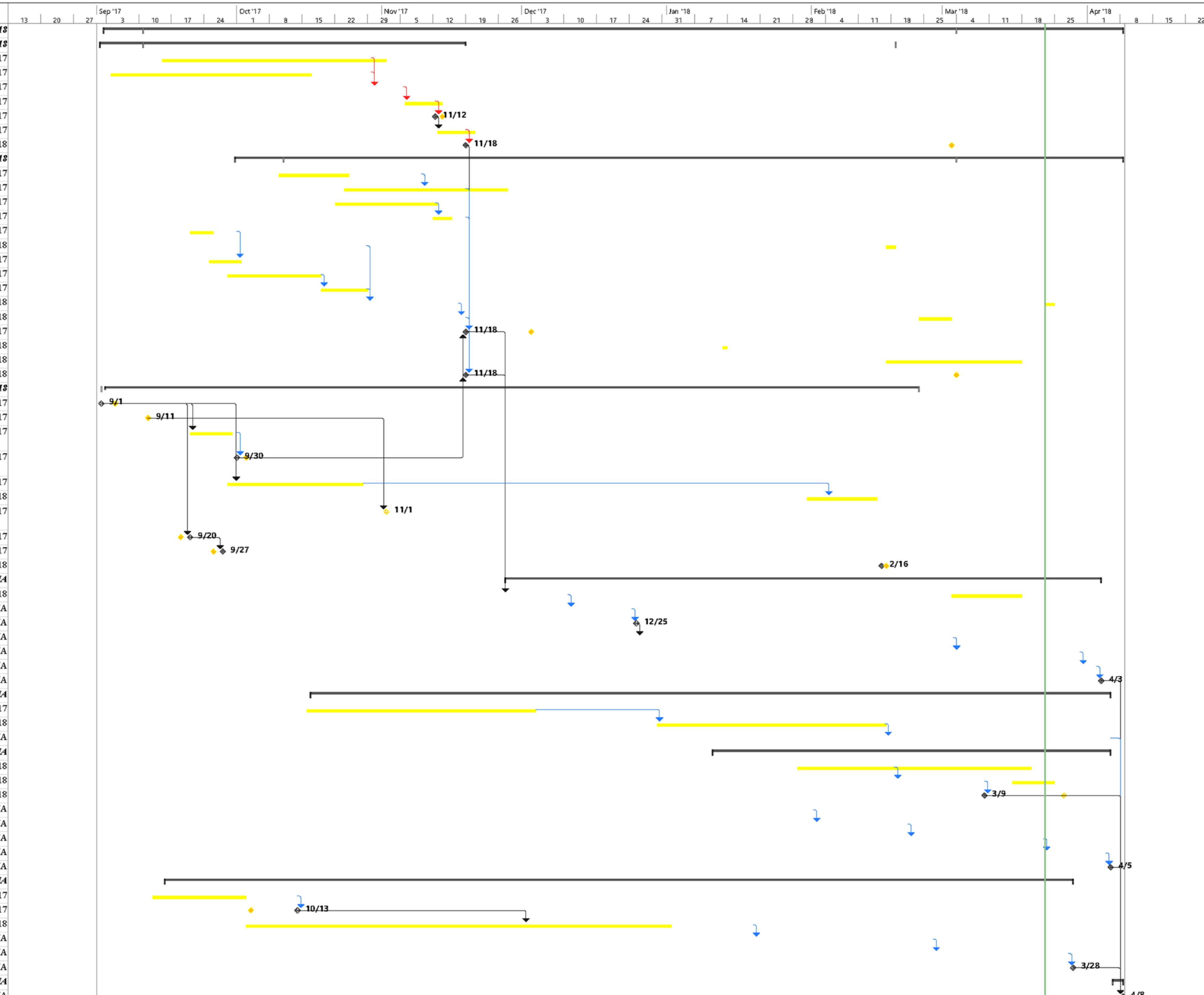
Flintlock was kept in a moist environment for the first five days of its curing cycle. At the same time an improved cool misting system was implemented to control any residual heat of hydration, and to eliminate the need for frequent refilling of humidifiers. Team members often checked whether the canoe was receiving sufficient moisture; if concrete dries during the moist curing cycle, the maximum strength of the concrete may not be achieved even if moisture is resupplied (Neville and Brooks 2010). At the 28th day, *Flintlock* will be removed from the hydration tent shown in Figure 7.

Figure 7. Hydration Tent

Beginning with wet sanding at 60-grit sandpaper, Lowell's construction and aesthetics team will work for two weeks to shape the exterior of the hull. The mold and canoe will then be removed from the table and the canoe will be flipped onto stands. The mold will then be carefully removed by cutting out each foam section, saving usable pieces for the following year. Residual drywall compound on the interior of the canoe will be removed afterwards. Team members will dry sand up to 1500-grit sandpaper. After which vinyl lettering will be adhered and two layers of sealer will be applied, resulting in a smooth and glossy finish.

Project Schedule

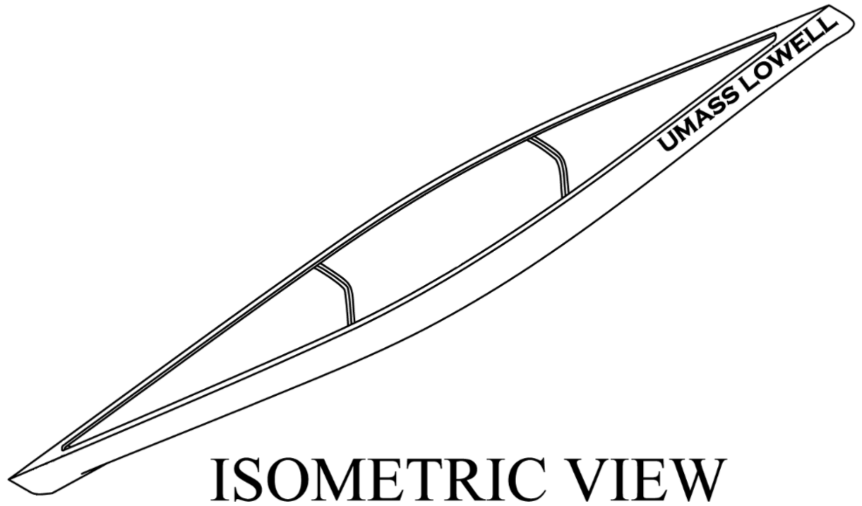
ID	Task Name	Planned Start	Planned Finish	Planned Duration	Actual Start	Actual Finish
1	***Umass Lowell Concrete Canoe Proje***	***Sat 9/2/17***	***Sun 4/8/18***	***225 days***	***Mon 9/11/17***	***Sat 3/3/18***
2	***Mix Design***	***Fri 9/1/17***	***Sat 11/18/17***	***81 days***	***Mon 9/11/17***	***Sun 2/18/18***
3	Mix Material Procurement	Fri 9/1/17	Sun 10/29/17	60 days	Fri 9/15/17	Wed 11/1/17
4	Aggregate Research	Fri 9/1/17	Sun 10/29/17	60 days	Mon 9/4/17	Mon 10/16/17
5	Preliminary Mix Testing	Sun 10/29/17	Sun 11/5/17	7 days	Tue 10/17/17	Mon 9/25/17
6	Secondary Mix Testing	Sun 11/5/17	Sun 11/12/17	7 days	Mon 11/6/17	Mon 11/13/17
7	Final Mix Chosen	Sun 11/12/17	Sun 11/12/17	0 days	Mon 11/13/17	Mon 11/13/17
8	Final Mix Tested	Sun 11/12/17	Sat 11/18/17	7 days	Mon 11/13/17	Mon 11/20/17
9	Prebatching of Materials	Sat 11/18/17	Sat 11/18/17	0 days	Fri 3/2/18	Fri 3/2/18
10	***Canoe Construction***	***Sat 9/30/17***	***Sun 4/8/18***	***196 days***	***Wed 10/11/17***	***Sat 3/3/18***
11	Hydration System Updating	Wed 10/11/17	Thu 11/9/17	30 days	Tue 10/10/17	Tue 10/24/17
12	Hyrdation System Construction	Thu 11/9/17	Sat 11/18/17	10 days	Tue 10/24/17	Mon 11/27/17
13	Table Updating	Sun 10/22/17	Sun 11/12/17	21 days	Sun 10/22/17	Sun 11/12/17
14	Table Construction	Sun 11/12/17	Sat 11/18/17	7 days	Sun 11/12/17	Wed 11/15/17
15	Hull Design in Prolines 7	Thu 9/21/17	Sat 9/30/17	10 days	Thu 9/21/17	Mon 9/25/17
16	Mold Material Procurement	Fri 9/29/17	Sat 10/28/17	30 days	Sat 2/17/18	Sun 2/18/18
17	Modeling in Solidworks	Sun 10/1/17	Sat 10/21/17	21 days	Mon 9/25/17	Sun 10/1/17
18	Aesthetic Designing	Fri 9/29/17	Wed 10/18/17	20 days	Fri 9/29/17	Wed 10/18/17
19	Aesthetic Modeling	Thu 10/19/17	Sat 10/28/17	10 days	Thu 10/19/17	Sat 10/28/17
20	Flintlock Mold Cutting	Sat 10/28/17	Fri 11/17/17	20 days	Fri 3/23/18	Sat 3/24/18
21	Flintlock Mold Finishing	Fri 11/17/17	Sat 11/18/17	2 days	Sat 2/24/18	Fri 3/2/18
22	First Canoe's Placement Day	Sat 11/18/17	Sat 11/18/17	0 days	Sat 12/2/17	Sat 12/2/17
23	First Load Test	Sat 4/7/18	Sun 4/8/18	1 day	Sat 1/13/18	Sat 1/13/18
24	Second Load Test	Sat 2/17/18	Sat 2/17/18	1 day	Sat 2/17/18	Sat 3/17/18
25	Flintlock Placement Day	Sat 11/18/17	Sat 11/18/17	0 days	Sat 3/3/18	Sat 3/3/18
26	***Project Management***	***Sat 9/2/17***	***Fri 2/23/18***	***180 days***	***Sat 9/2/17***	***Fri 2/23/18***
27	Project Planning Meeting	Fri 9/1/17	Fri 9/1/17	0 days	Mon 9/4/17	Mon 9/4/17
28	Rules Released	Mon 9/11/17	Mon 9/11/17	0 days	Mon 9/11/17	Mon 9/11/17
29	Preparation of Laboratory Facilities	Thu 9/21/17	Sat 9/30/17	10 days	Thu 9/21/17	Fri 9/29/17
30	Safety Inspection of Laboratory Facilites	Sat 9/30/17	Sat 9/30/17	0 days	Mon 10/2/17	Mon 10/2/17
31	Fall Outreach and Recruitment	Sat 9/30/17	Fri 10/27/17	28 days	Fri 9/29/17	Fri 10/27/17
32	Spring Outreach and Recruitmer	Sun 2/4/18	Fri 2/23/18	20 days	Wed 1/31/18	Wed 2/14/18
33	Preliminary Project Schedule Submitted	Wed 11/1/17	Wed 11/1/17	0 days	Wed 11/1/17	Wed 11/1/17
34	First General Meeting	Wed 9/20/17	Wed 9/20/17	0 days	Mon 9/18/17	Mon 9/18/17
35	Second General Meeting	Wed 9/27/17	Wed 9/27/17	0 days	Mon 9/25/17	Mon 9/25/17
36	Emergency Meeting	Fri 2/16/18	Fri 2/16/18	0 days	Fri 2/16/18	Fri 2/16/18
37	***Canoe Finishing***	***Mon 11/27/17***	***Tue 4/3/18***	***132 days***	***Sat 3/3/18***	***NA***
38	Moist Curing	Mon 11/27/17	Sun 12/10/17	14 days	Sat 3/3/18	Sat 3/17/18
39	Wet Sanding	Sun 12/10/17	Sun 12/24/17	14 days	Sat 3/17/18	NA
40	Mold Removal	Sun 12/24/17	Mon 12/25/17	1 day	NA	NA
41	Dry Sanding	Mon 12/25/17	Sat 3/3/18	70 days	NA	NA
42	Aesthetic Additions	Sat 3/3/18	Fri 3/30/18	28 days	NA	NA
43	Canoe Sealing	Fri 3/30/18	Mon 4/2/18	4 days	NA	NA
44	Canoe Finished	Tue 4/3/18	Tue 4/3/18	1 day	NA	NA
45	***Paddling***	***Mon 10/16/17***	***Thu 4/5/18***	***177 days***	***Mon 10/16/17***	***NA***
46	Fall Try-Outs/Practice	Mon 10/16/17	Sun 12/3/17	50 days	Mon 10/16/17	Sun 12/3/17
47	Off-Season Conditioning	Sat 12/30/17	Fri 2/16/18	50 days	Sat 12/30/17	Fri 2/16/18
48	Spring Paddling Practice	Fri 2/16/18	Thu 4/5/18	50 days	Fri 2/16/18	NA
49	***Educational Work***	***Wed 1/10/18***	***Thu 4/5/18***	***88 days***	***Wed 1/10/18***	***NA***
50	Design Paper Rough Drafts	Wed 1/10/18	Sun 2/18/18	40 days	Mon 1/29/18	Mon 3/19/18
51	Design Paper Editing	Sun 2/18/18	Fri 3/9/18	20 days	Fri 3/16/18	Sat 3/24/18
52	Design Paper Submitted	Fri 3/9/18	Fri 3/9/18	0 days	Mon 3/26/18	Mon 3/26/18
53	Presentation Script Developmen	Thu 1/11/18	Thu 2/1/18	21 days	Fri 3/16/18	NA
54	Presentation Design	Thu 2/1/18	Wed 2/21/18	21 days	Mon 3/19/18	NA
55	Presentation Peer Critique	Wed 2/21/18	Thu 3/22/18	30 days	NA	NA
56	Presentation Practice	Thu 3/22/18	Wed 4/4/18	14 days	NA	NA
57	Presentation Finished	Thu 4/5/18	Thu 4/5/18	1 day	NA	NA
58	***Aesthetics***	***Fri 9/15/17***	***Wed 3/28/18***	***201 days***	***Wed 9/13/17***	***NA***
59	Theme Research	Thu 9/14/17	Fri 10/13/17	30 days	Wed 9/13/17	Mon 10/2/17
60	Theme Chosen	Fri 10/13/17	Fri 10/13/17	0 days	Tue 10/3/17	Tue 10/3/17
61	Theme Development	Fri 12/1/17	Fri 1/19/18	50 days	Tue 10/3/17	Mon 1/1/18
62	Aesthetic Material Procurement	Fri 1/19/18	Mon 2/26/18	40 days	Sat 2/17/18	NA
63	Tabletop Display Construction	Mon 2/26/18	Tue 3/27/18	30 days	Mon 3/12/18	NA
64	Tabletop Display Finished	Wed 3/28/18	Wed 3/28/18	1 day	NA	NA
65	***Competition***	***Fri 4/6/18***	***Sun 4/8/18***	***2 days***	***NA***	***NA***
66	New England Regional Competi	Fri 4/6/18	Sun 4/8/18	2 days	NA	NA



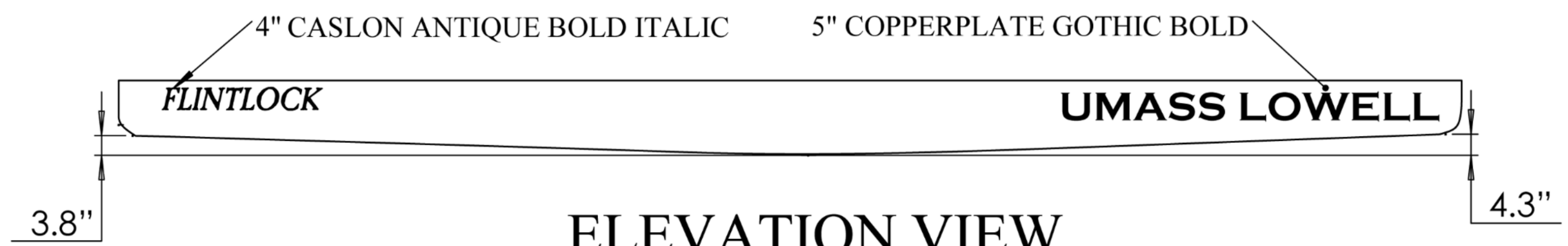
Project: Project Schedule
Date: Fri 3/23/18

Task | Milestone | Summary | Critical | Actual Task | Actual Milestone | Actual Summary

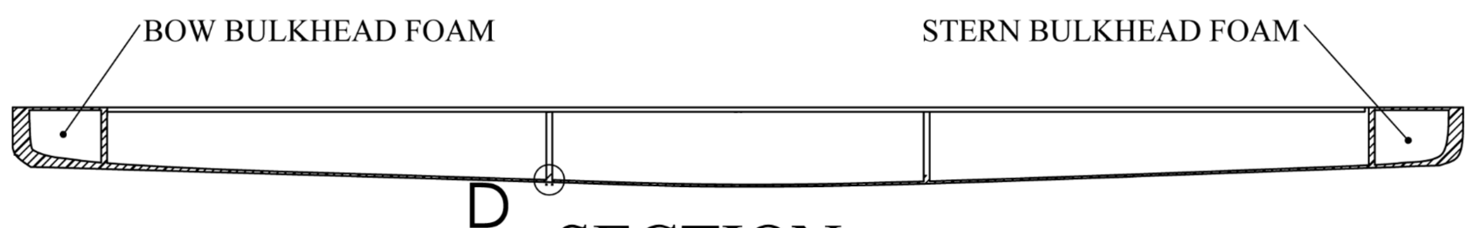
Construction Drawing



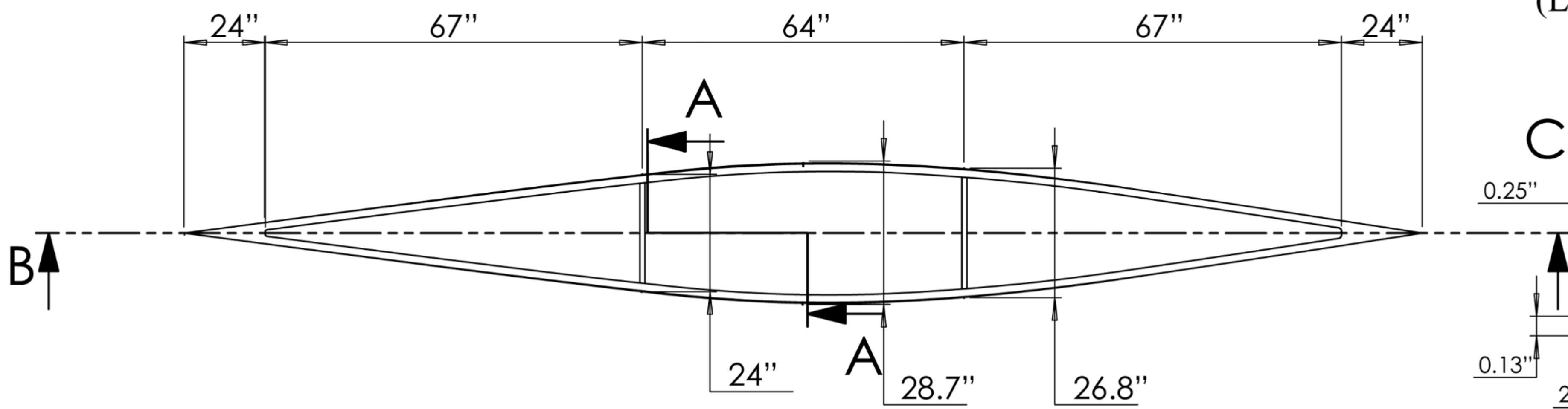
ISOMETRIC VIEW



ELEVATION VIEW

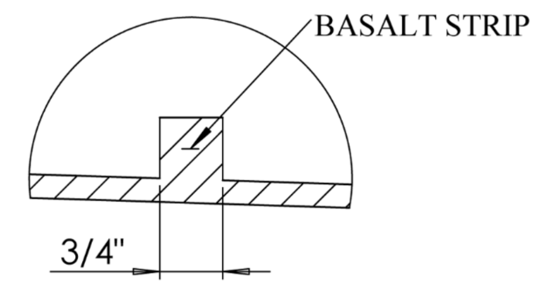


SECTION B-B

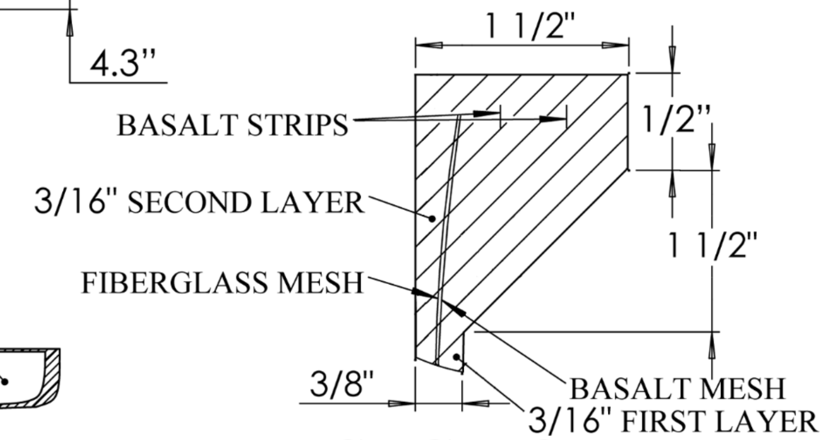


PLAN VIEW

DETAIL D

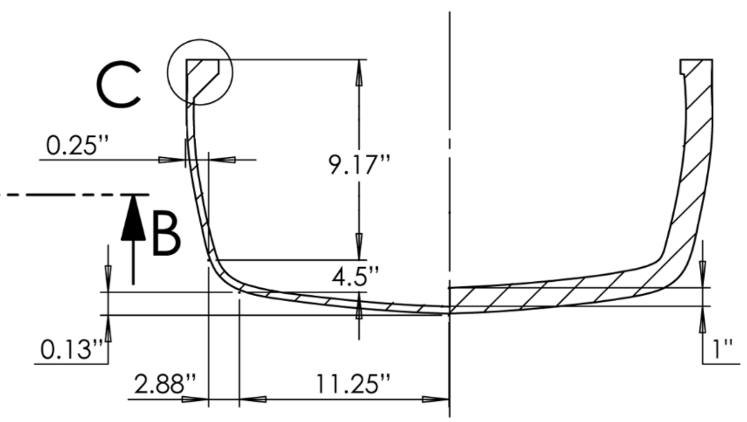


DETAIL C



SECTION A-A

(LEFT) TYPICAL CROSS SECTION
(RIGHT) RIB SECTION



UMass Lowell

Bill of Materials	
Qty.	Description
47.95 lbs.	Portland Cement
4.78 lbs.	Silica Fume
11.31 lbs.	Metakaolin
6.39 lbs.	K15
25.82 lbs.	Expanded Shale
1.92 lbs.	Pigment
2.03 gal.	Latex
2.54 lbs.	PVA Fibers
13.20 fl. oz.	HRWR
16.87 fl. oz.	SRA
60 sq. ft.	Basalt Mesh
60 sq. ft.	Fiberglass Mesh
2 cub. ft.	XPS Foam
1 gal.	Sealing Agent

FLINTLOCK
Construction Drawing

- Drawings not to scale
- Bulkhead foam used for floatation, comprised of 2" pieces glued together, stays >1" inside concrete on all sides

Engineer	Emily Schneider
Drawn	Emily Schneider
Checked	Campbell Narron
Date	3/26/18

Appendix A - References

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Appendix B – Mixture Proportions

MIXTURE DESIGNATION: ***FLINTLOCK*** (COLOR VARIES, MIX WITH RED PIGMENT IS SHOWN)

Cementitious Materials

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Type 1 White Portland Cement	*3.15*	*3.05*	*598.98*	*Total Amount of cementitious materials 800.00 lb/yd^3 c/cm ratio 0.75*
White Silica Fume	*2.20*	*0.44*	*59.76*	
High-Reactivity Metakaolin	*2.60*	*0.87*	*141.26*	

Fibers

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (mass/volume) (lb/yd^3)*	
.375" PVA Fibers	*1.3*	*0.39*	*31.78*	*Total Amount of Fibers 31.78 lb/yd^3*

Aggregates

Aggregates	*ASTM C330**	*Abs (%)*	*SG$_{OD}$*	*SG$_{SSD}$*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
3M™ K15	*N*	*0*	*0.15*	*0.15*	*79.76*	*79.76*	*8.52*
Expanded Shale	*Y*	*18.25*	*1.6*	*1.92*	*283.59*	*335.35*	*2.84*

Admixtures

Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Silpro C-21 Latex	*9.2*	*759.09*	*20%*	*364.36*	*Total Water from Admixtures, $\sum w_{admx}$ 384.41 lb/yd^3*
ADVA ® Cast 575 HRWR	*8.9*	*20.77*	*40%*	*7.16*	
Eclipse ® Floor 200 SRA	*7.7*	*26.21*	*1%*	*12.89*	

Solids (Latex, Dyes and Powdered Admixtures Only)

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Silpro C-21 Latex	*1.87*	*0.75*	*87.30*	*Total Solids from Admixtures 111.30 lb/yd^3*
Red Pigment	*4.90*	*0.08*	*24.00*	

Water

	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w: 343.63*	*5.51*
Total Free Water from All Aggregates, lb/yd^3		*$\sum w_{free}$: -40.78*	
Total Water from All Admixtures, lb/yd^3		*$\sum w_{admx}$: 384.41*	
Batch Water, lb/yd^3		*w_{batch}: 0.00*	

Densities, Air Content, Ratios and Slump

	Cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	*800.00*	*31.78*	*415.11*	*111.30*	*343.63*	*∑M:1701.82*
Absolute Volume of Concrete, V, (ft^3)	*4.36*	*0.39*	*11.36*	*0.83*	*5.02*	*∑V:21.96*
***Theoretical Density, T,** (=∑M / ∑V)*	*77.50 lb/ft^3*		***Air Content** [= (T – D)/T x 100%]*			*24.54 %*
Measured Density, D	*58.48 lb/ft^3*		***Slump, Slump flow***			*0.5 in.*
water/cement ratio, w/c:	*0.57*		***water/cementitious material ratio, w/cm:***			*0.43*

VOLUME CALCULATION

$$\frac{\text{MASS}}{62.4\frac{lb}{ft^3} \times \text{S.G.}} = \text{VOLUME}$$

PORTLAND CEMENT

$$\frac{598.98\,lb}{62.4\frac{lb}{ft^3} \times 3.15} = 3.05\,ft^3$$

SILICA FUME

$$\frac{59.76\,lb}{62.4\frac{lb}{ft^3} \times 2.20} = 0.44\,ft^3$$

METAKAOLIN

$$\frac{141.26\,lb}{62.4\frac{lb}{ft^3} \times 2.60} = 0.87\,ft^3$$

PVA FIBERS

$$\frac{31.78\,lb}{62.4\frac{lb}{ft^3} \times 1.30} = 0.39\,ft^3$$

K15

$$\frac{79.76\,lb}{62.4\frac{lb}{ft^3} \times 0.15} = 8.52\,ft^3$$

SHALE

$$\frac{283.59\,lb}{62.4\frac{lb}{ft^3} \times 1.60} = 2.84\,ft^3$$

LATEX

$$\frac{87.30\,lb}{62.4\frac{lb}{ft^3} \times 1.87} = 0.75\,ft^3$$

PIGMENT

$$\frac{24\,lb}{62.4\frac{lb}{ft^3} \times 4.90} = 0.08\,ft^3$$

WATER

$$\frac{343.63\,lb}{62.4\frac{lb}{ft^3} \times 1.00} = 5.51\,ft^3$$

Theoretical Density

$$\frac{\Sigma\text{MASS}}{\Sigma\text{VOLUME}} = \text{DENSITY}$$

$$\frac{1671.35\ lb}{21.96\ ft^3} = 5.51\ \frac{lb}{ft^3}$$

Air Content

$$\frac{(\text{THEORETICAL DENSITY} - \text{MEASURED DENSITY})}{\text{THEORETICAL DENSITY}} \times 100\% = \text{AIR CONTENT}$$

$$\frac{77.50\ \frac{lb}{ft^3} - 58.48\frac{lb}{ft^3}}{77.50\ \frac{lb}{ft^3}} \times 100\% = 24.50\%$$

Water/Cement Ratio

$$\frac{\text{MASS WATER}}{\text{MASS CEMENT}} = \text{W/C RATIO}$$

$$\frac{343.63\ \frac{lb}{ft^3}}{598.98\ \frac{lb}{ft^3}} = 0.57$$

Water/Cementous Material Ratio

$$\frac{\text{MASS WATER}}{\text{MASS CEMENTOUS MATERIAL}} = \text{W/CM RATIO}$$

$$\frac{343.63\frac{lb}{ft^3}}{800.00\frac{lb}{ft^3}} = 0.43$$

Aggregate Concentration

$$\frac{\text{VOLUME SHALE}}{\text{VOLUME AGGREGATE}} \times 100\% = \text{SHALE PERCENT}$$

$$\frac{2.84\ ft^3}{11.36\ ft^3} \times 100\% = 25\%$$

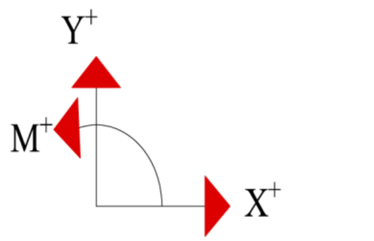
Appendix C – Example Structural Calculation

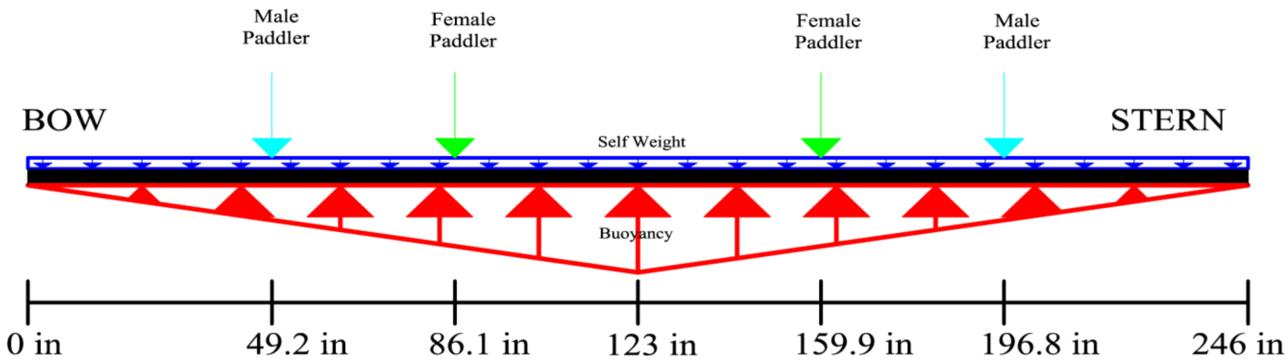
Scenario:

Four person co-ed race, where the canoe is regarded as a simply supported beam and the paddlers are considered as point loads. The male paddlers are positioned at locations equal to 20% and 80% of the total length of the canoe (as measured from the bow). Female paddlers are positioned at locations equal to 35% and 65% of the total length of the canoe (as measured from the bow). Non-transformed cross-sectional properties are used.

Assumptions:

- ★ Total weight of the canoe is 200 lb
- ★ Self-weight is a uniformly distributed load
- ★ Buoyancy is a distributed force increasing uniformly to the center
- ★ The length, ℓ, of the canoe is 246 in
- ★ Male paddler, P_M, provides 175 lb load
- ★ Female paddler, P_F, provides 145 lb load





Shear and Bending Moment Equations:

- ★ To determine governing equations for shear and bending moment, the canoe was cut in half
- ★ Canoe Weight Constant = (Weight of Canoe) / (Length of Canoe) ➔(200 lb) / (246 in) = 0.813 lb / in
- ★ Buoyancy Force = (Sum of Paddler Loads and Canoe Weight) ➔(175 lb * 2 + 145 lb * 2 + 200 lb) = 840 lb
- ★ Buoyancy Force Intensity, w, at center = (Buoyancy Force) / (Length / 2) ➔(840 lb / 123 in) = 6.829 lb / in
- ★ Due to proportional triangles ➔(w / x) = (6.829 lb / in) / (123 in) or $w = (0.056 \text{ lb / in}^2)x$

∫Distributed Load Ratios = V(x) Equation

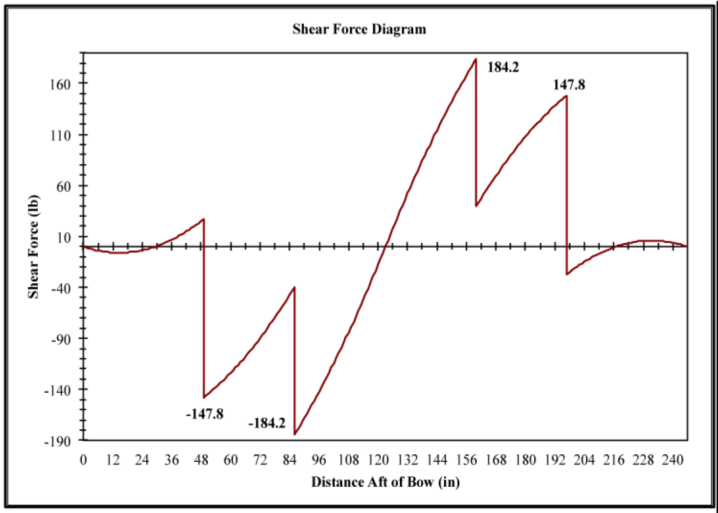
∫V(x) Equation = M(x) Equation

Variable	Ratio	V(x)	M(x)
Buoyancy	$0.056x$	$0.0278x^2$	$0.00925x^3$
Canoe Weight	-0.813	$-0.813x$	$-0.4065x^2$
Male Paddler	N/A	-175	$-175x$
Female Paddler	N/A	-145	$-145x$

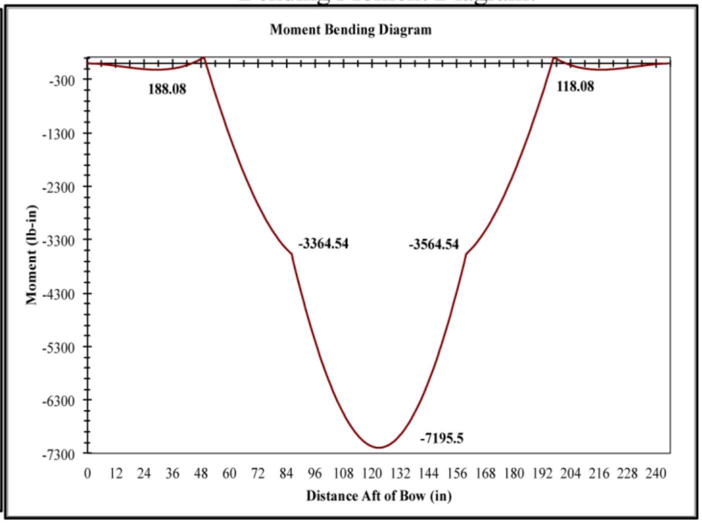
Distance from Bow	V(x)	M(x)
$x_0 = 0$ in	$0.0278x_0^2 - 0.813x_0 = 0$ lb	$0.00925x_0^3 - 0.4065x_0^2 = 0$ lb-in
$x_1 = 49.2$ in	$0.0278x_1^2 - 0.813x_1 - P_M = -147.8$ lb	$0.00925x_1^3 - 0.4065x_1^2 - P_M(x_1 - x_1) = 118.08$ lb-in
$x_2 = 86.1$ in	$0.0278x_2^2 - 0.813x_2 - P_M - P_F = -184.2$ lb	$0.00925x_2^3 - 0.4065x_2^2 - P_M(x_2 - x_1) - P_F(x_2 - x_2) = -3{,}564.54$ lb-in
$x_3 = 123$ in	$0.0278x_3^2 - 0.813x_3 - P_M - P_F = 0$ lb	$0.00925x_3^3 - 0.4065x_3^2 - P_M(x_3 - x_1) - P_F(x_3 - x_2) = -7{,}195.5$ lb-in
$x_4 = 159.9$ in	$0.0278(\ell - x_4)^2 - 0.813(\ell - x_4) - P_M - P_F = 184.2$ lb	$0.00925(\ell - x_4)^3 - 0.4065(\ell - x_4)^2 - P_M((\ell - x_4) - (\ell - x_5)) - P_F((\ell - x_4) - (\ell - x_4)) = -3{,}564.54$ lb-in
$x_5 = 196.8$ in	$0.0278(\ell - x_5)^2 - 0.813(\ell - x_5) - P_M = 147.8$ lb	$0.00925(\ell - x_5)^3 - 0.4065(\ell - x_5)^2 - P_M((\ell - x_5) - (\ell - x_5)) = 118.08$ lb-in
$x_6 = 246$ in	$0.0278(\ell - x_6)^2 - 0.813(\ell - x_6) = 0$ lb	$0.00925(\ell - x_6)^3 - 0.4065(\ell - x_6)^2 = 0$ lb-in

Shear and Bending Moment Diagrams:

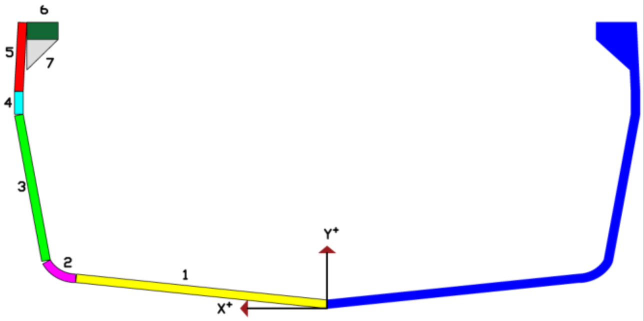
Shear Diagram:



Bending Moment Diagram:



Centriod and Moment of Inertia:



Segment	Area (in^2)	$\bar{Y}$ (in)	$A\bar{y}$ (in^3)	d (in)	I_x (in^4)	I_x+Ad^2 (in^4)
1	4.01	0.75	3.02	4.48	0.05	80.53
2	0.56	2.00	1.13	3.23	0.59	6.47
3	2.42	5.31	12.87	0.08	8.44	8.45
4	0.38	8.99	3.37	3.76	0.03	5.33
5	1.13	10.99	12.46	5.76	0.86	38.47
6	1.00	12.13	12.10	6.90	0.05	47.59
7	0.88	10.58	9.36	5.35	0.09	25.40

*Note: Moment of Inertia values were obtained by transforming the cross section into simple geometric shapes. The following formulas were used for calculations

Formulas for segments 1, 3, 4, 5 and 6:

$A_{Rectangle} = b * h$ $\quad\quad$ $I_{xRectangle} = (b * h^3) / 12$

Formulas for segment 2:

$A_{Annulus} = [(\pi)(r_o^2 - r_i^2)] / 4$ $\quad\quad$ $I_{xAnnulus} = [(\pi)(r_o^4 - r_i^4)] / 24$

Formulas for segment 7:

$A_{Triangle} = (b * h) / 2$ $\quad\quad$ $I_{xTriangle} = (b * h^3) / 36$

$\Sigma Area = 10.39\ in^2$ $\quad$ $\Sigma A\bar{Y} = 54.30\ in^3$ $\quad$ $\bar{Y} = \Sigma Ay / \Sigma A = 5.23$ in $\quad$ $C_c = -\bar{Y} = -5.23$ in

*Note: Moment of Inertia was calculated for half of the cross section, so the calculated value was multiplied by 2.

$\Sigma\ I_x + Ad^2 = 625.1\ in^4$ $\quad$ $I_x = 1{,}250.2\ in^4$

Maximum Compressive and Tensile Stresses:

Height of Section: 13.56 in $\quad$ $C_c = -5.23$ in $\quad$ C_t = Height of Section - C_c = 13.56 in

Dynamic Amplification Factor, DAF: 1.25 (Paradis, 2007)

Mix Design Safety Factor, MDF: 2.5

Design Compressive Stress: $f_{cMax} = (DAF * MDF * M_{Max} * C_c) / I_x$

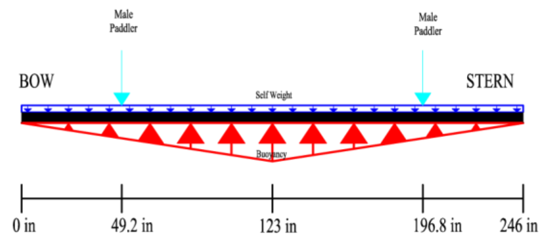
$f_{c\,Max} = [(1.25) * (2.5) * (7{,}790\text{ lb-in}) * (-5.23\text{ in})] / 1{,}250.2\ in^4 = -101.84\text{ lb / in}^2$

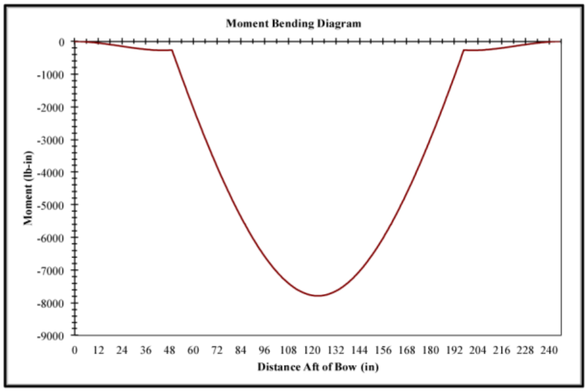
Design Tensile Stress: $f_{tMax} = (DAF * MDF * M_{Max} * C_t) / I_x$

$f_{t\,Max} = [(1.25) * (2.5) \bullet (7{,}790\text{ lb-in}) * (8.33\text{ in})] / 1{,}250.2\ in^4 = 162.2\text{ lb / in}^2$

Scenario Comparison:

Male Paddlers:





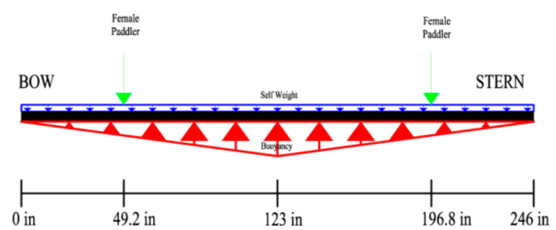
$M_{(max)}$ = -7,790 lb-in

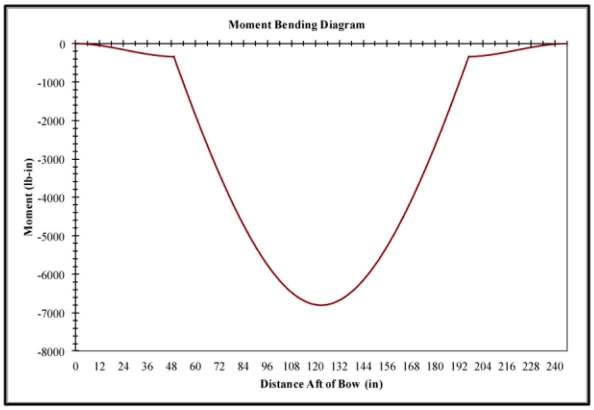
$V_{(max)}$ = 171 lb

f_c = -101.84 lb / in^2

f_t = 162.2 lb / in^2

Female Paddlers:





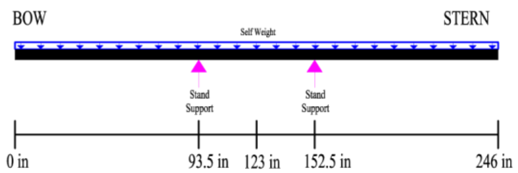
$M_{(max)}$ = -6,806 lb-in

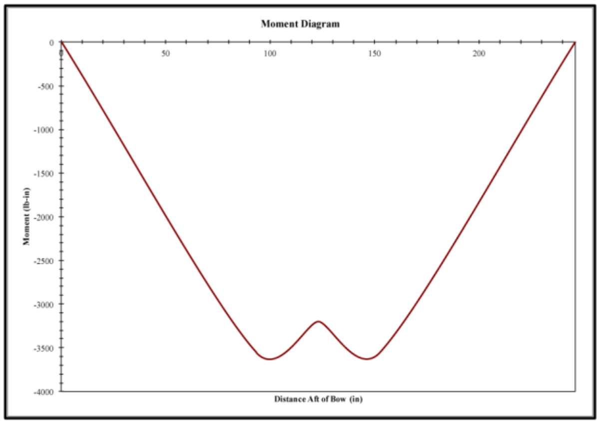
$V_{(max)}$ = 145.8 lb

f_c = -88.97 lb / in^2

f_t = 141.71 lb / in^2

UML Stand:





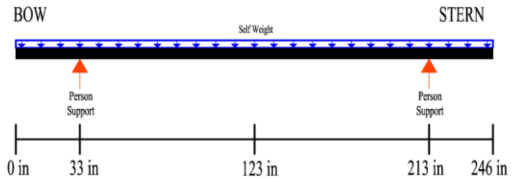
$M_{(max)}$ = -3,553.76 lb-in

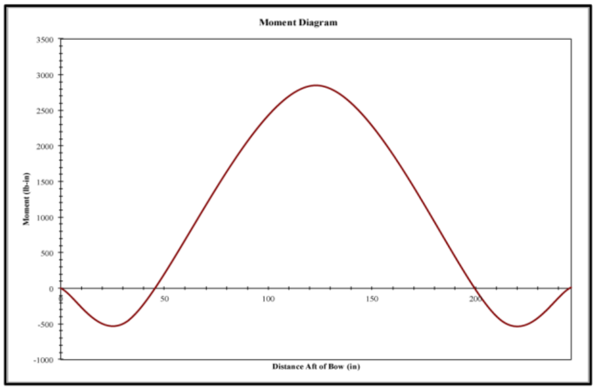
$V_{(max)}$ = 76.02 lb

f_c = -46.46 lb / in^2

f_t = 73.99 lb / in^2

Carry:





$M_{(max)}$ = 2,850 lb-in

$V_{(max)}$ = 73.17 lb

f_c = -37.26 lb / in^2

f_t = 59.34 lb / in^2

Appendix D – Hull Thickness/Reinforcement and Percent Open Area Calculations

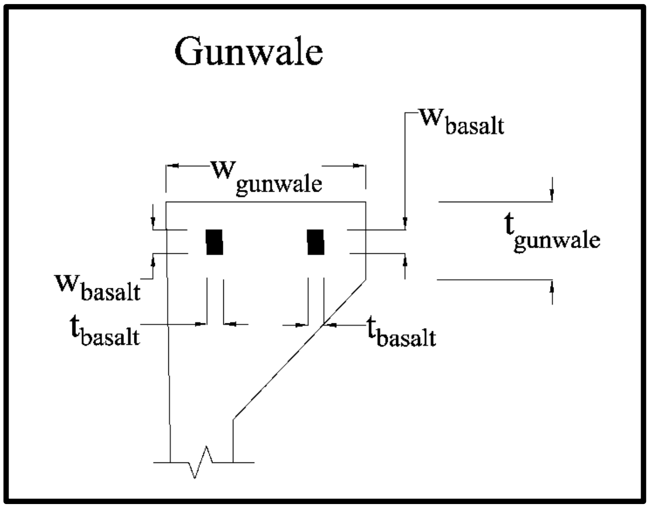
Hull Thickness/ Reinforcement:

*Note: figures not to scale

$[(t_{mesh} / t_{concrete}) \cdot 100] \leq 50\%$
$[(w_{mesh} / w_{concrete}) \cdot 100] \leq 50\%$

Gunwale:

$t_{basalt} = 0.04$ in
$w_{basalt} = 0.16$ in
$t_{gunwale} = 0.5$ in
$w_{gunwale} = 1.50$ in



$[(w_{basalt} + w_{basalt})/ w_{gunwale}]\cdot 100$

$[(0.16 \text{ in}/ (0.5 \text{ in})]\cdot 100 =$

$32\ \% \leq 50\%$ ✓

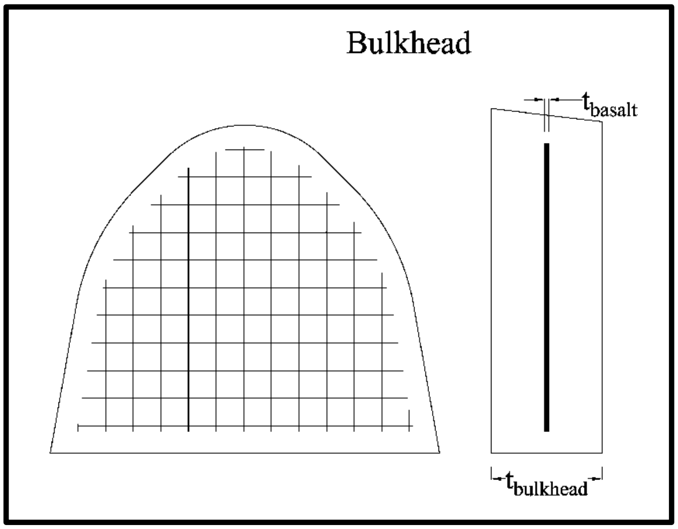
$[(t_{basalt} + t_{basalt})/ (t_{gunwale})] \cdot 100$

$[(0.04 \text{ in} + 0.04 \text{ in})/ (1.50 \text{ in})]\cdot 100 =$

$5.33\ \% \leq 50\%$ ✓

Bulkheads:

$t_{basalt} = 0.04$ in
$t_{bulkhead} = 1.0$ in



$[(t_{basalt})/ (t_{bulkhead})]\cdot 100$

$[(0.04 \text{ in})/ (1.00 \text{ in})]\cdot 100 =$

$4.00\ \% \leq 50\%$ ✓

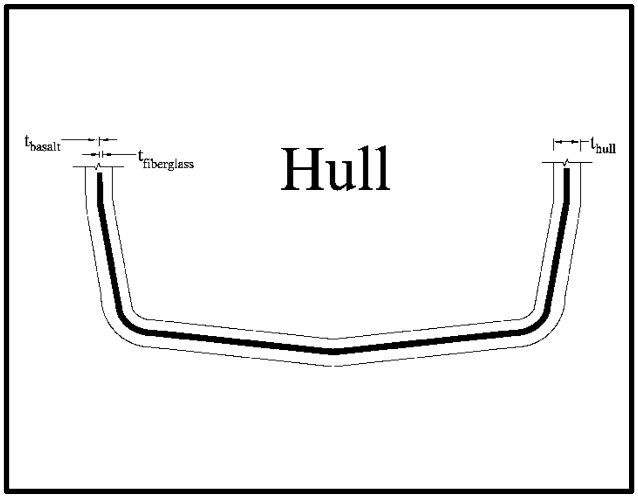
Hull:

t_{basalt} = 0.04 in
$t_{fiberglass}$ = 0.03 in
$t_{gunwale}$ = 0.375 in

$[(t_{basalt} + t_{fiberglass})/\ t_{hull}]\cdot 100$

$[(0.04\text{ in} + 0.03\text{ in})/\ (0.375\text{ in})]\cdot 100 =$

18.75 % ≤ *50%* ✓



Ribs:

t_{basalt} = 0.04 in
w_{basalt} = 0.16 in
t_{rib} = 1.0 in
w_{rib} = 0.75 in

$[(t_{basalt})/\ (t_{rib})]\cdot 100$

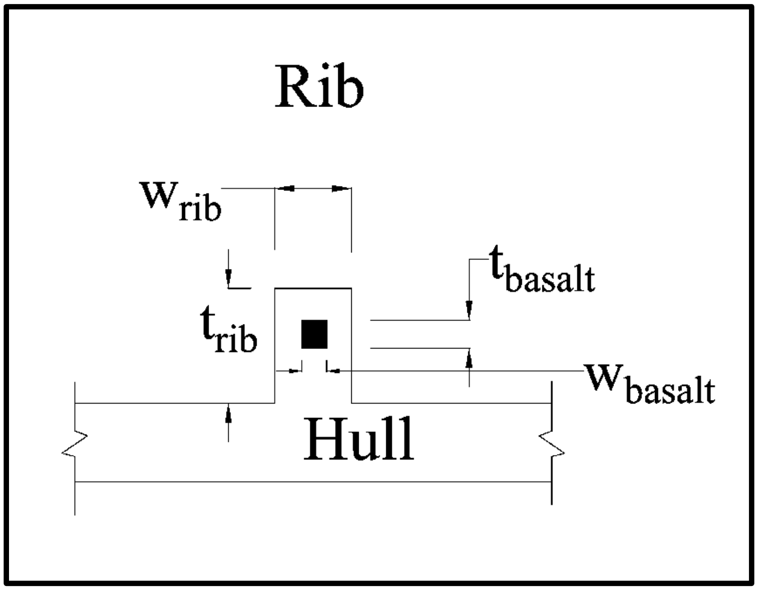
$[(0.04\text{ in})/\ (1.00\text{ in})]\cdot 100 =$

4.00 % ≤ *50%* ✓

$[(w_{basalt})/\ (w_{rib})]\cdot 100$

$[(0.16\text{ in})/\ (0.75\text{ in})]\cdot 100 =$

21.33 % ≤ *50%* ✓



***All Reinforcements meet guidelines stated in NCC Rules and Regulations 2018**

Open Area:

Minimum Percent Open Area (POA)
POA = $[(\Sigma Area_{open} / Area_{total}) \cdot 100] \geq 40$ %

n_1 = number of apertures along sample length
n_2 = number of apertures along sample width
d_1 = spacing reinforcing (center to center) along sample length
d_2 = spacing reinforcing (center to center) along sample width
t_1 = thickness of reinforcing along sample length
t_2 = thickness of reinforcing along sample width

POA: Fiberglass Mesh

d_1 = aperture dimension + 2 $\cdot$ (t_1/ 2) → (0.89 in + 2 $\cdot$ (0.12 in/ 2)) =1.01 in

d_2 = aperture dimension + 2 $\cdot$ (t_2 /2) → (1.0 in + 2 $\cdot$ (0.18 in/ 2)) = 1.18 in

$Length_{sample} = n_1/d_1$ → [(10) $\cdot$ 1.01 in] = 10.1 in

$Width_{sample} = n_2 \cdot d_2$ → [(10) $\cdot$ 1.18 in] = 11.8 in

$\Sigma Area_{open} = n_1 \cdot n_2 \cdot Area_{open}$ → $10 \cdot 10 \cdot 0.89$ in^2 = 89 in^2

$Area_{total} = Length_{sample} \cdot Width_{sample}$ → 10.1 in $\cdot$ 11.8 in = 119.18 in^2

POA = $\Sigma Area_{open} / Area_{total} \cdot$ 100% = 89 in^2/ 119.18 in^2 $\cdot$ 100 = 74.3% $\geq$ 40% ✓

POA: Basalt Mesh

d_1 = aperture dimension + 2$\cdot$ (t_1/ 2) → (1.00 in + 2 $\cdot$ (0.24 in/ 2)) =1.24 in

d_2 = aperture dimension + 2$\cdot$ (t_2 /2) →(1.0 in + 2 $\cdot$ (0.16 in/ 2)) = 1.16 in
$Length_{sample} = n_1/d_1$ → [(10) x 1.24 in] = 12.4 in

$Width_{sample} = n_2 \cdot d_2$ → [(10) x 1.16 in] = 11.6 in

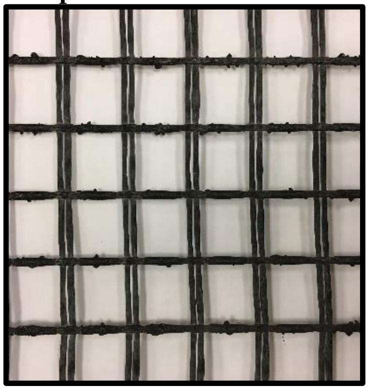
$\Sigma Area_{open} = n_1 \cdot n_2 \cdot Area_{open}$ → = ($10 \cdot 10 \cdot 1$ in^2)= 100 in^2

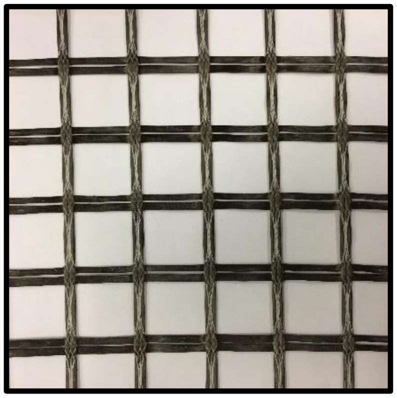
$Area_{total} = Length_{sample} \cdot Width_{sample}$ →(12.4 in x 11.6 in)= 143.84 in^2

POA = $\Sigma Area_{open} / Area_{total} \cdot$ 100% → (100 in^2/ 143.84 in$^2 \cdot$100 in)= 69.5% $\geq$40% ✓

*Mesh meets guidelines stated in NCC Rules and Regulations 2018

Samples of Mesh Used:


Sample 1: Fiberglass Mesh


Sample 2: Basalt Mesh


Sample 3: Strand of Basalt used for Ribs and Gunwales