JESTER

UMass Lowell

2017 Concrete Canoe Design Paper

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Executive Summary

The University of Massachusetts Lowell (UMass Lowell) campus became an official educational institution in 1895, then known as the Lowell Textile School. At that time it concentrated on training workers for the city's booming textile industry. In 1975, the school became known as the University of Lowell following the merger of the Lowell Technological Institute and Lowell State College. In 1991, it was absorbed into the UMass system and became known as the University of Massachusetts Lowell.

For the 17,000 students that attend UMass Lowell, the university offers 122 bachelor's, 43 master's, and 36 doctoral degrees within the six colleges located at UMass Lowell (About UMass Lowell 2017). The Francis College of Engineering has a distinguished reputation for its hands-on education, and its students are widely views as hardworking, dedicated, and well-prepared for their future careers (Francis College of Engineering 2017).

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 2nd in 2014 with *Vanguard*, 1st in 2015 with *Backfire* (8th at NCCC), and 8th in 2016 with *Sockeye*.

This year, Lowell sought to simplify and update time-intensive construction methods used in the past. With the help of the Plastics Engineering Department at UMass Lowell, *Jester*'s mold was milled on site in a 3-axis CNC milling machine (Construction, Page 9). The result of the new method for creating the mold was a more precise product that required less manual labor to fabricate. The team developed new hull design specifications (Table 1) with goals to improve overall performance.

Table 1. ***JESTER*** Specifications

Weight	210 lbs (estimated)
Length	20 ft 6 in
Width	28 in
Depth	13.8 in
Average Thickness	3/8 in
Reinforcement	Basalt Mesh Fiberglass Mesh
Colors	Red, Yellow, Green, White

Table 2. Concrete Properties

Plastic Unit Weight	61.9 pcf
Oven-Dried Unit Weight	57 pcf
Compressive Strength	1990 psi
Tensile Strength	310 psi
Flexural Strength	900 psi
Slump	1/2 in
Air Content	17.0%

Research into the behavior of expanded shale as a new lightweight aggregate resulted in a final mix design capable of withstanding the rigors of competition (Table 2). Improvements were also made to the curing process. In addition to the misting system and humidifiers used in previous years, vaporizers were utilized and uniquely engineered on site to reduce the effects of heat produced during hydration and to minimize moisture loss.

In addition to the improvements and innovations made by the mix, construction, and analysis teams, Lowell focused on rebuilding a team that had been reduced to a small number of active members. Through focused recruitment, a new team was created that included students from all grades. Project management planned objective-based meeting times and hands-on learning sessions for all members, new and old. The involvement of freshmen and sophomore students showed significant improvements from the previous year, and future teams are expected to have large numbers of returning members.

Inspired by the technological advances and early industrial progress of the medieval age, Lowell focused on representing the vibrant colors, elegance, and exhilarating lifestyle of medieval royalty. Because this project is as entertaining as it is educational, Lowell chose to commemorate the medieval character who best represents that spirit. With these goals accomplished, the 2017 UMass Lowell Concrete Canoe Team is proud to present: *Jester*.

Project Management

Due to the continued success of the existing system, the managerial structure for Lowell functioned similarly to past years. Minimal changes occurred to accommodate for inexperienced team members and a regional competition held earlier than usual. Following the 2016 season, two co-project managers, one field manager, four team captains, and three officers were selected for the team's 2017 entry. To allow expertise to grow within the management structure, Lowell kept the 2016 co-project managers together in their same roles. The dual project manager system prevented both individuals from being overworked, and allowed for more frequent communication with all other members. The project managers worked with other members and faculty to schedule team meetings, promote team activities, recruit new members, and manage fiscal matters.

Each team captain directed one of the four project subdivisions: hull design and structural analysis, mix development and testing, construction and aesthetics, and paddling. 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 calculated in Microsoft Project by determining tasks that had no slack. The project managers held captains meetings as a resource to answer any questions or concerns regarding the project schedule, and to keep all captains informed of progress made by other groups (Quality Assurance/Quality Control, Page 2).

Table 3. Major Project Milestones

Milestone	Planned Date	Actual Date	Reason for Variance
Jester Hull Design*	10/9/16	10/9/16	-
Mold Cut	1/14/17	2/7/17	Software and Machine Limitations
Practice Placement	12/3/16	Did Not Occur	Time Constraints
Jester Mix Selection*	1/26/17	2/9/17	Research and Rule Compliance
Jester Placement Day*	1/28/17	2/11/17	Mold and Mix Not Ready
Jester Finishing	3/21/17	NA	-
Design Paper Submission	3/10/17	3/7/17	Deadline Not Known During Planning

*Denotes Critical Path

Jester's team was composed of 22 members accumulating a total of 3,950 person-hours (Figure 1), representing an increase in amount of time worked on *Jester* versus *Sockeye* by 274%. However, as *Sockeye*'s team was both small and inexperienced, and was working on a vastly reduced project schedule. A more valuable comparison for *Jester* is against *Backfire*; compared to *Backfire*, Jester features a reduction in person-hours by 18%. This reduction in person-hours can be attributed to innovation of mold construction techniques, member experience from 2016, and better time management.

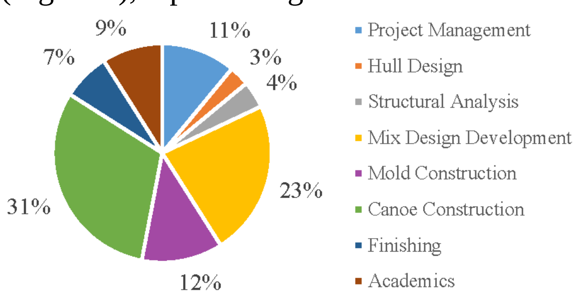


Figure 1. Person-Hour Allocation

Jester's financial plan was based upon previous experience, with an operating budget set at $9,040. This budget accounted for material procurement and construction. With multiple innovations made by Lowell, new materials and tools were purchased to encourage research of those innovations.

Lowell selected an experienced team member to be *Jester*'s safety officer. As safety officer, this member made sure all MSDS were placed in a notebook that was kept where every member or the mix team and construction team could easily find it. After coordinating with the UMass Lowell Senior Safety Specialist, the safety officer organized safety training for key team members, and ensured that no construction or mix work was performed without proper safety equipment worn, a safety analysis performed, and a trained team member present.

Quality Assurance / Quality Control

The project managers planned and held captains meetings beginning in September following the release of the NCCC 2017 Rules and Regulations. During meetings, team captains updated management and other members on research that had been done, materials that had been tested, techniques that were being used, and calculations that had been performed. This served as a method of reviewing each other's work, making sure every team was acting in compliance with the rules, and keeping all teams on similar schedules. A quality control officer was appointed to oversee all aspects of the project and ensure that standards placed by management were met and all teams stayed compliant with the rules.

Nearly all materials used this year were purchased during the current school year. The only exceptions were fiberglass mesh, metakaolin, and silica fume. The process by which new materials were chosen, acquired, and checked for compliance is outlined in Figure 2.

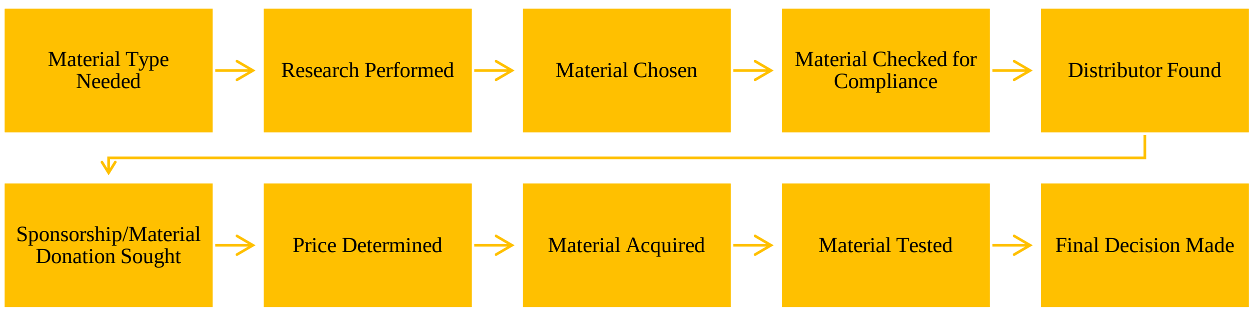


Figure 2. Quality Control Process for All Materials

Lowell took great care to locate, review, and understand MTDS and MSDS of every material that was used. Any important information not provided on either sheet was found either through testing by the relevant 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 during any point in construction or mixing.

Key construction and mix 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 were responsible for all actions performed by untrained members. Lowell's quality control officer and safety officer jointly dictated that no construction or mixing could be done unless a trained team member was present.

As soon as the NCCC 2017 Rules and Regulations were released, Lowell had dedicated members who read either the entire document or individual sections to ensure compliance in all aspects of the project. Team members took notes of all rule changes and the quality control officer could begin checking that all teams were in complete understanding of all relevant rules. With the NCCC providing a Facebook page where all RFI's were answered publicly, all questions and answers could be analyzed by team members on their own time.

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

ORGANIZATION CHART

Co-Project Managers

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

Field Manager

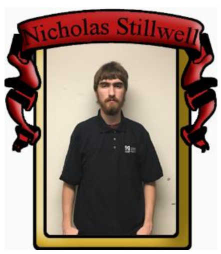
Responsible for managing captains, scheduling, process documentation, and overseeing daily operations.

Mix Design Captain

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

Mix Team

Chris Cantin
Dylan Shaffer
Emily Schneider
Mary Joens
Nicholas Stillwell
Owen Gannon
Pedro Lopez
Steven Htet



Design &Analysis Captain

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

Analysis Team

Campbell Narron
David Nguyen
Shiv Bhardwaj

Construction & Aesthetics Captain

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

Construction Team

Arthur Jacques
Campbell Narron
Chris Cantin
Dylan Shaffer
Emily Schneider
Grace Federiconi
Kat Evasius
Kraig Scharn
Nicholas Stillwell
Pedro Lopez
Zachary Koutonen
Zachary McDonough

Members

Name	Year	Years Involved	Active Participant
Rebecca Gonsalves	Grad	4	3
Zachary McDonough	Grad	4	2
Chris Cantin	Jr	3	0
Shiv Bhardwaj	Jr	3	0
Kristin Bartone	Sr	2	2
Campbell Narron	Jr	2	2
Emily Schneider	Jr	2	2
Nicholas Stillwell	Jr	2	0
Mary Joens	So	2	1
Pedro Lopez	So	2	1
Zachary Koutonen	So	2	0
Alex Buntin	Sr	1	1
Alanna Grondine	Jr	1	1
Ryan Fisk	Jr	1	1
Owen Gannon	Jr	1	0
Arthur Jacques	So	1	0
David Nguyen	So	1	0
Dylan Shaffer	So	1	0
Kraig Scharn	So	1	0
Steven Htet	So	1	0
Kat Evasius	Fr	1	1
Grace Federiconi	Fr	1	0

Faculty Advisor: Gary Howe

Paddling Captain

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

Paddling Team

Alanna Grondine
Alex Buntin
Campbell Narron
Emily Schneider
Josh Gittings
Kat Evasius
Kristin Bartone
Pedro Lopez

Safety Officer

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

Sustainability Officer

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

Graduate Consultants

Rebecca Gonsalves
Zachary McDonough

Quality Control Officer

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

Hull Design and Structural Analysis

The past two years, Lowell used the same hull design. It was originally created for the 2015 entry *Backfire* and was also used for 2016's *Sockeye*. This hull was designed as a planing hull in order to vastly reduce wave drag and wetted hull area. This created a canoe that would accelerate faster and achieve a high speed (*Backfire* 2015). After observing that hull design for two years, Lowell determined that during a race, the amount of time the canoe was moving fast enough to plane was insignificant. Therefore, the team decided to use a new hull design that did not utilize a large bow rocker and instead cut through the water. After analyzing previous hull designs and understanding the limited experience of new paddlers, the team designed primarily for stability and maneuverability.

A flat bottom provides initial stability, whereas a rounded bottom is used for secondary stability. As a racing canoe, secondary stability is the more critical parameter, but initial stability cannot be ignored. By using a rounder bottom toward the bow and a flatter bottom toward the stern, as well as softer chines toward the bow and harder chines toward the stern, an ideal blend of initial and secondary stability was achieved. This hybrid format 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 for improved tracking and turning. The V-notched bow decreases impeded lateral water flow, which means better tracking as well as better maneuverability.

The free surface effect was a new consideration this year. As races progress, paddlers will splash more and more water into the canoe. As that amount of water increases, the moment on the canoe increases as the water moves further from the center of gravity (Gudmundsson 2009). This creates listing, which means a slower and less maneuverable canoe. Lowell considered using one longitudinal rib to combat this effect. However, this rib would be disruptive to paddlers, and as a result this element was disregarded. Instead, three transverse ribs were placed 32 inches apart to prevent longitudinal sloshing of water, as well as to enhance paddler ergonomics and provide transverse support.

An asymmetrical design with the center of gravity located aft of center was chosen to increase maneuverability. Lowell chose flared sidewalls with a slight tumblehome near the gunwales to increase secondary stability and to improve paddler efficiency. *Vanguard*, Lowell's 2014 canoe, had all the parameters that were desired, so it was used as a baseline from which to work and was fine-tuned in Prolines© 7. Efforts were then made to decrease wave drag at 9 ft/s, decrease wetted hull surface area, and increase freeboard. Table 4 shows Lowell's four previous canoes compared to *Jester*.

Table 4. Design Parameters for Two-Male Loading

Canoe Name	*Moswetuset*	*Vanguard*	*Backfire/Sockeye*	*Jester*
Overall Length	236 in	246 in	238 in	246 in
Maximum Depth	13.50 in	12.85 in	13.96 in	13.78 in
Bow Rocker	3.50 in	3.67 in	6.68 in	3.67 in
Stern Rocker	5.00 in	4.64 in	4.64 in	3.91 in
Wave Drag at 9 ft/s	10.75	9.25	6.75	8.78
Wetted Hull Area	31.08 ft^2	32.20 ft^2	30.79 ft^2	32.13 ft^2
Freeboard	8.06 in	7.63 in	8.62 in	8.29 in

Lowell decided to analyze *Jester* in five different loading scenarios: two-male race conditions, two-female race conditions, four-paddler race conditions, two-person carry, and static display. Transportation was not considered, as the canoe will be fully supported during transportation and will receive insignificant stress. Structural analysis spreadsheets were developed in Microsoft Excel to assist the analysis team in performing 2D analysis.

Jester was modeled as a simply supported beam that was subjected to bending about the longitudinal axis. Previous Lowell teams have found that adding ribs and gunwales can reduce critical stresses by up to 43% compared to a featureless canoe (Moswetuset 2013). Ribs had already been added to alleviate the free surface effect and for paddler ergonomics. The decision was made to add gunwales to increase the moment of inertia about this axis and therefore reduce stress in the canoe.

Point loads representing paddler weights were applied to all race conditions. Lowell modeled two-person loading with loads acting at 54 inches and 192 inches aft of bow, and four person-loading with loads acting at 54 inches, 107 inches, 139 inches, and 192 inches aft of bow. A uniform distributed load represented the dead load of the canoe, and a uniform distributed load with an equivalent load equal to the equivalent dead load plus the sum of all point loads represented the buoyant force acting on the canoe as a support.

Two-person carry and static display conditions were nearly identical. Both were modeled with a uniform distributed load representing the dead load of the canoe and two supports representing either the people carrying the canoe or the supports on the stand. For two-person carry, the supports were placed 34 inches and 212 inches aft of bow. For static display, the supports were placed 91 inches and 155 inches aft of bow.

The analysis team used an estimated weight for the canoe of 210 lbs, and chose to use 175 lbs for all male paddlers and 145 lbs for all female paddlers. Shear and moment diagrams created as a result of this comprehensive analysis can be seen in Figure 3. Lowell then calculated maximum tensile and compressive bending stresses at critical locations based on the principles of the mechanics of materials.

The highest bending moment (M_{max}) was found during coed loading, and was located at both 107 and 139 inches aft of bow. The extreme fiber distances were c_t = 8.59 inches and c_c = 4.97 inches. I_x was hand calculated using theories of mechanics of materials. Lowell's analysis team then calculated maximum tensile and compressive bending stresses (σ_b) using Equation 1.

$$\sigma_b = \frac{M_{max}c}{I_x} \quad \text{(EQ 1)}$$

The team 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 this simple 2D analysis. Lowell plotted these magnified stresses alongside *Jester*'s failure envelope (Development and Testing, Page 8), and determined that *Jester* would be strong enough to withstand all combinations 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 *Jester*

Parameter	Demand (psi)
Tensile	115
Compression	67

Development and Testing

With the introduction of the new rule that 25% of aggregate volume must not be glass microspheres and/or cenospheres and must be compliant with ASTM C330, the mix design team faced a big challenge. The team needed to find a suitable material that would keep the unit weight of concrete low without vastly reducing concrete strength. Because the mix design team was mostly young and inexperienced, Lowell decided to rely upon research done by previous teams to find a baseline mix that could be updated based on new research and testing.

Jester's analysis team reported a magnified tensile stress of 115 psi, which was used as the governing stress in the canoe. In order to reach this requirement, Lowell used *Backfire*'s mix as a baseline (0.65 w/cm, 40% CP, 390 psi tensile strength, 1800 psi compressive strength) to begin the design process as shown in Figure 4.

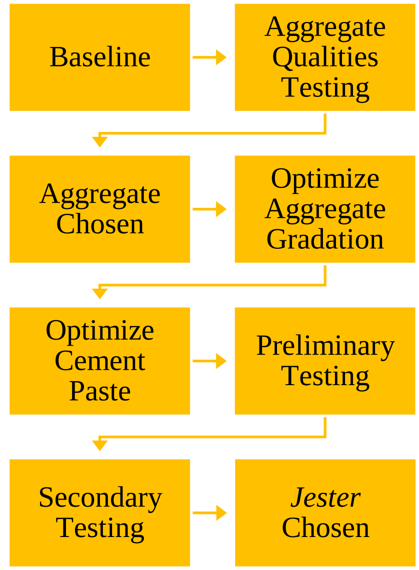


Figure 4. Iterative Design Approach

After selecting a baseline mix from which to work, Lowell began investigating different lightweight aggregates that could be used to comply with the rule that 25% of aggregate volume must be compliant with ASTM C330. Pumice, perlite, and expanded shale were three options that were made available to the mix design team. The team considered Perlite because it is an ultra-lightweight material, and could help keep the unit weight very low. The first bag of perlite received was promising due to its weight, appearance, low cost, and properties. However, before a test mix had been made, the mix design team found they had been unintentionally misinformed by the supplier; the perlite was not certified under ASTM C330, but rather under ASTM C331 and C332.

Pumice was the next material to be examined. While pumice powder can be used as a cementitious material, the particle size of pumice as an aggregate is much larger, and therefore has no cementing properties. Pumice forms as a volcano's molten lava rapidly cools. As this occurs, gas bubbles in the lava become trapped inside the solid being formed (Chandra and Berntsson 2002). After the team acquired free samples of pumice, problems arose. Only two of the three samples were compliant with ASTM C330. However, these two forms of pumice were mine grade pumice, and were visually unappealing. They were also far denser and more absorbent than the processed pumice, which met all the requirements of the mix team except for gradation. Unable to procure a custom gradation of processed pumice in time for testing, the mix design team had to once again look elsewhere.

Expanded shale is a processed material that derives from shale, a sedimentary rock. Expanded shale is created inside a rotary kiln, where gas bubbles form inside the heated shale. Once cooled, expanded shale contains gas bubbles inside the particle, not outside. This means that not only is expanded shale a lightweight aggregate, with a typical oven dry specific gravity around 1.5, but it also is far less absorbent than other lightweight aggregates. This combination of being lightweight and having a low absorption made for exactly the material the mix design team was looking for, and after material was donated to the team, testing could begin.

Before preliminary mixes could be made, Lowell needed to determine important material properties of expanded shale. Using ASTM C128, the team calculated oven-dry specific gravity, saturated surface-dry specific gravity, and absorption. Using ASTM C566, the team determined as-received moisture content. With these values, corrections for hydration sources could be accurately calculated, and a consistent mix could be accomplished.

Bond strength of Portland cement based concrete is directly related to the hydration of Portland cement. During the hydration reactions of belite (C_2S) and alite (C_3S), calcium-silicate-hydrate (C-S-H) and hydrated lime (CH) are produced. This is shown in Equations 2 and 3, respectively.

$$2C_2S + 7H_2O \rightarrow C\text{–}S\text{–}H + CH \qquad \text{(EQ. 2)}$$

$$2C_3S + 7H_2O \rightarrow C\text{–}S\text{–}H + 3CH \qquad \text{(EQ. 3)}$$

Hydrated lime is hydrophilic and will continuously weaken concrete over time. In the concrete matrix, hydrated lime crystals will stack on each other, creating large zones where colloidal C-S-H gel cannot fill. This results in weak spots in the poorly proportioned concrete matrix. Alternatively, in a matrix created by adding pozzolans to the mix, pozzolanic filler and colloidal C-S-H fill the voids. Lowell was able to eliminate the impact of hydrated lime by taking the CH created in Equations 2 and 3 and using it as the limiting reagent in the pozzolanic reaction (Equation 4):

$$\text{Pozzolan} + CH \rightarrow C\text{–}S\text{–}H \qquad \text{(EQ. 4)}$$

By considering both molar weights and percentage by volume of each material used in the hydration process, volumetric proportions for type 1 Portland cement, high-reactivity metakaolin, and silica fume were perfected at 70%, 20%, and 10% respectively. A comparison of a high hydrated lime content cement matrix against an ideal one is shown in Figure 5.

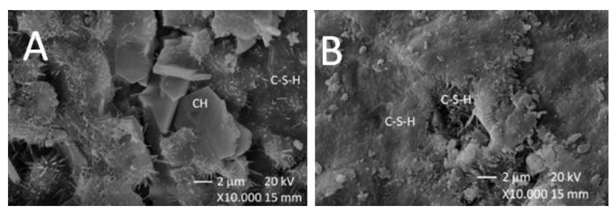


Figure 5. Comparison of (A) High Lime Content Matrix and (B) Ideally Proportioned Matrix (Trigo and Liborio 2014)

This was a much larger aggregate than normally used by Lowell, so previous mix designs were no longer useful as a baseline for aggregate gradation. Dating back to *Mosswetuset* in 2013, all of Lowell's competition canoes have used multiple sizes of glass microspheres in a distribution that maximizes the bonding surface area of concrete. By holding this gradation constant and decreasing hydrated lime content, stresses can be decreased within the interfacial transition zone by allowing more bonding potential due to increased C–S–H content (Kosmatka et al. 2011). Without this consistent aggregate gradation, the effects of previously tested aggregate gradation were no longer useful. As K15 has a lower specific gravity than S38HS, K15 was chosen to be the only aggregate used in addition to expanded shale. Because of its comparatively high specific gravity, the expanded shale was limited to 25% by volume, with K15 taking up the final 75%.

Jester's mix was designed to withstand all stresses after 3/8 inch PVA fibers were added to the mix in a volumetric proportion of 2%. However, as a factor of safety, fiberglass and basalt reinforcement meshes were added across the entire hull to increase resistance to flexure and punching shear, and basalt mesh strips were placed in gunwales and ribs. Basalt mesh was a new addition, as it could provide for more flexural strength than bidirectional carbon grid (BCG) (*El Fey* 2016). Lowell has used fiberglass and BCG together since 2014, as the two layers of mesh supplement the concrete in resisting tensile forces, flexure, and punching shear. With no more BCG available to the team, and knowing that basalt mesh would be a better alternative, the team decided to invest in basalt mesh for the canoe. Enough basalt mesh was purchased for Lowell to use in at least two future canoes. The team chose a layering scheme where one layer of basalt mesh and one layer of fiberglass mesh would be placed directly next to each other in the middle of the layers of concrete.

This year's team considered two admixtures: Eclipse® Floor 200 Shrinkage Reducer and ADVA® Cast 575 Super Plasticizer. These admixtures were used at the manufacturer's minimum recommended dosage rates in order to decrease shrinkage and achieve desired workability. Silpro® C-21 Liquid Latex was used as the sole hydration source, and it contained a solids content of 20%. This dosage of latex was able to entrain air at 17.04% by volume, which kept the unit weight of concrete down without causing pocketing. Due to the small volumes of shrinkage reducer and super plasticizer per batch, but the large number of batches needed for placement day, numerous small containers capable of holding and delivering liquid were required. For this, team members collected plastic water bottles destined to be thrown away, and after their use they were properly cleaned and recycled.

Beginning preliminary testing, Lowell chose to save on material cost and reduce its environmental footprint by using 2x4 cylinders in place of 3x6 cylinders for tension testing (ASTM C496) and compression testing (ASTM C39). The cylinders meant that testing required about 1/5 of the materials necessary, which meant a decreased environmental footprint. Flexure beams were tested under third point loading (ASTM C1609).

Backfire's 0.65 w/cm mix was used as a baseline to create a variety of mixes. Preliminary testing found a major flaw in the preliminary w/cm for the new mix. All of these mixes were soupy and entirely unworkable. This was not a small deviation from the desired workability, but was a large step outside the range of acceptable workabilities. Major adjustments needed to be made to the w/cm ratio, and the mix team designed a second set of mixes. For this second set, w/cm ranged from 0.40 to 0.55. This time, the workabilities were in the range that Lowell was looking for. Ultimately, a mix with w/cm of 0.45 was chosen due to its ideal workability and high tensile strength.

The final engineering properties of *Jester*'s mix were determined from 3x6 cylinders and flexure beams, all of which were cast on placement day. 28-day tensile and compressive strengths were used in Mohr's Failure Theory (Beer et al. 2012) to formulate a failure envelope. This envelope was plotted against the Mohr's stress circle (Figure 6), and the mix was determined to be strong enough for all types of stress. A comparison of this mix with four of Lowell's previous canoes is in Table 6.

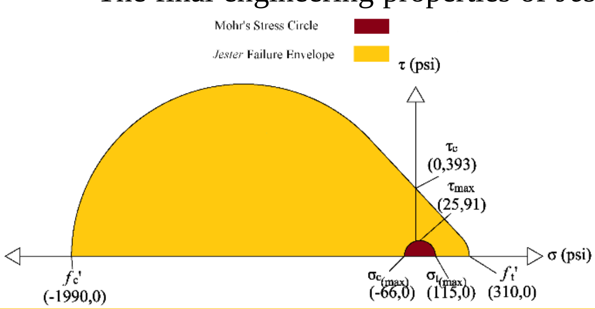


Figure 6. Mohr's Failure Envelope Plot

Table 6. Comparison of Lowell Mixes

Canoe	w/cm	%CP	Unit Weight (pcf)	Tensile Strength (psi)	Compressive Strength (psi)
Jester	0.45	40%	61.9	310	1990
Sockeye	0.65	40%	44.3	330	940
Backfire	0.65	40%	40.5	390	1800
Vanguard	0.6	35%	41.1	240	1158

Construction

Following the completion of the hull design, the process of creating the mold for the canoe began. Previous teams had researched the possibility of using a CNC milling machine to create the mold for the canoe, but had not been able to locate a machine to use. After discussions with the Plastics Engineering department at UMass Lowell, the team reached an agreement to use the 3-axis machine on school premises. The use of this machine would create a much more accurate mold than previous techniques, and would vastly reduce the amount of time necessary to cut and shape the mold. This was an entirely new method of creating the mold and techniques were developed as the process began.

A shell of the canoe created in Prolines© 7 was transferred to Solidworks where the rest of the features in the canoe could be created (gunwales, bulkheads, and ribs). A complete male mold was then modeled from this completed canoe model. The mold model was then sectioned in various sizes so that each section could fit in the machine. After being split longitudinally down the middle, the mold was cut into 6 sections per half with lengths ranging from 32 inches to 39 inches. Each of these 12 sections was then converted to an appropriate file type and brought into Mastercam, where similar cutting paths were planned for each section. Based on the geometry of the mold and machine, Lowell was required to purchase a new tool and holder because the Plastics Department did not own a combination that could cut the mold adequately. Once all cutting paths were completed, they were converted to G-code that could be read by the CNC milling machine.

Lowell chose extruded polystyrene (XPS) foam as the mold material. XPS is water resistant, strong enough to support the load of concrete placed upon it, and has a small cell structure. Thus, being milled in a CNC milling machine would not damage the foam by pulling chunks out. 2-inch thick XPS sheets were rough cut and glued together to create custom sized foam blocks that could fit in the machine. In order to keep the end mill from hitting the table when the toolpath brought the bit slightly below the bottom of the section, each block was placed on a 1/2-inch thick sheet of foam. The block and the sheet were both secured to a 3/4-inch plywood board that was bolted to the cutting table. The team took care to ensure that the back edges of each block, sheet, and board were flush with each other before every cut began. This reduced the setup time between milling sections and also maintained a consistent product in the machine.

Sections took between 1.5 and 4 hours to cut, ending with a finishing raster pass creating a scallop height of 0.015 inches. The individual sections were then glued together to create a full mold, and the mold was briefly sanded in order to eliminate the scalloping. A comparison of the finish can be seen in Figure 7. Some imperfections remained after this sanding, and a thin layer of joint compound was applied to the mold. Once hardened, the joint compound was sanded to create a smooth finish. Three ribs were hand routed into the mold spaced 32 inches apart (Hull Design and Structural Analysis, Page 5). These ribs were not cut during machining of each section due to limitations of the machine and tools. After the ribs were routed, a thin coat of polyurethane was applied to prevent joint compound absorbing moisture from the concrete during placement and curing.

Figure 7. Comparison of Machine Finish vs. Sanded Finish

Aesthetic elements were then projected onto the mold and routed in the center of the canoe, where the surface is flatter and paddlers sit less frequently. This is the first year Lowell has used this technique to create 3D elements in this area of the canoe; previous attempts at making 3D elements had been limited to the bulkheads and sidewalls. Release agent was sprayed on the mold as the last preparation before placement occurred.

Jester was placed in early February. Two days before placement, all dry cementitious materials were hand-sieved to aid a more consistent mix. The day before placement, all dry materials were batched out, and on placement day all wet materials were added to pre-batched buckets. All materials were measured by weight, using multiple identical scales that read values to the nearest .00001 pounds.

Placement of the concrete travelled from the bow to the stern, starting with a 3/16 inch first layer, integrally colored with red pigment. Wooden depth checkers were used to maintain a constant thickness throughout each concrete layer. Before the second layer, basalt mesh was placed along the length of the hull, followed by a smear of concrete to keep the mesh in place so that fiberglass mesh could also be placed along the length of the hull. As each type of mesh had the same size openings, efforts were made to keep the grids aligned with each other as best as possible. Each rib received a strip of basalt mesh, and gunwales received two strips of basalt mesh. This created a skeletal reinforcement structure for the canoe.

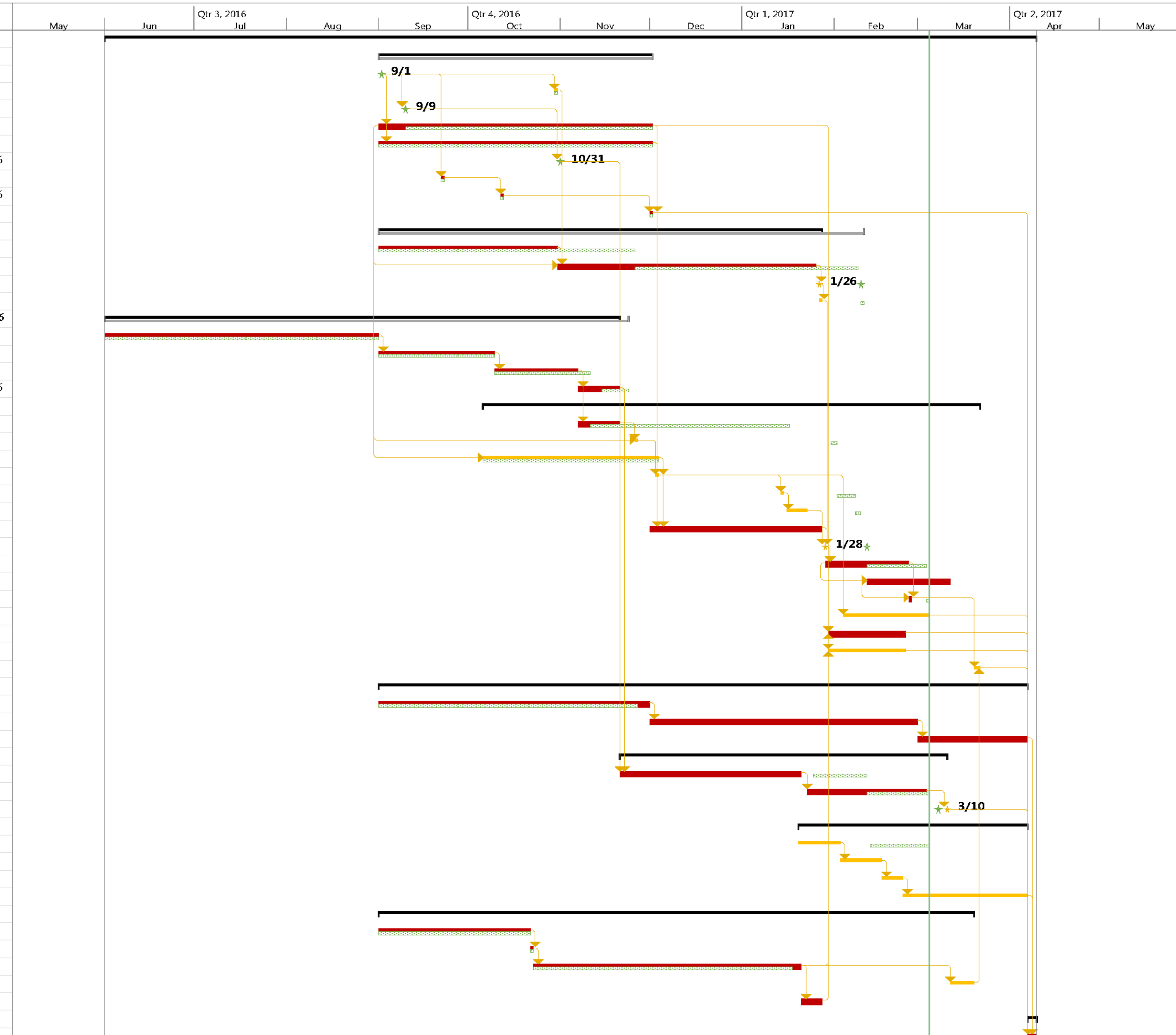
Just before the first layer reached the 3D elements, the routed areas received concrete in different colors, and were immediately covered up by the continuing first layer. A second layer of 1/4 inch concrete followed behind the first layer. The second layer was composed of different stripes of colors. In order to determine the locations where concrete would change colors, string was laid on top of the first layer. The second layer was placed up to the string, at which point the string was removed and colors changed. At the completion of the second layer, the total hull thickness was 1/2 inch, providing a buffer to account for irregularities that were sanded down to complete the average hull thickness of 3/8 inch.

Jester was kept in a humidified environment for the first 5 days of its curing cycle. Subsequently, it was covered in permeable burlap fabric, and an intermittent misting system was switched on. After Jester had been in the hydration tent for 14 days, the burlap fabric was removed and wet sanding began. At the 21^{st} day, *Jester* was removed from the hydration tent. Team members checked whether the canoe was receiving sufficient moisture; if concrete dries during a 21-day moist curing cycle, the maximum strength of the concrete may not be achieved even if moisture is resupplied (Neville and Brooks 2010). The inclusion of an intermittent misting system was a benefit that reduced electrical consumption, as only a small amount of electricity is required to run it compared to the amount needed to run multiple humidifiers 24 hours a day for 21 days.

Starting with wet sanding at 60-grit sandpaper, Lowell's construction team worked for a week to shape the exterior of the hull using Lowell's refined shadow sanding technique. The mold was then removed from the table and the canoe was flipped onto stands. The mold was then carefully removed by cutting out sections at mid-span until enough had been removed to pry sections out of the rest of the mold and canoe. Excess joint compound on the interior of the canoe was removed thereafter. Team members will dry sand and progress to 1500-grit sandpaper. Vinyl lettering will be adhered at the bow and stern, and two layers of sealer will be applied, resulting in a smooth and glossy finish.

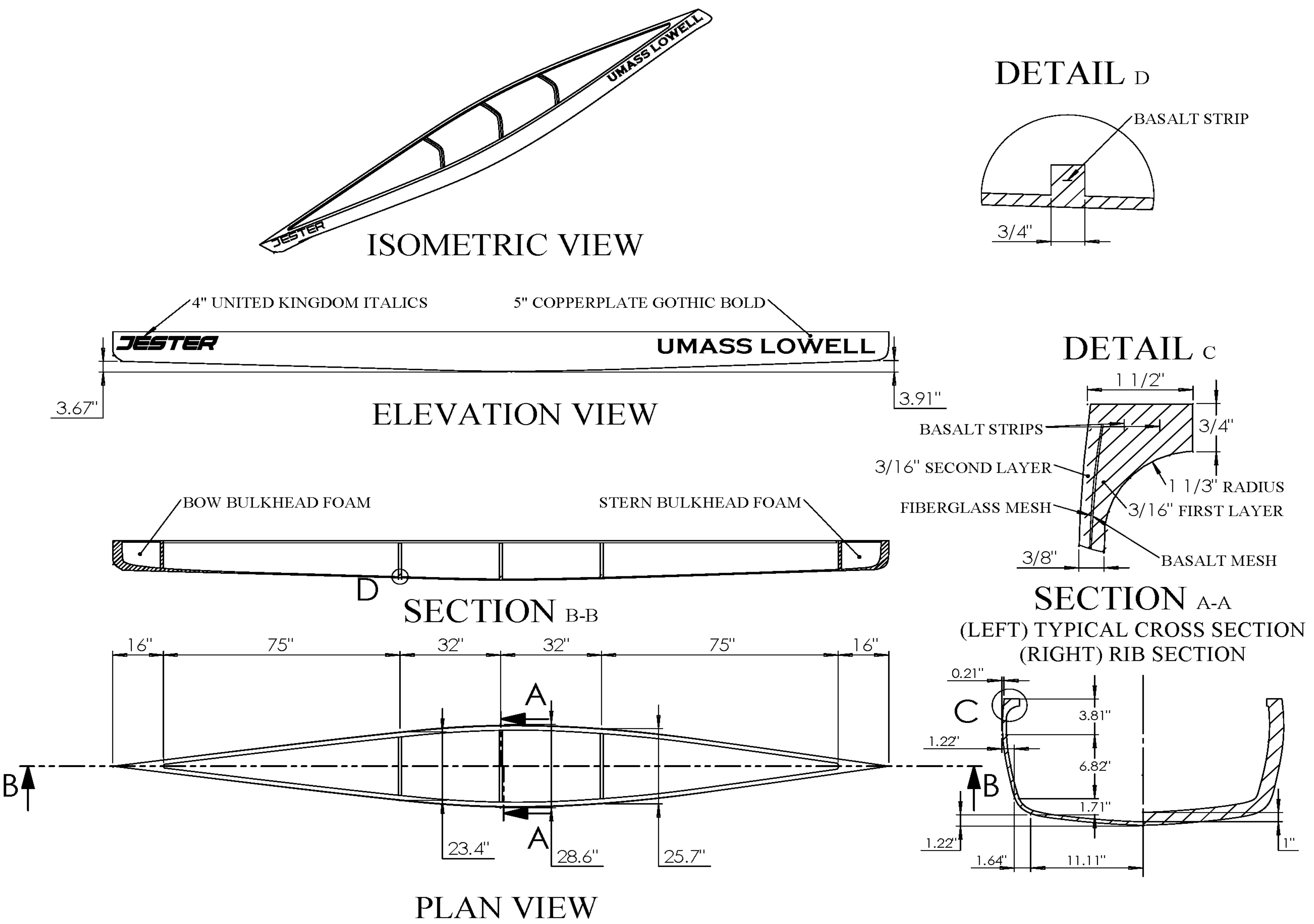
Project Schedule

ID	Task Name	Planned Start	Planned Finish	Actual Start	Actual Finish
1	**UMass Lowell Concrete Canoe Project**	**Wed 6/1/16**	**Sun 4/9/17**	**Wed 6/1/16**	**NA**
2	**Project Management**	**Thu 9/1/16**	**Thu 12/1/16**	**Thu 9/1/16**	**Thu 12/1/16**
3	Project Planning Meeting	Thu 9/1/16	Thu 9/1/16	Thu 9/1/16	Thu 9/1/16
4	Safety Inspection of Laboratory Facilities	Sun 10/30/16	Sun 10/30/16	Sun 10/30/16	Sun 10/30/16
5	Rules Released	Fri 9/9/16	Fri 9/9/16	Fri 9/9/16	Fri 9/9/16
6	Material Procurement	Thu 9/1/16	Thu 12/1/16	Sat 9/10/16	Thu 12/1/16
7	Outreach and Recruitment	Thu 9/1/16	Thu 12/1/16	Thu 9/1/16	Thu 12/1/16
8	Preliminary Project Schedule Submitted	Mon 10/31/16	Mon 10/31/16	Mon 10/31/16	Mon 10/31/16
9	First General Meeting	Thu 9/22/16	Thu 9/22/16	Thu 9/22/16	Thu 9/22/16
10	Second General Meeting	Wed 10/12/16	Wed 10/12/16	Wed 10/12/16	Wed 10/12/16
11	Team Chosen	Thu 12/1/16	Thu 12/1/16	Thu 12/1/16	Thu 12/1/16
12	**Mix Design**	**Thu 9/1/16**	**Fri 1/27/17**	**Thu 9/1/16**	**Fri 2/10/17**
13	Mix Design Material Research	Thu 9/1/16	Sun 10/30/16	Thu 9/1/16	Fri 11/25/16
14	Mix Design Testing	Mon 10/31/16	Wed 1/25/17	Sat 11/26/16	Wed 2/8/17
15	Jester Mix Selected	Thu 1/26/17	Thu 1/26/17	Thu 2/9/17	Thu 2/9/17
16	Placement Day Pre-Batching	Fri 1/27/17	Fri 1/27/17	Fri 2/10/17	Fri 2/10/17
17	**Hull Design**	**Wed 6/1/16**	**Sun 11/20/16**	**Wed 6/1/16**	**Wed 11/23/16**
18	Hull Design Research and Evaluation of Sockeye	Wed 6/1/16	Wed 8/31/16	Wed 6/1/16	Wed 8/31/16
19	Hull Design in Prolines 7	Thu 9/1/16	Sun 10/9/16	Thu 9/1/16	Sun 10/9/16
20	Hull Modeling in Solidworks	Mon 10/10/16	Sun 11/6/16	Mon 10/10/16	Thu 11/10/16
21	Structural Analysis	Mon 11/7/16	Sun 11/20/16	Tue 11/15/16	Wed 11/23/16
22	**Construction**	**Thu 10/6/16**	**Tue 3/21/17**	**Thu 10/6/16**	**NA**
23	Mold Planned in Solidworks and Mastercam	Mon 11/7/16	Sun 11/20/16	Fri 11/11/16	Mon 1/16/17
24	Practice Mold Cut in CNC Machine	Sat 11/26/16	Sat 11/26/16	Tue 1/31/17	Wed 2/1/17
25	Table Updated	Thu 10/6/16	Sat 12/3/16	Thu 10/6/16	Sat 12/3/16
26	Practice Placement Day (DID NOT OCCUR)	Sat 12/3/16	Sat 12/3/16	NA	NA
27	Jester Mold Cut in CNC Machine	Sat 1/14/17	Sat 1/14/17	Thu 2/2/17	Tue 2/7/17
28	Mold Finished by Hand	Mon 1/16/17	Sun 1/22/17	Wed 2/8/17	Thu 2/9/17
29	Cooling System Re-Design (DID NOT OCCUR)	Thu 12/1/16	Fri 1/27/17	NA	NA
30	Jester Placement Day	Sat 1/28/17	Sat 1/28/17	Sat 2/11/17	Sat 2/11/17
31	Jester Moist Curing	Sun 1/29/17	Sat 2/25/17	Sun 2/12/17	Fri 3/3/17
32	Jester Sanding	Sun 2/12/17	Sat 3/11/17	Sat 2/25/17	NA
33	Jester Mold Removal	Sun 2/26/17	Sun 2/26/17	Sat 3/4/17	Sat 3/4/17
34	Sectional Construction	Sat 2/4/17	Sat 3/4/17	Sat 2/25/17	NA
35	Display Table Construction	Mon 1/30/17	Fri 2/24/17	Wed 2/1/17	NA
36	Stand Construction	Mon 1/30/17	Fri 2/24/17	Wed 2/1/17	NA
37	Canoe Sealing	Mon 3/20/17	Tue 3/21/17	NA	NA
38	**Paddling**	**Thu 9/1/16**	**Thu 4/6/17**	**Thu 9/1/16**	**NA**
39	Fall Try-Outs/Practice	Thu 9/1/16	Wed 11/30/16	Thu 9/1/16	Sat 11/26/16
40	Off-Season Conditioning	Thu 12/1/16	Tue 2/28/17	Thu 12/1/16	NA
41	Spring Paddling Practice	Wed 3/1/17	Thu 4/6/17	NA	NA
42	**Paper**	**Mon 11/21/16**	**Fri 3/10/17**	**NA**	**NA**
43	Design Paper Rough Drafts	Mon 11/21/16	Fri 1/20/17	Wed 1/25/17	Sat 2/11/17
44	Design Paper Editing	Mon 1/23/17	Fri 3/3/17	Sun 2/12/17	Sat 3/4/17
45	Design Paper Submitted	Fri 3/10/17	Fri 3/10/17	Tue 3/7/17	Tue 3/7/17
46	**Presentation**	**Fri 1/20/17**	**Thu 4/6/17**	**Mon 2/13/17**	**NA**
47	Presentation Script Development	Fri 1/20/17	Thu 2/2/17	Mon 2/13/17	Sat 3/4/17
48	Presentation Design	Fri 2/3/17	Thu 2/16/17	Sun 3/5/17	NA
49	Presentation Peer Critique	Fri 2/17/17	Thu 2/23/17	NA	NA
50	Presentation Practice	Fri 2/24/17	Thu 4/6/17	NA	NA
51	**Aesthetics**	**Thu 9/1/16**	**Sun 3/19/17**	**Thu 9/1/16**	**NA**
52	Theme Research	Thu 9/1/16	Fri 10/21/16	Thu 9/1/16	Fri 10/21/16
53	Theme Chosen	Sat 10/22/16	Sat 10/22/16	Sat 10/22/16	Sat 10/22/16
54	Theme Development	Sun 10/23/16	Fri 1/20/17	Sun 10/23/16	Tue 1/17/17
55	Canoe Aesthetics	Sun 3/12/17	Sun 3/19/17	NA	NA
56	Display Aesthetics	Sat 1/21/17	Fri 1/27/17	NA	NA
57	**Competition**	**Fri 4/7/17**	**Sun 4/9/17**	**NA**	**NA**
58	New England Regional Competition	Fri 4/7/17	Sun 4/9/17	NA	NA



2017 UMass Lowell Project Schedule | Planned Tasks | Planned Milestones | Critical Tasks | Planned Summary | Actual Tasks | Actual Summary | Actual Milestones

Construction Drawing



UMass Lowell

Bill of Materials	
Qty.	Description
48.37 lbs.	Portland Cement
4.83 lbs.	Silica Fume
11.41 lbs.	Metakaolin
6.44 lbs.	K15
22.18 lbs.	Expanded Shale
1.94 lbs.	Pigment
3.69 gal.	Latex
2.57 lbs.	PVA Fibers
13.23 fl. oz.	HRWR
16.95 fl. oz.	SRA
60 sq. ft.	Basalt Mesh
60 sq. tt.	Fiberglass Mesh
2 cub. ft.	XPS Foam
1 gal.	Sealing Agent

JESTER
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	Campbell Narron
Drawn	Campbell Narron
Checked	Emily Schneider
Date	3/3/17

Appendix A – References

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Appendix B – Mixture Proportions

MIXTURE DESIGNATION: *JESTER* (COLOR VARIES, MIX WITH YELLOW PIGMENT IS SHOWN)

CEMENTITIOUS MATERIALS

Component	Specific Gravity	Volume (ft³)	Amount of CM (mass/volume) (lb/yd³)	
Type 1 White Portland Cement	3.15	3.00	590.66	Total Amount of cementitious materials 788.88 lb/yd³ c/cm ratio 0.71
White Silica Fume	2.20	0.43	58.93	
High-Reactivity Metakaolin	2.60	0.86	139.29	

FIBERS

Component	Specific Gravity	Volume (ft³)	Amount of Fibers (mass/volume) (lb/yd³)	
.375" PVA Fibers	1.30	0.39	31.34	Total Amount of Fibers 31.34 lb/yd³

AGGREGATES

Aggregates	ASTM C330	Abs (%)	MC_{stk} (%)	SG_{SSD}	Base Quantity (lb/yd³) OD	Base Quantity (lb/yd³) SSD	$Volume_{SSD}$ (ft³)	Batch Quantity (at MC_{stk}) (lb/yd³)
3M™ K15	N	0	0	0.15	78.65	78.65	8.40	78.65
Expanded Shale	Y	13.7	5.1	1.78	270.91	308.14	2.77	284.73

ADMIXTURES

Admixture	lb/gal	Dosage (fl.oz/cwt)	% Solids	Amount of Water in Admixture (lb/yd³)	
Silpro C-21 Latex	9.2	792.19	20%	359.34	Total Water from Admixtures, $\sum w_{admx}$ 378.41 lb/yd³
ADVA® Cast 575 HRWR	8.9	20.48	40%	6.74	
Eclipse® Floor 200 SRA	7.7	26.24	1%	12.33	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)

Component	Specific Gravity	Volume (ft³)	Amount (mass/volume) (lb/yd³)	
Silpro C-21 Latex	1.87	0.77	89.84	Total Solids from Admixtures 108.51 lb/yd³
Yellow Pigment	4.20	0.09	23.67	

WATER

	Amount (mass/volume) (lb/yd³)		Volume (ft³)
Water, lb/yd³		w: 355.00	5.69
Total Free Water from All Aggregates, lb/yd³		$\sum w_{free}$: -23.41	
Total Water from All Admixtures, lb/yd³		$\sum w_{admx}$: 378.41	
Batch Water, lb/yd³		w_{batch}: 0	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	fibers	aggregates	solids	water	Total
Mass of Concrete, M, (lb)	788.88	31.34	386.79	108.51	355.00	∑M: 1670.52
Absolute Volume of Concrete, V, (ft³)	4.29	0.39	11.17	0.86	5.69	∑V: 22.40
Theoretical Density, T, (=∑M / ∑V)	74.58 lb/ft³		Air Content [= (T – D)/T x 100%]			17.04%
Measured Density, D	61.87 lb/ft³		Slump, Slump flow			0.5 in.
water/cement ratio, w/c:	0.60		water/cementitious material ratio, w/cm:			0.45

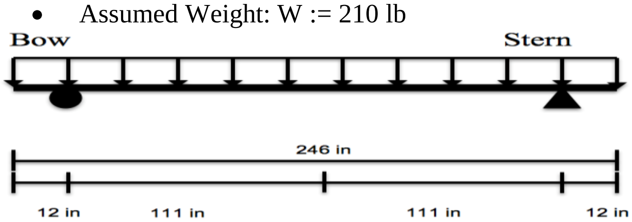
Appendix C – Example Structural Calculations

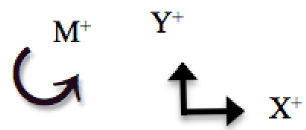
Assumptions:

- Canoe is simply-supported on display stands
- Stands located 1 foot (12 in) from ends at an equal height

Canoe Properties:

- Overall length: L := 246 in
- Assumed Weight: W := 210 lb





Critical Shear, V(x) and Critical Moment, M(x):

X_0 := 0 in X_1 := 12 in X_2 := 123 in X_3 := 234 in X_4 := 246 in

Load Constant, *w* := (Distributed Weight) / (Length) → (210 lb / 246 in) := 0.854 lb/in

M_A := 0 := $F_{BY}(X_3 - X_1) - W((X_4/2) - X_1)$

0 := (F_{BY})(234 in – 12 in) – (210 lb)((246 in/ 2) – 12 in)

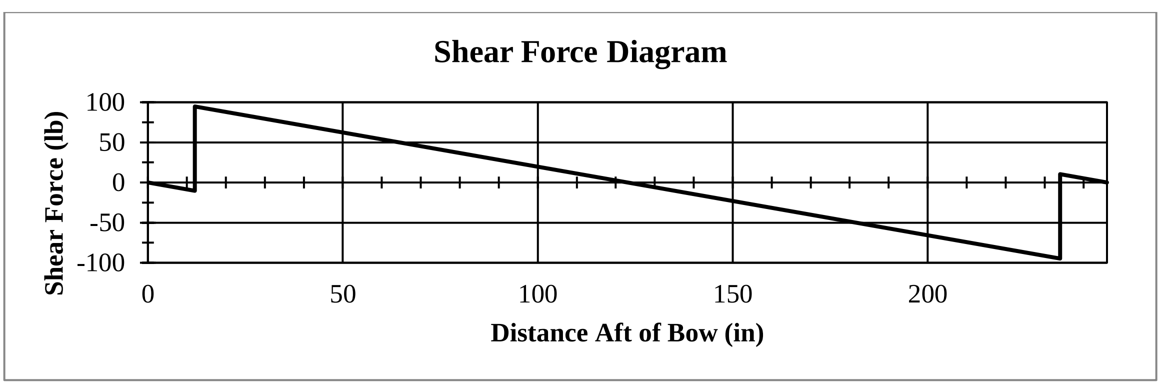
F_{BY} := 110 lb

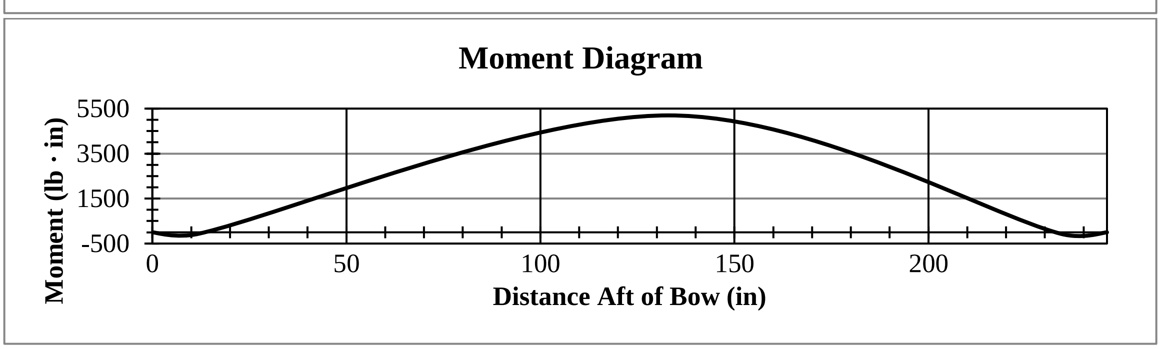
Loads are distributed Symmetrically

F_{BY} := F_{AY} := 110 lb

Table 1:

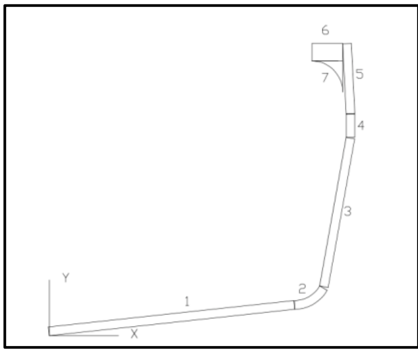
Location/Distance:	**Shear Diagram:**	**Moment Diagram:**
X_0 := 0 in	$V_0 := w \cdot X_0$:= 0 lb	M_0 := ($V_0 \cdot X_0$)/ 2 := 0 lb · in
$\Delta X_{0\to1}$:= 12 in	$V_1 := V_0 + w \cdot \Delta X_{0\to1}$:= - 10.24 lb	$M_1 := M_0 + (V_1 \cdot \Delta X_{0\to1})$/ 2 := - 61.46 lb · in
X_1 := 12 in	$V_2 := V_1 + F_{AY}$:= 94.76 lb	
$\Delta X_{1\to2}$:= 111 in	$V_3 := V_2 + w \cdot \Delta X_{1\to2}$:= 0 lb	$M_2 := M_1 + (V_2 \cdot \Delta X_{1\to2})$/ 2 := 5,197.50 lb · in
$\Delta X_{2\to3}$:= 111 in	$V_4 := V_3 + w \cdot \Delta X_{2\to3}$:= -94.76 lb	$M_3 := M_2 + (V_4 \cdot \Delta X_{2\to3})$/ 2 := - 61.46 lb · in
X_3 := 234 in	$V_5 := V_4 + F_{BY}$:= 10.24 lb	
$\Delta X_{3\to4}$:= 12 in	$V_6 := V_5 + w \cdot \Delta X_{3\to4}$:= 0 lb	$M_4 := M_3 + (V_5 \cdot \Delta X_{3\to4})$/ 2 := 0 lb · in





Moment of Inertia:

*Note: Moment of Inertia values were obtained by transforming the cross section into simple geometric shapes. By using the following formulas, with the help of hand-drafting tools, for calculations



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	1.96	0.05	15.39
2	0.56	2.00	1.13	1.13	0.59	1.31
3	2.42	5.31	12.87	12.87	8.44	409.86
4	0.38	8.99	3.37	3.37	0.03	4.29
5	1.13	10.99	12.46	12.46	0.86	176.73
6	1.00	12.13	12.10	12.10	0.05	146.17
7	0.38	11.05	4.19	4.19	-0.35	6.32

$I_{x\ half}$:= 760.09 in^4
I_x := 1,520.17 in^4

Y := $\Sigma A\bar{y}/\Sigma$Area

ΣArea := 9.89 in^2
ΣAy := 49.14 in^3

Y := 4.97 in

Formulas used for finding segment areas and moment of inertia:

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

$A_{Rectangle} := b \bullet h$ $\qquad$ $I_{xRectangle} := (b \bullet h^3)/12$

Formulas for segment 2:

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

Formulas used to find segment 7:

$A_{Square} - A_{Circle} \rightarrow := [b^2] - [(\pi \bullet r^2)/4]$ $\qquad$ $I_{xSquare} - I_{xCircle} := [(\pi)(r^4)]/\ 16$

Determination of Maximum Compressive and Tensile Stresses:

Height of sectional: 13.56 in
c_c:= -Y := - 4.97 in
c_t:= Height – Y := 8.59 in

Dynamic Amplification Factor, DAF: DAF := 1.25 (Paradis, 2007)
Mix Design Safety Factor, MDF: MDF := 2.5

Design Compressive Stress:

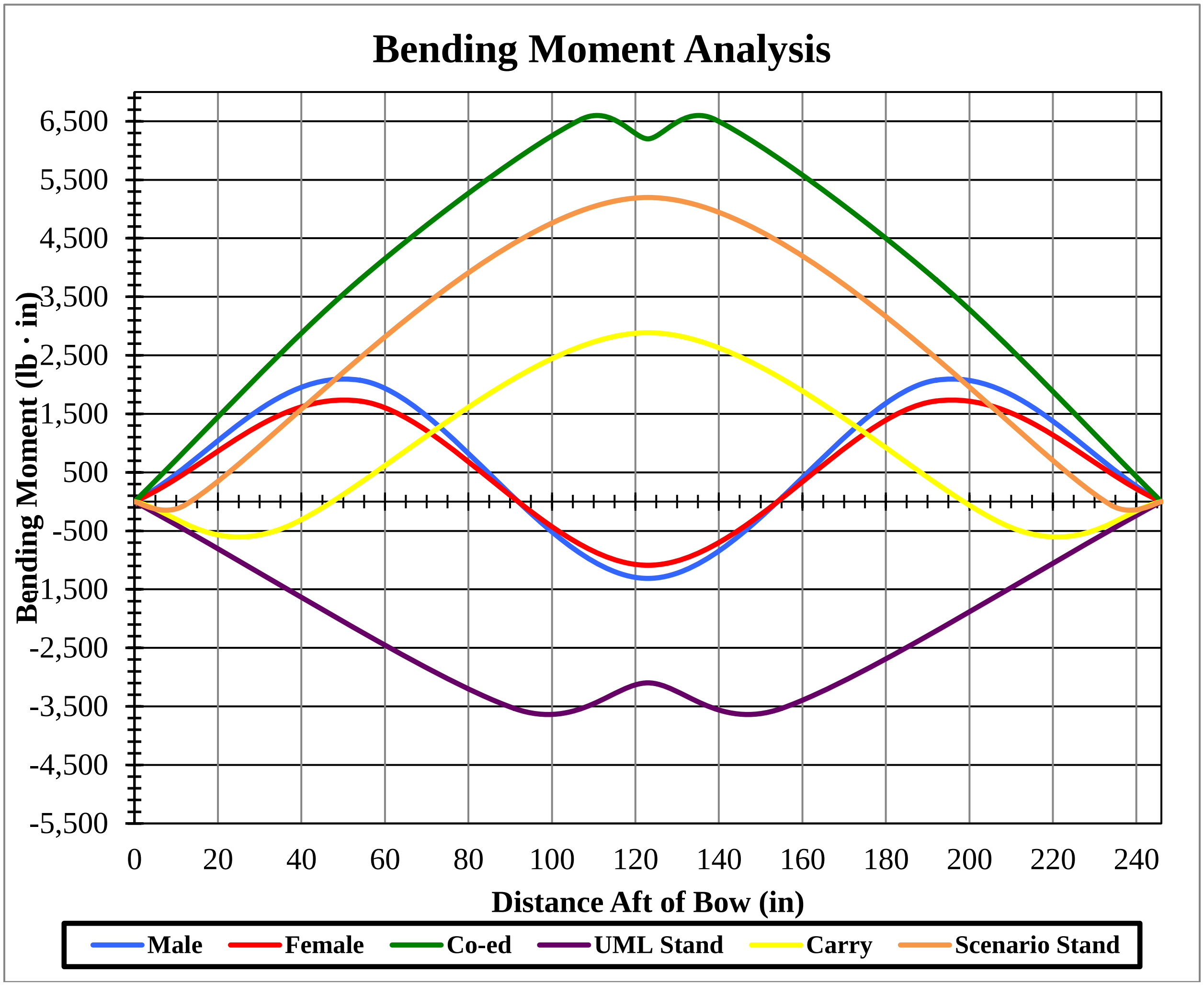
$f_{cMax} := (DAF \bullet MDF \bullet M_{Max} \bullet C_c) / I_x$
$f_{cMax} := [(1.25) \bullet (2.5) \bullet (5{,}197.50\ lb \bullet in) \bullet (-4.97\ in)]/\ 1{,}520.17\ in^4 := -53.10\ lb/\ in^2$

Design Tensile Stress:

$f_{tMax} := (DAF \bullet MDF \bullet M_{Max} \bullet C_t) / I_x$
$f_{tMax} := [(1.25) \bullet (2.5) \bullet (5{,}197.50\ lb \bullet in) \bullet 8.59\ in)]/\ 1{,}520.17\ in^4 := 110.13\ lb/\ in^2$

Assumptions:

- Canoe is modeled as a simply supported beam
- Paddler loads have been assumed as point loads
- Dead load is considered to be uniform across the length of the canoe
- Buoyant load is considered to be uniform across the length of the canoe



Situation:	Max Bending Moment (lb · in):
Male	2,074.39
Female	1,718.78
Co-ed	6,532.58
UML Stand	3534.57
Carry	2,887.50
Scenario Stand	5,197.50

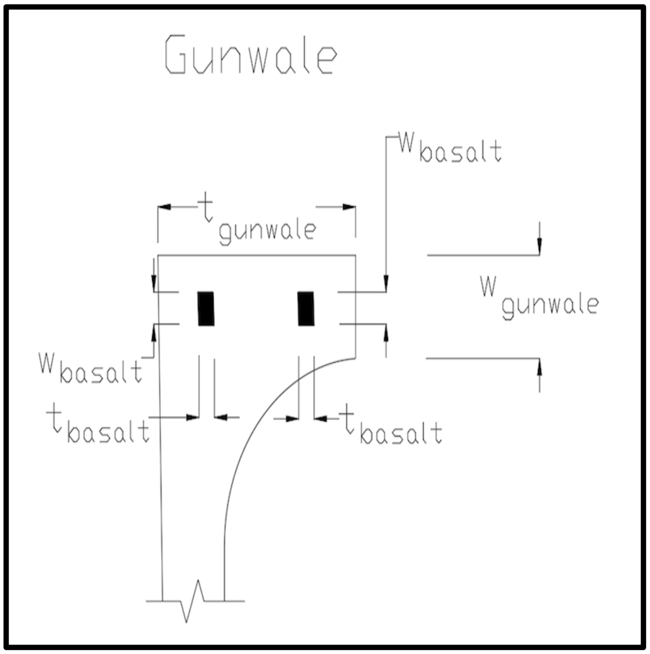
Appendix D – Hull Thickness/Reinforcement and Percent Open Area Calculations

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
$t_{gunwale} = 0.75$ in
$w_{gunwale} = 1.50$ in

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

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

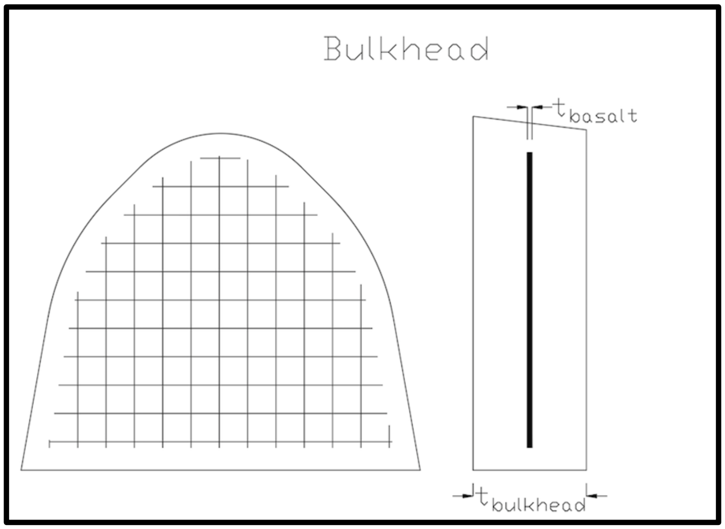
$21.33\ \% \leq 50\%$ ✓

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

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

$5.33\ \% \leq 50\%$ ✓

Bulkheads:



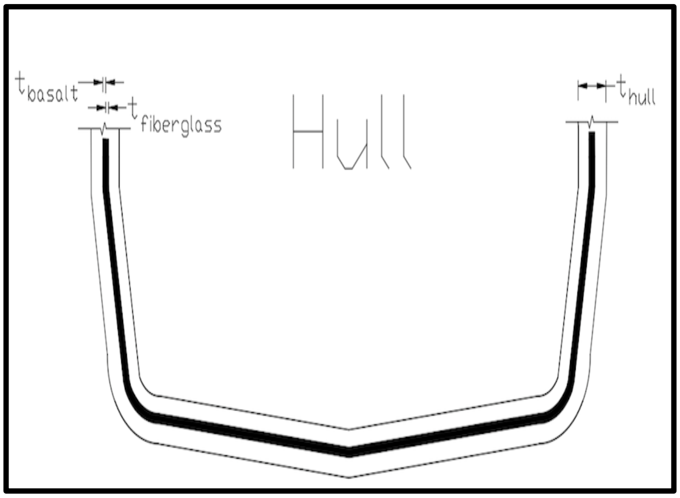
$t_{basalt} = 0.04$ in
$t_{bulkhead} = 1.0$ in

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

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

$4.00\ \% \leq 50\%$ ✓

Hull:



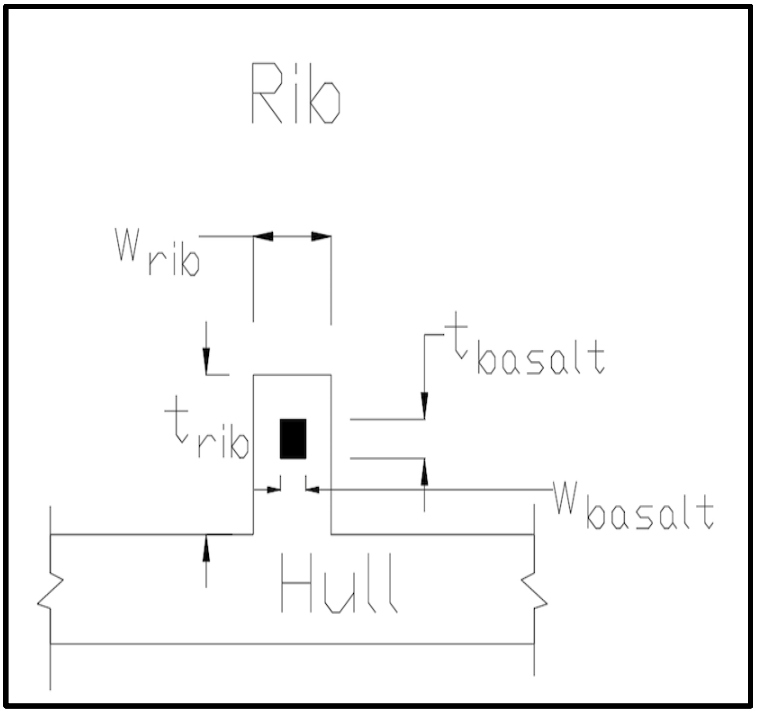
t_{basalt} = 0.04 in
$t_{fiberglass}$ = 0.03 in
$t_{gunwale}$ = 0.375 in

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

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

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 NCCC 2017 Rules and Regulations**

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

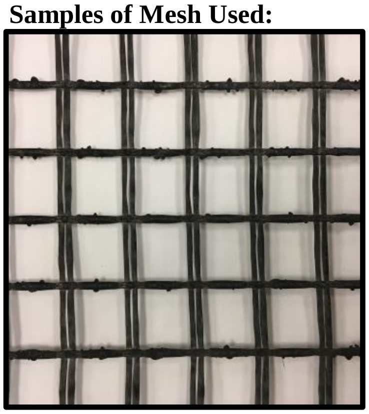
$\Sigma Area_{open} = n_1 \cdot n_2 \cdot Area_{open}$ → = ($10 \cdot 10 \cdot 1$ in^2)= 100 in^2

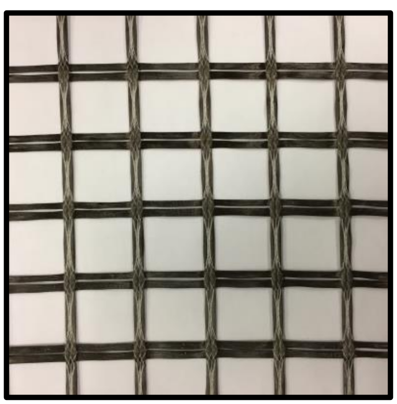
$Area_{total} = Length_{sample} \cdot Width_{sample}$ →(12.4 in x 11.6 in)= 143.84 in^2

POA = ΣAreaopen / Areatotal $\cdot$ 100% = (100 in^2/ 143.84 in$^2 \cdot$100 in)= 69.5% ≥40% ✓

*Mesh meets guidelines stated in NCCC 2017 Rules and Regulations

Samples of Mesh Used:


Sample 1: Fiberglass Mesh


Sample 2: Basalt Mesh


Sample 3: Strand of Basalt used for Ribs and Gunwales