Backcountry

Michigan Technological University
Design Report 2018

Table of Contents

List of Figures

List of Tables

Executive Summary

Inspired by the landscape surrounding Michigan Technological University (Michigan Tech) and the 2018 Winter Olympic Games, The Michigan Tech Concrete Canoe Team has dedicated this year's project to their love of snow. The Michigan Tech Concrete Canoe Team is notably familiar with cold weather. Averaging over 170 inches of snow every year (Michigan Technological University 2018), Houghton, Michigan is a popular hub for skiers, snowboarders, snowmobilers, and hockey fans of the Midwest. Michigan Tech was founded in Houghton in 1885 as a mining college, and today offers several majors in programs such as engineering, mathematics, pre-health, chemistry, and forestry. Michigan Tech's official values encourage "the exploration and creation of all possibilities through innovative use of skills and knowledge" (Michigan Technological University 2018).

Table 1. Properties of Backcountry

Backcountry (2018)	
Weight (estimate)	230 lbs.
Colors	Light blue, gray, red, orange, yellow, black
Maximum Length	20 feet
Maximum Width	29 inches
Maximum Depth	13.54 inches
Average Thickness	3/8th inch
Primary Reinforcement	GlasGrid® 8511
Secondary Reinforcement	PVA-RFS400, PVA-RFS4000

Likewise, the Michigan Tech Concrete Canoe Team strives to use creative thinking to improve upon previous years' accomplishments using new methods, materials, and designs. Navigating the backcountry requires trust in one's fundamental skills and willingness to advance into the wild unknown. This theme translates to the team's approach to their 2018 canoe: to depend on knowledge passed down through the years while also exploring any new paths that could provide improved results. For example, a hull design used 15 years ago served as a baseline for this year's canoe, but alterations were made based on performance of last year's canoe, *Free Range*. A material new to the team was used as the primary reinforcement, and a redesigned concrete mixture testing scheme decreased the cost and time needed to select the final structural mix. The structural analysis committee developed a more accurate assessment of the canoe's strength requirements, and the team executed more sustainable practices when handling leftover material from previous years.

The Michigan Tech Concrete Canoe Team has competed in the North Central Student Conference since 1992. In the last three years, the team has placed 1st at the conference competition and placed 11th, 8th, and 11th in 2015, 2016, and 2017, respectively at the national competition. The Michigan Tech Concrete Canoe Team aims to "send it" in 2018 with this year's canoe, *Backcountry*.

Table 2. Properties of the 2017-2018 Concrete Mixture

Mixture	**Unit Weight (pcf)**		**Strength (psi)**				**Air Content (%)**
	Wet	Oven-Dry	Compressive		Tensile		
			14-Day	28-Day	14-Day	28-Day	
Structural	74.1	72	1930	2360	410	450	-11.0
Pigmented Finishing	94.5	92	990	1050	100	120	-0.6
Composite Flexural Strength: 1610 psi							

Project and Quality Management

Toward the end of the 2017 spring semester, the Michigan Tech Concrete Canoe Team selected two new project managers for the 2017-2018 school year. Additionally, committee head positions were filled through nominations and a voting process within the full team. The project managers' roles include overall logistics of the project, creation and preservation of the project schedule, and delegation of the committee heads. A new treasurer was elected; this team member works alongside the project managers to maintain budget control and set goals for team spending. Furthermore, the newly established construction manager position was filled by a team member with experience in handling materials, mix design, casting, and finishing techniques.

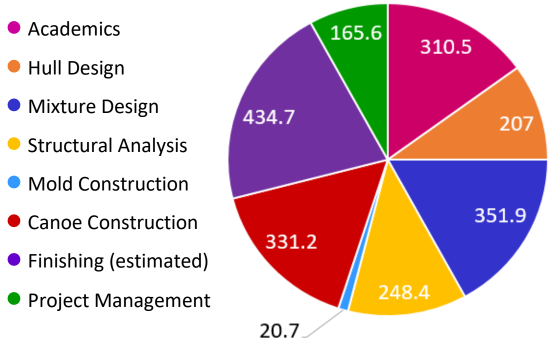


Figure 1. Breakdown of Person-hours by Category

After filling the leadership positions, the project managers held a meeting with every committee head to establish the necessary milestones for each committee. The project managers then created the project schedule based on these meetings. The major milestones for the overall project were hull design determination, mixture design selection, primary reinforcement determination, casting, demolding, and Project Overview and Technical Addendum (POTA) and Design Paper submission. The critical path was determined by identifying activities that, if delayed, would postpone the entire project schedule. While the new concrete mixture testing scheme decreased the time and material needed last year to select the final mixture, an error recorded in a mix table caused a delay in the final selection. Because the planned schedule allowed an extra two weeks, this delay did not affect the project duration. Overall, an estimated 2070 person-hours were committed to the entire project. A breakdown of this number is shown in Figure 1.

The team's safety program experienced a major overhaul due to relocation of the team workspace. Every team member completed university laboratory-specific safety training including job hazard analysis, crystalline silica awareness, personal protective equipment, and hazard communication. In conjunction with these programs, the team's safety committee communicated a "safety focus of the week," which was discussed at each weekly team meeting. Furthermore, the safety committee head and project managers held brief reviews of safety concerns before large-group activities including casting, demolding, and sanding.

To finance project and travel costs, the Michigan Tech Concrete Canoe Team publicizes their work amongst personal friends, family, team alumni, and the local community. For example, team members spent a day volunteering at a local grocery store to help promote the project while also interacting with the community. In addition to private monetary donations, the team also relies on donations from Michigan Tech academic departments and material donations from companies in close relations with the team. Combining these fiscal sources, the team was able to cover its estimated expenses of $12,000 for the year.

To improve the team's environmental sustainability practices, members were encouraged to identify positive uses for canoes from previous competitions rather than disposing of them. The team was successful in this endeavor; the most aesthetically pleasing sections of the old canoes have been reserved to be displayed in academic buildings on campus. The leftover pieces are stored in the team workspace to use as examples of past aesthetic techniques. Social sustainability is maintained through both short-term and long-term communication methods. In the short term, committees constantly give progress updates to the team through email to keep everyone on the same page. In the long term, each committee has an instruction document written and updated by previous committee heads so that previous knowledge is transferred and mistakes are not repeated. Additionally, team alumni stay in close contact with the team to provide professional advice and expertise when needed.

Last year, a new Quality Control & Quality Assurance (QC/QA) procedure covering the entire project was formally created, focusing on seven primary divisions: communications control, compliance control, document control, technical review, schedule control, material procurement, and training (Michigan Tech Concrete Canoe Team 2017). This program has since been altered to comprise only three over-arching divisions for less complication, as shown in Table 3.

Table 3. Quality Management Program

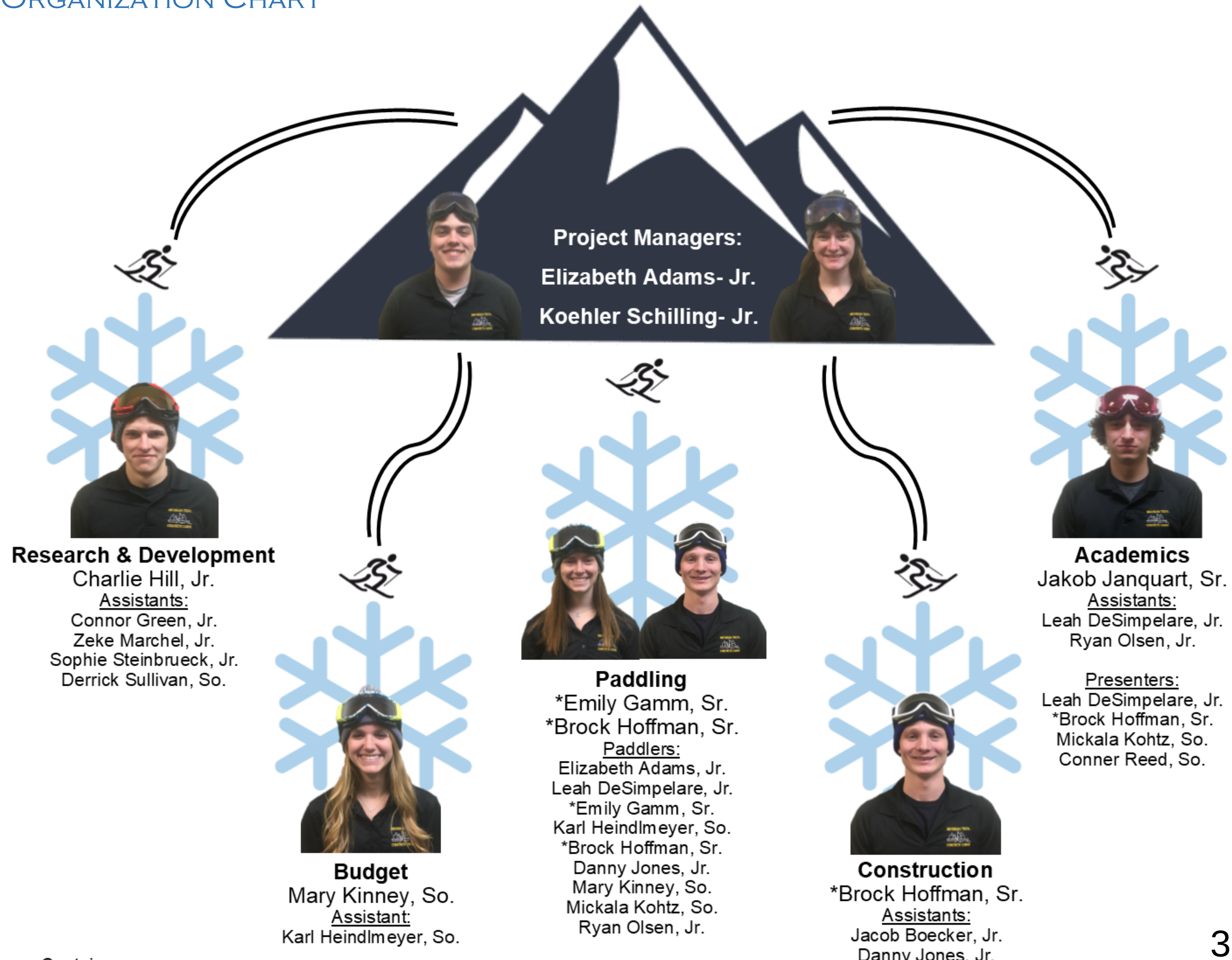
Schedule Control	Communications
	Material Procurement
	Budget
Compliance Control	Technical Review
	Documentation
Knowledge Control	Training
	Recruitment
	Things Learned

The primary goal of schedule control was to ensure the final product was completed on time and to its intended design. In order to meet this goal, the project managers required each committee head to submit a preliminary plan of action at the beginning of the fall semester. Based on those plans, the project managers held the committees to firm deadlines to guarantee continuous project progression. In order to avoid delays of milestones, efficient material procurement was held to the utmost importance. When a committee requests more material, the treasurer promptly communicates with the department budget coordinator, who finalizes the purchase through the team's account. Using this process, the committees are able to focus on testing rather than making purchases on their own and waiting to be reimbursed. The treasurer also periodically meets with the team advisor in order to keep each other up to date on team financial matters and plan the budget for the future.

Compliance control is the team's formalized effort to avoid missteps or deductions at the competition. All design data and calculations are reviewed by experienced team members before submission. The project managers compiled all Request(s) for Information (RFIs) published by the Committee on National Concrete Canoe Competitions and distributed them to the appropriate committee head in order to keep them updated on rulings. The project managers held a mock final product judging session to prepare team members in assembling the canoe stands, display table, and cross section to competition standards. Finally, all documentation and files from previous years are kept organized in a central database accessible only by team members. This allows for committee heads to review information from previous years when considering their goals of the project.

Knowledge control includes all initiatives taken by the team to progress academically. Diversity in members' expertise is highly valued, so the Michigan Tech Concrete Canoe Team recruits heavily throughout the year. As a result, the team is currently made up of students in 10 different majors. Year-to-year knowledge transfer is maintained through a "things learned" document, where previous committee heads write instructions and advice for members entering new positions. The team encourages all members to participate in as many aspects of the project as possible. The resulting comprehensive experience gives new members the well-rounded knowledge and training needed to assume leadership roles in subsequent years.

Organization Chart



*Team Captains

Hull Design

The hull design of *Backcountry* began with an assessment of the performance and handling of the hull design of past years. The team is fortunate to still have many of its wooden prototype canoes from teams dating back to the early 2000's. After testing many of these designs, paddler feedback was assessed to determine what favorable design aspects could be drawn from the array of boat designs. One design in particular, that of Michigan Tech's 2003 entry *SISU*, drew considerable praise for its performance (Michigan Tech Concrete Canoe Team 2003). The hull design committee decided to utilize many of the design aspects of this 2003 hull in its 2018 entry *Backcountry*.

Figure 2. Prototype Construction

To complete this task, some basic performance goals were established to ensure *Backcountry* would perform as a competitive canoe in competition. These goals included maintaining strong straight-line tracking and travel velocity while still preserving a strong turning ability and stability.

Backcountry, much like its inspiration *SISU,* features a slender deep bow, narrow parabolic stern, and relatively flat and wide amidships. The committee experimented with different hull lengths with the design software PROLINES 98 and concluded that a length of 20 feet optimized the balance between maximum velocity and frictional resistances. A slight rocker was included to counteract a decrease in maneuverability due to the longer hull while maintaining the focus on straight-line tracking. The beam width was reduced by 4.9 inches, increasing the length-to-beam ratio. This increased ratio indicated a slimmer hull, leading to less wave-making resistance and more efficient paddling. Increased height was added to the bow to prevent the boat from collecting water at high speeds.

Table 4. Hull Design Comparison

	SISU (2003)	*Free Range* (2017)	*Backcountry* (2018)
Length (ft.)	20.0	20.0	20.0
Length/Beam Ratio	9.210	9.682	9.096
Freeboard (ft.)	0.480	0.529	0.475
Rocker – Bow (in.)	1.92	2.67	2.34
Rocker – Stern (in.)	1.82	4.75	2.10

A lauan wood prototype of this design was constructed for practical analysis (Figure 2). The hull design committee theorized that a canoe's straight-lining ability largely depends on the size of its rocker. Realistic race tests were conducted by the paddling team, comparing this prototype to ones built in previous years. The paddlers confirmed that when straight-lining, fewer paddle side switches were needed to maintain the direction of the boat at high speed. Thus, Backcountry's design proved to be a desirable balance of straight-line tracking, speed, and maneuverability when compared to other Michigan Tech canoe entries.

Structural Analysis

The primary goal of the structural analysis committee was to identify, calculate, and locate the critical stresses experienced by *Backcountry*. This information was then applied to create an accurate and comprehensive evaluation of this year's design to establish necessary material design strengths and ensure the structural integrity of the canoe when delivered to competition.

To maximize the accuracy of the analysis, cross sections were taken at 1-inch increments along the length of the 20-foot canoe. Each of these 239 cross sections were then broken down to their coordinate geometry using Autodesk® AutoCAD and analyzed using Microsoft Excel. The coordinate points were assembled as rectangular areas with a width of 3/8th inch. After adding gunwales and accounting for overlaps and gaps, the areas, centroids, moments of inertia, second moments of inertia, and torsional constants were calculated for each cross section.

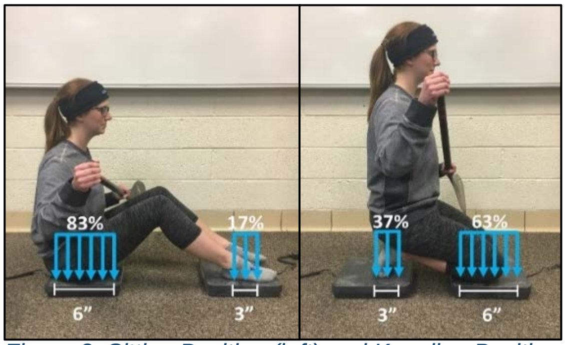


Figure 3. Sitting Position (left) and Kneeling Position (right)

Five loading cases were considered when conducting the analysis: transportation, display, and men's, women's and co-ed racing conditions. The transportation case was designed to model the boat in the trailer en route to competition: a beam with uniformly distributed weight evenly supported on the top and bottom. Similarly, the display case was modeled as a beam with uniformly distributed weight resting on two supports.

Race cases were modeled as paddler weights, canoe weight, and a buoyant force unique to each scenario. Paddler weights were estimated as 170 and 200 pounds for a female and male, respectively. To account for dynamic loading, these weight values were increased by 20%. The structural analysis committee decided that modeling the paddlers as linearly distributed loads would provide greater accuracy rather than using point loads. Additionally, a paddler was modeled in either a sitting or kneeling position with a front and back linearly distributed load. Through testing using two scales, the committee determined a kneeling paddler places 63% of their weight on the front distributed load and 37% on the back, while a sitting paddler places 83% of their weight on the back distributed load and 17% on the front (Figure 3).

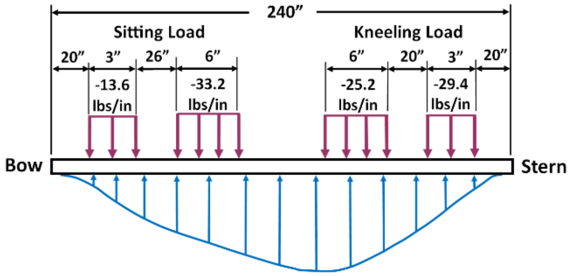


Figure 4. Buoyant Force due to Paddler Loads and Canoe Weight

Buoyant forces experienced by the boat were calculated from cross section data. Because of the uneven weight and the asymmetrical design of the canoe, the nonlinear buoyant forces needed to be resolved. To solve for these buoyancy forces, an iterative Microsoft Excel function was used to apply various longitudinal tilts to the loaded canoe until the center of buoyancy was balanced with the center of gravity and the sum of the moments equaled zero. At this point, the buoyant force at each cross sectional increment had been determined. This unique buoyant force distribution is shown in Figure 4. Next, the two-dimensional analysis was performed. Individual cross section data was compiled in Excel, shear stresses were evaluated, bending moments were resolved, and maximum loading cases were determined.

After performing this analysis, the hull design committee recognized that the maximum shear experienced by the canoe arose in all five racing conditions with kneeling paddlers. Furthermore, the men's racing condition was the controlling scenario, where *Backcountry* was required to withstand a tensile stress of 247 psi in its gunwale cap and a compression stress of 230 psi along its chines. These requirements were then used by the mixture and reinforcement committees in material testing.

Development and Testing

The primary goals of the mixture committee this year were to find an improved ASTM C330 compliant aggregate, increase the workability of the mixture for troweling, and maintain a unit weight of 65 pcf or lower.

Figure 6. Uncrushed Shale

A combination of the structural mixes *Old Faithful* (Michigan Tech Concrete Canoe Team 2016) and *Lutum* (Michigan Tech Concrete Canoe Team 2017) was used in consideration for this year's structural mix, *Powderstash*. *Old Faithful* had an exceptional strength-to-weight ratio, leading the committee to again utilize Class C Fly Ash and an identical Poraver® gradation ratio for the final mixture. *Lutum* implemented the ASTM C330 aggregate rule and a binder blend that proved to be effective in strength while still maintaining a relatively low weight. Brought together, these two previous successes provided a solid baseline to start the mix design process in 2018. 7 and 14 day intervals for compressive strength (ASTM C39), split tensile strength (ASTM C496), and unit weight (ASTM C138) were used for comparing individual mixes and deciding which mix to use in this year's canoe. During the curing phase, cylinders were submerged in water for the first 7 days (after a 12 hour setting period) in an effort to promote better hydration of tricalcium silicate, which is associated with concrete's initial setting and early strength development. Furthermore, due to water's relatively high specific heat, being submerged helped maintain a more consistent curing environment.

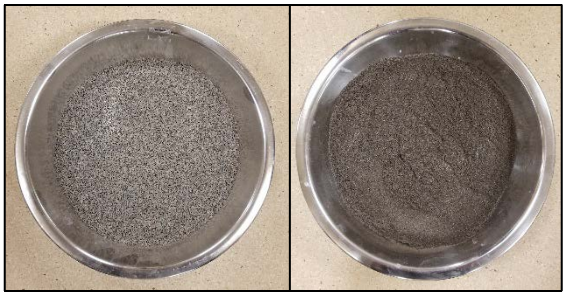


Figure 5. Crushed Shale Passing No. 8 Sieve (left) and No. 16 Sieve (right)

In an effort to become more environmentally and economically sustainable, a new testing scheme was designed that would allow for a final mix to be selected earlier in the schedule while testing fewer mixes. In previous years, a tier system was utilized to develop the final mix. Each tier was designed to test a specific aspect of the concrete mix, which was then carried onto the next tier in order to ultimately reach a final design. This year, the initial steps taken by the mixture design committee were to compile the previous three years of mix designs and testing results. The computer software JMP was used to analyze this information. Several multiple regression models were run in an effort to first determine which aspects and material species most directly impacted the ultimate strength of the concrete mixes. The next step was to understand how the ratios of these species directly affected the overall strength of the mix design. More precise models were again constructed, honing in on the selected species. The resulting information indicated material species and ratio in a mix design. From here, a baseline was set for concrete testing.

The binder blend implemented in the structural mixture was chosen after analyzing this year's testing data. The mixture committee found that a combination of portland cement (ASTM C150), blast furnace slag, and fly ash produced the most ideal strength-to-weight ratio. A 60/10/30 blend of cement, slag, and fly ash, respectively, yielded the highest compressive strength and maintained the low unit weight desired by the committee. In previous years, the team sought to create a white mixture to yield more vibrant finishing and aesthetic detail. This was no longer necessary, as the team used a thin layer of finishing mix across the entire length of the canoe.

Continuing last year's research of ASTM C330 compliant aggregates, one of the main goals this year was to create a refined aggregate to better meet the needs of the mix in terms of workability, finishing, and overall strength. Due to the team's experience with the material, expanded shale was the preferred aggregate to further develop. While it provided adequate strength and met ASTM standards, some of the drawbacks of shale were its increase to unit weight and its coarse shape, making it difficult to trowel and finish. To help combat these undesired physical properties, the coarse aggregates were crushed using a roller (Figures 5 and 6). After the shale aggregates were crushed, tests were done to calculate both the specific gravity and absorption rate (ASTM C128). While maintaining the Poraver® ratio used in *Old Faithful*, 3M™ K1 and Elemix® proportions were decided based on workability balanced with compressive strength. The final aggregate proportions are shown in Figure 7.

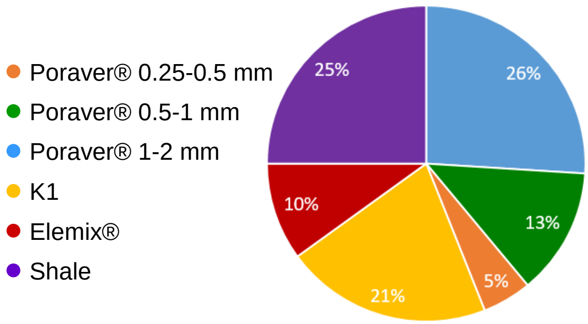


Figure 7. Aggregate Proportions by Volume

Seeking to reduce cost and material usage, the mixture committee opted to utilize previous years' research and experience to determine the optimal fibers for use as secondary reinforcement. *Lutum* incorporated an equal blend of Nycon®-PVA RFS4000 and RFS400. Because this combination met the strength requirement and would maintain a workable mixture, the mixture committee chose to continue its use in the structural mix. Additionally, this was the most cost effective option because all the fibers used this year were excess from last year.

Due to a misinterpretation of compliance, the admixture used previously, SikaLatex®-R, needed to be replaced. Through conversations with other teams at competition, the mixture committee became familiar with QUIKRETE® Concrete Acrylic Fortifier. The committee decided to implement this material due to its performance during testing and short procurement time.

Table 5. Aggregate Properties

Aggregate	Specific Gravity	Absorption (%)
Poraver® 1-2 mm	0.41	20
Poraver® 0.5-1 mm	0.45	25
Poraver® 0.25-0.5 mm	0.68	30
K1	0.13	22
Elemix®	0.042	5.5
Shale	1.22	36

Once a final mixture was attained, compressive strength (ASTM C39), split tensile strength (ASTM C496), and unit weight (ASTM C138) tests were performed. Because the mixture passed all requirements set by the structural analysis committee, the design was deemed satisfactory.

The reinforcement committee established two primary goals this year: improve workability while maintaining or increasing the concrete's composite flexural strength. Last year's reinforcement, 5mm Basalt Mesh, proved difficult for trowelers to handle because it stretched and fell apart easily. Thus, the committee searched for a more rigid reinforcing mesh to serve as the primary reinforcement of the canoe. Based on information gained from research and observation of other teams at the national competition, the reinforcement committee decided to investigate the use of fiberglass mesh. Additionally, some teams suggested a layering scheme involving both fiberglass and carbon fiber, leading the reinforcement committee to research

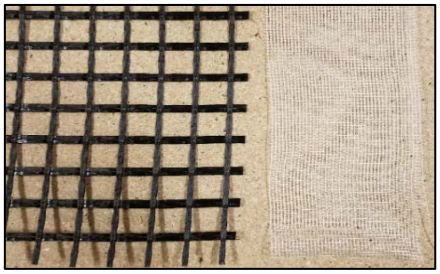


Figure 8. GlasGrid® 8511 (left) and Fibreglast® (right)

Figure 9. ASTM C1341-13 Flexural Bend Test

carbon fiber as well. Carbon fiber was not pursued further, however, because of team alumni advice and lack of success with the material in the past. Therefore, the committee moved forward with fiberglass.

Meshes to be tested were selected based on compliance with competition rules, strength values reported by other teams, and technical data sheets of the products. Because the material was new to the team, the reinforcement committee pursued two fiberglass meshes with contrasting specifications: GlasGrid® 8511 and Fibreglast® Scrim Fabric. These meshes differed significantly in aperture size, rigidity, and price – GlasGrid® 8511 was donated to the team. To validate the decision to continue or discontinue its use as the primary reinforcement, 5mm Basalt Mesh was tested alongside the two fiberglass samples.

To analyze the composite, advisors in the Materials Science and Engineering department suggested the team follow ASTM C1341-13 rather than ASTM D790, which is intended for reinforced plastics and insulating materials. ASTM C1341-13 specifies a 3-point bend test for fiber-reinforced advanced ceramic composites. Following this standard, 14 in. x 3 in. beams were made with two layers of reinforcing mesh between three 1/8th inch layers of concrete, simulating the composition of the canoe. Wooden molds were assembled to these dimensions to avoid the need to cut the composite samples. Beams without reinforcement were also tested as a baseline. Because the final structural mixture was not selected until after reinforcement testing, the mixture used in the composite testing was a compliant mixture similar to the structural mixture used last year. The results of this testing, along with other attributes considered, are shown in Table 5.

Qualitative reinforcement testing also took place at troweling practices, where trowelers used samples of each reinforcement and gave feedback to the reinforcement committee. While the fiberglass samples never fell apart like the Basalt, the wall sections tended to bend inward, due to how tightly the mesh was rolled before being cut. In testing, this proved to be an issue with adding layers of concrete once the reinforcement was placed.

Table 6. Primary Reinforcement Specifications

Reinforcement	Composite Flexural Strength (psi)	Open Area (%)	Price ($/yard)
5mm Basalt Mesh	598	62.6	7.13
GlasGrid® 8511	1204	60.7	0.00
Fibreglast®	456	50.7	4.05

Considering these listed variables, the reinforcement committee selected GlasGrid® 8511 as the primary reinforcement in the canoe. With more than double the flexural strength of last year's reinforcement, a more rigid structure, and no cost to the team, this fiberglass mesh stood out as the prime option of the three samples tested. To remedy its issue with bending inward after placement, the reinforcement committee pre-cut sections before casting day and used plywood and weights to hold them flat.

Construction

Once the hull design was completed, the project managers ordered a high-density polystyrene foam mold. This material has been consistently used by the team in the past because of its machinability, low weight, low cost, and durability. The hull design was machined into the foam material, creating a cavity mold consisting of six separate pieces. To prepare the mold for casting day, the mold pieces were held together using scrap pieces of plywood and screws left over from the previous year's display table. Furthermore, team members applied several layers of epoxy over a two-week period to facilitate the eventual removal of the boat.

Figure 10. Mixing of Concrete Batch on Casting Day

During the fall semester, the Quality Control/Quality Assurance (QC/QA) committee held mock troweling sessions on a weekly basis. In an effort to reuse material, the team saved mold pieces from former canoes to practice troweling. These sessions helped recruit, inform, and acclimate new members to different troweling techniques, as well as improve the existing skill sets of returning troweling team members. Additionally, the team members practiced using different concrete mixes and primary reinforcement samples to give feedback on their workability to the mixture and reinforcement committees.

A week prior to casting day, eight members were assigned a section of the boat to trowel, and four members were chosen to work as "QC/QA monitors." The QC/QA monitors measured the thickness of the concrete layers and informed the trowelers when the concrete was too thick or too thin. 3D-printed depth gauges set to 1/8th, 2/8^{ths}, and 3/8^{ths} of an inch were used to conduct these measurements. Five days before casting day, the entire team measured the materials needed for the concrete mixture. These materials were separated into bagged batches to save time and ensure consistency in the mix. Primary reinforcement was pre-cut to design specifications to decrease time between troweling layers of the boat.

Casting day began with a full team meeting led by the project managers, construction manager, and safety chair to review the safety program and highlight potential hazards involved with the casting process. The laboratory was cooled to 55°F to prevent cold joints from forming in the concrete.

Figure 11. Application of the First Layer of Concrete

To begin the construction of the canoe, the trowelers used concrete trowels to place a 1/8th inch layer of concrete on the inside of the mold (Figure 11). Once the QC/QA monitors verified consistency in thickness, reinforcement sections were positioned to cover the length of the boat (Figure 12). The concrete troweling process was repeated for a second and third layer with a second layer of reinforcement in-between. The temperature of the casting room was closely monitored throughout the cast to ensure consistent conditions. Entering casting day, the construction manager set a goal to finish each concrete layer within an hour. This goal was met, as each layer took no more than 55 minutes to complete. Upon completion of the third layer of concrete, foam endcaps were inserted into each end of the canoe and covered with concrete, which was troweled to the desired shape. Pre-cut gunwale cap molds were secured at the top interior perimeter of the boat using bar clamps and wooden wedge clamps (Figure 13). To complete the construction process, a strip of reinforcement was sandwiched between two layers of concrete in the gunwale cap molds.

Figure 12. Reinforcement Placement

The project managers chose to use an ambient cure because of the team's familiarity with the process. Using a makeshift tent of sheet plastic and electric room humidifiers, the boat's curing environment was kept at 70% humidity and 70°F. These conditions were maintained for two weeks to allow for cement hydration. To remove the canoe, the mold was carefully disassembled piece by piece while team members held the canoe off the ground. Once fully released, the canoe was placed on open cell foam.

Soon after removal of the mold, the team began sanding the boat, starting with 80 grit sandpaper and gradually increasing to 1000 grit. Between each sanding session, excess concrete dust was removed from the canoe using a vacuum. Additionally, an air ventilation system was used during all finishing activities.

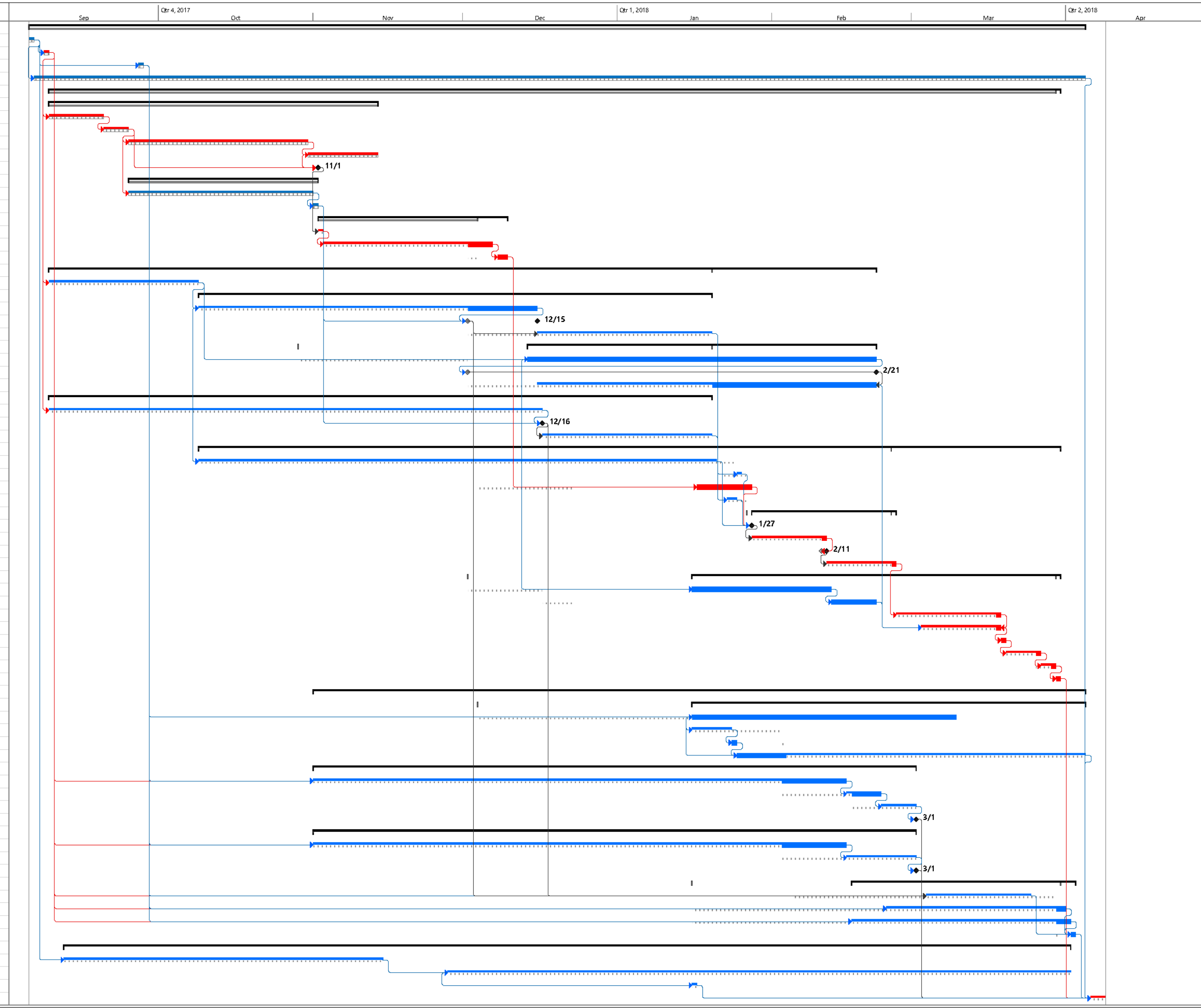
Figure 13. Gunwale Cap Construction

Considered a success last year, pigmented concrete was again used as the primary aesthetic constituent. Starting in January, the aesthetics committee head led several testing sessions to determine the best way to apply the mixture. All aesthetic testing was conducted using sections of the practice canoe from two years ago. This proved to be both a sustainable application of old material and a comfort to the project schedule, as most of the aesthetic testing was completed before the canoe cured. As a result of the testing, paintbrushes and sponge-brushes were used to apply pigmented concrete to the surface of the canoe. The aesthetics committee sought to make the outside of the boat as smooth as possible and attempted to create textured aesthetic components on the inside. Once the aesthetics were completed, two coats of a water based sealer were applied to the canoe, and the sealer was wet sanded with 1000 grit sandpaper for a polished finish.

With these final touches, *Backcountry* was completed. The Michigan Tech Concrete Canoe Team used inspiration from their local natural landscape to create a final product that embodied the wintry spirit of the upper peninsula of Michigan.

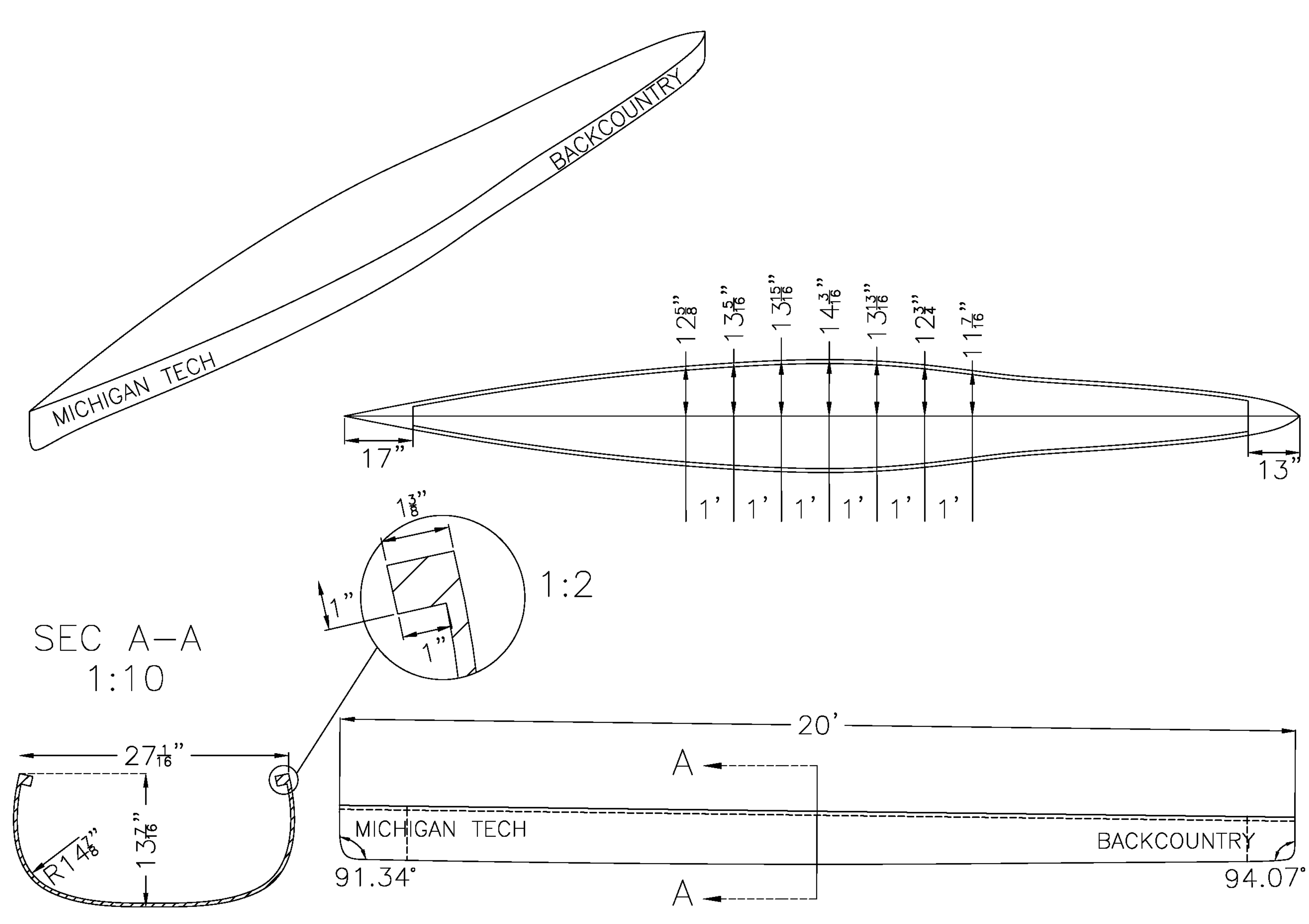
Project Schedule

ID	Task Name	Baseline Start	Baseline Finish	Start	Finish
1	**Project Management**	**Tue 9/5/17**	**Wed 4/4/18**	**Tue 9/5/17**	**Wed 4/4/18**
2	Notice to Proceed	Tue 9/5/17	Tue 9/5/17	Tue 9/5/17	Tue 9/5/17
3	Rules Released	Fri 9/8/17	Fri 9/8/17	Fri 9/8/17	Fri 9/8/17
4	Theme Decision	Wed 9/27/17	Wed 9/27/17	Wed 9/27/17	Wed 9/27/17
5	Fundraising	Wed 9/6/17	Wed 4/4/18	Wed 9/6/17	Wed 4/4/18
6	**Canoe Development**	**Sat 9/9/17**	**Thu 3/29/18**	**Sat 9/9/17**	**Fri 3/30/18**
7	**Hull Design**	**Sat 9/9/17**	**Mon 11/13/17**	**Sat 9/9/17**	**Mon 11/13/17**
8	Hull Design Research	Sat 9/9/17	Tue 9/19/17	Sat 9/9/17	Tue 9/19/17
9	Draft Hull Design	Wed 9/20/17	Sun 9/24/17	Wed 9/20/17	Sun 9/24/17
10	Prototype Construction	Mon 9/25/17	Mon 10/30/17	Mon 9/25/17	Mon 10/30/17
11	Prototype Testing	Tue 10/31/17	Mon 11/13/17	Tue 10/31/17	Mon 11/13/17
12	Final Hull Design Determination	Wed 11/1/17	Wed 11/1/17	Wed 11/1/17	Wed 11/1/17
13	**Structural Analysis**	**Mon 9/25/17**	**Wed 11/1/17**	**Mon 9/25/17**	**Wed 11/1/17**
14	Analysis	Mon 9/25/17	Tue 10/31/17	Mon 9/25/17	Tue 10/31/17
15	Analysis Results	Wed 11/1/17	Wed 11/1/17	Wed 11/1/17	Wed 11/1/17
16	**Mold Fabrication**	**Thu 11/2/17**	**Sun 12/3/17**	**Thu 11/2/17**	**Sat 12/9/17**
17	Release Hull Dimensions	Thu 11/2/17	Thu 11/2/17	Thu 11/2/17	Thu 11/2/17
18	Foam Sized and CNC Milled	Fri 11/3/17	Fri 12/1/17	Fri 11/3/17	Wed 12/6/17
19	Mold Pick Up and Delivery	Sat 12/2/17	Sun 12/3/17	Fri 12/8/17	Sat 12/9/17
20	**Mix Design**	**Sat 9/9/17**	**Fri 1/19/18**	**Sat 9/9/17**	**Wed 2/21/18**
21	Material Procurement for Testing	Sat 9/9/17	Sun 10/8/17	Sat 9/9/17	Sun 10/8/17
22	**Structural Concrete Mix Design**	**Mon 10/9/17**	**Fri 1/19/18**	**Mon 10/9/17**	**Fri 1/19/18**
23	Binder, Aggregate, and Fiber Testing	Mon 10/9/17	Fri 12/1/17	Mon 10/9/17	Fri 12/15/17
24	Final Structural Mix Design Selection	Fri 12/1/17	Fri 12/1/17	Fri 12/15/17	Fri 12/15/17
25	Final Structural Mix Material Procurement	Sat 12/2/17	Fri 1/19/18	Sat 12/16/17	Fri 1/19/18
26	**Finishing Concrete Mix Design**	**Sun 10/29/17**	**Fri 1/19/18**	**Thu 12/14/17**	**Wed 2/21/18**
27	Finishing Concrete Testing	Sun 10/29/17	Fri 12/1/17	Thu 12/14/17	Wed 2/21/18
28	Final Finishing Concrete Selection	Fri 12/1/17	Fri 12/1/17	Wed 2/21/18	Wed 2/21/18
29	Final Finishing Mix Material Procurement	Sat 12/2/17	Fri 1/19/18	Sat 12/16/17	Wed 2/21/18
30	**Reinforcement**	**Sat 9/9/17**	**Fri 1/19/18**	**Sat 9/9/17**	**Fri 1/19/18**
31	Material Procurement and Testing	Sat 9/9/17	Sat 12/16/17	Sat 9/9/17	Sat 12/16/17
32	Final Reinforcement Selection	Sat 12/16/17	Sat 12/16/17	Sat 12/16/17	Sat 12/16/17
33	Procurement of Final Reinforcement Quantities	Sun 12/17/17	Fri 1/19/18	Sun 12/17/17	Fri 1/19/18
34	**Construction**	**Mon 10/9/17**	**Sat 2/24/18**	**Mon 10/9/17**	**Fri 3/30/18**
35	Casting Practices	Mon 10/9/17	Wed 1/24/18	Mon 10/9/17	Sat 1/20/18
36	Pre-Batching Final Structural Mix	Mon 1/22/18	Fri 1/26/18	Thu 1/25/18	Thu 1/25/18
37	Mold Assembly	Mon 12/4/17	Fri 12/22/17	Wed 1/17/18	Sat 1/27/18
38	Pre-Cutting Reinforcement	Mon 1/22/18	Fri 1/26/18	Tue 1/23/18	Wed 1/24/18
39	**Final Casting**	**Sat 1/27/18**	**Sat 2/24/18**	**Sat 1/27/18**	**Sun 2/25/18**
40	Concrete Placement	Sat 1/27/18	Sat 1/27/18	Sat 1/27/18	Sat 1/27/18
41	Initial Cure with Mold	Sun 1/28/18	Sat 2/10/18	Sun 1/28/18	Sun 2/11/18
42	Mold Removal	Sat 2/10/18	Sat 2/10/18	Sun 2/11/18	Sun 2/11/18
43	Final Curing	Sun 2/11/18	Sat 2/24/18	Mon 2/12/18	Sun 2/25/18
44	**Finishing & Aesthetics**	**Sat 12/2/17**	**Thu 3/29/18**	**Tue 1/16/18**	**Fri 3/30/18**
45	Testing Pigments	Sat 12/2/17	Sat 12/16/17	Tue 1/16/18	Mon 2/12/18
46	Test Gradient Technique	Sun 12/17/17	Fri 12/22/17	Tue 2/13/18	Wed 2/21/18
47	Sanding	Sun 2/25/18	Sat 3/17/18	Mon 2/26/18	Sun 3/18/18
48	Interior and Exterior Design	Fri 3/2/18	Sat 3/17/18	Sat 3/3/18	Sun 3/18/18
49	Finish Aesthetic Design	Sun 3/18/18	Sun 3/18/18	Mon 3/19/18	Mon 3/19/18
50	Sealing	Mon 3/19/18	Sun 3/25/18	Tue 3/20/18	Mon 3/26/18
51	Sealing Cure	Mon 3/26/18	Wed 3/28/18	Tue 3/27/18	Thu 3/29/18
52	Finishing Complete	Thu 3/29/18	Thu 3/29/18	Fri 3/30/18	Fri 3/30/18
53	**Communications**	**Wed 11/1/17**	**Wed 4/4/18**	**Wed 11/1/17**	**Wed 4/4/18**
54	**Oral Presentation**	**Mon 12/4/17**	**Wed 4/4/18**	**Tue 1/16/18**	**Wed 4/4/18**
55	Design Presentation	Mon 12/4/17	Mon 1/15/18	Tue 1/16/18	Fri 3/9/18
56	Presenter Auditions	Tue 1/16/18	Fri 2/2/18	Tue 1/16/18	Tue 1/23/18
57	Select Presenters	Sat 2/3/18	Sat 2/3/18	Wed 1/24/18	Wed 1/24/18
58	Presentation Practice	Sun 2/4/18	Wed 4/4/18	Thu 1/25/18	Wed 4/4/18
59	**Design Paper**	**Wed 11/1/17**	**Thu 3/1/18**	**Wed 11/1/17**	**Thu 3/1/18**
60	Paper Outline and Draft	Wed 11/1/17	Fri 2/2/18	Wed 11/1/17	Thu 2/15/18
61	Professional Reviews	Sat 2/3/18	Fri 2/16/18	Fri 2/16/18	Thu 2/22/18
62	Final Revision and Refinements	Sat 2/17/18	Thu 3/1/18	Fri 2/23/18	Thu 3/1/18
63	Design Paper Submission	Thu 3/1/18	Thu 3/1/18	Thu 3/1/18	Thu 3/1/18
64	**Project Overview and Technical Addendum**	**Wed 11/1/17**	**Thu 3/1/18**	**Wed 11/1/17**	**Thu 3/1/18**
65	Information Collection & Formatting	Wed 11/1/17	Fri 2/2/18	Wed 11/1/17	Thu 2/15/18
66	Final Revision	Sat 2/3/18	Thu 3/1/18	Fri 2/16/18	Thu 3/1/18
67	Final Submission	Thu 3/1/18	Thu 3/1/18	Thu 3/1/18	Thu 3/1/18
68	**Product Display**	**Tue 1/16/18**	**Fri 3/30/18**	**Sat 2/17/18**	**Mon 4/2/18**
69	Cross Section Construction	Mon 2/5/18	Thu 3/29/18	Sun 3/4/18	Sat 3/24/18
70	Table Top Display Construction	Tue 1/16/18	Thu 3/29/18	Sat 2/24/18	Sat 3/31/18
71	Stands Construction	Tue 1/16/18	Thu 3/29/18	Sat 2/17/18	Sun 4/1/18
72	Display Components Complete	Fri 3/30/18	Fri 3/30/18	Mon 4/2/18	Mon 4/2/18
73	**Physical Conditioning**	**Tue 9/12/17**	**Sun 4/1/18**	**Tue 9/12/17**	**Sun 4/1/18**
74	Outdoor Paddling Practice	Tue 9/12/17	Tue 11/14/17	Tue 9/12/17	Tue 11/14/17
75	Indoor Paddling Practice	Tue 11/28/17	Sun 4/1/18	Tue 11/28/17	Sun 4/1/18
76	Determination of Paddlers	Tue 1/16/18	Tue 1/16/18	Tue 1/16/18	Tue 1/16/18
77	**North Central Conference**	Fri 4/6/18	Sun 4/8/18	Fri 4/6/18	Sun 4/8/18



Baseline Milestone ◆ Baseline Summary Actual Task Actual Milestone ◆ Actual Summary Critical Path Baseline Task

Michigan Technological University 2017-2018 Final Project Schedule



Michigan Technological University

I.D.	DESCRIPTION	QTY.
1	Federal White Type 1 Portland Cement	116.04 LB
2	Blast Furnace Slag	23.96 lb
3	NYCON RFS4000(30mm) PVA	1.11 lb
4	NYCON RFS4000(19mm) PVA	1.11 lb
5	GlasGrid 8511	128.0 ft^2
6	SHALE	49.77 lb
7	DOW Extruded Polystyrene Foam	1.45 ft^3
8	3M Glass Bubbles K1	3.60 lb
9	Poraver 1–2 mm	14.07 lb
10	Poraver 0.5–1 mm	7.64 lb
11	Poraver 0.25–0.5 mm	8.60 lb
12	Poraver 0.1–0.3 mm	14.10 lb
13	Elemix	0.56 lb
14	Direct Colors Concrete Pigments	2.50 lb
15	Armor WB25 Acrylic Sealer	1.50 gal
16	BASF Glenium 3030 NS	0.14 gal
17	Quikrete Concrete Acrylic Fortifier	0.10 gal
18	Silhouette Glossy Permanent Vinyl	5.00 ft^2

Construction Drawing

DRAWN BY: CONNER REED	CHECKED BY: JAKOB JANQUART
DATE: 2/25/2018	SHEET: 12
SCALE: 1:25 OR AS NOTED	

Appendix A – References

ASCE/NCCC. (2018). 2018 American Society of Civil Engineers National Concrete Canoe Competition Rules and Regulations. ASCE. <http://www.asce.org/rules-and-regulations/> (November 9, 2017).

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Michigan Technological University. (2018). “Snowfall Records and Contests.” Alumni and Friends, <http://www.mtu.edu/alumni/favorites/snowfall/index.html> (January 2, 2018).

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Cover photo shot in Lac la Belle, Michigan, courtesy of Tristan Kolb.

APPENDIX B – MIXTURE PROPORTIONS

MIXTURE DESIGNATION: STRUCTURAL

CEMENTITIOUS MATERIALS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Federal White Type 1 Portland Cement	3.15	2.35	462.3	*Total Amount of cementitious materials* **770.6** *lb/yd^3* *c/cm ratio* **0.60**
Blast Furnace Slag	2.99	0.41	77.1	
Class C Fly Ash	2.6	1.43	231.2	

FIBERS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (mass/volume) (lb/yd^3)*	
Nycon PVA-RFS4000	1.3	0.105	8.5	*Total Amount of Fibers* **17** *lb/yd^3*
Nycon PVA-RFS400	1.3	0.105	8.5	

AGGREGATES							
Aggregates	*ASTM C330**	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
Poraver 1-2 mm	No	20	0.41	0.49	89.38	107.26	4.19
Poraver .5-1 mm	No	25	0.45	0.56	46.57	58.21	2.07
Poraver .25-0.5 mm	No	30	0.68	0.88	26.12	33.96	0.80
Elemix	No	5.5	0.042	0.044	4.09	4.31	1.64
K1	No	22	0.13	0.16	22.53	27.49	3.39
Digeronimo Haydite - #8 Sieve	Yes	36	1.22	1.66	226.31	307.78	4.04

ADMIXTURES					
Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Concrete Acrylic Fortifier	10.1	28.02	30	11.93	*Total Water from Admixtures, $\sum w_{admx}$* **12.6** *lb/yd^3*
BASF GLENIUM 3030NS	9.2	6	79.7	0.67	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES ONLY)				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Concrete Acrylic Fortifier	1.20	0.10	7.48	*Total Solids from Admixtures* **7.48** *lb/yd^3*

WATER			
	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd^3		*w*: 215.76	3.46
Total Free Water from All Aggregates, lb/yd^3		$\sum w_{free}$: -109.51	
Total Water from All Admixtures, lb/yd^3		$\sum w_{admx}$: 12.60	
Batch Water, lb/yd^3		w_{batch}: 312.67	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	770.6	17	429.50	12.60	312.67	$\sum M$: 1542.37
Absolute Volume of Concrete, V, (ft^3)	4.19	0.210	16.14	0.10	3.46	$\sum V$: 24.10
Theoretical Density, T, (=$\sum M / \sum V$)	64.4 lb/ft^3		***Air Content [= (T – D)/T x 100%]***			-11.04%
Measured Density, D	72.4 lb/ft^3		***Slump, Slump flow***			2 in.
water/cement ratio, w/c:	0.47		***water/cementitious material ratio, w/cm:***			0.4

** Indicate if aggregate, other than manufactured glass microspheres and/or cenospheres, is compliant with ASTM C330.*

MIXTURE DESIGNATION: FINISHING

Cementitious Materials

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Federal White Type I Portland Cement	3.15	5.2	*1013.5*	*Total Amount of cementitious materials* **1266.9**lb/yd^3 *c/cm ratio* ***0.8***
Blast Furnace Slag	2.99	1.4	*253.4*	

Fibers

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of Fibers (mass/volume) (lb/yd^3)*	
Nycon PVA-RFS4000	1.3	0	*0*	*Total Amount of Fibers* __*0*__ *lb/yd^3*
Nycon PVA-RFS400	1.3	0	*0*	

Aggregates

Aggregates	*ASTM C330**	*Abs (%)*	*SG_{OD}*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*Volume (ft^3)*
					OD	*SSD*	
Poraver 0.1-0.3mm	*No*	35	.85	1.15	*191.08*	275.96	4.86
Poraver 0.25-0.5mm	*No*	30	.68	.88	*58.36*	75.87	1.79
Digeronimo Haydite #16 sieve	*Yes*	36	1.22	1.66	*126.45*	171.97	2.26

Admixtures

Admixture	*lb/gal*	*Dosage (fl. oz / cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Concrete Acrylic Fortifier	*10.1*	*28.02*	*30*	*19.61*	*Total Water from Admixtures, $\sum w_{admx}$* __***21.1***__ *lb/yd^3*
BASF GLENIUM 3030NS	*9.2*	*8*	*79.7*	*1.48*	

Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Concrete Acrylic Fortifier	1.2	0.10	7.48	*Total Solids from Admixtures* __***22.48***__ *lb/yd^3*
Pigments-Various Colors	2.25	0.11	15.00	

Water

		Amount (mass/volume) (lb/yd^3)	*Volume (ft^3)*
Water, lb/yd^3		*608.11*	*9.75*
Total Free Water from All Aggregates, lb/yd^3		*-110.11*	
Total Water from All Admixtures, lb/yd^3		*21.09*	
Batch Water, lb/yd^3		*697.14*	

Densities, Air Content, Ratios and Slump

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	1266.9	0	395.69	21.09	697.14	*2380.8*
Absolute Volume of Concrete, V, (ft^3)	6.51	0	9.70	0.21	9.75	*26.17*
Theoretical Density, T, (=∑M / ∑V)	*90.96 lb/ft^3*		*Air Content [= (T – D)/T x 100%]*			*-0.6*
Measured Density, D	*91.50 lb/ft^3*		*Slump, Slump flow*			*9in*
water/cement ratio, w/c:	0.60		*water/cementitious material ratio, w/cm:*			0.48

** Indicate if aggregate, other than manufactured glass microspheres and/or cenospheres, is compliant with ASTM C330.*

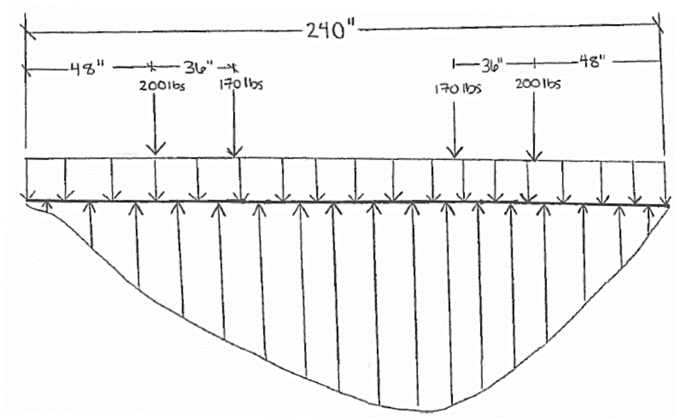
Appendix C – Example Structural Calculation

Analysis of a simply supported canoe with four paddlers from the co-ed race.

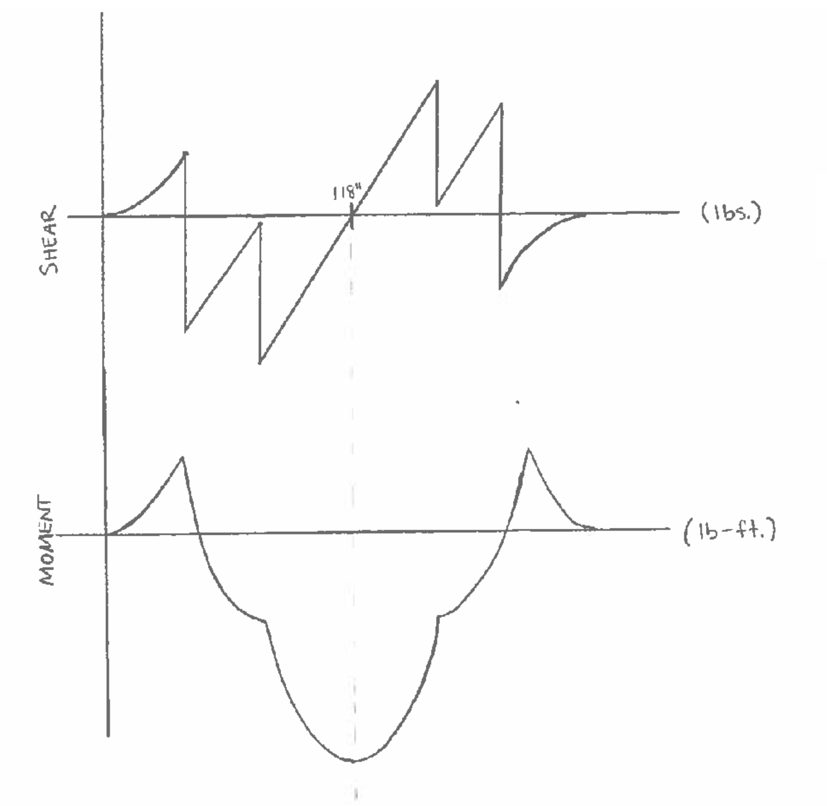
Assumptions

- Canoe theoretical weight →136 lbs = 136lbs / 240in = 0.68lbs/in
- Plane sections remain plane
- Weight of canoe is uniformly distributed
- Paddlers are point loads
- Material is homogenous
- Buoyancy modeled as distributed force dependent on individual cross sections' properties

Free Body Diagram



Resulting Shear and Bending Moment Diagrams



Max = 217 lbs

Max = -11842.9 lbs-ft

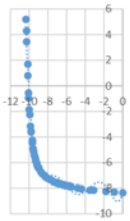
occurs at cross section 118" from bow

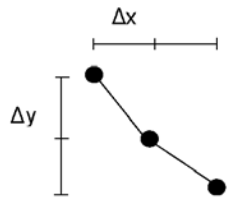
Cross Sectional Properties (needed to find canoe self-weight)

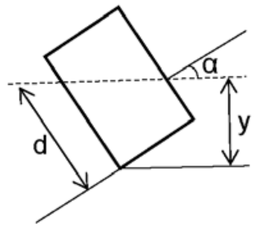
- The process used to obtain cross section properties involves breaking each cross-section into pieces, based on the number of control points for the profile curve. The sample calculations below are for the cross-section 118 inches from the bow, which is the midpoint of the canoe. Cross-section 118 has 48 control points. Properties were calculated for one side, and doubled if necessary.

Control Points

Point	x (in)	y (in)
1	-11.01	-5.03
2	-10.88	-5.03
3	-10.84	-5.47







Gunwale y location =5.129 in

Keel y location = -8.744

$$I = \frac{bd}{12}(d^2\cos^2(\alpha) + b^2\sin(\alpha))$$

$$A = b * d$$

$$\bar{y} = \frac{1}{2}(d * \cos(\alpha) + b * \sin(\alpha))$$

$$\alpha = \pi - \left|\tan^{-1}\left(\frac{\Delta y}{\Delta x}\right)\right|$$

$$d = \sqrt{(\Delta x)^2 + (\Delta y)^2}$$

$$b = 0.375in$$

Piece	Δx (in)	Δy (in)	α (rad)	d (in)	A (in^2)	I_c (about piece centroid) (in^4)	$\bar{y}$ (from bottom point) (in)	$\bar{y}$ from coor. Axis (in)
1	0.123	-0.331	-0.36	0.35	0.13	.0014	.0015	-5.26
2	.0463	-0.109	-0.40	0.04	0.04	.0001	.0004	-5.48

Cross Section 118" dimensions

After all properties are calculated for each piece, section properties can be found:

Area A: Sum of all areas, multiplying by two → A= 18.03 in^2

Location of neutral axis, $\bar{y}$ using A and centroids, location of neutral axis can be found: $\bar{y} = \frac{\sum A*C}{\sum A}$ = -1.75 in

I_x: Given I_c, A, $\bar{y}$ and location of neutral axis, I_x about the x-axis can be found using parallel axis theorem. $I_x = \sum I + \sum(a * d^2)$ = 659.27in

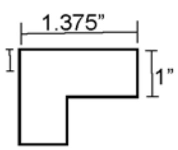
Gap s and overlaps

Using angles between pieces; areas, centroids, and moment of inertia for gaps and overlaps were calculated. In depth examples of this procedure, which relies on breaking each gap/overlap into pieces, would exceed the page limit of this appendix.

For cross section 118:

A_{gap}= 0.21 in^2 $\bar{y}$ from coor. Axis= -3.57 I_x about x-axis = 5.27

Gunwale Caps



A_{cap}= 1.37 in^2 $\bar{y}$ from coor. Axis= 4.42in

I_x about x axis= 43.03 in^4

Total cross section properties (adding together appropriately)

A= 19.03 in^2 I_x= 680.79 in^4

$\bar{y}$= 5.1294 in I about neutral axis= 586 in^4

Internal Stresses

$\sigma = \frac{My}{I}$ y gunwale = 5.129 in

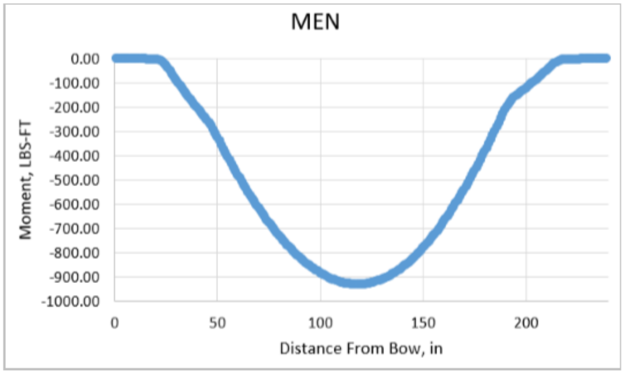
y keel = -8.7439

$\sigma_{gunwale}$ = 11842.9 in-LB * 5.129in/588in^4 = **102.65 psi**

σ_{keel} = 11842.9 in-LB * -8.7439in/588in^4 = **176.71 psi**

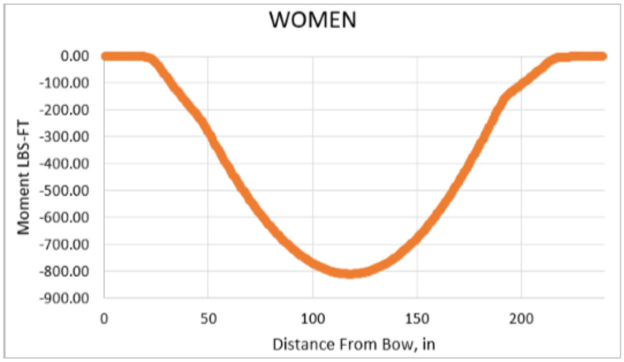
Load Case Comparisons

The Men's scenario describes the loads associated with the men's race. Includes boat weight, Buoyant Forces, and paddler weights



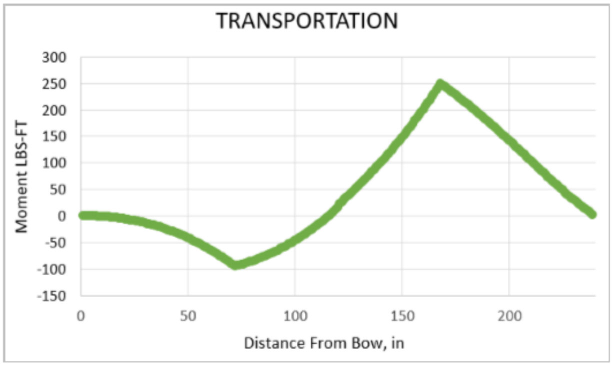
Max Stress = 197.06 psi

The Women's scenario describes the loads associated with the men's race. Includes boat weight, Buoyant Forces, and paddler weights



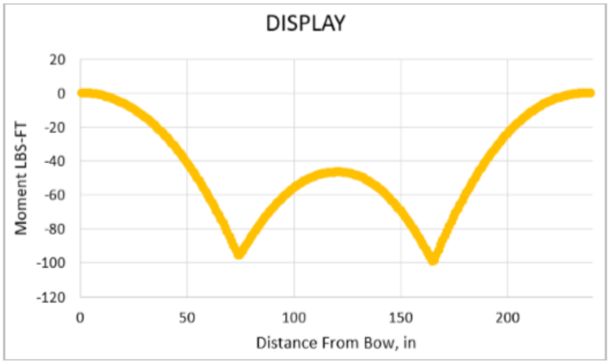
Max Stress = 172.04 psi

The Transportation case describes the loading conditions associated with transporting the boat to competition,. Includes distributed boat weight and forces enacted upon the boat by our shipping container



Max Stress = 32.87 psi

The display case represents the loading condition of the boat on stands during display. Modeled as two point loads representing the stands, and distributed canoe dead weight



Max Stress = 33.71 psi

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

HULL THICKNESS CALCULATIONS

Calculations per Section 4.3.1

Annotation

T_1 = 0.045 in — Average thickness of first layer of reinforcement, GlasGrid 8511 Mesh, measured in accordance with Section 4.3.1

T_2 = 0.045 in — Average thickness of second layer of reinforcement, GlasGrid 8511 Mesh, measured in accordance with Section 4.3.1

T_h = 0.375 in — Nominal thickness of the canoe hull

Determine that the reinforcement at any point in the canoe will not exceed 50% of the total hull thickness.

Solution

Within the canoe, a maximum of two layers of GlasGrid 8511 were used along the bottom of the canoe.

$$\frac{T_1 + T_2}{T_h} * 100 = 24.0\%$$

The two layers of reinforcement make up approximately 24.0% of the hull. This value is less than the maximum value of 50% outlined in section 4.3.1, demonstrating compliance.

GUNNEL CAP THICKNESS CALCULATIONS

Calculations per Section 4.3.1

Annotation

T_1 = 0.045 in — Average thickness of the layer of reinforcement, GlasGrid 8511 Mesh, measured in accordance with Section 4.3.1

T_h = 1.375 in — Nominal thickness of the gunwale cap

Determine that the reinforcement at any point in the canoe will not exceed 50% of the total hull thickness.

Solution

One layer of GlasGrid 8511 Mesh was used throughout the gunnel cap.

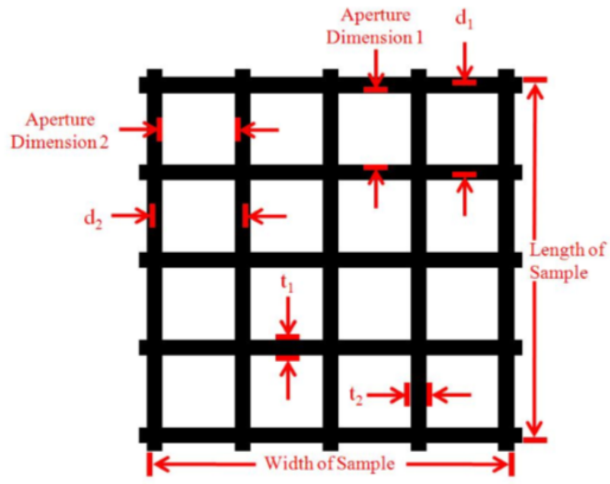
$$\frac{T_1}{T_h} * 100 = 3.27\%$$

The layer of reinforcement makes up approximately 3.27% of the gunnel cap. This value is less than the maximum value of 50% outlined in section 4.3.1, demonstrating compliance.

PERCENT OPEN AREA CALCULATIONS

Calculations per Section 4.3.2

Sample: GlasGrid 8511 Mesh



Sample of Reinforcement

Given

$n_1 = 9$ Number of apertures along length

$n_2 = 5$ Number of apertures along width

$t_1 = 0.262$ in Average thickness of reinforcement along length

$t_2 = 0.173$ in Average thickness of reinforcement along width

Aperture_Dimension_1 = 0.737 in

Aperture_Dimension_2 = 0.808 in

d_1 = Aperture_Dimension_1 + 2*(t_1/2) $d_1 = 0.99$ in Average spacing of reinforcement (center-to-center) along the sample length

d_2 = Aperture_Dimension_2 + 2*(t_2/2) $d_2 = 0.98$ in Average spacing of reinforcement (center-to-center) along the sample width

Determine Solution Percent Open Area (POA) for the GlasGrid 8511 Mesh

$Length_{Sample} = n_1 * d_1$ $Width_{Sample} = n_2 * d_2$

$Length_{Sample} = 8.98$ in $Width_{Sample} = 4.91$ in

$Area_{Open}$ = n_1*n_2*Aperture_Dimension_1*Aperture_Dimension_2

$Area_{Total} = Length_{Sample} * Width_{Sample}$

$Area_{Open} = 680\ in^2$ $Area_{Total} = 1120\ in^2$

$POA = (Area_{Open}/Area_{Total})*100$ POA = 60.7%

The POA is greater than the 40% minimum required, demonstrating compliance.