FREE RANGE

2017 CONCRETE CANOE DESIGN REPORT

MICHIGAN TECHNOLOGICAL UNIVERSITY

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Executive Summary

The rich history of agriculture is deeply rooted in the makings of the United States. From the invention of the cotton gin in 1793 to the sustainable technologies of today, agriculture has always played an extensive role in the American economy and workforce. Farmers require a dedicated dawn-til-dusk work ethic and extensive knowledge of the practice to prosper in their field. The agriculture business is constantly changing as advanced techniques and procedures are put into practice. In the same way, the Michigan Tech Concrete Canoe Team aimed to incorporate prior knowledge and skills with new methods and ideas in the creation of this year's entry, *Free Range.*

Michigan Technological University (Michigan Tech) is located in Houghton, MI, a city known for its historical significance in the copper mining industry. Founded in 1885, Michigan Tech offers a student body of more than 7,000 students a world-class education while being surrounded by an impressive natural landscape. Michigan Tech's mission to discover through innovation and research embodies the objective of the Michigan Tech Concrete Canoe Team as well – to improve upon previous years' performances through exploration of new materials, designs, and operations.

Table 1. Properties of the 2016-17 canoe

Free Range (2017)	
Weight (estimate)	208 lb.
Colors	Yellow, Brown, Green, Blue
Maximum Length	20 ft.
Maximum Width	25.5 in.
Maximum Depth	14 in.
Average Thickness	$3/8^{th}$ in.
Primary Reinforcement	5mm Basalt Mesh
Secondary Reinforcement	Nycon® RFS4000

Since 1992, the Michigan Tech Concrete Canoe Team has competed in the North Central Student Conference. In addition to taking first place at the regional competition in each of the last eight years, the team has also made 17 total appearances at the national competition, placing 8^{th}, 11^{th}, and 8^{th} in 2014, 2015, and 2016, respectively.

The 2016-2017 season was dedicated as one of growth and prosperity. The structural analysis committee progressed by including shear stresses due to torsional loading and considering punching shear as a failure mode. The research and development committee produced a mixture lighter than water while using aggregates conforming to ASTM C330, and the committee implemented a new secondary reinforcement and latex modifier into the mixture as well. The aesthetics committee investigated new methods of finishing to create a more sophisticated design, and rigorous paddling training throughout the season helped strengthen and prepare paddlers for competition. To honor the hardworking and innovative spirit of the agriculture industry, the Michigan Tech Concrete Canoe Team is proud to present *Free Range*.

Table 2. Properties of the 2016-17 concrete mixtures

Mixture	Unit Weight (pcf)		Strengths (psi)				Air Content (%)
			Compressive		Tensile		
	Wet	Oven-Dry	14 Day	28 Day	14 Day	28 Day	
Structural	64.8	62.1	1400	1530	230	245	4.0
Patching	103.3	101	1080	1180	145	150	7.4
Pigmented Finishing	107	105	1020	1100	130	135	5.2
Composite Flexural Strength: 1150 psi							

Project Management

After competing in the 2016 North Central Regional Competition, the Michigan Tech Concrete Canoe Team selected a new project manager and committee heads for the 2016-2017 school year. The senior and junior project managers supervised the project as a whole, concentrating on knowledge transfer, preservation of the team's schedule, and communication between committees.

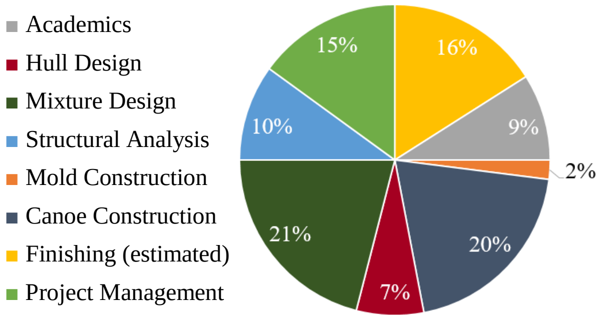


Figure 1. Breakdown of person-hours without paddling

Additionally, the team created a construction manager position to lighten the project managers' responsibilites. The construction manager oversaw all activity done in the workspace including prototype creation, casting, display table assemblage, cross-section fabrication, and aesthetic work. The construction unit was one of the five main units within the team, the other four being engineering, administrative, management, and paddling, as shown on the organization chart (Page 3). All committee heads were expected to abide by the team schedule and report weekly to project managers to ensure consistent progress.

Once the leadership positions were established, the project managers arranged a meeting with each committee head to record and schedule the necessary milestones for each committee. The project managers then created the overall schedule based on the input from the committee heads. The major milestones for the overall project were mixture selection, mold procurement, casting, and demolding. The critical path was determined by identifying activities that, if delayed, would affect the entire project schedule (Page 11). The team's project schedule was developed used a dual critical path. This year the team experienced a two-week delay from the initial schedule. This delay was due to aggregate selection, and the time was made up during sanding. The project managers estimate 2130 total person-hours were dedicated to the whole project. A breakdown is shown in Figure 1.

The team treasurer was in charge of handling all financial activity as well as establishing a budget for each committee. The project managers worked closely with the treasurer throughout the year to ensure the budget was both realistic and being followed. The team fundraising committee head directed all initiatives to promote the project and acquire sufficient funds. To finance materials, travel costs, and associated fees, the Michigan Tech Concrete Canoe Team worked to publicize the project among family, friends, alumni, and the local community. The resulting private donations, when combined with monetary donations from Michigan Tech academic departments and material donations from trusted companies, exceeded the team's estimated costs of $13,000 this year.

The team safety committee head used last year's three-tier safety program as a baseline for 2016-17. To begin, the committee head met with each committee to discuss all safety precautions necessary for planned activities. Secondly, the project managers held a full team meeting at the workspace to inform all team members of general safety procedures. Lastly, "toolbox talks" were led by experienced members whenever other members tried new tools and procedures.

Maintaining sustainable practices was important to this year's team. The team's social sustainability was preserved through knowledge transfer. Connections with alumni and local companies benefited the team's economic sustainability. Environmental sustainability was achieved through lean practices in the mixture design testing and extensive use of last year's practice canoe for aesthetic testing.

Quality Assurance / Quality Control

The Michigan Tech Concrete Canoe Team has a long-standing quality management procedure in place to ensure all factors of the project plan are completed as intended. This year, the project managers formally divided the quality management plan into seven different sections: technical review, schedule control, communications control, compliance control, document control, material procurement, and training. The team used these seven branches to ensure *Free Range* was delivered on schedule and to its intended specifications.

For technical review, the project managers assigned an experienced team member to check all design calculations. By doing so, the team was confident that data and calculations used in the Design Paper were accurate and consistent. Furthermore, each committee head was advised to review his/her "things learned", a document created by each previous committee head at the end of each year, pertaining to the specific committee. These documents ensure that committee heads have a working knowledge and history of testing and techniques in their area of focus.

At the beginning of the year, the project managers assigned each committee head to write a schedule report in which each task to be completed by the committee was addressed and defined. Within the report, time frames for each task were estimated based on previous experience. This information formed the basis of the overall project schedule. Before each new phase of the project, committee heads reviewed their report to ensure the project was on schedule.

With many different tasks occurring simultaneously, strong communication between team members was imperative. Email updates and reminders, in addition to weekly meetings, assisted in keeping team members up to date on all progress within the team. Additionally, meeting minutes were recorded at each meeting and distributed to all members.

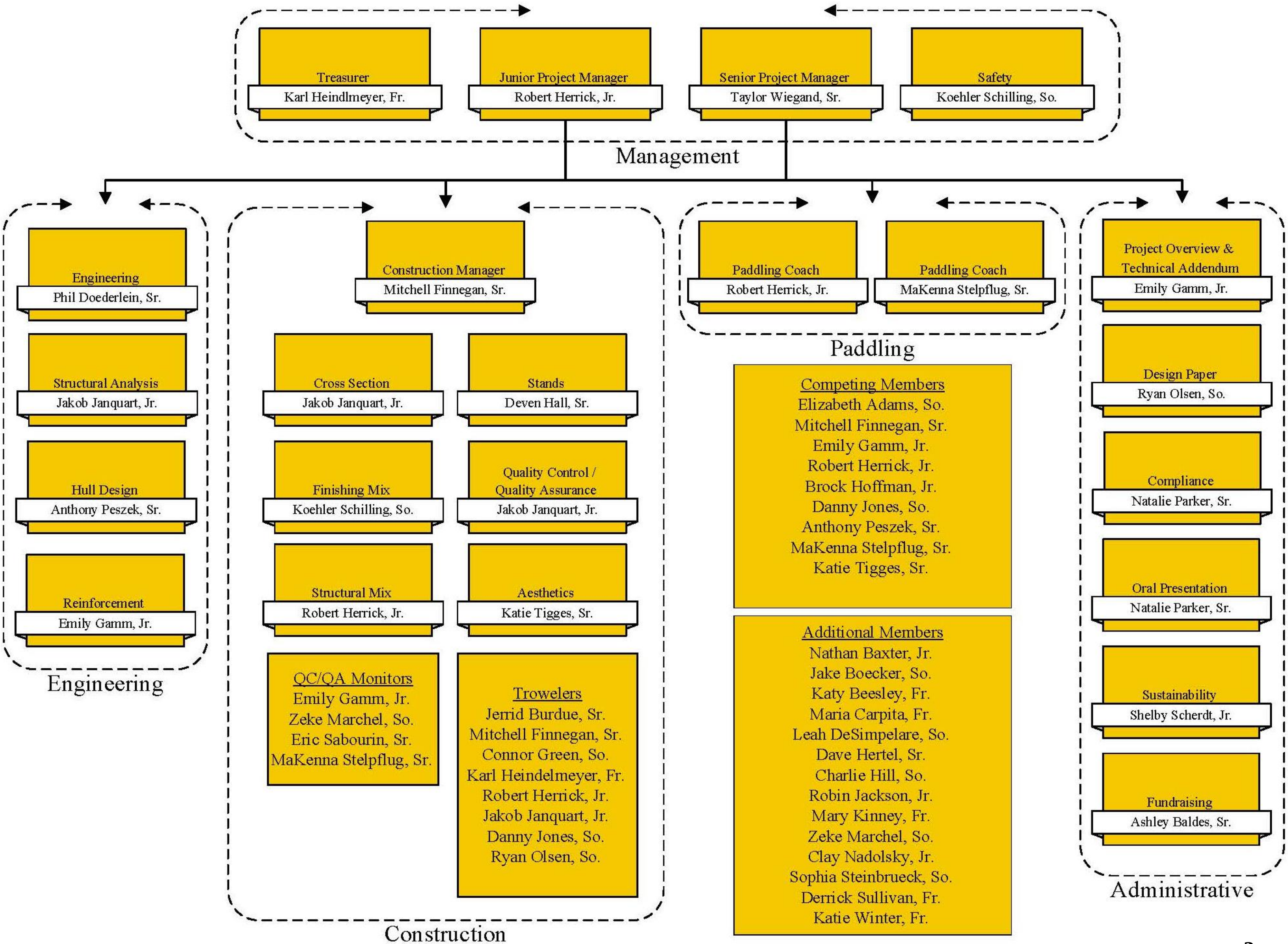
Through compliance control, all committee heads sent their Request(s) for Information (RFIs) to the compliance committee head, who in turn either advised the committee head or submitted the RFI to the Committee on National Concrete Canoe Competitions (CNCCC). Because the compliance committee head checked for errors and redundancies of other RFIs, the team was certain submitted RFIs were both clear and essential. Additionally, the compliance committee head sent all RFIs released from the NCCC to the respective project teams to keep every committee updated on rulings. Finally, the committee head held a mock display judging session to prevent deductions at competition.

The team uses a secure, centralized database for all document storage to exercise efficient document control. This provided a system in which all team files could be accessed only by team members, allowing for quick and secure exchange of documents. Furthermore, it acts as storage for all documents, test results, and electronic files from previous years for review.

Productive material acquirement was achieved by establishing a new procurement method. When more material was needed, all material purchases were approved by a project manager before submission. All payments went through the treasurer, who then monitored tracking and delivery.

To ensure both safety and quality, team members received training before using any power equipment; experienced members also advised any design work or calculations. This method of training acts as knowledge transfer for the team and ensures there are no gaps in the team's proficiency in producing a quality product.

ORGANIZATION CHART



Hull Design

When developing the hull design to be used in 2017, the team first considered the favorable and unfavorable factors in the design of last year's canoe, *Denali* (MTU 2016). Using feedback from the paddlers, the hull design committee determined that turning ability and initial stability were the most significant concerns to be addressed this year. Additionally, prevention of structural cracking was a main priority due to issues with previous years' canoes. High freeboard, which causes the paddlers to lean against the walls during turns, as well as a sharp change in cross-sectional area, leading to stress concentrations, were ascertained to be the causes of this cracking. These observations, combined with the paddler feedback, assisted the hull design committee in deciding upon the following goals: to increase turning ability, mitigate dramatic changes in cross-sectional area, and improve the primary stability of the canoe. With these goals in mind, *PROLINES 98* (Vacanti Yacht Design LLC. 1998) was used to model the geometry of *Free Range* using *Denali* as a baseline for its turning ability.

Table 3. 2015-16 and 2016-17 hull design comparison

	Length (ft.)	Length/Beam Ratio (ft./ft.)	Freeboard (ft.)	Rocker – Bow (in.)	Rocker – Stern (in.)
Denali	19.0	8.3	0.631	4.0	3.0
Free Range	20.0	9.682	0.529	2.67	4.75

First, the hull design committee removed the bulge used in previous years' canoes to reduce the amount of structural cracking. By doing so, stress concentrations that resulted in microcracking at the beginning and end of the bulge were eliminated. Additionally, the canoe length to beam ratio increased by 24% from last year's design. This increase in ratio indicates a faster, more slender canoe, leading to reduced resistance due to wave making as well as an overall increase of paddler efficiency.

Next, the hull design committee replaced the rounded-bottom hull with a hybrid hull. This hybrid hull incorporated a shallow arch profile in the bow to help cut through the water and a flat bottom hull in the stern for stability and easier turning ability. Also, the sweeping rocker was replaced with a square rocker to maintain the canoe's straight-lining capability.

When the hull design was finalized, the construction team fabricated a lauan wood prototype to provide a qualitative assessment. Concerns arose among the paddlers regarding the prototype's straight-line tracking and initial stability. The hull design committee decided to lengthen the canoe by 1 foot to improve the overall straight-line tracking, and the bow profile was flattened for initial stability. With these final modifications completed, the hull design committee goals were met.

Structural Analysis

This year, the structural analysis committee incorporated a refined evaluation to analyze stresses resulting from all loads being applied to the canoe in multiple loading cases. The goal of this assessment was to obtain material strength requirements to ensure *Free Range*'s overall integrity at competition.

The initial action taken by the committee was to review ways in which previous canoes had failed to determine which failure modes needed to be evaluated for full structural characterization. After investigating past failures, two distinct weaknesses were determined: local failure directly under a paddler and global failure during the buoy turn in a race. Failure from paddler loading was attributed to punching shear, while failure during the buoy turn was attributed to flexural bending coupled with shear stresses due to torsional loading induced from a paddler's weight shift while paddling.

To estimate stresses associated with these failure nodes, punching shear, bending, and torsional analyses were needed. Seven load combinations were considered for the straight line analysis: five race cases dependent on an individual's preferred paddling position, plus transportation and display conditions. The transportation condition was modeled as a distributed load extending along the length of the support while secured in travel. The display condition was modeled as a uniformly distributed load canoe weight resting on two supports. For race loading, male and female paddler weights, estimated at 200 and 170 pounds respectively, were increased by 20% to account for dynamic loading. Each paddler was then represented by two linearly distributed loads with weights being proportioned between front and back contact points, depending on paddlers' kneeling or sitting position.

To perform the bending analysis, a model of the canoe was divided into one-inch cross-sections along the length. Rectangular areas were calculated between adjacent control points along the spline curve using Microsoft Excel (Microsoft 2013). The committee accounted for overlaps and gaps between the rectangles and added gunwale caps. This process was repeated along the length of the canoe for all one-inch cross-sections. Areas, centroids, second area moments of inertia, and torsional constants were calculated based on these combined components.

To perform bending moment and shear calculations, the canoe was modeled as 3/8 in. thick with a unit weight of 62 pcf. The committee recognized that some degree of a paddler's load is transferred horizontally during a buoy turn, inducing torque. To incorporate this, the torsional loads from a paddler's weight shift and draw strokes were modeled. Considering each cross-section to be a thin-walled open section, the shear stresses due to torsional loads were found. Shear stresses were combined with normal stresses from the bending analysis to resolve principle stresses for each loading condition. It was determined that a maximum principle tensile stress of 231 psi and a maximum principle compressive stress of 239 psi occurred during the co-ed race scenario.

Next, the committee resolved stress attributed to punching shear. Load cases considered were a contact point from the kneeling or sitting position of both a male and female paddler. The maximum load case was determined as a male paddler in a kneeling position with 63% of the paddler's 240-pound dynamic load being transferred through one knee. Using a nominal thickness of 3/8 in. and a contact area of 6 in. by 3 in., a maximum punching shear stress of 20.2 psi was calculated.

A safety factor was applied to each of the calculated stresses. Utilizing a new method, a safety factor of three was determined based on eight criteria consisting of structural analysis accuracy, material costs and weight, consequences of failure, and production quality (Burr 1995). This resulted in principle stresses of 693 psi in compression and 717 psi in tensile.

Table 4. Concrete compressive and tensile strength requirements

	Compressive Requirement (psi)	Tensile Requirement (psi)
Bending + Shear	200	218
Punching Shear	406	N/A

Understanding that the primary reinforcement would assume some of the strain through the cross-section and being unable to reasonably test a composite in compression and tension, the committee used the rule of mixtures to calculate required concrete tensile and compressive strengths (Askeland 1989). Using the strength of the selected reinforcement (Page 8) and the principle stresses with applied safety factors, concrete strength requirements were found. The committee then calculated compressive requirements from punching shear stress using American Concrete Institute Building Code Requirements for Structural Concrete (ACI 2014) section 22.6.5.2. Concrete strengths were compared against each other to determine controlling benchmarks for the mixture design committee (Table 4).

Development and Testing

This year, the mixture committee established three main goals: to implement "lightweight" aggregates that conform to ASTM C330, to find a suitable replacement for micro fibers, and to discover new ways of increasing sustainability within the mixture committee. Considering the implementation of new aggregates and the need for the canoe to pass a swamp test, the committee set a weight standard of 63.5 pcf.

The structural mixture *Old Faithful* (MTU 2016) was used as a baseline for this year's mixture because of its strength-to-weight ratio. Individual mixtures were tested at 7 and 14 day intervals for compressive strength (ASTM C39), split tensile strength (ASTM C496), and unit weight (ASTM C138).

After review of previously recorded data, the mixture committee decided each Poraver® aggregate size would be held to the same ratio of total Poraver® volume in the baseline mixture. This ratio, developed from multiple years' data, ultimately relaxed the mixture committee schedule by saving two weeks of testing.

When choosing a binder blend, the committee understood a white finish was desired for aesthetic finishing purposes. Therefore, white binders, such as blast furnace slag, were considered. Furthermore, the use of a pozzolan was desired in the mixture to increase long term strength properties. Lightweight, silica-based Vitrified Calcium Aluminio-Silicate (VCAS) pozzolans were considered based on the team's previous use and knowledge of the product. The committee implemented VCAS not only for both its natural white color and its pozzolanic properties. Adding a pozzolan to the blend would ultimately help reduce the calcium hydroxide (C-H) content formed during the hydration process of portland cement (ASTM C150) and other cementitious materials. Because C-H formation restricts the hydration process from occurring by blocking water migration to unhydrated calcium silicates (C-S), there was an overall desire to mitigate its production. VCAS was thus chosen due to its high silica-based content, which when in the presence of water, becomes silicic acid and chemically bonds with the C-H, forming calcium silica hydrate (C-S-H), the key product of concrete hydration.

Considering the new task of integrating lightweight aggregates conforming to ASTM 330 into the mixture design, the mixture committee conducted initial research, leading to the discovery of recycled polyactic acid (PLA), pumice, bottom ash, and shale-based aggregates. Further research into the individual properties of each aggregate prompted the mixture committee to move to the testing stage for each aggregate. For each new aggregate being tested, a scanning electron microscope (SEM) was used to evaluate the bonding between the binders and aggregates, as well as determine the level of hydration occurring within the binder blend itself (Figure 2).

In light of producing a more sustainable mixture, the committee looked into using PLA as an aggregate in the mixture. Using a Granu-Grinder, recycled 3D printed objects were used to create aggregates for testing. A gradation was then found for the ground up PLA particles. Using the imaging software ImageJ (Rasband 1997), particle sizes were analyzed. Then, using a Feret diameter analysis, a particle-sized distribution was formulated from which an aggregate gradation was interpreted. With a specific gravity of 1.24, initial testing showed the PLA was

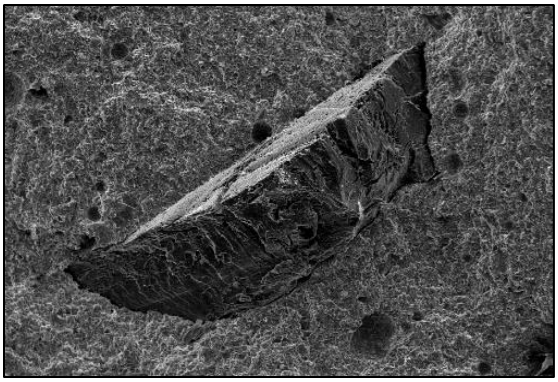


Figure 2. SEM photograph of PLA concrete bonding matrix

capable of increasing compressive strengths; however, mixtures came out well above the set weight standard. With the implementation of Elemix®, a lightweight synthetic aggregate, weight standards were able to be met, and the strength reductions typically seen with the use of Elemix® were alleviated through the use of the PLA. SEM results on PLA mixtures showed there was little to no bonding between the cement paste and the smooth finish of the recycled 3D printed pieces. Because of this information and the lack of ASTM C330 certification, PLA was left out of the final mixture.

When testing the pumice aggregate, the largest challenge was creating mixtures light enough for compliant use in the canoe. Although long-term strengths were noticeably higher than those of the other aggregates due to its natural pozzolanic properties, the small grain size and high specific gravity led to a significant volume needed, producing heavy mixtures. While other lightweight aggregates such as Poraver® and Elemix® were used to try to offset the weight increase, mixtures became noticeably granulated due to the amount of larger, lighter aggregate.

The mixture committee initially considered bottom ash to be the best option of the three aggregates chosen, since it had the lowest specific gravity. However, during testing the committee noticed the aggregate's water demand was significantly higher than that of its contenders. As a result, a higher water-to-cement ratio was needed to achieve full hydration and maintain workability for troweling. Consequently, the bottom ash mixtures had a considerable decrease in strength.

When testing the shale aggregate, meeting weight standards proved difficult as with the other two aggregates. Due to the larger gradation of the shale, however, less aggregate mass was needed to meet volume requirements; other aggregates were able to be used to produce feasible mixtures for the final product.

At 14 days, the committee noticed that with respect to chemical reactivity, the pumice had formed the greatest bond with the binders, while the bottom ash and shale had moderate to high levels of bonding. The committee then examined the hydration level, discovering that the levels of C-H were considerably lower than that of the baseline mixture as a result of the addition of the VCAS pozzolan.

The committee also sought a suitable replacement for Nycon®-PVA RECS15 fiber. In previous years, these microfibers caused difficulties in producing a smooth finish on the canoe. The aim was to find a replacement that improved this quality while having negligible, if not improved, effects on the strength and workability of the mixture. Research produced another Nycon®-PVA product, RFS400, which was chosen to be tested as a replacement for RECS15 due to its ability to produce a smoother finish. When considering tensile and flexural strengths, RFS400 ranked higher than RFS4000 but lower than RESC15; in parallel testing with RESC15, the committee concluded that RFS400 was able to increase compressive strengths without sacrificing tensile strength.

Additionally, the mixture committee explored possible replacements for the latex modifier Xypex® Xycrilic. Through research, the committee identified SikaLatex®-R, which had very similar properties as Xypex®. Parallel testing showed that the two latex modifiers were nearly equal in raising the strengths of the mixture. SikaLatex®-R was thus chosen as the new latex modifier because of its lower cost.

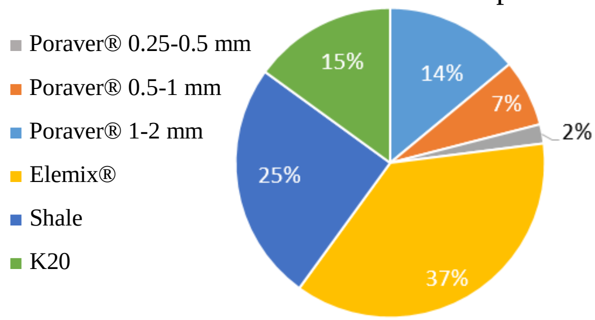


Figure 3. Aggregate proportions based on total aggregate volume

Taking into account the results of the SEM testing and individual testing of each aggregate, the mixture committee decided that the final mixture, *Lutum*, would be created using a ternary blend of white portland cement, blast slag, and VCAS pozzolans along with an aggregate base containing shale, Poraver®'s, Elemix®, and K20 (Figure 3).

When considering the primary reinforcement for *Free Range*, the reinforcement committee first examined the reinforcement used in the year previous, 5 mm Basalt Mesh. While this reinforcement encompassed all significant material properties deemed necessary by the committee, it lacked one quality brought to attention by the trowelers – workability. Thus, the reinforcement committee sought to find a new primary reinforcement that incorporates similar material properties as 5 mm Basalt Mesh and is easier to construct in the boat. Extensive research did not yield a product that was comparable in both physical properties and cost while providing improved workability.

Figure 4. ASTM D790 3-point flexural testing

Based on team knowledge of previous performance, the reinforcement committee decided to test three types of reinforcement: 5 mm Basalt Mesh, 10 mm Basalt Mesh, and Kevlar® 4009-1. In order to compare the reinforcements, the reinforcement committee desired to view how each reinforcement performed as it would in the concrete composite. The committee decided to analyze both the modulus of elasticity and the maximum stress of the three reinforcements being considered.

The committee used a baseline mixture to cast composite plates representing a typical cross-section of the canoe in order to analyze the change made by each reinforcement. Fibers were not included in the mixture because their distribution, nonuniform direction, and structural properties would skew flexural data for proper reinforcement comparison. Each plate was cast in the same manner as the canoe – three 1/8 in. layers of concrete divided by 2 layers of reinforcement. The reinforcement committee administered three-point flexural testing in accordance with ASTM D790 to simulate bending, which the composite would experience in the canoe. This test is shown in Figure 4. The results confirmed that the Kevlar® 4009-1 reinforcement sample did not have a comparable maximum bending stress or modulus of elasticity with the Basalt mesh samples. When comparing the 5 mm and 10 mm Basalt samples, the 10 mm sample had a slightly higher maximum bending stress. The 5 mm sample had a higher modulus of elasticity and fell within the range of 2-6×10^6 psi, which is the average modulus of elasticity of normal strength portland cement concrete. This property is important because it describes the stiffness of the material and the amount of stress it can undergo before permanently deforming. Therefore, the 5 mm Basalt mesh, when combined with concrete, is able to withstand a higher maximum allowable stress before deforming than 10 mm Basalt mesh and Kevlar® 4009-1. The results also show that the 5 mm Basalt sample had the lowest percent maximum strain seen at the first crack, justifying its higher modulus of elasticity. The reinforcement committee decided the 5 mm Basalt mesh is the best choice for primary reinforcement because of its higher modulus of elasticity and its maximum bending stress comparable with that of 10 mm Basalt mesh.

Table 5. Primary reinforcement comparison

	Kevlar® 4009-1	Basalt 5mm	Basalt 10mm
Cost ($/linear ft.)	11.84	7.13	6.41
Open Area (%)	48	62.6	74.5
Max Bending Stress (psi)	440.5	1031	1563
Modulus of Elasticity (psi)	153,539	306,560	200,554

Construction


Figure 5. Trowelers applying the first layer of concrete

After the hull design committee finalized the hull design, the project managers ordered a high-density polystyrene foam mold. This material was chosen for its machinability, low cost, and durability. The final design was milled into the foam using a CNC machine, creating a two-piece female mold. Seven coats of epoxy were applied in the weeks leading up to casting day. The mold pieces were then bolted together at each end and secured to a table. Movement of the mold during casting was prevented by using wooden blocks along the bottom edges.

The team held mock casting sessions to train a new casting team consisting of trowelers and quality control/quality assurance (QC/QA) monitors. During the fall semester, the casting team used quarter and half sections of previous molds to practice troweling concrete and improve troweling techniques. Subsequently, eight trowelers were assigned to separate sections of this year's canoe, including two end cap sections. QC/QA monitors used 3D-printed depth gauges to check concrete layer thickness.

In the week prior to casting day, a meeting was held to discuss proper safety and construction procedures. Additionally, each team member was given specific duties to make the day as successful and organized as possible. Materials to be used in the mixture were measured and separated into batches two days before casting to save time and reduce the chance of missteps by the mixture committee come casting day.


Figure 6. QC/QA monitors applying the primary reinforcement

On casting day, the casting room was first cooled to 55°F to prevent cold joints from forming and ensure the concrete would have an extended initial set time. A release aid was applied to the mold prior to the start of construction to ease the eventual removal of the canoe.

Using typical concrete trowels, the boat was cast onto the female mold in three layers, each 1/8 in. thick. Figure 5 exhibits the placement of concrete. Two continuous layers of primary reinforcement were placed, one before and one after the placement of the second layer of concrete. Arrangement of the first layer of reinforcement is shown in Figure 6. Each layer was cast within 60 minutes with an additional 10 minutes allotted for the placement of reinforcement between layers. The temperature of the casting room was closely monitored throughout the cast to ensure consistent conditions.

Figure 7. A foam endcap

Upon completion of the third layer of concrete, foam endcaps were inserted into each end of the canoe, covered with concrete, and troweled to the desired shape. An example of a foam endcap is shown in Figure 7. Pre-cut female gunwale cap molds were secured at the top interior perimeter of the boat using C-clamps. The remaining reinforcement from the first layer was cut flush with the top of the boat, while the reinforcement from the second layer was cut down to a one-inch length from the top of the canoe. The gunwale caps were cast by laying a thin layer of concrete into the molds, folding the inch of reinforcement into it, and packing the remaining space with concrete. This entire process required one hour to be completed.

An ambient curing process was chosen by the team, which required curing conditions of 70% humidity and a room temperature of 70°F. These conditions were maintained for two weeks to allow for cement hydration. Following the curing period, the canoe was removed from the mold and prepared for aesthetic finishing techniques.

Exterior sanding began with 80 grit sandpaper and was gradually increased to 1000 grit. The canoe was frequently cleaned using compressed air. As a safety precaution, dust from the boat was removed using vacuums, and an air ventilation system removed it from the room. The patching mixture was applied to the exterior of the canoe to create a smooth and consistent finish.

Figure 8. Application of the finishing mixture using a paint sprayer

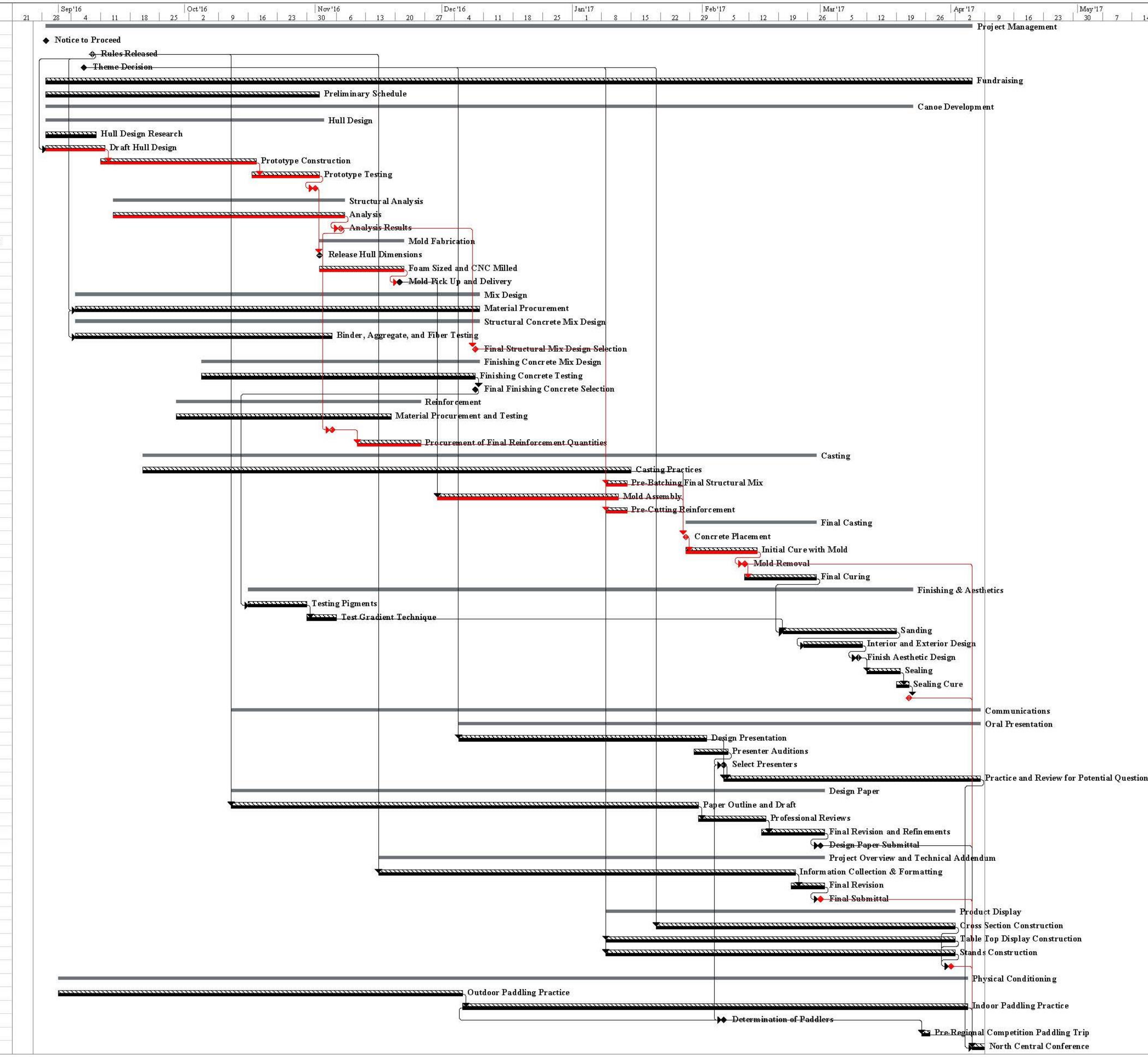
With the continued restriction on stain, the aesthetics team urgently sought new tactics to achieve a pleasing finished product. To reach this goal, the team decided to test the concept of utilizing pigmented concrete to add detail and color to the canoe. This contrasts last year's model, as *Denali* depended primarily on inlay and outlay techniques to develop the canoe's aesthetics. The team chose to use pigmented concrete because it opened the possibility of creating greater variety of color and detail on the canoe.

In an effort to be more sustainable, the aesthetics committee performed all testing on last year's practice canoe. As a result, the team could be sure the methods tested would work, and no new concrete plates needed to be cast. Testing for pigmented concrete consisted of experimenting with different pigmentations to be added to the prospective finishing mixture. Several different pigments were tested, including powdered pigments and liquid pigments. Powdered pigments thickened the mixtures to point where they were no longer applicable for their intended use on the exterior of the canoe. Additional water and superplasticizer were added to the finishing mixtures to aid in the application process.

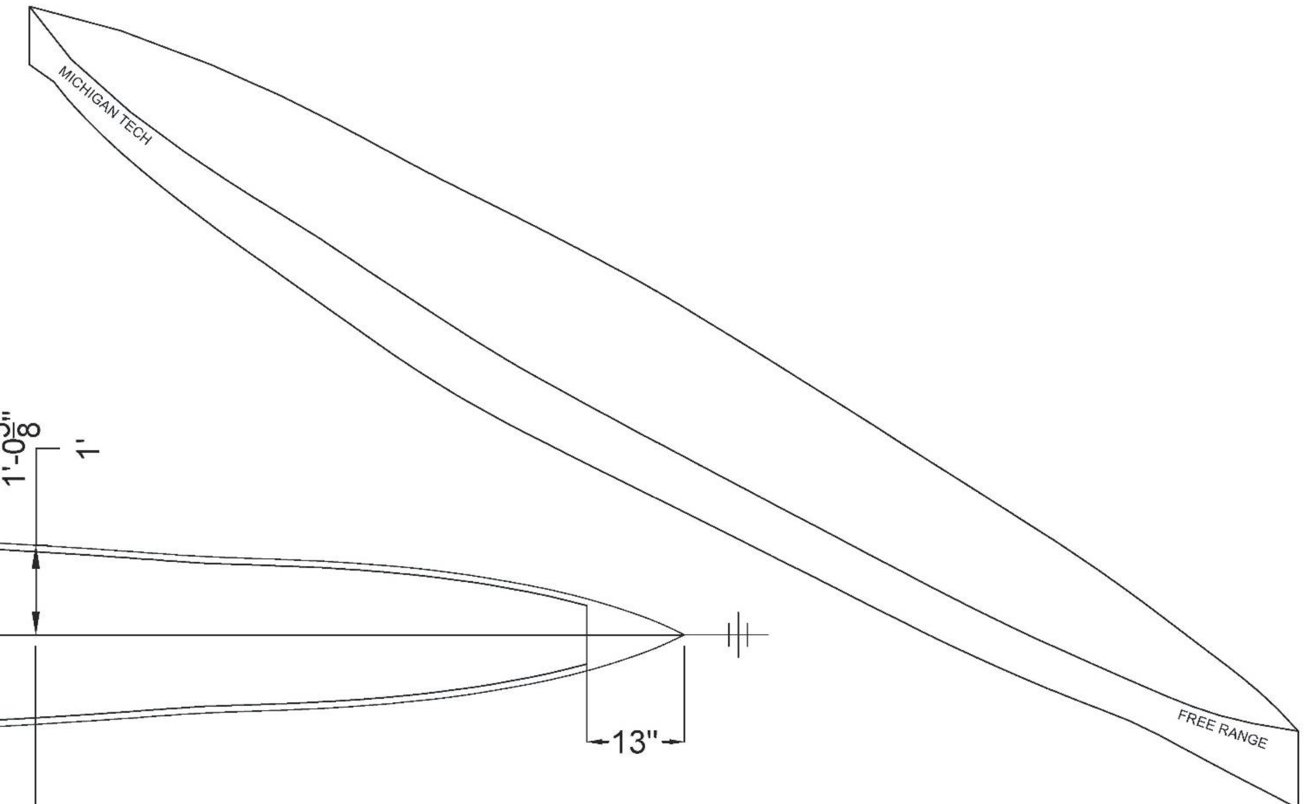
With further testing, the aesthetics committee found that the colored finishing mixture was easily applied to the exterior surface of the canoe simply by using a paintbrush. Additionally, the committee successfully attempted to use a paint sprayer to apply even coats of the mixture over larger areas. This technique was also adopted to create details on the canoe using stencils. Use of the paint sprayer is presented in Figure 8.

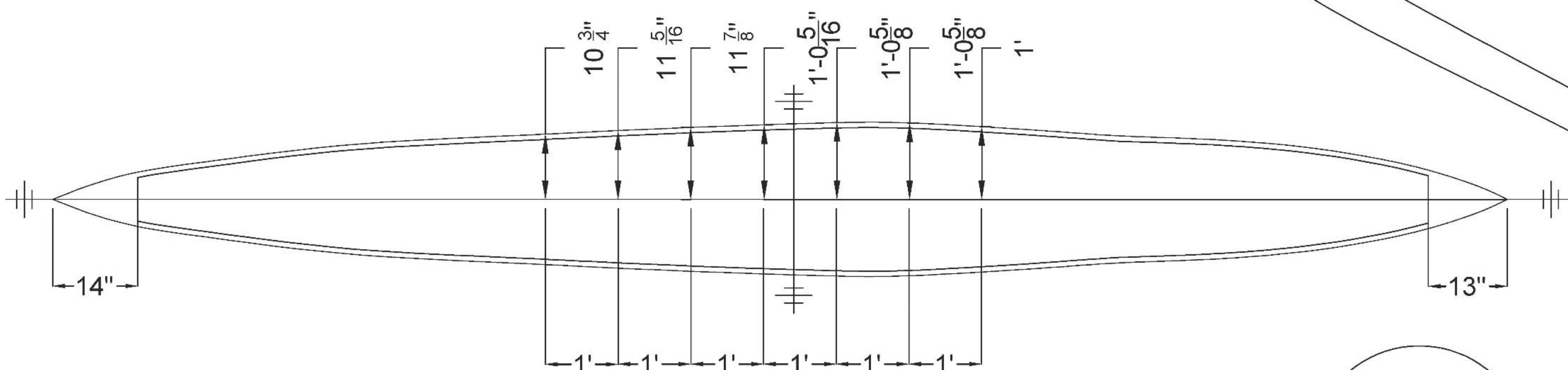
The team used two coats of ChemMasters® Crystal Clear-A sealer to enhance aesthetics and protect the final product from water penetration. Finally, the sealer was wet sanded with 1000 grit sandpaper, providing a smooth finish.

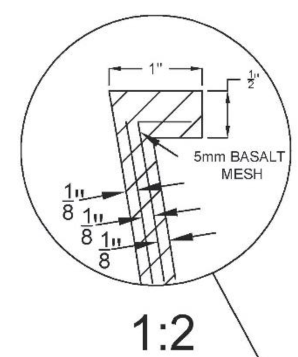
ID	Task Name	Baseline Start	Baseline Finish	Actual Start	Actual Finish
1	**Project Management**	**Mon 8/29/16**	**Wed 4/5/17**	**Mon 8/29/16**	**Wed 4/5/17**
2	Notice to Proceed	Mon 8/29/16	Mon 8/29/16	Mon 8/29/16	Mon 8/29/16
3	Rules Released	Fri 9/9/16	Fri 9/9/16	Fri 9/9/16	Fri 9/9/16
4	Theme Decision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

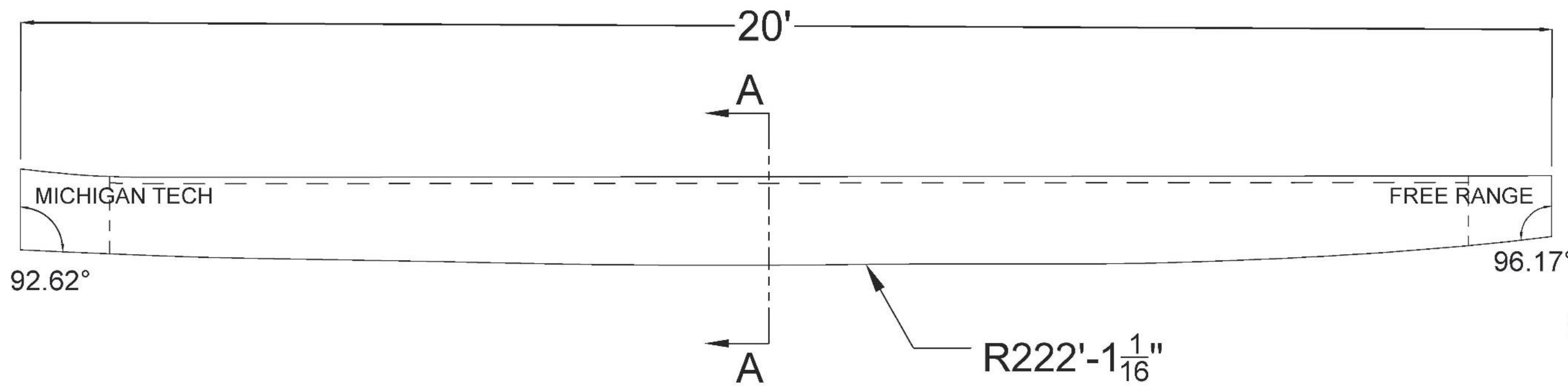


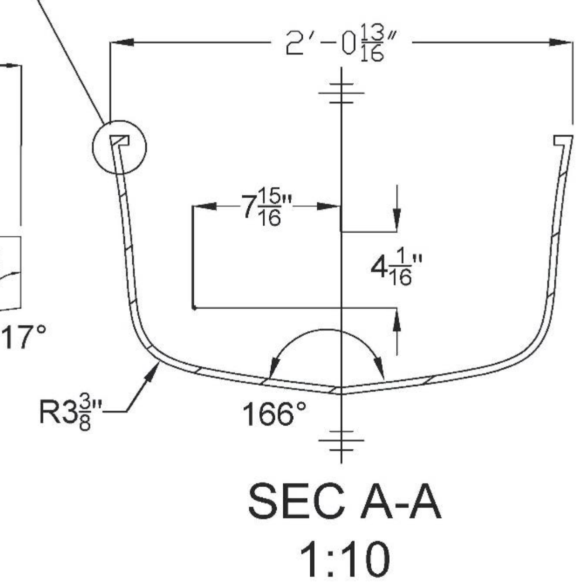
Critial Path — Actual — Actual Milestone ◆ — Summary — Baseline — Baseline Milestones ◇











Michigan Technological University

1885

Michigan Technological University
Concrete Canoe
1400 Townsend Drive
Houghton, MI 49931

FREE RANGE

BILL OF MATERIALS

I.D.	DESCRIPTION	QTY.
1	FEDERAL WHITE TYPE I PORTLAND CEMENT	451.7lb
2	BLAST FURNACE SLAG	225.8lb
3	VCAS POZZOLANS 160	75.3lb
4	NYCON® RFS4000(30mm) PVA	8.50lb
5	NYCON® RF4000(19mm) PVA	8.50lb
6	SBS-5mm BASALT MESH	123.8ft²
7	DOW® EXTRUDED POLYSTYRENE FOAM	2ft³
8	HAYDITE EXPANDED SHALE	391.4lb
9	3M GLASS BUBBLES K20	28.3lb
10	PORAVER® 1.0-2.0mm	73.8lb
11	PORAVER® .05-1.0mm	41.0lb
12	PORAVER® 0.25-0.5mm	16.4lb
13	ELEMIX	14.4lb
14	BASF GLENIUM 3030 NS	2.0lb
15	CHEMMASTERS® CRYSTAL CLEAR-A	1.5gal
16	SILHOUETTE GLOSSY PERMANENT VINYL	5ft²
17	DIRECT™ COLORS CONCRETE PIGMENTS	2.5lb
18	SIKA LATEX R	0.25gal

CONSTRUCTION DRAWING

DRAWN BY: KATIE WINTER	SCALE: 1:25 OR AS NOTED
CHECKED BY: PHILIP DOEDERLEIN	SHEET: 12
DATE: 2/22/2017	

Appendix A - References

ACI (American Concrete Institute). (2014). *Building Code Requirements for Structural Concrete,* Standard 318-14. Second Printing. ACI, Farmington Hills, MI.

ASCE/NCCC. (2017). 2017 American Society of Civil Engineers National Concrete Canoe Competition Rules and Regulations. ASCE. < http://www.asce.org/rules-and-regulations/> (Dec. 18, 2016).

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ASTM. (2014). *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete, C138/C138M-14.* West Conshohocken, PA.

Burr, Arthur Houghton. (1995). *Mechanical Analysis and Design.* Prentice Hall, Englewood Cliffs, N.J.

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Vacanti Yacht Design LLC. (1998). *PROLINES 98* [Software]. Anacortes, Washington: Vacanti Yacht Design LLC. (Sept. 8, 2016).

Cover photo courtesy of:
Hackey, Nicole. "Fun On The Farm With Pictures". Prairie Princess. Online at
<http://deeretomyheart.blogspot.com>

Appendix B – Mixture Proportions

MIXTURE DESIGN: STRUCTUAL

CEMENTITIOUS MATERIALS

Component	*Specific Gravity*	*Volume (ft³)*	*Amount of CM (mass/volume) (lb/yd³)*	
Federal White Type I Portland Cement	3.15	2.3	*451.7*	*Total Amount of cementitious materials* ***752.8****lb/yd³* *c/cm ratio* ***0.9***
Blast Furnace Slag	2.99	1.21	*225.8*	
VCAS Pozzolan 160	*2.6*	*0.46*	*75.3*	

FIBERS

Component	*Specific Gravity*	*Volume (ft³)*	*Amount of Fibers (mass/volume) (lb/yd³)*	
Nycon PVA-RFS4000	1.3	0.105	*8.5*	*Total Amount of Fibers* *17 lb/yd³*
Nycon PVA-RFS400	1.3	0.105	*8.5*	

AGGREGATES

Aggregates	*ASTM C330**	*Abs (%)*	MC_{stk} *(%)*	SG_{SSD}	*Base Quantity (lb/yd³)*		*Volume*$_{SSD}$*, (ft³)*	*Batch Quantity (at* MC_{stk}*) (lb/yd³)*
					OD	*SSD*		
Poraver 1-2mm	No	20	5.86	.41	*62.29*	74.75	*2.92*	65.94
Poraver .5-1mm	No	25	5.24	.45	*32.78*	40.97	*1.46*	34.49
Poraver .25-.5mm	No	30	7.5	.68	*12.61*	16.39	*0.39*	13.55
Elemix	No	5.5	0.03	.04	*13.47*	14.21	*5.42*	13.47
K20	No	.5	9.8	.2	*27.11*	27.25	*2.18*	29.77
Shale	Yes	10	.86	1.5	*359.72*	395.69	*4.23*	362.81

ADMIXTURES

Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd³)*	
Latex-R	*8.51*	*28.02*	*15*	*11.92*	*Total Water from Admixtures,* $\sum w_{admx}$ ***14.15*** *lb/yd³*
BASF Glenium 3030NS	*9.20*	*20.27*	*79.7*	*2.23*	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)

Component	*Specific Gravity*	*Volume (ft³)*	*Amount (mass/volume) (lb/yd³)*	
Latex-R	**1.02**	**.11**	**7.06**	*Total Solids from Admixtures* ***7.06*** *lb/yd³*

WATER

	Amount (mass/volume) (lb/yd³)		*Volume (ft³)*
Water, lb/yd³		*w*: 254.06	*4.07*
Total Free Water from All Aggregates, lb/yd³		$\sum w_{free}$: -49.21	
Total Water from All Admixtures, lb/yd³		$\sum w_{admx}$: *14.15*	
Batch Water, lb/yd³		w_{batch}: 289.13	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP

	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	*752.8*	17	520	14.15	296.68	*∑M:1663.7*
Absolute Volume of Concrete, V, (ft³)	3.97	*0.21*	*16.6*	*.11*	*4.07*	*∑V:24.69*
Theoretical Density, T, (=∑M / ∑V)	63.8	*lb/ft³*	***Air Content [= (T – D)/T x 100%]***			*2.8 %*
Measured Density, D	62.1	*lb/ft³*	***Slump, Slump flow***			*.6 in.*
water/cement ratio, w/c:	.56		***water/cementitious material ratio, w/cm:***			.375

MIXTURE DESIGN: PATCHING

CEMENTITIOUS MATERIALS				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Federal White Type I Portland Cement	3.15	5.04	*990.7*	*Total Amount of cementitious materials* ***1651.2**lb/yd³* *c/cm ratio* ***0.9***
Blast Furnace Slag	2.99	2.65	*495.3*	
VCAS Pozzolan 160	*2.6*	*1.02*	*165.1*	

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/yd³*
Nycon PVA-RFS400	1.3	0	*0*	

AGGREGATES								
Aggregates	*ASTM C330**	*Abs (%)*	*MC_{stk} (%)*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*$Volume_{SSD}$, (ft^3)*	*Batch Quantity (at MC_{stk}) (lb/yd^3)*
					OD	*SSD*		
Poraver .01-0.3mm	No	35	7.5	.068	*145.26*	196.1	*4.62*	156.15
K20	No	0.5	9.8	.2	*59.70*	60	*4.81*	65.55
Pumice	Yes	0.2	.86	2.35	*83.93*	84.1	*0.57*	84.65

ADMIXTURES					
Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Latex-R	*8.51*	*17.8*	*15*	*16.61*	*Total Water from Admixtures, $\sum w_{admx}$* ***17.3** lb/yd³*
BASF Glenium 3030NS	*9.20*	*8*	*79.7*	*1.93*	

SOLIDS (LATEX, DYES AND POWDERED ADMIXTURES)				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Latex-R	**1.02**	**.11**	**7.06**	*Total Solids from Admixtures* ***7.06** lb/yd³*

WATER			
	Amount (mass/volume) (lb/yd^3)		*Volume (ft^3)*
Water, lb/yd³		*w*: 577.90	*9.26*
Total Free Water from All Aggregates, lb/yd³		*$\sum w_{free}$*: -33.84	
Total Water from All Admixtures, lb/yd³		*$\sum w_{admx}$*: *18.54*	
Batch Water, lb/yd³		*w_{batch}*: 593.20	

DENSITIES, AIR CONTENT, RATIOS AND SLUMP						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	*1651.1*	0	306.36	18.54	593.2	*$\sum M$:2569.2*
Absolute Volume of Concrete, V, (ft^3)	8.71	*0.000*	*10.00*	*.11*	*9.26*	*$\sum V$:28.09*
Theoretical Density, T, (=$\sum M / \sum V$)	91.5	*lb/ft³*	*Air Content [= (T – D)/T x 100%]*			*-6.5 %*
Measured Density, D	97.8	*lb/ft³*	*Slump, Slump flow*			8 *in.*
water/cement ratio, w/c:	.58		*water/cementitious material ratio, w/cm:*			.35

MIXTURE DESIGN: PIGMENTED

Cementitious Materials				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount of CM (mass/volume) (lb/yd^3)*	
Federal White Type I Portland Cement	3.15	4.36	*856.7*	*Total Amount of cementitious materials* ***1427.9****lb/yd^3* *c/cm ratio* ***0.9***
Blast Furnace Slag	2.99	2.30	*428.4*	
VCAS Pozzolan 160	*2.6*	*0.88*	*142.8*	

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 (%)*	*MC_{stk} (%)*	*SG_{SSD}*	*Base Quantity (lb/yd^3)*		*$Volume_{SSD}$, (ft^3)*	*Batch Quantity (at MC_{stk}) (lb/yd^3)*
					OD	*SSD*		
Poraver .01-0.3mm	No	35	7.5	.068	*83.44*	112.64	*2.65*	89.69
K20	No	0.5	9.8	.2	*67.6*	67.6	*5.42*	73.86
Pumice	Yes	0.2	.86	2.35	*45.1*	45.1	*0.31*	45.40

Admixtures					
Admixture	*lb/gal*	*Dosage (fl.oz/cwt)*	*% Solids*	*Amount of Water in Admixture (lb/yd^3)*	
Latex-R	*8.51*	*17.8*	*15*	*14.36*	*Total Water from Admixtures, $\sum w_{admx}$* ***15.8*** *lb/yd^3*
BASF Glenium 3030NS	*9.20*	*4*	*79.7*	*0.83*	

Solids (latex, dyes and powdered admixtures)				
Component	*Specific Gravity*	*Volume (ft^3)*	*Amount (mass/volume) (lb/yd^3)*	
Latex-R	**1.02**	**0.11**	**7.06**	*Total Solids from Admixtures* ***22.06*** *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		*w:* 762.30	*12.22*
Total Free Water from All Aggregates, lb/yd^3		*$\sum w_{free}$:* -16.39	
Total Water from All Admixtures, lb/yd^3		*$\sum w_{admx}$:* *15.20*	
Batch Water, lb/yd^3		*w_{batch}:* 763.50	

Densities, Air Content, Ratios and Slump						
	cm	*fibers*	*aggregates*	*solids*	*water*	*Total*
Mass of Concrete, M, (lb)	*1427.9*	0	208.95	15.20	763.50	*$\sum M$:2415.54*
Absolute Volume of Concrete, V, (ft^3)	7.53	*0.000*	*8.38*	*0.22*	*12.22*	*$\sum V$:28.35*
Theoretical Density, T, (=$\sum M / \sum V$)	85.20	*lb/ft^3*	*Air Content [= (T – D)/T x 100%]*			*-11.2%*
Measured Density, D	96.0	*lb/ft^3*	*Slump, Slump flow*			11 *in.*
water/cement ratio, w/c:	.89		*water/cementitious material ratio, w/cm:*			.5

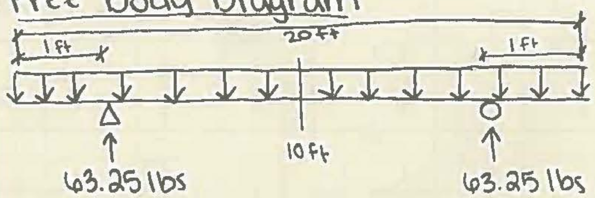
Appendix C – Example Structural Calculations

Analysis of a simply supported canoe on display stands

Assumptions

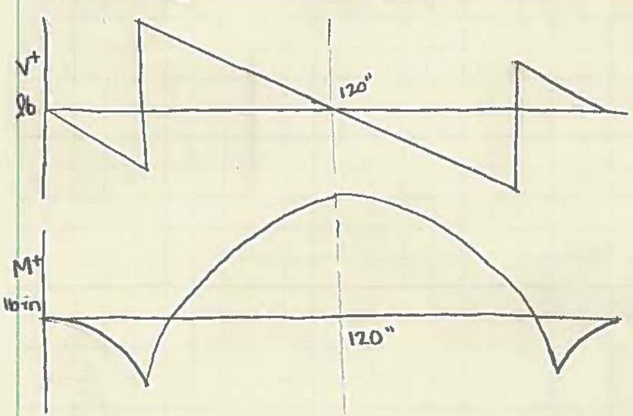
- Canoe theoretical weight ⇒ 126.5 lbs
- Plane sections remain plane
- Weight of canoe is uniformly distributed
- Stands are point loads
- Material is homogenous

Free Body Diagram



$R_A = \frac{126.5}{2} = 63.25 \text{ lbs}$

Resulting Shear, Bending Moment Diagram



$V = 0 \text{ lb} @ 120 \text{ in}$

$M = 3442.15 \text{ lb-in}$

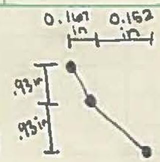
Cross Sectional Properties (needed to find canoe self weight)

- 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 120 inches from the bow, which is the midpoint of the canoe. Cross section 120 has 92 control points. Properties were calculated for one side, and doubled if necessary

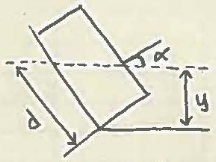
2/3

Control points

Point	x(in)	y(in)
1	-12.39	5.13
2	-12.22	4.21
3	-12.06	3.28



gunwale y location = 5.1317 in
Keel y location = -8.7305 in

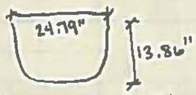


$I = \frac{bd}{12}(d^2\cos^2\alpha + b^2\sin\alpha)$
$A = b \cdot d$
$\bar{y} = \frac{1}{2}(d\cos\alpha + b\sin\alpha)$
} From Engineer's Edge www.engineersedge.com/calculators/Section_square.case_9.htm

$\alpha = \pi - |\tan^{-1}(\Delta y/\Delta x)|$ $d = \sqrt{(\Delta x)^2 + (\Delta y)^2}$
$b = 0.375$ in

Piece	Δx(in)	Δy (in)	α(rad)	d (in)	A (in²)	Ic (about piece centroid) (in⁴)	ȳ from bottom point (in)	ȳ from coor. axis (in)
1	0.167	-0.926	0.18	0.94	0.35	0.025	0.43	4.64
2	0.152	-0.928	0.16	0.94	0.35	0.03	0.43	3.71

Cross section 120" dimensions



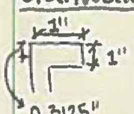
- After all properties are calculated for each piece, section properties can be found:
  Area, A: Sum of all areas, multiplying by two ⇒ $A = 16.93$ in²
  Location of neutral axis, $\bar{y}$ using A and centroids, location of neutral axis can be found: $\bar{y} = \frac{\Sigma(Ac)}{\Sigma A} = -2.13$ in
  Ix: Given Ic, A, $\bar{y}$ and location of neutral axis, Ix about the x-axis can be found using parallel axis theorem.
  $I_x = \Sigma I + \Sigma(ad^2) = 640.61$ in⁴

Gaps 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 120:
A gap = 0.21 $\bar{y}$ from coor axis: -3.66in Ix about x-axis: -5.35

Gunwale Caps



A cap = 1.00 in² $\bar{y}$ from coor. axis = 4.63in
Ix about axis = 21.50 in⁴

Total Cross Section properties (adding together appropriately)

A = 18.13 in² Ix = 667.49 in⁴
$\bar{y}$ = -1.77 in I about neutral axis = 610.9 in⁴

Internal Stresses

$\sigma = \frac{My}{I}$ Y gunwale = 5.1317 in
Y keel = -8.7305 in

$\sigma_{gunwale} = -3442.15 \text{ in-lb} \left(\frac{5.1317 \text{ in}}{610.9 \text{ in}^4}\right) = -28.9$ psi

$\sigma_{keel} = -3442.15 \text{ in-lb} \left(\frac{-8.7305 \text{ in}}{610.9 \text{ in}^4}\right) = 49.19$ psi

3/3

Comparison of various load case results

The results of the various loading scenarios are listed in the table below. These results were found by analyzing the cross sections located at the greatest moment. The cross section data was then used to find max shear and stress to compare to the stands load case performed in the pages prior.

	Max Shear (lbs)	Max Moment (lb-in)	Max Stress in keel (psi)	Max Stress in gunwale (psi)
Co-ed Sprint	-216.7	-8795.13	146.1	-137.9
Men's Sprint	-206.2	-12331.7	153.0	-142.7
Women's Sprint	187.9	-9761.9	125.1	-115.8
Men's Endurance	-207.6	-10367.6	-114.1	117.1
Women's Endurance	-178.9	-10784.2	133.7	-124.7
Transportation	35.82	2991.7	19.3	-17.4
Stands	56.9	3442.2	48.19	-28.9
Display Day Stands	34.5	-1186.98	19.0	-17.2

Distinctions between men's and women's events come from paddler weights. Distinctions between sprint and endurance events come from the competing paddler's desired sitting/kneeling position. It can be seen that men's sprint has the highest stress when analyzing in pure bending. The display day stands loading case represents where the stands will actually be placed. You can see a decrease in stress by moving the stands in.

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

HULL THICKNESS CALCULATIONS

Calculations per Section 4.3.1

Annotation

$T_1 = 0.0022$ in — Average thickness of first layer of reinforcement, 5 mm Basalt Mesh, measured in accordance with Section 4.3.1

$T_2 = 0.0022$ in — Average thickness of second layer of reinforcement, 5 mm Basalt Mesh, measured in accordance with Section 4.3.1

$T_h = 0.0375$ 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 5 mm Basalt Mesh were used along the bottom of the canoe.

$$\frac{T_1 + T_2}{T_h} * 100 = 11.73\%$$

The two layers of reinforcement make up approximately 11.73% 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

$T_1 = 0.0022$ in — Average thickness of first layer of reinforcement, 5 mm Basalt Mesh, measured in accordance with Section 4.3.1

$T_h = 0.625$ 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 5 mm Basalt Mesh was used throughout the gunnel cap.

$$\frac{T_1}{T_h} * 100 \quad = 3.52\%$$

The two layers of reinforcement make up approximately 3.52% 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: 5mm Basalt Mesh

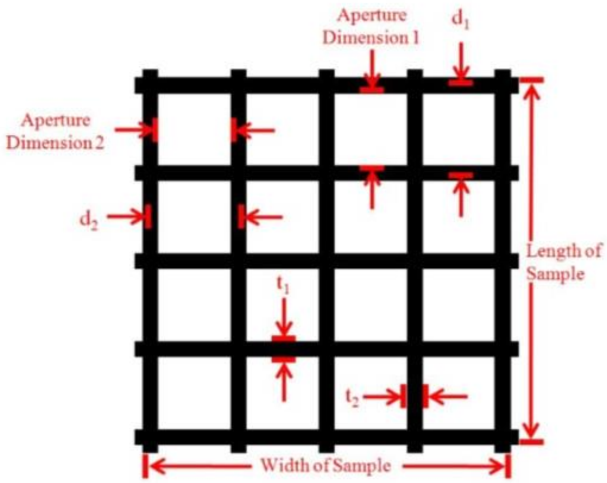
Given

$n_1 = 6$ Number of apertures along length

$n_2 = 6$ Number of apertures along width

$t_1 = 0.024$ in Average thickness of reinforcement along length

$t_2 = 0.036$ in Average thickness of reinforcement along width



Sample of Reinforcement

Aperture_Dimension_1 = 0.164 in

Aperture_Dimension_2 = 0.185 in

d_1 = Aperture_Dimension_1 + 2*(t_1/2) $d_1 = 0.19$ in Average spacing of reinforcement (center-to-center) along the sample length

d_2 = Aperture_Dimension_2 + 2*(t_2/2) $d_2 = 0.26$ in Average spacing of reinforcement (center-to-center) along the sample width

Determine Solution Percent Open Area (POA) for the 5 mm Basalt Mesh

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

$Length_{Sample} = 1.13$ in $Width_{Sample} = 1.54$ in

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

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

$Area_{Open} = 1.09\ in^2$ $Area_{Total} = 1.74\ in^2$

$POA = (Area_{Open}/Area_{Total})*100$ POA = 62.6% The POA is greater than the 40% minimum required, demonstrating compliance.